Errors of Commission in HRA – NPSAG Phase 1 project

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Abstract: In most current Probabilistic Safety Assessments (PSAs), failures to respond as called for by procedure are modelled as errors of omission (EOO): a response is modelled as being executed correctly or not executed at all. The consequences of incorrect responses are generally not addressed. A human failure that leads to an incorrect response is often referred to as arising from an error of commission (EOC) [1].

EOC means the potential to make a situation more serious. While EOCs are generally considered out of the PSA scope due to the difficulties in systematical identification, modelling and quantification, it is a desire for many PSA and human reliability analysts to improve EOC analysis to have a better understanding of the EOC contribution to the plant risk. The U.S. Nuclear Regulatory Commission (NRC) Human Reliability Analysis (HRA) Good Practice NUREG-1792 recommends that EOCs should be addressed in future PSAs and as a minimum a search should be performed for conditions that make EOCs more likely [2].

This paper presents the results from an EOC project supported by the Nordic PSA Group (NPSAG) during 2017 [3]. The phase 1 project included two main tasks: (1) a literature review on the requirements, methods and existing research and application studies related to EOCs; (2) an international survey on how EOC is included in the world wide nuclear power plants. The findings were discussed in a seminar and initial recommendations were proposed to NPSAG on how to study EOCs in the PSA including identification, modelling, quantification and preventions.

Keywords: HRA, Error of Commission (EOC).

1. INTRODUCTION

EOC means the potential to make a situation more serious. Historically, EOCs of Category C (Post-initiators, actions taken after the initiating events) are not modelled in PSAs because of difficult systematic identification of events as well as the difficulty in modelling the consequences (impacts) of such errors. As defined in IAEA 50-P-10 [4], this is the type 2 'Aggravating actions/errors' among the Category C human actions. These actions are a special set of commission errors that occur post-fault and potentially significantly aggravate the accident progression. It is challenging to identify and model these actions. Only collaboration between the human reliability analysts and the system analysts can identify significant Type 2 post-initiators that are to be incorporated into the PSA.

Many of the current PSA requirements such as the ASME Standard [6] do not explicitly address EOCs. However, there were already some research studies and pilot applications on how to identify and model EOCs in PSA context such as ATHEANA [7] and Commission Errors Search and Assessment (CESA) [8, 9]. Some countries have set up specific requirements on EOCs, e.g. UK ONR requires credible misdiagnosis should be identified and modelled correctly [10].

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In some plants, Category C EOCs are incorporated in the error probability estimation, even though their impacts are not explicit included in the structure of the logic model. For example, THERP [5] includes EOC probabilities of selecting a wrong switch from an array of switches. However, the impact of the wrong selection on the plant risk is typically not modelled.

In summary, most current PSAs have only handled Category C EOCs implicitly (e.g. as part of a base HEP) without a systematic or adequate search for and modelling of this type of errors in the plant risk model. The need to consider EOCs has long been recognized and progresses have been made to identify EOCs without performing an exhaustive search.

In order to provide practical recommendations on EOC treatment, i.e. identification, quantification and prevention, the Nordic PSA Group (NPSAG, with SSM, Ringhals, Forsmark, OKG and TVO as stakeholders) funded the EOC project from the beginning of 2017. The project is expected to have multiple phases.

The objective of the NPSAG EOC phase 1 project is to (1) perform a thorough literature review on the requirements, methods and existing research and application studies related to EOCs; (2) to perform an international survey on how EOC is included in nuclear power plants worldwide and in the research works that have been performed in international organizations; (3) to provide initial recommendations to NPSAG on how to study EOCs in the PSA including identification, modelling, quantification and preventions; and (4) to suggest a reasonable R&D plan for NPSAG stakeholders in relation with EOC issues.

This paper summarizes the results/findings from the first phase of the NPSAG EOC project as it was completed in 2017. Note that the phase 2 project is currently being performed to implement the suggestions in the case studies for a NPSAG member plant. The phase 2 project will be completed by the end of 2018.

2. EOC DEFINITIONS AND THE TYPES OF HUMAN ERRORS

2.1. EOC Definitions

EOC is defined in different ways in the literature and thus it is interesting to review them. THERP [5] defines the EOC as incorrect performance of a task (or action), and define EOO as failure to perform a task (or action). EOC includes selection error, error of sequence, time error (too early or too late) and qualitative error (too little or too much). EOC and EOO are incorrect human outputs, which can be a result of some errors (causes): an error in interpretation, misreading, etc.

Julius et al [1] defined EOC as an error which leads to a failure of a system (s) or function (s) required to mitigate an accident, or an inappropriate actuation of a system or function. They pointed out that modelling specific EOC requires identification of reasons for erroneous actions. This is because EOCs are not necessarily associated with predefined actions or responses, and the set of possible actions is virtually unlimited. Thus the identification of error opportunities, error modes and expressions requires an understanding of the causes of errors and the specific context in which the errors are likely to occur. Three broad categories of error mode were further proposed:

- global misdiagnosis (selection of an inappropriate procedure),
- local misdiagnosis (intentional human system interaction) and
- slip (unintentional human system interaction).

In recent U.S. literatures (e.g. NUREG-1792 [2], ATHEANA [11]), EOC is defined as a human failure event resulting from an overt, unsafe action, that, when taken, leads to a change in plant configuration with the consequence of a degraded plant state. Examples include terminating running safety-injection pumps, closing valves, and blocking automatic initiation signals. This definition is consistent with the shorter definition used in the development of CESA which is the performance of an inappropriate action that aggravates a situation.

EOC is defined by the latest IAEA TECDOC 1804 [12] as incorrectly performing a system-required task or action, or performing an extraneous task that is not required and might lead to worsening the accident progression or cause an initiating event.

2.2. EOC and Three Categories Of Human Actions

As defined in IAEA 50-P-10 [4], there are three categories of human actions for incorporation in PSA:

- Category A actions that cause equipment or systems to be unavailable when required post-fault.
- Category B actions that either by themselves or in combination with equipment failures lead directly to initiating events/faults.
- Category C actions occurring post-fault. These can either occur in the performance of safety actions or can be actions that aggravate the fault sequence.

From this definition, EOC can be any of the three categories. Quite many of the Category A and B human actions modelled in the plant PSA are EOC type. Examples include the system/equipment misalignment after testing, human introduced LOCA, etc.

However, EOCs of Category C are historically not modelled in PSAs because of difficult systematic identification of events as well as the difficulty in modelling the consequences (impacts) of such errors. This is the type 2 ‘Aggravating actions/errors’ of category C human actions.

2.3. EOC and the Types of Human Errors

James Reason [14] classifies the human errors into:

- Slips: unintentional error in execution stage, e.g. inadvertent selection of a wrong item when attempting to execute a planned action. Slips are associated with skill based actions in Rasmussen’s decision making model.
- Lapses: unintentional error in memory storage stage, i.e. omissions to perform an action during a planned sequence of activities
- Mistakes: intentional error in planning stage, e.g. incorrect understanding of a situation. Mistakes are associated with rule based and knowledge based actions in Rasmussen’s decision making model.
- Violations, where deviating from safe practices is intentional.

EOC can be either mistakes or slips according to the above definition. EOCs from mistakes should be the focus of the study as recovery is less likely when the operators have incorrect understanding of a situation. EOCs from slips might also have negative impacts to the plant status, however they are easier to be recovered as human has the correct intention.

3. LITERATURE REVIEW SUMMARY

A thorough literature review on the requirements, methods and EOC related research and application studies was performed in the Phase 1 project. The review includes:

- EOC requirements in current international and national HRA guidelines;
- The findings from the existing EOC research and application studies;
- A detailed study of three relevant HRA methodologies/applications in their treatment of EOC. These are ATHEANA, CESA and the recent UK EDF Energy study on EOC.

3.1. EOC Related Requirements in the Relevant Guidelines

Relevant international and national guidelines were reviewed. There is currently no EOC specific requirement in many of the guidelines, e.g. the ASME PRA Standard [6], NRC Regulatory Guide 1.200 [14], Swedish regulatory requirements [15] or Finland's PSA guideline (YVL A.7) [16], etc.

However EOC issues are covered in some guidelines. Some examples are summarized in Table 1.

Table 1: EOC Requirements in the HRA Guidelines

HRA Guidelines	Relevant EOC Requirements
NUREG-1792 HRA Good Practices[2]	• Good Practice #1: Address EOCs in Future HRAs/PRAs (Recommendation). • Good Practice #2: As a Minimum, Search for Conditions that May Make EOCs More Likely. Even if the recommended first good practice above is not performed, the use of risk in any issue assessment should at least ensure that conditions that promote likely EOCs do not exist.
IAEA-TECDOC-1804[12]	• Post-initiator HFEs: Significant errors of commission, i.e. actions that lead to additional functional unavailabilities, or inappropriately initiate system are identified.
ENSI-A05/e, Switzerland's guide on PSA [17]	• Whether personnel actions with negative impact on the accident sequence ("Errors of Commission" - EOCs) have been identified shall be stated. In the case that EOCs have been identified, their consequences and possible countermeasures shall be discussed.
UK ONR technical assessment guide (TAG) on HRA [10]	• The dutyholder has identified pre-accident human errors (including maintenance, testing and calibration activities, plant alignment activities), direct initiating event human errors, human errors during the course of fault sequences and post-accident human errors (omissions, detection, diagnostic and decision errors, commission errors etc. and common cause human failures). • The dutyholder has considered plausible deviations from normal plant conditions or fault sequences that might cause additional human errors leading to exacerbated or additional fault sequences. • Occasions for misdiagnosis of the situation by the operators have been analyzed systematically. HFEs resulting from identified credible misdiagnosis have been modelled correctly (e.g. human actuations due to misdiagnosis that change the course of an accident sequence will normally be modelled in the event trees. Un-required switching off of systems due to misdiagnosis will normally be modelled in the fault trees).

3.2. Review of the Selected EOC HRA Methodologies/Studies

Many of the existing HRA methods do not address EOCs related to intentional acts caused by a misunderstanding of the situation that could lead to the loss of a critical function. For example in the use of THERP, the potential for simple slips and lapses in response execution are covered, but identification and treatment of situations that might lead crews to take unsafe actions is not considered. THERP focuses only on EOCs in response execution, such as slips, and does not suggest how to model the consequences of the EOCs.

There are a number of studies which tried to understand EOC and even to fill the gap, e.g. the OECD NEA working group on Risk Assessment (WGRISK) efforts in EOCs [18-20], EXAM-HRA project [21], NKS Study on EOCs in the Nordic plant operating experience [22], MERMOS [23], MDTA [24], Julius et al. [1], Macwan and Mosleh [25].

Three HRA methods/studies were chosen for a detailed review: ATHEANA [7], CESA [8-9], and UK EDF Energy recent EOC studies [26].

3.2.1. The ATHEANA method

ATHEANA [7] provides guidance for searching for situations when the operators are placed in an unfamiliar situation where their training and procedures are inadequate or do not apply, or when some other unusual set of circumstances exists. Such situations are said to have an error forcing condition (EFC) in ATHEANA terminology. In addition, because situations with a strong EFC may not always be likely, ATHEANA also addresses evaluating and quantifying behaviour in the more nominal case that is typically modelled in a PSA.

ATHEANA has been applied or tested by a number of countries in a number of projects [18], including the recent international HRA empirical study [27].

In the empirical study, the ATHEANA analysis provided a number of possible outcomes for each human failure event (HFE), which successfully identified the sources of failure. For most of the more challenging HFEs, the ATHEANA team's qualitative discussion matched the observations well.

Compared with most other HRA methods, ATHEANA relies less on templates and forms and more on the skill of the analysts in documenting their decision process. Without such documentation, the traceability of ATHEANA would be negligible. The requirement to have team members who have an operational background is clearly a very strong feature of the method, since this clearly helped in identifying the potential error modes. The ATHEANA approach of providing a framework for evaluating the impact of context on human error probabilities (HEPs) by considering potential failure modes is most valuable when there is an identifiable error forcing context or contexts.

The latest developed quantification, relying on expert elicitation, needs to be clearly documented. The quantification would be very difficult to reproduce in that a different set of experts might provide very different assessments [11].

3.2.2. The CESA method

In later 1990s, the Paul Scherrer Institut (PSI) developed the EOC identification method CESA. So far three pilot studies have been performed in Switzerland for one PWR and two BWR NPPs in their level 1 full power PSAs. The fourth pilot study will be conducted for a PWR plant in Switzerland and there is a plan to apply the method in the external event scenarios, to analyze recent operational experiences involving EOCs, and to further improve the CESA-Q quantification method [28].

The main idea underlying the method is to catalogue the key actions that are required in the procedural response to plant events and to identify specific scenarios in which these candidate actions could erroneously appear to be required. The catalogue of required actions provides a basis for a systematic search of context-action combinations, which results in a set of EOC situations to be examined in detail.

CESA's basic identification scheme therefore proceeds from actions to the affected systems to scenarios, i.e. action–system–scenario. This contrasts, for instance, with schemes that proceed from scenarios (a given initiating event), to the functions (systems) required in these, to actions that could fail these functions. The latter, a scenario–system–action approach, is characteristic of ATHEANA.

The CESA method consists of four steps:

- Step 1. Catalogue required operator actions
- Step 2. Identify EOC events linked to important systems

- Step 3. Identify specific EOC scenarios (EOC opportunities)
- Step 4. Characterize the EOC scenarios in detail and quantify

The findings from the PSI two pilot studies are summarized in Figure 1, one for PWR and one for BWR. The scope of the studies includes EOCs occurring during accidents initiated when the plant is at full power, by internal initiating events [8-9].

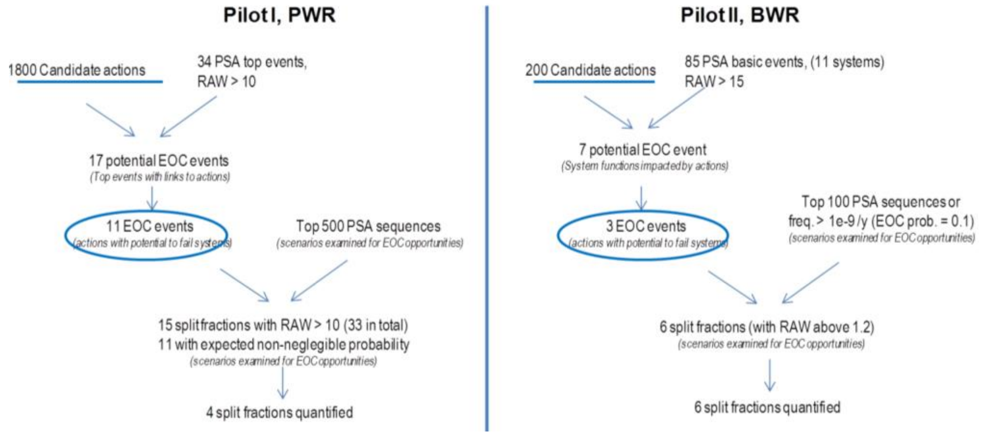

Figure 1: Overview of the results in the first two PSI pilot studies

3.2.3. UK EDF Energy studies on EOCs

A number of research activitites were carried out by and on behalf of EDF Energy Nuclear Generation Ltd to explore options for the identification and assessment of EOC [26].

It is proposed that the more complex EOC can only occur at the points in a process where the operator has to make a decision and that simple EOC within actions are already considered in the error identification process. The task analysis should therefore explicitly identify decision points so that the potential EOC can be explored. The identified EOC can then be assessed using qualitative and quantitative HRA methods.

The basis of the proposed EDF Energy method is that the gap is not primarily in identification of errors where the subject completes the wrong action. Rather, it is that the negative consequences of such actions are not identified or assessed.

The proposed method therefore adapts the current HRA methodologies to:

- Identify potential EOC in task execution ;
- Identify how such errors would manifest themselves using task analysis, e.g. Hierarchical Task Analysis (HTA), Decision Action Diagram (DAD), and Tabular Task Analysis (TTA);
- Look explicitly for EOC at points in the task where a decision has to be made. At these Decision Points (DPs) more complex EOC could occur.

The proposed approach was trialed on a new safety case claim and it was shown to be both practical and useful. In the trial the quality of the task analysis was improved, EOC were identified and assessed without significant amount of resources being needed.

4. INTERNATIONAL SURVEY REGARDING HRA EOC TREATMENT

A survey on HRA EOC in PSA context was sent out to international contacts in nuclear power plants and associated organizations in March 2017. By September 2017, 18 replies were received covering Europe, Asia, Africa, and North America. The following nuclear power plants and technical organizations filled in the survey: Forsmark (Sweden), Ringhals (Sweden), OKG (Sweden), Risk Pilot (Sweden/Finland), Fortum (Finland), TVO (Finland), NEL (Japan), CNPE (China), SNERDI (China), SNPI (China), IRSN (France), NECSA(South Africa), Tractebel and Bel V (Belgium), RELKO (SLOVAKIA), EDF Energy (UK), Jensen Hughes (US, not plant specific), Callaway (US), KAERI (South Korea).

As pointed out by several of the repliers, quite many Category A and B events can be seen as a type of EOCs and they are typically included in the PSA model.

For Category C EOCs, the following findings can be derived from the survey from the repliers to the specific question:

- 4 organizations (24% of 17 total repliers) have explicitly considered Category C EOCs and the impacts in PSA;
- 7 organizations (41% of 17 total repliers) have considered Category C EOCs in their HRA method quantification. However it is not clear if the impact of EOC is considered (leading to exacerbated or additional fault sequences);
- 6 organizations (35% of 17 total repliers) clearly stated that Category C EOCs are not considered

With regard to the importance of the EOCs in the PSA model, the following findings can be derived from the 17 repliers to this question:

- 7 repliers consider EOC is important (among them 4 repliers consider EOC is important in general, 3 repliers explicitly point out that category B EOC is important);
- 4 repliers consider EOC has low importance;
- 6 repliers consider it is not sure or information not available.

With regard to the contentedness with the current EOC treatment, 4 repliers (22% of the 18 repliers) consider they were satisfied, 12 repliers (67% of the 18 repliers) consider it should or could be improved, and 4 of them plan to improve it in the future.

5. CONCLUSIONS AND RECOMMENDATIONS

While Category C EOCs are generally considered out of the PSA scope due to the difficulties to systematic identification, modelling and quantification, it is a desire for many PSA and HRA analysts to improve EOC analysis to have a better understanding of the plant risk.

It is not yet known how significant it is that most methods do not explicitly search for and evaluate EOCs, particularly with respect to EOCs occurring as a result of misdiagnosis. The recognition that EOCs have contributed to the serious events (including in other domains such as aviation), suggests that at least the minimal guidance on EOCs in the good practices should be considered.

The results from the first phase of this EOC project can be summarized with the following recommendations and conclusions: [3]:

- A minimal guidance on EOCs in the good practices should be considered
- The category C type of EOCs and their impacts are the focus of the EOC issue that is currently missing in PSA study. Usually the interesting EOCs are closely related to the decision errors which lead to worsening the accident progression or cause an initiating event.

- EOC identification: An effective process for identification of the important EOCs should be developed. Opportunities for EOCs can be huge in a complex system like a NPP. It is essential to develop an effective identification/screening process to focus resources on the most important EOCs and their effects. The experiences gained in the existing efforts, e.g. PSI CESA applications, ATHEANA applications and UK EDF Energy studies, are already quite good to formulate a good process. The identified important EOCs from these studies could be good start points to form the list of EOCs. Also as suggested by the survey feedback from Tractebel and Bel V (Belgium), each important equipment can be checked to see if an EOC should be considered. An international database for the important EOC actions and relevant scenarios could also form a good basis for future new studies.
- EOC Modelling: It could take very different contexts to lead to an EOC than to an EOO, and therefore the dependencies on events downstream in the PRA logic model could be different. Such considerations are relevant to later events in trees and for the cutset or sequence recovery analysis. When the EOC impact is considered, the logic model is most likely to be altered. In case the above discussed dependency issue and logic issue are not relevant, it might be possible to add EOC HEP contribution to the original modelled HFE, which means the HEP for the HFE is made up of EOC contributions and EOO contributions.
- EOC Quantification:
    - Just like different HRA methods are used in different plants, it is expected that EOC quantification will be performed using different HRA methods in different plants. It is good to keep some consistence in one PSA model. It is also recommended that the experiences learned from ATHEANA and CESA quantification (CESA-Q) could be incorporated in the HRA quantification improvement.
    - Expert judgement would very likely play more important roles in EOC quantification. Thus documentation is very important.
    - In the future, EOC error modes and specific HEP data for the new digitalized plant can be collected
- Recommendations on EOC Preventions/mitigations: When the EOC prone conditions are identified, it is recommended to:
    - Improve the plant information/operating crew interface to make sure clear and adequate information is present
    - Improve the procedure and operator training so that both of them cover the actual plant situation very well.
    - From the PSI pilot study experiences, the potential safety improvements are mainly in procedures.

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