

# Analysis and Models of Operators Activities in Complex Natural Life Environments\*

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## 1. Activities, Operators, Environments

### 1.1. Delimitation of the Domain

The domain of ergonomic studies explored in this paper is intentionally limited in accordance with the three following assumptions: (1) Operators actual activities have to be distinguished from the tasks they are requested or supposed to perform; (2) operators working in natural life environments have to be distinguished from anonymous and universal human beings; (3) complex natural life environments have to be distinguished from the interfaces, as the whole has to be distinguished from one of its parts.

As an inference from (1), this paper will not review the numerous and interesting papers concerning the analysis and modelling of tasks (a recent review on task analysis is presented by J. Algera, 1988). As an inference from (2), this paper will not review the innumerable papers, mainly in cognitive psychology, and more generally in cognitive sciences, concerning the “basic mechanisms” of human beings. As an inference from (3), this paper will not review the large quantity of papers concerning the domain of “Human-Computer Interaction», where the “human” is often some “naive user” confronting an “interface”.

Concerning this delimited and limited domain of activity analysis, this paper is led to quote

more European references than American ones, and among the European, more French-speaking (French and Belgian) ones. The geographical and historical specificity of this French-speaking orientation is commented on by De Keyser et al. (1988), and in French by De Keyser (1988b). Concerning more or less directly the same domain, one can quote also the following books or general articles, in English: Goodstein et al. (1988); Hollnagel et al. (1986); Montmollin and De Keyser (1986); Rasmussen (1986); Rasmussen et al. (1987); Wisner et al. (1988); and in French: Daniellou (1986); De Keyser (1988); Hoc (1987a); Leplat (1985b); Montmollin (1986b; 1990); Spérandio (1987; 1988); De Keyser & Van Daele (1990); Amalberti et al. (1991). The journal, *Le Travail Humain* (largely in French, edited by J.-M. Hoc) is regularly publishing articles and special issues concerning this topic (e.g. De Keyser, 1988a; Hoc & Visser, 1988). The other references in this paper do not pretend to constitute an exhaustive review of the published studies; they are given as typical examples.

The three distinctions mentioned earlier will now be briefly developed.

### 1.2. Operators Exist

In ergonomics, cognitive engineering, and related areas, the very large majority of published studies are not empirical but apodictic and

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\* NPP = Nuclear Power Plant (nota do editor)

normative. When studying a work situation (the operator in the control room of NPP\* or a refinery, the clerk in a bank, the pilot of a fighter plane ...), the model of the operator in this situation is, indeed, built following the requirements of the task the latter is asked to perform. These requirements are generally derived from technical documents concerning the machines, the processes, the organization; from statistical data concerning performances when accessible; and from interviews with the operators and the hierarchy. The result is a model of the ideal operator, "designed", or rather imagined by the analyst, as a part of the work situation designed by the engineer. This model could be implemented (and sometimes actually is) in some automation, or expert system, when the same objectives can be reached by replacing the operator in the system by some non-biological component. Occasionally, and in any case after its design, this normative model is validated by comparison with the actual behaviour of the operator. But in reality it often appears that it is the human behaviour itself which is "validated", and assessed as "normal" if in conformity with the prescribed behaviour.

The overwhelming conclusion of all the ergonomic studies of work analysis studies which, in contrast to the normative ones, try to model the natural activities of the operator, is that these activities never conform to the prescribed tasks. This is also true, and perhaps particularly so, for the successful operators. The rationalistic and optimistic conception of F. W. Taylor, and of his modern followers, splitting the work into preparation (by the engineer) and execution (by the operator) actually succeeds only if the operator is intelligent, and not only obedient; that is, if by heuristics, technical cunning and personal adaptive competency, the operator controls the natural situations, which never seem to occur exactly as they were supposed to.

Nevertheless, Taylor and his modern followers are not completely wrong. The chemico-physical

processes, and the administrative ones as well, are rational, and no industry survives without strong normative constraints concerning the tasks. Operators are not just free artists. Indeed, they always have to adapt their activity to at least some of the characteristics of the prescribed tasks, as they were designed by the hierarchy, but (fortunately) they also exist by themselves - they do not just blindly follow the prescribed procedures. Prescribed tasks cannot be considered as dogmas, but they can serve as guides. In fact, the objectives of the tasks (production, quality, security, etc) cannot be reached without some organizational constraints, nor without the personal contribution of operators. In short, real work is a dialectical interaction between normative tasks and intelligent activities. Thus, in this perspective, there is no relevant work analysis without analysis and modelling of the operator's activity.

Such an interaction also works at the methodological level: models for analysing operators' activities can sometimes be "borrowed", as tentative models, from the normative task domain. Work analysis is empirical.

On the distinction between task and activity in ergonomics, see Leplat and Hoc (1983); on performance models, see Roth and Woods (1988); a good example is given by Visser (1988), of the actual opportunistic organization of the activity as deviation from the theoretical plan.

### 1.3. Operators are Operators

Operators are not to be considered as universal human beings, whose universal characteristics and limits could be discovered and measured from any *homo sapiens* (for instance an undergraduate student), allowing the construction of general "laws". This assumption is derived from the great difficulty in practice of reducing always very specific and complex work situations to a limited

number of components, which could be universal enough as to explain, by re-combination, all the possible diverse situations. It is derived also, and particularly, from the symmetrical empirical impossibility of reducing the always specific complex activities, that is the local “stories”, to a limited number of universal broad characteristics, which could be relevant for the description of all the possible diverse working “stories”. In short: activity analysis is more oriented towards time than typology. Thus, ergonomic activity analysis here is less ambitious - and less easy. It is not like the “Lego basic box”, which allows a child to build an unlimited number of objects with a limited number of basic building blocks.

This mistrust about the universal models is primarily concerned with the old-fashioned topologies of aptitudes and capacities, as established by differential psychology. But this mistrust also concerns the cognitive models now in fashion, issued from the cognitive psychologists’ flirtation with cognitive scientists in the area of Artificial Intelligence (AI), particularly Expert Systems. These models - for instance describing “the structure of knowledge” - are attractive, but for the analysis of local particular operators’ activities, they are just hypothetical suggestions.

The methodological conclusion of this assumption is that ergonomic analysis and modelling of activities cannot be anything but natural field analysis, in an ecological perspective. Laboratory experiments are considered here as analysis of the experimental situation itself, and nothing else. Experimental situation is almost never real work situation. Therefore, data from laboratory experiments are useful, but in the same way that data concerning the behaviour of monkeys in cages are useful for the explanation of the behaviour of wild monkeys in the wild.

There is no industrial environment where workers have to solve the Tower of Hanoi problem eight hours a day, every day, and get paid for it. Time is considered differently as well: minutes and hours are considered in laboratory experiments, whereas weeks, months and even years are relevant in natural situations. In the laboratory, complexity has to be avoided to allow for the control of very few independent and dependent variables; in contrast, complexity has to be respected in field work<sup>1</sup>.

That is never easy. Thus, whenever possible, full-scale simulation is an acceptable compromise, because the objective is to insert into the simulated system as many independent variables as possible, which nevertheless can be partially controlled (an opportunity seldom possible in a natural situation). Meanwhile some “field experiments” are sometimes possible, but mostly in the domains where costs are less relevant (e.g. NPP, aviation).

In this context, there is no such discipline as “applied ergonomics”<sup>2</sup>. Models and theories are required to cope with experienced operators working in natural complex situations. But what about the requirement of “scientificness”, if the analysed situations, and the corresponding activities, are so complex, specific, and local that any generalization of the results is practically impossible? Unfortunately, generalization in this domain is only possible at a relatively high level of abstraction, resulting in a proportionally low level of effectiveness. That is the reason why ergonomists dealing with activity are at a loss when they have to speak about the results. Any discourse is generalization, and, in any case, the problems they have to cope with are, more and more, problems of (re)design and the transfer of technology, which requires at least some generalization. The provisional answer to this

<sup>1</sup> For technological and economical reasons, the fields studied by today’s ergonomics are unevenly distributed: Process control (from Nuclear Power Plants to bus traffic), office automation, or computer programming are on the whole better represented than rural, artistic or managerial occupations...

<sup>2</sup> That does not mean that the journal *Applied Ergonomics* is not an excellent one!

contradiction is that the format of the models and methods can be partially generalized, but the content and data themselves cannot - except very cautiously.

Concerning simulation, laboratory experiments, and field studies, see Bisseret (1988); Funke (1988); Leplat (1982); Lewkowitch (1988); Montmollin (1986a); and Moray (1986).

#### 1.4. Operators do not Work with Interfaces Alone

The best-known example of ergonomic/human factors realization - at least in advertising - is still the chair. It is of course essential for any operator, from the office clerk to the fighter pilot, not to be hampered by a badly designed chair. But what about the operator's work, or more precisely, activity? That person's task is not to be seated, but to write, for example, an administrative report, or to fight hostile aircraft. The chair is only one part of the whole "work situation" which includes, hardware such as the displays, or software such as the meaning of an alarm, or even the "programs" operators are constructing for personal use.

Interfaces presenting information (e.g. VDU), are certainly more important today than chairs. A large quantity of studies devoted to their design concern the physical dimensions (e.g. contrasts on the screen), and the psychological ones as well (e.g. format of information on the screen). But, as in the case of a chair, the question here is: Interfaces for what? Experienced operators are not naive users who have to be convinced to buy or to use a friendly microcomputer; they are people who have to solve problems not directly concerning the interface, but rather, a complex environment, for instance an unusual incident in a chemical process, or a conflict between the planes above an exceptionally overcrowded airport. Natural life environments cannot be reduced to interfaces, even when interfaces are the only windows between the operator and the environment (which is seldom the case). The more complex the environment, the more this

ecological approach is relevant.

Concerning what they call the "natural problem solving habitat", E. M. Roth and D. D. Woods (1988 p.41), identify "the three mutually constrained factors: (1) the problem-solving (or cognitive) demands imposed by the world to be acted on; (2) the capacities and architecture of the agent or agents who act on the world; (3) the external representation through which the agent experiences that world". This "external representation" is, in this instance, clearly a representation of something for someone for the purpose of something.

This conception of interfaces as interfaces *only* is particularly relevant when analysing the work of operators in process control. In these settings (e.g. NPP, chemical plants, refineries, steel factories, etc), the process itself cannot be directly observed by the operators. The information they need for their activity is artificially coded, and displayed on walls and, recently, on additional screens. The display of information is generally more or less analogical with the physical process itself, that is, the "machine" in the man-machine system. If "sophisticated" engineers try to "facilitate" (in their opinion) the work, by transfer to the screen(s) of the totality of information, which moreover is modified and interpreted by some intermediate software, it could happen that for the operator the task is no longer the control of the process, but more the interpretation and control of the interface, which becomes the "object" of the operator's work. This is not always the best solution!

On this "irony of automation", see Bainbridge (1983); Guy and Lejon (1988); Hellman (1988) "abandoning the plain surface"; Kasbi (1988); and the section "Ergonomics in informatics: Contribution from work analysis" in Patesson (1986). A critical analysis of the HCI paradigm is presented by Carroll (1989).

## 2. Analysis and Modelling of Operators' Activities

As a consequence of this severe limitation of the domain (specific local activities of operators working in specific local complex environments), the empirical studies we can now rapidly review cannot be structured as if some metamodel could allow elegant generalizations. The state of the art is at present, better described as a catalogue of roughly gathered "cases" than as a coherent theory about some general cognitive laws. Nevertheless, broad categorization of models of operators' activities can be suggested. These models are not alternative; they can often be used simultaneously.

The main distinction proposed here is between: (i) models of individual or collective cognitive processing activities, overt or covert, which convey the operators along temporal paths, from one state to another in the "stories", or "scenarios", which are constructed by their interaction with their working environment, and (ii) models of the acquired cognitive structures, or competencies (knowledge, know-how, meta-knowledge, etc) hypothesised by the ergonomist in order to explain the processing of information, both individual and collective.

As human error is nowadays a crucial topic in ergonomical analysis, it will be treated separately, by way of conclusion.

### 2.1. Cognitive Processing Activities

Operators reason, that is, they control their actions. They make inferences, starting with a "sign", or some meaningful information, and ending with a conclusion, or "decision". What are these "signs"? What significance is given by the operator to the many bits of information flowing from the environment to the mind? Any particular significance is always given in relation to a task, that is, to the constraints the operator will have to cope with. How, if any, can we identify these

"starting signs" and the final "conclusions"? Is the operator's reasoning split by goals and sub-goals? In other words, what are the models of the "course of action", for the very minute analysis of this "semiotics of working activities", or succession of events and actions, with a sophisticated accent on the meaning (for the operator) of these events and actions? (On this topic, see Boel & Daniellou, 1984; Pinsky & Theureau, 1987a, b; Theureau, 1991; Valot & Amalberti, 1989.)

Among the diverse models of, or approaches to, operators' cognitive activities, correlated with the diverse objects of work analysis, the following seem the most frequently used:

(i) Models centred on diagnosis and problem-solving: (Alengry, 1986; Bainbridge, 1984; Fichet-Clairfontaine, 1985; Hoc, 1987c; Housiaux, 1988; Navarro, 1987; Samurçay & Hoc, 1989). In industrial and administrative natural situations the interesting thing is actually not the "problem solving", but the "problem setting" activity (if the problem is clearly defined, there is some predetermined procedure for solving it). In other words, the very challenge is the construction of the problem, not the finding of the solution. That is one of the reasons not to reduce the natural world problem-solving paradigm to the classical experimental one.

(ii) Models centred on analogies and representations (Bainbridge, 1988; Leplat, 1985a; Montmollin & de Keyser, 1986). Analogy seems a rather common modality of reasoning for experienced (as opposed to novice) operators. This powerful heuristics allows the operator to "identify" rapidly a "situation", dispensing with the whole algorithmic process of diagnosis, but sometimes it also allows stubbornly false identifications. Such "identifications", or "comprehensions", are commonly called "representations" by psychologists, a very polysemic concept indeed, with a variety of different meanings such as: psychological phenomena (e.g. "patterns", or "images"); permanent functional knowledge; and

collective social ideologies. Here “representations” are considered as part of cognitive activities.

(iii) Models centred on temporal aspects of work (Boel & Daniellou, 1984; Decortis, 1988; Fichet-Clairfontaine, 1985; Hoc, 1987a, b; van Daele, 1988). Numerous micro-analyses are exploring the place of time in the process of reasoning, particularly in process control, where time is the great actor, and often the great enemy. Time means anticipation for the operators. As an example of the importance given by operators to time constraints, it has been observed that reasoning is oriented more on consequences than on causes.

(iv) Models centred on strategies, regulations, changing of level, planning. It often seems relevant for the description of cognitive activities to identify some “meta-reasoning”, which allows the operator not to be limited with a too proximate temporal horizon, or a too limited set of cognitive tools. The models concerning strategies (De Keyser, 1988b; Montmollin, 1990; Rasmussen & Jensen, 1974) describe here the set of behaviours exhibited as an operator gradually reaches a decision and takes action to deal with a poorly defined problem, or a problematic situation. Common examples of strategy are the general “data driven” reasoning, or in contrast, the construction of a hierarchy of goals and subgoals (see also “conduite”). Regulation (Faverge, 1972; Faverge et al. 1966) is a concept originated by J.-M. Faverge, whose studies concerning this topic were influenced by the cybernetical models (the search for a stable state). This concept now seems often synonymous with strategy (see for instance Cellier, 1987; Dorel & Queinnec, 1980; Terssac, 1980; for the East European aspects of the concept of regulation, see Hacker, 1980). Spérandio (1972), analysing the activity of air flight controllers, demonstrated that their procedures were modified, according to the number of planes (i.e. the “workload”), following a model of discontinuous changing of

levels of activity. A similar behaviour is described by Stassen et al. (1988, p.252), as “a combination of human performance and mental load during human supervisory tasks”. Vermersch (1976; 1978) transposed the Piagetian “stages” into the work domain, showing the modifications (“accommodation”) of modalities of reasoning following the possibilities of “assimilation” of the difficulties of the task. The three well-known stages (skill, rule, knowledge) of Rasmussen’s model (e.g. Rasmussen, 1986) can also be considered as a model of levels giving operators the opportunity to adapt their behaviour following the characteristics of the occurring events (e.g. an unusual incident in process control). Planning and the making of plans and schemas was studied by J.-M. Hoc in various situations (mainly the activity of programmers in informatics), both from theoretical and empirical points of view (Hoc, 1987a; Samurçay & Hoc, 1989).

Until recently, models of collective activities were a rather neglected area in ergonomic research. The workplace, and the operator isolated in this workplace, were the dominant paradigms. When oriented to the collective aspects, a majority of studies were devoted to the normative allocation of tasks, and to the corresponding design of prescribed communication, which is a different topic. Social psychologists for their part have seldom observed interactions in real professional groups, coping with real work situations.

Communications and interactions in the workplace are no longer a sort of “post-scriptum” to the work analyses of individual operators, but are becoming more and more the central and direct object of analyses. Activities are analysed through the communications (mainly verbal) they bring about. Particularly interesting is when communication is mediated, e.g. by radio or phone.

Concerning the explored areas of collective activities, and communications, see Falzon

(1989); Falzon et al. (1988); Hollnagel and Weir (1988); Kasbi (1988); Lacoste (1983; 1991); Navarro (1987); Savoyant and Leplat (1983); Swaanenburg et al. (1988); and Theureau and Pinsky (1983). In this domain there are also some interesting contributions from American ethno-methodologists (see for instance Hutchins, 1983; 1987; and Scribner, 1985).

As the object of work analysis here is the activity of information processing (as opposed to the task which has to be performed), the methodologies are directly linked with the models of activity. The aforementioned enumeration lists some of the models or approaches proposed by the ergonomists, but as every new work situation has to be analysed as specific, the analyst has to be cautious not to adopt too rapidly, by analogy, a model adapted to some familiar situation previously analysed. One of the more sensible decisions concerns the determination of the units pertinent for each analysis (that is, pertinent for the aims of each analysis). It is not an easy task. If too "micro", the analysis may never end or the results will be too sophisticated. If too "macro" some crucial element could be missed. There is yet in this domain a lot of work for methodological (i.e. theoretical) ergonomics. For instance, what is a "decision"? Following the scale of the analysis, a "decision" could be the only final conclusion of a very long sequence of reasoning. Some interesting examples are given by D. Dorner in the managerial area (Dorner, 1987; see also Fischhoff, 1986, and the collective book edited by Rasmussen et al., 1991). But every micro action, like looking at a display, could also sometimes be named a "decision". Stop rules in work analysis are always a challenge.

Concerning the sensible topic of verbalization analysis, there is, fortunately, a fairly large quantity of field studies, including the contribution of such exotic (for ergonomists) scientists as linguists, sociolinguists, or specialists in "natural logics". See for instance Bainbridge (1979); Caverai (1988);

Cleeremans (1988); Falzon et al. (1988); Grize (1981); Lacoste (1981; 1983); Navarro (1987); Pollack (1985); Praetorius and Duncan (1988); and Theureau and Pinsky (1983).

## 2.2. Competencies

In the ergonomic perspective described here, competencies is the conventional term for acquired relatively stable cognitive memorised structures, enabling the operator to act or to perform a specific task, or a family of similar tasks.

A trivial example of the distinction between activity and competency is the contrast between remembering (a behaviour, which can be recorded, and is part of a "story"), and memory (which does not exist, except as an imaginary construction by the psychologist to explain the remembering). A less trivial and more ergonomical example could be the temporal succession of inferences overly made by an operator in the control room to cope with a dysfunctioning of the process, on one hand, and, on the other hand, the knowledge about this process which is supposed, by the ergonomist, to be necessary for such inferences and which may not be stated explicitly by the operator alone.

Part of competencies are different modalities of knowledge (declarative, procedural, of functioning, of use...), know-how, memorised roles and acquired routines, meta-knowledge, i.e. thinking about one's own knowledge, and also "representations" (here as structures, as opposed to representations, as part of the cognitive process).

Meta-knowledge is a recent and promising topic. Operators are often neither behaving nor reasoning in conformity with how they "know" they should behave and reason. They "discuss" their own knowledge (e.g. of procedures), and adapt it to the present circumstances. They can be conscious of such a "discussion". It seems that in complex systems, efficient operators have such a

flexible, adaptive, i.e. intelligent, competency.

There are many theoretical and practical problems concerning competencies. What is their genesis, and particularly what is the nature and function of experience? Experience is indeed a strange and challenging, although common concept. Everyone apparently knows what it is, but nobody is really able to describe and explain it. Even in highly proceduralised systems, the experience of operators is a necessity, although often recognised only tacitly by the hierarchy. Other linked problems concern levels of abstraction, hierarchies, inclusions, and commonalities of cognitive structures. Possibilities of transformation, transfer, and more generally generalization of competencies are very practical questions in technically evolving industries. Workers have to adapt themselves to some new, but often similar tasks. What do "new" and "similar" mean for the operator? To what extent are the professional local competency dependent on prerequisites? What sort of (re)training is necessary? Is an "on the job training" possible? More generally, what is a relevant technical education?

Competency differs from skill, if skill means a more general capacity (e.g. "manual skill", not restricted to a precisely identified task, or family of tasks. Competency differs also from expertise (as in the Expert System vocabulary). Expertise here is meant only as "excellent" competency, thus referring more to the abstract activity involved in performing a task imposed by the expert system technology, rather than to real daily activity of the living expert. In this perspective, extraction of knowledge is regularly derived from interviews, not from observation or recording of activities.

The diverse psychological models concerning "schemata", "frames", "mental models" etc. can certainly help the ergonomist to model the cognitive structures necessary to explain the operators' activities, but these models have

always to be implemented and adapted, if possible, to the local stories. An incident situation is not "schematized" by the operator in a nuclear power plant the way it is "schematized" as incident situation by a programmer debugging perverse software.

Competencies also differ from aptitudes and abilities, which are much too abstract and general traits, unable to explain the actual local professional activities. They also differ from their social counterparts, qualifications; but this difference is now a stimulating common field of research between ergonomists and sociologists (for instance through the concept of tacit skill).

Analysis of competencies is indeed difficult. The operators themselves, when interviewed, tend to describe their prescribed tasks, and the corresponding knowledge, not the actual processes and knowledge. A fairly good technical opportunity for the analysis of natural competencies is given when they are in a dynamic state: their genesis (from novice to expert); their transformation (from one task to another one, for instance when a process is automatized); their transfer (from one operator to another, for instance during "on the job" training by a senior worker); more generally their communication, for instance in a working team.

On competencies and knowledge in ergonomics, see Caverni (1989); De Keyser (1987); Hoc (1987a, b); Leplat (1986; 1990); Montmollin (1986b); Montmollin and De Keyser (1986); Norros and Sammatti (1986); Ochanine (1981); Roth and Woods (1988); Stassen (1986); Stassen et al. (1988)<sup>3</sup>.

### 3. By way of Conclusion: "Human Error" or "Human Failure"?

An unexpected issue of the ergonomic studies of operators' activities is the critical discussion of

<sup>3</sup> In France, half a dozen of these in ergonomics are at the present time prepared on these topics, in hospitals, control rooms, workshops in mechanics, and administrative settings.

the popular concept of “human error”, supposed to explain incidents and accidents. There is, for instance, in case of railways or road accidents, a traditional orientation to pinpoint the human error made by the driver. Actually, there is some very suggestive and useful psychological and ergonomical taxonomies on human errors (particularly by Reason, 1987; 1990; see also Goodstein et al., 1988; Leplat, 1985b; Rasmussen et al., 1987).

Nevertheless, the ergonomic orientation sketched in the preceding pages is different, concerning the role of operators in incidents and accidents.

Considering the dynamic activities (the local operators’ “stories”), analyses lead to the conclusion that—with the very rare exception of drunkenness or sudden madness—the so-called erroneous decisions, or unsafe acts, were the final result of often long and sophisticated reasoning, with deep roots in the operators’ whole professional experience (or inexperience). Rather than to focus on the “error”, it seems more efficient to speak of human “failure”, resulting from large sequences of reasoning and acting, often in a very rational way. In this perspective, there are no longer isolated local errors, but cognitive activities issuing in situations which are assessed as “incidents” or “accidents” by the social environment. The common conception that accidents derived resulting from human error(s) is often directly derived from the normative models of work. Human error is defined as deviation from the prescribed task, which is considered as “normal” (i.e. the “norm”). There is no consideration of the fact that these deviations are also, and largely more often, the only way to avoid an accident...

As activities cannot be explained without the sustaining competencies, the conclusion concerning human failure is that the final word is on the side of these professional competencies. The better, that is the deeper, the more flexible, the higher the probability that the operator will

become an efficient “manager of the unexpected”. More constraining rules and procedures, more disciplinary regulations do not appear to be the only solution to the problems of safety.

Complex natural life environments require complex natural life activities and competencies.

On this conception of human failure, see the aforementioned references, and Amalberti (1989); Daniellou (1986); Leplat and Rasmussen (1987); Norros and Sammatti (1986).

## References

ALENGRY, P. (1986). Recherche des inadéquations du système homme-machine dans le cadre de l'évaluation d'un dispositif assistance a l'operateur intégré sur des chaînes de fabrication automatisées. In R. Patesson (Ed.), *L'homme et l'écran. Actes du Colloque de Nivelles, 1985*. Bruxelles: Presses de l'Université Libre de Bruxelles.

ALGERA, J.A. (1988). Task analysis and new technologies. In V. De Keyser, Th. Qvale, B. Wilpert, & S.A. Ruiz Quintillana (Eds.), *The meaning of work and technological options*. Chichester: John Wiley.

AMALBERTI, R. (1989). Vigilance, attention, automatisisation et conduite de processus. In *Entretiens "Science et Défense" Paris, May*, Bellicize Publishers, 123-131.

AMALBERTI, R., MONTMOLLIN, M. DE, & THEUREAU, J. (Eds.). (1991). *Modèles de l'analyse du travail*. Liège: Mardaga.

BAINBRIDGE, L. (1979). Verbal reports as evidence of the process operator's knowledge. *International Journal of Man-Machine Studies*, 11, 411-496.

BAINBRIDGE, L. (1983). Ironies of automation. *Automatica*, 19 (6), 775-779.

BAINBRIDGE, L. (1984). Diagnostic skill in process operation. In M. L. Matthews, & R. D. G. Webb (Eds.), Reviews. *Proceedings of the 1984 International Conference on Occupational*

*Ergonomics*, 2. Toronto, Canada.

BAINBRIDGE, L. (1988). Types of representations. In L. P. Goodstein, H. B. Andersen, & D. E. Olson (Eds.), *Tasks, Errors and Mental Models. A Festschrift to celebrate the 60th birthday of Professor Jens Rasmussen*. London: Taylor and Francis.

BISSERET, A. (1988). Modeles pour comprendre et réussir. In J. P. Caverni, C. Bastien, P. Mendelsohn, & G. Tiberghien (Eds.), *Psychologie cognitive: Modèles et méthodes*. Grenoble: Press Universitaires de Grenoble.

BÖEL, M., & DANIELLOU, F. (1984). Elements of process control operator's reasoning: Activity planning and system and process response-time. In *Ergonomics Problems in Process Operations*. European Federation of Chemical Engineering Publications, (Series N38): The Institute of Chemical Engineering and Pergamon Press.

CARROLL, J. M. (1989). Evaluation, description and invention: Paradigms of human-computer interaction. In M. C. Yovits (Ed.), *Advances in Computers: Vol. 28*. New York: Academic Press.

CAVERNI, J. P. (1988). La verbalisation comme source d'observables pour l'étude du fonctionnement cognitif. In: J. P. Caverni, C. Bastien, P. Mendelshon, & G. Tiberghien (Eds.), *Psychologie cognitive: Modèles et méthodes*. Grenoble: Presses Universitaires de Grenoble.

CAVERNI, P. (Ed.). (1989). Psychologie de l'expertise (Special issue). *Psychologie Française*, 33 (3).

CELLIER, J.-M. (1987). Processus cognitifs et activités de régulation. *Bulletin de Psychologie*, 40, 379, 331-332.

CLEEREMANS, A. (1988). Relations entre performance et connaissances verbalisables dans le contrôle de processus. *Le Travail Humain*, 51 (2), 97-111.

DANIELLOU, F. (1986). *L'opérateur, la vanne, l'écran. L'ergonomie dans la transformation des industries de processus*.

Montrouge: ANACT.

DECORTIS, F. (1988). Dimensions temporelles de l'activité cognitive lors des démarrages de systèmes complexes. *Le Travail Humain*, 51 (2) 125-138.

DE KEYSER, V. (1987). Structuring of knowledge of operators in continuous processes: Case study of a continuous casting plant start up. In J. Rasmussen, K. Duncan, & J. Leplat (Eds.), *New technology and human error*. Chichester: John Wiley.

DE KEYSER, V. (Ed.). (1988a). L'ergonomie des processus continus (Special issues). *Le Travail Humain*, 51, (1 & 2).

DE KEYSER, V. (Ed.). (1988b). De la contingence à la complexité: L'évolution des idées dans l'étude des processus continus. *Le Travail Humain*, 51. (1), 1-18.

DE KEYSER, V., DECORTIS, F., & VAN DAELE, A. (1988). The approach of Francophone ergonomics: Studying new technologies. In V. De Keyser, Th. Qvale, B. Wilpert, & S. A. Ruiz Quintanilla (Eds.), *The meaning of work and technological options*. Chichester: John Wiley.

DE KEYSER, V., & VAN DAELE (Eds.). (1990). *L'ergonomie de conception*. Brussels: De Boek Université.

DOREL, M., & QUEINNEC, Y. (1980). Régulations individuelles et interindividuelles en situation d'horaire alternant. *Bulletin de Psychologie*, 33, 465-471.

DÖRNER, D. (1987). On the difficulties people have in dealing with complexity. In J. Rasmussen, K. Duncan, & J. Leplat (Eds.), *New technology and human error*. Chichester: John Wiley.

ELLMAN, R. (1988, June 14-16). Human factors and personal computing: From surface to structure. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference, Oulu, Finland, II, 313-319.

FALZON, P. (1989). *Ergonomie cognitive du dialogue*. Grenoble: Presses Universitaires de Grenoble.

FALZON, P., AMALBERTI, R., & CARBONNEL, N. (1988, June 14-16). Man-machine dialogue: The role of interlocutor models. In *Man-machine systems, analysis, design and evaluation*, Preprints of the IFAC/IFIP/IEA/IFORS conference, Oulu, Finland, II, 511-516.

FAVERGE, J.-M. (Ed.). (1966). *L'ergonomie des processus industriels*. Bruxelles: Institut de Sociologie de l'Université Libre de Bruxelles.

FAVERGE, J.-M. (1972). L'analyse du travail. In M. Reuchlin (Ed.), *Traité de psychologie appliquée. Vol. 3*. Paris: Presses Universitaires de France.

FICHET-CLAIRFONTAINE, P. Y. (1985). *Étude ergonomique de l'influence de la conception de la salle de commande, de la stabilité du processus, et de la diversification de la production sur l'activité des opérateurs dans 4 unités de processus continu*. Unpublished thesis, Université Paris-Nord.

FISCHOFF, B. (1986). Decision making in complex systems. In E. Hollnagel, G. Mancini, & D. D. Woods (Eds.), *Intelligent decision support in process environments*. Berlin: Springer-Verlag.

FUNKE, J. (1988). Using simulation to study complex problem solving: A review of studies in the FRG. *Simulation & Games*, 19 (3), 277-303.

GOODSTEIN, L. P., ANDERSEN, H. B., & OLSEN, S. E. (Eds.). (1988). *Tasks, errors and mental models. A Festschrift to celebrate the 60th birthday of Professor Jens Rasmussen*. London: Taylor and Francis.

GRIZE, J.-B. (1981). Discours et connaissances. *Communication & Cognition*, 14, 343-367.

GUY, M., & LEJON, J. (1988, Oct 19-20). Ergonomic analysis of operator activities in conventional control rooms for implementation of centralized CRT-key board equipment. *Proceedings of the 7th European annual conference "On human decision making and manual control"*. Paris: Electricité de France.

HACKER, W. (1980). *Allgemeine Arbeits-und-*

*Ingenieurpsychologie. Psychische Struktur und Regulation von Arbeitstätigkeiten*. Berlin: VEB Deutscher Verlag der Wissenschaften.

HOC, J.-M. (1987a). *Psychologie cognitive de la planification*. Grenoble: Presses Universitaires de Grenoble.

HOC, J.-M. (1987b). Prise de conscience et planification. *Psychologie Française*, 32 (4), 247-252.

HOC, J.-M. (1987c). Analysis of cognitive activities in process control for the design of computer aids. An example: the control of blast furnaces. In H. J. Bullinger, & B. Shakerl (Eds.), *Human computer interaction - INTERACT87*. Amsterdam: Elsevier.

HOC, J.-M., & VISSER, W. (Eds.). (1988). Psychologie ergonomique de la programmation informatique (Special issue). *Psychologie Française*, 51 (4).

HOLLNAGEL, E., MANCINI, G., & WOODS, D. D. (Eds.). (1986). *Intelligent decision support in process environments*. Berlin: Springer-Verlag.

HOLLNAGEL, E., & WEIR, G. (1988, June 14-16). Principles for dialogue design in man-machine systems. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference, Oulu, Finland, I, 269-273.

HOUSISAX, A. (1988). Supports d'information centralisés et diagnostic en situation d'urgence dans un centre néonatal. *Le Travail Humain*, 51 (1), 173-184.

HUTCHINS, E. (1983). Understanding Micronesian navigation. In D. Gentner, & A. L. Stevens (Eds.), *Mental models*. Hillsdale, NJ: Lawrence Erlbaum Associates.

HUTCHINS, E. (1987, June 23-26). *The ontogenesis of a Quatermaster*. Paper presented at the *First International Workshop "Activity, Work and learning"*, Karjaa, Finland.

KASBI, C. (1988, Oct 19-20). Les aspects organisationnels de la conduite dans la validation du simulateur S3C. *Proceedings of the 7th*

*European annual conference "On human decision making and manual control"*. Paris: Electricité de France.

LACOSTE, M. (1983). Des situations de parole aux activités interprétatives. *Psychologie Française*, 28, 231-238.

LACOSTE, M. (1991). Les communications dans le travail comme interactions. In R. Amalberti, M. de Montmollin, & J. Theureau (Eds.), *Modèles de l'analyse du travail*. Liège: Mardaga.

LEPLAT, J. (1982). Le terrain, stimulant (ou obstacle) au développement de la psychologie cognitive. *Cahiers de Psychologie Cognitive*, 2, 115-130.

LEPLAT, J. (1985a). Les représentations fonctionnelles dans le travail. In S. Ehrlich (Ed.), *Les représentations (Special issue)*. *Psychologie Française*, 30 (3-4).

LEPLAT, J. (1985b). *Erreur humaine, fiabilité humaine dans le travail*. Paris: Armand-Colin.

LEPLAT, J. (1986). The elicitation of expert knowledge. In E. Hollnagel, G. Mancini, & D. D. Woods (Eds.), *Intelligent decision support in process environments*. Berlin: Springer-Verlag.

LEPLAT, J. (1990). Skills and tacit skills: A psychological perspective. *Applied Psychology: An International Review*, 39, 143-154.

LEPLAT, J., & HOC, J.-M. (1983). Tâche et activité dans l'analyse psychologique des situations. *Cahiers de Psychologie Cognitive*, 3, 49-63.

LEPLAT, J., & RASMUSSEN, J. (1987). Analysis of human errors in industrial incidents and accidents for improvement of work safety. In J. Rasmussen, K. Duncan, & J. Leplat (Eds.), *New technology and human error*. Chichester: John Wiley.

LEWKOWITZ, A. (1988, Oct 19-20). Les simulateurs: Des outils de recherche privilégiés pour l'ergonomie. *Proceedings of the 7th European annual conference "On human decision making and manual control"*. Paris:

Electricité de France.

MONTMOLLIN, M. DE (1986a). Analysis of the competence of operators confronting new technologies: Some methodological problems and some results. In F. Klix, & H. Wandke (Eds.), *Man-computer interaction research*, Macinter. Amsterdam: Elsevier.

MONTMOLLIN, M. DE (1986b). *L'intelligence de la tâche: Éléments d'ergonomie cognitive*, (2nd ed.). Berne: Peter Lang.

MONTMOLLIN, M. DE (1990). *I'ergonomie* (rev. ed.). Paris: La Découverte.

MONTMOLLIN, M. DE, & DE KEYSER, V. (1986, Sept 10-12). Expert logic versus operator logic. In G. Mancini, G. Johannsen, & L. Martensen (Eds.), *Analysis, design and evaluation of man-machine systems, Proceedings of the 2nd IFAC/IFIP/IEA/IFORS conference*, Varese, Italy, 1985. Oxford: Pergamon Press.

MORAY, N. (1986). Modelling cognitive activities: Human limitations in relation to computers aids. In E. Hollnagel, G. Mancini, & D. D. Woods (Eds.), *Intelligent decision support in process environments*. Berlin: Springer-Verlag.

NAVARRO, C. (1987). Communications fonctionnelles et complexité des tâches dans le pilotage d'un avion de ligne. *Le Travail Humain*, 50 (4), 289-304.

NORROS, L., & SAMMATTI, P. (1986). *Nuclear power plant operator errors during simulator training*. (Research Rep. No.446). Espoo: Technical Research Centre of Finland.

OCHANINE, D. (1981). (Transl.) In *L'image opérative*. Paris: Université Paris I.

PATESSON, R. (Ed.), (1986). *L'homme et l'écran. Actes du colloque de Nivelles, 1985*. Bruxelles: Editions de l'Université Libre de Bruxelles.

PINSKY, L., & THEUREAU, J. (1987a). *L'étude du cours d'action. Analyse du travail et conception ergonomique*. Paris: Collection d'ergonomie et de neurophysiologie du travail du CNAM, 88.

PINSKY, L., & THEUREAU, J. (1987b).

Description of visual "action" in "natural" situations. In J. K. O'Reagan, & A. Lévy-Schoen (Eds.), *Eye movements: From physiology to cognition*. Amsterdam: Elsevier.

POLLACK, M. E. (1985). Information sought and information provided: An empirical study of user/expert dialogues. In L. Borman, & B. Curtis (Eds.), *Human factors in computing systems, II*. Amsterdam: North-Holland.

PRAETORIUS, N., & DUNCAN, K. D. (1988). Verbal reports: A problem in research design. In L. P. Goodstein, H. B. Andersen, & S. E. Olsen (Eds.), *Tasks, errors and mental models. A Festschrift to celebrate the 60th birthday of Professor Jens Rasmussen*. London: Taylor and Francis.

RASMUSSEN, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering*. New York: North-Holland.

RASMUSSEN, J., BREHMER B., & LEPLAT, J. (Eds.). (1991) *Distributed decisionmaking: Cognitive models for cooperative work*. Chichester: John Wiley.

RASMUSSEN, J., DUNCAN, K., & LEPLAT, J. (Eds.). (1987). *New technology and human error*. Chichester: John Wiley.

RASMUSSEN, J., & JENSEN, A. (1974). Mental procedures in real-life tasks: A case of electronic trouble-shooting. *Ergonomics*, 17, 293-307.

REASON, J. (1987). (Chap. 1, 2, 5, 7, 11). In J. Rasmussen, K. Duncan, & J. Leplat (Eds.), *New technology and human error*. Chichester: John Wiley.

REASON, J. (1990). *Human error*. Cambridge: Cambridge University Press.

ROTH, E. M., & WOODS, D. D. (1988). Aiding human performance. I: Cognitive analysis. *Le Travail Humain*, 51 (1), 139-172.

SAMURÇAY, R., & HOC, J.-M. (1989). De l'analyse du travail à la spécification d'aides à la décision dans des environnements dynamiques. *Psychologie Française*, 33 (3), 187-196.

SAVOYANT, A., & LEPLAT, J. (1983). Statut et fonction des communications dans l'activité des équipes de travail. *Psychologie Française*, 28, 243-253.

SCRIBNER, S. (1985). Vigotsky's uses of history. In J. W. Wertsch (Ed.), *Culture, communication and cognition. Wigotskian perspectives*. Cambridge, MA: Harvard University Press.

SPÉRANDIO, J.-C. (1972). Charge de travail et régulation des modes opératoires. *Le Travail Humain*, 46 (2), 229-238.

SPÉRANDIO, J.-C. (1987). L'ergonomie du travail informatisé. In C. Lévy-Leboyer, & J.-C. Spérandio (Eds.), *Traité de psychologie du travail*. Paris: Presses Universitaires de France.

SPÉRANDIO, J.-C. (1988). *L'ergonomie du travail mental* (2nd ed.). Paris: Masson

STASSEN, H. G. (1986). Decision demands and task requirements in work environments: What can be learnt from human operator modelling. In E. Hollnagel, G. Mancini, & D. D. Woods (Eds.), *Intelligent decision support in process environments*. Berlin: Springer-Verlag.

STASSEN, H. G., JOHANSSON, G., & MORAY, N. (1988, June 14-16). Internal representation, internal model, human performance model and mental workload. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference, Oulu, Finland. I, 252-261.

SWAANENBURG, H. A. C., ZWAGA, H. J., & DUIJNHOUVER, F. (1988, June 14-16). The evaluation of VDU-based man-machine interfaces in process industry. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference. Oulu, Finland. I, 129-134.

TERSSAC, G. DE (1980). Activité mentale et régulation des conduites: Étude de quelques postes dans l'industrie chimique. In C. Benayoun, G. de Terssac, Y. Lucas, M. Membrado, & E. Soula (Eds.), *Les composantes mentales du travail ouvrier*. Montrouge: ANACT.

- THEUREAU, J. (1991). Les raisonnements dans le travail. In R. Amalberti, M. de Montmollin, & J. Theureau (Eds.), *Modèles de l'analyse du travail*. Liège: Mardaga.
- THEUREAU, J., & PINSKY, L. (1983). Action et parole dans le travail. *Psychologie Française*, 28, 225-264.
- VALOT, C., & AMALBERTI, R. (1989). Les redondances dans le traitement des données. *Le Travail Humain*, 52, (2) 155-174.
- VAN DAELE, A. (1988). Écran de visualisation ou communication verbale? Analyses comparatives de leur utilisation par des opérateurs de coulée continue en sidérurgie. *Le Travail Humain*, 51 (1), 65-79.
- VERMERSCH, P. (1976). *Une approche de la régulation de l'action chez l'adulte. Registres de fonctionnement, déséquilibre transitoire et microgénèse*. Unpublished thesis. Paris: Université René-Descartes.
- VERMERSCH, P. (1978). Une problématique théorique en psychologie du travail. *Le Travail Humain*, 41 (2), 263-278.
- VISSER, W. (1988, June 14-16). Towards modelling the activity of design: An observational study on a specification stage. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference. Oulu, Finland. I, 51-56.
- WISNER, A., DANIELLOU, F., PINSKY, L., & THEUREAU, J. (1988, June 14-16). Process supervision and control: Design of technical systems and organization. Training of operators. In *Man-machine systems, analysis, design and evaluation*. Preprints of the IFAC/IFIP/IEA/IFORS conference. Oulu, Finland. II, 511-516.