Development of a Visual Interface for the Assessment of the Common Performance Conditions in Human Reliability Analysis

Piero Baraldi, A. Sogaro, M. Konstandinidou, Z. Nivolianitou

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P. Baraldi
Department of Energy, Polytechnic of Milan, Milan, Italy

A. Sogaro
Department of Chemistry, Materials and Chemical Engineering, Polytechnic of Milan, Milan, Italy

M. Konstandinidou & Z. Nivolianitou
National Center for Scientific Research "DEMOKRITOS", Athens, Greece

ABSTRACT: Within the European project Virthualis, a tool for the estimation of the human error probability of actions in industrial context has been developed. This tool combines the Cognitive Reliability And Error Analysis Method (CREAM) with the fuzzy logic principles and allows, on the basis of the analyst assessment of the Common Performance Conditions (CPCs), to evaluate the Human Error Probabilities. The objective of this work is to develop a visual interface for the safety analysts that are going to use this tool for Human Reliability Analysis. In order to increase the repeatability of the CPC assessment, the proposed interface is based on the use of anchor points that represent prototype conditions of the CPCs. Furthermore, a detailed description of the anchor points in terms of sub-items characterizing the CPCs is adopted to facilitate the CPC assessment and make the whole process more transparent.

1 INTRODUCTION

VIRTHUALIS is a European Research Project on Industrial Safety with the overall objective of evaluating and, where possible, reducing the risk level in production plants and storage sites with the integration of Virtual Reality and Human Factors methods (www.virthualis.org). Within the project, a specific tool based on the combination of the Cognitive Reliability And Error Analysis Method (CREAM) with the fuzzy logic principles (Konstandinidou et al. 2009, Konstandinidou et al. 2006, Marseguerra et al. 2007) has been developed for the estimation of Human Error Probabilities (HEPs) in industrial context. The tool, named Fuzzy Probability Estimator (FPE), requires as input from the safety analyst the assessment of the Common Performance Conditions (CPCs) characterizing the given contextual scenario in which the task is performed. The assessment should be provided in the form of numerical values representing, on appropriate scales, the different aspects of the context that influences human actions.

The objective of this work is to develop a visual interface for safety analysts who need to assess the CPC for their safety analysis using the FPE or for other Human Reliability Analysis purposes. The interface should be easy to use, able to guarantee the repeatability of the assessments, even if used by different analysts and should allow for systematic tracing of the reasoning steps that lead to a given CPC assessment.

The proposed interface is based on the use of anchor points that represent prototype conditions of the CPCs (Zio et al. 2009). In order to facilitate the assessment, each CPC has been described in details by using specific sub-items as proposed in the taxonomy presented in (Kim and Jung, 2003). The allocation of the anchor points on the CPC numerical scales has been performed by interviewing four human factor experts and by appropriately aggregating their judgments.

The idea is that the comparison of the context in which the human task is performed can be evaluated against “prototype” conditions and this should increase the repeatability of the CPC assessment given that different analysts refer to the same anchor points in their analyses. Furthermore, the detailed description of the anchor points in terms of sub-items characterizing the CPCs should facilitate the CPC assessment and make the whole process more transparent.

The work is organized as follows. Section 2 presents the basic concepts of the FPE. Section 3 describes the proposed anchor point method and the procedural steps followed for the interface construction. Section 4 discusses the final interface and its use by a safety analyst. Finally, the last section summarizes the conclusions of the work.

2 THE FUZZY PROBABILITY ESTIMATOR

The FPE is a tool that estimates Human Error Probabilities for specific actions in specific contexts. The estimation is based on the CREAM methodology (Hollnagel 1998) with the use of a Fuzzy Expert System (Zadeh 2008).

In particular, the human cognition model of CREAM assumes that the human failure probability depends directly on the level of control that the human operator has over the contextual scenario in which he/she is requested to perform the action. The level of control is discretized into four modes in ascending order of control and performance reliability, and thus in descending order of human failure probability: scrambled, opportunistic, tactical and strategic. A typical failure probability interval is associated to each control mode. For the given contextual scenario in which the task is performed, the control mode is determined by nine CPCs that qualify the context in terms of linguistic descriptors. Those CPCs are:

- adequacy of organization,
- working conditions,
- adequacy of man machine interface and operational support,
- availability of procedures and plans,
- number of simultaneous goals,
- available time, time of the day,
- adequacy of training and experience,
- crew collaboration quality

The linguistic descriptor of each CPC is associated to a particular contextual effect on the performance reliability, in terms of whether it is improved, reduced, or not significantly modified. The number of CPCs improving and reducing performance reliability are mapped to the context-specific control mode and corresponding failure probability interval.

In order to explicitly incorporate the uncertainty and ambiguity inherent in the method, a fuzzy extension of CREAM has been proposed. Basically the nine CPCs are treated as linguistic variables whose characterizing terms (the linguistic descriptors of the CPCs levels) are mathematically expressed in terms of Fuzzy Sets disposed on a [0,100] rating range. Figure 1 reports, as an example, the partition in fuzzy sets of the CPC “adequacy of organization”.

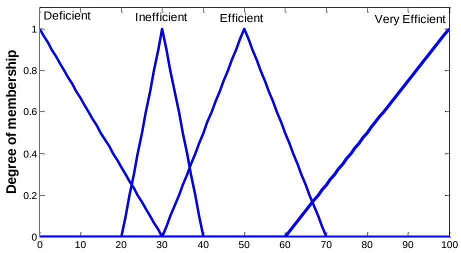

Figure 1: Fuzzy partition of the CPC “adequacy of organization”.

Notice that an important feature of the FPE is that it allows overlapping of the CREAM CPC levels to represent the fact that in the common perception, the transition between the linguistic concepts associated to the levels (e.g. from “efficient” to “very efficient” for the CPC “adequacy of organization”) is not crisp, but often uncertain and ambiguous. This is formally accounted for by introducing overlapping fuzzy sets to represent the CPC levels.

3 THE ANCHOR POINT METHOD FOR CPC ASSESSMENT

The use of the FPE requires as input from the safety analyst the numerical values representing the CPC assessment. However, since these CPC values are assigned on abstract and continuous scales, it is not clear what means to assign a value to a CPC, e.g. what does an “adequacy of organization” of 33 mean?”. The linguistic labels representing the Fuzzy Sets (e.g. “deficient”, “inefficient”, “efficient”, “very efficient”) for the CPC “adequacy of organization) proposed to the analyst by the FPE may help in this task, but they are not enough to guarantee the “repeatability” of the CPC assessment. For example a CPC judged as “deficient” for an analyst may be judged as “inefficient” by another analyst.

Concrete guidance to the analyst in assessing the CPCs can be provided through anchor points that represent prototype conditions of the CPCs appropriately allocated on their scale (Figure 2). This should increase the repeatability of the CPC assessment task, since the anchor points give a clear meaning to the corresponding values on the CPC scales. For example all situations similar to anchor point C will be assessed with a value close to 42.

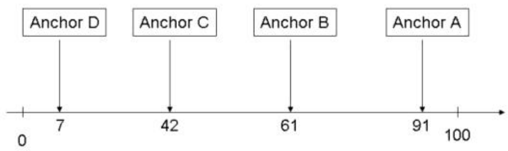

Figure 2: Example of anchor points allocation in a scale [0,100].

The procedure followed in this work to select the anchor points and to allocate them on the CPC scales is organized in the following four steps.

Step 1) A fuzzy expert establishes the scales for each CPC (for example, [0,100]) and the shape and support of the fuzzy sets representing the CPC levels.

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Step 2) A list of anchor points is established.

Step 3) Human Factors (HF) experts are asked to allocate the anchor points on the scales of the CPCs, i.e. to assign a numerical value to each anchor point. HF experts are required to be familiar with the basic concept of Human Reliability Analysis (HRA) and with the "classical" CREAM method.

Step 4) The allocations proposed by the different experts are aggregated in order to obtain the final position of each anchor point to be used in the interface.

Next Subsections 3.1 – 3.4 illustrate the application of the 4 steps of the procedure with respect to the CPC "adequacy of organization". The same procedure has been followed for all nine CPCs.

3.1 *Scales and Fuzzy sets shape and support*

The scales and partitions in fuzzy sets of the CPC have been taken from (Konstandinidou et al. 2006) and reported with reference to the CPC "adequacy of organization" in Figure 1.

3.2 *List of anchor points*

The procedure followed to associate a list of anchor points to each CPC is based on the identification of sub-items describing the CPCs. In particular, each CPC has been described by using the sub-items proposed in the taxonomy by Kim and Jung, (2003) as presented in Table 1. Different conditions may arise:

• CPCs characterized by only two subitems. Two limiting conditions for each sub-item (one positive and one negative) have been considered, leading to the definition of four anchor points, i.e. the four possible combinations of the sub-items conditions (Figure 3).

Anchor A:	Anchor B:	Anchor C:	Anchor D:
Subitem 1= P	Subitem 1= P	Subitem 1= N	Subitem 1= N
Subitem 2= P	Subitem 2= N	Subitem 2= P	Subitem 2= N

Figure 3: List of anchor points proposed for a CPC characterized by two sub-item. P indicates positive conditions, N negative conditions.

• CPC characterized by more than 2 sub-items. The sub-items are grouped into families formed by sub-items with a high degree of affinity and two limiting conditions are associated to the sub-items of the family: all positive sub-items or all negative sub-items. Figure 4 shows an example of possible list of anchor points for a CPC characterized in terms of five sub-items, grouped into two families.

Anchor D	Anchor C	Anchor B	Anchor A
Family A = N	Family A = N	Family A = P	Family A = P
Subitem 1= N	Subitem 1= N	Subitem 1= P	Subitem 1= P
Subitem 2= N	Subitem 2= N	Subitem 2= P	Subitem 2= P
Subitem 3= N	Subitem 3= N	Subitem 3= P	Subitem 3= P
Family B = N	Family B = P	Family B = N	Family B = P
Subitem 4= N	Subitem 4= P	Subitem 4= N	Subitem 4= P
Subitem 5= N	Subitem 5= P	Subitem 5= N	Subitem 5= P

Figure 4: List of anchor points proposed for a CPC characterized by two families of sub-items (Family A and Family B). P indicates positive conditions, N negative conditions.

For example, the sub-items characterizing the CPC "adequacy of organization" are:

- Plant specific prioritized goals/strategies
- Attitude towards training
- Safety/economy trade-off
- Routine violations

and they can be grouped into two families: the first containing the sub-items: "Plant specific prioritized goals/strategies" and "Safety/economy trade-off", the second the sub-items: "Attitude towards training" and "Routine violations.

The resulting anchor points are:

A1: Plant specific prioritized goals/strategies and safety economy trade-off. Good attitude towards training and no routine violations;

B1: No Plant specific prioritized goals/strategies and no safety economy trade-off. Good attitude towards training and no routine violations;

C1: Plant specific prioritized goals/strategies and safety economy trade-off but bad attitude towards training and routine violations;

D1: No Plant specific prioritized goals/strategies and no safety economy trade-off. Bad attitude towards training and routine violations.

Finally, if more than two families result from this aggregation of the sub-items, a hierarchy between the families have been proposed and only the most important families have been considered to define the anchor points.

3.3 *Expert allocation of the anchor points*

Four VIRTHUALIS HF experts have been asked to allocate the anchor points on the CPC scales, i.e. to assign a numerical value to each anchor point previously defined. Table 2 reports, as example, the allocation proposed by the four experts for the four anchor points A1, B1, C1 and D1 of the CPC "adequacy of organization".

Table 1: Sub-items used in the allocation of the anchor points for the 9 CPCs.

CPC (CREAM)	**Sub items according to the taxonomy of Kim & Jung (2003)**
Adequacy of organization	Plant specific prioritized goals/strategies
	Attitude towards training
	Safety/economy tradeoff
	Routine violations
Working conditions	Task location
	Accessibility
Adequacy of MMI and operational support	Type of man machine interaction
	Information availability
	Clearness of meaning
	Distinguish ability of information
	Control display relationships
	Value of critical parameters
	Trend of critical parameters
	Number of dynamic changing variables
	Degree of alarm avalanche
Availability of procedures and plans	Availability
	Format or type
	Clarity of instruction and terminology
	Decision – making criteria
	Logic structure
Number of simultaneous goals	Number of simultaneous goals/tasks
	Priority between goals/tasks
	Conflict between goals
Available time	Available time vs. required time
Time of the day	Day/night time
	Shift over
Adequacy of training and experience	Adequacy of training
	Experiences/practices of real operating events
	Learning of past events/experiences
	Career of operators
Crew collaboration quality	Clearness in role/responsibility definition
	Direction, type, method, protocol
	Standardization in instruction/information delivery
	Team collaboration/cooperation
	Adequacy of distributed workload

3.4 *Aggregation of the experts' allocations*

Since the experts usually propose different allocations for the anchoring points, in order to obtain the final interface of the FPE it is necessary to aggregate their different judgments. In this framework, different techniques have been proposed for the aggregation of numerical judgments given by different experts (Clemen and Winkler 1999, Stone 1961). In this work, the final interface has been obtained by taking the mean of the values assigned by the experts to each anchor point. It has been verified that different aggregation techniques such as taking the median of the values proposed by the experts lead to very similar results.

Table 2 reports also the final allocation of the anchor points of the CPC "adequacy of organization".

Table 2: Allocation of the anchor points of the CPC "adequacy of organization" by the four experts and final allocation of the anchor points.

	Expert 1	Expert 2	Expert 3	Expert 4	Final allocation
A1	100	90	90	80	90
B1	40	70	60	30	50
C1	20	30	30	40	30
D1	0	10	10	20	10

Notice that the final choice of allocating the anchor point B1 in correspondence of 50, the most representative value of the linguistic label "Efficient" (Figure 2), seems justified since for two of the four experts the anchor point B1 characterizes only the linguistic label "Efficient".

4 THE FINAL INTERFACE

The analyst who is going to use the FPE will interact only with the CPC scales and anchor points. Figure 5 shows the interface for a generic CPC characterized by the anchor points of Figure 4.

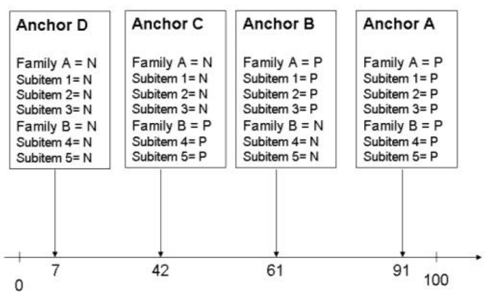

Figure 5: Example of final interface proposed to the analyst for the assessment of the CPC considered in Figure 4.

To demonstrate the assessment process, let us consider a case in which an analyst has to evaluate, using the interface as shown in Figure 5, a situation characterized by sub-items 1 and 2 as positive and sub-items 3,4,5 as negative. In this case, the analyst will choose a CPC value between the position of anchor B and C. The real position in this interval will be chosen according to his/her judgment (Figure 6).

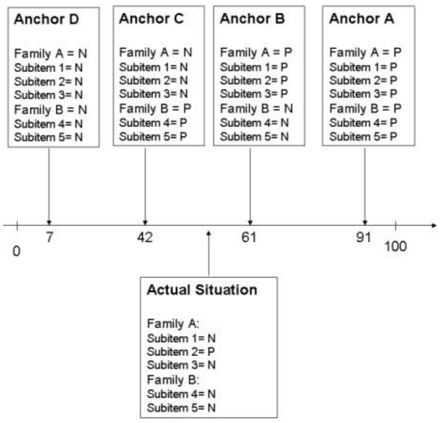

Figure 6: Analyst assessment of the CPC value.

The procedure described in the previous paragraphs was followed for every CP with relevant families and with specific anchor points defined in each case.

From a general point of view, after the completion of the process the following observations have been made:

1) None of the final allocations of the anchor points is with value 0 or 100. This means that the experts judge that the proposed anchor points are not the worst or best possible conditions for the CPCs.

2) The questionnaire sent to the experts implicitly suggests a ranking of the anchor points, proposing, for each CPC, as first item of the list the anchor point characterizing the best condition and as last item the worst condition. Also the ordering of the anchor points in the middle of the list implicitly suggests the opinion of the authors of the questionnaire. However, three of the four experts have proposed, for at least one of the CPC, to modify the proposed order of the anchor points. This means that the expert correctly felt free to modify the proposed ordering of the anchor points. Furthermore, notice that after the aggregation of the 4 expert judgments, the obtained positions of the anchor points agree with the proposed ordering.

5 CONCLUSION

The estimation of human error probabilities either through the use of the FPE tool developed for the specific project or for the purposes of human reliability analysis requires the assessment of the CPCs (or generally of the working/industrial context). In this respect, the activity object of the present work has been devoted to the development of a visual interface which facilitates the analyst in the assessment of the CPCs. The proposed interface is based on the use of anchor points that represent prototype conditions of the CPCs. A procedure for establishing the lists of anchor points, based on the identification of sub-items to be associated to each CPC, has been proposed. The allocation of the anchor points on the CPC scales has been performed by interviewing four HF experts and by appropriately aggregating their judgments.

Notice that, using the proposed interface, the comparison of the human task to be evaluated with the prototype conditions guides the analyst in the CPC assessment. Since different analysts refer to the same anchor points, the repeatability of the CPC assessment results increased. Furthermore, the identification of sub-items describing in details the CPCs and the use of those sub-items in the description of the anchor points make the CPC assessment a more transparent process, allowing the easier tracing of the reasoning steps that lead to a given CPC assessment.

In order to verify the performance of the proposed interface, this research activity should be developed by collecting the opinions of analysts that use the interface for their human reliability analysis. Further work should also be devoted to the verification of the repeatability of the obtained CPC assessment. In this respect, experimental tests should be conducted by asking to two groups of analysts to assess the CPCs, with only one of the two groups using the proposed interface, and by analyzing the variability of the obtained assessments in the two groups.

Finally, notice that, although this work has been focused on the assessment of the common performance conditions used by the FPE, the methodology here proposed for the development of the visual interface can be easily adapted to the elicitation of the performance shaping factors of other HRA methods.

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ACRONYMS

CPCs Common Performance Conditions
CREAM Cognitive Reliability & Error Analysis Method
FL Fuzzy Logic
FPE Fuzzy Probability Estimator
HEP Human Error Probability
HF Human Factors
HRA Human Reliability Analysis
PSFs Performance Shaping Factors

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