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Empirical Evidence Of HRA Dependence In Operational Events

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In the current Probabilistic Safety Analysis (PSA) practice, the unit of analysis for Human Reliability Analysis are the so-called Human Failure Events (HFE). An HRA is performed for each identified HFE to be incorporated in the PSA models (fault trees and event trees). For accident sequences including multiple failure events, the issue of dependence across the HFEs arises, because of performance influences possibly persisting across the subsequent HFEs.

Analyses of dependence can have a decisive quantitative impact on HRA and PSA results. In state-of-the-art PSA, dependence analysis is frequently based on Decision Trees (DTs) that link performance conditions to the applicable level of dependence (e.g. low, moderate, high). DTs are considered a simple and pragmatic solution and often provide convincing results, although they treat some performance aspects very simplistically, e.g. the procedural paths related to the actions underlying the multiple HFEs. Furthermore, the relationships underlying the DTs are not based on empirical data, but on judgment.

In line with the general trend of current HRA research to improve empirical and modeling foundations, recent advances in HRA dependence include development of foundational definitions (Paglioni and Groth, 2022), of dependence modelling idioms (Paglioni and Groth, 2022), a data-informed attempt based of the HUman Reliability data EXtraction (HuREX) framework (Kim et al., 2023), and the dependence analysis module of the Integrated Human Event Analysis System for Event and Condition Assessment (IDHEAS-ECA), aiming at a stronger basis on cognitive science (USNRC, 2021).

As a further step to strengthen empirical basis for dependency analysis, the present work analyzes evidence from operational events involving multiple human failures, in nuclear power plants (Podofillini and Dang, 2023). The analysis aims at the identification of performance factors influencing dependence, as it manifests from operational evidence. Although not covered by the present work, the subsequent goal would be to evaluate the coverage of the above factors by state-of-the-art DT implementations.

The operational events have been selected from the International Reporting System for Operating Experience (IRS) (https://nucleus.iaea.org/Pages/irs1.aspx), an international system to exchange operational experience of nuclear power plants, managed by the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA). Since it was not possible to directly identify IRS events involving multiple human failures, the search proceeded by progressively restricting the set of potentially relevant events. The IRS events characterized by “multiple failures or multiple errors” were first selected (about 2000 events). Then, for only selected Countries to further restrict the search, the titles of the events were quickly reviewed in search for events possible involving multiple human failures (considered countries: Belgium, Czech Republic, Finland, France, Germany, Sweden, Switzerland, USA - counting about 500 events). This led to the selection of about 50 events, which were further screened based on the information included in the event description. Finally, six events were retained for further analysis.

The narratives of each operational event and of each human failure were reviewed, along with the contributing factors as identified by the corresponding IRS event report. By comparing the contributing factors across the multiple failures, the common influencing factors are identified, referred to as “coupling factors”. The presence of a coupling factor indicates that the same specific failure cause (e.g. a simulator fidelity issue) has acted on both HFEs, thus making the failure of the pair more likely than the failure of each HFE.

The small number of cases available for analysis does not allow generalizing conclusions, yet some remarks can be derived, specifically for the analyzed cases. Indeed, the identified coupling factors can be grouped as:

- work practice-related: e.g. related to deficiencies in supervisory control, safety attitude, application of informal procedures, questioning attitude;
- task-related: characteristics carrying over across multiple tasks, e.g. some common elements of complexity, concerns in previous task influencing decisions on the subsequent task;
- knowledge-related: training, experience, general plant knowledge, e.g. simulator fidelity issues, inadequate plant knowledge, precursor learning.

Task-related factors have the strongest influence on dependence, because they generally manifest as specific performance drivers for the multiple tasks. Work practice-related and knowledge-related factors do not appear as main drivers for the dependence, rather as secondary, detrimental influencing factors. While their coupling effect may not be as strong as for task-related factors, work-practice and knowledge-related factors pose an important challenge to HRA dependence analysis. These factors are generally connected with safety culture and organizational factors, which in turn are often not explicitly covered by HRA, even in independent HFE analyses. In cases when task-related factors are not present over multiple HFEs, coupling by work-practice and knowledge-related factors may be overlooked, thus assuming HFE independence. This may have important effects on the overall PSA results: depending on the value of the independent failure probability, the “jump” from “no” to “low” dependence can be significant. This aspect is under further investigation by the authors.

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