Evaluation of operator support system from the perspective of reducing human error probability

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Abstract: Human error is considered as a major contributor to the historical events and accidents in nuclear power plants. Various operator support technologies have been proposed and developed so far, however, only a few of them have been applied in practice because nuclear industries hold a conservative view on the introduction of intelligent technologies into main control rooms to aid decision-making of operators. Since the development of a fault-free software product is impossible, the most basic requirement for the application of a theoretically imperfect operator support system is expected so that further increase of the possibility of human error occurrence should be avoided. This paper takes the operators starting Chemical and Volume Control System (RCV or CVCS) by soft controls in advanced main control room as an example to demonstrate the role of an Operator Support System (OSS) in human error reduction and the its potential problems in misleading operators. The analysis results show that a systematic trade-off analysis should be made for an OSS before it is introduced into the main control room and human error analysis technologies can serve for this purpose.

Keyword: advanced main control room; soft control; operator support system; human error; nuclear safety

1 Introduction

The advanced MCRs utilize digital and computer technologies and are featured by large display panels, computerized procedures as well as soft controls by mouse, touch screen and so on[1]. The introduction of digital computer systems can provide operators with much more operational information of plant systems and a more convenient way in undertaking monitoring and control activities[2] on one hand, and will increase the operators' cognitive loads in information processing on the other hand. Furthermore, the monitoring and cross-checking of operators' actions become more difficult. Accordingly, comparing with traditional MCR, human error probabilities of operators in the advanced MCRs may be improved or worsened.

The idea of introducing Operator Support Systems (OSSs) into the MCRs for easing operators' cognitive and workloads can be traced back to the Three Mile Island accident. During the past three decades, various OSSs for assisting operators in monitoring[3], alarm analysis[4], fault diagnosis[5], risk monitoring[6,7] and emergency operating procedure presentation[8] have been proposed and developed. However, only a few of them have been actually applied so far. On one hand, nuclear power companies hold a conservative attitude on intelligent technologies for the fear of introducing new risks into MCRs. On the other hand, the operators especially skilled operators are more prone to their experiences rather than the suggestions given by computers.

There are many reasons for operators' reluctance to turn to an OSS for help. For example, the operators can complete their tasks very well even in the absence of the guidance of an OSS if a task very is very easy or familiar to them. On the contrary, for a complex situation that the operators have never been experienced, the guidance by an OSS may not always reliable enough to be trusted. As a computer software product, an OSS will no doubt exist residual defects or even errors which are impossible to be fully identified and erased. In some certain conditions, they may be triggered and result in incorrect results which may mislead the operators to make wrong decisions. In addition to incorrect results, lack of observable operational information may lead to

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uncertainties in the reasoning process and results of an OSS. It will require operators to have extra knowledge on how the OSS processes plant data to yield the results in order to verify the rationality of the results given by the OSS.

An acceptable OSS must convince the operators to follow its instruction without degrading their abilities in correct decision making. It is a very intuitive feeling that the effectiveness of an operator utilizing an OSS is different from the others, depending on many factors such as the complexity and urgency of missions, the operator's experience and skills, the human-machine interface design of OSS and the interactive modes between OSS and operators. Therefore, a systematic trade-off analysis for these factors should be made for an OSS before it can be introduced into the MCR. This paper presents a theoretical study on an quantitative assessment of an OSS in human error reduction from a probability theory point of view.

2 Human error estimation model

This paper takes the operators starting the Chemical and Volume Control System (RCV or CVCS) at a Pressurized Water Reactor (PWR) plant under normal cold shutdown condition as an example. The structure of the whole operating procedures is shown in Fig.1.

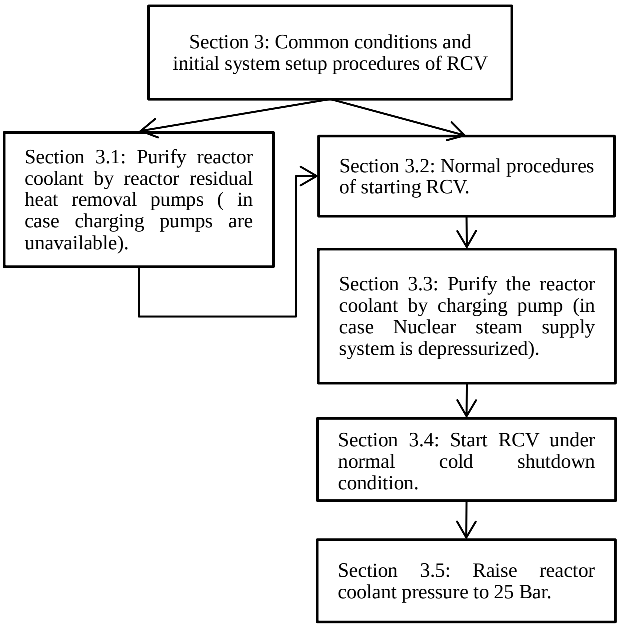

Fig.1 Common conditions and initial system set-up procedures of RCV.

One of the major tasks entitled Section 3.3 is used to purify the reactor coolant by charging pump of RCV and is selected for analysis. It involves 19 subtasks and 70 steps which will be implemented on 4 computer screens. Figure 2 shows one of the soft control screens of the RCV.

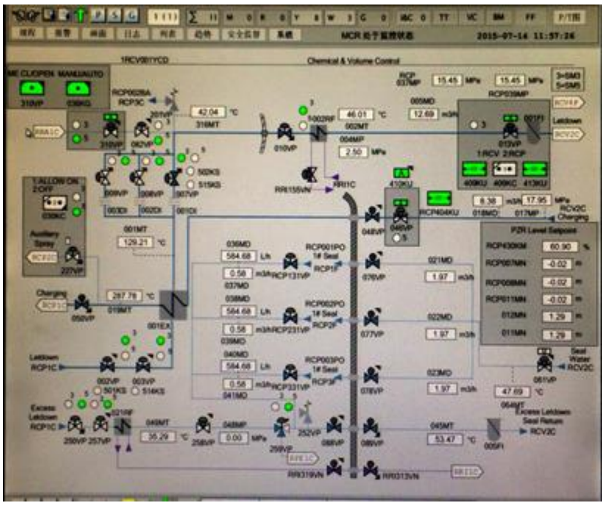

Fig. 2 Soft control screen of the RCV.

2.1 Modelling hypotheses

The human error modeling and quantification take the following hypotheses.

(1) Subtasks 1, 5 and 6 will turn to other procedures for implementing and subtasks 9 and 18 require for in-situ operations (as shown in Table 1). These 5 subtasks are not within the scope of this study.

(2) The level of HMI is devided into three levels: high, medium and low, according to the level of HMI design and whether or not there exist indicators for operators to confirm their execution results.

- High: there is indicators that operators were able to confirm the execution results or operating status can be confirmed in MCRs.
- Medium: there is indicators normally located.
- Low: there is no indicators that operators were able to confirm the execution results.

The design level of HMI in this study as shown in Fig.1 for the soft control of starting RCV is considered as medium.

(3) The allowed mission time (the total time required for RCV startup) is 60～120 minutes.

(4) Operators implement the control tasks independently without any supervision.

2.2 Task sequence analysis

The task analysis results of RCV starting procedures are shown in Table1. The subtasks, steps as well as the human error modes are presented in Table 2 where the human errors of soft control are classified into the following 8 modes[9]:

(1) operation selection omission (E0)
(2) operation execution omission (E1)
(3) wrong screen selection (E2SS)
(4) wrong device selection (E2DS)
(5) wrong operation (E3)
(6) mode confusion (E4)
(7) inadequate operation (E5)
(8) delayed operation (E6)

Table 1 Task sequence of RCV starting procedures

<table>
<tr><th>Task</th><th colspan="2">Subtasks</th></tr>
<tr><td rowspan="22">Purify the reactor coolant by charging pump（NSSS was already depressurized）</td><td colspan="2">1. Ensure the volume control tank under nitrogen blanket (Go to procedure S1RCV003)</td></tr>
<tr><td colspan="2">2. Close the letdown valve</td></tr>
<tr><td colspan="2">3. Close the charging valve</td></tr>
<tr><td colspan="2">4.Fully open the isolating valve of RRA-RCV line</td></tr>
<tr><td colspan="2">5. Start a charging pump (Go to S1RCV005)</td></tr>
<tr><td colspan="2">6. Change the inlet of charging pump to RCV02BA (Go to Section 3.2)</td></tr>
<tr><td colspan="2">7. Open the containment isolating valve "130VD"</td></tr>
<tr><td rowspan="2">Establish the injection flow of shaft-seal #1</td><td>8. Open the isolating valve of seal-water injection</td></tr>
<tr><td>9. Instantaneously open the injection valve of shaft-seal#1（maximum to 15%）</td></tr>
<tr><td colspan="2">10. In-situ execute the first part of operation sheets in Section 3-03 of procedure S1RCV001</td></tr>
<tr><td colspan="2">11. Open the containment isolating valve "082VP"</td></tr>
<tr><td colspan="2">12. Open the isolating valve of charging line</td></tr>
<tr><td rowspan="3">Gradually open the low-pressure letdown valve to avoid water hammer</td><td>13. Connect the switch to RCP037MP</td></tr>
<tr><td>14. Set the handed control console to be "Automation"</td></tr>
<tr><td>15. Adjust the 013VP controller to ensure the RCP pressure at initial valve</td></tr>
<tr><td colspan="2">16. Manually increase the charging flow to ca. 10m^3/h according to the readings of 018MD</td></tr>
<tr><td colspan="2">17. Connect the tee valve to demineralization plant</td></tr>
<tr><td colspan="2">18. In-situ execute the second part of operation sheets in Section 3-03 of procedure S1RCV001</td></tr>
<tr><td colspan="2">19. Adjust RCV013VP controller to keep the system pressure of RCV, check the letdown flow readings and monitor the water level of 002BA</td></tr>
</table>

NSSS: Nuclear Steam Supply System

Table 2 Procedure steps of sub-tasks

Steps	Human Error Mode (Ej)							
	0	1	2SS	2DS	3	4	5	6
2.1 Select Subtask2	√							
2.2 Select "1RRA001YCD" screen			√					
2.3 Click "013VP" control				√				
2.4 Click "CLOSE" button		√			√			√
2.5 Click "OK" button		√						
3.1 Select Subtask3	√							
3.2 Select"1RCV001YCD" screen			√					
3.3 Click "046VP" control				√				
3.4 Click "CLOSE" button		√			√			√
3.5 Click "OK" button		√						
4.1 Click Subtask4	√							
4.2 Click "310VP" button				√				
4.3 Click "AUTO" button						√		√
4.4 Click "OK" button		√						
4.5 Set 100% Opening		√					√	√
4.6 Click "OK" button		√						
7.1 Select Subtask7	√							
7.2 Select "1REA001YCD" screen			√					
7.3 Select "130VD" control				√				
7.4 Click "OPEN" button		√			√			√
7.5 Click "OK" button		√						
8.1 Select Subtask8	√							
8.2 Select "1RCV002YCD" screen			√					
8.3 Click "060VP" control				√				
8.4 Click "OPEN" button		√			√			√
8.5 Click "OK" button		√						
9.1 Select Subtask9	√							
9.2 Select "1RCV001YCD" screen			√					
9.3 Select "061VP" control				√				
9.4 Set the opening no more than 15%		√					√	√
9.5 Click "OK" button		√						
11.1 Select Subtask11	√							
11.2 Click "082VP" Control				√				
11.3 Click "OPEN" button		√			√			√
11.4 Click "OK" button		√						
12.1 Select Subtask12	√							
12.2 Click "048VP" control				√				
12.3 Click "OPEN" button		√			√			√
12.4 Click "OK" button		√						
13.1 Select Subtask13	√							
13.2 Click "409KC" control				√				
13.3 Select "Set to RCP"		√			√			√
13.4 Click "OK" button		√						
14.1 Select Subtask14	√							
14.2 Click "408KU" control				√				
14.3 Click "AUTO" button						√		√
14.4 Click "OK" button		√						
15.1 Select Subtask15	√							
15.2 Click "413KU" control				√				
15.3 Locate "INT" at initial value		√					√	√
15.4 Click "OK" button		√						
16.1 Select Subtask16	√							
16.2 Click "046VP" control				√				
16.3 Click "MANU" button						√		√
16.4 Click "OK" button		√						
16.5 Set the flow to 10m^3/h		√					√	√
16.6 Click "OK" button		√						
17.1 Select Subtask17	√							
17.2 Select "1RCV002YCD" screen			√					
17.3 Click "017VP" control				√				
17.4 Set the location to demineralization plant		√			√			√
17.5 Click "OK" button		√						
19.1 Select Subtask19	√							
19.2 Select "1RCV001YCD" screen			√					
19.3 Click "013VP" control				√				
19.4 Adjust the flow of 005MD to be same as that of 018MD		√					√	√
19.5 Click "OK" button		√						

The formula for estimating the Human Error Probability (*HEP*) of each subtask *i* is[10]:

$$HEP_i = 1 - \left\{ (1 - R_0 E_0) \prod \frac{1 + K\left(1 - \sum_{j \neq 0} R_j E_j\right)}{1 + K} \right\} \quad (1)$$

where E_j represents the *HEP* of the j^{th} human error mode, R_j represents the recovery failure probability of the j^{th} human error mode (j=1, 2SS, 2DS, 3, 4, 5, 6), K represents the dependency level (K=19, 6, 1, 0 correspond to low dependency, medium dependency, high dependency and complete dependency, respectively). Lee *et al*. proposed a decision tree of determining the level of dependency for soft control by considering four factors including similarity and separation between control devices, repeated action steps and group soft control[10].

Taking the Subtask2 as an example, the *HEP* estimation formula is:

$$HEP_2 = 1 - \left\{ \begin{array}{l} (1 - R_0 E_0) \times (1 - R_{2SS} E_{2SS}) \times (1 - R_{2DS} E_{2DS}) \times \\ \left[1 - (R_1 E_1 + R_3 E_3 + R_6 E_6)\right] \times (1 - R_1 E_1) \end{array} \right\} \quad (2)$$

By examining the applicability of all subtasks to these factors, a low dependency is considered to exist between Subtasks 2 and 3, 7 and 8, as well as 11 and 12. Therefore, the formulas for estimating *HEPs* of Subtasks 3, 8.1 and 12 are revised as follows:

$$HEP_3 = 1 - \left\{ \begin{array}{l} \dfrac{1 + 19 \times (1 - R_0 E_0)}{20} \times \dfrac{1 + 19 \times (1 - R_{2SS} E_{2SS})}{20} \times \\ \dfrac{1 + 19 \times (1 - R_{2DS} E_{2DS})}{20} \times \\ \dfrac{1 + 19 \times \left[1 - (R_1 E_1 + R_3 E_3 + R_6 E_6)\right]}{20} \times \\ \dfrac{1 + 19 \times (1 - R_1 E_1)}{20} \end{array} \right\} \quad (3)$$

$$HEP_8 = 1 - \left\{ \begin{array}{l} \dfrac{1 + 19 \times (1 - R_0 E_0)}{20} \times \dfrac{1 + 19 \times (1 - R_{2SS} E_{2SS})}{20} \times \\ \dfrac{1 + 19 \times (1 - R_{2DS} E_{2DS})}{20} \times \\ \dfrac{1 + 19 \times \left[1 - (R_1 E_1 + R_3 E_3 + R_6 E_6)\right]}{20} \times \\ \dfrac{1 + 19 \times (1 - R_1 E_1)}{20} \end{array} \right\} \quad (4)$$

$$HEP_{12} = 1 - \left\{ \begin{array}{l} \dfrac{1 + 19 \times (1 - R_0 E_0)}{20} \times \dfrac{1 + 19 \times (1 - R_{2DS} E_{2DS})}{20} \times \\ \dfrac{1 + 19 \times \left[1 - (R_1 E_1 + R_3 E_3 + R_6 E_6)\right]}{20} \times \\ \dfrac{1 + 19 \times (1 - R_1 E_1)}{20} \end{array} \right\} \quad (5)$$

Since the procedures have to be performed step by step without any deviation, the formula for estimating the *HEP* of the whole task of starting RCV under the cold shutdown condition is:

$$HEP = 1 - \prod_{\forall i} (1 - HEP_i) \quad (6)$$

2.2 *HEP* estimation of soft control without supervision (case I)

A soft control action is treated as either a primary task or a secondary task. A primary task will provide a control signal to plant systems, while a secondary task is to access information or control, or change control mode[10]. The K-HRA method[11]shown in Fig.3 can be used to determine the recovery failure probability of a primary task. It can be seen that under the hypotheses of study the recovery failure probability of a primary task R_p is 0.2 (See the branch starting from Available Time $60 \le AT \le 120$, via HMI Level Medium and no Supervisor, to *HEP* of Recovery Failure 0.2). Furthermore, the recovery failure probability of a secondary task R_s is assumed as 0.01 (an order of magnitude lower than R_p) by considering a secondary task is simpler and less prone to error than a primary task.

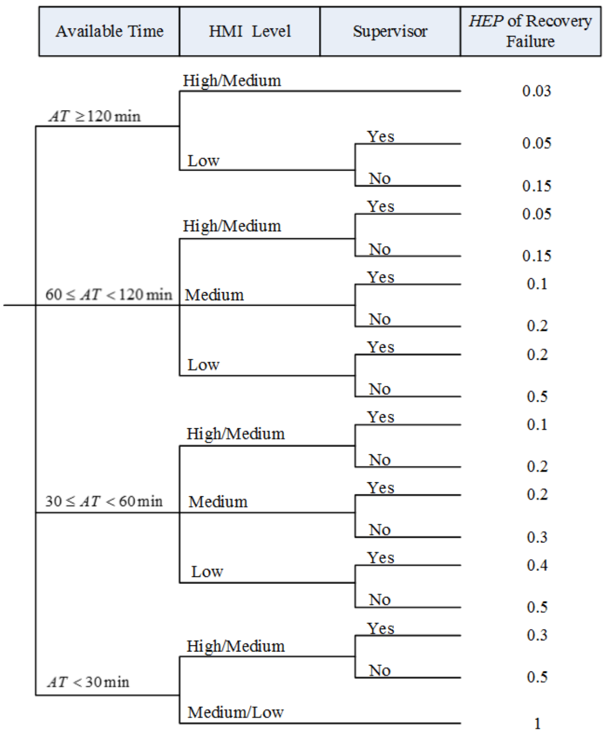

Fig. 3 Decision tree for determining the recovery failure probability of a primary task.

Table 3 presents the nominal human error probabilities of soft control, where the q_{50}, q_5 and q_{95} denote the median as well as 5% and 95% quantiles of statistical data[11]. In this study, each type of this data are assumed to represent the level of *HEPs* corresponding to normal operator, skilled operator and less-skilled operator. Using the equations (1) to (6), the *HEPs* of the whole task implemented by the three types of operators are listed in Table 4. It can be seen that the *HEPs* are high because the procedures contain quite many steps and operators have to find and recover their errors in any step by themselves without supervision before they move to the next step. Especially the Subtasks 4, 14 and 16 have much higher *HEPs* because they involve "mode confusion" failure modes of which *HEP* is much larger than the others.

Table 3 Statistical data of *HEP* before error recovery

Human Error Modes	Probability	
	q_{50}	$[q_5, q_{95}]$
E0	4.10E-3	[1.80E-3, 7.70E-3]
E1	6.61E-4	[2.00E-4, 1.50E-3]
E2SS	2.09E-2	[1.60E-2, 2.70E-2]
E2DS	8.10E-3	[5.50E-3, 1.14E-2]
E3	7.70E-3	[4.50E-3, 1.20E-2]
E4	5.27E-2	[4.00E-2, 6.80E-2]
E5	1.59E-2	[9.40E-3, 2.50E-2]
E6	7.70E-5	[6.00E-7, 6.50E-4]

Table 4 *HEPs* of starting RCV without supervision

Subtask	*HEPs*		
	Skilled	Normal	Less-skilled
2	1.55E-3	2.93E-3	5.05E-3
3	1.48E-3	2.78E-3	4.79E-3
4	1.04E-2	1.50E-2	2.13E-2
7	1.55E-3	2.93E-3	5.05E-3
8	1.48E-3	2.78E-3	4.79E-3
9	2.53E-3	4.56E-3	7.64E-3
11	1.39E-3	2.72E-3	4.78E-3
12	1.32E-3	2.58E-3	4.54E-3
13	1.39E-3	2.72E-3	4.78E-3
14	8.45E-3	1.16E-2	1.57E-2
15	2.37E-3	4.36E-3	7.37E-3
16	1.04E-2	1.49E-2	2.10E-2
17	1.55E-3	2.93E-3	5.05E-3
19	2.53E-3	4.56E-3	7.64E-3
Whole task	4.74E-2	7.47E-2	11.32E-2

In NPPs, the human errors can be greatly reduced through cross-checking the operators' control actions by the team members or remote technical support centers. In the following section, we assume this kind of supervision will be made by an OSS and then evaluate its effect on human error reduction. According to the roles of an OSS in assisting operators' decision making, an OSS can be treated as an adviser or a commander.

3 Effect of supervision on human error reduction

3.1 OSS without misleading (Case II)

In this case, the information provided by an OSS is only suggestive. A consensus is expected to be reached between the operators and the OSS, otherwise the operators will take actions according to their own judgments. As shown in Fig.3, it can be known that R_p is 0.1 which means the OSS will help operators in finding their cognitive and omission errors and contribute a 50% reduction of recovery failure probability to the operators without supervision. The *HEPs* of the whole task are estimated using the equation (1) and Table 5 presents the calculation results. Comparing with the first case, the *HEPs* of the whole task by three types of operators are all reduced by nearly 47%.

Table 5 *HEPs* of operators restarting the RCV with supervision by an OSS

HEPs		
Silled	Normal	Less-skilled
2.50E-2	3.95E-2	6.04E-2

According to the total probability equation, the *HEP* of the whole task can be expressed by:

$$HEP = \left(HEP \middle| R_p = 0\right) \times \left(1 - R_p\right) + \left(HEP \middle| R_p = 1\right) \times R_p \quad (7)$$

where

$\left(HEP \middle| R_p = 0\right)$: is the *HEP* of the operators failing in implementing the whole task when all primary task errors can be recovered.

$\left(HEP \middle| R_p = 1\right)$: is the *HEP* of the operators failing in implementing the whole task when no primary task errors can be recovered.

According to the equation (1),

$$\left(HEP \middle| R_p = 0\right) = 1 - \left(1 - E_0 R_0\right) \prod \frac{1 + K\left(1 - \sum_{i=2SS,2DS} R_i E_i\right)}{1 + K} \quad (8)$$
$$= 1 - \alpha$$

$$\left(HEP \middle| R_p = 1\right) = 1 - \alpha \prod \frac{1 + K\left(1 - \sum_{j=1,3,4,5,6} E_j\right)}{1 + K} \quad (9)$$
$$= 1 - \alpha\beta$$

where α is a probability of operators successfully implementing all secondary tasks, β is a probability of operators successfully implementing all primary tasks without any recovery. Therefore, the equation (7) can be rewritten as:

$$\begin{aligned} HEP &= (1-\alpha)\times(1-R_p)+(1-\alpha\beta)\times R_p \\ &= (1-\alpha)+\alpha\times(1-\beta)\times R_p \end{aligned} \quad (10)$$

The equation (10) indicates that the *HEP* of the whole task is a linear function of R_p. As shown it Fig.4, the *HEP* ranges from $1-\alpha$ to $1-\alpha\beta$, in which $1-\alpha$ is the failure probability of operators in executing the secondary tasks, and $1-\alpha\beta$ is the failure probability of operators in realizing the whole task without recovering any primary task error. The value of $1-\alpha$ is the lower limit of human error reduction which depends on how well the HMIs are designed and how familiar the operators are with the operating procedures and the HMIs for soft control. The lower values of $1-\alpha$ and $1-\alpha\beta$, as well as the narrower range of $[1-\alpha, 1-\alpha\beta]$ are expected. The higher levels of HMIs and the more the operators are familiar with the HMIs and operating procedures, the lower the value of $1-\alpha$ has. The value of β depends on how complex the task is and how well the operators execute soft controls through HMIs. Thus, the value of $1-\alpha\beta$ indicates the upper limit of *HEP* which mostly depends on the inherent factors of a HMI system and comprehensively reflects the qualities of HMIs for soft control, the complexity of operator procedures, the abilities of operators in the situation awareness and successfully executing operating procedures through HMIs without any human error happening. Moreover, technical supports by team or/and computer are of more significance to the operators who has a wider range of $[1-\alpha, 1-\alpha\beta]$.

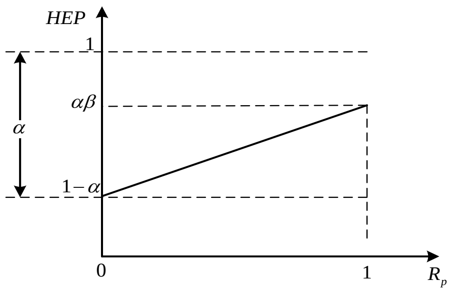

Fig. 4 Linear functional relationship between *HEP* and R_p.

The *HEPs* of the whole task as a function of R_p are shown in Fig.5 in which the pink line, the green line and the blue line represent the *HEPs* of normal, skilled and less-skilled operators, respectively. The different gradients of lines indicate that an OSS is of the more helpful for reducing human errors of the less skilled operators.

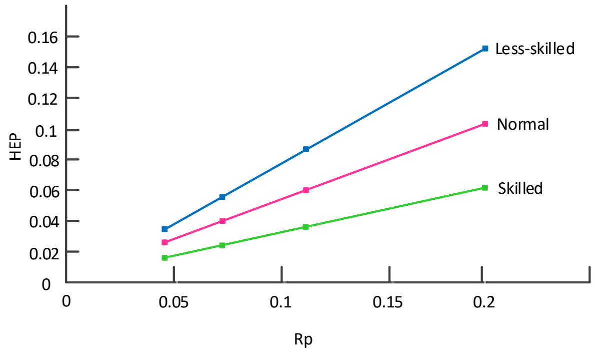

Fig. 5 *HEPs* of operators implementing the whole task under supervision by an OSS changing with R_p.

3.2 OSS with misleading (Case III)

In some special cases, for example, the operators are facing an unfamiliar problem or under an urgent situation, the operators may have no confidence in their judgments and are inclined to follow the suggestions of an OSS. Therefore, it exists such a possibility that an OSS may mislead the operators from their original correct decisions. The following equation can be used for estimating the *HEP* of operators realizing a task by following the instructions of an OSS with a probability of misleading the operators.

$$HEP' = 1-\left\{ \begin{aligned} &\{1-[R_0E_0+R_0'\times(1-E_0)]\} \\ &\prod \frac{1+K\left(1-\sum_{i\neq 0}[R_iE_i+R_i'\times(1-E_i)]\right)}{1+K} \end{aligned} \right\} \quad (11)$$

where R_0' is a fault probability of an OSS in misleading the operators to error mode E0 and R_i' is a fault probability of an OSS in misleading the operators to error mode Ei. The fault probability of OSS can be estimated by several methods, for example, using software complexity and the integrity of the verification and validation (V&V) process[12].

The contribution of an OSS to human error reduction is:

$$C = \frac{HEP' - HEP}{HEP} \quad (12)$$

The evaluation results of the effects of an OSS with 0.1%, 0.2%, 0.3% and 0.4% misleading probabilities on the human error reduction are listed in Table 6. The calculation conditions are same as that in Case II. For simplifying the analysis, assume the misleading probabilities of both R_0' and R_i' are equal, denote as R'.

Table 6 Contributions of an OSS in *HEP* reduction by considering misleading problems

Statistical Data	$R' = 0.1\%$	$R' = 0.2\%$	$R' = 0.3\%$	$R' = 0.4\%$
Skilled	28.0%	8.68%	-10.4%	-29.4%
Normal	35.2%	23.3%	11.4%	-0.42%
Less-skilled	39.3%	31.5%	23.9%	16.3%

In practice, operators may adapt a flexible strategy to use an OSS and make compromises between Case II and Case III, that is, they will partially follow the instructions of the OSS and partially make a decision by themselves. Thus, the human error probability will fall in between corresponding values of Case II and Case III as shown in Table 7.

Table 7. *HEP* of operators in case of adapting a flexible strategy for using an OSS with misleading problems

Statistical Data	Skilled	Normal	Less-skilled
R'=0.1%	[1.80E-2, 2.50E-2]	[2.56E-2, 3.95E-2]	[3.67E-2, 6.04E-1]
R'=0.2%	[2.28E-2, 2.50E-2]	[3.03E-2, 3.95E-2]	[4.14E-2, 6.04E-1]
R'=0.3%	[2.50E-2, 2.76E-2]	[3.50E-2, 3.95E-2]	[4.60E-2, 6.04E-1]
R'=0.4%	[2.50E-2, 3.24E-2]	[3.95E-2, 3.97E-2]	[5.06E-2, 6.04E-1]

It is obviously that an OSS with a probability of misleading operators will weaken its role in human error reduction. It can be seen from Table 6 that the contribution of an OSS decreases with its misleading probability increasing. In this case study, the OSS will play a negative role in human error reduction for skilled operators when its misleading probability increases to 0.3%, however, it will be still useful for the normal and less-skilled operators. If the misleading probability reaches to 0.4%, the OSS will lose its role in human error reduction for normal operators. Therefore, the design and application of an OSS should consider not only the benefits of the OSS, but also weigh the risk of its misleading issues.

4 Conclusions

Human error is considered as a major contributor to the nuclear events or accidents in the NPPs. Applying computerized operator support systems for enhancing human reliability of operators in the main control rooms at NPPs has been appealed for many years. Various operator support technologies haven been proposed and developed in laboratories, however, they are rarely used in practice because their reliability have not convinced the nuclear industries enough. The validation of an OSS is traditionally taken by simulation experiments by comparing the performance of operators with and without the help of OSS. However, there are still the doubts that simulation cases are usually limited and could not cover all situations of NPP actual operation.

This paper presents a method of evaluating the effects of an OSS from the reduction of human error probability point of view which has universal significance in theory. The proposed method can be used as a supplement to the simulation experiments of OSS for increasing the nuclear industry's acceptance of OSS. It should be noted that the case studies in this paper were much simplified. However, it still well demonstrated that the way of operators' decision-making under instructions of an OSS and the reliability of an OSS are crucial to the applications of OSS in NPPs. The design of an OSS should focus on not only its functions, but also the needs and skills of operators. Systematic experiments for a reasonable probabilistic estimation for the various human errors of operators in soft controls should be conducted in order for a better estimation of acceptable fault probability of OSS.

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