Modelling application for cognitive reliability and error analysis method

Fabio De Felice [#1], Antonella Petrillo [#2], Armando Carlomusto [#3], Ugo Romano [*4]

[#] Department of Civil and Mechanical Engineeringn-University of Cassino and Southern Lazio
via G. Di Biasio, 43 – Cassino (FR), Italy
[1] defelice@unicas.it
[2] a.petrillo@unicas.it
[3] a.carlomusto@unicas.it
[*] INAIL Direzione Regionale Lazio
via Nomentana, 74 – Roma (RM), Italy
[4] ur.romano@inail.it

Abstract—**The automation of production systems has delegated to machines the execution of highly repetitive and standardized tasks. In the last decade, however, the failure of the automatic factory model has led to partially automated configurations of production systems. Therefore, in this scenario, centrality and responsibility of the role entrusted to the human operators are exalted because it requires problem solving and decision making ability. Thus, human operator is the core of a cognitive process that leads to decisions, influencing the safety of the whole system in function of their reliability. The aim of this paper is to propose a modelling application for cognitive reliability and error analysis method.**

Keyword-Human Reliability Analysis, Human Factor, Safety, Cream Method, Simulation

I. Introduction

In response to ever-changing market needs, there has been a diffusion of technologically advanced plants that can provide flexibility and timeliness in production. Over the past years, technological developments have led to a decrease of accidents due to technical failures. However, it is impossible to talk about system reliability without considering the failure rate of all its components. The use of these advanced technologies, beside managerial advantages, has led to reliability issues specifically intended as the probability that a system fulfills the assigned mission. To the reliability concept are closely related risk and workers' safety that may be directly and indirectly affected by the processes on site.

In this context one of the most "critical" components is "man", whose rate of error changes the rate of breakdowns of components with which it can interact. This has highlighted that the "human factor" contributes significantly in accident dynamics, both statistically and in terms of severity of consequences.

It has been observed that system failures due to human intervention are not negligible [1]; in particular, some sources report that human error is the cause of failure systems which, in many cases, have disastrous consequences due to man - machine - environment interaction. In fact, estimates agree that the errors committed by man are causes over 60% of accidents and for the remaining part the causes are due to technical deficiencies. Generally, in reliability systems studies [2], [3], assessment focuses on industry processes and technologies constituting it, disregarding aspects that depend on human factors and its contribution to the same reliability system; but it should be noted that human error is a major contributor to the risks and reliability of many systems: over 90% in nuclear industries [4], over 80% in chemical and petro-chemical industries [5], over 75% of marine casualties [6], and over 70% of aviation accidents [7], [8]. Thus, in order to ensure effective prevention of dangerous events, the role of humans in accident dynamics should be considered during risk assessment processes [9].

The researchers' great efforts to propose models of human behaviour [10] favouring numerical values of error probability in order to predict and prevent unsafe conduct are clearly evident [11], [12].

Nowadays, the analysis of human factors constitute a highly interdisciplinary field of study not yet well defined, therefore, a complete and universally accepted taxonomy of different types of human errors and causes determining them, does not exist. We note that the objective difficulties of governing the human factor and human error have made many experts believe that the conduct of prevention and safety were related to a person's intrinsic characteristics, such as personality traits. [13], [14].

Fortunately, in recent years, technological advances have shifted human intervention from a direct commitment to the simple manual control of automatic machine processes.

For this reason, starting from high risk industrial areas, such as nuclear, aerospace and petrochemical, up to individual SMEs, there was the need to analyze techniques of risk analysis with human factor evaluation methodologies, collected under the name Human Reliability Analysis (HRA).

Human Reliability Analysis identifies errors and weaknesses in a system by examining methods of work including those who work in the system. HRA falls within the field of human factors and has been defined as the application of relevant information on human characteristics and behaviours to the design of objects, facilities and environments that people use [15].

HRA techniques may be used retrospectively, in accident analysis, or more likely prospectively to examine a system. Most approaches are firmly grounded in a systemic approach which sees the human contribution in wider technical and organizational contexts [16], [17]. The purpose is to examine task, process, system or organizational structure for where weakness may lie or create a vulnerability to errors, not to find fault or apportion blame. Any system in which human error can arise can be analyzed with HRA, which in practice, means almost any process in which humans are involved [18], [19].

These human reliability analysis methodologies are born first of all to be applied in the nuclear energy field, where it is greater than the risk of a relevant accident. Furthermore, the application of these methodologies is not trivial and requires a high level of training.

Thus, the aim of the present paper is to:

1. Extend the application of a methodology for human factor study (CREAM methodology) to the tasks performed by operators in SMEs;
2. Simplify that methodological approach through the development of a simulation software.

This simulation approach allows to extend the survey to any type of mechanical processing that involves a significant human intervention, with consequent reduction of risks of accidents and errors made in the company.

The paper is structured as followed. In Section II CREAM approach is presented; in Section III the methodological approach is analyzed through a real case study. Finally in Section IV conclusion and results are presented.

II. CREAM Approach

CREAM methodology was developed by Eric Hollnagel in 1998 following an analysis of already in place HRA methods. It is the most widely utilized second generation HRA technique and is based on three primary areas of work; task analysis, opportunities for reducing errors and possibility to consider human performance with regards to overall safety of a system.

This methodology is a technique used in HRA for the purposes of evaluating probability of a human error occurring throughout completion of a specific task. From such analyses measures can then be taken to reduce likelihood of errors occurring within a system and therefore lead to an improvement in the overall levels of safety. HRA techniques have been utilized in a range of industries including healthcare, engineering, nuclear, transportation and business; each technique has varying uses within different disciplines. Compared to many other methods, it takes a very different approach to modelling human reliability.

There are two versions of this technique: basic version and extended version. Basic version provides an initial screening of human error, to understand the error probability range. Instead, extended version uses the results of basic version to obtain the detailed value of error probability.

The application of the extended version is needed when the probability of action failures is acceptably low. These have in common two primary features: ability to identify importance of human performance in a given context and a helpful cognitive model and associated framework, usable for both prospective and retrospective analysis. Prospective analysis allows likely human errors to be identified while retrospective analysis quantifies errors that have already occurred.

CREAM methodology is based on a cognitive model which presents an error classification that integrates individual, technical and organizational factors and provides a step by step description of operator performance analysis. In particular, classification is based on two principles (Fig.1):

- human error may be related with its manifestations, called phenotypes, and its causes, called genotypes;
- phenotypes are result of interaction between genotypes and environment.

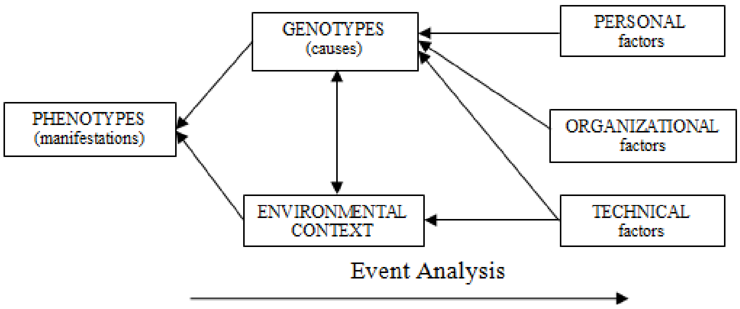


Fig. 1. Interaction between phenotypes and genotypes

The identified cognitive model for CREAM methodology is called “CoCoM” (Contextual Control Model). In Fig.2 is shown Contextual Control Model.

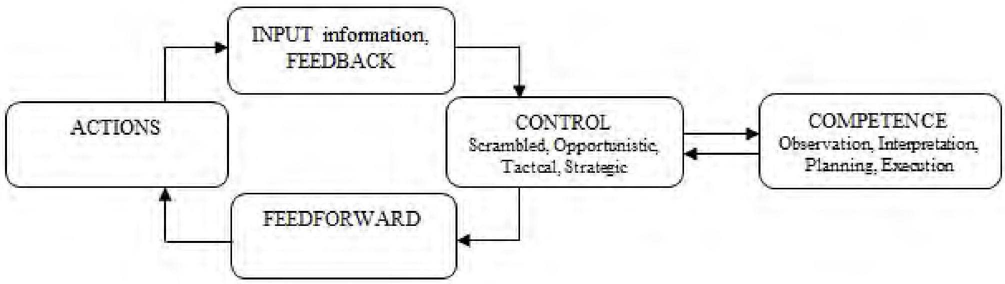


Fig. 2. Contextual Control Model “CoCoM”

Through this model it was possible determine requested cognitive functions level in order to implement the analysed performance. The cognitive model application takes place via the individuation of total occurrence of CoCoM functions in performance. Cognition concept is included in the CoCoM model through use of four basic “control modes” which identify differing levels of control that an operator has in a given context and characteristics which highlight occurrence of distinct conditions. The control modes which may occur are as follows (Fig.3):

- *Scrambled control*: choice of forthcoming action is unpredictable or haphazard;
- *Opportunistic control*: next action is determined by superficial characteristics of situation, possibly through habit or similarity matching. Situation is characterized by lack of planning and this may possibly be due to the lack of available time;
- *Tactical control*: performance typically follows planned procedures while some ad-hoc deviations are still possible;
- *Strategic control*: plentiful time is available to consider actions to be taken in light of wider objectives to be fulfilled and within the given context.

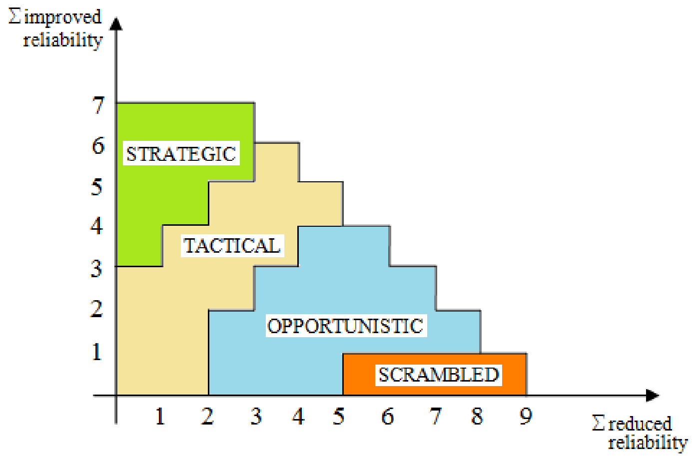


Fig. 3. Relations between Common Performance Conditions (CPCs) score and control modes

Error probability intervals classified on the basis of the various control modes are the following (Table I):

TABLE I
Error Probability Intervals

Control Modes	Error Probability interval
STRATEGIC	0.5E-5 < p < 1E-2
TACTICAL	1E-3 < p < 1E-1
OPPORTUNISTIC	1E-2 < p < 0.5E0
SCRAMBLED	1E-1 < p < 1E0

The particular control mode determines level of reliability that can be expected in a particular setting and this is in turn determined by collective characteristics of relevant CPCs.

CREAM methodology (basic and extended version) consists in the following steps:

BASIC VERSION

- Step 1. Hierarchical Tasks Analysis (HTA);
- Step 2. CPCs evaluation;
- Step 3. Control Mode/error interval determination;

EXTENDED VERSION (if needed)

- Step 4. Requested cognitive profile construction;
- Step 5. Possible failure modes of cognitive functions;
- Step 6. Error probability definition.

The main advantages of this methodology are: the technique uses the same principles for retrospective and predictive analyses; the approach is very concise, well-structured and follows a well laid out system of procedure; the technique allows for the direct quantification of HEP; it also allows evaluator using the CREAM method to specifically tailor the use of technique to contextual situation [20]; [21]. Instead, the main criticism are: this technique requires a high level of resource use, including lengthy time periods for completion; CREAM also requires an initial expertise in field of human factors in order to use technique successfully and may therefore appear rather complex for an inexperienced user; CREAM does not put forth potential means by which identified errors can be reduced; time required for application is very lengthy.

III. A Case Study of a human Reliability Analysis

In the present paragraph the CREAM methodology applied in a real case study is presented. In Fig. 4 phases and activities involves the model are shown. Here below the methodological approach is presented.

PHASE 1: MODEL DEFINITION

In the present phase the model is defined. We applied the model in the mechanical sector.

Activity 1.1 - Definition of the scenario

The aim of the activity 1.1 is to define:

- *the reference organizational scenario of mechanical sector*. It was outlined a description of the mechanical sector organization, through the analysis of main organizational and productive aspects including: time and processing methods; duty cycles; human aspects of work.
- *the sample survey definition (SMEs)*. It was conducted a research of several local companies. SMEs were selected through a sampling reportedly to the economic activity sector. The aim was to identify the most significant realities from the point of view of safety management in the workplace, with an emphasis on processes/activities in which are concentrated reliability operators problems'.

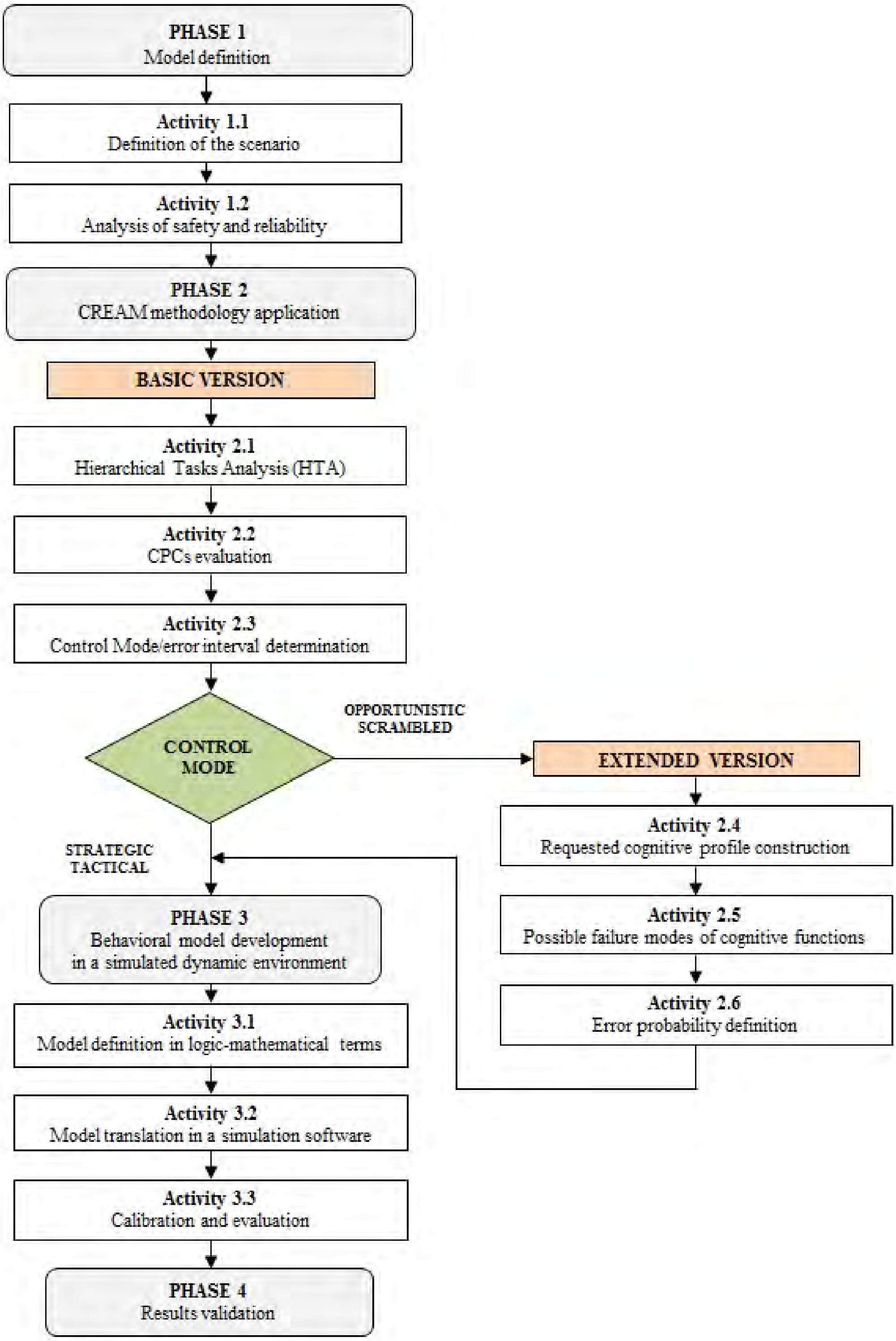


Fig. 4. CREAM methodology approach for case study

Activity 1.2 - Analysis of safety and reliability

The most critical activities are analyzed, such as: Welding, Lathing, Drilling, Punching, Stamping, Pressing, etc. Check list and safety data sheets were defined according to risks associated for each activity. In Fig. 5 is shown an extract of data analyzed.

Name	**LATHING**	
Description	The lathe is a machine tool used for the machining of a workpiece placed in rotation.	
Risks	Accidental contact.	
Prevention and Protection	The machine must not be used in an explosive atmosphere. Safety shields Interlocking devices	

Fig. 5. Sample of safety check

PHASE 2: CREAM METHODOLOGY APPLICATION

In the present phase CREAM methodology is applied. Basic Version and Extended version is analysed.

BASIC VERSION

Activity 2.1 - Hierarchical Tasks Analysis (HTA)

In a logical time sequence, specific operators' tasks are ordered. In this example is analysed the *lathing* process of a specific SME (Table II).

TABLE III
Task Analysis of Lathing Process

Turning – Task Analysis			
ID	GOAL	ID	ACTIVITY
1.01	Machine set-up and work piece positioning	1.01.01	Open spindle
		1.01.02	Position and progress bar
		1.01.03	Close spindle
1.02	Machine assistance	1.02.01	Start spindle
		1.02.02	Approach the tool
		1.02.03	Cutting depth setting
		1.02.04	Select automatic feed
1.03	Work-piece removing	1.03.01	Stop the machine
		1.03.02	Space out the tool
		1.03.03	Remove and store the work-piece

Activity 2.2 - CPCs evaluation

CPCs evaluation is made. The expected effect on the reliability of performance is shown in Table III.

TABLE IIIII
CPCs Table Representation and Evaluation

CPCs	**Qualitative level**	**Expected effect**
Adequacy of organisation	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	Not significant
	Incompatible	Reduced
Adequacy of man-machine interaction and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced

Feasibility of procedures and plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Not significant
	Matching current capacity	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporarily inadequate	Not significant
	Continuously inadequate	Reduced
Time of day	Day time	Not significant
	Night time	Reduced
Adequacy of training and preparation	Adequate (high experience)	Improved
	Adequate (low experience)	Not significant
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Not significant
	Deficient	Reduced

Activity 2.3 - Control Mode/Error Interval determination

In the present activity CPCs characterization is made.

TABLE IVV
CPCs Characterization

Common Performance Conditions	**Associated Judgment**
Appropriateness of organization	Reduced
Work place conditions	Improved
Appropriateness of man/machine interaction	Reduced
Feasibility of the procedures and planning	Reduced
Number of simultaneously tasks carried out by the operator	Not significant
Available time	Improved
Time of day in which the activity is carried out	Reduced
Adequacy of training and experience of worker	Not significant
Level of collaboration and interaction of department staff	Reduced
∑ Improved	**2**
∑ Reduced	**5**

Considering the relations between CPC score and control modes (Fig.3), it was possible determine the Control Mode. According to the previous results, the Control Mode is “Opportunistic” and it is necessary to apply the extended version.

EXTENDED VERSION

Activity 2.4 - Requested cognitive profile construction

The purpose of this step is to define the Cognitive Profile considering dependencies between cognitive activities and CoCoM functions as shown in the following table (Table V):

TABLE V
Methodological Matrix of Cognitive Activities

COGNITIVE ACTIVITY	**CoCoM Functions**			
	Observation	**Interpretation**	**Planning**	**Execution**
Coordinate			X	X
Communicate				X
Compare		X		
Diagnose		X	X	
Assess		X	X	
Execute				X
Identify		X		
Maintain			X	X
Monitor	X	X		
Observe	X			
Plan			X	

Set		X		X
Adjust	X			X
Examine	X			
Verify	X	X		

In the specific case of lathing it has (Table VI):

TABLE VI

GOAL	ACTIVITY	Cognitive activity	CoCoM Functions			
			Observation	**Interpretation**	**Planning**	**Execution**
Machine set-up and work piece positioning	Open spindle	execute				X
	Position and progress bar	execute				X
	Close spindle	execute				X
Machine assistance	Start spindle	execute				X
	Approach the tool	set		X		X
	Cutting depth setting	adjust	X			X
	Select automatic feed	execute				X
Work piece removing	Stop the machine	execute				X
	Space out the tool	execute				X
	Remove and store the work piece	execute				X

Methodological Matrix of Cognitive Activities for Lathing

Activity 2.5 - Possible failure modes of cognitive functions

In the present activity, the error of cognitive function is identified through the use of the following error modes, relating lathing operations (Table VII; Table VIII):

TABLE VII
Cognitive Functions and Error Modes

Cognitive Function	CoCoM Functions	
	Error Modes	**Mode description**
Observation	O1	Observation of the wrong object
	O2	Mistaken identification due to errors or partial identification
	O3	Not carried out observation due to oversights
Interpretation	I1	Wrong and incomplete diagnosis
	I2	Decision errors due to not carried out or incomplete analysis
	I3	Not timely interpretation
Planning	P1	Wrong target identification
	P2	Inadequate and incomplete planning
Execution	E1	Wrong actions execution
	E2	Not timely actions execution
	E3	Performing actions on wrong items
	E4	Performing actions without exact sequence
	E5	Non-execution of actions

TABLE VIII
Application on Lathing Operations

ACTIVITY	Cognitive Activity	CoCoM Functions												
		Observation			**Interpretation**			**Planning**		**Execution**				
		O1	**O2**	**O3**	**I1**	**I2**	**I3**	**P1**	**P2**	**E1**	**E2**	**E3**	**E4**	**E5**
Open spindle	execute										X			
Position and progress bar	execute									X				
Close spindle	execute										X			
Start spindle	execute												X	
Approach the tool	set									X				
Approach the tool	set				X									
Cutting depth setting	adjust		X											
Cutting depth setting	adjust										X			
Select automatic feed	execute										X			
Stop the machine	execute												X	
Space out the tool	execute													X
Remove and store the work piece	execute										X			

Activity 2.6 – Cognitive Failure Probability (CFP) definition

Starting from the table of CFPs corrective factors (Table IX) and nominal values of CFPs (Table X), are determined “weighting factors” (Table XI) to adjust nominal values of CFPs and obtain the final values of Cognitive Error Probability (Table XII).

TABLE IX
Correction Factors of CFPs

CPCs	Qualitative level	Expected effect	OBS	INT	PLA	EXE
Adequacy of organization	Very efficient	Improved	1.0	1.0	0.8	0.8
	Efficient	Not significant	1.0	1.0	1.0	1.0
	Inefficient	Reduced	1.0	1.0	1.2	1.2
	Deficient	Reduced	1.0	1.0	2.0	2.0
Working conditions	Advantageous	Improved	0.8	0.8	1.0	0.8
	Compatible	Not significant	1.0	1.0	1.0	1.0
	Incompatible	Reduced	2.0	2.0	1.0	2.0
Adequacy of man-machine interaction and operational support	Supportive	Improved	0.5	1.0	1.0	0.5
	Adequate	Not significant	1.0	1.0	1.0	1.0
	Tolerable	Not significant	1.0	1.0	1.0	1.0
	Inappropriate	Reduced	5.0	1.0	1.0	5.0
Feasibility of procedures and plans	Appropriate	Improved	0.8	1.0	0.5	0.8
	Acceptable	Not significant	1.0	1.0	1.0	1.0
	Inappropriate	Reduced	2.0	1.0	5.0	2.0
Number of simultaneous goals	Fewer than capacity	Not significant	1.0	1.0	1.0	1.0
	Matching current capacity	Not significant	1.0	1.0	1.0	1.0
	More than capacity	Reduced	2.0	2.0	5.0	2.0
Available time	Adequate	Improved	0.5	0.5	0.5	0.5
	Temporarily inadequate	Not significant	1.0	1.0	1.0	1.0
	Continuously inadequate	Reduced	5.0	5.0	5.0	5.0
Time of day	Day time	Not significant	1.0	1.0	1.0	1.0
	Night time	Reduced	1.2	1.2	1.2	1.2
Adequacy of training and preparation	Adequate (high experience)	Improved	0.8	0.5	0.5	0.8
	Adequate (low experience)	Not significant	1.0	1.0	1.0	1.0
	Inadequate	Reduced	2.0	5.0	5.0	2.0
Crew collaboration quality	Very efficient	Improved	0.5	0.5	0.5	0.5
	Efficient	Not significant	1.0	1.0	1.0	1.0
	Inefficient	Not significant	1.0	1.0	1.0	1.0
	Deficient	Reduced	2.0	2.0	2.0	5.0

TABLE X
Nominal Value of CFPs

Cognitive Function	CoCoM Functions		
	Error Modes	**Mode description**	**Nominal value**
Observation	O1	Observation of the wrong object	1.0E-3
	O2	Mistaken identification due to errors or partial identification	7.0E-3
	O3	Not carried out observation due to oversights	3.0E-3
Interpretation	I1	Wrong and incomplete diagnosis	2.0E-1
	I2	Decision errors due to not carried out or incomplete analysis	1.0E-2
	I3	Not timely interpretation	1.0E-2
Planning	P1	Wrong target identification	1.0E-2
	P2	Inadequate and incomplete planning	1.0E-2
Execution	E1	Wrong actions execution	3.0E-3
	E2	Not timely actions execution	3.0E-3
	E3	Performing actions on wrong items	5.0E-4
	E4	Performing actions without exact sequence	3.0E-3
	E5	Non-execution of actions	3.0E-2

TABLE XI
Assessment of CPCs Effects on Cognitive Function Failures

Common Performance Conditions	Associated Judgment	CoCoM function			
		OBS	INT	PLA	EXE
Adequacy of organization	Reduced	1.0	1.0	1.0	1.0
Working conditions	Improved	0.8	0.8	1.0	0.8
Adequacy of man/machine interaction and operational support	Reduced	5.0	1.0	1.0	5.0
Feasibility of procedures and plans	Reduced	2.0	1.0	5.0	2.0
Number of simultaneously goals	Not significant	1.0	1.0	1.0	1.0
Available time	Improved	0.5	0.5	0.5	0.5
Time of day	Reduced	1.2	1.2	1.2	1.2
Adequacy of training and preparation	Not significant	1.0	1.0	1.0	1.0
Crew collaboration quality	Reduced	2.0	2.0	2.0	5.0
TOTAL INFLUENCE OF CPCs		**9.6**	**0.96**	**6.0**	**24**

TABLE XII
Adjusted CFPs for Cognitive Function Failures

ID	Task	Error mode	Weighting factor	Adjusted CFP
1.01.01	Open spindle	E2 (3.0E-3)	24	7.2E-2
1.01.02	Position and progress bar	E1 (3.0E-3)	24	7.2E-2
1.01.03	Close spindle	E2 (3.0E-3)	24	7.2E-2
1.02.01	Start spindle	E4 (3.0E-3)	24	7.2E-2
1.02.02	Approach the tool	I1 (2.0E-1)	0.96	1.92E-1
		E1 (3.0E-3)	24	7.2E-2
1.02.03	Cutting depth setting	O2 (7.0E-3)	9.6	6.72E-2
		E2 (3.0E-3)	24	7.2E-2
1.02.04	Select automatic feed	E2 (3.0E-3)	24	7.2E-2
1.03.01	Stop the machine	E4 (3.0E-3)	24	7.2E-2
1.03.02	Space out the tool	E5 (3.0E-2)	24	7.2E-1
1.03.03	Remove and store the work piece	E2 (3.0E-3)	24	7.2E-2

From Table XII is possible determine the value of Cognitive Failure Probability. The probability value is included in the "opportunistic" control mode range (1.0E-2 < p < 0.5E0), as shown by the basic version of methodology.

PHASE 3: BEHAVIORAL MODEL DEVELOPMENT IN A SIMULATED DYNAMIC ENVIRONMENT

Activity 3.1 - Model definition in logic-mathematical terms

The implemented logical-mathematical model provides the determination of the organization CPCs. The questionnaire is performed according to the specifics organizational conditions. The logical-mathematical model provides:

1. Production processes cycle defining;
2. Formulation of questions about CPCs;
3. Translation of answers in numerical terms of quality level achieved in the CPCs evaluation;
4. Determination of MTO reliability and the identification of control mode (strategic, tactical, opportunistic, scrambled);
5. The extension of model numerical evaluation, in case the reliability interval is not satisfactory;

6. Identification of actions to be implemented to improve reliability, with evaluation of the probability of error in numerical terms.

Here below are shown identified questionnaires and improvement actions, that allow the translation of a mathematical model in a business decisions support software (Table XIII, Table XIV).

TABLE XIII
Evaluation Questionnaire for CPCs Analysis

CPCs	Evaluation Questionnaire
Adequacy of organisation	Are the work-spaces well organized?
	Is the available equipment status checked regularly?
	Does the organization adopt safety management systems?
	Does the organization adopt quality management system?
Working conditions	Are the physical spaces for handling adequate?
	Are the work-station lightning condition adequate?
	Is the environmental noise level, which is subjected the operator, acceptable?
Adequacy of man-machine interaction and operational support	Are the machine controls easily accessible?
	Is the work-station designed according to ergonomic principles?
	Is the work-station equipped with a easily visible control panel?
	Is the work-station equipped with computerized controls?
Feasibility of procedures and plans	Are manual and/or documents relating to operational procedures available?
	Do the documents contain detailed procedures for machines operation?
	Do the documents contain detailed procedures for safety devices control?
Number of simultaneous goals	Does the operator perform simultaneous control tasks?
	Does the work-programming involve the monitoring of a single work-station?
	Is the work-loads distribution appropriate?
Available time	Are the displacement and execution times commensurate with appropriate ergonomic positions?
	Does the processing cycle provide a minimum rest period for the operator?
	Were assigned times evaluated with analytical procedures?
Time of day	Are there only day-shifts?
	Is the activity carried out in a single shift?
Adequacy of training and preparation	Is provided a minimum period of supervised training for non-expert operators?
	Is the staff trained about the use of machinery and related risks?
	Is the use of the machinery allowed only to operators with five years of proven experience?
Crew collaboration quality	Is the collaboration quality between operators sufficient and adequate to the tasks?
	Is the cooperation quality between operators satisfactory?
	Is the level of trust between the department operators satisfactory?
	Is the social climate good inside the department?

TABLE XIV
Improvement Performance Actions on CPCs

CPCs	Improvement Performance Actions
Adequacy of organisation	Reorganization of work-spaces
	Implementation of a quality management system
	Implementation of a safety management system
	Periodic checks program of equipment
Working conditions	Adaptation of physical space and layout of work-station
	Improvement of workstations lighting
	Reduction of noise levels and/or adoption of appropriate protection devices
Adequacy of man-machine interaction and operational support	Adaptation of machines controls accessibility
	Adaptation of work-place ergonomic conditions
	Adaptation of work-station control panel
	Endowment of computerized controls in work-station
Feasibility of procedures and plans	Predisposition of manuals and written procedures
	Predisposition of handling procedures with visual details
	Predisposition of controls safety devices procedures with visual details
Number of simultaneous goals	Linearization procedures of control tasks
	Tasks assignment on a single work-station, if possible
	Work-loads redistribution and balancing
Available time	Time adaptation to favourable ergonomic conditions

	Rest time adaptation in processing cycles
	Time assessment with analytical procedures
Time of day	Reduction of night shifts, if possible
	Reduction in double shifts, if possible
Adequacy of training and preparation	On the job training and tutoring
	Theoretical and practical professional training
	Specialization plans for department
Crew collaboration quality	Actions of promotion and encouragement of collaboration
	Improvement actions and training for collaborative work
	Actions to encourage the improvement of confidence level among workers
	Actions to encourage social cohesion among department workers

Activity 3.2 - Model translation in a simulation software

The developed simulation software has the characteristics of a DSS (Decision Support System) [22]. It allows a self-evaluation of productive organization reliability, in terms of man-machine-environment interaction, thus being able to determine the safety characteristics in the workplace. The application was developed in Microsoft Visual Basic referring to configuration parameters on a database created in Microsoft Access. This software provides, after the administration of evaluation questions, the identification of actions to improve safety that affecting the Reliability Index (RI). The reliability index represents the probability of error referring to the table I.

Activity 3.3 - Calibration and evaluation

Here below is illustrated, through some user interface screen-shots, the evaluation and calibration of simulation software. Calibration and evaluation were carried out by subjecting to the software the case study analyzed above. To this end, the following steps were followed:

1. Block diagram of analyzed production process;
2. Questionnaires elaboration;
3. Determination of error index with any improvements.

Block diagram of analyzed production process

The user selects blocks relative to the processes flow to be analyzed, always starting from the “start” symbol. The meanings of available blocks are the following:

- **Start**: Start process;
- **Act**: Process activities;
- **In**: Materials input;
- **Out**: Materials output;
- **End**: Stop process.

Here below the screen-shot of the lathing process (Fig. 6):

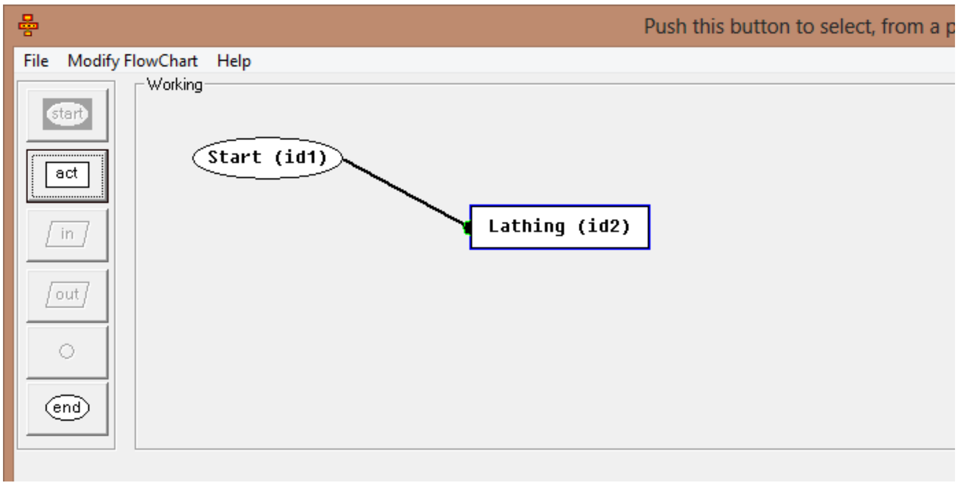


Fig. 6. Screen-shot of block diagram definition

Questionnaires elaboration

After the definition of process block diagram, are proposed questions developed in the simulation model (Fig.7):

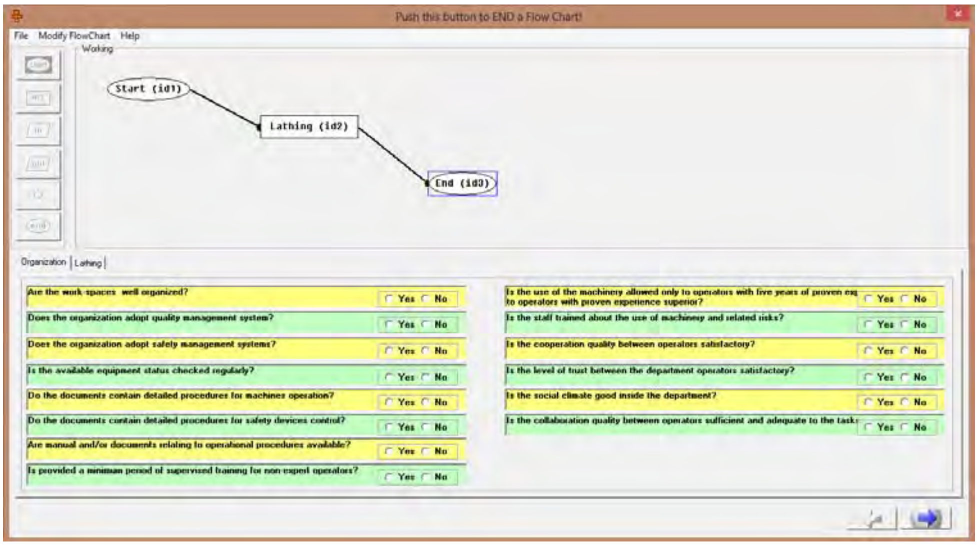
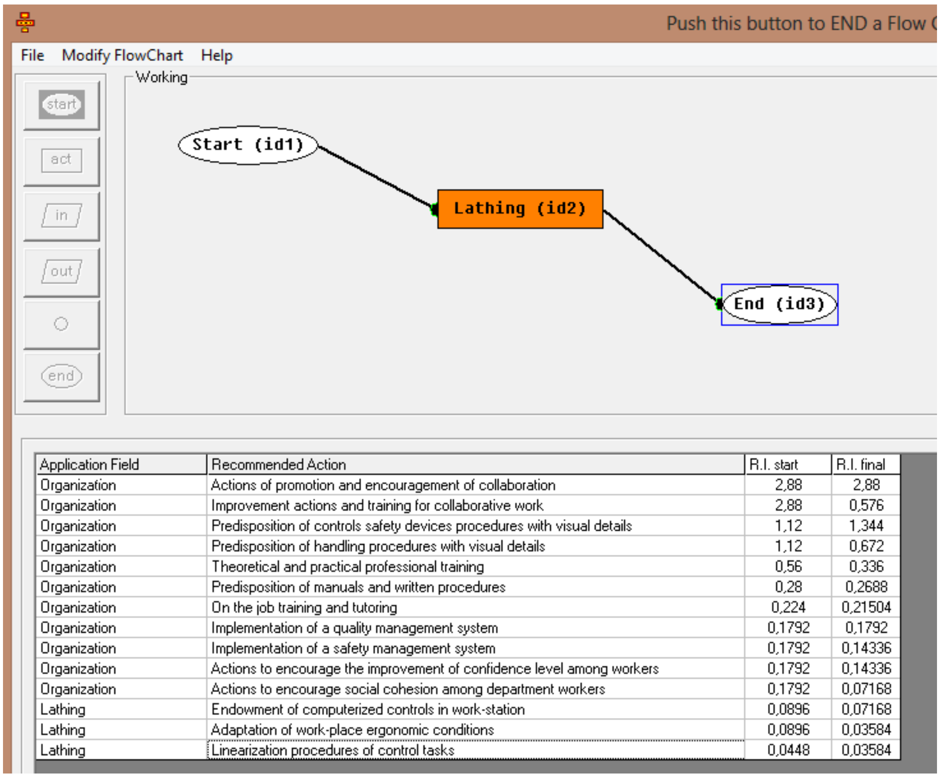


Fig. 7. Screen-shot of questionnaires

Determination of error index with any improvements

After answering all the questions, the algorithm gives us the results. (Fig.8):



Application Field	Recommended Action	R.I. start	R.I. final
Organization	Actions of promotion and encouragement of collaboration	2,88	2,88
Organization	Improvement actions and training for collaborative work	2,88	0,576
Organization	Predisposition of controls safety devices procedures with visual details	1,12	1,344
Organization	Predisposition of handling procedures with visual details	1,12	0,672
Organization	Theoretical and practical professional training	0,56	0,336
Organization	Predisposition of manuals and written procedures	0,28	0,2688
Organization	On the job training and tutoring	0,224	0,21504
Organization	Implementation of a quality management system	0,1792	0,1792
Organization	Implementation of a safety management system	0,1792	0,14336
Organization	Actions to encourage the improvement of confidence level among workers	0,1792	0,14336
Organization	Actions to encourage social cohesion among department workers	0,1792	0,07168
Lathing	Endowment of computerized controls in work-station	0,0896	0,07168
Lathing	Adaptation of work-place ergonomic conditions	0,0896	0,03584
Lathing	Linearization procedures of control tasks	0,0448	0,03584

Fig. 8. Screen-shot of outputs

There are three possible kinds of output: green, orange and red (Fig.8):

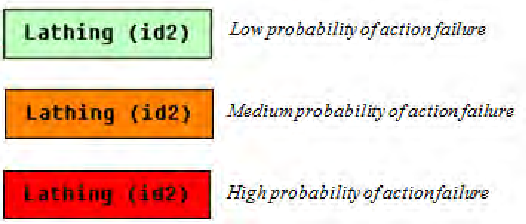


Fig. 8. Example of outputs for lathing process

When the process block is green, the probability of action failure is low and therefore there is no need to make change. Instead, when the block turns orange/red, the probability of action failure is medium/high, and therefore there is the need to act by using improvement actions proposed in the software.

PHASE 4: RESULTS VALIDATION

In our case study the colour of process block is orange and the probability of action failure is included in the “opportunistic” control mode range. Thus the simulation, through running several iterations, proposes a lot of actions to improve the reliability index, in order to move the control mode from “opportunistic” to “tactical” ($1E\text{-}3 < p < 1E\text{-}1$).

IV. CONCLUSIONS

In the present paper we proposed a modelling application for cognitive reliability and error analysis method. The model is a novel approach and it is a very promising tools useful in order to manage the “human factors” in production process. In fact, the importance of human factor studies in production processes has grown substantially. Considering that most of the production processes are made by the combination of man and machine, the ideal condition to ensure high safety standards is to monitor and manage both components of this binomial. Until recently, as already mentioned, only the technological process for safety improvement and process reliability was considered.

But today, thanks to the Human Reliability Analysis, the attributed importance of human factor reliability has almost reached the importance of machines reliability. As for other factors, human errors, in every field, cannot be erased but can only be controlled. For this reason, in recent years, many researches in human reliability analysis have been carried out.

Then, in order to face the problem of reliability in a unitary perspective, it is desirable to have a continuous and increasingly intense dissemination of HRA methodologies. In particular, it is necessary that these methodologies assume a degree of completeness and portability so that we can ensure their application in different fields.

Therefore, it would be desirable, for a correct dimensioning of the prevention system, to apply techniques for human reliability analysis in an integrated way to design work environments and therefore spread the values of safety to all the organization. Summing up the following are the main guidelines identified for future research:

- It is desirable to develop more precise frameworks and empirical testing of the performance measures, action research.
- It is necessary to develop more industry studies.

Definitely the study revealed that Human Reliability Analysis is still a fruitful research area and distinctive statements have been traced for the need of further research.

REFERENCES

[1] B., Kirwan, Practical Guide to Human Reliability Assessment. Taylor and Francis (CRC Press), London, 1994.

[2] R. E., Barlow and F. Proschan, Statistical Theory of Reliability and Life Testing. Holt, Reinhart and Winston, New York, 1975.

[3] A. Høyland, M. Rausand, System Reliability Theory. John Wiley and Sons, New York, 1994.

[4] J. Reason, The contribution of latent human failures to the breakdown of complex systems. Philosophical Transactions of the Royal Society of London. B327(1241) 475-484, 1990.

[5] S. G. Kariuki and K. Lowe, Integrating human factors into process analysis. Reliability Engineering and System Safety. 92 1764-1773, 2007.

[6] J. Ren, I. Jenkinson, J. Wang, D. L. Xu and J. B. Yang, A methodology to model causal relationships in offshore safety assessment focusing on human and organisational factors. Journal of Safety Research. 39 87-100, 2008.

[7] R. L. Helmreich, On error management: lessons from aviation. British Medical Journal. 320(7237) 781–785, 2000.

[8] E. Hollnagel, Cognitive Reliability and Error Analysis Method – CREAM. Elsevier Science, Oxford, 1998.

[9] F. Longo, A.G. Bruzzone, Modelling and simulation applied to security systems Summer Computer Simulation Conference 2005, SCSC 2005, Part of the 2005 Summer Simulation Multiconference, SummerSim 2005, Pages 183-188.

[10] S. French, A. J. Maule and K. N. Papamichail, Decision Making: Behaviour, Analysis and Support. Cambridge University Press, Cambridge.

[11] A. Silvestri, F. De Felice, A. Petrillo. Multi-criteria risk analysis to improve safety in manufacturing systems. International Journal of Production Research 50 (17) , pp. 4806-4821, 2012

[12] G. Di Bona, V. Duraccio, A. Silvestri, A. Forcina. Validation and application of a safety allocation technique (integrated hazard method) to an aerospace prototype. 32nd IASTED International Conference on Modelling, Identification and Control, Innsbruck, 11-13 February 2013

[13] F. De Felice, A. Petrillo. Methodological Approach for Performing Human Reliability and Error Analysis in Railway Transportation System. International Journal of Engineering and Technology Vol.3 (5), 2011, 341-353.

[14] D. Falcone, G. Di Bona, V. Duraccio. A. Silvestri. Integrated hazards method (IHM): A new safety allocation technique. Proceedings of the IASTED International Conference on Modelling and Simulation , pp. 338-343, 2007.

[15] E. Grandjean, Fitting the Task to the Man. Taylor and Francis, London, 1980.

[16] D. E. Embrey, Data Collection Systems. Human Reliability Associates, Wigan, 2000.

[17] M. Lyons, A. Sally, M. Woloshynowych, C. Vincent, Human Reliability Analysis in healthcare: A review of technique. International Journal of Risk & Safety in medicine, 2004.

[18] O. Sträter, The use of incidents for human reliability management. Safety & Reliability, Vol. 26, No. 2 pp 26-47, 2006.

[19] P. C. Cacciabue, Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training. Reliability Eng System Safety RE & SS 83, 229–240., 2004.
[20] P. Salmon, N. A. Stanton and G. Walker, Humans Factors Design Methods Review. Defence Technology Centre, 2003.
[21] I.S. Kim Human reliability analysis in the man-machine interface design review. Annals of Nuclear Energy 28 (2001) 1069-1081.
[22] F. De Felice, A. Petrillo, Productivity analysis through simulation technique to optimize an automated assembly line. Proceedings of the IASTED International Conference, June 25 - 27, 2012 Napoli, Italy. Applied Simulation and Modelling (ASM 2012) DOI: 10.2316/P.2012.776-048 – pp 35-42.