SIMULATORS IN NUCLEAR-REACTOR CONTROL-ROOM HUMAN FACTORS RESEARCH & DEVELOPMENT

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Abstract:

Simulator studies are powerfull means to know, design and manage the complexity of nuclear-reactor control, if they are, along with their scenarios, correctly designed for that purpose. This contribution to an international state of the art of the use of nuclear-reactor control-room simulators in human factors research and development precises the trends and novelties in the use of the results, in the theories and methodologies and in the construction of the simulated situations, i.e. in the conditions for an efficient use of the techniques of simulator design.

Keywords:

Complexity, Human Factors, Nuclear-reactor control, Simulator design, Simulator use.

INTRODUCTION

In 1985, it was perfectly reasonable for an overview of “ human factors aspects of simulation ” (Jones et al., 1985) to be practically entirely devoted to just flight simulators, and just military flight simulators at that. These days, it would be impossible not to also consider the nuclear industry and - though to a lesser extent - car driving, navigation, air-traffic control, processing industries, and even anaesthesia and surgery

Subsequent to a scan of the existing literature, discussions with some French researchers[1], some visits to Japanese, North-American and European research centres[2], we will go over the current trends in the use of simulators of nuclear-reactor control rooms for human factors research and development purposes. As we assist today to a transfer of notions and methods from the aviation industry to the nuclear one, we will consider also some influential studies using cockpit simulators.

Our presentation will be neither neutral nor detached. It will be based on what we have learnt from our own studies, mainly on nuclear-reactor control room simulators (Jeffroy et al., 1998) but also on navigation and driving simulators, and, more generally, on our experience in the construction and use of simulated situations in relation to course-of-action-centred design (Pinsky, 1992; Theureau and Jeffroy, 1994). This experience results in putting the emphasis, in this presentation, not on the techniques of simulator and scenario design, but on the theoretical and epistemological conditions for an efficient use of them.

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[1] René Amalberti (CERMA), Geneviève Filippi (EDF), François Jeffroy (CEA), Janine Rogalski (CNRS) and Thérèse Villame (Renault).

[2] Most of these visits were made in the second half of 1996 on the request of the Human Factors group of the Safety and Reliability Studies (ESF) department of the Research and Development Division (DER) of Electricité de France (EDF) as part of an “International state-of-the-art review on the use of simulators in hazardous industries for purposes other than training (Theureau, 1997 and Theureau et al., 1997). They concerned: Man-Machine Pyschology Unit, VTT Automation, Espoo, Finland (Leena Norros, Kristina Hukki et al.); Human Factors Program, Westinghouse Science & Technology Center, Pittsburg, USA (Emilie Roth, Randy Mumaw et al.); Man-Machine System Research, OECD Halden Reactor Project, Halden, Norway (Jon Kvalem, Erik Hollnagel et al.); NASA-AMES Research Center, Moffet Field, USA (Kathleen Mosier, Judith Orasanu et al). In what follows we refer to these entities as VTT-Espoo, Westinghouse-Pittsburg, OECD-Halden, and NASA-AMES respectively. A visit in Human Factors Department, Nuclear Power R&D Center, Tokyo Electric Power Company (TEPCO) (Tatsuo Muramatsu, Ryutaro Kawano, Yutaka Furuhama, Yasuo Wakabayashi, Minako Fujiie, Yuriko Yoshizawa, Keiko Mutoh), Kashiwasaki Kariwa Nuclear Power Station and BWR Operator Training Center Corporation, was made in September 1998. All these people gave unvaluable contributions to this reflection, but must not be considered responsible of its defects.

1. LIVING, SOCIAL AND CULTURAL COMPLEXITY

The interest of the use of simulators in research and development concerning nuclear-reactor control rooms stems from the necessity we have today to design and manage their living, social and cultural complexity. For that purpose, we must know sufficiently the underlying dynamics of this complexity. The knowledge of the deviations it shows from what is prescribed by the management helps to set up the problem but not the solutions. What do we mean by " living, social and cultural complexity " in matters of nuclear-reactor control? We characterize this way the system made of the control room, including its diverse operators. In fact, if we consider the control room, the classical definition of complexity (many elements and many different kinds of relations between them) is not sufficient. We need at least the Santa-Fe Institute definition: " systems with many different parts which, by a rather mysterious process of self-organization, become more ordered and more informed than systems which operate in approximate thermodynamic equilibrium with their surroundings " (Cowan et al., 1995). And it's itself not enough to take in account the presence of human actors who have the peculiarity to be autonomous, i.e. to behave at every moment in relation with a subjective view of the whole system, including themselves (their " situation at hand ") and who interact at this moment with elements of this situation which have been shaped as relevant by their past interactions up to that moment.

To be studied, such a living, social and cultural complex system can't be breacked up into simpler sub-systems to be studied apart from each other and aggregated afterwards to get the complex system. The reason is that complexity gives rise to important phenomena which can be missing in the simpler sub-systems studied separately. It doesn't mean that only natural control situations should be studied, which would result in a limited kind of hypotheses and validation. It means that, through systematic studies of natural control situations, that is of the real complexity to manage, hypotheses can be made which give way to the design of relevant simulated situations, less and less complex and easier and easier to manage, the study of which allows more precise hypotheses to be more thoroughly tested. It is not a matter of breacking up into simpler sub-systems, but a matter of building up simpler, then more manageable, but still relevant situations.

To study such a living, social and cultural complex system, one needs also, at least ideally, to practise both inductive and deductive method. Inductive methods proceed from data to concepts by descriptive generalization. Deductive methods proceed from an a priori mathematically organized view of the tasks to be performed to the concrete concepts describing the empirical systems. If one stucks to the first one, one takes risks of getting pure clinical analysis, that is poor generalization. If one stucks to the second, one takes risks of " misplacing concreteness " (Whitehead, 1978), that is of taking the a priori for the real, of finding in the real what one has put a priori in it.

With that in mind, we can now address the current trends of human factors simulator studies in the use of the results (section 2), in theories and methodologies (section 3), and in the construction of the situations simulated (section 4).

2. USE OF THE RESULTS

The results of the studies in full-scale simulators or in sufficiently rich and relevant part-task simulators, like those of studies in natural situations, are by construction, multi-uses: design of control rooms and of their organizations, devices and procedures (human-machine interfaces, paper or computer driven procedures, operation manuals); Probabilistic Human Reliability Studies (PHRA). Nethertheless, a few of these uses are dominant and increasing: (1) An increasing number of simulators studies aim at preventing potential negative effects of automation, following cockpit studies (Mosier and Skitka, 1996); (2) There still exist more Verification & Validation studies than studies integrated in the design process, in spite of the possibilities open by part-task simulators; (3) More interest exists in the improvement of training and certification; (4) More emphasis is put on qualitative aspects of human reliability analysis than on its quantative aspects; (5) Still a poor interest is expressed in testing from a human factors point of view the design of procedures, yet drastically changed and computerized in different ways all around the world since Three Miles Island events. We will insist on points (4) and (5).

Probabilistic Human Reliability Analysis

As the essential purpose of studies on nuclear power plant control room simulators is often to provide data for Probabilistic Human Reliability Analysis (PHRA), we will consider more thoroughly this point. Many studies continue to implement the conventional methodology initiated by A. Swain, which bypass the operators'cognitive activity (Miller and Swain, 1986). Different research and development teams tend to query the relevance of this conventional methodology in various ways. At VTT-Espoo, a recent objective of the psychological research group is to integrate cognitive analysis of control activity into the new stochastic dynamic model called the " marked point process " (Arjas and Holmberg, 1995). It matches well with the idea by which one should analyze the construction of the action and not model it in some way as a predefined sequence. At Westinghouse-Pittsburg, the human factors research group works upline of PHRA by implementing a checklist of cognitive task requirements produced from simulator tests (Roth et al., 1994). At OECD-Halden, one integrates a similar concern to a structured approach for contribution to PHRA, called CREAM (Cognitive Reliability and Error Analysis Method). The principle of the approach is to combine two interpretation methods, the first of which (" basic method ") is a logical progression of the customary behaviourism of PHRA, and the second (" extended method ") a logical progression of cognitivism (Hollnagel, 1998). Let us consider the second method. Through it, the sequences of events occured are interpreted in terms of the cognitive activity profile required by the task, and the errors likely to occur are determined (qualitative step). One then calculates a probability of failure (quantitative step). The qualitative step of this second method is a clear recognition of the kind of complexity which is involved in nuclear power control, or at least of a crucial aspect of it. It is likely to produce empirical and practical results without waiting for the quantitative step. This introduction of a qualitative and cognitive step before the quantative step is also present, but with the emphasis on the co-operation in the control room and the inspiration of the " socially-distributed-cognition " framework (Hutchins, 1995), in the French EDF project MERMOS[3].

Procedures

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[3] This project is developed by P. Le Bot, E. Desmares, C. Bieder, F. Cara and J.L. Bonnet.

In the nuclear field, procedures occupy a particularly important place and, since the Three Mile Island incident, new paper-based and computerized procedures have been developed throughout the world. In Japan, apart some guidelines for the supervisor in case of incident/accident, the operators still use their distributed knowledge about the procedures without any paper-based and a fortiori computerized supports. In France, computerized “ state-based procedures ” are now replacing “ event-based procedures ” for emergency operation. It is also planned for them to replace event-based procedures in normally disturbed situations in the future. In Westinghouse, a system of emergency procedures has been developed that combines rather than substitutes symptom-based procedures (developed along principles similar to state-based procedures) for event-based procedures. These different sorts of procedures have led to very few cognitive studies, particularly on simulators. Apart our own recent study (Jeffroy et al., 1998), the only study of this type that we can refer to was carried out at OECD-Halden when two support systems were compared (Hallbert and Meyer, 1995). These cognitive studies of procedures should be developed in the future.

3. THEORIES AND METHODOLOGIES

Much work is being done practically everywhere on innovation and development of data-collation and analysis methods. This work can be characterized by: (1) a reduction in the ambitions of cognitive simulation and a return to process-tracing methods; (2) a trend towards eclectism, that is the coexistence of heterogeneous or even contradictory theories and methods, and search for theoretical and methodological complementarities; (3) a tendency to go beyond traditional cognitive psychology by means of the still-confused notion of situation awareness coming from human factors research in aircraft piloting; (4) a tendency to consider cognitive aspects of cooperation within the control crew, with distributed computerized information, and to develop the corresponding methods and theories. All these trends or novelties are different ways to deal with the complexity of nuclear power control, and we will precise all of them. We must also point out an important issue only recently tackled in VTT-Espoo: the evolution of operators’ competence and confidence in the automated systems, which requires longitudinal studies and theoretical developments.

Reduction in the ambitions of cognitive simulation and return to process-tracing methods

Just a few years ago, cognitive simulation - computer modelling of control activity, based on a symbolic representation of the task and considerations derived from experimental psychology - was the lode star for simulator studies. It still is today, but instead of expanding, this perspective vanishes. For example, the series of studies by (Roth et al., 1994) was developed within a broader project undertaken by the Nuclear Regulatory Commission (NRC) to study the performance of the control crew during simulated emergencies and make a cognitive simulation of the cognitive activities involved. In a past series of studies, two variants of an ISLOCA (leak from the high pressure reactor coolant system to the low pressure residual heat removal system) were studied on a full-scale simulator. But generalization of the results of this study encountered many limitations: (1) solely ISLOCA incidents; (2) control crews made up of training staff and not actual operators; (3) only one crew for each ISLOCA variant; (4) control crews made up of two persons, and not the usual three to five. The simulated situation was far removed from a real full-scale situation as far as the composition of the control crew was concerned. Also, the cognitive simulation developed dealt only with certain of the cognitive activities engendered. It was therefore decided to develop a new, more extensive series of empirical studies with richer simulated situations. It was planned to at the same time develop the cognitive simulation, but it was decided to first focus on the empirical study because of the difficulties, cost, and time entailed. To our mind, this postponement implicitly reflects the relative failure of cognitive simulation in its current form, with respect to both knowledge of activities in complex dynamic systems and to design and management. We feel that at the moment use of this tool is of interest only if: (1) it develops in connection with a systematic analysis of activities and not on the basis of symbolic representation of the task and general considerations derived from experimental psychology; (2) it is restricted to modest objectives in both theoretical and practical terms. This is the case, for example, in collective activities in an emergency rescue service or in air-traffic control, as presented in (Pavard, 1994).

This limitation on the ambitions of cognitive simulation raises the problem of seeking out new channels for modeling obeying to a new paradigm of cognition, that is new deductive methods.

Waiting for the solution of this problem, at the moment it is leading to a renewal of what some authors call “ process-tracing methods ”, i.e. a kind of inductive methods. These process-tracing methods are related to the methods of French-language occupational ergonomics analysis, and more specifically to those of course-of-action analysis and their collective interlinking (Theureau and Jeffroy, 1994). This is not entirely fortuitous since, like course-of-action methods, they go back to (Newell and Simon, 1972) who, at the dawning of cognitive psychology and Artificial Intelligence as we know it today, developed a new - or at least renewed - fashion for validation of theories and models which stressed systematic description of verbal protocols collated at the same time as the activity was in progress and which gave a secondary status to conventional experimentation and statistical analysis. The essential instruments of this kind of validation were the problem-solving graph and computer simulation, the ancestors of process-tracing methods and cognitive simulations. The decline in the ambitions of cognitive simulations results in process-tracing methods being reinstated to a position they had lost since (Newell and Simon, 1972), except in certain French-language research in ergonomics. Let us look at another example of development of process-tracing methods: the “ realistic ” approach developed in studies by VTT-Espoo research group on a full-scale simulator. As is explained in (Hukki and Norros, 1994), the approach is contextual (including the social situation), dynamic (acts are not considered as isolated events) and subject-centred (the operators'point of view is considered to be essential). The researchers speak of situated activity or socially constructed activity, or quite simply of activity in the sense of (Vygotsky, 1978). Today, therefore, the main references in the psychological litterature that interest these researchers are those which are associated with an effort to set up process-tracing methods (Klein et al., 1993; Harré and Steams, 1995, Smith et al., 1995). Similar process-tracing methods are developed in the ANACONDAS project at EDF (Filippi et al., 1998), in line with French-language occupational ergonomics analysis (Theureau and Jeffroy, 1994).

Eclecticism and searching for theoretical and methodological complementarity

Eclecticism - the coexistence of heterogeneous or even contradictory rationalizations - has been frowned on in academic world since the philosophical debates of the 19th century. Indeed, if one looks no further, eclecticism can be a major hindrance to research. But if it is considered that it reflects both recognition of a complexity and the limits of the methods and theories available for controlling this complexity in a given scientific and technical conjuncture, eclecticism is certainly to be preferred to dogmatism, from the points of view of the future and of the resolution of immediate practical problems.

Let us examine, for example, (Amalberti, 1996) on the control of hazardous situations. This author proposes to link two models, an “ understanding/action model ” dealing with control activity, and a “ contextual control model ” dealing with in-depth defences which make it possible to accept the initial risk and/or to check that the accepted risk does not degenerate into loss of control. But he also proposes to at the same time consider a “ pot pourri ” combining “ workload ”, “ stress ”, and “ fatigue ” for which - quite rightly - he is careful not to formulate any kind of model.

Similarly, in nuclear-reactor control-room simulator studies carried out in OECD-Halden, experiments were run with a range of different methods based on different concepts between which the links were tenuous or non-existent. This is the case of many cockpit and nuclear studies and - it must be stressed - the case of those with the greatest ambition and the closest connections with the practical problems of design.

This eclecticism is expressed as a principle in the current programme of tests on a Japanese nuclear simulator (Kijima, 1993). In the Japanese research, as in most of the research in the nuclear field in other countries, Rasmussen's “ model ” is used to classify the data of verbal protocols (Kawano and Fujiie, 1996), or to isolate certain phenomena within the overall activity (Salazar-Ferrer, 1995), because of its heuristic value, certainly, but above all because of the few constraints it implies to the use of other theoretical imports.

We would point out that eclecticism often rhymes with consideration of new problems. This is the case for the night-control simulator studies which are starting to be carried out at OECD-Halden (Morrisseau et al., 1996) and those carried out recently for the US NRC (Baker, 1995). It is also the case for simulator studies of co-operation and collective aspects of control activity (Hallbert and Sebok, 1996).

It should also be noted that each moment of scientific progress builds on the sediment left by previous steps. Thus, with regard to the reactor emergency-control study in Japan, things went from behaviourism (phase 1, 1984-1986, centred on the notion of human error) to cognitive psychology (phase 2, 1987-1989, centred on clarification of cognitive processes), then to social psychology (phase 3, 1990-1992, centred on the relationship between communication and control-crew performance). Today, notions and methods derived from these three theoretical and epistemological paradigms coexist (Kijima, 1993).

If today's buildup of heterogeneous methods and notions requires clarification, the same applies to most of these methods and notions individually. This is the case, in particular, of the notion of work load and of methods for assessing it, be they objective or subjective. As will be seen in what follows, it is also the case of the notion of situation awareness and its evaluation methods.

The conquests of situation awareness

The notion of situation awareness (SA) that came into being in cockpit studies is invading the nuclear field. It has become emblematic of the presence of man in highly automated technical systems. Still, situation awareness is unanimously considered to be a vague notion which has multiple definitions and gives rise to multiple complementary or alternative methods (Garland and Ensley, 1995). The definitions that follow are just two chosen from a multitude of others because of their radical theoretical heterogeneity: “ the condition of the knowledge of the persons or the mental model of the situation around them ” (Ensley); “ dynamic cognitive coupling of an agent and a situation ” (Flach). According to other authors, situation awareness is thus: “ a concept for aggregation rather than for analysis ”; “ too clear, too holistic, and too attractive ” a construct about which one might wonder if its utility compensates its complexity ”; a “ default construct ”, i.e. that we appreciate most when it is absent (“ when someone loses his situation awareness, the result is a crash ”). Some authors stress the “ family resemblance ” between the notion of situation awareness and that of work load, especially mental work load : same fuzziness, same practical necessity in the absence of better established notions, same measurement problem. In fact, the notion of situation awareness reflects both the incapacity of traditional cognitive psychology to answer the practical questions of control of complex dynamic systems, and the efforts to go beyond this traditional cognitive psychology, whereas no alternative has yet fully asserted itself. Its fuzziness is evidence of a scientific crisis that has not yet been resolved, but its very existence evidences the need to give the designers of complex dynamic systems if not clear criteria, then at least a principle concerning the relationships to be established between human operators and automatic systems: maintain the situation awareness of operators. It is therefore worth examining what can be done to clarify this notion.

In (Sarter and Woods, 1991), a preliminary clarification of the notion is made by showing that it cannot be the equivalent of " effective conscious knowledge ", for " that would suggest that only the information in work memory could be considered to be aware ", and by considering that " any definition of situation awareness must refer to the information that is available or that can be activated, when it is relevant for evaluating a situation and dealing with it ". If one agrees with these authors, the notion of situation awareness can be assimilated to that of potential actuality proposed in the course-of-action theory (Theureau and Jeffroy, 1994; Jeffroy et al., 1998) as part of an human cognition paradigm alternative to that of " man as an information-processing system " most authors dealing with situation awareness continue to refer to. The definition of potential actuality is close to Flach's definition of situation awareness mentioned previously. The potential actuality at a given moment is considered as a set of expectations selected and structured by the " agent's involvement in the situation " at that moment among the expectations produced by the past course-of-action. This " agent's involvement in the situation " is itself the product not of the situation at hand but of the entire course-of-action up until that point. The notion of potential actuality is thus built up in a way that is strictly the converse of the usual notion of situation awareness. Along this usual notion of situation awareness, what comes first is the situation independently of the person involved or agent, whereas along the notion of potential actuality, what comes first is the involvement in the situation inherited from the past course-of-action, independently of the instantaneous situation.

This divergence between the current notion of situation awareness and that of potential actuality has important methodological consequences. If the situation does indeed come first, a method for documenting situation awareness which involves freezing the simulator at certain times during the scenario and asking the operators to answer a questionnaire on the situation is legitimate. If, on the other hand - as in the course-of-action theory - the involvement in the situation comes first, this sort of intrusion into the control activity changes radically this involvement in the situation and is incapable of producing data reflecting the potential actuality. Potential actuality can only be reconstructed indirectly, through analysis of the control activity, that is through process-tracing methods.

The freezing method is used in the SACRI (Situation Awareness Control Room Inventory) method, as part of the OECD-Halden international research and development programme, which adapts to the nuclear power industry the SAGAT method (Situation Awareness Global Assessment Technique) developed in cockpit studies. On the contrary, in (Roth et al., 1994; Zsambok and Klein, 1995), the question of situation awareness is re-examined following (Klein, 1995). These authors propose to study situation awareness through the control activity, i.e. in the same way as one studies potential actuality, by process-tracing methods.

Discovery of cooperation

Problems of cooperation in aircrews, as in nuclear-reactor control crews, are increasingly being dealt with on simulators. This is the case of the Japanese nuclear simulator test programme (Ujita et al., 1995; Kijima, 1995). It is the case in the OECD-Halden international programme (Hallbert and Sebok, 1996) and in the Westinghouse-Pittsburg programme. It is also the case in different cockpit studies (Rogalski et al., 1994; Smith et al., 1995). Some of this research into collective activity develops evaluations of the situation awareness of the crew as well as of its individual members (Prince et al., 1995; Zsambok and Klein, 1995).

Despite the difficulty of addressing collective phenomena from the point of view of conventional cognitive psychology, the principle of which is “ methodological individualism ”, these studies do not generally develop new theoretical notions, and restrict themselves to eclectically aligning individuals and groups, individual cognitive psychology and non-cognitive social psychology. A good example of this trend is that of the research by Salazar-Ferrer (1995): to an innovative cognitive analysis of the reasonings of operator diagnosis is added an analysis of the co-operative activity of the operators, which is restricted to a statistical study of communications that eliminates any consideration of their dynamics and of their relationship with the dynamics of the activity as a whole. We would wish, however, to draw attention to a series of studies developed since 1991 by E. Hutchins and his colleagues on different full-scale flight simulators which suggest, in line with (Hutchins, 1995), a new approach in terms of “ socially-distributed-cognition ” which is both social and cognitive.

4. CONSTRUCTION OF THE SIMULATIONS

Studies of human activity using simulators run into the problem of what it costs to conduct them, the problem of integrating them into the process of designing new systems, and the problem of relationships between the simulator and its scenarios and real situations. We observe: (1) More and more use of part-task simulators, more and more rich and flexible and less and less expensive, due to the progress in computer techniques, in order to test alternative design options; (2) More use of usual training or certification simulated situations, with methodological cautions and limits and a consideration of training design issues; (3) More linkage of incidental/accidental simulator studies with retrospective incident/accident studies; (4) A growing but still modest interest for the study of natural, normally disturbed, situations, in order to insure a better relevance of the simulations and to know better the transfer made by the operators from the situations they usually live in to incidental/accidental situations; (5) A tendency to build simulation scenarios from theoretical hypotheses concerning control activity, and not only from practical and empirical hypotheses. We will insist on trends (1) and (5), due to their epistemological and practical consequences.

Full-scale and part-task simulations

When people talk of simulators, they usually mean an ideal simulator, a full-scale one. The point of part-task simulators is to represent another ideal fulfilling another function. For example, at the NASA-AMES aerospace research centre, part-task simulation begins when pilots are not put in an exact replica of a real cockpit that reproduces the accelerations and movements of the actual aircraft. From this point of view, the HAMMLAB nuclear-reactor control room simulator of the international OECD-Halden programme is a highly sophisticated part-task simulator. What is new is less the reality of part-task simulation (it might be said that traditional human factors studies concern situations of this type) than the very notion of part-task simulation (as a simplification and reduction of full-scale simulation and not as a complication of psychological experimentation) and the fact that today's information-technology brings part-task simulation closer to full-scale simulation. Several considerations lead to studies being carried out on part-task simulators. The first two are the interconnected considerations of cost and integration into the design process: a part-task simulator costs less and is more quickly designed, transformed, or enhanced with new systems than a full-scale simulator. It therefore allows for easier comparison - from the point of view of control activity - of design alternatives for such new systems. The other considerations are of an theoretical and epistemological nature, and imply two parallel orientations.

The first orientation arises explicitly or implicitly from a recognition of the living, social, and cultural complexity. For the supporters of such a theory and epistemology, natural situations do not simply add complications to experimental situations. As we have written in the first section, they add complexity and thus engender cognitive phenomena, some of which can be radically different. The resulting method for acquiring scientific knowledge of these cognitive phenomena starts from studies in natural or close-to-natural conditions (particularly when, as for certain emergency situations, it is absolutely necessary to use the simulator) in order to determine the cognitive phenomena involved. It works towards studies on part-task simulators especially designed to examine these cognitive phenomena more precisely and better validate them, but the pertinence and validity of these studies depend on the first studies. In the context of this recognition of the living, social, and cultural complexity, both full-scale and part-task simulators take on a scientific function instead of just a practical function or a role as ill-adapted substitutes for experimental situations in the laboratory.

The second orientation arises out of a theory (implicit) and epistemology (explicit) of “ Lego ” (internationally reputed children's building-block game) by which complexity is considered to be both capable of and having to be attained by putting together simple elements - or generic concepts of what is simple - produced by the laboratory situation studies. Part-task simulation is then thought out in relation to the ideal of laboratory experimentation. It is no longer thought out from the point of view of simulation. This is similar to traditional human factors studies. The only difference between a part-task situation and a laboratory situation, from this point of view, is that because of the practical interests involved, researchers benefit from greater material resources than if they were to remain in their laboratory.

A large number of studies on part-task simulators encountered in the literature result from this second orientation. Their scientific interest is secundary relative to rigorous experimental procedures in the laboratory and field studies, full-scale simulator studies, or sufficiently rich part-task simulator studies developed from the simulator point of view. Nevertheless, their practical merits are not to be overlooked. They help demonstrate the interest of developing part-task simulators for integration of human factors into design processes. Their results can be re-interpreted in connection with a theory and epistemology of complexity in relation with rigourous studies in the natural situation or on full-scale simulator. On the contrary, the researches of the Westinghouse-Pittsburg group are along the first orientation (Roth et al., 1994). At OECD-Halden, both orientations co-exist. In summing up 10 years of test and evaluation studies in (Folleso and Volden, 1993), it is considered that a high degree of realism was attained, to the detriment of systematic control of the experiments, and therefore suggested reducing realism in order to increase control, starting with the less realistic and more controlled studies in order to “ demonstrate effects of vital aspects of the system ”, and then using more realistic situations to more broadly test the validity of their hypotheses. On the contrary, in (Kvalem et al., 1996), it is suggested to put “ less stress on well controlled experimentation and more on simulated field studies to analyze complexity ” as a long-term prospect for the use of the HAMMLAB simulator.

Design of simulation scenarios

It is commonplace to design the simulation scenarios in order to test practical and empirical hypotheses, such as the hypothesis of performance improvements due to a given system, or various organizational arrangements for the control crew. What is new is the trend to build scenarios from theoretical notions in order to test theoretical hypotheses regarding control activity, and not only practical and empirical hypotheses. This trend is seen in certain full-scale simulator studies and in most of part-task simulator studies, both in those that tend to stick close to the epistemological paradigm of Lego and those that - more or less implicitly, it must be said - consider part-task work from the simulator point of view, therefore in relation with the paradigm of living, social, and cultural complexity. The series of studies by (Roth et al., 1994), for example, dealt with two variants of ISLOCA (Interfacing System Loss of Coolant Accident) and two variants of LHS (Loss of Heat Sink) with eleven complete crews of real operators for each event. The model of cognitive activities linked to operator behaviour in the emergency situations involved comprises two components: situation assessment and response planning. Situation assessments are the building-blocks of the situation awareness (see above). Response planning corresponds to the decision to take a course-of-action, bearing in mind a particular situation assessment. The two ISLOCA variants were especially designed to make the situation assessments difficult. The objective was to create situations in which the control crews would have to identify and isolate the breach without explicit guidance. The emergency procedures did indeed include ISLOCA procedures, but it was possible to create situations where the control crews could not find the ISLOCA procedure through the network of emergency procedures. The specific dynamics of the event led the operators to a LOCA (Loss of Coolant Accident) procedure. As for the two LHS variants, they were designed to be demanding in terms of both situation assessment and response planning.

Testing theoretical hypotheses and not only practical and empirical ones on simulators is properly speacking making scientific research on simulators, that is creating the conditions for the development of effective and innovative practical and empirical methods.

CONCLUSION

Such trends in the use of the results, in the theories and methodologies and in the construction of simulated situations, leave room to an use of the techniques of simulator design in matter of knowledge, design and management of the complexity of nuclear-reactor control which will prove more and more efficient in the future.

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