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Assessing Effects Of Human Success Event On Dependency Between Human Failure Events Based On EMBRACE Method

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Abstract

This paper proposes a method for assessing the effects of a human success event (HSCE) on the dependency between human failure events (HFEs) in human reliability analysis (HRA). Many HRA practitioners have conducted dependency assessments with the assumption that two HFEs become independent when an HSCE intervenes between the two HFEs. However, this assumption should be reviewed and updated considering that recovery of inappropriate mental models shall not be given for granted in case of any HSCE, but only if this is of relevance for the subsequent HFE. The EMBRACE (Empirical data-Based crew Reliability Assessment and Cognitive Error analysis) dependency method is thus modified in this work to model how an intervening HSCE affects the conditional probability of the subsequent HFE. The EMBRACE dependency method evaluates the time resource constraints that exist between two events, the task infeasibility from similar procedure flows, the mental model linkage related to procedures and instrument information, and the performance shaping factor impact from the antecedent HFE. This paper presents a modified equation to calculate the conditional HEP of the subsequent HFE considering the effects of the HSCE on the mental model revision and the time margin change. Some implications of the equation are also discussed based on application cases. The paper improves the state-of-practice on dependence analysis by considering the relevance of the intervening HSCE as well as by doing so in a reproducible and objective way (i.e. via the introduced formula). Yet, given the complexity of the issues and the potentially strong influence on the risk profile, validation efforts are still required before its use in industrial applications.

Keywords: conditional probability, dependency assessment, human error probability, human reliability analysis, human success event

1. Introduction

Human reliability analysis (HRA) is a tool to estimate human error probabilities (HEPs) of human failure events (HFEs), which imply significant interactions between humans and complex systems. The outputs of HRA are often combined with component failure probabilities in event trees or fault trees to visualize the entire risk of complex systems through, e.g., probabilistic risk assessment. This type of risk model allows to enumerate combinations of the component failure events and the HFEs involved in responding to each accident scenario. These HFEs are typically analyzed singularly, i.e. without explicit consideration of the effect of earlier failures during a given scenario. However, when multiple HFEs appear in the same sequence, because some human actions can be affected by several contextual factors connected with other events, the HEPs of the subsequent HFEs need to be adjusted or replaced with conditional HEPs given the antecedent HFEs. Therefore, several dependency methods have been developed and employed to assess the dependency relationships between HFEs and quantify the conditional HEPs considering these relationships (EPRI, 2016; Gertman et al., 2005; Kichline et al., 2021; Čepin, 2008; Kim et al., 2023).

Many HRA researchers have recognized that the existence of a human success event (HSCE) between two HFEs can relax the influence of the antecedent HFE on the subsequent HFE (Whaley et al., 2007). The main reason for the relaxation of dependency is that HSCEs provide human personnel with opportunities to reassess accident situations and correct faulty mental models used in antecedent HFEs (Whaley et al., 2007; Whaley and

Kelly, 2012; EPRI, 2016). For example, the EPRI HRA calculator evaluates dependency levels based on a decision tree, which derives the zero-dependency level (i.e., two HFEs are independent) when an HSCE intervenes between two HFEs (EPRI, 2016).

However, due to the lack of a scientific basis for the quantification of dependency, the extent that HSCE intervention reduces the conditional HEP of the subsequent HFE has not been sufficiently discussed. The assumption that two HFEs with an HSCE between them are independent of each other is widely used by many risk analysts, but this assumption in application may produce results that are not reasonably conservative. For example, as described in (Podofillini et al., 2024), the analysis of operational events shows that an HSCE does not necessarily imply independence across the antecedent and subsequent HFEs. Whaley et al. (2012) emphasized that an incorrect mental model can be recovered by new or additional cues, system feedback, and different perspectives from other personnel. It should also be noted that new information does not always secure an opportunity to correct all incorrect mental models. Accordingly, it is reasonable to say that only the part of the mental model that is related to the new information can be reformed by a new cue. Thus, current research supports the theory that an intervening HSCE ***does affect*** the dependency between the antecedent and subsequent HFEs.

In this study, we aim to model how an intervening HSCE affects the conditional probability of the subsequent HFE based on the EMBRACE (EMpirical data-Based crew Reliability Assessment and Cognitive Error analysis) dependency assessment method (Kim et al., 2023). The dependency method separately evaluates the time resource constraints that exist between two events, the mental model linkage related to procedures and instrument information, and the impact of performance shaping factors (PSFs) from the antecedent HFE. As this method is based on a mathematical equation, it not only allows to transparently and traceably quantify the dependency but also can be extended by supplementing or adjusting some variables. The impact of an HSCE can also be mathematically integrated into the equation.

2. Background

This section briefly introduces the EMBRACE dependency method (Kim et al., 2023). This method views that four main factors form the dependency between two HFEs.

- ***Resource impact***: This method mainly deals with the temporal overlap between the two HFEs. Because this dependency assessment method was basically designed to support internal level 1 risk assessment, it is not assumed that the staffing level is degraded by the antecedent HFE. It is also thought that there is no spatial interference between operators for the two HFEs if the tasks corresponding to the HFEs do not temporally overlap. Therefore, EMBRACE calculates the time insufficiency of the task performance in the subsequent HFE after completion of the tasks belonging to the antecedent HFE.
- ***Feasibility impact***: In some cases, the antecedent HFE renders performance of the tasks for the subsequent HFE infeasible. This method does not consider changes in equipment availability or accessibility due to the antecedent HFE since these changes are separately modelled by fault trees or event trees. Instead, it quantifies the impact of a failure in a common procedural part for both HFEs. For example, if the procedure transition task leading to the actions for the antecedent and subsequent HFEs fails, both HFEs will be infeasible.
- ***Mental model impact***: The cognitive understandings or projections of operators regarding plant dynamics, accident progressions, causality, and consequences of HFEs are expected to be barely fixed unless significant cues are presented (Kim et al., 2023). This method recognizes that the cues from instrumentations and procedures are significant sources of mental models and calculates the similarities of procedure progressions and instrumentation cues between two HFEs.
- ***PSF impact***: The change in task complexity or stress because of the results of the antecedent HFE is assessed in this method. In the case of spontaneous cue occurrence, for example, it is expected that the task complexity of the subsequent HFE will increase. Severe accident situations can be another source of a PSF change. However, other PSFs are not included in the impact assessment because their states are not negatively influenced by the antecedent HFE or their changes are unpredictable in usual cases.

Considering the above impacts, equation (1) was previously developed to calculate the conditional HEP of the subsequent HFE (B) given the antecedent HFE (A), i.e., $P(B|A)$:

$$P(B|A) = \left[TRI_{A,B} + \left\{PTS_{A,B} + CRD_{A,B}\right\} * RF_{A,B}\right] * CS_{A,B} + P(B) * ACE_B \quad (1)$$

where $\boldsymbol{TRI_{A,B}}$ is the temporal resource insufficiency (TRI) of event B after completion of the time required for event A, $\boldsymbol{PTS_{A,B}}$ is the procedure transition similarity (PTS) between the two events, $\boldsymbol{CRD_{A,B}}$ is the cue recognition dependency (CRD) between the two events, $RF_{A,B}$ is the recovery factor (RF) of event *B* considering the time margin of event *A*, $CS_{A,B}$ is the crew sameness of the two events, *P(B)* is the individual HEP of event *B*, and ACE_B is an additional contextual effect (ACE) of event *A* on event *B*.

The values of the six variables in equation (1) are determined in the following way. As shown in equation (2), $TRI_{A,B}$ is calculated from the lognormal function of the ratio between the time required and time available because many empirical studies have shown that human performance time can be represented by a lognormal distribution. Kim and Kim (2023) presented a survey of the distribution fitting studies. Equation (2) shows that the time available for the subsequent HFE is counted after the end point of the time required for the antecedent HFE:

$$TRI_{A,B} = 1 - \Phi\left[\ln\left\{\left(Ta_{B,end} - Tr_{A,end}\right)/\left(Tr_{B,end} - Tr_{B,start}\right)\right\}/\sigma\right] \tag{2}$$

where Φ is the cumulative probability function of the standard normal distribution, $Ta_{B,end}$ and $Tr_{A,end}$ are the end points of the time available for event *B* and the time required for event *A*, respectively, and σ is the shape parameter of the lognormal distribution.

$PTS_{A,B}$ evaluates the sequence similarity of the transition steps and final steps for the two HFEs. The Smith–Waterman algorithm (Smith and Waterman, 1981) was employed to calculate the similarity score of the two events, as described in equation (3). The score is then normalized by the maximum possible score to provide $PTS_{A,B}$ as a ratio value. Equation (3) reads:

$$H_{AB}(i,0) = 0 \; for \;\; 0 \leq i \leq m$$

$$H_{AB}(0,j) = 0 \; for \;\; 0 \leq j \leq n$$

$$if \;\; a_i = b_j, w\left(a_i, b_j\right) = w(match)$$

$$if \;\; a_i \neq b_j, w\left(a_i, b_j\right) = w(mismatch)$$

$$H_{AB}(i,j) = max \begin{Bmatrix} 0 \\ H_{AB}(i-1,j-1) + w\left(a_i, b_j\right) \; Mach/Mismatch \\ H_{AB}(i-1,j) + w(a_i, "\_") \; Match \; with \; blank \\ H_{AB}(i,j-1) + w\left("\_", b_j\right) \; Match \; with \; blank \end{Bmatrix}, 1 \leq i \leq m, 1 \leq j \leq n, \tag{3}$$

where a_i and b_j are the *i*th procedure step of the antecedent HFE and the *j*th step of the subsequent HFE, respectively, w(a_i, b_j) is the similarity value of the two aligned steps, and $H_{AB}(i,j)$ is the maximum similarity score of the two sequences from the initial step to the *i*th and *j*th steps.

Based on evidence found from the HuREX (human reliability extraction) data (Kim et al., 2020), $CRD_{A,B}$ takes a value of 0.5 when the two HFEs are stimulated by the same instrumentation cues. If the locations of the cues or the interface objects are different or an additional cue is generated, then $CRD_{A,B}$ is 0.

$RF_{A,B}$ deals with the recovery possibility of an incorrect mental model by voluntary re-examinations of past procedures. If the time margin of the subsequent HFE is longer than the sum of the re-examination time and the time margin of the antecedent HFE, $RF_{A,B}$ is 0.5. If the time margin of the subsequent HFE is no longer than the sum or recovery attempts by operators are not expected, then $RF_{A,B}$ is 1.

In this method, it was assumed that the resource impact and mental model impact are effective only when the crews carrying out the tasks in the two HFEs are the same. If the crews are different, the temporal resources of the subsequent crew do not interfere with the antecedent crew, and different viewpoints can be generated be the antecedent crew. Therefore, $CS_{A,B}$ is 1 when the two crews are same, while $CS_{A,B}$ is 0 when they are different. Here, the crew implies a shift team including the control room operators and field operators, not an individual operator.

On the basis of estimates from expert opinions and empirical data, ACE_B is 5 if the PSF level of the subsequent HFE is changed according to the result of the antecedent HFE. Practitioners can review whether the task complexity level or stress level is accelerated by the antecedent HFE compared to its original level.

3. Dependency assessment under success event intervention

This paper mathematically models the effect of an HSCE intervening between two HFEs on the dependency between the two HFEs. This study generally considers basic human events in a risk model, typically represented by fault trees or event trees. These human events correspond to the purposes of various tasks related to understanding accident situations and operating equipment. Because most HSCEs are not generated in the cutset, HRA practitioners should analyze the scenarios to identify HSCEs. For example, the opposite results of HFEs in an event tree could be anticipated to find the HSCEs. Similar to the EPRI (2016) method (EPRI, 2016), direct recovery of the antecedent HFE is not regarded as an HSCE, but an action included in the HFE itself. This issue is discussed here in Section 4.

3.1. Effect of the success event on the dependent relation

Based on the present method, it is discussed the extent to which an HSCE can alleviate the dependency between two HFEs based on the four factors presented above. First, a reduction in the temporal resource impact is expected in the case of the HSCE requiring a significant performance time. If the HSCE intervenes, its performance time may affect the temporal resources of the subsequent HFE. However, if the time required of the HSCE are negligible and the tasks belonging to the two HFEs are performed according to procedures or trained practices, the temporal effect of the HSCE will be minimal. Second, an HSCE does not usually transform the procedural flow of the subsequent HFE. This means that an HSCE has no significant effect on the feasibility impact of the subsequent HFE. If the HSCE changes the flow of the procedure, the analyst can redefine the step sequence of the subsequent HFE and calculate the PTS.

Third, the PSF level of the subsequent HFE may change because of an HSCE. For example, the stress level of the subsequent HFE may be relieved by the HSCE. In this case, the effects of the antecedent HFE and intervening HSCE on the PSF levels should be predicted. Finally, as Whaley et al. (2012) stated, an HSCE has the potential to correct inappropriate mental models utilized in the antecedent HFE. The HSCE provides an opportunity to re-evaluate the situation and break the dependency between the two events. However, in this situation, it is necessary to consider the cognitive or contextual connection between the antecedent HFE and HSCE. This is because information that is completely unrelated to the antecedent HFE cannot change the mental model of the antecedent HFE (Kim et al., 2023).

3.2. Modified equation of conditional HEP

The equation to estimate the conditional HEP of the subsequent HFE considering an HSCE intervention can be written as follows:

$$P(B|A,S) = \left[TRI_{A,S,B} + \left\{PTS'_{A,B} + CRD_{A,B} - PTS_{A,S} - CRD_{A,S}\right\} * RF_{A,B}\right] * CS_{A,B} + P(B) * ACE'_{B}, \quad (4)$$

where S is the HSCE intervening between the two HFEs, $PTS'_{A,B} - PTS_{A,S} \geq 0$, and $CRD_{A,B} - CRD_{A,S} \geq 0$.

This equation indicates that the $TRI_{A,B}$ is needed to reassess considering the time required of the HSCE. The following formula could be an instance of the updated calculation for the temporal resource reduction.

$$TRI_{A,S,B} = 1 - \Phi\left[\ln\left\{\left(Ta_{B,end} - Max(Tr_{A,end}, Tr_{S,end})\right)/\left(Tr_{B,end} - Tr_{B,start}\right)\right\}/\sigma\right], \quad (5)$$

Equation (4) also implies that $PTS_{A,B}$ and $CRD_{A,B}$, which are the estimators of the mental model impacts, are reduced by $PTS_{A,S}$ and $CRD_{A,S}$. It is noteworthy that $PTS_{S,B}$ and $CRD_{S,B}$ are not included in this equation. Similar HSCE procedural or instrumentation cues to the cues of the subsequent HFE cannot ensure that the inappropriate mental model used in the antecedent HFE will be corrected. Instead, if $PTS_{S,B}$ and $CRD_{S,B}$ are significantly high, the sum of $PTS_{A,S}$ and $CRD_{A,S}$ may be high when the two HFEs have similar cues. Otherwise, the sum of $PTS_{A,B}$ and $CRD_{A,B}$ will be low when the antecedent HFE cues are different from those of the subsequent HFE. In both cases, this equation produces a low value of $P(B|A)$. For example, if the HSCE and subsequent HFE are initiated by a pressurizer level cue, then $CRD_{A,B} - CRD_{A,S}$ is very low. This is because if the cue of the antecedent HFE is also pressurizer level, $CRD_{A,S}$ will be high, while if the antecedent HFE is stimulated by another cue, $CRD_{A,B}$ will be low.

The prime symbols (i.e., $PTS'_{A,B}$ and ACE'_{B}) emphasize that practitioners are required to review whether the HSCE will change the procedure flows or the PSF levels of the subsequent HFE. In other words, the impacts of the HSCE on the psychological states or task flows of the next events should be evaluated before dependency quantification. The fact that only $RF_{A,B}$, $CS_{A,B}$ and $P(B)$ in the above formula are the same as equation (1) means that the existence of the HSCE can have significant effect of the dependency between the two HFEs.

When $CRD_{A,S}$ is calculated, practitioners should analyze whether the instrumentation cue stimulating the HSCE can provide different viewpoints that might change the mindset involved during the antecedent HFE. Therefore, as when calculating $CRD_{A,B}$, it should not be concluded that $CRD_{A,S}$ is 0 just because the cue objects of the antecedent HFE and the HSCE are different. If the cues of the HSCE are linked to the same safety goal as the cues of the antecedent HFE and they pertain to the same system, then $CRD_{A,S}$ can be 0.5.

4. Implication for applicable cases

Results of the proposed equation depend on given risk models and contexts. Nevertheless, the proposed method provides some general considerations for dependency assessments.

4.1. Relevance of success event to a failure event

There are cases where an HSCE is included that is not fully related to the antecedent HFE; Figure 1 shows an example event tree related to such a situation. In this example, there is an HSCE for AC power recovery between two HFEs for heat removal of the secondary system (antecedent HFE) and feed-and-bleed operation (subsequent HFE). All actions for the HSCE or HFEs are prescribed in the procedure for a station blackout accident in the plant. Thus, in terms of $PTS_{A,S}$, the HSCE for AC power recovery is expected to contribute to mental model recovery. However, the instrumentation objects for heat removal of the secondary system and AC power recovery are different. The safety goals that can be achieved by both sets of tasks are also different (former: heat removal of reactor coolant system, latter: securing essential power). Therefore, it is reasonable to say that the HSCE for AC power recovery is not effective in reducing the dependency between the two HFEs regarding $CRD_{A,S}$.

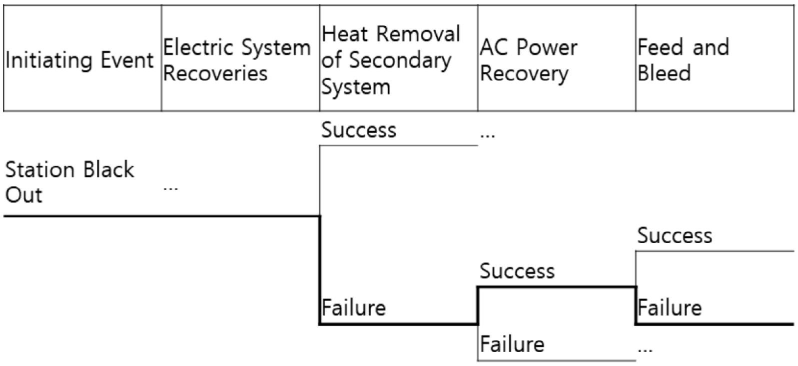

Fig. 1. Event tree for station blackout.

Figure 2 presents another similar example of an event tree featuring an HSCE intervening between two HFEs, in a loss of coolant accident (LOCA) scenario. The two HFEs are the failure to secure safety injection (antecedent HFE) and to conduct injection using the shutdown cooling system (subsequent HFE), while the HSCE is required to rapidly cool down the reactor coolant using the secondary system. As in Figure 1, since the human actions for the safety injection, the rapid cool down, and the injection using the shutdown cooling system are written in the same procedure, the $PTS_{A,S}$ will increase and *P(B|A)* will be consequently reduced. But the instrumentations for the safety injection and the rapid heat removal are different, as are their safety goals. Therefore, it is hard to conclude that the HSCE using the secondary system can make the two HFEs independent. Of course, because the instrumentation cues associated with the two HFEs are different, $CRD_{A,B}$ is expected to be low.

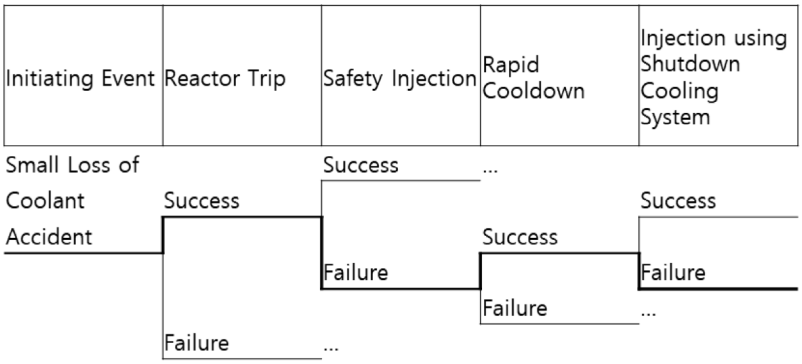

Fig. 2. Event tree for loss of coolant accident [adapted from the case in EPRI (2016)].

4.2. Successful reactor trip between pre-trip and post-trip events

Equation (4) does not support that the pre–initiating event actions are always independent of the post–initiating event actions. Most pre–initiating HFEs usually have a very long time available; hence, their dependencies on the post–initiating HFEs are weak due to $RF_{A,B}$ or $CS_{A,B}$ in general. In addition, the procedures for pre–initiating event actions and post–initiating event actions are totally different in most cases. However, some initiating event actions are temporally close to the time of reactor trip. Therefore, if the initiating event actions and the reactor trip actions have no association of procedures or instrumentation cues, the reactor trip actions may not be effective to modify inappropriate mental models and have temporal influences on the subsequent HFE.

4.3. Direct recovery action

In this method, a direct recovery action from the antecedent HFE is not considered an HSCE. Some analysts may subdivide human events into action units and represent their recovery actions as one HSCE (e.g., a basic event of event trees). In this case, because the contextual relationship between the antecedent HFE and HSCE is very close, Equation (4) can be used to conclude that the HSCE will modify all inappropriate mental models associated with the antecedent HFE. But this is not a sufficiently conservative statement. Because the recovery action is performed within the context of the antecedent HFE, it is more reasonable not to view that the recovery action will provide a new independent opportunity to modify the existing understanding of the context.

5. Conclusion and future work

In this study, a quantitative method for estimating the impact of an HSCE was presented based on the EMBRACE dependency method. In addition, based on the presented method, we reviewed various cases regarding the HSCE impacts that can be found in risk models. The EMBRACE dependency method clearly distinguishes the main elements of dependency and mathematically integrates their effects. Accordingly, this method allows the derivation of a logical basis for dependency assessment results. The impacts of an HSCE on the dependency between two HFEs can also be mathematically modelled and explained with more rationale, as shown in this paper. In other words, the proposed method can clearly quantify the impact of HSCEs on the modification of incorrect mental models and the reduction of the temporal resource.

The present study has the following limitations. First, theoretical or empirical validations are required to secure the legitimacy of the formulas. In particular, the proposed method assumes that similar cues of an HSCE to cues of an antecedent HFE will modify the incorrect mental model in proportion to their similarity. There may be cases where operators succeed in the HSCE tasks while maintaining an incorrect mental model. To understanding these phenomena, more theoretical and experimental research on the impact of HSCE is needed in the future. Although it would be very difficult to collect and analyze empirical data on all dependency factors, there is a need to evaluate the usefulness and rationality of the mathematical models from various experts. Second, the guidance is not concretely established for determining the sameness of the task goals during calculation of $CRD_{A,S}$. The task goals of the instrumentation cues can be differently distinguished because there are various levels of task goals; Figure 3 shows an example. Practitioners can basically classify the task goals based on the critical safety functions (i.e., the top-level goals in Figure 3). The task goals can also be characterized depending on whether the instrumentation belongs to the primary system, the turbine system, or the electrical system. But it remains important to develop guidelines in conjunction with a discussion of how operators' mental models are interconnected with the systems and task goals. Third, the EMBRACE dependency method relies on the assumption that human actions are conducted based on a systematic procedure system. Consequently, some skill-based or knowledge-based tasks that are not instructed by procedures may not be clearly analyzed to estimate $PTS_{A,B}$ or $PTS_{A,S}$. To analyze uninstructed tasks, it is important to manifest the action sequences of the HFE tasks and compare the sequences by assuming that there are implicit procedures for the tasks in the operator's mind. In this case, practitioners should examine how similar the actions of the sequences are and how they can affect the understanding of the situation.

Despite the above weaknesses, the proposed method represents a first attempt to establish a numerical basis for quantitative relationships determining dependency. It overcomes the insufficiently conservative assumption that an HSCE guarantees the independence of two HFEs, and enables more realistic conditional HEP calculation.

In the future, we plan to apply the method presented in this paper to various scenarios and validate the results through empirical data and expert opinions.

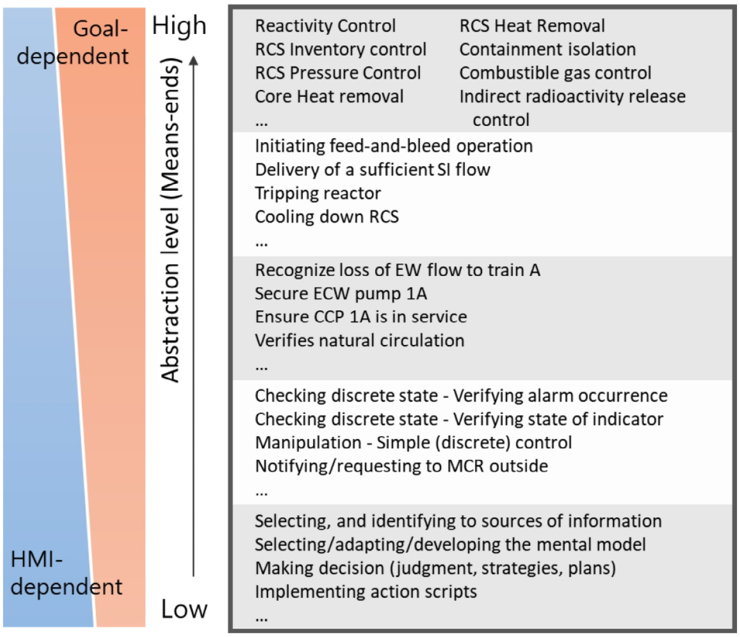

Fig. 3. Different task goal levels according to means–ends relationships (Kim, 2020).

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References

Čepin, M. 2008. DEPEND-HRA—A method for consideration of dependency in human reliability analysis. Reliability Engineering & System Safety, 93(10), 1452-1460.

EPRI 2016. A Process for HRA Dependency Analysis and Considerations on Use of Minimum Values for Joint Human Error Probabilities. 3002003150, Palo Alto, CA: Electric Power Research Institute

Gertman, D., Blackman, H., Marble, J., Byers, J., & Smith, C. 2005. The SPAR-H human reliability analysis method. NUREG/CR-6883, INL/EXT-05-00509, Washington DC: US Nuclear Regulatory Commission

Kichline, M., Xing, J., & Chang, Y. J. 2021. Integrated Human Event Analysis System Dependency Analysis Guidance (IDHEAS-DEP). RIL 2021-14, Washington, DC:US Nuclear Regulatory Commission
Kim, Y. 2020. Considerations for generating meaningful HRA data: Lessons learned from HuREX data collection. Nuclear Engineering and Technology, 52(8), 1697-1705.
Kim, Y., Kim, J., Park, J., Choi, S., & Kim, H. 2020. An HRA Method for Digital Main Control Rooms-Part II: Estimating the Failure Probability Due to Cognitive Error, KAERI/TR-8065/2020, Daejeon: Korea Atomic Energy Research Institute.
Kim, Y., Kim, J., & Park, J. 2023. A data-informed dependency assessment of human reliability. Reliability Engineering & System Safety, 239, 109539.
Kim, Y., Kim, W. S. 2023. Which Distribution Best Describes Human Performance Time?. Transactions of the Korean Nuclear Society Autumn Meeting 2023, Gyeongju, Korea.
Podofillini, L., Dang V. N. 2024. HRA dependence emerging from operational events: identification of influencing factors. Proceedings of the 34th European Safety and Reliability Conference, Cracow, Poland.
Smith, T. F., & Waterman, M. S. 1981. Identification of common molecular subsequences. Journal of molecular biology, 147(1), 195-197.
Whaley, A. M., Boring, R. L., Blackman, H. S., McCabe, P. H. & Hallbert, B. P. 2007. Lessons learned from dependency usage in HERA: Implications for THERP-related HRA methods. In 2007 IEEE 8th Human Factors and Power Plants and HPRCT 13th Annual Meeting (pp. 322-327). IEEE.
Whaley, A. M., Kelly D. L. 2012. Guidance on Dependence Assessment in SPAR-H. (No. INL/CON-12-24796). Idaho National Lab.(INL), Idaho Falls, ID (United States).