

RAK-1**NKS/RAK-1(95)R2**

SURVEY OF METHODS FOR INTEGRATED SEQUENCE ANALYSIS WITH EMPHASIS ON MAN-MACHINE INTERACTION

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SUMMARY

A literature study on non-dynamic human reliability assessment methodologies has been performed. The study is included in subproject 3 of the NKS/RAK-1 project concerning Integrated Sequence Analysis.

The literature study was performed in order to compile and assess different recent methods. One specific objective was to propose some of these methodologies for use in the sequence analysis task.

The survey focuses on non-dynamic (monotonic) methodologies. One semi-dynamic method, HITLINE, is presented. Reference [1] provides a summary of approaches to dynamic methods for analysis of man-machine-interactions.

The survey shows that most of the new methodologies are dynamic. Completely new monotonic methodologies are rare. The main effort in the monotonic area seems to be enhancements concerning the treatment of psychological and cognitive behaviour in already established methodologies

In the survey, books, journals, and data-bases were used. More than 200 references were found. Six methods in those references were chosen for a more thorough investigation. They are briefly presented in the report:

- Enhancement of SLIM-MAUD
- INTENT
- COGENT
- HIET
- HITLINE
- HRMS

HIET and COGENT are recommended for further analysis and are suggested to be used in subproject 3.

Already established methodologies and dynamic methodologies have not been taken into consideration in the present report.

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1 INTRODUCTION

This report presents a literature study concerning recently developed monotonic methodologies in the human reliability area.

The work was performed by RELCON AB on commission by NKS/RAK-1, subproject 3. The topic of subproject 3 is "Integrated Sequence Analysis with Emphasis on Man-Machine Interaction".

The purpose with the study was to compile recently developed methodologies and to propose some of these methodologies for use in the sequence analysis task.

The report describes mainly non-dynamic (monotonic) methodologies. One exception is HITLINE, which is a semi-dynamic method. Reference [1] provides a summary of approaches to dynamic analysis of man-machine-interaction, and explains the differences between monotonic and dynamic methodologies.

2 LITERATURE SURVEY

The survey considered information in books, journals, and data bases. The following data bases were used to find references for further studies:

- The Engineering data-base (IEA), KTHB, Studsvik
- Science Citation Index, KTHB
- Compendex, KTHB
- PsycLIT, SPPB

More than 200 references were found.

Reference [1] presents some of the so called dynamic methodologies, which recently have been developed. Most efforts for developing a second generation of HRA-methodologies seem to have been spent on these dynamic methodologies.

Dougherty comments on the need to improve the HRA methodologies concerning dynamic and cognitive aspects [7]. Most of the new methodologies consider these dynamic and cognitive aspects.

Completely new monotonic methodologies are rare. The main effort in the monotonic area seems to be enhancements concerning the treatment of psychological and cognitive behaviour in already established methodologies (the expression "established methodologies" refers to methodologies that were in general use before 1990).

Different HRA methodologies are presented and discussed in references [2] - [6]. Only the established methods are found in these references.

The following methodologies were chosen for a more thorough investigation:

- Enhancement of SLIM-MAUD
- INTENT
- COGENT
- HIET
- HITLINE
- HRMS

These methods are briefly described in sections 3.1-3.6.

3 METHOD DESCRIPTIONS

Each section presents the year when the method is developed, the contact persons and a brief description of the method itself. The development year is set to the year of the earliest reference found in the literature study.

The description sections are to a large extent excerpts from the references [9] - [20]. Thus, more details can be found in these references.

3.1 EVOLUTIONARY ENHANCEMENT OF THE SLIM-MAUD METHOD

Developed: 1992

Contact person: Jalal H. Zamali, BG&E, Calvert Cliffs

Description: One of the established methodologies in the HRA-domain is SLIM-MAUD [8]. The methodology described in [9], assigns plant-specific human error rates (HERs) for individual plant examinations based on procedural difficulty, on configuration feature, and on the time available to perform the action. This methodology is an evolutionary enhancement of the success likelihood index methodology (SLIM-MAUD) for use in systemic scenarios. It is based on the assumption that the HER in a particular situation depends of the combined effects of a comprehensive set of performance-shaping factors (PSFs) that influence the operators ability to perform the action successfully. The PSFs relate the details of the systemic scenario in which the action must be performed according to the operator's psychological and cognitive condition.

A detailed operator action description is completed for the subjective analysis of each action. This description documents all the objective information available about a particular action. It includes the following information:

- detailed written description of the scenario
- description of the task to be performed, the failure criteria, and specific equipment actions

- objective description of the factors affecting performance, including preceding and concurrent actions, crew training and experience, a list of the applicable procedure steps, and the available indications.

Based on the information in the detailed description, the PSFs for each HER are rated on simple monotonic scales from 0 to 10 and inserted into an equation of the following general form:

$$SLI = \sum (W_i * V_i) + \sum (W_j * (10 - V_j)),$$

where W_i = weighing factor

V_i = indirectly acting PSF values (ratings)

V_j = directly acting PSFs.

”Directly acting” means the higher the PSF value, the higher the likelihood of success; ”indirectly acting” means the PSF makes success less likely.

The SLIs for each phase of the operator response model:

- identification, diagnosis, and response

and for each of the three classes of operator action:

- skill-based, rule-based, and knowledge-based

leading to the use of six SLI equations (one for identification, one each for rule- and knowledge-based diagnosis, and one each for skill-, rule-, and knowledge-based response). The HER are related to the SLI via a decreasing logarithmic relation.

The weighting factors for the PSFs were calculated by using expert judgement.

3.2 INTENT

Developed: 1990

Contact person: David I. Gertman, Idaho National Engineering Laboratory.

Description: INTENT, reference [10], complements THERP, reference [11], regarding a subset of errors of commission known as errors of intention. INTENT is a methodology which estimates probabilities associated with decision based errors. These errors are not ordinarily incorporated into probabilistic risk assessment (PRAs) due to both the difficulty in postulating such errors and to the lack of a method for estimating their probabilities from existing data. By failing to include decision based errors in their analyses, most PRA practitioners seriously underestimate the true contribution of human actions to system failure. Two sources, Nuclear Computerised Library for Assessing Reactor Reliability (NUCLARR) and licensee reports (LERs) were reviewed and two methods, HSYS and SNEAK, were used to identify a generic list of twenty potential errors which may be manifest as erroneous acts. Four categories of influence emerged from the data: consequence, attitudes, response set, and dependency. Corresponding

human error probabilities (HEPs) for each error were generated by expert judgement methods. Some examples are shown in Table 1.

Table 1. Source categories and estimates of HEP upper and lower bounds for errors of intention. (Excerpt from reference ([10]).

Source categories for errors of intention	HEP UB	HEP LB	EF
<i>1.0 Action consequence</i>			
3. Tolerate an out of range situation with minor consequences.	3.6 E-1	1.0 E-2	6
<i>2.0 Attitude leading to circumvention</i>			
7. Checkers performing QA tolerates discrepancy	1.2 E-1	1.2 E-3	10
<i>3.0 Crew response set</i>			
14. Multiple fault situation, crew solves the more minor fault.	1.2 E-1	1.2E-3	10
<i>4.0 Resource dependencies</i>			
17. Inadequate communication results in improper actions	2.0 E-1	3.3 E-3	8

The error factor (EF in table 1), reflects the interval between the upper and the lower bound of the human error probability (HEP). The basic human error probability (BHEP) (nominal conditions) divided with the error factor gives the HEP LB, and the BHEP multiplied with the error factor gives the HEP UB.

Generic importance weights were computed for each of eleven PSFs believed to affect the 20 decision based errors. Seven of these eleven PSFs are shown in Table 2 for errors of intention number three and seventeen. A high PSF weight means a high impact on the HEP.

Table 2. Mean normalised PSF weights for two out of twenty decision based errors (Excerpt from reference ([10]).

Error of intention no	Motivation	Stress	SRK	Experience	Safety culture	Training	Communication
3	8	8	9	9	10	11	7
17	7	12	8	10	8	10	9

3.3 COGENT

Developed: 1991

Contact person: David I. Gertman, Idaho National Engineering Laboratory

Description: COGENT, reference [12], [13], is a graphic representation method for adapting an existing technology - human reliability analysis (HRA) event trees, used to support event sequence logic structures and calculations - to include a representation of the underlying cognitive activity and corresponding errors associated with human performance. The analyst is presented with three potential means of representing human activity: the NUREG/CR-1278 HRA event-tree approach, reference [11]; the skill-, rule-

and knowledge-based paradigm, reference [14]; and the slips, lapses, and mistakes (mistakes are divided into "mistakes" and "small mistakes") paradigm, reference [15], [16]. The above approaches for representing human activity are integrated to produce an enriched HRA event tree - the cognitive event tree system (COGENT) - which, in turn, can be used to increase the analyst's understanding of the basic behavioural mechanisms underlying human error and the representation of that error in probabilistic risk assessment. The above mentioned taxonomies are combined to yield the following: $S_{s,l,sm}$, $R_{s,l,m}$, $K_{l,m}$. $S_{s,l,sm}$ means that in the skill-based domain the different types of error are slips, lapses or small mistakes. In the knowledge-based domain there will only be lapses or mistakes, $K_{l,m}$. The ordinary HRA event tree and the cognitive event tree system are shown in Figures 1 and 2. The scenario represented in the trees is reactor operator failure for an safety features actuation system trip response to a loss of coolant accident.

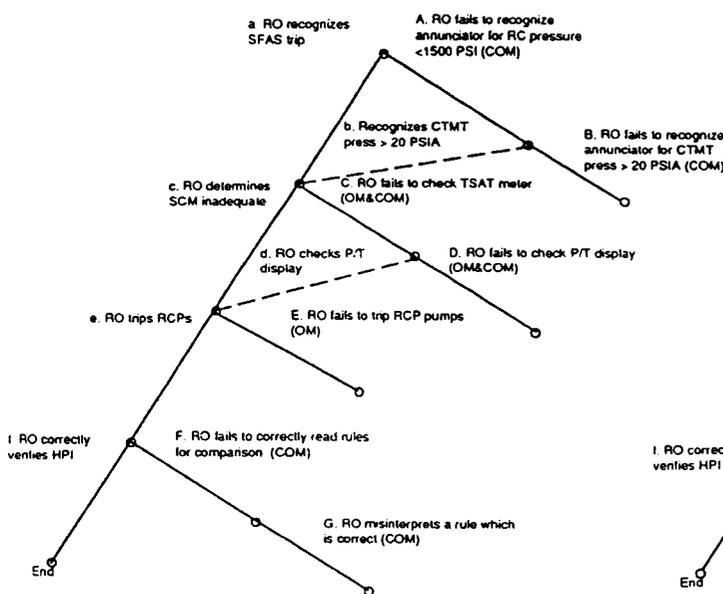


Figure 1. HRA event tree
(From reference [13])

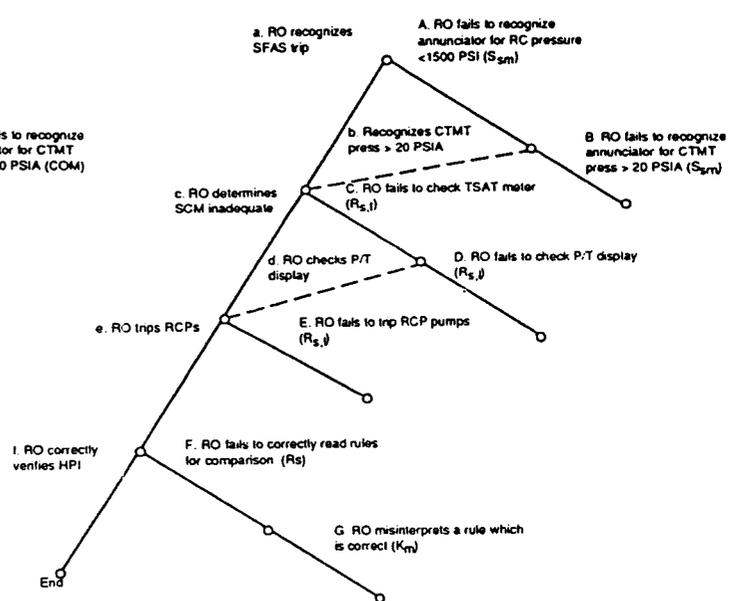


Figure 2. Cognitive event tree system
(From reference [13])

The type of errors modelled in Figure 1 are the typical errors of omission (OM) and commission (COM) described in reference [11]. Recovery paths are indicated and would be included in part of the normal calculation of the failure rate for recognition and action related to SFAS actuation.

Figure 2 presents the same HRA event tree shown as in Figure 1, with the exception that all failures presented in Figure 1 are now acknowledged as either slips, lapses, simple mistakes, or mistakes, *and* as either skill-based, rule-based, or knowledge-based behaviour.

With COGENT, a means of enriching HRA event trees has been introduced. Using this technique, it is possible to bridge an existing gap between the modelling needs of HRA practitioners and the classification schemes of today's cognitive theoreticians. The HRA tree logic structures will support the representation of various subtask types, error

modes, and failure-rate estimates available in sources other than THERP. Practitioners will have to decide whether existing quantitative estimation methods such as THERP, DNE (direct numerical estimation), SLIM-MAUD sessions etc. are an adequate means by which to determine human error probability estimates for placement on cognitive event trees such as COGENT.

3.4 HITLINE

Developed: 1994

Contact person: A. Macwan & A. Mosleh, Dep. of Materials and Nuclear Engineering, University of Maryland.

Description: The HITLINE, Human Interaction TimeLINE, reference [17], generates a representation of different action sequences in time. It provides a methodology to incorporate operator errors of commission (EOCs) in nuclear power plant probabilistic risk assessments (PRAs). This is done by taking the results from the level 1 PRA which consist of end states of event trees (ETs), that signify a combination of success / failure of the appropriate system and the impact on the plant in terms of safe plant state or core damage. Information about success / failure of systems is also extracted from the fault trees (FTs). This information, along with information about plant configurations in terms of systems and functions, as well as physical and thermal-hydraulic information, plant EOPs and other factors that influence operator errors, is used to construct HITLINES.

At a broad level, the methodology consists of the following major steps:

- screening;
- analysis of operator / plant interaction, and
- incorporation of operator / plant interaction into the plant logic model.

Screening is applied to combinations of hardware failures, instrument failure (InF), and Performance Influencing Factors (PIFs) to select the combinations that meet the criteria developed for that purpose. The criteria are based on the operator action or inaction causing a transition from one event tree branch to another. The screening results in a set of initial conditions that are used for operator / plant interaction analysis through HITLINE construction. This set includes combination of hardware states (availability / unavailability) selected after proper screening, other plant information including InF, EOPs, and PIFs. The combinations that meet the screening criteria form initial sets that are used as input for construction of HITLINE.

HITLINE sequences are generated by considering possible combinations of actions in the form of a forward branching tree in time.

The steps to developing a HITLINE are listed below:

- determination of top actions (branching points);
- determination of possible branches at each branching point;

- quantification of branches, and
- branch management by merging, termination and truncation.

The **top actions** for HITLINE essentially correspond to the steps (or block of steps) in procedures. They are ordered in phases in which the procedures are written.

Possible branches at each branch point (BP) could be, for example, errors like shortcut, skip and commission. What changes from one BP to another, in a given phase, is the likelihood of each possible action.

Quantification at each branching point is done through the multiple factors assigned to systematically assign the weights for different actions. Dependencies are carried from one branch point to another through the use of operator related variables such as operator diagnosis, and expectation about plant behaviour.

Merging is done for each BP as well as from one phase of EOP to another (or from one procedure to another). **Truncation** of branches is done by using a cut-off frequency. **Termination** is done on the basis of known plant consequences. When the combinations corresponding to any branch matches that of an ET sequence, with no further operator caused change in hardware status, the branch is terminated.

For each initial condition set, there is an associated HITLINE with multiple end states that correspond to different combinations on the ET. Similar end states within the HITLINE are combined and their frequencies added up (frequency refers to the frequency of the initial condition set multiplied by the conditional probability or weight of the HITLINE branch). Next, similar end states from the various HITLINES are combined, and their probabilities are added up and normalised. Since the ET sequence probability is used as an initial value for the HITLINE, the results of the HITLINE provide values of conditional probabilities that are adjusted to account for intentional errors.

After adding the probabilities, the total probability for each end state in the ET is used to reassign the probability of the sequence.

If the operator changes the status of the system, and if this action is not explicitly included in the ET, an additional top event (operator action) is inserted to the ET to make the impact of the error explicit and visible. This incorporation is done for the system or functions where operator's failure is not already accounted for in the PRA.

The description above is to a large extent excerpt from reference [17]. For a clearer picture of HITLINE, we strongly recommend reference [17].

3.5 EOP HIET

Developed: 1989

Contact person: M. Drouin et al, U.S NRC

Description: Emergency Operating Procedures - Human Interaction Event Tree (EOP HIET), reference [18], is a method for explicitly treating and quantifying operator

actions that are associated with human response to accidents. The EOP HIET is a way to model the progression of an accident from the human response point of view. The EOP HIET is basically divided into five steps. In the first step a detailed review of the EOP is performed. In this first step the critical safety functions (CSFs) that the operator needs to monitor and control are defined. The CSFs possible limits are also defined. During the second step, different events and associated systems that are needed to achieve the different limits of the CSFs are identified. Step 3 involves the actual construction of the EOP HIET. This third step includes required operator actions to make sure that the parameters (reactor power, reactor water level etc.) stay within the different limits of the CSFs. Step 4 includes developing supporting logic models for each decision (each branch in the EOP HIET). The fifth and last step is a quantitative assessment. To start with the probabilities could all be screened to the same number, e.g. 0.5, just to identify the different combinations that leads to a core damage. One advantage by using this method is the potential to identify earlier unknown key errors.

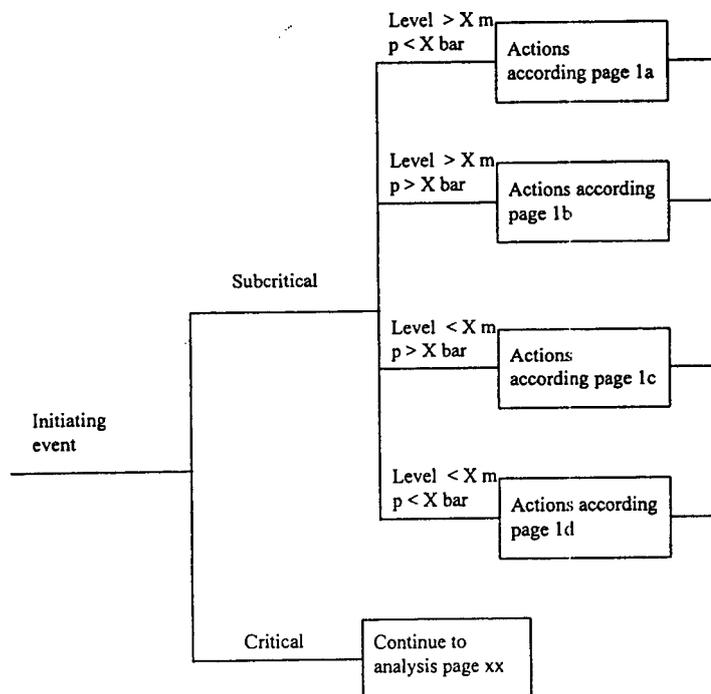


Figure 3. Human Interaction Event Tree

3.6 HRMS

Developed: 1989

Contact person: B. Kirwain, School of Manufacturing & Mechanical Engineering at the University of Birmingham.

Description: The HRMS, Human Reliability Management System, reference [19], [20], is a fully computerised HRA system which deals with all aspects of the HRA process. Its quantification module is based on actual data which is supplemented by Kirwain's own judgement on how data can be extrapolated to new scenarios/tasks, according to six major PSFs (the time-scale involved; the quality of the man-machine-interface;

training/experience/familiarity; the degree of adequacy of procedures; how the task is organised; the degree of complexity of the task). Like the SLIM method, the system can also carry out a PSF-based sensitivity analysis to determine how to reduce the likelihood of error, and like HEART, reference [21], the system provides error-reduction mechanisms.

The HRMS consists of the following modules and sub-modules

- Task Analysis module
 - HTA & STA (Hierarchical and Sequential Task Analysis)
 - TTA (Tabular Task Analysis)
- HEI module (Human Error Identification)
 - task-classification module
 - cognitive-error-analysis sub-module
 - human-error-analysis sub-module
- Representation module
- Quantification module (sensitivity analysis etc.)
- Error reduction module

The system is largely self-documenting, via print-outs etc., occurring at various stages in the program. This, among some other features, facilitates the quality assurance, especially concerning audibility and reproducibility.

4 RECOMMENDATIONS

The objective with NKS/RAK, subproject 3 is to analyse a number of sequences using a so called Integrated Safety Analysis (ISA) approach combining different safety analysis procedures. The five sequences to analyse are given in table 3.

COGENT and HIET EOP are identified as being the best candidates (among the methods presented in this report) in the continued work analysing the five sequences.

COGENT is well fitted for treatment of the cognitive aspects of human error. It is, for example, recommended for sequences which do not necessarily follow procedures.

HIET EOP, on the other hand seem to be better for situations which to a large extent are EOP-driven.

The reasons, according to our opinion, not to explicitly recommend Evolutionary Enhancement of the SLIM-MAUD Method, INTENT, HITLINE and HRMS are as follows:

The first method, Evolutionary Enhancement of the SLIM-MAUD Method, "merely" provides a new set of PSFs, and the second, INTENT, "merely" provides a generic list of 20 decision based errors. However, the results of these two methods can of course strengthen both COGENT and HIET EOP.

We judge HITLINE to be rather complicated to use without access to appropriate software.

HRMS is not commercially available.

The methods recommended to be used for analysis of each specific sequence are presented in the table below:

Table 3. Sequences and recommended methodologies.

Sequence number	Description	Proposed method
1	LOCA during shutdown	COGENT
2	Confused signal system in the control room	HIET EOP
3	Medium pipe size rupture	HIET EOP
4	Loss of residual heat removal system during cool down	COGENT
5	Steam generator tube rupture	HIET EOP

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