
A Model for Evaluating Possible Operator Errors Due to Diagnosing and Decision Making in Emergency Situations

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Abstract:

This article summarises a method for identifying, analysing and probabilistically evaluating possible operator actions, which are not required by procedures. Action performance can unintentionally degrade plant safety in emergency-situations investigated e. g. in level-two probabilistic safety analyses. Needs, principal steps, and major outcomes of model development as well as results of a first case-study application are outlined.

1 OBJECTIVE

This contribution presents a summary description of a model or method GRS developed for identifying, analysing, and evaluating possible nuclear power plant control room operators' actions, which are characterised by the following features:

- (1) The actions can be performed with the means provided by the control panels in the main control room and in the emergency control room.
- (2) Procedures require operators to carry out these actions under specified conditions.
- (3) In specific scenarios pertaining in particular to emergency situations, performance of these actions is inopportune, because they would degrade plant safety.
- (4) Either there are no procedures for coping with these scenarios, or if there are suitable procedures, they do not rule out operator's performance of additional, objectively inopportune actions from other procedures.
- (6) The scenarios are marked by factors, which can degrade or contribute to a degradation of operators' diagnosing and (or) decision making activities in such a way, that prerequisites for performing objectively inopportune actions seem to be fulfilled and that action performance seems to be required in the scenario in question.
- (7) All errors are unintentional ones, sabotage is excluded.

Assessment method development thus concentrates on actions, which belong to the class of so-called "Errors of Commission". Such actions are also called "extraneous", because they are not required by plant- and system-states. ([1], p. xiv).

The development of an assessment method for this type of action was supplemented by a case study application of this method.

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2 NEED FOR METHOD DEVELOPMENT

Development of a method for assessing the type of erroneous action described above was necessary for two reasons:

(1) Recent probabilistic safety analyses have been including possible scenarios in which such actions can become important.

(2) Human reliability analysis and evaluation methods, which were available at the time of the development activities summarised here, do not or do not sufficiently support the assessment of these actions.

Ad (1): Recent probabilistic safety analyses have included possible scenarios, which are characterised by the following features:

- Clear information about plant or system states is missing, which can be caused by e. g. unavailable or defective instrumentation or avalanches of information.
- Automatic measures for coping with the scenario and for overriding erroneous human actions are unavailable.
- Neither manuals nor training provide procedures or sufficiently detailed instructions for guiding operators' actions in such situations.

Under such conditions, operators' diagnoses and decision making regarding plant state and manual action gain particularly high importance, because these mental activities become a primary resource for finding suitable recovery actions and because possible, resulting recovery actions as well as inopportune measures can quite directly influence plant safety.

In the following, the general term of ad hoc actions will be used for manual interventions, which do not belong to any procedure manuals and (or) training provide for coping with the scenario in question. This term was preferred to others, which have already been in use, for reasons of terminological precision:

- Actions, which operators select on the basis of a careful analysis of the scenario in question, of the goals to be achieved, and of available options for goal attainment without support of a procedure, are also called knowledge-based actions ([2]). They are distinguished from skill-based action, which is prompted by specific signals, and rule-based behaviour, which is guided by instructions of procedures ([2]). In cognitive psychology, the term knowledge is used in a much broader sense. Cognition is a summary term for the mental processes of acquiring, storing, and applying knowledge ([3], p. 1). Knowledge is the stock of in principle retrievable results of learning and experience in memory. The definition of cognition includes skills and rules in the sense of Rasmussen, operators have learnt and which they are able to retrieve for application in a given situation. Since method development summarised here was based on concepts from cognitive psychology, terminological uncertainties regarding “knowledge” could be avoided by using the term “ad hoc action”, which emphasises the situation-specific performance of actions beyond the scope of procedures in manuals and (or) training.
- Such actions are also called non-required ones ([1], p. xiv), which means “not required by a particular procedure and (or) situation”. Inopportune actions are definitely not required, whereas development of successful ad hoc recovery

measures is implied and required by operators' general mission and responsibility for plant safety. Ad hoc action seemed to be a suitable general concept for non-required actions with either positive or negative consequences.

In order to include ad hoc actions in probabilistic safety analyses, these actions have to be identified, analysed, and evaluated in a systematic and valid way.

Ad (2): Human reliability analysis and evaluation methods which were available at the time of the research and development activities described here do not or do not sufficiently support the assessment of operators' ad hoc actions. This state of the art will be shown by specifying requirements methods for assessing ad hoc actions have to fulfill and by checking to which extent available methods meet these requirements. Both steps will be discussed in the next two sections.

3 REQUIREMENTS FOR A METHOD FOR ASSESSING AD HOC ACTIONS

Requirements were defined in order to provide firstly a clear basis for evaluating available methods and secondly guidance for the development of new ones.

The following requirements for assessment methods for ad hoc actions were developed and applied, comments will present necessary background information and reasons for requirement selection.

(R1) The method shall support the systematic identification of possible ad hoc actions in a given scenario and of their scenario-specific effects on plant safety.

This support is indispensable, if human reliability assessment is to be as complete as possible.

The method further has to provide a clear explanation, why possible ad hoc actions can become more or less likely to be carried out in a given situation. This general requirement can be concretized by considering essential characteristics of human response to a situation. An action is likely to become an option for coping with a particular situation,

- if this option is implied by the knowledge the actor is able to retrieve from memory in the given situation,
- if the actor judges this option to be suited for mastering the situation or for contributing to its mastery, and
- if this option is preferable to other options, which have also been retrieved from actor's memory.

Situation-specific knowledge retrieval depends on several factors. The most important ones will be stated in the following requirement:

(R2) The method shall show, how knowledge is situationally retrieved from memory, which also stores, what the actor has learnt about how to cope with more or less broadly defined types of situation, if more or less broadly defined goals have to be achieved. The method shall explicitly consider important factors and interactions between factors, which influence situation-specific knowledge retrieval, in particular: (a) availability and accessibility of knowledge in memory, (b) interactions of human sensory data processing with memory, which activate knowledge for recognising, mentally representing, and interpreting the situation to be coped with, (c) already retrieved knowledge, which can activate supplementary knowledge and block the retrieval of incompatible pieces of knowledge, (d) motivation, which contributes to the retrieval of

knowledge related to actor's needs, goals, and measures for goal attainment, (e) attention, which enhances knowledge retrieval for objects of sense and (or) thought, attention gets focussed on, and, finally, (f) stress, which can impair knowledge retrieval, if its amount deviates from a moderate level. The method shall show, how these and possible additional factors contribute to the selectivity of knowledge retrieval.

Retrieved knowledge is subject to processing for developing actor's mental representation of situation, goals, measures for goal achievement, and of the relationships between them. One important relation is the instrumentality of an action for attaining a particular objective under given circumstances. Mental representation is both process and outcome of supplying the actor with a subjectively coherent and valid account of the situation and with a rationale for determining how to proceed in order to attain his goal under the given circumstances. One option for preceding can be to do nothing.

Mental representation has to cope with possibly incompatible pieces of retrieved knowledge, which can be traced back to e.g. contradictory information on control panels. Important possibilities for contributing to coherence will be listed in the following requirement.

(R3) The method shall give a clear account of how retrieved knowledge about situation, goals, and possible actions for goal attainment gets organized to a coherent mental representation. The method shall in particular show, how this representation influences retrieval and processing of knowledge. Important kinds of impact are: (a) elimination of incompatible pieces of knowledge from the representation and (b) retrieval of knowledge, which can resolve incompatibilities. The method is to show how these and possible other factors can add to the selectivity of both knowledge retrieval and mental representations.

Mental representations influence retrieval of knowledge, by which representations can be supplemented, modified, and updated in response to changes of the situation, which can be caused by technical processes and (or) human action. This aspect is implied in requirement R2 (c) and is therefore not restated in R3.

A possible action becomes the more likely to be carried out, the more appropriate it is, according to actor's mental representation, for coping with the situation.

(R4) The method shall specify a rule for selecting a likely response (action or inaction) for performance in the given situation.

The next requirement is a direct consequence of the task of providing a method for quantitatively assessing reliability of human action.

(R5) The method has to support a quantitative evaluation of the probability, that possible ad hoc actions will be performed in scenarios, which are investigated in probabilistic safety analyses.

The last requirement is a safeguard against unwarranted assumptions model development could be based on.

(R6) It has to be shown, that a method for identifying, analysing, and assessing possible ad hoc actions is consistent with valid scientific knowledge.

4 REVIEW OF AVAILABLE METHODS

This review concentrated on methods for identifying, analysing, and evaluating inopportune ad hoc actions, whereas methods for ad hoc measures with positive impact on plant safety were neglected, because they are beyond the scope of the research and development activities to be described here. The review included studies which were published by the end of 2002. A brief check for this article showed, that results of this review still holds. They will be presented in the order of the requirements stated in section three.

Ad requirement R1: The review showed, that no detailed and systematic method for identifying inopportune ad hoc actions has been provided yet.

Ad requirements R2 – R4: Both basic and applied research abound with theories, methods, and results about how human cognition works and about how more or less specific tasks are cognitively coped with. A uncontroversial, comprehensive, detailed, and valid approach has not been developed yet. The state of the art can very briefly be summarised as follows:

- Basic research has been investigating retrieval of knowledge and knowledge processing in human memory in numerous theoretical and experimental studies. To all appearance, results have not been applied in analyses of operator's coping with complex real-world tasks.
- A great many studies has been carried out which show negative effects of so-called heuristics and biases i. e. simplifications and presuppositions, which can negatively influence human judgement and decision making. Both kinds of factor can contribute to erroneous diagnoses and inadequate response selection. They are therefore highly relevant for an assessment method for inopportune ad hoc actions. Research on heuristics and biases has mostly used very artificial tasks, which had to be performed by inexperienced subjects. Only very recently, researchers have started a few more detailed analyses of circumstances under which man applies heuristics and biases and of how heuristics and biases precisely influence knowledge retrieval, knowledge processing, and response selection ([4], p. 670f.). Results about heuristics and biases have therefore to be evaluated very carefully, if they are to be applied to complex real-world-tasks performed by experts.
- Basic and applied research activities have provided numerous models of how human cognition works on a more abstract level. This level does not support a detailed analysis of how performance shaping factors interact with human memory and knowledge processing, if a scenario has to be coped with. More sophisticated theoretical frameworks are needed for guiding detailed and systematic analyses of the possibilities for inopportune ad hoc actions.

Ad requirement R5: No method for estimating the probability of an inopportune ad hoc action in a given scenario had been published by the end of 2002, the target-date of this review.

- Human error probability estimates provided by established methods are available only for actions operators are required to perform by plant and system-states. Omission as well as commission errors can be evaluated probabilistically. Omission errors include the failure to perform a necessary activity in time. Quantifiable errors of commission in the area of required control room operator actions belong to two categories: Errors can be traced back to the selection of a wrong component on a control panel, because it is e. g. hard to distinguish from the required one. Or, if the operator selects the correct component, he can fail to change its state as required by plant or system state. In either case, the operator attempted to perform the necessary action, errors are therefore unintentional. It is added, for the sake of completeness, that most actions, whose erroneous performance can be evaluated probabilistically, belong to the skill- and rule-based level as defined by Rasmussen, i. e. these actions

are either prompted by a specific signal or prescribed by instructions of a procedure which belongs to manuals and (or) training programme ([2]). Additionally, only the probability of a correct diagnosis within a specified time-window can be estimated ([1], chapter 12).

- Probabilities of non-required actions cannot be estimated with available methods.

Ad requirement R6: The review revealed several aspects of available methods, models, and approaches, which do not conform to present-day scientific knowledge. These results are mostly too specific to be presented in this summary, an illustrative example is provided by assumptions about extremely small capacities of human short-term memory which would heavily restrict rate, precision, and reliability of human knowledge processing. This overrigid assumption had to be abandoned in the light of recent experiments.

In sum, the review showed that methods for identifying and quantitatively assessing inopportune actions had to be developed from scratch. Methods for analysing, how these actions can come about, have to consider aspects of knowledge retrieval, knowledge processing, and mental representation in the process of action selection. The next three sections will summarise the results of corresponding research and development activities

5 METHOD FOR IDENTIFYING INOPPORTUNE AD HOC ACTIONS

The method for identifying inopportune ad hoc actions includes the following steps:

(1) Scenarios which have to be considered are identified in close cooperation with experts on system- and event-analysis. A scenario is considered to be relevant, if the analysis shows, that (a) a substantial contribution to the overall result of a probabilistic safety analysis is to be expected, (b) the performance of some manual action under the boundary conditions of the scenario in question leads to core damages, whereas non-performance of this action does not, (c) operators have enough time to carry out this action, (d) control panels in main control room or emergency control room provide the necessary means for action performance, and (e) no automatic measures can irreversibly override this action.

(2) Available procedures belonging to manuals and (or) training are searched for instructions which require the actions identified in step one and which specify the criteria for action performance. Search is pragmatically restricted to professional experience of operators for two reasons: Firstly, recourse to professional experience is obvious in coping with unusual, abnormal, and beyond-design plant and system states. Secondly, non-professional experience depends on many factors like e. g. previous jobs or personal interests which are difficult to oversee.

(3) Boundary conditions of performing these actions in scenarios according to step one are researched. This is done by (a) defining the expected course of human action for mastering the scenario in question, (b) by identifying factors, which can cause or contribute to human failures including inopportune actions, and (c) by analysing possibilities for recovering these errors.

Step (3a) is based on established methods (e. g. [5]), for step (3b) a detailed inventory of relevant performance shaping factors was prepared for systematically guiding analyses. Example topics of this inventory are contents and design of procedures or kinds of information presented on control panels and information design. In step (3c), factors like e. g. alarms have to be considered with the support of available literature (e. g. [1], chapter 16ff.).

Step (3) was included in the method for identifying inopportune ad hoc actions, because it allows to check, if such an action has to be analysed and evaluated in detail with the

methods to be described in the next two sections or if it can practically be neglected because of e. g. numerous and (or) powerful recovery factors.

6 METHOD FOR ANALYSING HOW POSSIBLE INOPPORTUNE AD HOC ACTIONS CAN OCCUR

Method development comprised several steps, which were performed in accordance with relevant requirements specified in section three:

(1) Results of cognitive psychology and cognitive ergonomics were reviewed and evaluated with two objectives: Firstly, non-controversial and empirically valid key-features of human cognition in general and of cognitive support of task performance in particular were determined. Secondly, cognitive factors were identified, which can lead or contribute to the selection of inappropriate action. Basic conclusions for model development were drawn.

(2) With the outcomes of step one, a comprehensive model of human cognition and of coping with cognitively demanding tasks was developed, which shows, as systematically and precisely as possible, how interaction of boundary conditions of task performance with human and other psychological resources increase the possibility of a particular action.

(3) Outcomes of steps one and two were discussed with a leading expert in the area of cognitive psychology.

(4) A synoptic overview of results was developed to support practical application.

The following subsections will present more details on these steps.

6.1 Review and evaluation of the state of the art in cognitive psychology and cognitive ergonomics, consequences for model development

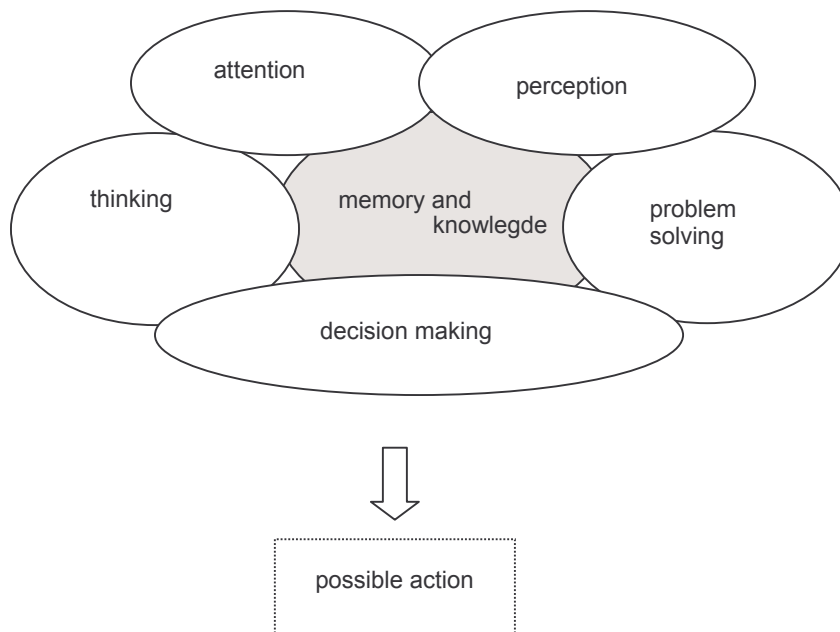
Cognitive psychology and cognitive ergonomics have been providing numerous and, to a large extent, controversially discussed theories, methods, and results. Similarly, available literature was searched for heuristics i. e. simplifications, biases i. e. presuppositions, and other factors which can negatively influence human judgement and decision making in general and his cognitive coping with tasks in particular. Results can be exemplified by the so-called halo-effect, according to which single or a few incompatible pieces of information can be neglected, if actor's representation of the situation is dominated by many other pieces of information, which are compatible with one another.

A method for practical application should not be based on concepts and outcomes which, to all appearance, are likely to be revised and (or) which are nor based on facts. This was the guiding principle for evaluating and selecting material from the body of scientific knowledge for method development, which led to several more specific conclusions regarding model development: (1) The model had to be based on clear, state of the art definitions to avoid terminological uncertainties. "Cognition" e. g. was defined in accordance with Neisser ([3], p. 1) as a summary term of mental processes of acquiring, storing, and applying knowledge i. e. traces of learning and experience. (2) Knowledge retrieval and processing had thus to be a key topic of model development. (3) Major cognitive subtasks or "functions" like e. g. attention, perception, and memory had to be distinguished, for which definitions and explanations of their contribution to diagnosing a given situation and to decision making regarding response had to be provided. (4) Interactions of cognition with stimulation, motivation and stress had to be considered, because they contribute to the selectivity of

knowledge retrieval and knowledge processing during task performance. Stimulation provides information about the situation, the person is interacting with. Motivation explains subject's selection of goals, his (her) sustained efforts to achieve goals, and the retrieval of related knowledge. Stress is known to degrade knowledge retrieval and knowledge processing.

6.2 Model of human cognition

The model integrates the cognitive subtasks or „functions“, which were defined and analysed in step one of method development (see 6.1). The resulting model is similar in structure to Swain's model ([1], p. 12-6ff.). Some cognitive functions were given other names in accordance with the more general terminology of cognitive psychology. Furthermore, the „components“ of knowledge and memory were included, which are missing in Swain's framework. The following picture represents the resulting model. In principle, this picture should contain arrows between all components, which indicate their interaction. These arrows were omitted for the sake of greater clearness. For the same reason, interaction with human sensory system, motivation, and stress were not represented.



This quite general model is supplemented by features, which characterise knowledge representation, knowledge retrieval and knowledge processing in human memory as well as response selction. These features reflect limits of human cognition, which are a product of man's evolution. These limits support quick and often quite efficient responses in pariular to changes of the situation, the individual is interacting with. But under specific circumstances, this evolutionary advantage can turn out to be counterproductive and lead to error. The final part (6.2.5) of this subsection presents a list of relevant factors of this kind. The preceding parts (6.2.1 to 6.2.4) provide essential qualitative background information about cognitive functions and about possible negative effects on these functions. A qualitative level of description was preferred, because precise quantitative statements about human cognition and its functioning are often too specific and (or) too controversial to be considered in a model for application in pracitical safety analysis.

6.2.1 Knowledge representation

Knowledge is networked, different pieces of knowledge can be linked either directly or indirectly, i.e. via more or less numerous other pieces of knowledge. Links can be more or less strong in particular as a function of learning. No detailed assumption about the precise form of knowledge representation and kinds of links is made, because these topics are controversially discussed in basic cognitive science.

6.2.2 Knowledge retrieval and processing

In the model, knowledge retrieval and processing are characterised by the following features:

(1) Knowledge has to be retrieved for use.

(2) Retrieval is process and outcome of a search- and activation-process in memory. Retrieval fails, if activation is too weak.

(3) Activated knowledge can deactivate incompatible pieces of knowledge. Since cognitive prerequisites for establishing coherence between pieces of activated knowledge are still under discussion, no precise assumptions about these mechanisms are introduced at the present stage of model development. Deactivated pieces of knowledge drop out of further processing.

(4) Activation and deactivation are spread via links between pieces of knowledge.

(5) Activation (or deactivation) can vary in intensity, which depends (a) on the intensity and duration of stimulation, (b) on motivation and (c) on activation (deactivation) by already activated pieces of knowledge.

Ad (5a): Stimulation of sense organs and nervous system by physical or chemical signals activates knowledge in human memory, if features of stimulation match those stored by knowledge. Data from sense-organs and nervous system interacting with sense organs get lost, if no knowledge can be retrieved from memory by which these data can be recognised, interpreted, and encoded for further cognitive processing. Sensory and neural activity caused by stimulation of actor's sense organs in the given situation thus become meaningful, if and only if they can be matched with knowledge, i. e. the result of prior learning and experience, the actor is able to retrieve. The precise details of this process are still under discussion, but the following principles hold. Stimulation becomes effective in knowledge activation,

- if it is sufficiently strong and persistent to cause marked effects on sense organs and nervous system.
- If it is not too strong, so that damages, aversion, or refusal to interact with the situation are avoided.
- If it is not too persistent, because sense organs and nervous systems adapt to unchanging stimulation, i. e. its effect decreases over time. Related aspects of a situation tend to be neglected. Salient changes of stimulation on the other hand are very likely to become effective and to highly influence actor's interpretation and coping with the situation in question.

Ad (5b): Motivation concentrates man's cognitive activity on those aspects of a given situation, which are related to his needs, goals, and measures for goal attainment. This concentration facilitates retrieval of relevant knowledge.

Ad (5c): Retrieval of additional knowledge by already retrieved knowledge is an established fact. Controversy is limited to the details of this retrieval process.

(6) Mental representation (i.e. process and result of integrating retrieved knowledge to form a diagnosis of the situation and a basis for decisions about action) is a self-organising process. Retrieved knowledge contains criteria and routines for establishing coherence of mental representation. Supporting knowledge is likely to be retrieved, incompatible pieces of knowledge are likely to be eliminated from the representation (see also (3) above).

6.2.3 Working memory

Processing of retrieved knowledge takes place in working memory. Memory structure and functioning is controversially discussed in basic research. Working memory was often identified with a short-term memory of extremely small capacity, which heavily constrains knowledge processing. Experiments show, that this restriction does not hold in general. According to these experiments, processing of expert knowledge is organised in such a way, that extremely narrow processing capacities can be by-passed. These experiments provided evidence in favour of larger but nevertheless limited working-memory capacity. Under specific condition like alarm avalanches, rate and amount of presented information can therefore still exceed processing limits and (or) the capacity of rapidly and coherently organising incoming information in a coherent way.

6.2.4 Response selection

Retrieved knowledge can include subject's knowledge about possibilities for achieving goals in the given situation. One option can be to refrain from action. According to the present model, a particular option is likely to be selected for performance, if the following condition holds:

Likelihood of possible actions or inaction depends on the degree to which mentally represented conditions and expected effects of the option in question match mentally represented characteristics of the situation and of the goal to be attained. The closer the correspondence, the more likely the option in question shall be. The actor will be likely to select the option with the best match, if he expects to attain his goal with the selected option. Goals can be changed or modified, if they seem or turn out to be difficult to achieve.

6.2.5 Factors increasing the likelihood of selecting a particular response

Mental representations are subject to factors, which can cause or contribute to the selection of an objectively wrong response to a given situation. The retrieval and processing principles stated above allow to systematically explain heuristics, biases, and other effects, which can degrade response selection.

The method distinguishes several groups of factor, some of which have already been mentioned above. If necessary, contents of factor groups will be commented on and illustrated with examples:

(1) Knowledge retrieval and processing depend on motivation and the goal-directed character of human behaviour. Related knowledge is much more likely to be retrieved and processed than other pieces of knowledge.

(2) Retrieval and processing depend on the availability and accessibility of knowledge. Highly available and easily accessible knowledge tends to determine mental representations. Actors may even be erroneously convinced, that a particular representation or account of the situation is true or highly plausible, because corresponding knowledge was quickly available and the interpretation of the situation seemed to be quite clear (“availability heuristic”).

(3) Mental representation depends on the main areas of subject’s learning, experience, and knowledge acquisition. This background forms the frame of reference for recognising and interpreting objects of sense, objects of thought, and entire situations. Recognition and interpretation depend on the similarity between objects (situations) to be recognised and referential objects (referential situations) retrieved from memory (“representativity heuristic”). This similarity can also be deceiving.

(4) Mental representations are subject to processes, which establish coherence between its parts. For the sake of coherence, particular aspects can be neglected, if they do not fit in or fit in well.

(5) Coping with stress, which is to be expected in emergencies, increases selectivity and imprecision of knowledge retrieval and processing. In high stress situations, processing tends to be disorganised.

(6) Working memory capacity limits can be exceeded by too many, rapidly incoming and (or) changing, and inconsistent alarms and indications. This can lead to similar effects like stress.

(7) Salience of and habituation to situational aspects can bias subject’s cognitive activities in general and attention in particular: Salient, new, and changing information easily captures human attention and becomes likely to be processed, whereas persistent, unchanging aspects of a situation tend to become ineffective.

Interactions between factors pertaining to these categories have to be taken into account.

Research of relevant factors included the identification of boundary conditions, under which they are to be expected or not.

6.3 Model evaluation by an independent expert

Prof. Dietrich Dörner (University of Bamberg), an internationally leading expert in the area of cognitive psychology, evaluated the outcomes of the research and development activities described in the preceding two subsections. He approved and encouraged his work with a highly favourable judgement.

6.4 Tool for practical application

Since the review did not require modifications of essential model characteristics, a tool for supporting practical application was developed.

A principle feature of cognitive phenomena like e. g. knowledge retrieval, knowledge processing, and mental representation is, that they cannot be directly observed. They have to be inferred from facts like objectively given boundary conditions of behaviour and directly observable responses to these conditions. In basic science, systematic observation in general and laboratory experiments in particular supply necessary information.

In practical contexts, resources of time and money required for this kind of research are normally not available, but the factors and effects presented above are sufficiently general and robust for being identified and analysed with the help of expert judgement regarding their contribution to possible inopportune action in a given scenario.

To support this kind of expert judgement, a synoptic overview was prepared which shows, under which situational conditions factors listed in 6.2.5 can become effective, how they can degrade the function of human cognition, and what kinds of consequence for reliable task performance have to be expected, if such a degradation takes place. Expert judgement has to be based on a careful analysis of task and working conditions and on data from interviews with competent personnel.

Support provided by these overviews can be exemplified by the halo-effect i. e. the possible neglect of a piece of information which is not consistent with the rest of the information about a specific object, topic, or situation. Plausibly, the greater the majority of mutually consistent pieces of information, the higher the possibility of neglecting a single or a few pieces of information, which do not fit into the general pattern. Halo-effects are less likely to occur, if discrepant information is related to actor's goal and (or) if it is so salient, that actor's attention gets focussed on it. The halo-effect can mainly degrade cognitive subtasks of thinking, problem solving, and decision making. Impacts on attention and perception with further reinforcement of halo-effects are possible, if the subject primarily looks for additional information, which is consistent with his overall picture of the situation. Possible consequences of a halo-effect are easy to infer: If particular pieces of information are neglected, erroneous decisions can be made regarding appropriate response to the situation.

7 METHOD FOR ASSESSING THE PROBABILITY OF INOPPORTUNE AD HOC ACTIONS

The method for assessing how probable a possible inopportune ad hoc action in the context of a particular scenario is based on expert judgement, since neither observations of operators' behaviour in simulators, nor operating experience, nor available human error quantification methods provide data which can directly be used for estimating the likelihood of these actions.

A rating scale was developed in order to support expert judgement and the estimation of error probabilities. The scale is composed of five categories, which describe progressively more and more disadvantageous conditions of task performance in general and of selecting a correct response under such conditions in particular. Similar categories are used by available approaches for evaluating the support of task performance by man-machine systems, which served as starting point for scale development ([6]). Plausibly, the worse conditions for task performance and response selection are, the higher the probability of erroneous action is judged to be. This principle was concretised in the following way:

- If the analysis does not reveal essential conditions of task performance which can negatively influence human diagnosing and decision making with respect to action, then the probability of an inopportune ad hoc action is zero. This does not rule out the possibility of other errors related to performance of required actions.
- If the greater part of these conditions have to be evaluated negatively and if there is no possibility for recovering a possible inopportune action, the probability is conservatively assumed to be one.

For intermediate categories results of a review of numerous probabilistic safety analyses were used ([7]). This review investigated the correspondence between more or less

unfavourable conditions for task performance and the range of probabilities of erroneous action according to Swain's method ASEP ([8]). These probabilities were used as a first estimate of the likelihood of errors belonging to the category of inopportune ad hoc action.

The following table shows the resulting scale for guiding expert judgement and estimation of error probabilities.

Category	Description: disadvantageous conditions for mastering a given scenario ...	Error Probability	Error Factor
1	...were not found	0	-
2	... are not essential, recovery of inopportune ad hoc actions is possible	0,01	10
3	...comprise some essential ones, recovery of inopportune ad hoc actions is possible	0,10	5
4	... mostly comprise essential ones, recovery of inopportune ad hoc actions is possible	0,50	5
5	... mostly comprise essential ones, recovery of inopportune ad hoc actions is <u>not</u> possible	1	-

Additional data can be provided by a more elaborate expert judgement method developed by GRS staff in a different project some years ago. The reader is referred to the relevant publication in the list of references ([9]).

8 CASE STUDY

A case study was performed in order to test the methods described in the three preceding sections by applying them to a well-documented instance of inopportune action. The 1979 accident at unit two of the Three Mile Island nuclear power plant was selected and reanalysed. Without going into details in the present article, the results of this case study can briefly be summarised as follows: (1) The reanalysis revealed many factors which can degrade human diagnosing and decision making activities. Results contribute to a good understanding of the causes and conditions of the inopportune action in question. The corresponding probability of inopportune ad hoc action was estimated to be 0,50 with an error factor of five. (2) In this first application and check, the methods described above turned out to be practicable.

9 OUTLOOK

Work presented in this article resulted in important contributions to the assessment of inopportune ad hoc actions by providing methods for identifying, analysing, and quantitatively evaluating these actions. These methods can be qualified to be either new or to be more sophisticated than other available ones. A first case study showed, that they are also practical to use. Method development and case study were documented in a report, which is going to be published soon.

Further research, development, and application activities are necessary. With respect to inopportune ad hoc actions, the methods presented here should be applied in probabilistic safety analyses, which go far beyond a case study reanalysis of one specific event. Application experience should be used for method improvements, if they turn out to be necessary. Furthermore, additional data for estimating error probabilities should be collected by systematically investigating experts' judgement of how likely inopportune ad hoc actions are under precisely described circumstances and by conducting appropriate experiments.

Operators can also derive recovery measures from their knowledge and experience, when coping with scenarios, for which manuals and (or) procedures do not provide particular procedures. A suitable method should be developed for identifying, analysing, and evaluating these actions in more comprehensive probabilistic safety analyses.

The method presented here concentrates on individual operator's diagnosing and decision making regarding response selection. Operators do not work in isolation, but in a team which is part of a larger organisation. Cooperation and communication interact with mental activities which can be influenced by this interaction in positive and in negative ways. Teamwork offers for example the possibility for detecting and recovering individual's errors, but this control can also be weakened by too close cooperation. Authority or authoritarian behaviour of a group member as well as pressure exercised by team majority can also increase dependence, opportunism, and conformity and degrade individual critical judgement. Methods should be developed for identifying such effects, for analysing their impact on task performance, and for assessing their contribution to human reliability for supporting more comprehensive and precise probabilistic safety analyses.

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