Comparison of two human factors approaches in an integrated evaluation/validation of a future emergency operating organization

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Abstract. This paper focuses on a Human Factors evaluation campaign that had associated Ergonomics and Human Reliability Analysis (HRA) for the evaluation of a future control room. This campaign was conducted within the framework of a broad design project and was performed in a full scale simulator with 3 futures operating teams. The aims and methods of both, ergonomics and HRA, are compared and their particularities and complementariness in the different stages of a HF evaluation campaign (preparation, data collection, analysis, conclusions and recommendations) are discussed. The results highlight their contribution to safety and risk analysis.

Keywords. Simulation, HF evaluation, design, HRA.

1. Introduction and background to study

For more than 10 years, Human Factors (HF) experts have been involved in designing control means for a future control room. The evaluation is part of the HF engineering programme and is the subject of an iterative simulation process (Labarthe, De la Garza, 2011). Since 2002 about ten HF evaluation rounds have been carried out combining different forms of simulation, according to the simulation resources and data available during the project development stages. The first simulations were made with static and dynamic mock-up, then, since 2009, on a full-scale simulator, reproducing the control means and operation of the future reactor. They are evaluations of all the control means aimed at analysing interactions and the coupling "Man-Machine-Imaging-Procedures-Organisation-Interfaces". The simulation has two objectives: as an evaluation tool, through a diagnosis based on analysing the operating team's activity and, as a prognostic tool, anticipating the characteristics of the future activity and safety risks. The evaluation aims therefore to ensure that the design choices are suitable for the operating requirements and the achievement of safety objectives in normal and emergency operation.

In this paper, we will focus on the HF evaluation round conducted in 2012 with a multi-disciplinary evaluation team combining Ergonomics and Human Reliability. This evaluation aimed to evaluate the team functioning in emergency operation in the control room. It involved 3 operating teams as initially planned for emergency operation, made up of 2 operators, an operations manager (the team leader) and a safety engineer (independent review line). Each team took part for a week in 5 scenarios (accidental transients) on the full-scale simulator. In addition, instructors were called in to prepare the accident scenarios, train the teams in advance, and control the simulator during the tests, then to support the post-test analysis. The aim of having distinct HF approaches was to compare and contrast points of view and methods to target issues relating to operating performance and safety, organisational inspection and review lines of defence, and how teams operate from an individual and group point of view, while interacting with the control means. Comparative analysis shows the complementarities of these two approaches and their distinctive methodologies in the various stages of an HF evaluation round: i) preparation, ii) performance and data collection, iii) analysis, iv) conclusions and recommendations. Thus, their contributions to safe design are highlighted.

2. Evaluation objectives of each discipline

2.1 Ergonomics: an evaluation of the sociotechnical system for design

The ergonomics evaluation aims to analyse interactions between the operating team members and the control means (interfaces, imaging, procedures, organisation). The group point of view is studied in relation to communications, problem-solving and decision-making by the team. This leads to a diagnosis of the current situation which makes it possible to understand the consequences of the actions performed, the difficulties encountered and decisions made by the team, as they interact with the control means. Five points guided the ergonomics evaluation, and consequently the diagnosis: i) identifying situations, according to knowledge about the existing situation (national and international feedback), ii) known accidental transients, iii) the specific technical features of the future reactor (considerable automation and computerisation), iv) malfunctions making the situation harder to manage and, v) complex situations because they are cumulative, while remaining plausible/realistic, and events of a separate order (for example, a fire combined with a thermohydraulic transient). For ergonomics, envisaging types of situations makes it possible to identify invariants, in terms of difficulties and risks as well as reliable individual and group operating methods or those that weaken the sociotechnical system being studied. It is then possible to make recommendations aimed at improving man-machine interactions and team operation. Prognostics in ergonomics starts from a diagnosis of the simulation situation and analysis of the appropriateness of the changes proposed in response to the recommendations to solve these problems and respond to the risks identified.

2.2 Human reliability: an evaluation of the sociotechnical system with regard to risks

Human reliability evaluation involves analysing how the operating system as a whole (team, procedures and interfaces) is capable of managing critical situations, from the point of view of safety and the reliability of the installation (like the MERMOS HRA method (Le Bot, 2007). For this, at EDF, human reliability is inspired on the one hand by functional and reliability engineering approaches (like Probabilistic Safety Assessments) and on the other by contributions from the humanities, in particular distributed cognition (Hutchins, 1995). Thus, the main actions required for safety in the situation considered are defined, and the reliability functions of the operating system are identified: action, inspection (conformity of performance with the actions decided by the group), review (adapting the actions decided by the group to the situation in progress), and reconfiguration (Le Bot, 2010). The evaluation is done first by examining the safety results, then going back to the characteristics of how the group and the entire operating system involved in these significant consequences for safety work. This is what is called evaluation of the "actual performance" during the simulation studied. To complete this evaluation which is made starting from the actual consequences to the process, human reliability also considers the "potential performance" of the operating system: that is to say that the important characteristics of the operating system observed during a simulation are transposed into other situations where their impact on safety might be significant, even if during the simulation that characteristic did not have an impact on safety (Pesme, 2012).

With this in mind, they may be led to consider not only the recurrent risky team behaviours, but also rarer behaviours if they prove to have a strong impact on safety. This double focus (actual and potential) makes it possible to target recommendations that represent a major impact on safety.

3. Comparative analysis of the methodological processes of the 2 approaches

3.1 Complementarities and differences in the preparation of the HF test protocol

At the heart of preparing an evaluation round are the choice and construction of the accidental transients (scenarios) that will be used according to the evaluation objectives.

Beyond the specific project constraints that limit the choice of situations to test (procedures, imaging and MMIs available at the time of the HF tests, developments in how the simulator operates with the design), *ergonomics* directs the choice in relation to the specific situations to test. This choice is guided by: the specific control means to be tested (technological innovation, procedures, and imaging that has been upgraded), and malfunctions that they want to ensure are adequately managed by the team. This is the case, for example, for an Automatic Diagnostics (AD), the principle of which has been worked on with the designers, tested a first time, then re-tested on several occasions in nominal operation and when it fails (De la Garza et al., 2012). The evaluation hypotheses are defined according to the control means evaluation objectives, and from the point of view of the expected individual and group operation of the teams. Operators must be capable of constructing for themselves a representation of the situation, of updating this representation, sharing a common reference system, solving problems as a team, and passing information to others.

For *human reliability*, the initial malfunctions are prepared specifically to cover all plausible situations, then the scenario is left to run without interfering with the operating team, even if there is an unexpected failure of the interface or procedures, or inappropriate action by the team: for this approach it is more important to focus on observing the operating dynamics, even if that leads to moving away from the expected situations. The study hypotheses are more general and relate to defining the main actions required for safety.

Nevertheless, what is common to both disciplines is that they base the analysis, without strictly speaking being an "experimental" process, on more or less detailed hypotheses, and on a certain number of variables when preparing the observations, while seeking to test situations with "ecological" validity (Vicente, 1999) and using a systemic approach. Accident situations must be representative of situations that might occur or which have already occurred in the world (feedback).

3.2 Complementarities and differences in data collection methods

Both approaches share an overall empirical methodology characterised by simulation sessions lasting 3 to 4 hours, observed in situ, followed by a group debriefing with the operating team (2 to 3 hours), prepared in advance by the evaluation team.

For the *observation*, it is desirable to have several observers in situ to get a sense of the group, and ideally they should be distributed between the control room and the instructor's control console (controlling the simulator and the running of the scenario). This poses space constraints when organising the observations as neither the operating team nor the instructors must be hindered in order to guarantee that the teams have test conditions that are representative of future situations.

Ergonomists focus the observations on individual (each operator station, each profession) and group activities, whereas human reliability experts focus on the actions carried out in the process and on key individual and group facts.

Several data collection tools and techniques are combined:

- Paper-and-pencil type collection in situ using a general grid to monitor the activity in progress.
- Audio and video collection from all the workstations.
- Other types of collection using tools according to the needs of the evaluation (e.g. adapting the Instantaneous Self Assessment tool for analysis of perceived workload).
- The simulator logbooks are kept as they enable analysis after the event, for example to confirm that an action was carried out and the exact time (starting cooling, opening a valve), or to have information on the state of the installation at any given moment (state of steam generators, containment pressure, closed valves).

However, only the *general grid* for paper-and-pencil type data-collection is also used by the human reliability experts. It is used to record a detailed chronology, decisions made, operating actions, problem-solving, etc. Only ergonomists carry out fine analysis after the event of the cognitive and collective activity based on audio recordings, followed for example by activity timelines.

For human reliability, it is a matter of observing all the operating team: the operators, as well as the operations manager and the safety engineer, as it is the entire operating system that is designed to manage situations. What is studied in more detail by human reliability experts is the state of the installation, so that they can understand the situations encountered by operators and the consequences of their operating actions.

Debriefing is conducted in different ways also. For example, ergonomists conduct debriefing using a framework based around the technical solutions and the difficulties identified in interactions with the others and the control means in the specific phases of the situation. They list problems relating to how the team operates, how they reconfigure themselves during peak loads, how they communicate in specific phases of emergency operation, and the difficulties that they face in using the control means (reporting an image that could lead to confusion, or from which important information is missing, reporting a point that is not clear or a gap in a procedure, lack of understanding about how an automated module works).

Human reliability experts use the debriefing to consolidate understanding of how the scenario ran, and key facts from the point of view of the parties involved (actions, inspections, reviews), and to draw from this the main directions of operations, team reconfigurations, and failure and stability phases in running the transient on the simulator.

The debriefing phases are necessary for ergonomists and human reliability experts alike to consolidate the chronology of events and the history of what took place.

3.3 Specific features of the analysis and interpretation of the facts observed

In an initial analysis, both approaches reconstitute the running of the scenarios according to a detailed chronology, but this is not established in exactly the same way. For ergonomists, it is important to have chronologies for each party involved in order to reach a group chronology. For instance, the impact of the organisational choices is evaluated by defining the roles assigned to each party. Human reliability experts establish a single chronology from the outset as distinguishing the parties is not essential (systemic point of view), but clarifying the operation (highlighting the main events and actions for safety) from a functional point of view: the organisational choices determine the functions carried out by the operating system (action, inspection, review, reconfiguration). The facts traced by both groups are complementary: human reliability experts will first emphasise malfunctions, how they are managed and the safety requirements carried out (within the deadlines or not), connecting them with the characteristics observed in the operating system situation (team, procedure, interface), whereas ergonomists will emphasise cognitive aspects of diagnostics, decision-making, problem-solving and communications in relation to managing the situation and difficulties using the control means (MMIs, instructions, etc.).

Human reliability experts will focus on the results for safety and then go back to the "organisational and human factor" elements that influenced them, as mentioned above: first of all concerning the actual results during the simulation ("actual performance"), then concerning the potential impact of the key facts observed, when they did not have an impact during this simulation but could do in a different situation ("potential performance"). Starting from the result makes it possible to bring out the characteristics relating to the most relevant "organisational and human factors" for safety, and thus to propose appropriate and priority recommendations concerning the overall safety of the installation.

Ergonomists, meanwhile, will reconstitute the detailed work activity of each party involved, and especially the cognitive activity relating to decision-making, work load, problem-solving, diagnostics and monitoring (Mérand, et al., 2013). The analysis is done based on the observations and video recordings that make it possible to supplement the chronologies. It may be necessary to listen to a debriefing again to confirm a point. The aim of this analysis is to understand individual operating methods, and how the team works as a whole interacting with the control means and the difficulties and risks identified in the situations, before then being able to give recommendations on how to make each element of the sociotechnical system more reliable.

3.4 Conclusions: specific contributions for safe design

The same study purpose may not have exactly the same meaning for ergonomists and human reliability experts. For example, the work load identified in certain sequences is considered to be an element that weakens the reliability of the sociotechnical system by ergonomists, if it has an impact on surveillance. It is a weakness in the sociotechnical system that must be remedied from either an organisational point of view or from the point of view of the control means. However, for human reliability experts, if nothing happens during the lack of surveillance, this is not necessarily a problem: in other words, this finding can be extrapolated only with great caution and if the risk is great (if something happened during this period, it cannot be certain that the surveillance failed). In addition, the difficulties encountered by the team will be analysed in relation to the control means by ergonomists. Thus, if the team comes up against a specific point or misses information on an important image, by putting it back in context, ergonomists will try to understand what led to this situation and how this difficulty could be avoided from the design point of view. Whereas, if these difficulties have no actual consequences or major potential consequences for safety, they will not be considered a priority from a human reliability point of view.

From the point of view of the conclusions, ergonomic analysis provides a diagnosis based on observation of the risks observed or deduced from the operation of the sociotechnical system (impacts on safety, availability, the environment, health, and security). Based on this, recommendations are made, classed in themes, discussed with the designers, analysed in terms of feasibility and reworked in terms of solutions, etc.

For human reliability, the analysis provides on the one hand a diagnosis of actual risks linked to the organisational and human factors observed (actual performance) and, on the other hand, diagnosis of the potential risks (potential performance) deduced from the key organisational and human reliability facts observed (concerning actions and the inspection and review lines of defence). The human reliability recommendations are justified first and foremost from a safety point of view.

4. Conclusion

Ergonomics and human reliability have separate and complementary analysis foci for an overall evaluation of future operating systems. They make it possible to compare and contrast points of view and tackle distinct questions on safety, operations and human factors. They do not always lead to a convergence in results, but that is not the aim, as, in addition, some results are specific to one field, as we saw with safety requirements for human reliability experts, and detailed cognitive analysis for ergonomists.

This approach is part of the Integrated System Validation phase of the Human Factors Engineering Programme of the design project. It is in the process of being consolidated so that it becomes an in-house benchmark for new design projects.

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