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Human factors impact on risk analysis of complex systems

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Abstract

This paper discusses the methods and techniques that are applied for including human factors considerations into risk analysis of modern plants. The application of new control design principles and the extensive use of automation have strongly modified the role of operators, who have progressively become supervisors of automatically performed procedures and decision makers in a context of shared management processes. This implies that cognitive functions and organisational factors affect risk analysis much more than behavioural and physical performances. Another crucial issue of human reliability assessment concerns the dynamic nature of human–machine interaction. This feature covers a wide spectrum of real situations, but demands quite complex and extensive data. These considerations favour the development of new and evolutionary techniques which must be confronted with the requirements and needs of different types of risk analysis be carried out for different objectives, such as quantitative risk analysis, safety management, accident investigation, risk-based decision making and risk-based regulations. Advantages and areas of application of different techniques are briefly discussed, without attempting to develop a detailed comparison.

Keywords: Human factors; Risk assessment; Human reliability assessment; Cognitive modelling; Human–machine interaction

1. Introduction

1.1. Scope of risk assessment in different industrial realms

The scope of risk assessment, as a methodology that enables to evaluate and estimate the risk associated with a system, has vastly changed over the last 10 years, progres-

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sively expanding its bearing to areas such as safety management, regulation development, and design [1]. While this growth proves the power and validity of the methodological approach, it also requires that new methods and techniques are developed so as to satisfy the requirements and specifications of new areas and domains of application. When standard probabilistic risk assessment (PRA), also called probabilistic safety assessment (PSA), or quantitative risk assessment (QRA) type analyses are performed, then the ''bottleneck'' of providing numerical measures of the likelihood of certain events and of their associated consequences is still a very important requirement to be satisfied. This implies that, independently of the specific application of risk assessment being performed, when the goal of the analyst includes the quantification of risk associated with a certain system, then two main conditions must be satisfied:

1. An adequate database, or at least a consolidated technique for data collection, has to be available which suits the theoretical construct that sustains the risk analysis; and
2. An appropriate methodological framework has to be applied, so as to link different methods and techniques utilised in the overall PRA/QRA application.

These issues have different implications and meaning for PRA/QRA methodologies according to different industrial domains. This is due to historical reasons related, on the one hand, to the nature of the involved industry and, on the other hand, to the evolution of regulations. The latter are somewhat dependent also on the occurrence of severe accidents in a particular industrial context.

Initially, there has been a progressive expansion of the risk-based approach from the aerospace industry, in connection with the analysis of electronic systems, to nuclear power plants, including nuclear production and waste facilities, and then to petroleum and chemical plants. However, the difference existing in physical and chemical processes as well as in control strategies and procedures, led to development of specific techniques dedicated to specific problems in each domain. As an example, the hazard and operability (HAZOP) analysis has been introduced in chemical industries as a qualitative approach for the formal systematic examination of the process and engineering intentions to assess the hazard potential of malfunctions and maloperations and the consequential effects. HAZOP has been estimated necessary for the preliminary assessment of a complex system that presents several processes, which occur in sequence or in parallel, each of them involving many hazardous chemical and thermodynamic reactions. In the nuclear domain, other issues have focused the attention of safety assessment, such as the evaluation of different ''levels'' of analysis according to whether the risk to be studied concerns the release within the nuclear core container (''PSA-level 1''), or within the reactor building (''PSA-level 2''), or to the atmosphere (''PSA-level 3'').

Safety regulations, and especially reactive measures imposed on the industry by safety authorities following severe accidents, have an even more important impact on the different evolutions of risk methods than the differences due to the type of processes. As an example, QRA in the chemical industry, defined as the identification of potential hazards, the estimation of consequences, the evaluation of the probability of occurrence and the comparison of the results against acceptability criteria, is nowadays part of a larger systemic approach, known as the safety management system (SMS). This method is a typical proactive measure for safety assessment, which considers a plant as an integrated system, and combines standards, guidelines, local procedures, auditing, safety policy, and QRA. The development and application of SMSs for accident prevention followed, in Europe, the occurrence of a number of very serious accidents in the late 1970s in the domain of chemical and process plants. Therefore, in the chemical industry, QRA is part of a larger systemic approach and has to provide the important measures of risk, in quantitative and qualitative terms, to sustain the other elements of SMS. In the nuclear domain, safety authorities have not retained the concept of SMS. However, the regulations of most countries demand that PRA analysis of ''level 3'' is performed, i.e. that the risk is calculated for the exposure of the population to the release of radioactive material and energy following an accident. Therefore, the probabilistic evaluation, and related uncertainty distributions, of the ''source term'' for the calculation of the effect of the population and environment become very important.

In this paper we will not develop any further this difference between the way in which risk assessment is intended in different industrial domains. However, it is important that, whenever a risk analysis is carried out for assessing or for estimating the safety level of a plant, the above differences between diverse industries and the scope associated to each risk assessment are carefully taken into consideration.

1.2. Human factors in risk assessment

The human contribution to risk assessment is an integral part of any analysis and the majority of the human reliability assessment (HRA) methods that have been developed and applied over the years, have seriously considered the above issues of data availability and integration within larger methodological framework. However, in the last two decades there has been a dramatic increase of human contribution to accident development, reaching levels of percentages of as high as 70%–80%, independently of the technological domain of application [2]. There are two main reasons for such relevant increase, namely: (a) the very high reliability and refinement of mechanical and electronic components; and (b) the complexity of the system and the role assigned to human operator in the control loop.

The very high reliability and refinement of mechanical and electronic components has vastly reduced mechanical faults and has enabled to manage all plant critical processes, even in the presence of system faults and malfunctions, thanks to redundancies and protection systems. This high reliability of hardware components impacts directly on the statistical contribution to accident of human errors, which become more and more visible in numerical importance.

The complexity of the system and the role assigned to human operator in the control loop. In practice, the extensive use of automation for process control has required that the human operator becomes primarily a supervisor of plant operations, performed by computerised systems. Thus, the working environments are much more demanding in terms of cognitive-reasoning abilities rather than sensory–motor skills. Systems behave and respond via the automation and interfaces, which follow the rules and principles provided by their designers. These are not always totally known or familiar to operators. Moreover, in accidental conditions, the dynamic characteristics of the sequence of events add to the inherent complexity of the situation and further complicate the decision making process [3,4]. These factors tend to reduce the number of human errors at behavioural-activity level, but also increase the impact of consequences when ‘‘errors’’ of reasoning or cognition, usually deeply rooted into the socio-technical context, manage to infringe the engineered protection system and become very difficult to control and contain.

This second issue affects also another important aspect of HRA that is conceptually very relevant and can be described as follows. Given the discussion on human errors, HRA should focus more on cognitive and organisational processes than on behavioural performance, i.e., the important human factors are mainly related to mental processes such as interpretation and planning/decision making rather than simple perceptions and reactions to physical events. As an example, according to a well known theory [5,6], human errors may be made at different levels of an organisation and the highest the level within the organisation, at which errors are made, the more influential and widespread are their consequences. Errors occurring outside the immediate control of a plant, such as at top management, design, or maintenance level are not instantly visible. They remain dormant, in a *latent* state, and can propagate and expand throughout the organisation affecting a high number of decisions and then become suddenly manifest at the level of *active* plant operation. In addition to this social aspect, the specific environmental working conditions and technical contexts in which accidents are generated and evolve, equally influence the behaviour of operators in active control, or ‘‘front line actors’’.

In summary, combining the above considerations on data and methodological requirements with the need to assign a more relevant role to HRA in risk assessment, with focus on cognitive and organisational factors, it becomes obvious that new generations or evolutionary HRA methods must be developed. In this way, the impact of human factors on modern complex systems may be allocated into a more realistic prospectus with respect to the expanded aims of risk analysis and the requirements of advanced technological control designs.

In this paper we will give an overview of methods that include new features of human factors consideration for risk analysis. In particular, we will discuss five basic elements that should be included in such methods, namely: retrospective and prospective analysis; task analysis; data and parameters identification; human–machine interaction (HMI) modelling; and dynamic reliability modelling. From this discussion, a generic framework, able to satisfy coherently the requirements of risk analysis will be identified. Finally, a review of current methods for studying human contribution to risk analysis will be carried out, in consideration of the findings and requirements identified in the preceding discussion.

2. Basic elements for HMI in risk analysis

This section will concentrate on the most important innovative features that have to be considered in human reliability methods for risk analysis. A first important aspect of the approach to be considered when performing human assessment to risk analysis is the general framework in which the HRA study is located. In particular, different levels of

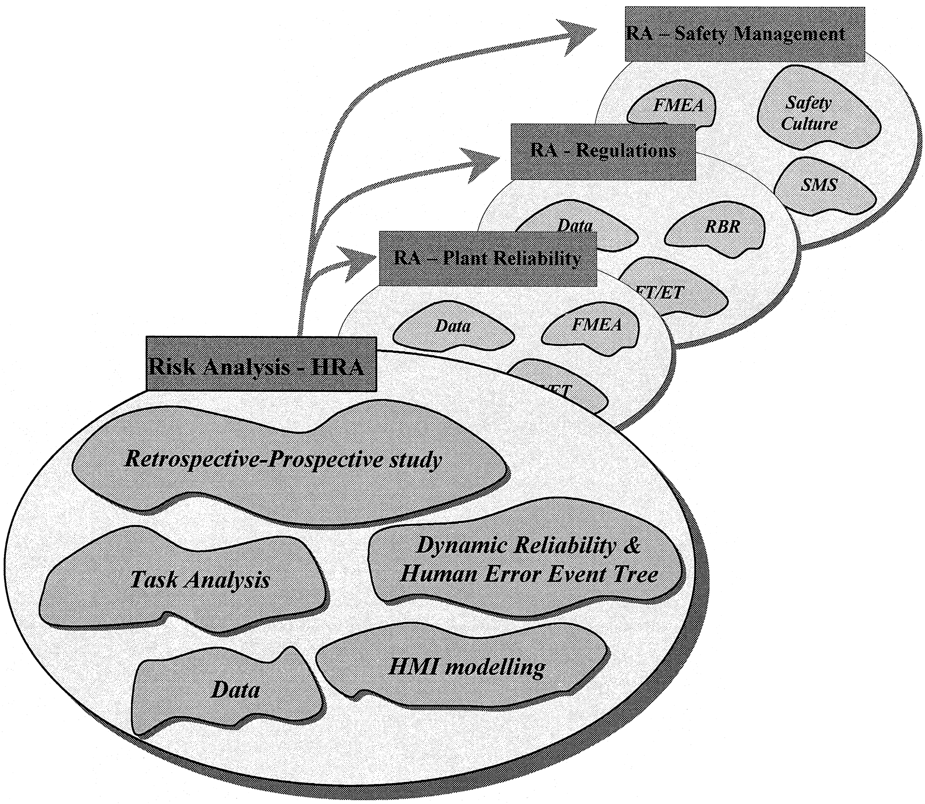

Fig. 1. Human reliability assessment methods for risk analysis scenarios.

depth are required if the HRA study has to support a plant reliability assessment or if it has to fit into the development of risk-based regulation, or if it has to contribute to a SMS (Fig. 1). In any case, appropriate methods and techniques have to be applied for considering key features of HMI in modern plant control. These techniques are usually based on consolidated theories of cognition and organisational behaviour.

We will argue here that the formalisation of human inappropriate behaviours, or manifestations of human error, is an already acquired methodology and that well-known techniques exist for representing human behaviour and chaining of events in accident analysis.

As an example, the use of human error trees (HET) is a formal way to describe human actions that can reasonably well fit similar approaches utilised to describe system performance for risk assessment, i.e. fault trees (FT) or event trees (ET).

The methods that have been developed in the last decade are focused around a number of specific issues, already briefly reviewed in Section 1. In particular, five important features have to be considered in a human reliability method:

1. Retrospective and prospective analysis;
2. Task analysis;

3. Data and parameters identification;
4. HMI modelling;
5. Dynamic reliability modelling.

We will discuss these features in more detail and then we will show how they may be integrated into a general framework for HRA.

2.1. Prospective and retrospective analysis

The plant/system past history and specific working context affect the performance of operators and must be included in any HRA method. The evaluation of past history requires that retrospective analysis be carried out, by which it is possible to learn the lesson from past experience and real accidents.

However, as HRA methods are applied mainly in prospective type of analyses, a certain amount of creative thinking and estimate of likely evolution of accidents are required. The need to apply creative thinking is, thus, an integral part of a prospective study and must support the HRA application.

These two types of accident analysis, i.e., retrospective and prospective study, are complementary, but different forms of the same process which aims at assessing the safety condition of a system. Their commonalties and differences need to be clearly identified in order not to generate confusion (Fig. 2).

In practice, retrospective analysis is oriented to the identification of ''data and parameters'', which can be derived from a structured analysis that combines ''study of

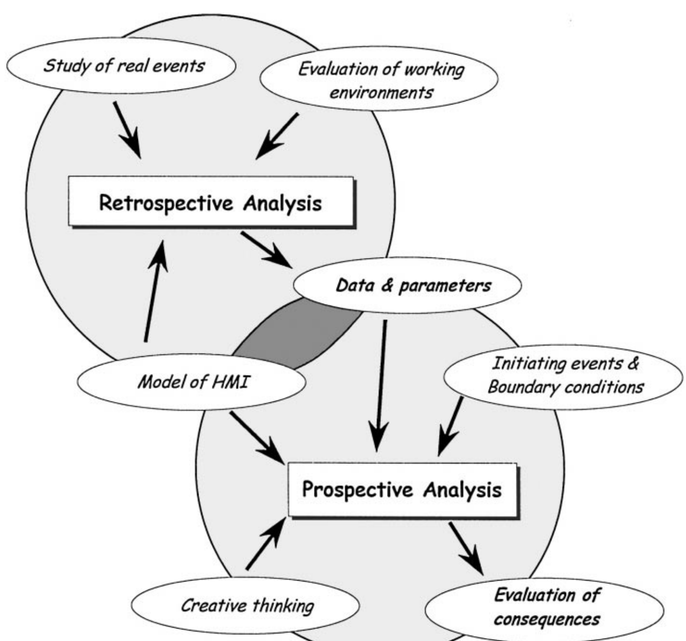

Fig. 2. Commonalties and differences of prospective and retrospective analysis.

past events'', observation and ''evaluation of working environments'' and ''models of HMI''. Such structured and formalised retrospective analysis must be applied almost normatively, defining well which type of data and info are to be obtained.

Prospective analysis aims at the ''evaluation of consequences'' and evolution of HMI scenarios, given selected spectrum of ''initiating events and boundary conditions'', and appropriate ''data and parameters'', predictive ''models of HMI'', and ''creative thinking''. The formal application of prospective analysis must also be structured and formalised, to a large extent.

The procedures applied for prospective and retrospective analysis bear certain similarities but contain also some important differences. The latter focus on the need for the analyst to understand how to make considerations for the prospective analysis based on the results of the retrospective study. The commonalties between the two approaches concern the HMI model and the identification of data and parameters. The former must include an error model and a predictive model of behaviour. The data and parameters are derived from the study of real events and evaluation of working environment and are applied for prospective type analyses. These common elements should be well identified, as they represent logical links between the two approaches.

2.2. Task analysis

The approach that is applied for collecting information on the tasks and procedures and for studying the working environment is based on formal task analysis methods. Task analysis was firstly developed in the 1950s, from the effort of attempting to formally decompose and describe overt human behaviour by a series of simple and elementary components [7]. The analysis of tasks is intended as a prerequisite for the assessment of the overall HMI, and offers a way to structure, by formal expressions, the envelope of procedures, actions and contextual facts characterising human behaviour in working environments.

As the role of operators has changed over the last decades, becoming mainly of supervisors than active actors, also the task analysis has been adapted to these new duties. From task analysis, the approach became the well known and much debated cognitive task analysis (CTA) [8]. Several methods exist for structuring CTA and for applying in practice CTA, so as to arrive at the expected results [3,9–11]. CTA plays a pivoting role in a process of information acquisition about the working environment, which is essential for the safety analysis and leads to the identification of relevant data and parameters (Fig. 3). This process is characterised by five main steps:

1. Preliminary selection of theoretical model and framework for HMI.
2. Definition of aims and boundaries of the analysis.
3. Cognitive task analysis.
4. Field study of working context.
5. Final selection of the theoretical paradigm of HMI.

In essence, CTA is the central step of an iterative process that follows the definition of aims and boundaries of HMI studies, and is instrumental for the filed study of real working context. By this iterative process, data, parameters, as well as simplifying hypotheses and assumptions are firstly ''guessed'' by engineering judgement and

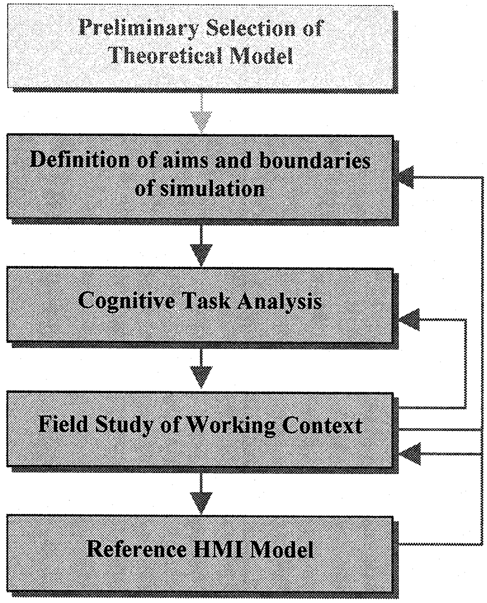

Fig. 3. Cognitive task analysis and field studies.

experience, then they are identified and progressively refined, leading to the definition of a model of human behaviour appropriate and acceptable for the specific HMI study at hand.

2.3. Data and parameters identification

Data and parameters for performing prospective studies are generated in many different ways, which relate to task analysis and to the retrospective study of past events.

More in general, input data, constant variables, parameters, and correlations between human, machine, and context can be gathered and collected in four general ways (Fig. 4).

- Data may be recorded from actual instances during human interaction processes. These data are collected in total absence of external observers.
- Data may be collected within actual working environments and organisations by direct observation of normal operations. This type of data can also be collected from laboratory experiments, with the obvious limitation derived from the use of a mock-up instead of the real working context and the advantage offered by the possibility to repeat the experiments.
- Data can originate from interviews and questionnaires at all levels of the organisation.
- Data are contained in mandatory and voluntary reports on accidents, incidents, and near misses.

All data collected and identified by the above techniques need to be classified in appropriate databases and are structured according to the HMI model which has been

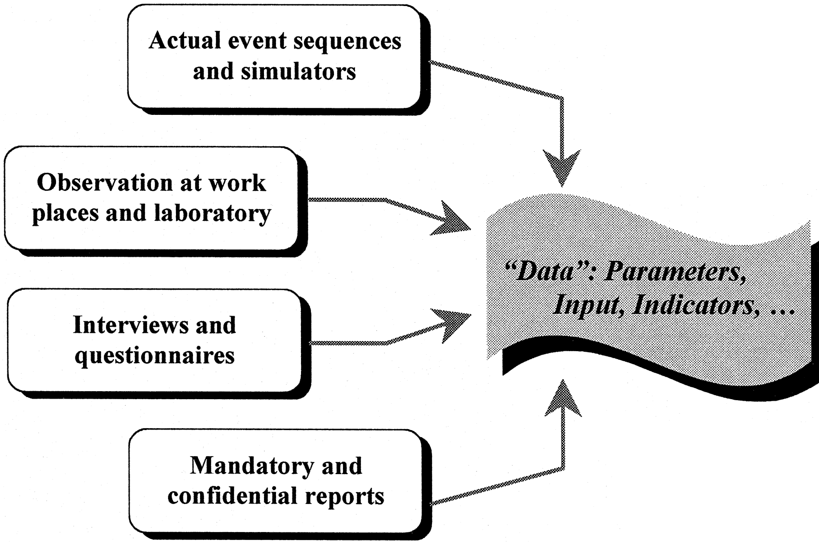

Fig. 4. Types of data for HMI analysis.

formulated and applied during the development of the task analysis. These data support the definition of important parameters, e.g., performance influencing factors, and of probabilities of human errors, that are utilised in risk assessment studies.

2.4. HMI modelling

The factor that ensures coherency between retrospective and prospective methods is the availability of common models or paradigms of HMI. These paradigms are coupled with equivalent representations of machine and working context to allow integrated studies, and make use of data and findings derived form the analysis of real events and actual working environments. A well-known and widely applied model of cognition is the so-called information processing (IP) paradigm, which assimilates human behaviour to the logical mechanisms of an information-processing device. For example, an IP model could be based on simple cognitive functions, like perception, identification, planning, and execution. These functions may be applied for simulation of sequences of cognitive and behavioural processes.

However, the application of the model to prospective and retrospective analysis needs to be differentiated. In retrospective study, the model is applied to real events, so as to identify the inappropriate activities that were not carried out according to expectations. These activities lead to the definition of root causes of the human errors. In substance, in retrospective study, the HMI model allows to associate errors to cognitive functions and contextual factors.

In prospective analysis, the same model is applied, so as to make use of the findings of the retrospective study. In addition, a certain amount of predictive power should be contained so as to allow consideration on accident evolutions and definition of safety measures.

2.5. Dynamic reliability modelling

There is one aspect of human reliability methods that needs special consideration: the question of dynamic reliability, or, more in general, the extension to safety assessment approaches that go beyond the classical FT/ET methodologies. Many researchers in the US, in Europe and other parts of the world, have debated the need for reliability methods that extend and overcome the limitations of FT/ET methods. In particular, the simple binary alternative of event trees and the dynamic aspect derived from the correlation between failures and physical behaviour of systems, sometime called dynamic reliability, have been tackled in many different alternative methods. These techniques have been mostly developed in relation to human reliability, but their arguments are equally valid and applicable to the system reliability assessment. Examples of these methods are the approaches discussed by Macwan and Mosleh [12] and Siu [13].

Fig. 5 shows an example of the type of results obtained by these methods: two different ways to represent time-dependency during an accidental sequence are presented, where actions (and system failures) occur at different times, in accordance with predicted evolution of HMIs. These types of formal representation correspond to two different methods proposed for considering the time dependence and allow to present human error events in a different form than the ''classical'' human error event tree.

The problem that arises, then, is that standard HET approaches match perfectly FT/ET formalisms, but do not consider dynamic interactions. On the other hand, dynamic reliability methods are very valid for considering time dependencies, but do not find an equivalent matching in overall PSA/QRA methods and can only be applied independently of all other analyses.

While the maturity of these techniques can be proven by the many and extended studies carried out by several authors on sample cases, their completeness and applica-

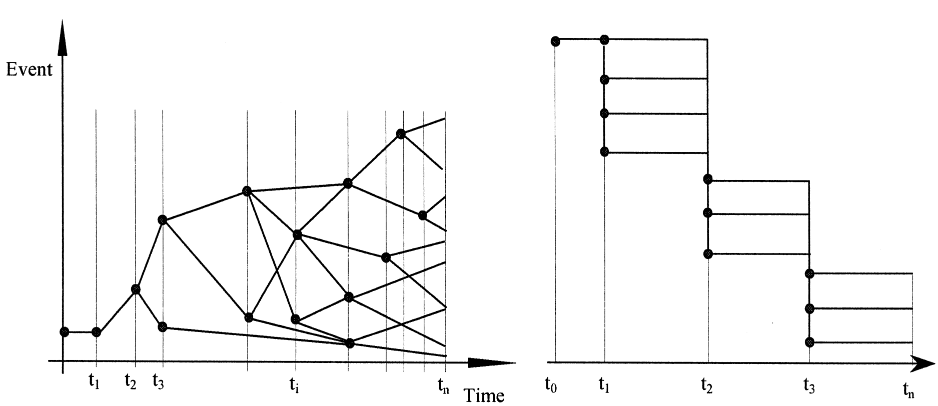

Fig. 5. Time dependent sequence of events.

bility to large scale analysis has never been fully evaluated by extended applications to overall PRA of real plants. These techniques have never been followed or sustained by more substantial efforts oriented to radical modification to PRA methodology, which is necessary in order to implement them in a structured way.

As human reliability methods have the objective of developing an approach that evaluates human contribution to PRA, they have to comply with the boundary conditions and limitations of PRA. It would therefore be irrelevant to apply dynamic reliability concepts in such methods, if they are not matched by equivalent efforts of modification of the whole PRA.

An area where these methods should be applied is the study of specific sequences or the analysis of special sub-systems of a plant, when a detailed representation of the system, its control procedures and mechanisms are manageable and equivalent analysis of human performances can be carried out.

3. Methods for risk analysis of HMI

3.1. Generic framework for HMI studies

The discussion carried out Section 2 concerned the development and definition of modelling approaches of HMI for safety and risk analysis. It is now possible to design a generic framework which identifies how specific methods and techniques have to be put into practice and should be coupled in order to reach the goals of each application. This generic framework is shown in Fig. 6.

The first steps of the framework cover the ‘‘analysis of working environment’’. This implies the performance of theoretical and empirical analysis that emphasise:

- The important data and parameters that may be utilised for the risk analysis;
- The procedures that show the most relevant human factors related aspects;
- The environmental and contextual (external) condition, as well as some personal (internal) factors, that may affect human error; and
- The actual manifestation of behaviour in performing tasks and control procedures.

This initial phase of the study may take quite sometime, as the analyst has to become acquainted with the practices as well as the policies that are implemented within an organisation and in a specific plant. The subsequent phase of the study requires the definition of reference models of human behaviour, system performance, and interaction between the two that is consistent with the field observations and previously performed analyses. These models represent the elements of coherent connection between ‘‘retrospective’’ and ‘‘prospective analysis’’. Retrospective analysis, as already discussed requires: (a) the structuring of accident in a temporal sequence of events and human inappropriate performances; (b) the application of a specific technique that combines human model, plant response, and associated classification of erroneous behaviours; (c) the identification of root causes of human errors; and (d) the actual data that may be fed to databases for use in prospective risk studies.

Prospective analysis requires the definition of the most appropriate technique(s), or approaches, for transforming models into computational tools and for defining the

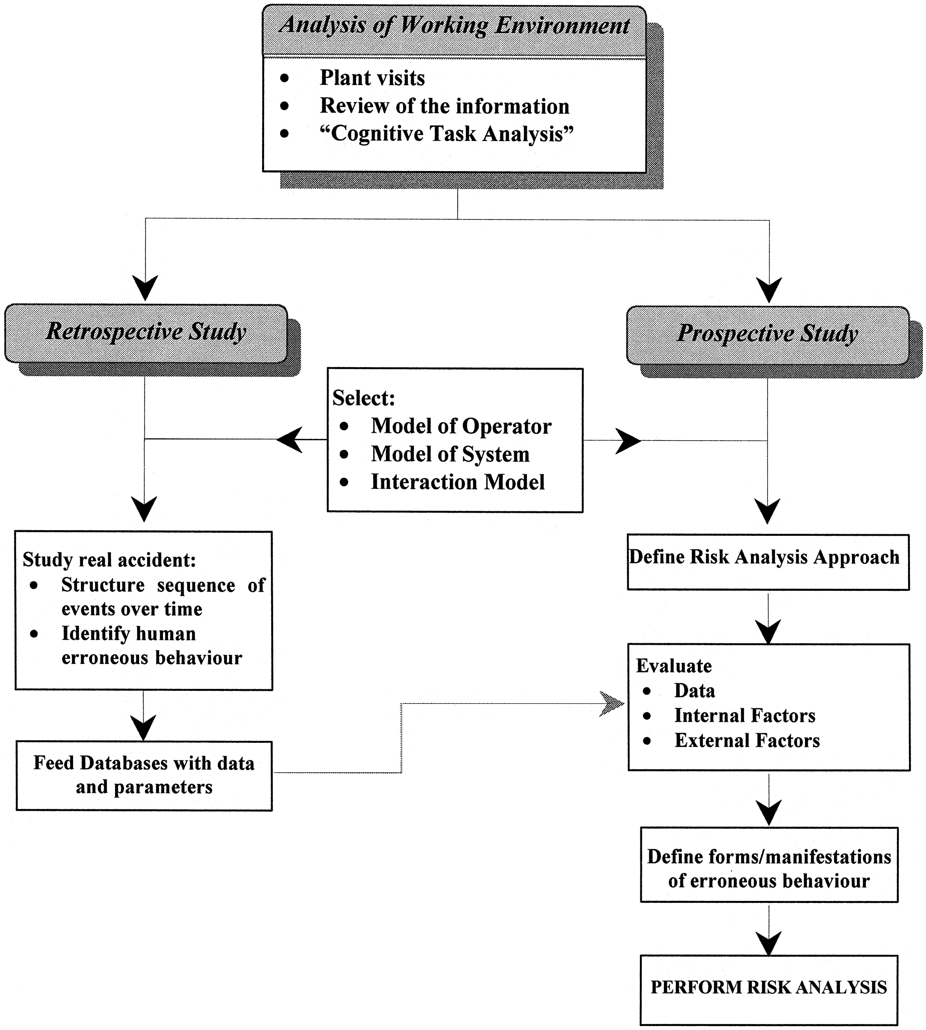

Fig. 6. Generic framework for human factors consideration in risk analysis.

structures by which to perform the risk analysis. Then, the data and factors that drive the simulation and represent the parameters affecting human behaviour have to be defined. The set of errors that will be studied by the simulation of HMI is then defined.

3.2. Classical and current methods for HRA in risk analysis

In the last 10–15 years of development of risk analysis methods, many studies have been performed and continuous research has been carried out in the area of HRA. However, while these studies were carried out, the engineering and safety assessment evaluation of real plant has been practically carried out by applying a number of methods, developed in the early 1980s, to support the quantification of human error and its application in PSA/QRA studies. These methods contain appropriate and applicable procedures and user's manuals [14] for the identification of the most appropriate data and the application of the methodology that leads invariably to the probabilities and uncertainty distributions associated with ''mission failure''.

As an example, the well-known method THERP [15] describes extensively and contains procedures to follow in order to identify all factors that affect human performance. In particular, the methodology requires that the analyst ''familiarises'', firstly, with the plant by visiting the control rooms, the actual plant, and all surrounding area. Then, it requires that a ''qualitative analysis'' is performed, by which plant control procedures are studied, and that extensive discussion with plant operators is carried out, so as to identify real working conditions, practices and customary attitudes of operators in managing the plant and applying standard and emergency operating procedures. These steps of THERP are instrumental for evaluating ''performance shaping factors'', ''dependencies'', ''level of uncertainty'' and effects of ''recovery'', which affect the ''basic'' human error probabilities and guide the construction of the HET.

This well developed procedure for application of THERP has been coupled with: (1) a database of basic human error probabilities, which contains a vast amount of probabilities associated with basic human actions; and (2) a number of analytical correlations that allow the modification of the basic human error probabilities in accordance with performance shaping factors, dependencies, and recovery.

These features and the existence of a database of basic human error probabilities have favoured the success and the widespread application of THERP.

The role assigned to operators in managing modern plants and the need to consider cognitive and organisational factors are the main reasons why new approaches have been studied and are nowadays under development. The generic framework that has been developed as result of the discussion on the basic elements for HMI in risk analysis can incorporate the new methods that exist and are currently being applied for risk analysis in different domains [16–19]. We will not develop here a comparison amongst these techniques, as this aim is outside the scope of the present work. However, we will compare the main methodological differences that can be identified between THERP, taken as reference approach of ''classical'' HRA methods, and the conceptual approach of ''modern'' approaches, based on the generic framework developed in the Section 3.1.

In principle, the conceptual differences existing between classical and current HRA methods are focused on two prominent points: (1) the methodology of analysis of working context and data evaluation; and (2) the approach for risk analysis and identification of mission failure.

3.2.1. Methodology of analysis of working context and data evaluation

When confronting the procedure for application of THERP for studying the working environment with the generic framework for human factors consideration in risk analysis (Fig. 6), at first glance, the differences do not seem so important. In both type of approaches (a) great emphasis is placed on ''familiarisation'' and understanding actual contexts in which operators work, (b) a database containing the relevant data and information for defining the probabilities of human erroneous behaviour is recognised as a necessary supporting element, and (c) the numerical quantification of mission failure is the final goal of the analysis.

However, in THERP the ''familiarisation'' was focused on behavioural activities, and did not demand a model of human behaviour, as the operator was considered as a ''machine''. Moreover, the analysis could easily be carried out by a safety analysis with engineering experience. In modern approaches this step (a) considers mainly cognitive and organisational factors [20,21], (b) requires a reference model of cognition and/or of group/organisation [22], and (c) needs to be carried out by a team of experts that include experienced operators, design/control engineers, work/cognitive psychologists [16,17].

These differences are very relevant and demand the development of new ways to approach the problem. However, as the general goals and structures of modern approaches remain unchanged with respect to THERP type approaches, one can argue that these methods represent ''evolutionary'' forms of HRA techniques rather than new approaches. In other words, the fact that cognitive and organisational factors have in fact replaced behavioural and individual aspects of operators is only related to new design concepts and new role assigned to operators, and, consequently these factors affect the ways in which the ''familiarisation'' process of THERP is carried.

3.2.2. Approach for risk analysis and identification of mission failure

When the approach for risk analysis and identification of mission failure is considered, then more substantial differences are identified. Primarily, the need to interface the outcome of the classical HRA methods with other QRA analyses implies that only a static approach is considered. This leads to the mission failure probabilities (and associated uncertainties) but does not expand the scope of the analysis to an accurate HMI study. Some current approaches, instead, promote the inclusion of dynamic reliability concepts as technique for performing the risk analysis [18,19]. In this way, the overall HRA approach becomes more complex, because it requires more calculation, more data, and more precise HMI simulation.

However, this offers the possibility (a) to exploit much more consistently the richness of data and parameters derived from the task analysis and from the study of working environment, (b) to evaluate the risk associated with the management of the plant not only for probabilistic assessment but also for design and training, and (c) to identify potentially dangerous sequences that was not possible to observe because of the intrinsic limitations of static analysis.

It is interesting to consider that in many modern plant, governed by high automation, many emergency operating procedures are independently started by protection and control systems and are implemented without any need of operator intervention or even consensus. In these cases, the role of the operator becomes very important in very special circumstances, when decisions about possible alternatives may be made, during the development of the process. In these cases, timing and dynamic evolution of the situation play a fundamental role and HRA contribution to QRA/PSA should be developed by applying dynamic techniques. A study in this sense has been performed and the need of applying dynamic reliability analysis vs. static approaches has been specifically identified [23].

4. Conclusions

The present paper has discussed the role of human factors analysis in the framework of risk analysis of a technical system. Whether the assessment is dedicated to a retrospective study of a real accident or to a prospective evaluation of a plant safety and protection system, the application of coherent methods is required to reach consistent and wide-ranging results. The generic framework that has been discussed is able to fit the most modern theories and techniques as well as the more ‘‘classical’’ and numerical approaches.

In the case of modern plants, the root causes of accidents and human errors, and, thus, the basic data for safety assessment can only be identified by the application of an accurate and structured method that accounts for the cognitive and social processes involved in the management of a system.

The other important area of innovation derived from the application of human factors analysis concerns the dynamic aspects of HMI. By dynamic techniques it becomes possible to consider specific sequences and accident paths that can not be screened by means of simpler static approaches. Moreover, the amount of information derived from accurate studies of socio-technical contexts is better exploited by dynamic analysis than by static ones.

Finally, it has to be accepted that the numerical outcomes of the study represent only one special type of outcome of the risk analysis. Other and more often deeper information, as well as, a different awareness of safety related issues can be obtained by non-numerical, i.e. descriptive, type of analysis. These cannot directly contribute to QRA as far as probabilities are concerned. However, they are very important in the development of other risk related analyses, such as in the case of development of SMS or for the evaluation of findings from an accident investigation and for assessment of the working context configuration and control procedures.

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