

Analysis of Human Reliability Considering a Sequence of Dependent Actions

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Abstract

In this paper Human Reliability Analysis (HRA) event trees are used to study the performance of an operator following written procedures. The procedures are regarded as sequences of specific human actions and each action is considered as a solitary unit for which an HRA event tree, HRA element, is made. The events appearing in the HRA event tree are presented.

Certain fundamental problems, called Human Features, exist in HRA. To cope with one of these Human Features, i.e. dependent human actions, a Dependence Model is presented and compared with other Dependence Models in literature.

Another Human Feature is the possibility to rectify an error: recovery. In this study the influence of recovery on the probability of occurrence of certain consequences has been investigated. The results show that the number of times the operator recovers his performance is insignificant.

1. Introduction

In nowadays complex installations, like nuclear power plants, the effect of wrong human performance can be rather great. It is, therefore, essential to make a profound analysis on human errors with regard to certain failure modes and failure probabilities. In a co-operation between the KEMA (Research institute of the Dutch electric supply companies and sponsor of this work) and the Delft University of Technology a study is performed having the aim to find an applicable method for the assessment of human reliability. This study restricts itself to 'rule-based behavior' which implies the performance of certain activities according to a written procedure (Rasmussen /1/).

At the moment the use of event trees is analysed in this study. The technique of using so-called Human Reliability Analysis (HRA) event trees is known as THERP (Technique for Human Error Rate Prediction, Swain et al. /2/). In case of rule-based behavior three Human Features exist: 1) the dependence among certain human activities, 2) the possibility of the operator to recover wrong performance and 3) the memory influences during recovery. The question which by this study has to be answered, is in what way these Human Features form serious problems for the use of event trees. The object of this paper is to present the results reached so far in answering this question.

2. HRA event trees

Each procedure to be performed by an operator, consists of specific actions. It makes sense to analyse each specific action separately. This will be done by making an HRA event tree of that action after which these trees or HRA elements can be joined together in order to reflect the entire procedure. Specific actions are, for instance, the adjustment of a switch, the reading of a meter, etc.

An HRA event tree is a graph of a set of events having the form of a tree by which almost each event reflects a possible human error. In Figure 1 an example of an HRA event tree and the related panel lay-out has been given. This example refers to the adjustment of a two-position switch, here switch 2, of a panel. On completing the tree, several consequences are possible. Here two categories of consequences will be considered: the termination consequence, \bar{z}_q , and the recovery consequence, \bar{r}_j . The second one, although mentioned a consequence, is not really a consequence, since it implies that the same and/or other actions of the procedure are (partly) repeated. It is agreed that a symbol with a dash reflects the consequence or event and one without a dash the relevant probability. With regard to Figure 1 where it is assumed that there is no dependence between the separate events, the consequence probability of adjusting the wrong switch 1, z_3 , equals for instance (if the effect of recovery is neglected):

$$z_3 = (1-D)(1-C)B(1-A) \quad \text{eq. (1)}$$

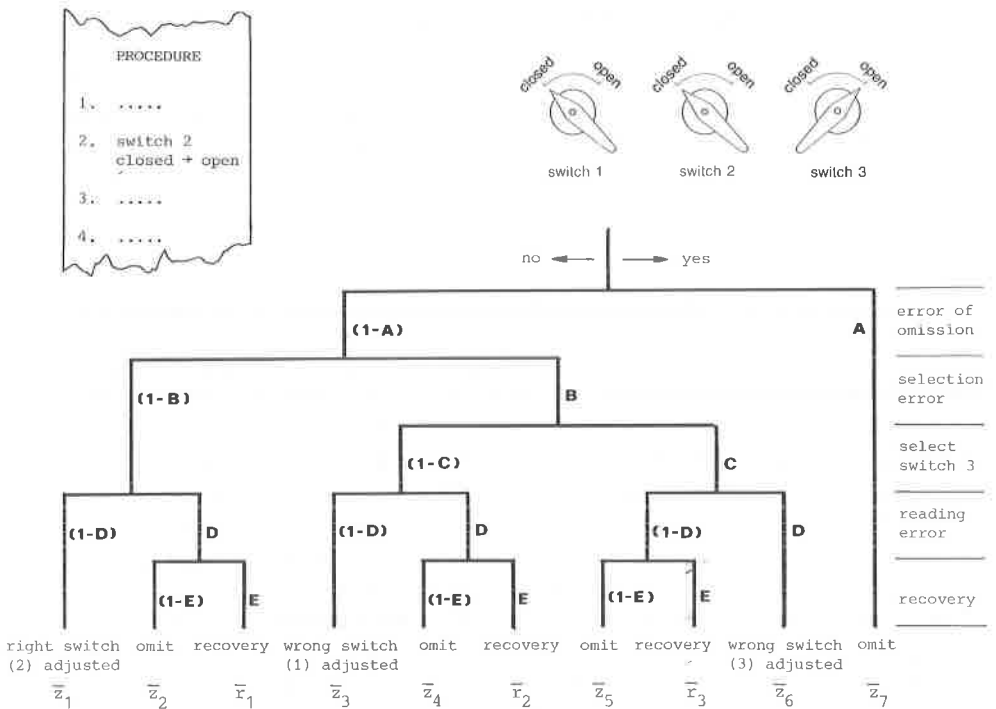


Figure 1. HRA element and the relevant panel lay-out and procedure.

3. Event classification

Figure 1 shows some of the possible errors that the operator is able to make. Based on Rasmussen /1/, Swain et al. /2/, and my own control room inspections a general event classification has been made as given in Table I. Part A contains the events that may be present in HRA elements and part B contains the events that may be present if HRA elements are combined to represent a procedure. When using HRA elements the following characteristics are valid :

- 1) The HRA element is a combination of the events of part A of Table I which, except for the 'specification' event, are present one time at the most;
- 2) The order of events in an HRA element is, except for the 'specification' event, the same as the order of the events in part A of Table I;
- 3) When the HRA elements are considered, the order of the HRA elements is given by the order in which the corresponding specific actions are performed by the operator.

In this study only a consideration is made of the external mode of malfunction, i.e. the immediate observable effects of human malfunction when a (part of a) procedure or only one specific action is performed. The underlying causes and performance shaping factors, factors influencing the value of a Human Error Probability (HEP), are not considered yet, because this should only imply a further specification for the benefit of a more reliable quantification. This is, however, not the aim of this paper.

Table I. Event classification

A Events that may be present in HRA elements

- 1) error of omission
specific action not performed (within the allotted time).
- 2) selection error
wrong manipulator (switch/setpoint) or wrong display (meter/graph) selected.
- 3) treatment error
error made at the selected manipulator or indicator e.g.
 -) reading error or,
 -) reversal error or,
 -) qualitative error (i.e. too much, too little) or,
 -) etc.
- 4) specification
further specification to be found necessary by the HRA analyst, e.g. event 3 in Figure 1.
- 5) recovery "yes" or "no"
the decision made by the operator after he has detected that he has done something wrong.

B Events that may be present when combining HRA elements to represent a procedure

- 1) sequential error
specific actions are performed in the wrong sequence "yes" or "no".
- 2) introduction of an extraneous action
the introduction of an undesired specific action "yes" or "no".

4. Human Features

One of the problems when using event trees for an HRA is the dependence between certain events. Dependence between two events causes the HEP of the second event to depend on success or failure of the first event. When dependence is present it is possible to determine the consequence probabilities from the separate event probabilities. This, however, can only take place if the probabilities of the separate events are adapted, so that the dependence is incorporated resulting in conditional HEP's (CHEP's). The dependence between events in one HRA element or a combination of HRA elements will be called Event Dependence.

A second Human Feature is the possibility of the operator to end at the consequence recovery (see Figure 1) after which he will repeat the same and/or other specific actions (partly). In that case he may correct himself or he may introduce one or several other failures.

A third Human Feature is the phenomenon that there may be memory influences during recovery. This yields that during recovery other HEP's may be present. The memory influences, namely, imply a dependence between the way of passing through the tree during recovery and before recovery, causing CHEP's. This dependence is called Recovery Dependence. An example of Recovery Dependence may be the behavior of the operator to pursue with the same error during recovery.

5. Dependence model

To calculate the CHEP's a Dependence Model can be used for several cases of Event and Recovery Dependence. Several Dependence Models exist to calculate the CHEP (Swain et al. /2/, WASH-1400 /3/). The model of /2/ has more advantages than that of /3/, but the model of /2/ could be improved especially with regard to the dependence domain which has a discontinue and non-proportional character. This study has resulted in a new Dependence Model which is expressed by the following formula:

$$\text{CHEP} = \text{Pr (failure|failure previous event)} = \frac{\text{DEP} - 100}{100} \cdot 1.5^{20} \cdot (1 - \text{BHEP}) + \text{BHEP} \quad \text{eq. (2)}$$

where BHEP is the original HEP without dependence, and where DEP is the continue rate of dependence. Figure 2 shows the effect of dependence on the CHEP for two Dependence Models. Other conditional

success and error probabilities can be derived from eq. (2).

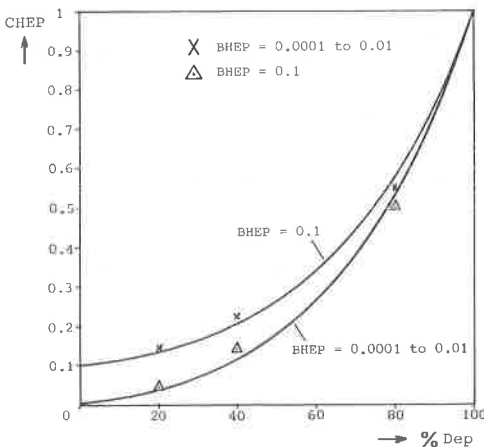


Figure 2.

The CHEP as a function of the percentage Event Dependence for different BHEP's. The curves result from the Dependence Model of eq. 2, the crosses and triangles from the Dependence Model of /2/.

6 Theoretical analysis of recovery

As a result of recovery the probability to end at a certain termination consequence (success or failure) will be different from that achieved by a direct multiplication of the probabilities belonging to the limbs in the HRA event tree. In the most simple case with no Event and Recovery Dependence, it can be shown that the same event tree is completely repeated (Heslinga /4/). In case of Figure 1 where the probability to end at the recovery consequence equals $R (= r_1+r_2+r_3)$, the probability to restart the tree is R . So the extra probability to end at \bar{z}_q , besides the original z_q , equals Rz_q , thus in total $z_q + Rz_q$. Since there are no memory influences, this continues to infinity, and so the probability to end at \bar{z}_q due to recovery becomes Z_q , where

$$Z_q = z_q + Rz_q + R^2z_q + \dots = \frac{z_q}{1-R} \quad \text{eq. (3)}$$

In Heslinga /4/ a theoretical model has been developed with regard to the performance of one specific action where Event and Recovery Dependence is taken into account with which a consequence probability (similar as eq. 3) can be calculated. At the moment an expanded theoretical model is under development where also Recovery and Event Dependence is taken into account, but where a sequence of specific actions (a procedure) is considered. Because it is rather difficult to investigate the influence of the three Human Features together, this expanded model has partly been finished. It refers to the situation where only recovery and a sequence of specific actions are present (no dependences). With this model an analysis has been performed to study the influence of recovery on the probability to reach certain termination consequences, in particular those consequences which have not a recovery possibility (e.g. in Figure 1: $\bar{z}_1, \bar{z}_3, \bar{z}_6$). The probability has been calculated to end at those consequences for the cases where the operator does not recover (in case of Fig. 1: z_q), where he recovers at most one time (in Fig. 1: $z_q + Rz_q$) and where he recovers infinite times (in Fig. 1: $\frac{z_q}{1-R}$). The procentual difference has been calculated between some of them, i.e. between zero and infinite times of recovery (ZI) and between one time and infinite times of recovery (OI), see Figure 3. Each HRA element has a recovery offshoot with probability 0.01. Both the curves are lower when smaller HEP's are present. Having the large uncertainty for the present HEP's in mind, the IO can be neglected. From this figure it can, therefore, be concluded that recovery is important, but that the number of times the operator recovers is unimportant. This means that there is no need to measure the number of times the operator recovers.

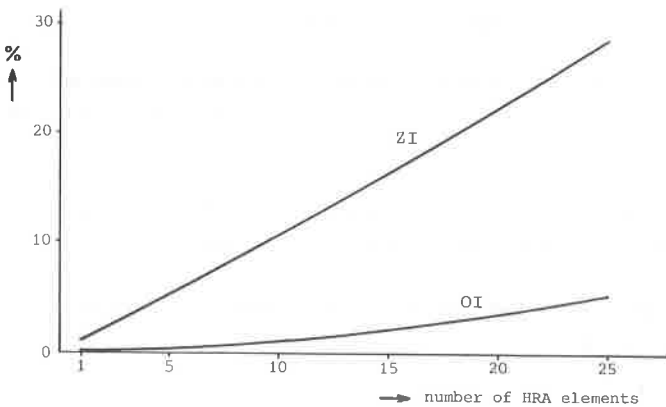


Figure 3. Procentual difference, ZI and OI, as a function of the number of HRA elements in one sequence.

7. Discussion

In this paper HRA elements have been introduced. The advantage of HRA elements is that an HRA event tree of a procedure consisting of several specific actions can be formed by combining prefabricated HRA elements. By making use of the elements, it is expected that someone not so familiar with HRA, can analyse a procedure with a lesser probability to overlook possible human errors. The use of HRA elements implies a more systematic approach of HRA than the use of THERP in its original form.

Some CHEP's can be calculated using a Dependence Model. In this paper a Dependence Model has been presented having a domain where the level of dependence can vary continually. The advantage of this Dependence Model is that a selection of a dependence level between some discrete point levels, for which Swain et al. /2/ gives some practical guidelines, is simply applicable. With regard to the Human Feature dependence, it is important to realize that at higher levels of dependence, the value of the BHEP becomes less important and the levels of dependence becomes relatively more important with regard to the consequence probabilities. Opposed to the BHEP's, the levels of dependence are more situation specific and more related to behavioral phenomena. This explains the lack of knowledge of recommended dependence levels to be used in HRA. Only Swain et al. /2/ gives a guide of a few pages for assessing levels of dependence. Therefore, at collecting human error rates for a data bank also considerable attention should be given to the collection of practical levels of dependence.

Because of the complexity in considering the three Human Features at one time, this paper has only investigated the influence of recovery. This investigation has been performed with regard to a sequence of specific actions where, during recovery, the complete procedure is repeated. The results show that recovery cannot be neglected, but that the number of times the operator recovers is unimportant for certain termination consequences having no recovery possibility. It can be shown that this conclusion is also valid for the case where the procedure is partly repeated. The results reached so far are a consequence of applying practical HEP's in a theoretical model which is only finished with regard to one Human Feature, i.e. recovery. In future, this theoretical model will be expanded taking into account Event and Recovery Dependence.

8. References

- /1/ Rasmussen, J., "Human errors. A taxonomy for describing human malfunction in industrial installations.", *Journal of Occupational Accidents* 4, 311-333 (1982).
- /2/ Swain, A.D., and Guttman, H.E., *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (NUREG/CR-1278)*, U.S. Nuclear Regulatory Commission, Washington D.C., 1983.
- /3/ WASH-1400, *Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants (NUREG-75/014)*, U.S. Nuclear Regulatory Commission, Washington D.C., 1975.
- /4/ Heslinga, G., *Analysis of Human Reliability on Performing a Specific Action*, Accepted for publication in *Reliability Engineering*.