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Understanding problem building: ergonomic work analysis

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The circumstances in which work is carried out in the real world are not usually taken into account in the modelling of work activities. The task is variable and often interrupted; the work teams are not always stable; feedback loops are numerous and complex making it difficult to diagnose disturbances. The theoretical models often overlook the physical aspects of the activity, for example fatigue, pain and danger, and the way these vary between individuals and within individuals at different times. The critical elements of the task are not always delimited according to the recommendations of the task. Operators have preconceptions about situations that are often useful but sometimes dangerous. Finally, each person reacts in terms of his personal culture. These elements are so important that it is necessary to single out a problem building phase that precedes and accompanies the more classic phase of problem solving. Ergonomic Work Analysis (EWA) is a tried and tested methodology which, as the result of studying behaviour in the work situation, provides an understanding of how the operator builds the problem, indicates any obstacles in the path of this activity, and enables the obstacles to be removed through ergonomic action.

1. Introduction

In 1932, in his book *Remembering: A Study in Experimental and Social Psychology*, Bartlett considered that formulating generalizations about 'the way people think' on the basis of what is revealed by laboratory experiments was a contradiction in terms. The validity of generalizing from experimental results is questionable because experimental situations are rather similar to each other and clearly different from the situations where the cognitive activities they attempt to model actually take place. Bartlett proposed that the observation of everyday activities in their own context should constitute the basis for the design of experiments. The experimental results, in turn, should suggest further observations.

This position is extremely important but, unfortunately, it has been frequently overlooked (Wisner 1972). Even today, the fundamental contradiction between reliability and validity cannot be attenuated without using the two-fold approach of observation and experimentation. This is the viewpoint that Tom Singleton has taken from his initial industrial experience in the 1960s to his latest perspectives for the 1990s. He has shown that this double approach is necessary both in ergonomics (Singleton *et al.* 1967, Singleton 1974) and in the study of real skills (Singleton 1978, 1979, 1981, 1983).

Experimental cognitive psychology has progressed considerably over the last 60 years and there is now much clearly established knowledge about the way in which human cognition works in the specific conditions of the laboratory. The level of attainment is far from comparable in the field of the 'observation of everyday activities in their own context', yet the specific purpose of ergonomics is to enable these everyday activities to take place favourably in their own context. Ergonomic action often leads to this context being modified in order to facilitate the everyday activities of operators. Therefore, ergonomics cannot do without these observations.

In 1958, in his book *Thinking: An Experimental and Social Study*, Bartlett treated these everyday activities with great modesty: 'All I can attempt is to select a few illustrations and to put forward, in a general way, and without detailed evidence, certain conclusions which may help to establish some important relations... between the tactics and aim of everyday thinking and those characteristic of thinking in the closed system, and in experiments' (p. 166). In this quotation, two words should be underlined, namely 'tactics' and 'aim'. Although laboratory experiments are a fairly good source of information about the properties of the human brain, they tell us little or nothing about the tactics used by the operator to make the most of these properties, namely memory, reasoning, motor programming, etc. These tactics can only be known through their enactment in work situations and through the observation of behaviour. Furthermore, these tactics can only be understood in terms of the aim in question. This aim often has contradictory aspects (speed–precision conflicts, human efficiency–cost, productivity–ethics, etc.). A complementary concept of a compromise between these various aspects of the aim must be introduced.

For the past 20 years the field of everyday thinking and, more particularly, thinking in the work situation, has been the subject of much interesting research, leading to the publication of conference proceedings and books. This work was the result of the co-operation—or at least of the dialogue—between psychologists and anthropologists. The research began at the end of the 1970s (Resnick 1976, Casson 1981, Fry 1984) and expanded into the field of work from the middle of the 1980s (Rogoff and Lave 1984, Dougherty 1985, Sternberg and Wagner 1986, Suchman 1987, Lave 1988, Resnick *et al.* 1991).

2. The need for ergonomic work analysis (EWA)

To a greater extent than the others Suchman (1987), who uniquely and explicitly identifies herself as an ergonomist, argues in favour of cognitive anthropology as opposed to experimental cognitive psychology. Despite the enormous documentation of the author and her fine work, it is in fact a rejection of cognitive psychology in the work situation. This position is based on the refusal of most cognitive psychologists and ergonomists to consider cognition, particularly in the work situation, as a legitimate field of activity. Certain French-speaking ergonomists have not adopted this attitude. From Suzanne Pacaud (1949) and Ombredane and Faverge (1955) they consider that ergonomic science and practice have a lot to learn from observing operators in the real world.

The first justification given by Ombredane (1955) is that

> for a system that is supposed to be constant in terms of the demands of the task, the operational attitudes and sequences may vary to a considerable extent from one individual to another and from one moment to another for the same individual ... The hazards of performance are directly due to the degree of indetermination of the demands of the task ... which are bound to be reduced ... on

> condition that the demands of the task are shown to the worker at the right time through reliable signs and information (p. 2).

An essential concept is clearly shown here: the difference between the prescribed work (the task) and the real work (the activity) linked to the concrete difficulties of the situation, to their perception by the operator, to the strategies he adopts to satisfy the demands of the work and, in particular, to the hazards. As Dejours (1993) wrote, one cannot avoid considering the creative aspect of any work activity. This is an intelligence of practice, a 'métis', the crafty intelligence already distinguished in ancient Greek vocabulary (Detienne and Vernant 1974).

Later, Ombredane (1955:) gives a definition of the signal as

> a perceptible data item which indicates the advisability of an act. At each moment of the work, the situation offers the worker significant aspects and possible indicators of the advisability of acts that are more or less probable ... Certain significant aspects of the task are foreseen and learned ... Others, whose number is indefinite, are unforeseen and are subject to discovery by the worker ... This discovery does not necessarily lead to clear awareness by the worker and becomes the source of impressions and 'glances' which are readily attributed to some natural gift of man (p. 9).

The previous text clearly states other basic justifications for ergonomic work analysis. By opposing the priority of the action motion on the tool or the machine, and by stressing the essential role of the signal, ergonomic work analysis radically sets itself apart from the work analysis conceived in the perspective of the 'time and motion study'. By pointing out the importance of the signals to be discovered by the operator, Ombredane shows the creative activity of work. By indicating that the worker is often unaware of the signals he discovers and, therefore, the bases of his decision, the author shows the existence of a cognitive unconscious that is clearly separate from the psychic unconscious and which may easily become conscious through an appropriate methodology: the explicitation interview (Vermersch 1990). The importance of the cognitive unconscious is an essential justification of the detailed observation of behaviour that constitutes the centre of ergonomic work analysis since it is through comparison of the behaviour observed and the way in which the operator represents his activities that forgotten knowledge appears and tactics, which are incomprehensible at first sight, are justified. Owing to a lack of comparison with detailed behaviour, the interview methodology is unable to discover such phenomena and its access to cognition and, hence, to the intelligence of the workers, is limited.

The extent of the field of observable behaviours is judiciously underlined by Ombredane (1955) in regard to proprioceptive information. Owing to its unconscious character, proprioceptive information is much more difficult to define and to integrate with didactics than the exteroceptive information contributed by the various aspects of technical systems. Burton *et al.* (1984) give good examples of ergonomic solutions to proprioceptive difficulties in learning to ski. Gatewood (1985) gave a very evocative title to his text on salmon fishing: 'Action speaks louder than words', thus underlining the extreme difficulty of verbalizing proprioception.

The ideas of Ombredane (1955) did not constitute a theoretical ensemble, but expressed a fundamental intuition: it is not the task and the worker that should be studied separately but the work itself, in order to determine ergonomic solutions and thus make a specific contribution to the sciences of man at work. Theoretical developments in this direction are only expressed at a later stage owing to a lack of concomitant development of knowledge about thought and action in the situation. Such a development has only been observed over the last 10 years. On the other hand, in French-speaking countries, ergonomic work analysis has become a precise methodology that is widely used by practising ergonomists in the most varied fields.

3. Methodology of ergonomic work analysis

Numerous texts describe the current methodology of ergonomic work analysis (Guérin *et al.* 1991). In principle, this methodology consists of analysis of the request, examination of the technical, economic and social conditions, analysis of the activities—the central element of the study—diagnosis, recommendations, simulation of work on the modified system and evaluation of the work in the new situation. Such a methodology is very awkward if it is followed completely. In fact, the complete process of work analysis is rarely necessary. For example, from experience the in-house ergonomist knows the validity of the request and the way in which it could be reformulated. He often has a simulator (automobile, nuclear industries, etc.). By contrast, the consultant ergonomist, who is often a general practitioner, has to make a detailed examination of the request and often reformulates it in order to be able to tackle the real questions that are often concealed beneath a trivial formulation of the request. He should also know the limits of any of his actions by taking into account the technical, economic and social realities specific to the company that brings him in; sometimes, he should endeavour to discover what these realities can teach him about the system or the specific workstation he is studying. Frequently the analysis of activities can be relatively restricted and concern only a few critical points since these are usual problems for which extensive ergonomic know-how is more or less available dependent on the experience of the consultant. This is then a 'short diagnosis' (Guérin *et al.* 1991).

The formulation of recommendations may be a rather simple, short-term phase. On the other hand, it may be the subject of a complex process in co-operation with designers and future users, especially if the future system has to be considerably different from the one described by the work analysis. Then the need for iterative simulation (Pinsky 1990, 1992) often appears. Sometimes it is necessary to use a particular methodology in order to define the probable future activities of a production system in preparation (Daniellou and Garrigou 1992).

The central and original part of ergonomic work analysis is the analysis of activities. Here, its most comprehensive form will be presented as constituted progressively by different authors including Theureau (1992). The concern for obtaining objective data leads the analyst to study the behaviour of the operator with the aim of exhaustiveness, leading to the selection not only of motor behaviour in relation to the tool or machine, as in time and motion study, but also the information collection behaviour (in particular, movements of the head and eyes) and communication behaviour (vocal and gestural). The last obviously has a particular status owing to its symbolic character. Naturally, these different behaviours may be the subject of recordings, measurements and statistics, but the most advantageous regrouping of these behavioural data is in terms of 'stories' that are easy to isolate and are located in a short space of time, for example, the correction of a typing error or the changing of a tool on a machine-tool. Sometimes, in complex activities, the 'stories' consist of several episodes separated by other activities, such as an attempt to solve a quality problem through repeatedly trying to adjust a machine or the preparation, execution, shipment and receipt of the results of a biological examination by a hospital nurse. Several 'stories' may be intermingled in a given period of activity.

The follow-up of such procedures is long. In particular, their analysis is tedious. Therefore, they cannot be multiplied and frequently the idea of submitting them to a statistical analysis has to be ruled out. Hence, the choice of the persons to be studied and the work periods to be studied is extremely critical. However, formulation of the request, the result of a process that is sometimes long, is an essential guide: the analysis of activities is made in the perspective of detection of the causes of one or more anomalies and of the changes to be made to the critical situation. The persons chosen are experienced and they are volunteers. This is an option that has been the subject of considerable discussion by ethnologists (Werner 1969, Gardner 1976, Boster 1985). It is obvious that, on the basis of a detailed analysis of the activities of a small number of persons over rather short periods, a systematic examination may be made of a limited number of critical phenomena in a rather large population over longer periods.

The effort of exhaustiveness in the observation of behaviour obviously has technical limits. Video recording may be useful, but it is liable to disturb the activities even more than an observer whose presence rapidly becomes familiar. On the contrary, the recording of speech on a tape recorder is indispensable as long as the conversation is analysed in detail, as shown by Hutchins (1981).

Often, the behaviours observed do not provide an understanding of the cognitive activities that underlie them, even when they are grouped in 'stories'. This is why specialists in ergonomic work analysis complement the observation of behaviour with a very different approach from the epistemological viewpoint: autoconfrontation. The rule is that these interviews should remain strictly limited to requests for enlightenment in regard to the observed facts for which the ergonomist has no explanation. Why watch such an indicator and disregard another which, in principle, is intended to give pertinent information in this phase of the course of action? Why observe the activity of a colleague which, in principle, has nothing to do with the task of the operator observed? Why use such a control in a phase where its use is not planned?

In principle, the autoconfrontation interview avoids any judgement of value, any concept of disobeying instructions, or implication of a wrong process. The questions are asked on the basis of what the ergonomist has noted or recorded; confrontation with the videotape recording is often instructive. The operators are surprised by the fact that they have ignored such and such an indicator, which they thought they were following, and by the fact that they very often observe a part of the technical system to which they did not think they attached such importance. They can easily explain certain behaviours that had surprised the observer, but may think for some time before recalling the explanation for an unusual operating method. It is obvious that autoconfrontation, which is often very beneficial, should be treated with great caution since the a posteriori reconstitution of a fictitious rationality is a permanent risk. However, the fact that the interview remains very close to the facts limits this risk to a certain extent. In any event, this process is much safer than an interview with no prior in-depth observation of behaviour.

The methodology described previously may be considered as relatively objective when relations with the machine dominate. However, work is increasingly an activity where inter-human communication prevails and even becomes exclusive. Under these circumstances, there is a risk in treating conversation as simple behaviour without raising the question of intersubjectivity and, in a more radical way, the question of the limits of ergonomics. Can this speciality include situations where the possible improvements do not concern the technical system? In the context of EWA, technical communications at work can be interpreted most often when they are part of a larger ensemble or different behaviours. However, the dialogue of the user and the employee at the counter of on the telephone, the patient's interview with the nurse or the doctor, and the discussion between the salesman and his potential customer are work activities, although they do not come under EWA since the contextualization of the language that is given by the situation and created by the dialogue itself (Gumperz 1992) cannot be disregarded. As such, the interlocutors use the dialogue to constitute 'frames' that enable them to state the theatre of everyday life (Goffman 1976) at any moment. It is obvious that these are dimensions of the activity that are of the greatest interest, but whose theoretical, sociolinguistic and ethnolinguistic references must be respected, otherwise serious errors of interpretation could take place. However, even in work analysis that does not include a conversation study, the question of the sense cannot be avoided. Work activities that are subjected to the most Taylorian of organization methods have aspects that belong to the meaning of work: why do semi-skilled workers increase their already considerable workload by sorting parts and modifying them a little, if not simply to respect their work ethics?

4. Problem building

Ergonomic work analysis and, in particular, its central element of analysis of activities, is an awkward method that involves many risks of error. Couldn't it be dispensed with as eminent ergonomists who use laboratory results, or results of experiments by organizing them using the theory of systems, have done? (Meister 1989). Cognitive psychology research, and the programmes whose construction it underpins, constitutes considerable progress in the knowledge of human functioning, enabling the construction of remarkable simulations of human behaviour, on condition, however, that the elements are known in the form of precise data and theorems. 'How people solve problems is no great mystery; we know enough about it to create computer programs that do it in a way that closely simulates human performance, step by step' (Simon 1992, p. 150). However, as shown by Neisser (1976), there are two forms of intelligence or, rather, two types of use of intelligence: 'natural' intelligence and AI. Neisser (1976) uses these initials to designate both Academic Intelligence and Artificial Intelligence in order to underline the fact that, in both cases, the classic situation of the school problem of mathematics applies where the data of the terms are necessary and sufficient to solve the problem as long as suitable theorems are used. Furthermore, an assurance is given that there is only one solution. Neisser also points out that the same people—academics—govern these two sectors of the science. These views appear caricatural to those who claim kinship with the connectionist school and advanced mathematical models. However, in all cases, a start is made with 'données', meaning 'given information'. For Simon (1992) we construct computer programs that can be given complex cognitive tasks, identical to those given to our human subjects, and that will predict the temporal path of human behaviour on those tasks (p. 151).

Once again, the word 'given' appears. Yet, in the reality of work, nothing is given. The operator and the operating team are not 'given information' in order to guard against defective operation of the technical system; they have to find it and are never sure if it is necessary or sufficient, whether the reasoning (theorem) is adequate and even if a solution exists; perhaps there is no solution or perhaps there are several. So what the operators have to do is not simply *problem solving*; beforehand they have to do *problem building*. As Simon (1992) wrote:

> The human mind is an adaptive system that chooses behaviours in the light of its goals, and as appropriate to context ... The link between goals and environment is mediated by learned strategies and knowledge. Behaviour cannot be predicted from optimality criteria without information about the strategies and knowledge agents possess or acquire ... The study of the behaviour of an adaptive system is not a logical study of optimization but an empirical study of the side conditions that place limits on the approach to the optimum (p. 160).

Problem building, the important field of cognitive psychology, which should be considered in real situations, is of essential importance in ergonomics since our discipline is aimed at helping the operator to solve difficulties without too many complications, and/or too much fatigue or errors. The study of the operator's behaviour in the real work situation, in order to understand the way in which he builds the problems, is of the empirical type; it is ergonomic work analysis. This affirmation is in line with that of Simon (1992), except that it is not simply a matter of explaining the 'side conditions' and the 'knowledge' of operators, but also their functional state.

It is interesting to review the variabilities liable to influence problem building by starting with the 'side conditions'.

1. *The variability of the task*
   This variability is essential. It was underlined from the beginning of EWA by Pacaud (1949), who showed that the work of telephonists in those days mainly consisted of compensating for these variations. Perrow (1967) proposed a classification of tasks based on their variability and the predictability of their variability, and suggested that a high variability and a low predictability of this variability required a flexible and decentralised work organization in which the operator could build and solve problems as and when events appeared. Wessel (1987), quoting from a report by the Nuclear Regulatory Commission (NRC), the American nuclear power plant inspection organization, pointed out that when one of the inspected nuclear power plants was shut down, a backlog of 12 000 repairs was discovered. This fact, noted in one of the most dangerous and most closely monitored industries in the world's largest industrial country, gives an indication of the doubt characterizing the situation of a great number of operators. These operators found it very difficult to specify the data that they used to solve their everyday problems. As a result, they were forced, at all times, to construct the bases on which they made their decisions.
2. *Instability of teams*
   Recent work has shown the importance of socially shared cognition (Resnick *et al.* 1991, Six and Vaxevanoglou 1993). Absenteeism, staff turnover and the use of temporary staff or staff belonging to a service rental company contribute to the instability of teams. Under these circumstances, diagnostic and procedural knowledge is no longer exchanged and checked with the same efficiency and so has to be continuously reconstructed by temporary teams on the basis of the expertise of each member of the team, which can be very poor. For Simon (1992), expertise is mainly a recognition of prior situations, recognition that is all the more uncertain when operators have been only recently allocated to the task.
3. *The complexity and multiplicity of feedback loops in production systems*
   Modern production systems, particularly in dangerous industries (nuclear power plants, chemical industrial systems, etc.), tend to have a great number of feedback loops. Often, the basic data (temperature, pressure, flow-rate) are not

available to operators. The only indications that operators have is their combination. These characteristics are also associated with what Perrow (1984) called interactions and coupling, meaning relatively close functional and spatial inter-relations between the separate parts of the system. These inter-relations enable, interfere with, or prevent a diagnosis being made of the state of the system in the time necessary for effective action to be taken. Operators in the Three Mile Island nuclear power plant were initially considered to be stupid by a Secretary of State in a hurry. In fact, they were bewildered by the fact they could not construct a representation of the system that was affected by three types of defective operation or breakdown. The diagnosis was only established 10 hours later by a group of top-level experts using data that had not been available to the operators (Perrow 1982).

The three aspects of the side conditions mentioned above are sufficient to show the inevitable character of the activity of problem building and to justify the need for EWA. It is obvious that, for us, these aspects are not side conditions but are an integral part of the work.

Other conditions specific to human functioning also require the creation of a space for problem building and a methodology needed to explore this space.

1. *The problematics of action at work cannot simply be related to a narrow definition of cognitive sciences*
   Ergonomists have known for some time that the entire body is involved in work and that the strategies adopted may be due to fatigue or protection against pain or danger. An examination of postures and the conditions of observation or action often gives an understanding of why important information and necessary manoeuvres are disregarded because they demand awkward or dangerous postures, and provoke pain, especially when they are repeated. These questions are all the more difficult to deal with when certain dimensions are unconscious (proprioception, balance). In addition, it may be noted that workers suffer from these physical dimensions of their work in a very unequal way according to their gender, age, stature, physical strength, handicaps and their state of health. These characteristics of the operators vary considerably over time for the same person in terms of health and working and living conditions.

   It is also undeniable that work is an essential place of psychodynamics (Dejours 1993) and that this may determine behaviour and speech that are a defence against anxiety. However, the interpretation of these facts require concepts that are totally different from those of psychology and cognitive ergonomics (Wisner 1989).
2. *The delimitation of critical elements of the task is neither stable nor foreseeable*
   It is known that the physical environment where work activities take place has an influence on their quality, as shown for example, by the experimental work of Mackworth (1950) on the effect of heat and noise on vigilance, However, it is necessary to go much further by admitting that users or operators may include in their work, and in their reasoning, facts and procedures that do not belong to what can be considered to be the data of their task. Lave (1988) showed that the eating habits of families and storage areas available in the house play a much more important role than the quality/price ratio for purchases in a supermarket. Klein (1989) described the circumstances of a serious military error and showed that considerations arising from the events of previous days led to the wrong

decision being taken because of a lack of data necessary to appreciate the trajectory of an aeroplane.

3. *Prestructuration of information and situations*
Since the first research carried out on Gestalt theory and more recent work on face recognition (Bruce 1990), it has been known that patterns are more easily perceived and encoded and more easily retrieved from memory and recognized than their constituent elements, which are sometimes very apparent. It is also known that this mechanism, which is very powerful in all perceptual modes, appears in the retrieval and recognition of complex situations that are either concrete, symbolic or abstract. These phenomena are of great importance in work activities. Often they are unconscious, although they may be recalled from the unconscious. Expert operators often act in an efficient way in situations that are sometimes dramatic and urgent because they have recognized them to resemble previous situations (Simon 1992). Unfortunately, there are also cases of the false recognition of perceptual or situational patterns, leading to harmful actions that, at first glance, appear unexplainable. It is only through an in-depth analysis of such events that their repetition can be avoided with modification of the technical system.

   In a more general way, the fact that the previous action was only possible thanks to a structuring of reality tends to induce structures that are similar to those of other real situations that can be very different. For example, it is noted that it is sometimes difficult to reuse CAD-CAM files if the constraints of the system to be designed are different from those of a previous system (Beguin *et al.* 1993).

4. *Anthropological diversity*
The culture of the operators plays a determining role in perception, comprehension, and decision. If the widest possible definition of culture is accepted, meaning everything in everyone's past that contributes not only to opinions but also to actions, the considerable variations in perception of the situation and the task by workers who may have very different pasts can easily be understood. Mention may simply be made of the diversity of everyone's linguistic resources in order to give an idea of these variations.

5. Conclusions

Knowledge of human capacities is actually considerable and enables remarkable modelling, particularly in the field of problem solving, despite increasing doubts about the dominant role of formal logic in human reasoning in situations (Cherniak 1986, Evans 1989). However, this success should not lead to the discovery of real activities, which are of remarkable complexity and variability, being disregarded. These facts, highlighted by EWA, explain the importance of another cognitive activity: problem building. Knowledge of the way in which operators build problems explains many more errors and accidents than the conditions under which the problem itself is solved. Many ergonomic recommendations may be formulated in such a way that they facilitate problem building. Work organization, training and efforts to reduce accidents are also the possible beneficiaries of EWA. Nor should the use of the results of EWA be underestimated in the design of models of the operator, as noted by cognitive engineering specialists (see, for example, Roth *et al.* 1992). In a way, Cognitive Environment Simulation (CES) constitutes a bridge between the approaches discussed in this text.

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