Applying human reliability analysis to high-risk industries: the case of process chemical industry for the polyethylene production.

Prof. Mario Tucci, Ing. Lorenzo Giagnoni,
Ing. Irene Cappelli
Dipartimento di Energetica "Sergio Stecco"
Sezione Impianti e Tecnologie industriali
Università degli Studi di Firenze
Via C.Lombroso, 6/17 - 50134 FIRENZE

Ing. Marcello Mossa Verre
Agenzia Regionale per la Protezione Ambientale della Toscana (ARPAT)
Via Nicola Porpora,22 - 50144 FIRENZE

Summary

Common reliability analysis, applying to high risk industry and better known as *Probabilistic Safety Analysis (PSA)*, considers complex systems from a technological point of view, in order to estimate its mechanical failure both for the elementary components and the assembly layers. In this approach, especially owing to shortage in common methodology (*Fault Tree Analysis*, *Functional Analysis* and so on), human factor is left out and human performance analysis is neglected.
The methodologies, collected under the label of *Human Reliability Analysis (HRA)*, is focused on human reliability and on parameters that influence it, both in quantitative and in qualitative approach.
This paper describes an application of second generation methodology to evaluate the human reliability in an high density polyethylene plant. The cognitive model is adopted in order to evaluate cognitive profile which is necessary for the workers to manage emergency; therefore we analysed coordination procedures associated to top events described in safety report. In order to bring analysis closer to real case, it was important to involve workers and to evaluate their observation, comment, judgment and behaviour consistence. The last paper part proposes a method which is useful for the interpretation of the results derived both from canonical model application and from the worker judgments.

Introduction

In high risk industry management, an important aspect is represented by human error, which can lead to accidents with adverse consequences. The area associated with identifying, analysing, and managing human error is generally known as ***Human Reliability Analysis (HRA)***. Historically, *HRA* is developed in two directions. The First Generation Methodology [7][19] is very close to *Probabilistic Safety Assessment* and the research is directed to define human error and to quantify human error probability without emphasizing its causes. In this way the methodology tries to correct the top event probability according to human performance, that is it assigns a probabilistic value to human error and it integrates this one as elementary base event in the fault tree analysis. The increasing interest among industries in qualitative approaches to *HRA* parallels a recent shift in perspective toward safety, away from blame cultures and toward a total quality management perspective that requires understanding of the underlying work related dynamics that give rise to human errors [3].
The Second Generation Methodology unties itself from quantitative approach and it looks for a complex system quality description, developing *man–machine interface models* [12] and *cognitive models*. Particularly these models are focused on describing the worker behaviour through cognitive functions, which represent specific rational actions. In *sequential cognitive model* [16] the worker behaviour is represented by a closed and rigid *step by step* going from one cognitive functions to another. In *cyclical cognitive model* [4] the worker logic is described like a loop through the different functions.

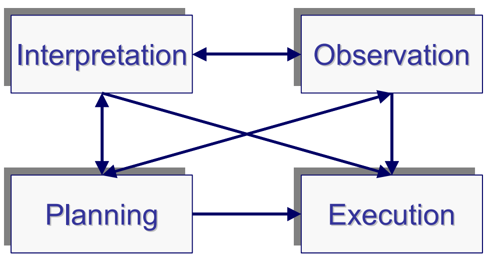

Figure 1 - Cyclical Cognitive Model by CREAM

In human reliability analysis, the domain is exactly defined by ***Cognitive Reliability and Error Analysis Method (CREAM)*** [4]; that is the ***Man-Technology-Organisation (MTO) integrated system***, considered as team *(Men)*, which works to get the same mission, acting on the mechanics of the process *(Technology)*, among the system organization and management *(Organisation)*.
HRA can be applied in a *backward* or in a *forward* way*:* in the first case the process is developed from the effects produced by an accidental event and tries to identify its root causes; in the second case the analysis aims to forecast the effect caused by an incorrect human performance. In both cases the analysis procedure evolves through the domain (*MTO system*) evaluation and it points out possible improvements in human performance; in other words the method permits to identify system factors that have negative influence on the human reliability and how to achieve a better performance modifying organisational structure, emergency management, written procedures, man-machine interface and so on.

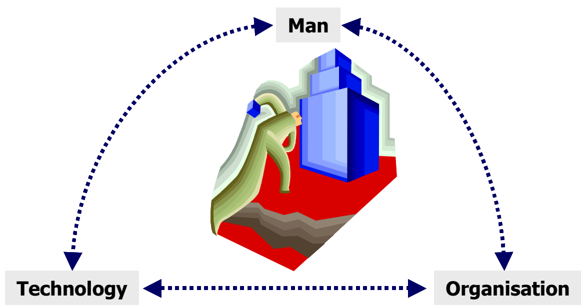

Figure 2 - Integrated System

In this application, a Second Generation Methodology was preferred, because it gives evidence of the *MTO system* influence on human performance and it helps in breaking down the organisation and management structure. This approach enters in details and scans the system in depth.
Furthermore the *cyclical model (CREAM cognitive model)* used in such methodology doesn't focus on external inputs towards

workers but on whole cognitive functions used to complete the task.
The methodology isn't rigorously followed, but it is integrated and modified in some elements in order to bring inquiry closer to the real case.

The chemical plant

The object of the analysis is a chemical plant for polyethylene production.
The chemical process goes through raw materials polymerisation, which are ethylene, butene, hexane, using catalysts and activators (alkylic aluminium). For the process service fluids are necessary, as hydrogen, steam, nitrogen and water. The product is high density polyethylene, stocked in fluff or in grains.
The system is ranked as high risk establishment for inflammable materials storage.
The productive plant is constituted by three main pipings: the polymerisation piping, the regeneration piping and the recycling piping. In Table 1 the pipings pressure and temperature range are showed.

Table 1 – Pipings Range

Piping type	Flux type	Pressure	Temperature
Polymerisation	Processing	40bar	25÷100 °C
Regeneration	Servicing	1bar	150÷290 °C
Recycling	Processing	12bar	25÷60 °C

The chemical process regulation parameters are:
- catalysts composition;
- polymerisation temperature (70-90 °C);
- raw materials concentration.

The polymerisation process is composed of depuration, chemical polymerisation, outgassing, distillation and depuration again in order to obtain the final product.
The raw materials are subjected to depuration treatments, according to their use. The polymerisation happens in a serpentine reactor, whose temperature is controlled from a water cooling. The polymer coming from the reactor is separated from unpolymerized ethylene, butene and it's stripped from hexane. From the distillation and the final depuration fluff is obtained, this can be directly stocked or sent to *finishing,* where it is transformed in grains or modified in colour or mechanical properties.
The process provides exhausted raw materials with a strong regeneration and it reintroduces them in the polymerisation piping.

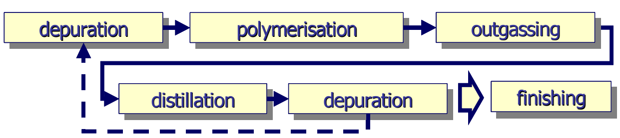

Figure 3 - Polymerisation functional block diagram

The application case

Definitions

In order to explain the analysis method, we are introducing some definitions:
- the ***analyst*** is the subject making the inquiry and he doesn't belong to the organisation, although knowing the methodology in depth.
- the ***expert*** is the subject who belongs to the organization and he is considered expert because he acts inside the system daily; he knows the technological aspect.
- the ***analysis domain*** is the Man-Technology-Organisation (MTO) integrated system, considered as team (Men), which works to get the same mission, acting on the mechanics of the process (Technology), among the system organisation and management (Organisation).
- The ***operative function*** identifies the organisational chart role and the assigned tasks

The *HRA* is applied considering the emergency condition following an accidental event: by means of the system safety report, it is possible to know written procedures, automatic safety systems and teams involved in emergency management. The methodology application makes it possible to understand the system reactivity to emergency situation.
The analysis is referred to some top events selected from the system safety report.
We can classify top events in five classes:
- *Explosion with overpressure and kinetic energy release;*
- *Inflammables release;*
- *Explosion in confined area as bunker with overpressure and kinetic energy adsorption;*
- *Flow release in torch;*
- *Flow release in atmosphere.*

Consequence analysis is obtained by mathematical models which quantify the involved area extension. In Table 2 we summarise consequence analysis according to standard values which appear in safety report and which have the following meaning:
Overpressure energy:
- SSD Structural Safety Distance: it is the distant where the overpressure is 0,2 bar; this overpressure level causes a piping and reinforced concrete structure damage and process mechanical component damage;
- SDP Safety Distance for People: it is the distance where the overpressure is 0,1 bar; this overpressure level causes a 99% life expectancy;

Irradiation energy:
- SSD Structural Safety Distance: it is the distant where the irradiation is 12,5kw/m^2; this irradiation level causes structural damage;
- SDPP Safety Distance for Protected People: it is the distant where the irradiation is 4,7kw/ m^2; this irradiation level causes a acceptable radiation, for long time, by worker with individual protection;
- SDUP Safety Distance for Unprotected People: it is the distant where the irradiation is 1,6kw/ m^2 ; this irradiation level causes a acceptable radiation, for long time, by worker without individual protection.

In consequence analysis, furthermore, we assumed wind velocity at 8 m/s, 4 m/s, 2 m/s, 1 m/s.
The emergency plan is based on:
- *Event Magnitude*: it is ranked in three levels: low, medium, high; this ranking depends on internal criterions and identifies the alarm inside the establishment;
- *Incidental place*: it represents the areas and departments involved in the risk. This one is necessary in order to chose emergency paths and safety meeting points;
- *Weather Conditions*: it permits to define the emergency management trough weather forecasting simulation in order to evaluate the accidental consequence development.

According to national laws[1] public authorities involving depends on the *event magnitude*; in particular, the medium alarm compels to warn authorities, otherwise the high one requires to pre-alarm them.
The organization chart was built according to role of workers in emergency condition (). These roles haven't the same holding in the plan conduction; in the emergency case, in fact, the workers are brought in teams trained in order to overcome the emergency. During the analysis, the attention was focused on the medium and lower level in organization chart, that is the polyethylene and the finishing teams. The defined *operative function* are :
- ***Polymerisation Foreman (PF)***;
- ***Polymerisation Control Room Foreman (PCRF)*** which oversees the polymerisation area in control room ;
- ***Polymerisation Assistant (PA),*** which helps *PF* in polymerisation area;

[1] D.Lgs. n. 334 (17/8/99) applying EU Directive 96/82/CE Seveso-bis, modifying and integrating D.P.R. n.175/88 (applying Seveso EU Directive 82/501/CEE).

- ***Polymerisation External Workmen (PEW)***, which control the polymerisation productive lines;
- ***Finishing Assistant (FA)***, which helps PF in finishing area;
- ***Finishing External Workmen (FEW)***, which control the finishing productive lines;
- ***Extruding Control Room Workman (ECRW)***, which oversees the finishing area in control room;
- ***Silos Control Room Workman (SCRW)***, which oversees the silos area in control room;
- ***Labo Control Workmen (LCW)***, which operate in control laboratory.

Furthermore in the organization chart there are other operative functions, which aren't rigorously analysed, but which are involved in the emergency. In particular the *alarm centre* and *operative centre* are the centres where information converges and where high level decisions are taken. The fire team (composed by *fire safety foreman*, *firemen* and *assistant firemen*) and the service team (composed by *service foreman* and *service workers*) support the emergency procedures in not directly involved areas.

The communication flows are considered, in particular the flows among the above mentioned *operative functions*. The communication passes trough four main channels; *interphone, telephone, RTX radio, bleeper*.

Looking at the safety report permits a good knowledge of emergency management system, therefore the evaluation is extended on all the emergency procedures collection. These procedures specify the behaviour to keep in emergency case, the first emergency intervention on the chemical process and the coordination.

Observing establishment and, in particular, the polymerisation control room, the process is overseen by means of a continuous chemical parameters monitoring. In the same room sprinkler actuation systems and emergency arrests are placed; furthermore meteorological indications are visible. In order to apply the analysis, we catalogued the man-machine interfaces in two categories:

- standard process man-machine interfaces:
  - process parameter indicators;
  - process management actuators;
  - alarm signals;
- emergency situation man-machine interfaces:
  - emergency arrests (manual);
  - sprinkler actuators (manual);
  - wind direction and wind velocity device.

Table 2 – Analysed Top Events

Top event	**Event description**	**Root causes**	**Wind**	**Explosion**		**Fire**			**Consequence analysis in contiguous area**
				DSS	DSP	DSS	DSP	DSN	
1	Hexane spilling on square during refuelling	- erroneous link between coupling flange - wear out of coupling flange	4m/s			10	14	20	Irradiation on tank
2	Hexane spilling during refuelling	- coupling flange failure - worker non-intervention	4m/s			20	30	45	Irradiation on tank Irradiation on tank
3	Hexane tank explosion	refuel area Fire	4m/s	16,8	6,8				Structural damage on hexane tank
4	Hexane tank explosion	Fault in protection system (nitrogen thinness)							Roof collapse on hydrogen storage Roof collapse on propylene storage Roof collapse on piping line Hexane tank fire
5	Hexane tank fire	Tank blow up	4m/s			18	37	60	Irradiation on hydrogen storage Irradiation on splinker control room
			8m/s			23	39	59	
6	Hexane catch basin fire	Tank overfilling	4m/s			44	68	110	Irradiation on hydrogen storage Irradiation on propylen storage Irradiation on splinker control room
			8m/s			50	70	105	
7	Flow releases from polymerisation reactor	Opening of second level relief valve	4m/s	17	5,9				Components failure on polymerisation line
8	Ethylene releases from reactor	Seals wear	1m/s			10	18	32	Irradiation on reactor Irradiation on strippers Irradiation on outgassing system
9	Reactor fire	Structural collapse worker non-intervention	1m/s			34	65	90	Irradiation on strippers Irradiation on outgassing system Irradiation on splinker control room
10	Reactor piping fire	coupling flange failure piping failure	1m/s			7	12,5	21,5	Irradiation on reactor Irradiation on strippers Irradiation on outgassing system
11	Alkylic alluminium storage fire	piping failure piping wear	1m/s			7	12,5	21,5	Flash in storage
12	Ethylene release from drying process	Opening of second level Relief valve		15,7	4,2				Irradiation on splinker control room

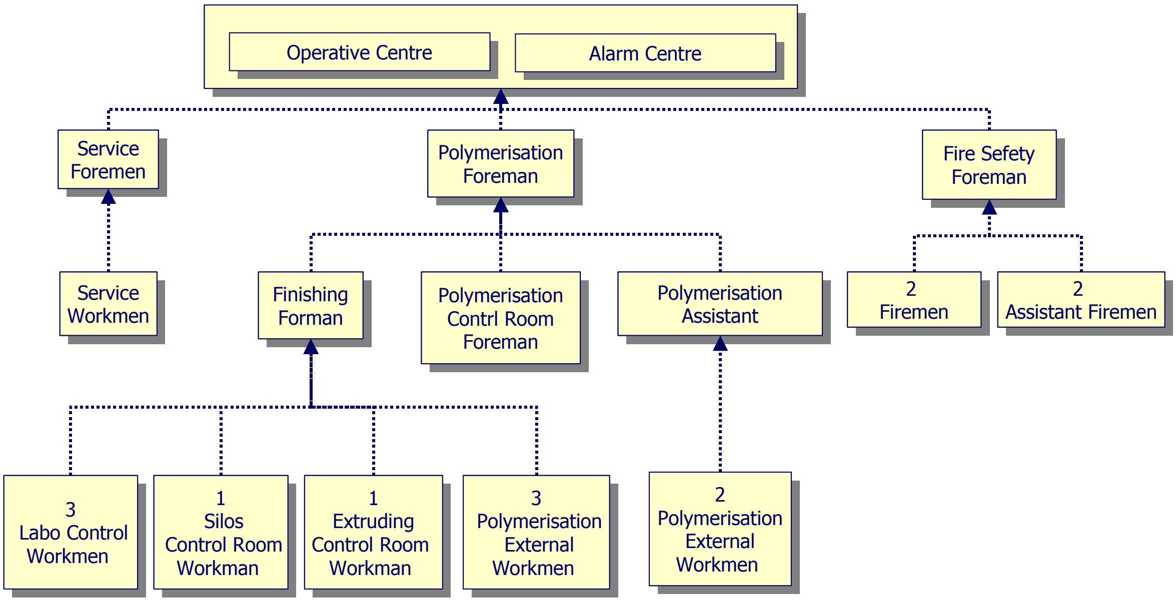

Figure 4 - Organisation Chart in Emergency Condition

The analysis method

For this case the Second Generation *CREAM* was chosen; in fact it seems to be a good approach for the specific object, thanks to its definition of the *analysis domain* and for its cyclical aspect.
CREAM[2] is based on ***classification schemes***, ***common performance conditions (CPCs)***, a ***cognitive model*** and a ***methodological procedure***.
The *classification schemes* collect and describe phenotypes, which represent the observable human errors, and genotypes, which represent the human error causes.
The *common performance conditions* are used to value the quality level of the *MTO integrated system*.
The *cognitive model* is cyclical and it's based on four principal *cognitive functions* (*planning*, *observation, interpretation* and *execution*) and thirteen *cognitive actions* linked to them.
The *methodology* can be applied in backward way (*Retrospective Analysis*) or in forward way (*Performance Prediction*).
In this application the forward way is carried on in order to put in evidence critical elements in *MTO system* and to individuate possible improvements in human error control.
In order to adjust the analysis to the real case, the inquiry method didn't follow exactly the *CREAM*, but it was developed in a previous phase consists in different steps. In particular the complete analysis was divided in two sequential phase: the ***preliminary phase*** and the ***operative phase***.
The *preliminary phase* consisting in:

- *Performance Items* definition;
- *Consistence in Analysis);*
- *Performance Items Analysis.*

The *operative phase* based on:

- *Hierarchical Task Analysis;*
- *Cognitive Task Analysis;*
- *Cognitive Model* application.

The preliminary phase

For the ***analyst*** the *preliminary phase* was fundamental in order to go deeper into system. This phase was oriented to collect information necessary to apply the analysis. The information was researched following officially accepted technology guidelines, establishment safety report, in field inquiries and advice expressed by workers in the interested area.

The technical guidelines is useful in order to evaluate if structural system conforms to safety standard.
The safety report is important in order to have an historical vision in failure and injury, and to know the results arising from risk assessment evaluation. Furthermore, it include Safety Management System, in particular, the internal and external emergency plans.
In field inquires are fundamental in order to assess the information extrapolated from the safety report and to have a real impact with working place and, in general, with producing process.
In order to define the data collection frame, the preliminary phase was started identifying ***Performance Items (PIs)***[3], which represent factors describing the *MTO integrated system* and influencing human performance. The *PIs* are selected on the base of the plant type and the adopted methodology; they identify categories of *homogenous elements* that belong to the *MTO system*. The chosen *PIs* are:

- ***skill***, it represents the worker ability in completing a procedure or a task [15];
- ***communication***, that is information flow [15];
- ***procedure***, that is operative and emergency written procedures [10];
- ***man-machine interface***, that identifies process control and operative systems which are utilised by workers.

The preliminary phase goes through ***Consistence in Analysis (CA)*** which is centred on the data collection dependability. In fact, on the one hand the analysis depends on the analyst skill, but on the other hand it depends on the data collection quality. Therefore the results of *CA* point out the maximum consistence level which the analysis could reach.
The main step of *preliminary phase* is the ***Performance Items Analysis (PIA)***; this one gives indication on *MTO* management and organization, furthermore this is integrated with human reliability evaluation through *cognitive model*.
The *PIA* output is a ***quality aggregate index (qa)*** evaluated for each *PI*.
Each *PI* consists in several *homogenous elements*, coupled with ***quality simple index (qs)***. The *qs* attribution is made by means of evaluation tables, where ***functions***, ***parameters***, ***function weights***, ***parameter weights*** and ***characteristics*** are enumerated.
The *functions* are descriptive of the specific *PI* and depend on independent *parameters*; i.e. for *skill item* the *personal factors function* depends on *age*, *familiar situation*, *physical status*, *available time*, which are independent *parameters*.

[2] In this paper main definitions about *CREAM* are presented; as the paper is centred on the application we recommend reading [4] for deeper information.

[3] The *PIs* are chosen among the *CPCs* and *PSFs*, considering which of them could have a greater influence on the human performance in this specific applicative case.

The *function weights* derive from the importance of function for the *homogenous element* evaluation and they change from an element to an other.
The *parameter weights* define the *parameter* influence on the *function* and they are invariant from an homogeneous element to an other.
Finally, the *characteristic* is the dominion where the parameter is defined.
Furthermore, concerning *skill item* evaluation, the operators attitude to team work is evaluated following a common psychological test.
In **Erreur ! Source du renvoi introuvable.** we present an extract of the evaluation table related to *procedure item*.

Table 3 - Evaluation table related to *Procedure Item*

Function	Parameter	Characteristic
Accessibility	availability	unavailable far from place performance far from place performance in specific place near to performance place
	support	in paper without any diagram in paper with diagram in software in paper and in software
Consistence	steps sequence	not identified not sequential not sequential only closely sequential
	key words	none definition and none use of them key wards are present, but they aren't defined explicitly key wards are present and they are defined explicitly key wards are present and they are linked to a specific cognitive model
	deviations	none contemplated deviation implicitly contemplated deviations one explicitly contemplated deviation more explicitly contemplated deviations
Quality	time	much low - < 1min low - 1min<t<5min medium - 5min < t< 1h long - <1h
	objective	not identifiable more parallel objectives more sequential objectives one objective only
	interruption	none contemplated interruption none possibility of interruption possibility of interruption in selected steps possibility of interruption in each step
	check	none contemplated verify it's not possible to verify the procedure correctness it's possible to verify the procedure correctness and to act reserve procedure it's possible to verify the procedure correctness and to repeat the same procedure

When *CA* is carried on by the analyst only, the *PIA* is run following two parallel ways: the first one considers the *analyst judgment* and the another one is based on the *experts judgment*. The *analyst judgment* and *expert judgment* are expressed on different parameters and the two parallel ways are carried on separately.
The analyst evaluates the system conformity to the technical and safety standard and expresses a judgment on *measurable* parameters which are significant for system physical features (i.e. the distance of control console from the emergency push-button).
The experts are asked for an opinion on *perceptible*, but not *measurable* features (i.e. the comprehensibility of a procedure). Since, this judgment is affected by an inevitable subjectivity, it is necessary to assign a weight in order to achieve a consistent analysis. So in this part, the attention is focused on the skill of interviewed expert in giving judgment on *perceptible* parameter.
The problem is resolved by ***Circular Triad Method*** [9] that is based on the *logical inconsistence*[4]. In an expert judgment, if the number of inconsistencies is low the expert judgment is consistent, otherwise, if the number of inconsistencies is high the expert judgment is not consistent.

Table 4 - Triad circular matrix related to *procedure item*, in particular to *procedure comprehensibilty* parameter.

Circular Triad											
ITEM which elements belong to	procedure										
expert oganization level	managment level										
EXPERT	expert 1										
evaluated FUNCTION	readeble precedure										
Elements number	9										
Evaluated Elements	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	ai	ai-a
1		1	0	1	1	1	1	0	1	6	2
2	0		1	1	1	0	0	1	1	5	1
3	1	0		1	1	0	0	0	0	3	-1
4	0	0	0		1	1	1	1	0	4	0
5	0	0	0	0		0	0	0	0	0	-4
6	0	1	1	0	1		0	1	0	4	0
7	0	1	1	0	1	1		1	1	6	2
8	1	0	1	0	1	0	0		0	3	-1
9	0	0	1	1	1	1	0	1		5	1

The number of inconsistencies ***N*** is found trough a matrix where:

- **n** number of homogenous elements belonging to PI, evaluated on the base of the **p** property;
- **Ei** i-element of the row, i=1…n;
- **Ej** j-element of the column, j=1…n;
- **eij** matrix element:
  - **eij**=1 if the expert judgment is Ei>Ej that is Ei better than Ej about the p property ;
  - **eij**=0 if the expert judgment is Ei<Ej that is Ej better than Ei about the p property.

The number of *logical inconsistencies (N)* is found as:

$$a = \frac{(n-1)}{2}$$

$$a_i = \sum_j e_{ij}$$

$$T = \sum_i (a_i - a)^2$$

$$N = \frac{n}{24}(n^2-1) - \frac{T}{2}$$

From *N* the theory permits to obtain the *inconsistence coefficient*, that is:

$$K = 1 - \frac{24N}{n(n^2-1)}$$

It's important to point out:

- $K \in R$, that is *K* is defined on a continuous domain
- $K \in [0;1]$, if *K* is close to 1 the consistence is much higher otherwise it is lower;
- the method is right only if n>3[5].

According to *inconsistence coefficient* definition, K can be considered the weight to assign to expert judgment.
An extract about triad circular matrix is showed in Table 4.

<u>Operative phase</u>

This phase follows *CREAM* guidelines. Firstly, the ***Hierarchical Task Analysis (HTA)*** is conducted: each procedure is reread and rewritten on the base of a hierarchical frame. In this way, procedures diagrams are built; they show the temporal – space logic of the procedure which is carried on.
Afterwards, the same procedures are submitted to the ***Cognitive Task Analysis (CTA)***: each selected task is linked to *cognitive functions* (human mental process) that are necessary to carry it.

[4] *Given A,B,C homogenous elements and chosen p as property as judgment criterion, if the judgement is:*
A(p)>B(p), B(p)>C(p), C(p)>A(p) there is a logical inconsistence
[5] That limit depends on matrix space free degree and on the constraints number which the experts signs expressing his judgment.

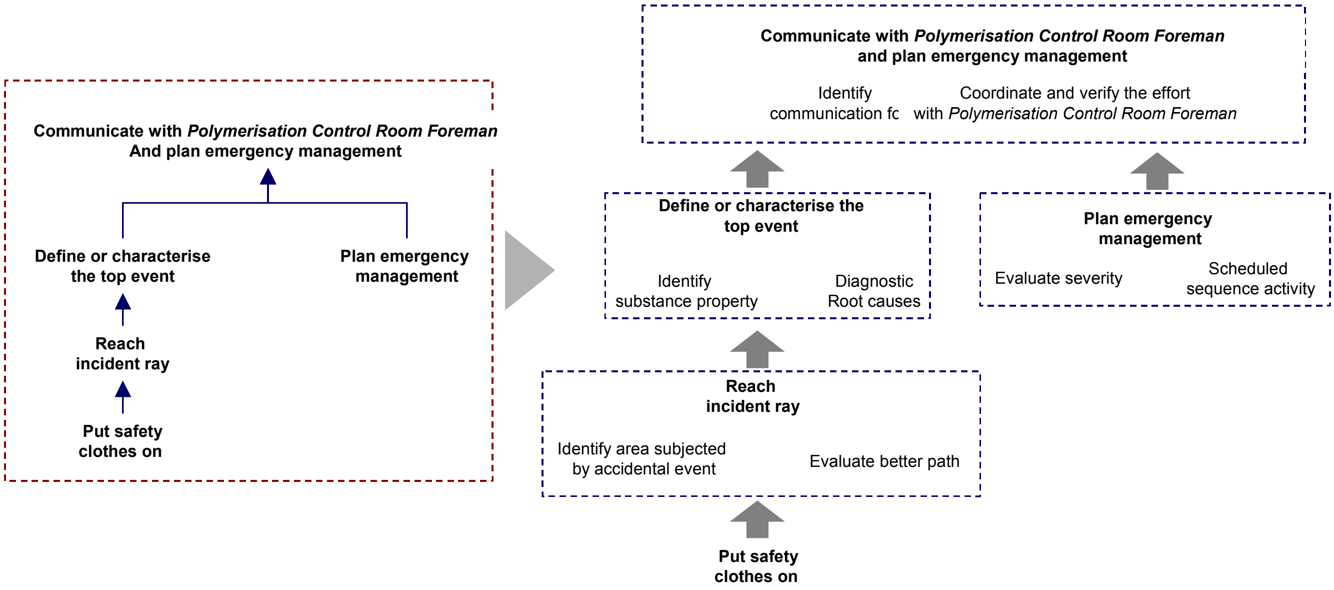

Figure 5 - HTA-CTH linked to an emergency procedure

The *CTA* is applied following the *CREAM* cognitive actions and cognitive functions. The emergency procedures, that are the object of the present paper, are behavioural instructions and they are expressed in a general way and so missing frame and formalism; so the *HTA* tries to formalise emergency procedure, like operative procedures (conduction plant instruction). Furthermore, in the emergency procedure there isn't any keyword, or cognitive word[6] which could help in the *CTA*. Therefore, this phase is influenced by the analyst skill and it depends on him closely (Figure 5).
Following *CREAM* tables, for each procedure the total occurrence of the *cognitive functions* is calculated and this is synthesised by the ***cognitive profile***. The *cognitive profile* points out the cognitive ability that is necessary to complete the analysed procedure. This profile depends on the hierarchical an cognitive task analysis only and it is independent from the *integrated system* evaluation resulted from the first phase.
In short in the *preliminary phase* the system evaluation is carried on and the *aggregate quality indexes* are found, in the *operative phase* procedures are analysed and the *cognitive profile* is built, finally it is able to correlate both outputs.
The quality level, assigned to a *PI* and expressed by aggregate index, modifies the *cognitive profile* that is necessary to operate a task according to emergency procedure. In order to point out that this influence is not uniform on all cognitive functions which compose the profile, the ***influencing coefficients*** are defined: they weight how much each *PI* influences the different *cognitive function*. The *influencing coefficients* are evaluated on the base of state of art in *PSA* and *HRA* research.
Afterwards, the ***correcting function*** was created: that combines the *aggregated quality indexes,* the *influencing coefficients* and the *cognitive functions:*

$$g_j(c_{ij}) = \frac{\sum_i (1 + c_{ij}(1 - qa_i))}{n_{PI}}$$

where:

- c_{ij} is influence coefficient of i-Item and j- cognitive function;
- qa_i is *quality aggregate index* on i-item;
- n_{PI} is item number evaluated.

Trough correcting function each cognitive profile is corrected in real cognitive profile. The final resulted profiles are the actual measure of cognitive ability to carry on the procedure, not only based on the written procedure, but based on the *MTO system* true quality.
This process is run for each emergency procedure assigned to *Polymerisation Foreman* and *Polymerisation Control Room Foreman*.

[6] This type of words, extrapolated in this case from a cognitive model, help the analyst in formalising the procedure and in applying the *CTA*.

Conclusion

Outputs review

The profiles show a large prevalence of *interpretation function* and *execution function* that reflect the procedure type analysed; in fact, these ones are behavioural and teams coordination instructions and they appear without frame and formalisation.
This output points out a possible problem in safety management; in fact, these functions are closer than the other to individual skills and they are hard to check. In this case, it's necessary to improve just worker skill and ability in order to reduce human error tendency.
The *planning function* is related to operative plans so, if *planning function* would be present, a right method to improve human performance could be rewriting and formalising the operative instructions. Otherwise *observation function* is related to the supervision of control and monitoring process systems, so it could suggest an improvement in man-machine interface and in general in technological aspects.
The bias towards the *execution* and *interpretation functions* is evident in *PCRF* procedures: this looks like a strange evidence thinking that the *PCRF* is just a process overseer and controller. This output can be explained if the system reaction type in the emergency condition is considered. In fact, the emergency overcoming is based on the control of the consequences by means of teams' interventions rather than by mean of the restoration of standard plant running.
In this sense, the cognitive model confirms the in field inquiry: control room is assembled with complex console which, on the one hand, permits the whole monitoring of the process, but on the other one it precludes real and dynamic actions on the process. Furthermore, it is possible to have cohabitation between analogical monitoring instruments and digital control units, it is able to generate an operative unreliability.
In the *PF* procedures, the cognitive profile is more balanced. In particular, in coordination procedure the *interpretation* and *planning functions* seem to be crucial because the *PF* has to understand the severity and he has to plan actions in order to overcome the emergency.
Correcting the cognitive profiles, *execution* and *interpretation functions* result more influenced by the *quality aggregated indexes.* That points out that the *MTO system* reaction is driven by a personal skill more than predefined written procedures.
This suggests that worker training should be directed to improve the system knowledge and operative ability in order to assure a correct interpretation of events and their optimum solution.
Furthermore, it should be possible to increase the planned actions, in particular where the human interpretation isn't

necessary. In this way the *interpretation function* would be lower and less influencing the correct procedure application.

Methodology discussion

Thanks to its clear and complete guidelines, the *CREAM* seemed really useful for driving the analysis procedure. Conversely, just because of its general approach, adjusting the method to the real case resulted onerous.
The *cognitive model* is an important tool to synthesize outputs, but the real cognitive profiles interpretation is significant only if *MTO evaluation* (that is represented by the *preliminary phase* in this case) is performed in depth.
In this sense the methodology presents some lacks: in fact, on the one hand the *MTO integrated system* quality importance is underlined, but on the other hand the criterion proposed in order to assess the quality level isn't consistent. In other words the evaluation closely depends on the *analyst* and the results interpretation is mainly related to *MTO system* impact to the *analyst*.
A possible answer to this problem seemed to be involving experts into analysis, but the integrating procedure was really long and not justified by the attained outputs.
Otherwise the cognitive model application permitted to deeply analyse emergency and operative procedures and to realise their lacks from the worker's point of view.

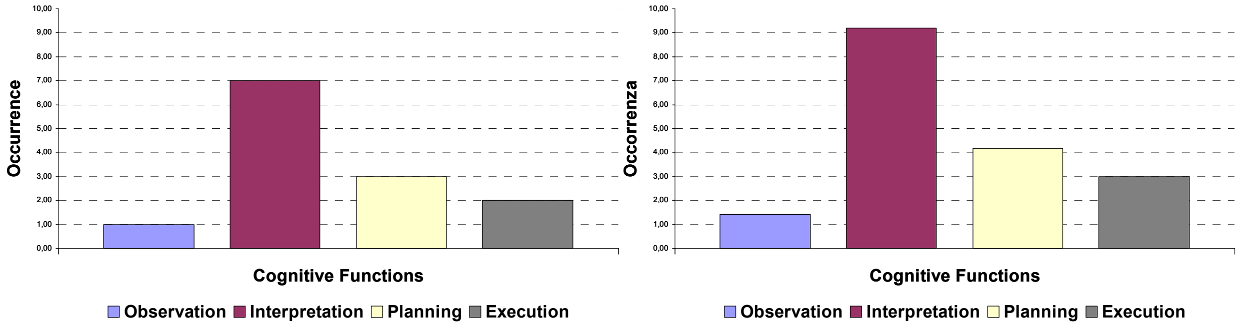

Figure 6 - Cognitive profile and Real Cognitive Profile of a Polymerisation Foreman

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