A Case Study for the Selection of a Railway Human Reliability Analysis Method

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1. INTRODUCTION

Human reliability analysis (HRA) plays a role of identifying and assessing the potential for human erroneous actions as an integral part of the probabilistic risk assessment (PRA). The Railway - Human Reliability Analysis (R-HRA) plays such a role in the railway risk assessment framework. Since human error occurs under a specific condition, HRA should consider this condition adequtely in assessing the human error probability (HEP).

This study introduces a case study that aims at selecting an appropriate R-HRA method by reviewing exisiting HRA methods. In nuclear and aviation industries, since the 1970's various HRA methods have been developed and are being used in risk assessments. Representatives are THERP [1], ASEP [2], HCR [3], SLIM [4], HEART [5], and so on. Among them, the most popular ones are THERP/ASEP and HEART. In Korea, a domestic standard HRA method, which is named K-HRA (Korean Human Reliability Analysis), has been developed and is currently in use in the nuclear industries [6]. The method has its basis on the THERP/ASEP method, and includes some important performance shaping factors (PSFs) and provides an analysts' guidance to support a consistent application of the method. Recently, the Rail Safety and Standard Board (RSSB) issued a rail-specific HRA method which incorporated some rail-specific taxonomy of human error [7].

In this study, we selected the K-HRA method, HEART, and the RSSB-HRA method as candidates, and derived the strengths and limitations of each method from the viewpoint of its applicability to the railway tasks and environments by applying them to some real events in the railway industry. And finally, the most appropriate method was suggested.

2. Review of HRA Methods

2.1 HEART

HEART provides a relatively simple framework composed of the generic task type (GTT) and a set of performance shaping factors (PSFs). The nominal error probabilities (NEPs) are given according to 9 GTTs, and 38 error-producing conditions (EPCs) or PSFs are used to increase the likelihood of an error occurrence. The general application steps are as follows:

- Step 1: Selection of GTT (Determination of the NEP)
- Step 2: Selection of PSFs relevant to task situations
- Step 3: Assessment of the rating of the selected PSFs
- Step 4: Calculation of the final HEP.

The final HEP is obtained by using the following equation,

- Final HEP = NEP * Π [$R(i)$ * ($W(i)$ - 1) + 1],

where the NEP is given for a selected GTT, and $W(i)$ and $R(i)$ are the weight and rating of the i-th PSF, respectively.

2.2 RSSB-HRA

The RSSB-HRA method purports to develop a rail-specific HRA method. The structure of the method is composed of two modules, i.e. the human error identification (HEI) module and the human error quantification (HEQ) module. The method provides a link between two modules, but each module can be used independently.

The process for HEI is as follows:

- Preparing stage: the stage for information gathering
- Step 1: Identification of the external error modes (EEMs)
- Step 2: Identification of the cognitive domains, the internal error mode (IEMs), the psychological error mechanisms (PEMs)
- Step 3: Identification of the performance shaping factors (PSFs)
- Step 4: Identification of error detection and recovery measures

It provides 24 EEMs in the realms of 'selection and quality', 'timing and sequence', and 'communication'. As a cognitive domain, it provides 5 domains such as perception, decision, memory, action, and violations, according to the Wicken's information processing model [8]. IEMs and PEMs are defined by each cognitive domain.

The process for HEQ is very similar to that of HEART except that the GTT of HEART is replaced by the generic error type (GET) and the set of PSFs are partly modified. The process for HEQ is as follows:

- Step 1: Selection of the GET (Determination of the generic error probability (GEP))
- Step 2: Selection of PSFs relevant to the situation
- Step 3: Assessment of the rating of the selected PSFs
- Step 4: Calculation of the final HEP

The GET is divided into 7 types based on the Wicken's model. For each GET, the GEP and the uncertainy bound are defined. The final HEP is obtained with the following equation for a given GET, and the weight ($W(i)$) and rating ($R(i)$) of the PSFs.

- Final HEP = GEP * Π [$R(i)$ * ($W(i)$ - 1) + 1]

2.3 K-HRA

The K-HRA method consists of the pre-accident HRA and the post-accident HRA. The pre-accident HRA model is to assess the human error events that occur during normal activities such as maintenance, test, and calibration. The post-accident HRA is for emergency tasks that are required after reactor trip. The reason for dividing HRA into two realms is that the characteristics of the tasks and situations under these two categories are differenct from each other.

2.3.1 The Pre-Accident HRA Model

The pre-accident HRA model only considers the possibility of execution errors by neglecting the diagnosis errors since the workers during normal activities perform a set of predefined tasks according to work procedures. The human error probabilities for normal activities are calculated by using the following equation:

- HEP = NEP * α * R,

where NEP is a norminal human error probability for which 5.0E-3 is assigned, α is an adjusting value by the PSFs, and R means the recovery failure probability of the supervisor.

2.3.2 The Post-Accident HRA Model

Since the diagnosis and situation assessment activities by the operators, in the post-accident situations, take on a relatively important position to cope with an accident, the post-accident HRA model assesses both possibilities of the errors in diagnosis and execution.

The diagnosis error probability is assessed by using the following equation:

- Pr(diagnosis error) = Pr(nominal) * α ,

where, Pr(nominal) means the nominal diagnosis error probability which is determined from the THERP diagnosis curve for the available time for diagnosis, and α is an adjusting value by PSFs.

The execution error probability is assessed by using the following equation:

- Pr(execution error) = Σ [Pr(unit activity) * R]

where, Pr(unit activity) means the execution error probability for a unit activity, and R is the recovery failure probability.

3. Case Study

3.1 Case Selection

Two cases are selected for the case studies. The first event is the signal passed at danger (SPAD), and the second one is the Gomo-Gyungsan real-end collision accident that happened in Korea, in 2003. The reason that we chose these two events is that the SPAD event is the most frequenct cause of the railway accident and the Gomo-Gyungsan accident is an event that resulted from multiple human error occurrences.

- Case 1: SPAD

SPAD is known as the most frequent contributor to the railway accident. The causes of SPAD can be classified according to Reference [9].

- Signal not seen due to a bad visibility
- Misjudging of which signal applies to the train in question
- Misunderstanding or disregard of the signal
- Misjuding the effectiveness of the brakes under particular circumstances
- Overspeeding in relation to braking performance and warning signal distance
- Broken driving sequence

Among the above described causes, this case study deals with the upper three causes.

- Case 2: the Gomo-Gyungsan real-end collision accident

A passenger train (#303) departing from the Kimcheon station for the Busan station collided with a freight train (#2661) from behind on the line between the Gomo and Gyungsan stations [10]. This accident occurred by a multiple of human errors under the condition that the trains were controlled by a communication method, not by an automatic blocking system (ABS), due to a maintenance work for signals. The human error events that intervened in this accident can be divided into 4 stages:

- HE-1: Missed safety actions for signals that should not be used for train operation at the Gomo station and between the Gomo and Gyungsan stations
- HE-2: The signaller at Gomo station started the freight #2661 train by displaying the starting signal not to be used then
- HE-3: The signaller at Gomo station passed the next passenger train (#303) without checking arrival of the preceding freight train (#2661) which were still on the railroad between two stations
- HE-4: The passenger train (#303) perceived the freight train (#2661) but failed to brake at right time.

This study selected HE-3 as a case which is considered to be the most closely related to the occurrence of the accident.

3.2 Application to Case 1

3.2.1 Application of RSSB-HRA

According to the analysis of the three categories of SPAD by using RSSB-HRA, the first two causes are induced from the error in signal perception, and the third one from the error in judgment (see Table 1). This shows that the SPAD event occurs due to the problems in human perception and judgment stage rather than in execution stage. The PEMs and PSFs relevant to each cause are also derived based on the taxonomy of RSSB-HRA, as shown in Table 1. Based on the qualitative analysis, the GET and GEP, the PSFs and their ratings are determined to produce the final HEP (Table 2). According to the quantative results, the first error mode, i.e. Driver fails to check a signal, showed the hightest likelihood of a failure. This is because some specific conditions such as the visibility of a signal or weather condition are reflected in the assessment.

Table 1. Qualitative analysis of case 1 by RSSB-HRA

Task Step	EEM	Domain & IEMs	PEMs	PSFs
Signal detection and stop	Driver fails to check signal	Perception-No detection	Perceptual discrimination failure Distraction/Pre-occupation Vigilance failure	Location of signals, Visibility, Alarms quality, In-cab environment
	Drive checked a wrong signal	Perception-misidentification	Spatial confusion	Location of signals, Visibility, Alarms quality, Experience, Familiarity
	Drive checked right signal but misunderstood/ disregard it	Decision-Misprojection	Mind set	Time pressure, Attitude, Alarms/warning quality, Confidence

Table 2. Quantitative assessment of case 1 by RSSB-HRA

EEM	**GET**	**GEP**	**PSF (max, rating)**	**PSF Value**	**HEP (GEP* $\prod PF_i$)**
Driver fails to check signal	Detection	1.11E-04	Ability to detect and perceive (10, 0.5) Unfamiliarity (17, 0.1)	PF_1=(9*0.5)+1=5.5 PF_2=(16*0.1)+1=2.6	1.59E-03
Drive checked a wrong signal	Perception	2.05E-05	Ability to detect and perceive (10, 0.5) Unfamiliarity (17, 0.1)	PF_1=(9*0.5)+1=5.5 PF_2=(16*0.1)+1=2.6	2.93E-04
Drive checked right signal but disregard it	Decision	1.65E-06	Time availability (11, 0.1) Risk perception (4, 0.5)	PF_1=(10*0.1)+1=1.1 PF_2=(3*0.5)+1=2.5	4.54E-06

3.2.2 Application of HEART

HEART method does not contain a qualitative analysis module. In the quantification using HEART the same PSFs and ratings are used as RSSB-HRA except for the GTT. According to the quantitative results (Table 3), the results by HEART show higher (2-order or more) values than the ones by RSSB-HRA. This is because the NEPs according to the GTTs do not reflect the SPAD related task characteristics.

Table 3. Quantitative assessment of case 1 by HEART

EEM	GTT	GEP	PSF (max, rating)	PF Value	HEP (GEP* $\prod PF_i$)
Driver fails to check signal	Routine, highly-practiced, rapid task involving relatively low level of skill	0.02	Ability to detect and perceive (10, 0.5) Unfamiliarity (17, 0.1)	PF_1=(9*0.5)+1=5.5 PF_2=(16*0.1)+1=2.6	0.286
Drive checked a wrong signal	Routine, highly-practiced, rapid task involving relatively low level of skill	0.02	Ability to detect and perceive (10, 0.5) Unfamiliarity (17, 0.1)	PF_1=(9*0.5)+1=5.5 PF_2=(16*0.1)+1=2.6	0.286
Drive checked right signal but disregard it	Routine, highly-practiced, rapid task involving relatively low level of skill	0.02	Time availability (11, 0.1) Risk perception (4, 0.5)	PF_1=(10*0.1)+1=1.1 PF_2=(3*0.5)+1=2.5	0.055

3.2.3 Application of K-HRA

The pre-accident HRA model is applied in this case. As shown in Table 4, the HEP results show different values depending on the level of MMI. However, it is shown that the PSFs used in the K-HRA do not treat the work situation or condition of this case adequately because the pre-accident model of K-HRA was developed for the normal activities of nuclear power plants. On the other hand, when the post-accident model is applied to this case, the HEP results in 1.0 due to a very limited available time.

Table 4. Quantitative assessment of case 1 by K-HRA

EEM	GEP	Task Complexity	Procedure	MMI	Recovery failure probability	HEP
Driver fails to check signal	5.0E-03	High (0.5)	Medium (1.0)	Low (2.0)	1.0	5.0E-03
Drive checked a wrong signal	5.0E-03	High (0.5)	Medium (1.0)	Low(2.0)	1.0	5.0E-03
Drive checked right signal but disregard it	5.0E-03	High (0.5)	Medium (1.0)	Medium (1.0)	1.0	2.5E-03

3.3 Application to Case 2

3.3.1 Application of RSSB-HRA

Table 5 shows the qualitative analyses of the RSSB-HRA for the HE-3 of case 2. The most appropriate internal error mode is a situational violation in the cognitive domain of Violation or the misprojection in the cognitive domain of Decision. The relevant PSFs are 'time pressure', 'workload', and 'complacency', and these factors are used as the terms of 'available time' and 'risk perception'. The final HEP is calculated to be 2.28E-3 by considering the GET and GEP and the level of the PSFs (Table 6).

Table 5. Qualitative analysis of case 2 by RSSB-HRA

Task Steps	EEMs	Domain-IEMs	PEMs	PSFs
3.1 Certify the arrival of the preceding train by telephone	Information not sought	Violation-Situational Decision-Misprojection	Risk recognition failure	Time pressure, Workload, Complacency
3.2 Passing of the next train after arrival of the preceding train	Action too early	Violation-Situational Decision-Misprojection	Risk recognition failure	Time pressure, Workload, Complacency

Table 6. Quantitative assessment of case 2 by RSSB-HRA

EEMs	**GET**	**GEP**	**PSF (max, rating)**	**PSF Value**	**HEP (GEP* ∏ PF_i)**
Information not sought	Decision failure	3.68E-5	Time availability (11, 0.9) Risk perception (4, 0.7)	PSF_1=(10*0.9)+1=10 PSF_2=(3*0.7)+1=3.1	**1.14E-3**
Action too early	Decision failure	3.68E-5	Time availability (11, 0.9) Risk perception (4, 0.7)	PSF_1=(10*0.9)+1=10 PSF_2=(3*0.7)+1=3.1	**1.14E-3**
Total HEP					**2.28E-3**

3.3.2 Application of HEART

The same PSFs and ratings are used as RSSB-HRA, but instead of the GET of RSSB-HRA, the GTT of 'Fairly simple task performed rapidly or given scant attention' is used. By considering that this GTT contains the meaning of the PSFs to be considered, the NEP value is used as it is without additionally reflecting the effect of the PSFs. The final HEP is 0.09 (Table 7).

Table 7. Quantitative assessment of case 2 by HEART

GTT	**GEP**	**PSF (max, rating)**	**PSF Value**	**HEP (GEP* ∏ PF_i)**
Fairly simple task performed rapidly or given scant attention	0.09	Time availability (11, 0.9) Risk perception (4, 0.7)	Already included in GTT	**0.09**

3.3.3 Application of K-HRA

The post-accident model of K-HRA was applied to the HE-3 event because the task is performed under the existence of time pressure. When the available time for diagnosis is assumed to be 2 minutes, the THERP diagnosis curve gives 1.18E+00 as a diagnosis error probability exceeding 1.0 (the highest value). Resultingly, the HEP produces 1.0 (Table 8).

Table 8. Quantitative assessment of case 2 by K-HRA

Diagnosis error (=1.0)		**Execution error (=0.05)**		**Final HEP**
Basic DEP	Adjusting factor	Error per unit activity	Recovery failure probability	
DEP(available time < 2min)=1.0	f(major activity(Y), MMI(M), training(M), Procedure(M)) = 1.0	f(task type: step-by-step, stress level: extremely high) = 0.05	1.0	**1.0**

4. Discussion and Conclusion

As shown in Table 9, the HRA results for the two cases are different more or less according to the method used. The RSSB-HRA method gives relatively lower values than others, and in the case of the post-accident model of the K-HRA method it gives a very high HEP value.

Table 9. Comparison of HRA results for Case 1&2

	RSSB-HRA	HEART	K-HRA
Case 1	4.54E-06 ~ 1.59E-03	2.18E-02 ~ 5.5E-01	1.25E-03 ~ 5.0E-03 (the pre-accident model)
Case 2	2.28E-3	9.0E-2	1.0 (the post-accident model)

The validity of the HEPs by the HRA methods is out of the scope of this case study because of a lack of available data for a comparison. But, the case study compares the strengths and limitations of each method from the viewpoint of the applicability to the railway tasks and environments. The applicability specifies how adequately the method represents the tasks and environments of the railway operation.

Firstly, as an overall problem of HRA, a quantification scheme for a violation type is absent. The RSSB-HRA provides detailed error modes in the qualitative module but no quantification framework in the quantitative module. This is applicable for all the HRA methods, thus this criterion is excluded for a selection of the R-HRA method.

The taxonomy of RSSB-HRA consists of error modes and PSFs. Since the taxonomy of error modes is constructed on the basis of the Wicken's model of human information processing by adding some rail-specific error modes, it provides a strength that can be used irrespective of a specific task. Also, the taxonomy of PSFs basically adopts that of HEART by modifying some PSFs according to the domain of the railway environments. But, it still depends on the analysts to decide which PSFs are considered for a given task, which may result in an inconsistent selection and assessment of the PSFs.

HEART provides the taxonomy of task types and PSFs that seem to be generic, but the current list of the GTT does not adequately represent the characteristics of the railway tasks. This not only makes the selection of a task type difficult, but it also has room to cause an inconsistency of the intra- and inter- analyst.

The K-HRA method provides systematic and proceduralised rules for the quantification of the HEP. But, it has some problems in using the method for the railway tasks. The first problem is that the division of the pre-accident and the post-accident model is difficult to apply to the railway tasks because for the railway tasks the boundary between the pre- and post-accident is not clear. The second problem is that the PSF taxonomy and quantification rules are not adequate for the railway tasks because they are equipped for nuclear environments. Another problem in the quantification schemes is that the THERP diagnosis curve could provide a very high value for a very short available time which may seem unreasonable for some tasks and situations.

Through the evaluation from the case studies, we judged that the RSSB-HRA provides the most appropriate HRA framework for the railway tasks and environments. The RSSB-HRA method still has some problems in an actual use for the risk assessment, such as higher resources for the whole analyses required, potential of producing an inconsistency between analysis results, and so on. Further modifications and refinements are needed for it to be adequately used for the railway risk assessment framework.

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