Error Prevention and Well-Being at Work in Western Europe and Russia

PSYCHOLOGICAL TRADITIONS AND NEW TRENDS

Edited by
Véronique De Keyser and Anna B. Leonova

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To our teachers
Jean-Marie Faverge and Alexey Nikolaevich Leontiev

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INTRODUCTION

Risks in the workplace are the by-products of our industrial systems; the unwanted remains, so to speak; the result of the contradictions within a society that increasingly pursues multiple and contradictory objectives in a frenzied, competitive race. When deciphered, these risks provide an interpretive grid for this same society. In this book, we show how these risks evolve, how they change and are confronted differently, depending on the cultures and political systems in which they arise, particularly in Western Europe and in Russia. We see how, over time, psychologists have unmasked the generally accepted idea that makes the victims mainly responsible for the troubles afflicting them. Are they being injured? They must have a predisposition to accidents (accident *proneness*). Are they making mistakes? They do not pay attention. Are they stressed or morally harassed (*mobbing*)? They are psychologically fragile…This deep suspicion of human nature has been translated into technological evolution by automation, at times pushed to the limits, which has, in fact, eliminated the human being from the regulatory loop. Alternatively, safety systems have been reinforced, depriving him of any initiative. For several decades, based on research including numerous in-field studies, researchers have underscored both the fragile nature of the individuals, when faced with constraints, as well as their remarkable efficiency in complex and even critical situations. These are two sides of the same coin. This efficiency is not, however, a given; it depends on the person's experience, his interactions with the environment, the technical and human resources available, the organization of the work, etc. Thus, the efficiency depends on the context in which people work.

The problem of human error prevention has a high social resonance. All over the industrialized world, the consequences of errors and system breakdowns can be dramatic. They were revealed to a large public in a most astonishing and tragic manner by catastrophes like Chernobyl, Three Mile Island, Bhopal, Challenger, Airbus, etc. Less visible but more frequent failures and accidents at ordinary working places do harm to economic interests and preservation of labor resources in concrete organizations and society as a whole. The psychological aspects of overcoming such damage are clearly understandable. A person, who makes errors or performs wrongly and, on the other hand, can suffer as a result must be at the center of attention. This is not a new problem or a sudden request to applied psychology. The past century was a time of intensive psychological studies that linked together different facets of this problem. They primarily related to ensuring work safety, job efficiency and health promotion of the worker in a real job situation. The realities of modern society and dynamic changes in professional life emphasize the necessity to integrate this knowledge and look for ways of assimilating it in practice.

In this book, we have made an attempt to overview different psychological schools, methodological traditions and contemporary approaches to human error prevention that have grown in European applied psychology. Doing so we looked both at the West and at the East that have been developing rather independently for many years. Such a general outlook helps not only to fill the gaps in the knowledge or make a simple comparison between traditions typical for different parts of the world, namely Western Europe and Russia. It can also be promising to establish a common framework of research and distinguish the lines envisaging further development. Therefore, in the discussion of the materials we intend to pay more attention to the points of intersections and complementary findings which have been accumulated in the Western and Russian research traditions.

It is easy to see the diversity of national traditions in the error prevention domain that exists in Europe. The decades of development in dissimilar economic and political conditions led to the establishment of different conceptual backgrounds and dominating prevention strategies. Various fruits ripened on the tree of European applied psychology, although the Western and Eastern branches have common roots hidden in classical experimental psychology and psychotechnics. The more practically asserted Western research dealt more with substantial error experience and accident analysis. Therefore, the majority of approaches directly concern the characteristics of wrong behavior and ways of improving it. Russian investigations of human error did not put such a definite accent on error analysis. They were mainly conducted within a broader framework of work safety and human reliability research. Prevention methods and tools were elaborated as a part of general optimization procedures designed for the elimination of various risk factors in the work structure.

There are no principal contradictions between the mentioned research traditions. Moreover, in many aspects they are cross-related and help to enrich the content of the two basic strategies of dealing with errors: (a) error prevention in the strict sense (understanding as reduction of risk factors and error occurrence), and (b) error management oriented mainly towards error handling and error training (Frese, 1991).

Realization of these strategies depends on the level of implementation of preventative actions. It may be a single worker who needs protection or aids (the individual level), an operation with complex technical devices (the level of man-machine interactions), an organization or a complex socio-technical system (the organizational level). Changes in working life and technological innovations have moved the focus of dominant research interests along this hierarchy. However, these dynamics cannot be considered as merely a one-way transition from an individual level to a more global organizational outline. Basic trends in West-European and Russian research demonstrate an interactive form of development.

Different conceptual paradigms, which come from the West and the East, can be matched within this perspective. *The theory of action* (Frese & Zapf, 1994; Hacker, 1985) and the Russian *Activity Theory* by Leontiev (1978), enthusiastically used in Western research, have a similar orientation to the contextual analysis of mechanisms of activity regulation. Cybernetic models and systemic descriptions of man-machine functioning elaborated in the francophone school of work psychology stimulated studies on human information processing in *Western cognitive psychology*. There is a relevant Russian version of this research - the so called *microstructural analysis* of cognitive and sensory-motor actions. In both of these approaches, mental strategies and characteristics of task performance are revealed by means of cognitive modeling (Broadbent, 1985; Kahneman, 1973; Velichkovsky, 1988). *Stress at work* is one of the most popular topics in contemporary Western studies. The same problems are investigated by Russian scholars within the concept of *human functional states*. Transactional models of occupational stress and the state regulation approach are easily integrated when specialists look for psychological interpretation of stress phenomena (Cox & Fergusson, 1994; Leonova, 1998).

The list of conceptual replications can be continued. A cross-correspondence between many basic constructs makes it possible to overcome the terminological barriers and empirical inconsistency of different research traditions. It does not only stimulate scientific communications, but enriches the instrumentation of practical work. A modern trend towards building a new safety culture in organizations (De Keyser, 1995; Wilpert, 1990) stresses the necessity to re-orient traditional norms and regulations in error prevention practice. The technocratic ideology has to change according to strong social, economic and individual needs. Therefore, many new problems are emerging in the field of work safety and error prevention. They appeal to a broader psychological experience compared to what was implied in traditional human engineering research. Below we will discuss a core part of these problems regarding their actual pragmatic value.

The reader may be surprised at times to find, beyond a superficial homogeneity, a disparity in tone between the two parts of the book, the first part devoted to Western Europe and the second, to Russia. This is due to the fact that even though there are common psychological roots linking Western and Eastern psychologists, the conditions in which the disciplines have evolved, the material possibilities to collect data, diffuse ideas and finance certain research topics were completely different, not to mention the cultural framework and respective socio-economic perspectives. Because of a lack of access to organizations, Russian psychologists turned to the study of the individual. Research in Western Europe has evolved towards an analysis of the organization, in order to diagnose it. Today, we see that the two traditions tend to merge. Western Europe can now take a step back from accident prevention and human error– the data is available. In Russia, this area is just opening up, to be reconstructed piece by piece.

The authors are aware that their book does not reflect the diversity of all work psychology traditions in Europe. In Western European countries for instance, many studies, many research centers and most universities are presently working on the problems evoked in this book. Northern European countries, such as the Scandinavian countries, the Netherlands, Germany, and Great Britain have a very strong tradition in studying well-being at work. The same can be said about Russia: Russia is a broad and complex country, with a large diversity of scientific approaches. Nevertheless, the goals of the authors can never be exhaustive. We try to present an epistemological reflection of the diffusion of psychological findings across Europe. How does research influence practices or influence the development of prevention tools for instance? The authors do not hesitate to illustrate their ideas with their own studies – but these studies are just brought into play to illustrate a point, never as normative examples.

The bias of this book, if there is a bias, is somewhere else. Obviously, the book is focused on a contextual approach to human error prevention. This approach is supported either by qualitative or by quantitative methodologies, but mostly by cross-fired methodologies. The contextual approach is a heritage of the Russian Activity Theory. In this approach, the role of the activity is central: it gives a meaning to research results and guides prevention practices. If this contextual approach can be considered as a bias, it can also be considered as a scientific paradigm. It is, at least, the identity mark of the book.

This book is the result of the cooperation of two research teams, one in Belgium - the Department of Work Psychology of the University of Liège, led by Professor Véronique De Keyser, and the second in Russia - the Laboratory of Work Psychology of the Psychology Faculty at Moscow State University, led by Professor Anna B. Leonova. It consists of two parts.

In *Part 1* the development of a global vision of work safety and error prevention problems from the Western European perspective are discussed:

Chapter 1 concerns the evolution of ideas and the actors of change. It shows how ideas in the matter of prevention have evolved during the course of recent decades: first accentuating the human predisposition to accidents, there was an evolution in the 1960's towards a critique of the organization. The current trend is once again to give the subject a central position as an actor in the system, emphasizing that in a transactional perspective he unceasingly negotiates a compromise between his own resources and the often constraining requirements of the environment. The transformation of research topics, which passed from accidents to human error, and today to stress, burnout and mobbing is also dealt with here. An accent is put on the psychologists who have marked this movement, not only by their ideas, but also because of their influence, and their network of friendship that stretched all across Europe. The early collaboration of psychologists with Russia is illustrated with the French example.

Chapter 2 describes the connections between research and prevention instruments. To what extent does research influence them? The Activity Theory and the concept of mediation of Vygotsky will serve as an interpretive grid for a series of instruments (tools): safety-reporting systems, training simulators, user-centered design and aids for the operator. This chapter attempts to show how, and under what conditions, these tools really become instruments: that is, to what extent they are adapted by the users and support their activity within a given context. The role of psychologists in this re-appropriation is highlighted, emphasizing interdisciplinary teams.

Chapter 3 offers a reflection on the notion of context through two examples of research conducted by a team at the University of Liège in high-risk sectors, anesthesia and aeronautics. Both of these long-term research projects, which are still underway, are primarily addressed to the field. The first, however, is very broad and covers multiple aspects of prevention, while the second is highly specialized, even technical, dealing only with complexity linked to automation in aviation.

Chapter 4 is about prevention practices in Western Europe. These practices are traversed by different dynamics: by the impetus of the European Commission, national legislation and structures, by high-risk domains such as aeronautics or the nuclear industry, local population dynamics and lastly, by specific enterprise policies. One sees that these practices are often very vigorous and enlightening, and that an awareness in favor of a veritable safety culture is being born in Western Europe, even if the concept of human error does not always find its place.

Part 2 is devoted to Russian research:

Chapter 5 explains the methodology and basic research in the field of safety and human error prevention. Starting from a historical perspective, many common roots with Western Europe are discovered. The Activity Theory as well as a central concept in Russian applied research, the human functional state, is discussed.

Chapter 6 explores the different methods of assessment and human error prevention used in Russian applied studies. The accent here is on evaluating the efficiency of these methods, particularly, that of the activity regulation approach, directly linked to the concept of the human functional state.

Chapter 7 presents two research projects conducted during the years by the Russian research team at the Moscow State University, the first on a highly automated sector and the other on fire-fighters in the Chernobyl Zone. The first attempts to highlight the relations between automation, task performance, psychological states and health through a series of indicators. The second concentrates on stress and mental health deterioration, depending on the type of fire-fighting job.

Chapter 8 illustrates the role of Russian psychologists in the area of safety at work and worker protection. Among different psychological preventive approaches existing in practice the implementation of self-regulation training and its long-term effects on well-being and performance at work are accentuated. Modern empirical approaches to psychological support of professional computerized activity are also discussed.

Finally, some integrated *Conclusions* are presented at the end of the book.

This book does not correspond to the old clichés, which are often too rigid and simplified. Among them there is such a common opinion that work psychologists are far from social and economic realities and are only interested in solving relationship problems in enterprises or in personnel selection. Another vulgar idea is that Russia is “a land of barbarity”, where health and safety at work were swept away from the concerns of its leaders decades ago. A public discussion about the Chernobyl Accident could symbolize the absence of any policy or effort in this area.

One more delusion is that in going from knowledge to action, from in-field research and decision to realization, there is but one step to be taken. All of these statements are obviously false. This book highlights the extremely diverse, and sometimes astonishing roles of work psychologists throughout Europe. For the very first time, the Russian approach in this area is presented. Above all, the work insists on time: the time it takes for mentalities to change, the time it takes for structures to be transformed, so that a new vision becomes reality. It takes long time, and technology and economics advance much faster, unceasingly creating new risks. Thus, this work also leads us to a reflection on the urgency of the matter.

Véronique De Keyser
Anna B. Leonova

PART 1

HUMAN ERROR PREVENTION
IN A WEST EUROPEAN PERSPECTIVE

CHAPTER 1

EVOLUTION OF IDEAS AND ACTORS OF CHANGE

V. DE KEYSER

1.1. ACCIDENTS, HUMAN ERROR AND WELL-BEING AT WORK IN WESTERN EUROPE

The problem of human error and well-being at work, so vigorous today in Western Europe, has its roots at the beginning of this century in the concern to protect the worker in his job. Different safety indicators, such as the frequency rate, degree of seriousness and the number of mortal accidents actually continue to decrease. Doubtlessly, numerous factors explain this favorable evolution: due to social pressure, with the birth of worker parties and trade unions, European countries have gradually created a real safety net to restrict accidents, occupational diseases and work pollution. A whole legislative arsenal has been created; commissions gathering together employers and trade unions have been organized in the work place and outside; occupational medicine has developed; safety services have progressively been structured and given very specific missions – and at the same time, both the nature and content of work have changed. Thanks to automation and computerization, the constraining physical side of work and often-dangerous handling is lighter and there is more and more mental work. Of course, this evolution is structured differently from one country to another – but European integration, the instruments and tools that Europe has developed over the last few decades and its vast research programs in safety and health tend to make the efforts of each converge. If it seems quite obvious that well-being at work covers both quantitative and qualitative indicators, and that ideas which are apparently isolated, such as safety, stress, work satisfaction, are in fact closely linked, this viewpoint has not always prevailed. In fact, psychology has oscillated in one century between two tendencies: to privilege the individual or the system as the analysis unit. Beyond a simple dichotomy of approaches, there are in fact two ideologies. Focusing research on the individual, particularly in the area of work accidents, obliterates the influence

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of the work environment on the appearance of the phenomenon. It searches for the cause and the response to the problem in the person. Focusing on the system assigns an identical status to man and machine, leaving in the shadow interpersonal differences, free will and emotions that are all an intimate part of work. Is there a third way? Perhaps the human being could be considered in context, as a reliability agent who helps to control the system, if he is technically supported in his activity. This is what prevention must do. This third path will be at the core of this book, and we will underline, each time it is possible, the Russian influence on Western European Work Psychology.

1.2. THE INDIVIDUAL

If safety was the primary concern of the different European countries, accident prevention was originally based on two trends. One was oriented toward techniques aimed at restricting the danger of machines and different environmental risks. The other, oriented towards the individuals, considered them as victims, but also as responsible for their accidents. That is why psychologists were called on to explain and help control the human factor, unpredictable and complicated by definition, before the First World War. The conviction that psychologists could offer good advice was supported by hopes given by the nascent psychotechnics. The question that dominated the psychological debate was “to whom do accidents happen?” The individual occupied the foreground and the psychotechnic tool should allow – at least that was what was thought - the detection of those individuals at risk and to exclude them from the job, or at least, from dangerous posts or responsibilities. In fact, the story of psychotechnics in this field consisted in substituting the old notion of accident proneness, firmly planted in minds, with that of accidentibility. Accident proneness meant a certain personal tendency to have accidents, based on inborn characteristics, while accidentibility is a self tendency, but based on acquired characteristics in the course of development and modeled on professional experience. The experimental paradigm used during all of this whole period was the comparison of poly-accidented persons - workers often injured during their professional lives - and uninjured persons, using diverse methods of measurement. It was in fact hoped that significantly different characteristics between the two groups would be found.

As France was a pioneer in this field, we will use examples from there. Professions involving driving vehicles, such as tramways, trains, cars or lorries were those which aroused the most interest, and this, quite early on. As of 1910, in fact, Lahy (in Paris) perfected the diffuse attention test for driving trams that would be used by the RATP (French Public Transport Company). This test measures the diffuse attention capacity of the driver when submitted to complicated visual and auditory stimulations following each other at irregular rates, with a background of street noises and movements. The responses were the complex reaction times of the feet and hands. The test results of poly-accidented people were found to be inferior to those of uninjured people. They always succeeded less well when a fixed rhythm was imposed. Lahy, soon joined by Pacaud, continued to explore this phenomenon; in 1936 they published a comparative study with the same paradigm for railroads based on testing of a large number of subjects: 200 injured people and 300 with no accidents (Lahy & Korngold (Pacaud), 1936). They emphasize the influence of constraints from imposed rhythms and speed, as the required functional plasticity. Functional plasticity means the possibility to adjust quickly to new orders. Poly-accidented people are individuals who lose control faced with unexpected situations that they must confront very rapidly, such as an unexpected incident in the work place. These results were used by Bonnardel (1953) when he perfected the complex reaction time test (RCB) in 1953 destined mainly for truck drivers and athletes.

In spite of the important investment on the part of the researchers, the results can be summarized in just a few words. In the field of psychomotor functions, Lahy and Pacaud underlined the influence of functional plasticity on accident occurrence. In the field of intelligence, a distinction is made between general intelligence, or logic, and concrete intelligence. There seems to be no relation between accidents and logical intelligence, except below a very low intelligence threshold. Bonnardel (1949), on the other hand, notes the influence of concrete intelligence, evaluated with Kohs' cubes. From the point of view of personality, research has taken a step backward compared with the psychoanalytic thesis of accident as self-punishment put forward by the Freudian school in 1914. They observe personality problems and difficulties in social relations in the poly-injured and new tools are created. Some remain highly impregnated by the psychoanalytic model, searching for the origin of psychodynamic conflicts leading to accidents in early childhood; others make fewer assumptions about causes, but give prominence to behavioral characteristics specific to poly-injured people. This is the case with the questionnaire by Jenkins (1956) that includes seven syndromes associated with the tendency to accidents: lack of attention, lack of discernment, feeling of social independence, lack of sensitivity to others, an irrational attitude towards loss incurrence, too much self-confidence, an aggressive social attitude and poor integration. As to sensorial deficit, the results are far from convincing, but as a precaution, sensorial tests are included in most selection test batteries for positions involving safety. Who would dare hire a one-eyed crane operator or a lorry driver that evaluates distances badly? A valid assortment of tools allows, as a rule, the detection of individuals at risk.

At the end of the 1950's the tests were subjected to violent criticism, both scientific and ideological. And this, especially in the fields of intelligence and abilities. In his book on mental tests published in 1976, Zurfluh reports at length on this criticism (Zurfluh, 1976). He explains in detail the Marxist criticism - the intellectual and scientific movement closely tied to ideas in the USSR which marked the post-war years. With the resolution of the Communist Party Central Committee of July 4, 1936, a debate in that country began between the Marxists and the test supporters. The Central Committee of the Party had already asked on September 5, 1931 that psychological research concentrate on educational problems. The tests and questionnaires were accused, and not without reason, of only reflecting a bio-sociological point of view. These tests looked for the causes of school failure in heredity and innate aptitudes. It must be noted that during that same period the Nazi Party had organized its entire school system on ideologies of talent and race and a policy of academically able students. As of 1933, it created schools for the elite, the "Napolas" (National Politische Erziehungsautalten) where students were selected by physical trials and mental tests. The USSR thus wanted to keep its distance from these positions, a distance certainly necessary, but one with too few nuances. In 1955 a delegation of French psychologists and teaching specialists, including Fraisse, Piaget and Zazzo were guests of the Pedagogical Science Academy in the USSR. During this meeting, Soviet psychologists, such as Teplov and Luria, criticized the exaggerated use of these tests in the USSR, but in a conversation with Zazzo, Leontiev called their systematic rejection leftist. In France, as of 1945, Naville attacked the idea of aptitude, which Pièron defined as specific and hereditary. He saw it rather as the result of interaction between the economic social environment (production system) and individual organizations. From 1949 to 1951, a debate developed in Britain around intelligence and psycho-technical practices. This debate is reflected in the review, The Modern Quarterly, with protagonists such as McPherson, Simon and Morris (see Zurfluh, 1976). It mainly concerns the intelligence concept and the relative importance of heredity and environmental factors. It denounces the philosophical illusion of psychometrists who, because they use intelligence tests that are non-verbal and abstract, believe themselves to be free from the weight of the educational environment. References to Soviet philosophy and reflection theory run like filigree in these passionate discussions. At the end of the fifties and the beginning of the sixties the criticism increased in most European countries as well as in the United States. It was there that Whyte published "The Organization Man" in 1956 that devotes one chapter to tests, with an appendix entitled "how to cheat in personality tests". The author assails personality tests in particular as being non-scientific and intended, above all, to test the "potential loyalty" of the candidates (Whyte, 1956). The impact of the work in Europe was great.

Accident prevention by selection was dragged into this criticism movement; the notion of proneness to accidents was targeted in particular. However, neither Lahy nor Bonnardel, both pioneers in safety selection, ever accredited the notion of an "innate" predisposition. They always noted the impact of the environment, and particularly the economic factor in ability development. Lahy was always extremely clear-sighted, as when in 1935, in a criticism of the intelligence concept, he asserts to have perceived how "economic factors stop the mental development of a whole class" (Lahy, 1935). But it appeared increasingly clear that excluding poly-injured people is not enough for good prevention: others like them follow, as if the work environment generated them. Therefore, it was toward this environment and its characteristics that attention turned as of the early 1960's.

1.3. MAN-MACHINE SYSTEMS

The 1960's were marked by a reversal of the accident problematic. From then on, the question was no longer "*to whom do accidents happen*?" but "*in what situations does the probability of accident increase*?" This marks a change from the causal model to the probability model: one no longer tries to determine the cause of an accident, but rather tries to detect, in the events preceding the accident, which sequence of factors allow its occurrence. How can this reversal be explained? In fact, psychotechnics proved disappointing and Europe had created enormous research programs. The Treaty of Rome anticipated health protection and worker safety. In the 1960's, CECA launched studies on safety in mines and the steel industry. It was the first time that such works were coordinated on the European level, with frequent contacts and follow-ups by teams from different countries. The impact of these studies on the way of viewing accidents and understanding their course was immense. By detecting the events preceding the accident, organizational failures, breakdowns and incidents, the researcher's view was no longer limited to the accident itself, but to a more vast succession of symptoms, expressing, according to Leplat and Cuny (1974), "the pathology of the whole system". The unit of analysis "man-machine system" replaced that constituted by the isolated individual. More and more interest was expressed towards the risk factors that precede an accident. They are, more often than not, latent within the organization, even in the absence of an accident, but are unexpectedly activated as a release mechanism – as in incidents when organizational change occurs. Even the very concept of safety tends to be abandoned: in studies one speaks rather of "reliability". Technically, *reliability* is the probability that a component of the system will not break down during a given time interval. Such borrowing from technical language is revealing. A breakdown is a perturbation, whatever kind it is. An accident is always likely – but never sure. Nevertheless, mathematically one can, with a good collection of data, estimate the probability of an accident. Thus, the ineluctable character is lost, that which is unpredictable and subject to human caprice. Prevention is possible: it must be directed at risk factors. The human being is only one risk factor among others, one of the elements of the man-machine system.

There are many reasons that encouraged researchers at that time to take into account criteria other than that of the accident in their analysis. The systematic perspective was in the air. Wiener's (1948) and Ashby's (1956) cybernetic approach, the mathematical theory of communication developed by Shannon and Weaver (1949) and von Bertalanffy's work (1968) on the systems theory, found echoes in all scientific domains. In the CECA safety programs, the research was awarded to university teams closely tied to the steel-making and mining circles. In France, Belgium, Germany and Italy, research drew its theories and models from the most innovative trends of the epoch; but this was applied research, anchored in the field**.** The man-machine system is the organization taken as a group of interacting cells, following a production objective, with profitability, safety and quality limitations. The interactions include exchanges of many kinds – information, products, raw materials, etc. – disposed to being observed and quantified. The system output is diverse: production and quality, but accidents, defects, breakdowns and incidents as well. All of these undesirable outputs are part of the same etiology, because the risks generated by the organization are passed on indiscriminately to one output or another. Take the classic example of maintenance. An irregular upkeep with no follow-up, may have different consequences. A poorly maintained machine may have a technical incident and product quality will be affected. It may also break down, and the stoppage could lower production rate. But this stoppage may have a more serious consequence because, as Faverge (1967) notes, statistically, accident probability increases when there is an incident, as a result of the dis organization caused by making up for losses. He adds:

> "Too often the reports are only snapshots taken at the moment of the accident; one notes the injured part of the body, what caused the injury, the person's gesture, etc. and one forgets to get information about what happened before; this is a great lacuna affecting the informative value of the accident report which reduces its use for prevention. It seems evident that an event of this kind must be apprehended from the chain of events which preceded it; the temporal dimension, even the "historical" dimension, is indispensable for the evolution of hypotheses concerning the causality of the phenomenon. Without a doubt, the idea of accidents strongly includes a certain notion of unpredictability, of suddenness, and herein is at least a part of the origin of those practices for which we question the value" (Faverge, 1967, p. 29).

When one really wants to limit accidents, it is useful to return to the chain of factors and to stick to the forewarning signs, more easily observable because they are more frequent. Take incidents, for example. They weigh heavily on safety, but they do not cause an accident every time. Minor injuries, signaled by a visit to the infirmary without a work stoppage, are indications of a certain level of safety or reliability. Thus, one sees that researchers multiply the substitution criteria for the accident, because if the theoretical and methodological bases of research reflect their epoch, they are firmly empirical. Their objective is to be able to observe the phenomenon of the accident on site and to avoid resorting to second-hand information, often marred by bias, omissions and causal attributions, as are accident declarations. Some are strictly reduced to this view; others are more subtle, leaving a distinct place for the operator. The French school, for example, strongly influenced by Soviet trends, left a privileged place for the operator as a regulator of the system. Far from being only considered a risk factor, he plays an essential role not played by machines: he detects, anticipates and controls incidents, preventing many accidents and catastrophes (Faverge, 1970). Other authors have adopted this view (Amalberti, 1996; De Keyser, 1972, 1987, 1989; Leplat & de Terssac, 1990).

However, in the sixties, the French approach completely obliterated the expression of emotion. It studied human behavior, explored the subject's knowledge but remained uninterested, at this time, in his discourse, his stress or even his suffering at work. This was not the case in Germany. Also influenced by Soviet psychologists, in the 1970's German researchers combined Activity Theory, from

Luria, Leontiev and Oshanin, with their tradition of psychology of depth, well illustrated by Wundt. The notion of stress thus appeared much earlier and the human being was considered in a comprehensive fashion, with his cognitive and emotional dimensions in research on safety.

1.4. THE INVENTION OF HUMAN ERROR

In the 1980's, the media literally imposed a notion, that of human error, which scientists accepted only with reluctance. Actually, this notion seems to be a retreat in comparison with the systemic standard that favored, as an analysis unit, the men-machines system and an approach to human reliability in the probability framework. Disasters such as those at Three Mile Island, Bhopal, then Chernobyl focused attention on the operator’s role, on his ability to control more and more technical and complicated systems and on the risk he represents, as the most fragile link in the chain – fragile because he is subject to forgetting, to fatigue, to emotions, to temporal pressure and to so many other factors. The old expression “errare humanum est” has gone astray from its meaning. Far from signifying that it is natural to make mistakes, and that it can even be good to do so, because it provides a source of apprenticeship, it too often becomes “Humans are fallible by nature”. Thus, it becomes advisable, whenever possible, to separate them from production, thanks to increasing automation and computerization

Why are scientists so suspicious of this notion, while finally adopting it in their written works? Different reasons for this suspicion can be proposed.

1.4.1. Definition of Error

This definition is full of ambiguity. In works by Leplat (1985, 1997), Norman (1981), Reason (1990), Woods, Johannesen, Cook and Sarter (1994), Hollnagel (1991), the definition that seems to emerge: discrepancy in relation to a reference recognized as correct (norm, model, theory, established knowledge) although the subject intended to conform to it. Degrees of freedom must exist to think or to act with respect to this reference (Reason, 1990). It is widely accepted that (Bagnara, Dimartino, Lisanti, Mancini & Rizzo, 1990, p. 3):

- Human errors should not be conceived as merely due to the incompetence of the operators, since in many cases they are the result of persons’ best attempts towards the accomplishment of desired and sensible goals.
- Human errors are multifaceted events.
- Human errors should be considered as man-machine mismatches, where the two components of the whole man-machine system enter a state of conflict partners in the system, it is crucial to find what has gone wrong (i.e. the potential conflicts between the two partners in the system), rather than to assess who has to be blamed for an error.

So, a misspelled word in a letter to a superior is probably an error because the intention of the author is without doubt to write according to a canonical form. On the other hand, someone wanting to hide his identity in an anonymous letter will not hesitate to make spelling mistakes that cannot be qualified as errors, as there is an intentional transgression of the norm.

However, the problem is the standard or the norm. It can come from at least four sources:

(1) the subject him/herself;
(2) an external expert;
(3) explicit rules;
(4) implicit rules given by habits.

Each of these sources has its variability. Individual norms vary from subject to subject: what is an error for one is not necessarily so for another; experts rarely agree in their judgements; explicit and formal rules change over time. As for the implicit rules, one knows from the work of sociologists like Bourdieu (1980, 1984), to what extent they reflect social practices and power structures.

1.4.2. The Context of Error and its Probability of Occurrence

One knows that certain contexts favor errors to the point of making them almost inevitable. So, is the night worker who is exposed to noise, heat and an intense workload inevitably more prone to error than an employee in an air-conditioned office who sets his own pace? What are we judging when we speak of error? Hollnagel (1991) made an interesting comment on this. He distinguishes three qualities of the man-machine system where lessening competence may bring about different kinds of errors. He highlights the variability of the context in which they may arise. These qualities are:

- Reliability: the quality of the system to carry out a certain function in well-defined conditions in a lapse of time. In this framework, an error could be the non-observance of a norm. For example, the pharmacist who, under perfectly normal conditions, makes a mistake in filling a doctor's prescription.
- Robustness: the quality that allows a system to assume a function in extreme experimental conditions. An example is the case of a night train conductor going through a red light because of a drop in vigilance or a micro-sleep.
- Adaptability: the quality that allows a system to accomplish a certain function in environmental conditions where normal procedures cannot be used. In this case, one must distinguish between situations that arise unexpectedly, where alternative procedures are foreseen, from entirely new situations where the plan to follow must literally be invented. One can imagine, in the first case, the mistake of a novice anesthetist who, faced with the worsening of a patient's condition, is unable to apply an

emergency procedure even though it is available. And in the second case, testing a treatment for a rare illness that, instead of ameliorating the patient's state, leads to a fatal outcome.

One intuitively feels, and research will prove it so, that context influences the probability of error. If in some cases, it appears to be fortuitous, in other cases, it is nearly inevitable. The degree of control a person has over his situation can vary enormously.

1.4.3. Bias in Attribution and Hindsight

Woods et al. (1994) declare clearly that attribution of error after the fact is a process of social judgement rather than an objective conclusion. These authors summarize these two aspects as follows:

- The genesis of an incident is produced by the linking of many factors. Nevertheless, depending on the analyst, on his function and his own interests, mechanisms of causal attribution will appear that will clarify, in a preferential way, one or another of those factors. Moreover, as at the beginning of the analysis of accidents, the risk exists that the analyst may neglect the dynamics of the incidental process to point the finger at the operator. Indeed, in an accident or disaster, the human gesture that provokes or that at least is not able to recover the situation is often the last link of the chain.
- Knowledge of a result modifies the memory of the past. The bias of hindsight defines error, because behavior that is resituated in its temporality and context appears natural. If, at the time of Moliere, it was normal to bleed a sick person to treat him, such a treatment would today appear barbarous, indeed even criminal. To call reasoning or action error is to pass social judgement, and such judgement is subject to numerous influences, social stereotypes, crystallizing the knowledge of time - and, under no circumstances, has a scientific status.

1.4.4. Consequences of Error

From the bias of hindsight, it is the consequences of the errors rather than the errors themselves that attract media attention. It is the link between error and disaster that justifies attention. Nobody is disturbed by the error of a postman who brings a letter to the wrong address, but everybody feels deeply distressed, and rightly so, by the error of a pilot who takes the wrong rate of descent and crashes into a mountain, like in the disaster of Mount St. Odile in France in 1992 (Monnier, 1992). Nevertheless, the consequences have nothing to do with the nature of the error. They have everything to do with the context, the technology used, the functions and the past history of the persons implicated. While every error does not necessarily lead to damage, and many errors are spontaneously recovered, the link between error and disaster is firmly fixed in the mind of the public, giving it bad publicity. These are the reasons why many scientists have been reluctant to use the concept of error, often preferring to speak of the incident process, of human reliability or, like Hollnagel (1991), of an "erroneous act". They did end up accepting that usage, so as not be cut off from the common language conveyed by the media, but did not do so without denouncing the ambiguous and relative character of the concept.

In 1981, a memorable NATO symposium was held in Roskilde in Denmark, under the leadership of Rasmussen, an engineer with close ties to the scientific community studying human factors. The topic was "Human detection and diagnosis of system failure" (Rasmussen & Rouse, 1981). Indeed, this symposium rallied and would link together for a long time many of those who had endeavored to prevent human error for some 20 years – in Europe as well as in the United States. This was primarily due to Rasmussen's charismatic personality and his extraordinary capacity to assimilate different theories within a frame model. He tirelessly derived different applications from his model that went round the world: interface conception, error classification and analysis of decision-making. Each stage of decision-making (Skill-Based, Rule-Based or Knowledge-Based Behavior) can be a source of error. Thus, in the generation of an action, there may be several cognitive errors (see Figure 1.1).

These errors may never lead to consequences, nor do they even touch the surface. A bad diagnosis does not always lead to bad treatment. In the case of infection, broad-spectrum antibiotics are very useful and allow a rough evaluation of pathogenic agent and the source of infection. In industrial production, many incidents are recovered and the state of the system is brought back to normal, while the identification of the causes of the problem remains vague. Rasmussen's ideas spread all over Europe and crossed the Atlantic. The RISØ Research Center in Roskilde rapidly became the turbulent place where all scientists interested in human reliability met, exchanged views, and argued. Rasmussen's close disciples in RISØ (Goodstein, Andersen & Olsen, 1988) contributed to his fame, but well known psychologists such as Leplat in France, Brehmer in Sweden, Duncan and Reason in the United Kingdom - all friends of Rasmussen - deeply enriched his psychological references. Vicente was among the main sources of Rasmussen's influence in the United States. He worked with Rasmussen in RISØ, and kept on, and even enlarged his cognitive approach in man-machine interface design. Vincente, together with Rasmussen, created the concept of an ecological interface (Flach, Hancock, Caird & Vicente, 1995; Hancock, Flach, Caird & Vicente, 1995; Rasmussen & Vicente, 1989). The goal of an ecological interface is to develop a meaningful representation of the process which is not just optimized for one particular level of cognitive control, but that supports all three levels of Rasmussen's cognitive model simultaneously. This design philosophy is intended to reduce the operator's cognitive load and the risk of human error.

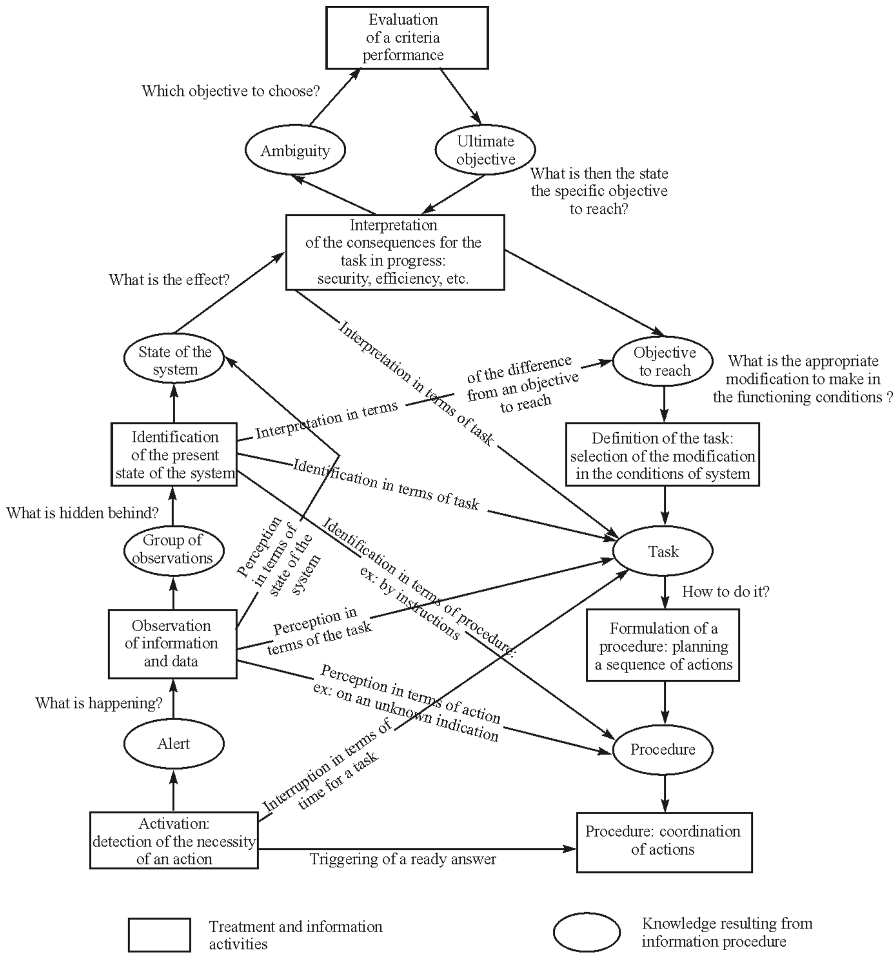

Figure 1.1. The decision-making model, called the "double ladder" by Rasmussen (1986). From left to right, successively from bottom to top and from down to up, one goes from detection to identification, then from evaluation to planning to execution. From top to bottom also, one successively finds control levels based on automatisms, rules and declarative knowledge. Finally, short circuits allow, in certain cases, to make economies in high levels of controls.

Reason, from Manchester University, was close to Rasmussen. Soon after Norman (1981), he insisted as much on the mode of action, automatic or controlled, as on the stage of information treatment where the error appears. He distinguished three types of errors: slips, that are errors in carrying out a plan when the attention mode is faulty; lapses, mainly caused by memory failure; and faults, linked to judgment and planning. In GEMS, his generic system of modeling error, he combined his own approach to error with Rasmussen's three-level model (see Table 1.1).

Table 1.1. Summary of the distinctions between skill-based, rule-based and knowledge-based errors

Dimention	*Skill-based errors*	*Rule-based errors*	*Knowledge-based errors*
Type of activity	Routine actions	Problem-solving activities	
Focus of attention	On something other than the task in hand	Directed at problem-related issues	
Control mode	Mainly by automatic processors (schemata)	(stored rules)	Limited, conscious processes
Predictability of error types	Largely predictable "strong-but-wrong" errors (actions)	(rules)	Variable
Ratio of error to opportunity for error	Through absolute numbers may be high, these constitute a small proportion of the total number of opportunities for error		Absolute numbers small, but opportunity ratio high
Influence of situational factors	Low to moderate; intrinsic factors (frequency of prior use) likely to exert the dominant influence		Extrinsic factors likely to dominate
Ease of detection	Detection usually fairly rapid and effective	Difficult, and often only achieved through external intervention	
Relationship to change	Knowledge of change not accessed at proper time	When and how anticipated change will occur unknown	Changes not prepared for or anticipated

However, Reason (1990) went well beyond this classification. He suggested a real model for decision in a state of uncertainty and postulates that faced with an imprecise problem for which he does not master all the facts, the individual puts heuristics into play, which allow him to reach satisfactory results most of the time. These heuristics are procedures of automatic search based on similarity matching and frequency gambling. Thus, during a flu epidemic, a family doctor who sees a patient with a fever and a cough that complains of aches will probably provisionally diagnose flu and see the patient five days later if the situation does not improve. This quick, inexpensive, heuristic act is of course not without risk. Some more serious illnesses than the flu can start with the same symptoms. Reason highlighted that error is often the price that must be paid for flexible cognitive functioning which adapts to the complexity of situations, despite human cognitive limits. Reason, like Rasmussen, provided an impetus from his work that first had a cognitive orientation and then opened up to ergonomic and organizational aspects.

Actually it is a European characteristic of applied research not to separate the cognitive aspects of human errors from the contextual and organizational ones. This was already part of Rasmussen's work and has been emphasized by Reason. Reason has developed a broad conceptual approach of risk management, in which human error is just one aspect of the functioning of the whole organizational system. He elaborated the concept of a healthy organization, and has tried to fill the gap between safety research and total quality management. This organizational approach was broadly adopted in Europe, and supported by various classification methods developed in different countries. It allowed human reliability to be taken into account not only in classical industrial plants but also in large scale systems such as transport systems, consumer goods distribution, information systems, etc. For instance, organizational and systemic approaches to traffic problems have integrated cognitive and ergonomic research findings. The ergonomics of the car and the intelligent aids to be developed to support the driver or to increase the safety of pedestrians have been related to a broad analysis and the regulation of traffic at a European level. The same effort, integrating organizational to cognitive engineering perspectives, was made in aviation, the railways, process industries, hospitals, etc. Some countries such as the Netherlands, or the Scandinavian countries have made impressive progress in this direction. In the Netherlands, for instance, many multidisciplinary research teams are working in safety science. The universities of Delft (Hale, 1998; Hale, 2000; Hale & Guldenmund, 1998), of Leiden (Wagenaar, 1993; Wagenaar & Groeneweg, 1987; Wagenaar, Hudson & Reason, 1990), of Eindhoven (van der Schaaf, 1992) are well known for the analysis methods they have developed, and the multiple safety applications they have implemented in various fields.

But engineers who design large scale risky systems have to go beyond the description of the complex phenomena leading to accidents or catastrophes. To make safe design decisions, they need to assess the probability of human error. But how can human error be quantified, taking into account not only externalized and observable errors, but also cognitive and internalized errors? It is without doubt Hollnagel, from Norway - a regular participant in Rasmussen's scientific debate - who went deeper in this direction. His ambition was in fact to join two trends that had evolved in parallel until then: Human Reliability Assessment (HRA), dominated by the engineers, and the cognitive approach to error, advocated by psychologists. The problem, as classically posed by HRA, is less in preventing error and in understanding it, than to balance, within a technical system which includes men and machines, the weight of human unreliability, and then to judge the acceptability of risk in order to guide technical and policy choices. How can procedures of traditional energy production be compared for risk to those of nuclear energy?

Answering such a question requires estimation of the probability of accidents, incidents and error as well as the consequences. Calculations were traditionally made starting from a classification of errors that likens the human being to a machine and where only behavior is taken into account (Swain & Guttman, 1983). Getting away from this mechanistic view, Hollnagel (1998) tries to reintroduce the cognitive aspects in the HRA vision in the heart of the method he proposes, CREAM (Cognitive Reliability and Errors Analysis Methods). He brings out the approximate knowledge that subjects may have of complex situations in which they are engaged and insists on the following points:

- The necessity, in the analysis of erroneous acts, of distinguishing phenotypes (their visible manifestations) from genotypes (their deeper causes).
- The necessity of examining the antecedents of acts as well as their consequences.
- The necessity of being able to predict both qualitative and quantitative erroneous acts.
- The importance of taking into account not only the procedures put into play by the subject in the action but the control modes of the situation as well. These modes, described by the author as strategic, tactical, opportunist or scrambled, are in fact a sort of broad continuum ranging from anticipative control of the situation to totally disorganized and unpredictable control.
- The necessity of preserving the systematic aspect of the appearance of the erroneous act in a given context, while conceding to the indispensable statistical breakdown and classification dear to HRA.

The complexity of technical systems, the approximate knowledge that operators may have, the constant compromises that they must make to manage as best they can, given their limited resources, are the leitmotivs in the work of Amalberti (1996) in France. Close to de Montmollin and Leplat in France, but having also worked with Rasmussen, he enriched the literature on human error with an empirical approach and by modeling the activity. Working in aeronautics, he studied pilots' strategies in dynamic and complex environments. Constantly faced with contradictory demands that are excessive in relation to the instantaneous resources that they can put into play, pilots develop strategies that allow them to unleash resources to manage, or even simplify, the complexity that surrounds them. This is the notion of cognitive compromise. Amalberti distinguishes two main ways of simplification. The first is diachronic and consists in managing resources as well as possible, using the temporal dimension. Planning and anticipation are the key elements. Creating a plan, adjusting it to real time, anticipating its evolution and the incidents that may occur are economic strategies, but constitute a capital of resources that can be put in action. The second way of simplification is simply understanding the situation, that is, cognitive control assisted by different representation levels that can be adjusted to existing resources. Here we are very close to Rasmussen's ideas. However, insists Amalberti, one can try to understand – but one can also renounce understanding everything. Cognitive compromise sometimes consists in renouncing understanding, in tolerating temporary misunderstandings and getting ahead by anticipating future misunderstandings. The author comes to this nearly paradoxical conclusion based on field observations,

> "There is still one situation where management of misunderstandings is no longer a choice, but a necessity, considering the accumulated difficulties. There again the operator must accept the idea of not understanding if his representation remains compatible with the preservation of the system with its safety and efficiency cover. The results obtained in aeronautics support the view that the most expert pilots are typically those who accept ignoring most transitory non-understood events that occur during the flight. Young pilots "open" activities of understanding for each event and find themselves quickly faced with the combined activities of understanding and piloting. As they are in a hurry, they end up committing errors at all levels: in piloting strictly speaking, by a decrease in anticipation and a loss of confidence, mostly in understanding, by revising the parts of the picture on which they are focusing, while neglecting the much more vital parts" (Amalberti, 1996, p. 157).

Regarding the error occurrence mechanism, Amalberti speaks of a break in cognitive compromise. The use of aids, for example computer assistance, has the effect of improving performance – but in an artificial manner – and decreasing the global number of errors, but increasing the risk of undetected errors (see Figure 1.2).

Situation complexity, approximate knowledge, simplification heuristics and cognitive compromises: one sees that gradually, behind the idea of human error, there is increasing difficulty for individuals to master the systems they are supposed to control. In the United States, Woods developed the same ideas. A friend of Rasmussen and Hollnagel, he spent some time in Roskilde. Familiar with the French ergonomic school (De Keyser & Woods, 1990), he first worked in the nuclear field and then in the areas of anesthesiology and aeronautics. He is a well-informed critic of both system automation and computerization, and with disciples such as Roth (Roth & Woods, 1988) in nuclear studies, Cook (Cook & Woods, 1994) in anesthesia, and Sarter (Sarter & Woods, 1991, 1992, 1994) in aeronautics, he unceasingly denounces "clumsy automations" which, rather than helping an operator in a critical situation, constitute an extra burden (Bainbridge, 1987). With Sarter, he studied the interactions of the pilot with the automatic pilot (Flight Management System), a system of automatic piloting to which tasks can be delegated via specific computerized modes. Woods noted the difficulties and some fundamental surprises created by the automation. In certain contexts, the pilot was incapable of understanding which mode he was in or how to disengage the automatic pilot in order to assume manual control. Here the pilot has, using the authors' term, "lost his situation awareness". It is well known that such a loss of awareness can lead to disasters in the air (Monnier, 1992) – see Chapter 3.

Even if Roskilde was an indisputable center of attraction for all research on human reliability in Westem Europe in the 1980's, one cannot ignore the important role played by the Bad-Homburg meeting. It was in this small German city that B.

Wilpert, Professor of the Technological University of Berlin, initiated annual meetings, marked by a series of publications (Bainbridge & Ruiz Quintanilla, 1989; De Keyser, Qvale, Wilpert & Ruiz Quintanilla, 1988; Hale & Baram, 1998; Hale, Freitag & Wilpert, 1997; Leplat & Hale, 1998; de Montmollin, 1990; Rasmussen, Brehmer & Leplat, 1990; Rasmussen, Duncan & Leplat, 1987; Roe & Andriessen, 1994; Vincent & de Mol, 2000; Warner, Wobbe & Brödner, 1989; Wilpert & Qvale, 1993) which were supported by the German Werner Reimers Foundation.

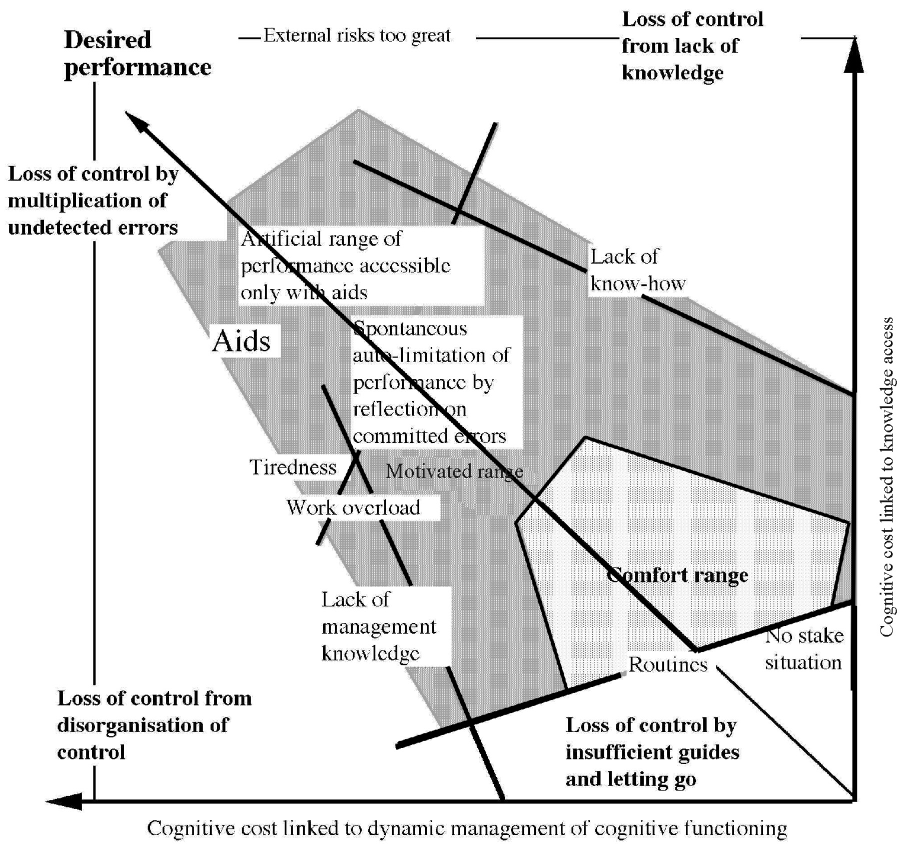

Figure 1.2. Cognitive compromises and performance (adapted from Amalberti, 1996).

The first themes of the international symposia were directly linked to human error and technical evolution, but they quickly broadened in scope. If the reliability of socio-technical systems remained at the heart of the debates, the problematic of change, either on technical, organizational or geopolitical level became more important. The Bad-Homburg meetings were less a framework for theoretical and methodical thinking, even though this was not absent from the debates, than for attentive and critical forums for emerging realities and the problems they pose for work psychologists, human reliability being just one of these. Unemployment, tele-commuting, atypical forms of work, and changes in values in Eastern Europe feed the debates. Out of these meetings, the European Network for Work and Organizational Psychology was born. Far from being confined to Western European scientists, its first goal was to bring together scientists from both East and West.

1.5. WELL-BEING AT WORK

The worrisome evolution of social Europe since the petrol crisis in 1975 has put risks such as unemployment and exclusion at the forefront. Even if they do not relegate the problems of safety and human error to second place, they are however recurrent themes in the literature as well as in the concerns of European institutions and policies of member states. How can the fracturing and dual evolution of society be avoided when one knows and sees that economic recovery does not always mean an increase in employment? The globalization of the market economy that inescapably affects all countries, has not only a direct impact on the citizen but also creates, more implicitly, indirect risks at the level of work (see Figure 1.3).

The flexibility demanded in enterprises, on the organizational as well as the individual level, the tension that weighs on everyone and employment instability all create phenomena that can no longer be ignored. Job insecurity, job dissatisfaction, stress, burnout, lack of organizational commitment are all nightmares of Human Resources managers because they carry hidden costs – just as delocalization, closings, mergers and restructurings are nightmares for workers. This painful atmosphere also leads to dynamic relational problems, such as mobbing, or aggressiveness of a group towards a scapegoat. Although these themes do not represent the entire economic picture, they cannot be neglected, and around them a scientific community is starting to form. Is it different from the one studying accidents and human error? To a certain extent, yes, even if they have begun to overlap. In the North, the Scandinavian countries, Germany and Holland have long been concerned by the damage caused by stress, burnout and mobbing (Becker, 1993; Frese & Zapf, 1994; Leyman, 1996; Lindström, 1996; Schaufeli, 1999; Schaufeli & Enzman, 1998; Vartia, 1996; Zapf, Dormann & Frese, 1996; Zapf, Knorz & Kulla, 1996). This concern is found both in their research and in the laws. They also sensitize public opinion and the different interlocutors in the work world, such as employers and trade unions. Though these themes were first developed in Northern Europe, they are quickly gaining ground in the South: in Italy, Spain (Peiro & Bravo, 1999) and Portugal.

It is certainly stress at work that has received the most attention, because of the damage it causes to society, as well as to enterprises and individuals. The first authors who considered stress, such as Selye (1956) or Grinker and Spiegel (1945), did not do so in an industrial setting. The Second World War was one of the first fields of application of the concept of stress affecting the performance of soldiers in combat. Stress increased soldiers' vulnerability towards death and injury and decreased the action potential of a combat group (Grinker & Spiegel, 1945).

Globalization and international competitiveness

TENSION		FLEXIBILITY		UNEMPLOYMENT	
Nature	*Risks*	*Nature*	*Risks*	*Nature*	*Risks*
More and more complicated technological investments	Increase in parameters to be watched Man becomes a supervisor Demand for continuous training Risk of human error	*Continuous working of machines*	Reduction of down time – management of more numerous parameters for the operation Greater training requirements and more systematic	*More and more exclusion*	Loss of confidence in the future and in the worth of the diploma
Increased speed of installation	Accident risk High mental load	*Just in time management*	Increased time pressure Constant auto evaluation and organisational evaluation	*Multiple government aids but scattered*	Mandatory label for the unemployed Complicated administrative system
Tight management of production parameters	Increased control	*Flexible team management*	Risk of losing social ties Increase in work accidents	*Attempts for re-insertion in the social economy*	Many failures due to lack of stable policies Disappointment
		Tele-commuting	Social isolation Decrease in quality of working conditions Return to piece work Loss of promotion Organizational difficulties		
		Flexibility of contracts for temporary work	Instability of work		
		Virtual enterprise	Social contacts Working conditions Work instability		

Figure 1.3. Risks introduced by globalization and international competitiveness (De Keyser, 1997a; Hansez & De Keyser, 1999).

Following the panic provoked in particular by bombing missions, the soldiers further fed the first reflections on post-traumatic stress. There is still a current trend in research dealing with this problem. Wars are far from over; increasing violence is found in schools; there is aggression where the victims are members of professions constantly exposed to the public: e.g., bus drivers, policemen, counter clerks, fund transporters, and postmen; accidents and natural disasters are all areas where urgent psychological intervention is vital. But what is more insidious is chronic stress from ordinary work that is defined as the

> "response of the worker faced with the demands of a situation for which he doubts that he has the necessary resources and for which he estimates that he must face up to" (De Keyser & Hansez, 1996, p. 133).

Born of repeated frustrations, conflicting objectives, role ambiguity, tensions in work relationships, heavy time pressures, and sometimes work conditions which remain unpleasant, this stress remains an everyday fact of life, despite the great improvements in this century in environmental quality and physical work load. The insecurity of the future and the fear of job loss, of not being able to face up to continuous demands under the threat of being marginalized and then excluded, all feed it. Much of today's literature concerns this stress. Among the most interesting models, and which explains both the influence of reasons for stress and subject variability, we cite the transactional model of professional stress of Mackay and Cooper (1987) (see Figure 1.4).

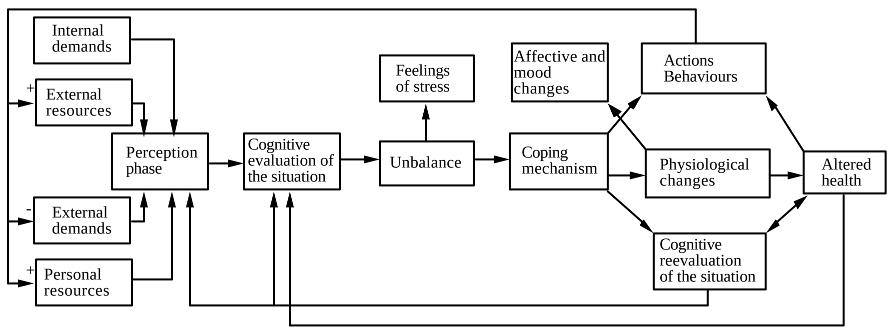

Figure 1.4. Transactional model of professional stress (Mackay & Cooper, 1987).

This model represents the individual regulation of stress agents (internal or external demands) by the subject: first in the cognitive evaluation he makes of the situation, and then in the mechanisms of adaptive coping he develops if the evaluation indicates an imbalance between demands and resources. Failure of these two successive mechanisms may, in the end, provoke health changes and the associated signs: an increase in errors and a decrease in work quality and productivity. This transactional model irresistibly evokes that of Amalberti's (1996) cognitive compromise in risky systems. Both deal with strategies of resource regulation in order to adjust to demands of constraining environments; both lead to breakdowns in case of ruptures in balance, on the one hand, stress, on the other, errors, and possibly accidents.

Very similar models explaining human adaptability as well as its possible failure have emerged from distinct scientific circles. The transactional perspective of stress at work emphasizes the feeling of situation control (Karasek, 1979, 1989; Sauter, Hurrel & Cooper, 1989; Steptoe & Appels, 1989). This feeling strongly influences stress reactions, hence worker well-being (Aronsson, 1989; Frankenhaeuser, 1981; Ganster, 1989a; Hurrell, Murphy, Sauter & Cooper, 1988; Spector, 1986; Steptoe & Appels, 1989). According to Ganster (1989a, b) it is indeed possible to intervene in the work place in terms of verifiability, indirectly bringing about a reduction in tension linked to work constraints. Parallel to this theoretical interest, questionnaire-type tools have been created, however, with evaluation of the concept by one-dimensional global scales as a major criticism (Arambasic, 1996; Glass, Mc Knight & Valdimarsdottir, 1993; Karasek, 1979, 1989; Knight, 1990; Mc Knight & Glass, 1995; Spector, 1986; Warr, 1990). Since then some authors have suggested the need to consider the multidimensionality of the concept, and have suggested scales with several control dimensions (Breaugh, 1985; Greenberger, 1981; Hansez & De Keyser, 1999; Jackson, Wall, Martin & Davids, 1993; Mc Laney & Hurrell, 1988; Sargent & Terry, 1998; Widerszal-Bazyl & Zolnierczyk, 1995). Our intention here, however, is not to criticize those instruments. Some are linked to a very specific environment, have no standardization possibility, and of which convergent and divergent studies are not always very solid. But once again we find in the place they devote to dimensions of control, the role of the context and its influence on performance and well-being at work.

Literature on accidents and human error has long insisted on factors shaping performance (Hollnagel, 1998), on the necessity of being able to adjust them and on the harmful incidences of a lack of control and autonomy at this level. Do we draw the same conclusion that Faverge (1967) did in the 1960's, when he spoke of system reliability? That accidents, incidents, errors – let us add stress, burnout and mobbing – are all due to the same factors, i.e., a general pathology of the production system, and is treating one tantamount to treating the others? This would be going too far. It is rather an analysis of on-site activity and the collection of empirical data that will allow the definition of appropriate prevention. On this point, Western European studies on stress rarely lead to what Murphy (1988) calls primary prevention – i.e., the attempt to eradicate stress factors, particularly by modifications in work organization. Despite numerous efforts (Murphy, Hurrell, Sauter & Keita, 1996), the majority of interventions are still programs centered on re-enforcing individual defenses, e.g., relaxation, the fight against alcoholism and smoking addiction, improving cardiovascular health or individual psychological counseling, rather than on organizational factors.

1.6. DISCUSSION

The evolution of ideas about risk in Western Europe discussed here covers nearly a century. Needless to say, our aim was not to be exhaustive. This is neither a history, nor even the beginnings of a history of work psychology in Western Europe. But what is clear is that beyond an improvement in work conditions since the beginning of the century, marked by unquestionable indicators such as the decrease in fatal accidents at work and the fight against occupational illness, new risks are appearing - and they change. The increasing complexity of technical systems and the worrisome evolution of a social Europe are new facts in the workplace. When considering the negative effects that occur, the first reaction will always be to accuse the human element, or at least to try to select him or treat him. This has been seen in accidents, in human errors and is still true today for stress, bumout and mobbing. It has taken the obstinacy of researchers for the importance of the context to emerge, and for prevention to be used in attacking the problem of the interaction between man and his environment. In this evolution of ideas, a significant role is left to individuals, friendship and scientific circles – particularly in East-West exchanges. This is the way ideas circulate, through these privileged channels. One question remains: does research, and in particular psychological research on risks at work, really influence prevention? The following chapters will try to answer this question.

CHAPTER 2

ACTIVITY AND INSTRUMENTS

V. DE KEYSER AND A.-S. NYSSEN

Western Europe produces many tools today to combat human error, to better understand and manage it. Some of these tools are still prototypes; others are already on the market. They include error collecting and classification methods, training tools, operator aids and design methods. Prevention is usually rooted in the following ideas:

- Human-centered design.
- Fault tolerant systems.
- Technical assistance and intelligent operator aids.
- "Manageable" system complexity.
- Generalization of simulators in training.
- Collection and classification of errors and incidents which are stored in databases, and continuously reintroduced in training, work organization and design.
- Growing emphasis on error recovery and error management.

But beyond these options, one may wonder if their conception or use has been influenced by any theory. In any case, this influence seems evident for Activity Theory, especially regarding the importance given to both the notions of context and instrument in this theory. The Activity Theory has been in existence for several decades. As a matter of fact, it appeared in the Soviet Union in the 1930's and was developed by great psychologists such as Vygotsky, Leontiev, Luria and Oshanin. Despite its distant origin, the theory has drawn growing interest both in Western Europe (Frese & Zapf, 1994) and the United States (Nardi, 1996b) in recent years. Many authors consider it a potential framework for human-computer interaction research. Activity Theory is contextual: it analyses human activity in its natural and dynamic environment. Kaptelinin (1996) has described its basic principles. Activity is goal-oriented. This means that there is a tension (motivation, desire, intention) in the subject towards an object, which provokes activity. Consciousness is built through interaction with the object. It is first of all a social process, mediated by

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

diverse types of tools, either material or conceptual, such as language. These tools crystallize the knowledge of a community at a given moment, but they also contribute to change the representation people have of the world (Vygotsky, 1962). For the mediation process gives rise to internalization – a distorted representation of the object created by and for the action. Oshanin (Ochanine, 1981) called this representation an operative image. Rabardel (1995), inspired by Vygotsky, developed a framework for the analysis and design of activities using tools, emphasizing mediation. Within a tool, he differentiated the artifact from the instrument. The artifact is the envelope, either material or symbolic, of the instrument. The instrument refers to the person's use, the appropriation and adaptation of the artifact when doing a task, which can be very different from the formal use prescribed by the designer.

In this chapter, our focus will be upon the examination of error prevention artifacts and we will consider to what extent they become instruments. This is to say to what extent these artifacts contribute to modify the way people understand the phenomenon of human errors and to what extent this change succeeds to prevent them. Sometimes, this change only occurs at an individual level, sometimes it is all the field which modifies its representation and its prevention practices. But to increase human error understanding and prevention is very often not the first goal of artifacts. At the first level, they are developed by designers to satisfy a specific goal. For instance, a safety-reporting system must allow people to collect data on human errors, incidents and accidents. At the second level, if artifacts really support human activities in context and modify their representation and their knowledge, then they become instruments. The question is: does a safety-reporting system really change the way people understand the process of error and incidents and their prevention practice? Only when this requirement is met does the artifact become a prevention instrument that facilitates activity in context, supports knowledge acquisition and, in turn, reduces human error without creating new forms of risk. Using this perspective we will analyze four prevention tools: safety-reporting systems, simulators, aids and design methods.

2.1. SAFETY-REPORTING SYSTEMS

Safety-reporting systems are in fact the returns of experience, which are starting to spread in companies. They have long been known in the field of aviation, but are also gaining ground today in the medical world. For example, some hospitals in Australia have a system for reporting incidents and errors in anesthesia (Runciman, Helps, Sexton & Malpass, 1998; Runciman, Webb, Klepper, et al, 1993**;** Runciman, Webb, Lee & Holland, 1993). The United States would like to put this technique into general use in American hospitals (Kohn, Corrigan & Donaldson, 1999). The same idea is starting to make its way in France and in Belgium, where a pilot experiment has been initiated in several Belgian hospitals[1]. But what is this approach based on, and what are the difficulties involved? In fact, it involves collecting and classifying errors, incidents and even accidents. This collection is vital for good management of the knowledge developed in the field. Results are then directed either to actors in the field or to decision-makers at a higher level. The complete reporting process comprises a series of stages.

Raw data about error incidents or accidents are collected and then transformed, at the first level of analysis, into a description (or a model), which enables people to better understand the phenomenon. For instance, an incident is described by a tree, showing the causal interrelations between the risk factors. Then, through statistical methods, it is possible to perform of second level of analysis in order to generalize and predict risk situations (Hollnagel, 1998; Nyssen, 1997, 1999). These critical situations are often called *prototypical risk situations*, situations where an incident or an accident becomes virtually inevitable, due to a specific combination of factors. For instance, the accumulation of latent failures in an organization associated with multiple technical changes and a decrease in the expertise of the workers is clearly a prototypical risk situation. However, not all safety-reporting systems refer to such a holistic view of risk, often treating each of the risk factors separately. Safety-reporting systems all have in common the fact that they ensure source confidentiality. Many of these systems operate on a voluntary basis. Everyone can thus feel free to report a problem. Beyond these common points, there are multiple differences.

2.1.1. Classification Schema or Model Schema

These are either theoretical or empirical, and sometimes a combination of both approaches. Among the theoretical models grounded on a cognitive classification, many are based on the work of Rasmussen (1986) and Reason (1990) - cf. Chapter 1.

But beside these well known theoretical classifications that inspire many safety-reporting systems, other empirical classifications exist, directly based on the context and domain specific knowledge. This is the case for the anesthetic safety-reporting system, GOC (Generic Occurrence Classification) established by Runciman et al. (1998) in Australia. This system has been introduced in several European hospitals (see Table 2.1). All the items are directly derived from anesthetic experience.

Table 2.1 shows only some of the items which help the reporter describe an incident. An interesting feature of the classification schema is that it includes, in Item 4, factors minimizing the incident. The picture that emerges from an incident is

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[1] "Développement d'un programme de signalement et d'analyse d'indicents critiques en milieu médical". Research contract n° PS/12/21 (1999 - 2003) - Belgian State, Prime Minister's Office -Federal Office for Scientific, Technical and Cultural Affairs. De Keyser V. (Promotor), Lamy M., Baele Ph. and Fagnart J. L. (Partners).

Table 2.1. Generic Occurrence Classification (Runciman et al., 1998). Item 4 from GOC explores in parallel the contributing factors and the minimizing factors in the occurrence of anesthetic incidents

	Factors contributing to incident	*Factors minimizing incident*	*Suggested corrective strategies*
ITEM 4 : Why it happened?	Communication problem…..CP	Monitor detection………..MD	Additional equipment …….AD
	Distraction…………………DI	Specify which monitor FIRST alerted to problem (one only) …………………………….	Additional monitor……….AM
	Drug Label…………………DL	Healthy patient……………HP	Additional training ……….AT
	Error of judgment…………..EJ	High awareness via QA activity……………….QA	Equipment checking Discipline………………..…EC
	Failure to check equipment .FC	Prior experience or training……………………EX	Equipment design improvement ……………...ED
	Fatigue ……………………FA	Re-check of equipment…...RE	Equipment maintenance discipline …………………EM
	Fault of technique…………FT	Relief anesthetist or staff change……………….RA	Fatigue alleviation routine ..FA
	Haste………………………HA	Skilled assistance…………SA	Improved communication….IC
	Inadequate assistance ……...IA	Supervision………………SU	Improved environment……..IE
	Inattention …………………IN	Other factor, specify……...OT	Improved supervision………IS
	Inexperience………………..IX	Nil…………………………NI	More manpower…………MM
	Lack of facility …………….LF		Quality assurance activity specify (e.g. AIMS/M&M, etc.)…..QA
	Lack of monitor…………..LM		Specific protocol development ………………SP
	Monitor problem…………..MP		Other strategy, specify ……OT
	Pre-op patient assessment inadequate or incorrect…….PA		Nil………………………….NI
	Pre-op patient preparation inadequate or incorrect……PP		
	Pressure to proceed…………PS		
	Relief anesthetist or staff change………………..RA		
	Sick anesthetist ……………SA		
	Sick patient………………...SP		
	Surgical team contribution…SC		
	Unfamiliar environment or equipment………………UN		
	Other equipment problem specify…………………….OE		
	Other stress, specify……….ST		
	Other factor, specify ……..OT		
	Nil…………………………NI		

thus not only a negative one; it stresses human reliability in the detection and regulation of the incident.

2.1.2. Relationships Between the Factors

In the reporting of an accident, different factors appear in chronological order, sometimes with causal links added. Some classification systems choose to reveal these links, others do not.

- With no links, one finds slots: every incident or error is put in a distinct category without any hypothesis about the links between the factors (Swain & Guttman, 1983).
- With links between the factors: one uses diagrams, such as event trees or fault trees or classification schemes which support the collect of data (see Figure 2.1).
- When the overall and systemic structure of the reported problem is maintained, one finds cases or scenarios. The analyst then avoids breaking down the incident into factors (Cook, Woods & Miller, 1998).

2.1.3. Exploitation

The exploitation of safety reports is a crucial point, if we support the view that they are to modify people's knowledge and understanding of the process of errors or incidents. Three possibilities exist:

- case by case. For example, incidents where anonymity is maintained, but which are reported in the company's internal newspaper, or discussed during training courses or at safety meetings;
- by quantification and statistical treatment of the findings. This is a level that is generally reached in high-risk sectors that closely monitor the evolution of errors and incidents;
- by predicting the probability of an incident or disaster. This prediction has long been the avowed objective of the Human Reliability Assessment (HRA) trend described by Hollnagel (1998). But nowadays attempts are also being made to define configurations of situations that entail a high probability of producing errors - and may therefore have disastrous consequences. They are what we have called prototypical accident situations.

However, the choice of model, the classification method and type of exploitation are far from being set in stone. They evolve with time and the essential thing is that they adapt themselves well to the people to whom these results are addressed. The progress made by British Airways in this respect is exemplary, and we will briefly describe their efforts.

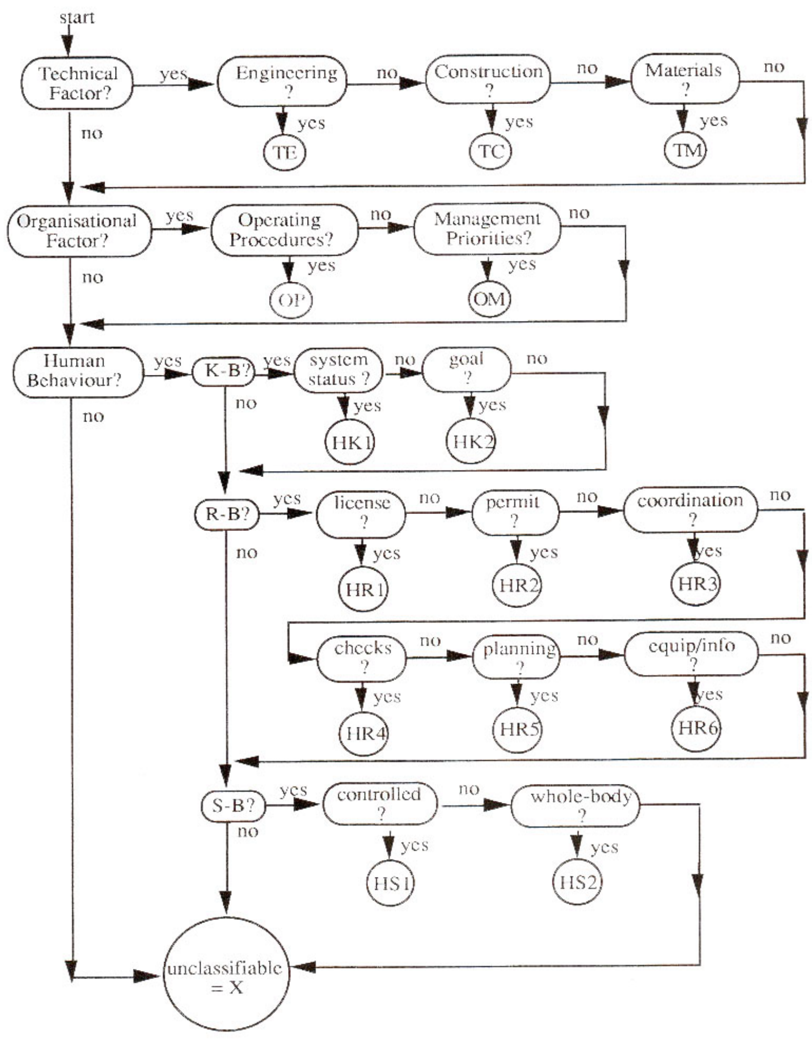

Figure 2.1. The complete Eindhouven classification model of system failure (van der Schaaf, 1992). It uses a 9-point checklist to collect all the relevant factors for the investigation of a specific incident. In this model, human error cannot be entirely separated from the technical and organizational context of task performance. The main category of human behavior is subdivided into knowledge-based behavior, rule-based behavior, and skill-based behavior, following Rasmussen (1986). A fixed order of analysis is advocated: first technical factors, then organizational factors, and only, as final step, human factors.

2.1.4. British Airways' Safety-Reporting Systems

Over the last three decades, British Airways has established three programs to monitor Flight Operations safety performance. In chronological order they are: the Special Event Search and Master Analysis (SESMA), the Air Safety-Reporting (ASR) program, and the Human Factors Reporting (HFR) program. All three are still in use, but we will only present the last one, the HFR program. The idea behind this evolutionary process was really to gain a better understanding of human errors, in order to manage them. As expressed by O'Leary,

> "What we need now is information on the day to day operational difficulties, stresses and human failures that flight crew, cabin crew, air traffic controllers, air traffic dispatchers and maintenance personnel experience on every one of their working days. It is only by understanding the organizational and environmental causes of under-performance and error that we can start to control and mitigate them" (O'Leary, 1999, p. 2).

HFR is the latest program developed by British Airways. Its goal is to discover not only what happens in an incident, but also why and how people have coped with the problem. Without this information, safety managers can only react to problems and not anticipate them in a proactive way. HFR is totally confidential, based in the Safety Service department (and not in Flight Operations) and is run by line pilots specially trained for the job. They are the only ones to know the names of the reporters. After a first analysis of the event as such, which sometimes motivates information feed-back to the line management, but always in an unidentifiable form, a second analysis is performed to determine the underlying structure of the event. It provides an abstract description of the case. The classification adopted is a sequence diagram, which relies on five groups of factors, assigned in either a positive way (i.e. safety enhancing), or a negative way (safety degrading). This type of assignment is extremely beneficial: it allows the highlighting of positive aspects of an incidental event, such as the positive actions of the crew in coping with the event, and indicates possible lines of prevention. The five categories are as follows: crew actions, personal influences, organizational influences, informational influences and environmental influences (see Table 2.2). It is a mixture of empirical categories and theory-based classification borrowed to Reason (1990) and Rasmussen (1986). Each of these categories is subdivided. For instance, the category "crew actions" includes, among other factors, the potential error types of Reason's model (cf. Chapter 1). The basic idea of the classification is that the crew's actions are influenced by the other four categories. The latter reflect the context of the crew's actions[2].

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[2] In the environmental influences category, we also find a meta-factor, the "Ops Problem" (Operational Problem), defined as "Any situation or event that threatens or could potentially threaten the safety of the aircraft or any of its occupants. An Operational Problem will require the crew to consider the implications of the event and if necessary to act to eliminate or control the threat". The Ops Problem factor helps the analyst parse the event into the causes and the recovery process, if it succeeds.

Table 2.2. Categories of factor assignment (O'Leary, 1999)

Crew Actions are of three distinct types. One type concerns the activities of handling the aircraft and its systems, e.g., “System Handling”. A second concerns the potential error types reflecting the Reason model of human error (Reason, 1990), e.g., “Action Slip”. The third is the largest set of factors that are derived from the NASA CRM Teamskills. These describe a number of activities involved in the safe management of flight, e.g., “Workload Management”.
Personal Influences describe the subjective feelings of physical and mental well-being, emotion, stress, motivation, and attention as described by the reporter. Examples are “Boredom”, “Personal Stress”, “Tiredness” and “Mode Awareness”.
Organizational Influences are those influences that are directly controlled by the company. For example, “Training”, “Technical Support”, and “Commercial Pressure”.
Informational Influences are also under the company's control but are a subset of the organizational influences dealing with operational information. Examples are “SOPs”, “Electronic Checklists” and “Navigational Charts”.
Environmental Influences are those influences over which neither the reporter nor the company has any control. Examples are “ATC Services”, “Technical Failure” and “Other Aircraft”.

Figure 2.2 is an example of the information the diagram database can provide. It compares the situational awareness of the crew in Glass fleet versus Steam fleet. Situational awareness is one of the factors in the Personal Influence category. It is itself divided into environmental awareness (the "world" outside the aircraft), mode awareness (the configuration and path of the aircraft induced by the computerized modes) and system awareness (operational status of the aircraft engineering subsystems). The ratio calculated takes into account the positive and negative assignments of the factors; it is a number varying from -1 (all the assignments are negative) to +1 (all the assignments are positive). Figure 2.2 shows very clearly that situation awareness is better controlled in Steam fleets than in Glass fleets, and that mode awareness is a problem in glass cockpits[3].

Today all aviation environments use a form of collection and classification of incidents and errors. However, the experience of British Airways remains exemplary from many points of view. It testifies to a pragmatic and evolutional approach, which started from solely technical concerns and widened its investigation to human error. This was done with a great deal of care and took into account the reactions of its environment. Over the years, methods have been refined, incorporating the latest scientific advances in the field, but clearly the objective here is not to do science: it is to understand error and act on it. The initial choice of method is less important

[3] The importance of situation awareness in glass cockpits will be evoked below in the aids section, but also in Chapter 3.

than knowing how it was introduced, whether it corresponds to what the environment expects at a given moment, whether it helps the environment to evolve and whether the method itself changes. It is all about a dynamic process and step-by-step progress. The example also shows the importance of confidentiality and the almost constant rejection of the idea of sanction: looking for the responsible party is often incompatible with the idea of proactive prevention. As far as the introduction of context in the approach to human error is concerned, it does admittedly correspond to the development of ideas in the field, but also puts the importance of the human factor into perspective. The latter is but a link in the incident chain. Moreover, British Airways insists, as Runciman did in GOC, on the contextual and human aspects that are positive, including, and doubtlessly above all, in incidents (Runciman et al., 1998). Therefore the light that is shed on the human factor is much more in accordance with our knowledge of reality, namely that man remains without doubt the best regulator and the best corrector of an incident. These principles are at the basis of the climate of confidence that has been established over the years in the application of the British Airways classification methods.

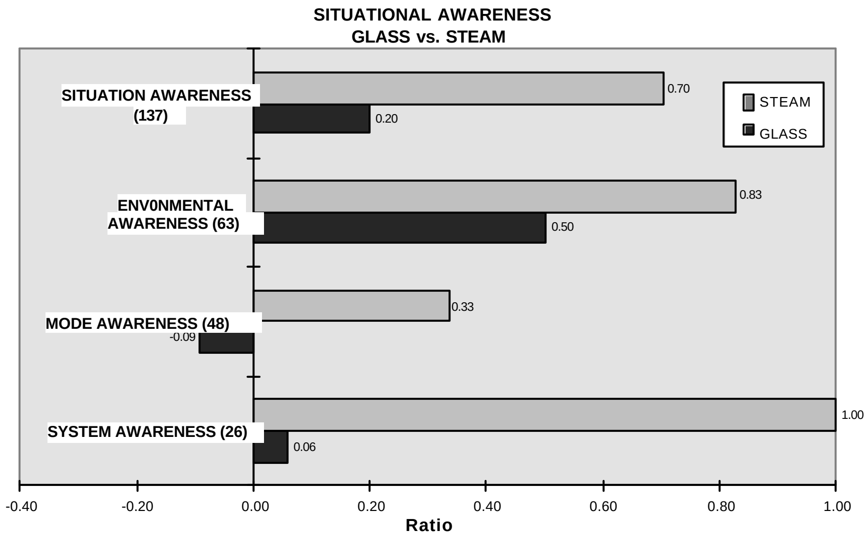

Figure 2.2. Situational awareness glass vs. steam (O'Leary, 1999).

2.2. SIMULATORS AS TRAINING DEVICES

To reinforce human reliability by training is one of the key issues in human error prevention policies. There are in fact many possible training methods. Some are focused on knowledge acquisition in a specific domain, others on cooperation within a crew, and still others on dealing with emergency situations, etc. Here we will present some advances in the use of training simu lators, but we will stress how the analysis of the activity, its regulation and the context must be emphasized. Too often, simulators are used on a normative way: to guide trainees to ad-hoc procedures or right and quick problem diagnoses. Few simulators act as real instruments to change the representation and the practice of both trainers and trainees. They are supposed to be templates of reality – what obviously they are not. We will discuss below how psychologists could mediate to process of knowledge generation between trainers and trainees, and act, themselves, as instruments.

2.2.1. Training and Performance Assessment: Methodological Problems

Simulators are mainly used in high-risk domains where operators cannot be trained in the real world for safety, economic or deontological reasons. They are also used in training operators who must perform adequately on their first exposure to critical situations. But simulators do not only have a didactic use: they allow human performance to be studied in a rather realistic context. As such, they contribute to a better understanding of the occurrence of human errors in various scenarios. Some authors have, however, stressed different problems in their use (Flexman & Stark, 1987; Leplat, 1989; Sanders, 1991). Performance parameters used for assessment in simulators must be related to the quality of performance in context. The difficulty stems from the fact that performance parameters in context are not always accessible and are not easy to identify. They must be inferred from in-depth analyses of human performance in naturalistic situations, which are still quite rare. Moreover, even if the simulated situation is perceived as stressful by the operator, it does not include all the organizational constraints and emotional aspects under which operators perform in the real system. Thus, the results of performance assessment in simulators must be tempered by data from field studies (De Keyser & Nyssen, 1999b; Nyssen, 1999).

There are different types of simulators, more or less resembling the real world; some apparently minor characteristics can dramatically change the nature of the activity of the trainees. We investigated practitioner performance on two kinds of training simulators, screen-based and full scale simulators, and compared it with data from field studies (De Keyser & Nyssen, 1999b; Nyssen & Javaux, 1996). The results showed to what extent the simulator's characteristics influence operator performance.

We observed that, in anesthesia simulators, the simulated surgical act is generally much shorter than in similar real operations with some of the anesthetist's acts having a quasi-immediate effect, while others have a realistic duration. These temporal distortions are much more important in screen simulators than in full-scale simulators. They prevent any internalization of duration. Moreover, the greater dynamics of simulated situations, especially in screen simulators, entails a specific control mode of the situation, which is more reactive than anticipatory. Moreover, simulators do not teach the complexity and the variability of the real world; they use regular, predictable problem situations. By definition, a training session is a kind of classical theatrical play with unity of time, location and action. Past, present, and future are shrunk into a very short time interval. The briefing tries to reconstitute the case history, but it concerns only the patient, not the monitoring systems, nor the medical team, nor the previous cases the team has already encountered in the past.

Even though the present is rather realistic, there is no future beyond the training session. It removes all consequences and social stakes associated with the case. This can be good from a training point of view, for it gives trainees the opportunity to learn from errors, without any risk to the patient. But of course, this does not reflect the complexity of the real world and could even prove dangerous if this simplification is not stressed in the course of the training.

2.2.2. Psychological Fidelity and the Mediation Cycle

Psychologists can assist technical instructors in filling the gap between naturalistic and simulated situations by carrying out field studies. These studies should focus on activity and its constraints in naturalistic environments. This raises the question of simulator fidelity. Fidelity refers to the degree of accuracy with which the simulator reproduces the system and its environment. It was long thought that increasing the physical and functional fidelity of the simulator improved the value of the training program. However, several studies have shown that lower-fidelity computer-devices could be useful in training (Jentsch & Bowers, 1998) and that some critical features of a real system, such as organizational aspects, are difficult to simulate, rendering simulation useless as a training tool. Simulator designers, taking advantage of simulator technology development, have continued the attempt to achieve complete representation of real systems. However, the main function of a simulator is not to duplicate reality, but to enhance learning. Simulator design should be determined according to the training goal. Emphasis has mainly been put on the acquisition by trainees of procedural knowledge and problem solving skills in order to control rare and potentially serious incidents (Gaba, Fish & Horward, 1994). However, as we noted before, naturalistic decision researchers have shown that in modern systems, dynamics and uncertainty appear to be the major difficulties for decision-makers. Operators deal with situation assessment and verification of the hypothesis, rather than with applying some predefined response. Thus, simulator-training goals should be determined through an analysis of human performance in naturalistic settings, rather than pre-defined criteria. The concept of psychological fidelity summarizes this new approach to simulator design. *Psychological fidelity* is the extent to which simulated situations generate psychological conditions of action similar to naturalistic situations, enhancing the learning of skills involved in naturalistic situations (Baker & Marshall, 1989; Grau, Doireau & Poisson, 1998; Leplat, 1989). Psychological fidelity stems from similarity between the conditions of action, rather than similarity between technical or functional characteristics *per se*. Because the conditions of action cannot be derived exclusively from formal task models, they must be determined through activity analysis. In addition, activity analysis defines the training and learning functions to be supported by the simulator. There is a complete mediation cycle, which continuously generates knowledge passing from technical instructors to trainees and to psychologists – see Figure 2.3.

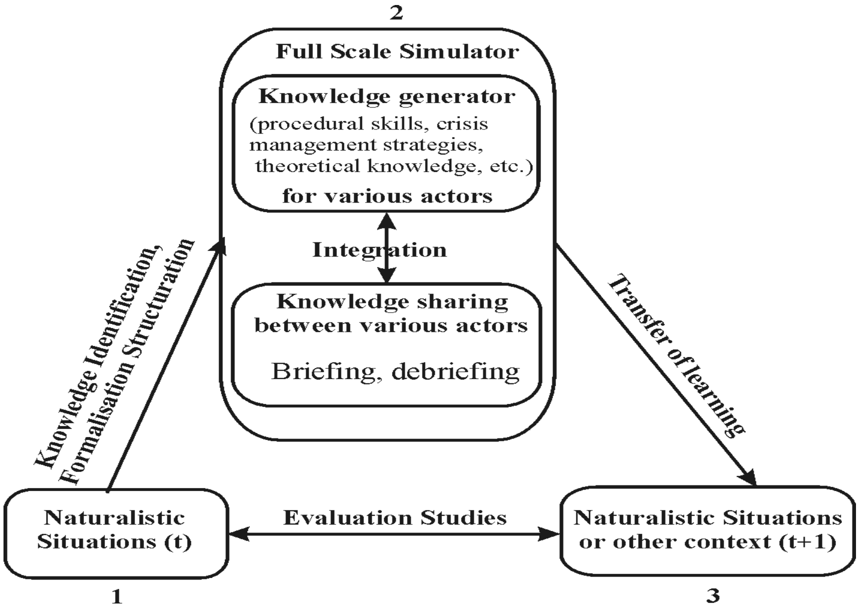

Figure 2.3. The mediation cycle (De Keyser & Nyssen, 2000). The mediation cycle starts with Step 1, this is to say an activity analysis in naturalistic situations. This analysis usually stresses the constraints and the difficulties inherent to these complex situations – for instance the role of the temporal constraints on human error occurrence. This knowledge is mediated by the psychologists to the trainers. It allows them to emphasize, in the simulator, what could be different from reality and to questions the psychological fidelity of the simulator. Then, during the session, and mostly during the debriefing the psychologist helps trainers to analyze, from a psychological point of view, how trainees have reacted, solve the problem, made errors. This debriefing session– sometimes based on video-records – is a privileged moment to share knowledge between the actors. The third step is the transfer of learning to the situation. Sometimes the psychologist is lucky enough to assess this transfer and to stress the remaining weakness in the trainees knowledge – bringing the information back to the first step of the cycle.

Simulated situations appear not as templates of reality, but as knowledge mediators between the trainees and reality. Psychologists convey information from field studies and stress the differences between the simulated situation and the cognitive and emotional demands of the real world. As such, they also play a mediation role (De Keyser & Nyssen, 2000; Samurçay & Rogalski, 1998).

Psychologists can also assist instructors in assessing the trainee's state of knowledge and skill, to create appropriate simulated situations, to provide extrinsic feedback, and to draw attention to the learner's self-monitoring behavior during the debriefing. The reciprocal relationship between the psychologist and instructors will in turn improve the training program's effectiveness.

2.2.3. Activity Regulation

Activity Theory tells us that activity is goal-oriented, and that it dynamically regulates itself in the course of the action. In simulator training sessions, technical instructors are very often focused on the trainee's technical performance, rather than on the activity regulation process. They want to know if the performance was good or bad; they want trainees to perform adequately, but generally do not exploit all the information, which, during the course of the training session, reveals an activity regulation process. For instance, what kind of errors do trainees usually make? Do they detect them spontaneously? How do trainees cooperate? Is this cooperation efficient or not? How do trainees interpret and understand the scenario? Research reveals that the quality of this regulation process is predictive of the quality of the performance - and that it should be observed, supported and enhanced during the training session (Samurçay & De Keyser, 1998). When psychologists and technical instructors cooperate within the same training team, the question is easy to solve. Psychologists generally observe and video record trainee's activity during the session, thus collecting and analyzing errors. Then, during the usual debriefing session, on the basis of this material, they provoke a retrospective analysis of the trainee's activity. Discussion spontaneously emerges on their strong and weak points, how they represented the problem, why they missed an important cue, which hypothesis should have been tested, etc. This reflection helps trainees to better control their activity in the future. But if the number of multidisciplinary teams that include psychologists in simulators is increasing, their participation remains informal. However, in Finland there is a team which has gone a step further in making this cooperation explicit.

2.2.4. VTT's Method for Simulator Training

In Finland, the VTT Automation team formed by psychologists and nuclear power plant simulator instructors has gone a step further. They have formalized this cooperation, and have developed a simulator training method (Analysis of Way of Acting) AWA, to enable technical instructors to judge and enhance trainees activity. The method includes tools such as diagrams and tables, which provide general frames for the description of a specific task situation, give criteria for observation and evaluation of the crew's activity and provide informative ways of giving feedback to the subjects. The method is subject centered, contextual and emphasizes the dynamics of the activity. According to Hukki and Norros (1998), the main training goal in the simulator should be the promotion of adequate ways of acting according to the situation. An appropriate description of the problem situation is important. This is the first step of the AWA method (see Table 2.3).

Table 2.3. Use of conceptual tools in simulator training (Hukki & Norros, 1998)

Phase	*Functions of conceptual tools provided by method*	*Contribution of trainers*	*Contribution of trainees*
Before simulator run	General frames for description of specific task situation	Description of specific task situation	
	General criteria for: - objects of observation of activity - evaluation of task performance - evaluation of habits of action	Creation of situational criteria for: - objects of observation of activity - evaluation of task performance - evaluation of habits of action	
During simulator run	Tools for observation of activity	Observation of activity	Task performance
	Tools for evaluations of: - task performance - habits of action	Evaluation of : - task performance - habits of action	
During debriefing	Tools for giving feedback	Presentation of evaluations of - task performance - habits of action	Presentation of arguments of: - task performance - habits of action
		Presentation of own basis of inference	Presentation of own basis of inference
		Discussion of developmental needs	Discussion of developmental needs
		Discussion of learning content of scenario	Discussion of learning content of scenario
After debriefing	Tools for documentation of situational descriptions and evaluation forms	Documentation of situational descriptions and evaluation forms	

The methodology developed by the authors takes into account two kinds of criteria to judge trainees activity during the course of the session. The first covers process control demands; the criteria are functional, and are based on the most important judgments and decisions people have to make in order to handle the disturbance situation described in the scenario. The second kind covers the *orientation* of the trainees, within the crew they form. The concept of orientation originally stems from Galperin (1992). It refers to the subjective way people frame and understand a situation and find the situational possibilities to act. Thus the situation is not described as a predetermined course of action, but from the point of view of the choice of actions and the critical information available for decision-making. This conceptual effort is consistent with Scandinavian tradition, which has always been very close to the field. It stems initially from the Russian Activity Theory, since the simulator must improve knowledge about an operator's mode of regulation. But the method also has French roots: Hukki and Norros stressed the importance given by subjects to the *interpretation* of the situation in the *course of action* (Theureau, 1996). Subjects have to be able to make sense of the situation, which is not given beforehand and emerges from interactions during the simulation process. In AWA, the method has really be appropriated by the team and has deeply contributed to change the representation trainers and trainees had of human errors.

2.3. OPERATOR AIDS

The world of aids is a fantasy world with a long history of glorious failures and patient victories. Designers may be dreamers, but reality wakes them up. They discover how difficult it is to assist activity in naturalistic situations: many aids are not used, are misused or induce new types of errors. Some, however, tremendously expand human capabilities. But if we compare the past and the present history of aids, a new fact appears. In the past, aids were designed to support work, and to reduce physical and cognitive constraints. Today, in many cases, work is designed to be supported by aids. The growing complexity of technical systems is no longer manageable by the operator without technical aids. This statement is shared by many observers of technical evolution, and was clearly evoked by Amalberti (1996) (see Chapter 1, Figure 1.2). Amalberti located an area he defined as an *artificial area of performance*, uniquely accessible to operators with aids. In this area, the cognitive demands associated with the performance, and the cognitive demands associated with the regulation of this performance are too high; they would lead to multiple errors. The basic question behind this statement is "what exactly is the status of the aids compared with the human being?" For Activity Theory, the answer is clear. Instrument and man are one, insofar as the instrument becomes a functional organ and man keeps it, or should keep it, under control. In contrast, the *theory of distributed cognition* (Nardi, 1996b), introduces a symmetry between man and artifacts, between natural and artificial agents. They cooperate in a joint cognitive system. Even more, the distributed cognition theory refutes the notion of an aid. In fact, taken literally, this term fixes the distribution of roles between humans and artifacts. The system they form is permanently adapting and organizing itself. Take the example of memory aids used in cockpits. Hutchins (1995) said:

> "to call a specific artifact a "memory aid" for pilots is to mistake the cognitive properties of the reorganized functional system for the cognitive properties of one of its human components. This artifact does not help pilots remember speeds; rather they are part of the process by which the cockpit system remembers its speeds" (p. 153).

In this conception, nothing is an aid *a priori*, but each artifact can become one at a given time, according to the context and requirements of the action. But the distributed cognition theory does not answer the very question Moray asked fifteen years ago: if the operator does not fully understand and master the situation, who else is actually in charge of this control (Moray, 1986)? Moray's answer was clear:

> "whichever component in a system (either a natural or an artificial agent) has the ultimate authority for its action must have complete knowledge of the properties of the system and must have complete control" (p. 275).

2.3.1. Clumsy Automation

Aids, instead of supporting human activity, very often fail in critical situations, when unexpected events change their usual working environment. This paradox was depicted by Bainbridge (1987) as the "irony of automation". Woods and his team have reported many cases of "clumsy automation" (Cook & Woods, 1994; Cook, Woods & Howie, 1992; Sarter & Woods, 1992; Woods, 1986), when aids increased operator's cognitive constraints at the very moment they should relieve these constraints. Among the reasons for these failures we can cite (O'Moore, 1995):

- A large mismatch between aid support and users' real problems.
- The communication gap between potential users and computer science, where the role of the aid is often unclear for the user.
- The absence of a coherent design philosophy: for instance, the method of knowledge representation may be inappropriate.
- The disregard of organizational issues: the complex environment where the system is used is not taken into account, nor its dynamics and uncertainty.

Recent accident investigations have revealed that the current generation of automated devices may have created new kinds of failure modes in the human-machine system by changing the nature of operators' roles in the process. Operators have become supervisory controllers who monitor systems, who intervene only when changes are necessary or when unanticipated situations occur. The operator has been removed from the control loop, decreasing system awareness, especially if feedback on automation and behavior is limited (Sarter & Woods, 1994, 1995). In fact, it should be noted that the more autonomous the machine, the more difficult it is to penetrate. Clearly, the amount of information on the screen ceases to increase, but the complexity of the system makes it difficult to provide an explicit representation of the functional information at the interface at all times. Some relevant sensorial information (auditory or tactile) has been taken away from the human operator's work environment. The speed of the process also adds to its complexity. Bainbridge and Ruiz Quintanilla (1989) insist on the difficulty encountered by operators when controlling machines which operate faster than they themselves, and possibly function very differently. In these working conditions a supervision and diagnostic role is particularly unsettling for a human operator.

Even if the growing complexity of installations means that from now on assistance is unavoidable in managing them, the current drift, i.e., an increase in aid at all levels, remains unjustified. In numerous companies, aid is proliferating despite remaining unused. This drift can be explained by the combined influence of three factors: 1) technological market push, 2) fear of human error, 3) growing complexity of technical systems. The fact that new devices create new demands on the individual and groups of practitioners responsible for operating and managing these systems is often overlooked. These demands can include new and modified tasks (setup, initialization, operating sequences, etc.) as well as new cognitive demands. There are new knowledge requirements (e.g. how the device functions), new communication tasks (instructing the automated device), new management tasks (finding the relevant data on the menu) and new attentional demands (tracking the automated device state and performance). The presence of these demands generates a risk of new forms of error and failure that can be classified as design-induced. In fact, these aids never succeed to become instruments in clumsy automation.

2.3.2. Various Types of Aids

Aid in itself is a rather general term. It refers to various technical systems that can be very different in their capacity for aid and man-machine cooperation. Many authors have tried to classify aids (De Keyser, 1988, 1996; Grosjean, 1994; Johannsen, 1986; Millot, 1988; Sheridan 1988a, 1988b), but there are too many variables related to this concept to enable agreement on a taxonomy. The various types of aids will be analyzed in this perspective:

- *Alarms and guidance aids:* These are aids intentionally designed to alert people and to guide their action. They are very widespread, can take different forms and leave the final decision of action to the operator. From process control rooms, to cars, aircraft and machines, alarm systems have a long past. They are supposed to alert people of a danger, more or less important, more or less urgent. But technical evolution has rapidly produced an inflation of alarms. In nuclear power plant control rooms for instance, there can be several hundred alarms displayed on the walls and on the operator's desk. If designers have made great efforts to process, filter and display these alarms in an economical way, in parallel, operators have succeeded implicitly in coping with this problem. Most of the alarms are either disregarded, e.g., operators may immediately disengage an alarm, because they think it is not important; it is a false alarm, etc., or they are largely anticipated. It is generally considered that operators anticipate more than 50% of the alarms. This does not mean they are useless. In fact they play a role as a *monitoring tool*, giving operators information about how far they can go when they take an action. Actually, alarms are good feedback systems. They contribute to creating a virtual safety envelope for operators. Through them, operators discover the safety limits of the system they control. The same can be said for guidance systems. In industry, there are a great number of guidance systems which, either on-line, or off-line, are supposed to guide the operator's actions. Most of the time, operators know what to do before receiving any computer advice. And guidance comes as a confirmation. From time to time the guidance fails, for all the variables of the situation have not been taken into account by the computer. In this case, the operators correct it implicitly. Generally, they are rather happy to show they can still win in a competition with the computer. However, sometimes inadequate alert systems, or inadequate guidance become stress factors, and people definitely refuse to use them.

- *Aids that enhance situation awareness*: The aim of this category of aids is to help operators to be aware of the situation, i.e., to make visible and affordable the relevant cues they need to perform their actions, without too much effort or too many cognitive demands. This covers devices such as screen images, virtual reality devices, databases, etc., which are supposed to enhance and correct the internal representation – *the operative image* – people have of the situation at a given moment. Such a broad domain is impossible to summarize in a few lines. Some years ago, Vicente and Rasmussen developed the seductive concept of an *ecological interface* to characterize an interface making the invisible visible, without forcing cognitive control to a level higher than that required by the demands of the task (Rasmussen & Vicente, 1989; Vicente & Rasmussen, 1988). Yet this interface must provide appropriate support for the different levels of cognitive functioning. The ecological philosophy is strongly based on a cognitive work analysis (Vicente, 1999). Today Norman (1999) talks about the invisible computer, which has to "disappear" in order to really assist people. How can the complexity of a naturalistic situation be restituted, without being complex? How can we simplify without being reductionist?

  Many attempts have been made, and Vicente is among the best. But the use of very abstract images does not seem helpful to operators who derive all their expertise from concrete and particular situations. Here some ergonomists go in the wrong direction. Instead of providing multiple and redundant sources of information to the operators, they are obsessed by the human's limitations, and they tend to select and oversimplify information. Field studies in process industries (Van Daele, 1993) have shown that control room operators only use a small proportion of the screen images they receive. These operators, however, rely on various other sources of information: call phones, auditory and tactile signals, direct view of the installation, etc. They try to build a much richer representation than that offered by the computer. Social contacts also play an important role in this enrichment. Up to now, most aids have been designed in isolation and are not integrated into a complete and multimodal information system. They focus on visual information, which requires permanent, selective attention, barely taking into account the cooperative and social aspects of the work. A good example of this problem is the party line in aviation. On planes, conversations between the crew and air traffic control are currently conveyed by radio. This channel does not filter the messages, so pilots can hear the air traffic control conversations with all the surrounding planes. This gives them a rather accurate situation awareness, which has already allowed the avoidance of catastrophic collisions (Dusire, 2000). But air traffic is increasing exponentially; the channel is becoming too crowded and messages are more and more difficult to understand. The risk of communication errors is growing. Researchers and designers are studying data link solutions with numerical transmission. With this technique, only messages relevant to a given plane would be addressed to the crew on a screen interface. Even if these messages still contain data about the position of other planes, all the information is visual. This design tendency is dominant. However an opposite view has emerged in virtual reality design. If virtual reality tools are not distinguishable at first glance from other aids, they reveal a more holistic approach for the user. They are based on the concept of *immersion* and reintroduce multimodal sensory information[4] as an important component of the feeling of presence (Witmer & Singer, 1998). The central role of the body thus returns to the stage.

- *Aids as "prostheses":* These aids are supposed to take full charge of physical or cognitive functions, either totally new or previously performed by operators. This is complete delegation. Many manual tasks have been delegated to machines in the past without any problem. Computerization and the present development of artificial intelligence have contributed to create aids that take charge of many human cognitive abilities: calculating, diagnosis, planning, scheduling, etc. If the model underlying these aids is good, they can be very efficient tools. Environmental constraints and the well-known limitations of humans (i.e. the limited span of working memory, sensitivity to stress and fatigue, etc.) make some of these tasks better performed by a computer. But on the other hand, the regular use of these tools reduces human expertise in a given task. There is no problem if this expertise is no longer needed and if responsibility of control is clearly on the machine's side, but if this is not the case, a high risk exists of inducing errors and problems. Few of these tools are really reappropriated by operators. Most of the time, they are just black boxes that people do not understand. However, Van Daele (1993) reports that in a steel industry plant, a planning device intended to work off-line was actually used on-line to generate diverse possible

[4] For tactile feedback, users can use special gloves, equipped with captors, which simulate touch sensation when they are in contact with an object.

scenarios of action. When operators had unexpected delays in production, they used the device to find out what the possible consequences of speeding up the process would be, without taking the risk of breakdowns and technical problems.

- *Flexible automation.* The very idea of a joint cognitive system is embodied in the concept of flexible automation (Millot, 1988; Vanderhaegen, Crevits, Debernard & Millot, 1994). In this case, there is supposed to be continuous and horizontal cooperation between aids and humans, between natural and artificial agents. In principle, tasks could be indistinctly performed either by humans or by computerized aids, depending upon the constraints at a given moment. These aids are specifically designed to support activity regulation. Multiple prototypes are based on this concept. GIDS (Generic Intelligent Driver Support), for instance, is an intelligent car prototype that evaluates the degree of help required by the driver according to the traffic and the driver's workload. It tells him/her when to turn and even brakes when the driver goes too fast (Michon, 1993)! Created to reduce driver workload and minimize the risk of errors, GIDS suffers from a lack of social acceptance; what intelligent driver would leave the control of his/her car to an intelligent system? There is also substantial doubt about the effective workload reduction introduced by such systems. The reliability of the artificial agent, how it takes into account context variability, how clearly its internal functioning is understood by the user, and how situation awareness can be supported by automation are all crucial issues. In aviation, autopilot assistance is very close to the concept of flexible automation. Despite designers' efforts to improve the system's usability and the overall remarkable performance of this aid, there are still unsolved human-machine interaction problems. The lack of transparency and the complexity of the tool, as well as the deficit in situation awareness it induces in some contexts (see Figure 2.2 and Chapter 3) create new kinds of driver errors.

2.3.3. EDF (Electricity and Gas of France) Virtual Reality Aids

For decades this company has developed policies and design tools to fight human error: error classification systems, ergonomic control room design, training methods, etc. Its Human Factors Department is a center of excellence in Europe. Among the possibilities offered by technological development, one of the most promising issues is virtual reality (VR). It allows what is not visible to be made visible, the manipulation of objects in a rapid, interactive and intuitive mode, and the control of repetitive commands (Wilson, 1997). Diverse instruments have been designed by EDF using this technology. Some are training instruments; others are regular aids supporting the agent's activity. Ergonomists and psychologists are involved in their design, evaluation and didactic use (Mancini, 2000). Virtual reality shares many problems with simulators. The question of its ecological validity seems to be central at first glance. But after reflection, it is clear that, just like simulators, virtual reality will never be a faithful template of the real world. Moreover, drawing lessons from the first VR training devices, EDF has introduced the concept of *distorted reality* (Drouin, 2000). For maintenance staff who have to be trained to intervene in nuclear power plants without penetrating inside the plant, the best solution is not to copy, but to deform reality. A distorted version could make more salient cues that need to be detected in maintenance tasks. This is exactly what Oshanin (Ochanine, 1981) had in mind with the concept of an operative image (see above). Thus to become instruments, virtual reality artifacts should maybe support a distorted representation of the word – this is an interesting paradox we have to meditate!

More than 300,000 people visit nuclear power plants in France each year: a transparent communication policy is thus crucial for the sector. This is why EDF designed *Visit*, a VR environment. This tool allows visitors to virtually penetrate into the usually forbidden areas of a nuclear power plant, e.g., the heart of the reactor. It combines different media such as video sequences of activities, objects to be manipulated in 3D, the visibility of invisible nuclear reactions such as neutron moderation, the reproduction of environmental auditory signals, etc. Ergonomists and psychologists were involved early in the design process to enable designers to include their conclusions in the design cycle of the tool (Mancini, 2000). They evaluated the presence feeling of visitors using the tool and then made diverse proposals to enhance this feeling. Such close cooperation between designers, users and human factors experts here, as in many other circumstances, proved to be very efficient. It is supported by a theoretical framework, itself strongly influenced by the Activity Theory.

2.4. USER-CENTERED DESIGN

Regarding these unintended side effects of technology development, several researchers have indicated the need to reevaluate the human-machine interaction at a fundamental level (Billings, 1997; Norman, 1993, 1999; Sheridan, 1995). The concept of *user-centered design* refers to this attempt. The fundamental principles of such new design approaches are: involvement of target-users in the design process, action-facilitation design and scenario-based design and error management. We will briefly discuss each of these principles.

2.4.1. Involvement of Target Users in the Design

The idea of involving users or domain experts in the design process is not really original, but its application has often been limited in practice to some particular design stages. It suffices to refer to the conception cycle schematized by Wickens, Gordon and Liu (1997) to be convinced. The authors chose not to state the numerous rings of retroaction which punctuate the cycle and render the procedure rather heavy. At the beginning of the cycle, potential users rarely converse with designers. It is the “human factors professionals”, sometimes psychologists, sometimes ergonomists, who provide designers with the frame of reference concerning the task, the work environment and users’ needs. As the prototype is developed, users are more easily included in the design process, especially for the validation of the prototype. This integration exists in various forms: questionnaires, observation of human-computer interactions in either experimental or actual work situations. At the end of the design process, the functionality of the product and, sometimes its impact on the work situation is assessed in real use, for a period of time. This phase is particularly important to identify how operators shape the artifact to use it as an instrument. The approach consists of keeping a record of the human-aid interactions and continuously comparing and analyzing the planned project with the real one. If a mismatch is observed between the users’ needs hypothesis and the actual operations in context, a change should be implemented, either in the product or in the work situation, in order to prevent the occurrence of design-induced errors. However, at this late stage, changing the product becomes unfeasible and procedures or training measures constitute, for the most part, the protective measures that ensure safety. Note that the principle of integrating the target users into the design process is only partly applied because of the time limits of the design project.

2.4.2. Action-Facilitation Design and Scenario-Based Design

From an Activity Theory perspective, aid systems should be designed to support operators in doing a task safely and efficiently in real work situations. Thus, the basis for development should not be the technology *per se*, but rather the operators’ needs in context under resource and time constraints. The concept of action facilitation was introduced by Roe (1984, 1988) and is based on the theoretical action work of Hacker (1985, 1986) and Rasmussen (1986). Following Arnold (1999), the *action facilitation approach* generated the formulation of interface design and evaluation recommendations (Arnold & Roe, 1989), a proposal for a new system design approach, so-called “Acting systems design”, the development of an interface evaluation approach (Arnold & Roe, 1989; Zijlstra, 1993) and an approach to the design or redesign of mental information work (Meijer & Roe, 1993). Activity can be decomposed into action preparation and action execution. The seven basic action facilitation recommendations developed by Roe (1984, 1988) are summarized by Arnold (1999) as follows (see Table 2.4).

Along the same line, but this time stressing the contextual point of view, is the *Scenario-Based Design*, a set of perspectives and approaches linked by a radical vision of user-oriented design (Caroll, 1997). This approach is not entirely new. For decades, systems developers have spontaneously used scenarios to envision future concrete use of their systems. But this informal practice has gained international acknowledgment, and the social content of the work is taken into account. To integrate context into the design, the task analysis stems from a scenario:

> "One key element in this perspective is the user-interaction scenario, a narrative description of what people do and experience as they try to make use of computer systems and applications. Computer systems and applications can and should be viewed as a transformation of user tasks and their supporting social practices" (Caroll, 1997, p. 3).

The activity analysis should be broad enough to include context but sufficiently detailed, so that design implications can be inferred. From this point of view, the recent contribution of Vicente (1999), is a major step to guide work analysis.

Table 2.4. Seven basic action facilitation recommendations (Arnold, 1999)

1. The user's orientation to the task(s) and the work environment as well as the design of action programs must be supported by offering relevant information and help for analyzing, problem solving, and decision-making. It should be made possible to store users' personal action programs.
2. Feedback should be given on operations and results in view of both the structure of the user's action program and the current level of regulation.
3. The user should be able to change his action program and/or the level of regulation in order to face unexpected situations or errors. It must be possible to interrupt, stop or change the dialogue at any time.
4. Information should be given on the progress of an action program in order to support cognitive control. In this respect, information should be given on the part(s) of the action program already completed, the part in progress, and the part(s) still awaiting execution. However, the presentation of this information should not interrupt execution of the ongoing action; on the contrary, it should be presented in a parallel fashion.
5. The user's natural tendency to increase his action efficiency should be supported by offering short and constant response times - by which a fluent and rhythmic series of motions are promoted – offering possibilities to execute more operations simultaneously, and stimulating users to perfect the execution of repetitive actions or operations.
6. An optimum should be reached concerning the user's mental effort. An adequate presentation of signals, text and windows can help to avoid an undesirable increase in mental effort. Furthermore, the postponement or rearrangement of parts of a task can help to avoid overloading, while, on the other hand, insertion or increasing complexity can help to avoid underloading.
7. An attempt should be made to accommodate existing differences between users concerning, for example, knowledge, abilities, skills, and work styles.

2.4.3. Error Management

Because it is impossible to prevent all possible human errors, human centered design should support error management (Frese, 1991), i.e., to increase both system error resistance and system error tolerance. Traditionally, the goal of software designers and industrial engineers is to reduce the occurrence of errors. In contrast, an error management strategy attempts both to reduce the number of errors and to limit the adverse consequences of those errors that still occur. Error management includes two principal ideas: error resistance and error tolerance. A *resistant error system* is one in which it is very difficult for a human operator to make an error (Billings, 1997). Design resistance includes, for instance, forcing functions that limit a sequence of user actions along particular paths, electronic checklists that assist in the complex task. However, as noted before, the use of new devices makes unpredictable errors possible. Tools, such as alarms that help people to detect errors, are critical to prevent the propagation of an error within the system, thus avoiding negative consequences. For this reason, several researchers pointed out that error detection and error handling are as important as error prevention. They called the capacity of the system to avoid the negative consequences of an error, *system tolerance*. Within a work situation, large numbers of errors are committed every day but only very few have bad consequences because most are caught by the various defenses protecting the system, allowing no propagation along possible accident trajectories. Tolerant design measures include: tools that enhance error detection, that increase the operators' understanding of the system, that limit the system in some acceptable mode, that monitor people's activities, that interpose safety barriers, etc.

2.5. DISCUSSION

In contrast to distribution cognition theory, which erases differences between artificial and natural agents in joint cognitive systems, Activity Theory calls for specificity for human beings. Humans are both highly reliable and unreliable (Faverge, 1970; Leplat & Terssac, 1990). Despite the fact that compared to computers, humans are "vague, disorganized, distractible, emotional, logical" they can also be considered as "creative, compliant, attentive to change, resourceful" (Norman, 1999, p.160). In complex naturalistic environments, their presence is a guarantee of safety, for they very often succeed in avoiding or mitigating the consequences of incidents. This early position of Activity Theory is entirely supported by evidence from field studies and incidents or accidents reports. It is no wonder then, if research rooted in this theoretical tradition favors tools that support activity and reinforce the operator as a natural defense against incidents. Error prevention artifacts are the same all over the world; safety-reporting systems, training devices, aids, and design methodologies are found worldwide. But in Western Europe, where Activity Theory has crossed national boundaries and can be considered as a common ground for work and organizational psychologists (De Keyser, 1997), a specific accent is put on context, activity regulation and mediation.

Context is not clearly defined in Activity Theory. It is a dynamic concept, which includes the activity, subject and object taken as a whole. But what is clear is that prevention tools have to take this concept into account. Numerous traces of this concern can be found in this chapter. That most safety-reporting systems grasp the incident process, with their contributing factors and their consequences, is a first step in this direction. But there is more to say about prototypical risk situations, simulator scenarios, scenario-based design and all the aids which are specifically designed to enhance situation awareness. They take into account activity in its natural environment, as a system. The emphasis put on field studies to increase the psychological fidelity of simulators and on the integration of end-users in the design cycle stems from the same concern. In order to adequately prevent human errors, one has to know the constraints and the resources of activity in naturalistic situations. Up to now, the privileged sources of information have been incident reports, and users or field studies.

Activity regulation has been interpreted from two points of view. At the end of 1960s, Faverge (1967, 1970) and with him the entire French work psychology school, pointed out how resourceful the operator was, acting as a natural regulator of the technical system, anticipating and detecting possible incidents. This regulation was system-oriented. At present, activity regulation is mostly subject-oriented. Instruments are designed to induce a reflective orientation in the subjects, leading them to look at their own activity, to correct their own errors, building a meta-knowledge about what they know and what they can do safely. The study by Hukki and Norros (1998) clearly shows this option. The fact that so many aids, designed as alarm or guidance systems, are anticipated and used as monitoring instruments, to help people to know "how far they can go and what are the exact limits of the technical system" goes in the same direction. Moreover, it is this same vein that we found in Action Facilitation Design, and even more so in the present error management trend. That people can spontaneously correct their own errors, if well supported by aids, training, etc. is the new philosophy. The corollary of this is that if errors occur, they can be recuperated, and their consequences mitigated.

Mediation is what instruments do, when they interface subject and object. Instruments change the internal representation people have of the world and their practice. They are knowledge generators. We have seen that some aids, the so-called prostheses, in principle designed to assist operators, are neither well understood by them, nor appropriated; they do not contribute to a real mediation. They are artifacts, often located in an area that Amalberti (1996) describes as an artificial performance area (see Chapter 1, Figure 1.2). But many aids, either because they have been very well designed, or because people have found an unexpected use for them, are actually knowledge generators. However, mediation cannot be restricted to technical tools. In this chapter there are various examples in which the mediators are human beings. When researchers mediate findings from the field to simulators as technical instructors, as in Hukki and Norros (1998) or in De Keyser and Nyssen (2000), they act like instruments in a knowledge generation process (see Figure 2.3). This very special role of research as well as the concept of context will be explored in more detail in Chapter 3.

CHAPTER 3

RESEARCH AND CONTEXT

V. DE KEYSER, A.-S. NYSSEN, I. HANSEZ AND D. JAVAUX

3.1. CONTEXT, COMPLEXITY AND FIELD

In this chapter we will present two studies on human error prevention, carried out by our laboratory at the University of Liège in Belgium. They aim to illustrate one of the possible approaches to treat this problem in Western Europe. The first study takes place in anesthesiology, the second one in aeronautics: two risky environments where human error may have catastrophic consequences. But before describing the studies, some concepts have to be clarified. For instance, what we mean by environment, domain, field, context and complexity, for these concepts are at the core of the human reliability problem.

We do not differentiate between environment, situation and world: for us, these concepts include anything, which surrounds an operator - technology, individuals, institutions, ideologies, etc. *A domain* is a set of symbolic rules, and procedures: anesthesiology, aeronautics as well as linguistics or mathematics, are domains in which knowledge has to be acquired. *A field* is composed of actors-persons or institutions - acting in a domain. They work, communicate, collect information, diffuse knowledge, support new ideas, etc. Aeronautics and anesthesiology are not only domains: they are also fields, with people or institutions, who will have an influence on human error prevention.

Context is more difficult to define. Research about human error has unceasingly shown the importance of context both in the origin of error and in its consequences (Faverge, 1967; Hollnagel, 1998; Reason, 1990). Nevertheless, there is little agreement about the way to define it, to describe it and to predict what in an environment may be pertinent to the operator. Nardi (1996a) compared three contextual theories: situated cognition, the Activity Theory and distributed cognition (see Table 3.1). In the first of these theories, the context emerges from the interaction of the operator and his environment – whether it concerns men or machines. It can only be described by observation of the activity *in situ*, and is non-predictable. In the Activity Theory, the context is the whole activity; it surrounds the

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

subject, the object, and the course of the action at the same time. Since the action is directed and its objectives planned to a certain extent, the context can be predicted. And this holds true, even if, during the course of action, one can observe a slip in the objective due to the regulation of the activity in the special circumstances encountered. In distributed cognition, the context is very close to the concept of "man-machine systems", since, at the same time, it surrounds the directed activity with an entity composed of natural agents, the operators, and artificial agents, the intelligent devices. According to this theory, the two types of agents are endowed with identical status and properties: intentions, memory, power of decision, cooperation, etc. Here again, and up to a certain point, the context can be described, even if in the activity, the interaction of circumstances implies a distribution of different roles between the agents. If these theories define the context differently, they are, however, always linked to the activity, and make the environment from all that is around, which may be stable or variable, and, at the same time, is a place of resources and constraints.

Table 3.1. Comparison between three contextual theories (adapted from Nardi, 1996a)

Situated Action	*Activity Theory*	*Distributed Cognition*
1. Emphasis is on the emergent, contingent nature of human nature and the way activity grows directly out of the particularities of a given situation. 2. The unit of analysis is thus not the individual, nor the environment, but a relation between the two. 3. The "setting" is defined as a relation between acting persons and the arena (context) in which they act. 4. The "arena" is a stable institutional framework.	1. Emphasis is on the finality of a behavior. 2. The unit of analysis is an activity. 3. A subject is a person or group engaged in an activity. 4. An object is what is held by the subject, motivating his/her activity, giving it a specific direction (cf. motivation) (cf. goal). Objects (in the sense of objectives) can change during the course of action. 5. Actions are goal-directed processes that must be undertaken to fulfill the object. 6. Operations are more unconscious routine processes. 7. The key idea is mediation by artifacts. Artifacts are the instruments, signs and language that mediate activity and are created by people to control their own behavior. 8. The context is the activity itself.	1. Emphasis is on the distribution of knowledge between individuals and their environment, the world. 2. The unit of analysis is a cognitive system composed of individuals and the artifacts they use. 3. The approach is the classic approach of traditional cognitive science, but emphasizes the representations of knowledge both in the "heads" of individuals and in artifacts.

In line with Nardi, but in a more pragmatic way, we define the context as "the subset of the environment which is meaningful to the operator". But how can we describe and, especially, predict what in the environment will be activated and become pertinent to the operator? Three means exist and they highlight the context differently (see Figure 3.1).

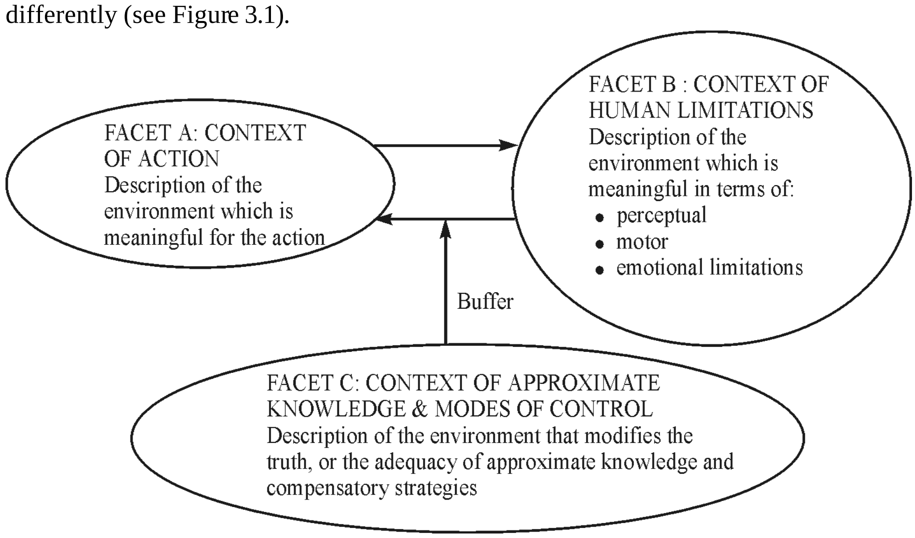

Figure 3.1. Three different facets of context (De Keyser & Javaux, 1999).

The first hinges directly on Activity Theory. *Context* is a set of objectives, means and conditions which intervene in the activity – and which can be approached in a predictive way by task analysis. This allows one to define in advance what in an environment will be necessary for the task and thus to create a favorable context for the action. On the other hand, the absence of means that are indispensable for reaching certain objectives will be the source of complications and potential errors for the operator. This path is the one that many ergonomists follow when they try to study activity in its context and at the same time, to decrease the probability of error (see Figure 3.2).

A second way to view the context goes back to analyzing the constraints, which directly complete with the perceptive, motor, cognitive and emotional limits of the operator in the environment. For example, the organizational constraints, the work atmosphere, time pressure, social climate, etc. This way of seeing things is close to what Hollnagel (1998) calls the "performance-shaping factor". Good models of human functioning are necessary. In this way, the theoretical models of evaluation of cognitive complexity, associated with the use of software (Card, Moran & Newell, 1983; Kieras & Polson, 1985), rely on knowledge of the limits of the work

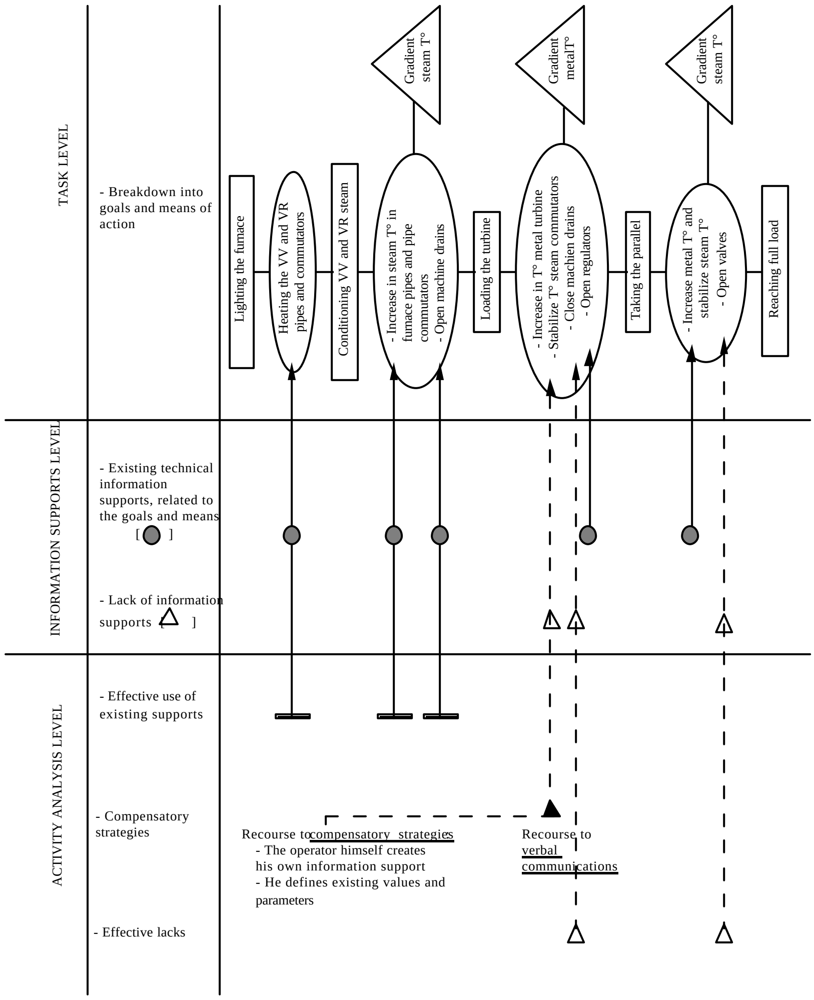

Figure 3.2. Three analysis levels for display design: the case of an electric power-plant start-up (De Keyser, 1988). The basic idea beyond the schema is to break down the analysis into three levels:

1. *first a task level with a classical cognitive task analysis;*
2. *then an information supports level. At this level, the information required for the task is elicited, with a distinction between the existing supports and deficiencies;*
3. *finally a field activity level. At this stage, the analysis reveals which supports are used, which informational needs have been fulfilled despite a lack of support by the operator's compensatory strategies, and which needs are still unsatisfied and thus potential sources of complexity and error.*

memory, resources of attention, and perceptive skills. When these limits are exceeded the performance deteriorates and errors occur. But by taking into account only these two facets of the context, one freezes the individual and misses out on his extraordinary resources, and flexibility. Common sense and daily experience show us that excellent performance is achieved in constrained environments, which, in principle, exceed human limits. If an operator, with a limited work memory, manages to deal with information that is distributed over thousands of indicators in a short time, it is because he uses knowledge and effective control strategies that go beyond the limits. Many operators today admit that the knowledge, that allows each one to adjust to complicated situations, is approximate, operative, and incomplete but effective in most cases (Masson, Malaise, Housiaux & De Keyser, 1993). Thus an operator who has only an imperfect mental model of the evolution of a process could hardly anticipate but would have a reactive control, multiplying short-term actions and feedback checks. The performance may be excellent. This is why approximate knowledge and adequate control modes act as a buffer: despite the well known human limitations they allow people to adjust to very complex contexts. There are, however, situations where an approximate knowledge may no longer be operative. This will be our third approach to the context. This context modifies the truth or the adequacy of approximate knowledge and compensatory knowledge.

Complexity is an even more ambiguous concept than context. For despite the fact that many papers on human reliability start with sentences like “the increasing complexities of technical systems introduce new risks of human error” there is little agreement on what the concept covers, and how to measure or to predict the effects of complexity on human performance. We will define *complexity* as a relational property directly derived from a mismatch between the operator and the context he/she is supposed to control. But before going deeper into this definition, closely related to our context definition, let us have a look at the literature. Pedersen (1990) considers that there exist many sorts of complexity in man-machine interactions. He distinguishes, for example, objective (system) and subjective complexity (in other words representational complexity, and operator complexity). He also describes a computational complexity, which is a measure of complexity based on computer science. But authors like Woods (1988), Van Daele (1993), and Amalberti (1996), have tried to characterize which contextual factors are sources of complexity for an operator. This view allows an objective description of the context, but is anthropocentric, from the point of view of the operator. Actually, they closely integrate objective and subjective complexity. Such factors as the number of components of the system, multiple variable retroactions, risk, process dynamics, unclearness and conflicts of goals, lack of feedback from an action, characteristics of the agents, the level of automation, temporal pressure, etc. have been enumerated. This typology of factors is interesting. It points out how one could minimize the risk in a given situation. But some of these factors are difficult to operationalize. How can we say for instance that the number of components of a system is too high? To go beyond the limits of the typological approach, authors have proposed models based on the notion of cognitive complexity. They stem from the hypothesis that the complexity of man-machine interaction reflects the complexity of the cognitive processes involved in the interaction. The Cognitive Complexity Theory (CCT) introduced by Kieras and Polson (1985) is a well-known attempt in this direction. The CCT is actually both an alternative and a sophistication of the GOMS model (Card et al., 1983), widely used in the Human-Computer Interaction community. Just as GOMS, the CCT starts from the idea that the action of the operator on the interface relies on procedural representations, which could be represented as hierarchical plans. The user's knowledge is described in this model as production rules. The model takes into account the limits of the working memory, considered as a working space where the activated rules and the internal variables describing the current goals and states are temporarily stocked. The CCT is a computational based approach: the computational complexity of the cognitive processes. The measure of complexity is given by the number of production rules necessary to simulate the cognitive processes. If the CCT has very often been used to predict performance in very simple interaction tasks, and in situations, which only evolve through the user's action, other more recent models have tried to adapt to complex and dynamic situations, such as MIDAS (Corker & Smith, 1993; Pisanich & Corker, 1995), and EPIC (Kieras & Meyer, 1995). But these models do not integrate the approximate knowledge developed by an operator very well, and the fact that in some contexts this knowledge is operative, and in others not.

Let us come back to a complexity definition. *Complexity* is relational property of the interaction between the operator, and the context he/she is supposed to control. In short, a mismatch between them. But when the context is defined by the activity (see Figure 3.1, Facet A) this mismatch always reflects a lack of resources in the context to achieve the goals: missing information, the absence of technical means, inadequate procedures, no transparency of the prescribed goals etc. The ergonomic approach of complexity is close to this definition. When the context is described as competing with the internal human limitations - perceptual, cognitive, and emotional ones - the stress is on other aspects (see Figure 3.1, Facet B). For instance the CCT emphasizes the amount of information to be processed, which could compete with the span of the working memory. Along the same line, we could find a description or contexts implying emotional complexity - to be an hostage in a terrorist attack, to speak in public or on television, to face violence, etc. - or perceptual complexity - to drive in the fog, to follow a conversation in a noisy assembly, etc. There is a mismatch between the constraints of the context and the human resources available. But what about approximate knowledge? In this case complexity will arise in contexts in which either approximate knowledge or compensatory strategies that are very often associated with it, suddenly fail: what Amalberti (1996) called "a breakdown in the cognitive compromise". This is the third approach to complexity, linked to Facet C of Figure 3.1.

But why we mention the *field*? For a very simple reason: in human reliability research, results are primarily directed to the field. The first goal is human error prevention and this can only be achieved if the field captures new data, diffuses them, transforms the knowledge domain and changes its practices and safety culture. Researchers are just as in Vygotsky's definition: instruments that support the change of the field. This point of view is ethical and methodological at the same time. Ethical because it is difficult to imagine that a theme so highly sensitive as human error could be treated for the sole advantage of the scientific community. Methodological because nothing credible can be addressed to the field by researchers who do not have a deep knowledge of the targeted domain. This takes time, effort, and money. We are very lucky in our laboratory, to have been supported for many years by the Belgian Scientific Policy for the anesthesiology study, and by the French Civil Aviation (SFACT), and the Belgian Scientific Policy (PAI, SSTC) for the aeronautic study.

3.2. PREVENTING HUMAN ERROR IN ANESTHESIA

3.2.1. The Risk of Error and Accident

The risk in anesthesia never ceases to decline, thanks to advances in medical science, drugs and technologies. Here, the patient’s security is the prime objective of the entire medical team. However, incidents are often given very high media coverage and remind one every day that no anesthetic operation, as minor as it might be, is totally devoid of risk. It is estimated in Belgium today that for the 900,000 patients anesthetized each year, 1215 serious accidents must be expected of which 378 may be deaths or severe cerebral damage – that is, a rate of 0.4 deaths for 1000 anesthesia’s (De Keyser & Nyssen, 1991). It is in this very delicate environment that human error plays a part. When it appears, it is most often during an anesthetic incident, or it is a factor among others. But the courts hardly ever consider the context, which might favor the occurrence of human error. It is the latter that they sanction, more and more often. This movement began in the United States and is gaining ground in Europe. In the United States, ten years ago, there were already 900 lawsuits for medical error for which the compensation could reach 400,000 dollars. These figures are getting higher and higher. The insurance premiums asked of anesthetists are becoming very high and this cost is passed on to the patient. Other economic incidents occur. One notices an inflation of examinations and analyses demanded by doctors to cover them in case a problem shows up. This drift is gaining in Europe today but the reactions, which are very positive on the security side, are counter-balancing it. In fact, the emotion provoked by the risk of anesthesia does not have only negative effects. In 1986, the Harvard Medical School Department of Anesthesia adopted standards concerning the minimum amount of monitoring necessary for the supervision of the patient and the checking of anesthetic instruments before use. At the same time this is progress because errors will decrease and it offers an enormous market for inventors of medical instruments. The security standards at Stanford have now been adopted in different European countries. Anesthetic simulators are multiplying to make sure of the training of young anesthetists. Interdisciplinary research, mixing anesthetists and psychologists around the problem of human error are no longer unusual. The research that we have carried out in Belgium is in this framework. When it began in 1991, it was pioneering in a sensitive, but still fallow, field. Eight years later, this field has been greatly structured and we will examine the methodologies used to arrive at this result and the main acquired knowledge.

3.2.2. The Anesthetic Task and the Technical Evolution in the Domain

The surgeon operates and the anesthetist manages the tolerance of the patient's body for this invasive act. He does it by plunging the patient into a state of unconsciousness, assuring the functioning of the vital functions, and by abolishing the sense of pain. That is, by pushing back the subject's limits towards a state where any small irregularity could tip the scale towards death. The more the ease the surgeon is guaranteed – for example, complete muscle relaxation by curare – the narrower the margin in which the anesthetist can act. The more the surgeon is in a hurry, the more conflict there is and the precise, meticulous work of the anesthetist may explode, sometimes causing novice anesthetists, without equal status to that of the surgeon, to take risks. An entire team is around them: interns, nurses, supervision monitoring devices; and around these, the hospital with its economic constraints, time pressure, the weight and sometimes the incoherency of its administrative organization. In short, a system, where one often has the impression that the main roles are played by three: the patient, the surgeon and the anesthetist.

The patient's condition is characterized by a series of variables, of which some are taken care of by supervisory instruments and others remain in an informal form.

The sensors connected to the patient supply integrated information these days often on screens situated in the proximity of the anesthetist. In the sense that it is he who will decide the actions to program, on the basis of the indications, this latter stays in the control loop. If at present, the anesthetist is still "in the loop": that is to say, if he treats the information transmitted on the monitors and if he decides on the actions to take, it is no longer the case with new kinds of instruments, such as the computerized push-syringe. In normal situations, that is, without incidents, the system works in a closed loop, from the reception of information to the action, without intervention by the anesthetist (see Figure 3.3).

More than 200 hours of observation in operating rooms and interviews with anesthetists have permitted the extraction of a generic cognitive task analysis, usable no matter what the length and type of surgical intervention (see Figure 3.4). The analysis is hierarchical and comes from a breaking down of objectives and means. This analysis will be useful, as shall be seen, to define the anesthetist's information needs, which must be met by the supervisory instruments. In addition, the temporal constraints of the task show up because they show very clearly the necessity of anticipation, planning and synchronization, which can be a source of error.

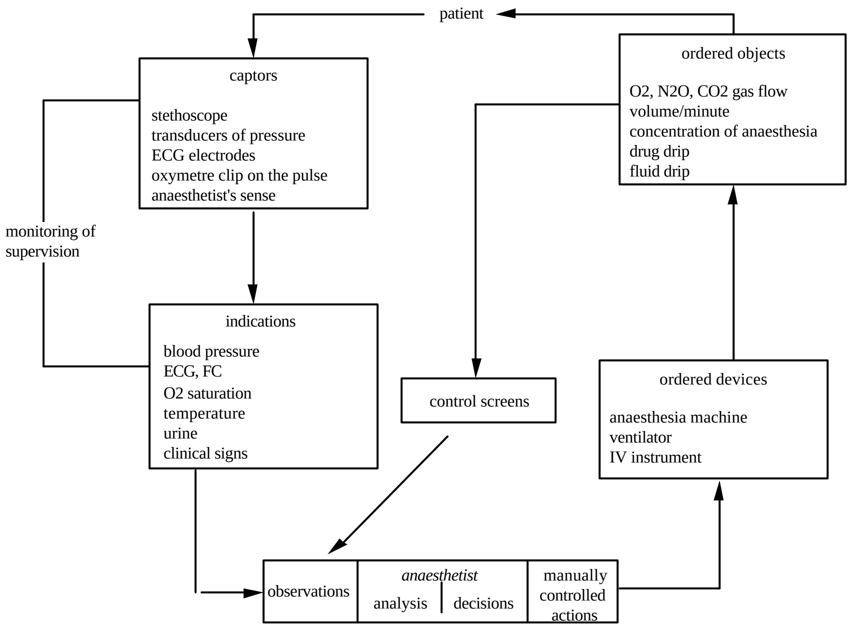

Figure 3.3. Representation of the man-machine system (adapted from Gravenstein "Monitoring surgical patients in the operating room" (1979). Courtesy of Charles C. Thomas, Publishers, Springfield, Ill.).

What the cognitive analysis does not show, but field observations reveal, are the contextual elements that add to the complexity of the task. Among these are the sources of variability: the variability of the work teams, which prevents the formation of tacit habits of collaboration; the variability of patients means that no patient reacts as another; the variability of the operation, because at the heart of the same kind of operation there are important differences; the variability of the instruments and the operating rooms whose lay out are not always identical. So there are many elements which the anesthetist gradually manages to control in his expertise, but which are traps for beginners and take up their attention: for example, one knows that intubations or extubations are critical moments when constraints of synchronization as well as delicate handling can arise at the same time. Thus, apart from the patient's condition and his evolution, risks appear that are tied to the anesthetist, to the task, to the contextual variability, to the criticality of certain phases of the surgical intervention.

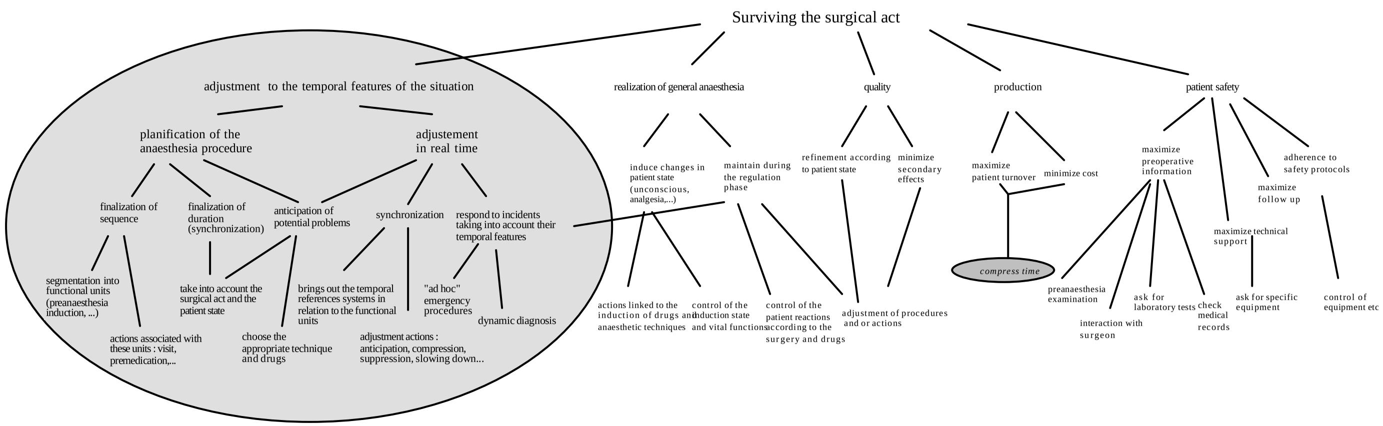

Figure 3.4. Cognitive analysis of the task, which emphasizes the temporal constraints of the task (De Keyser & Nyssen, 1999).

3.2.3. The Collection of Errors

Today there are many collections of errors and incidents in anesthesia (Cook, Woods & McDonald, 1991; Cooper, 1984; Cooper, Newbowers, Long & McPeek, 1978, 1991; Runciman et al., 1998; Runciman, Webb, Klepper et al., 1993; Runciman, Webb, Lee et al., 1993) and one could rightly wonder if everything on the subject has not already been written. To what extent could new data still help improve prevention? Already in 1984, at the end of extended research on the sources of incidents in anesthesia, Cooper proposed some potential strategies of prevention. At the top of the list were the training of anesthetists, work organization, supervision, and the design and ergonomics of the supervisory instruments (see Table 3.2).

Table 3.2. Potential strategies for prevention and detection of incidents (Cooper, 1984)

1.	Extra training for anesthetists	25%
2.	Better organization	13%
3.	Better supervision or advice from a colleague	12%
4.	More elaborate monitoring	11%
5.	Better designed equipment	11%
6.	Preliminary check of the material	6%
7.	Better pre-operative evaluation	6%
8.	Better communication	6%
9.	Better outline of the work	5%
10.	Stricter selection or refusal criteria	3%

Fifteen years after this study, one could make the same report, and yet, what efforts have been made to improve the security and the comfort of the patient and how far we have come in the awareness of anesthetists in relation to human error! The real question is whether we must still look for incidents and errors and collect them. There are several possible answers:

- The method of collecting the data directly influences the factors brought to light. Therefore, for example, the study by Cooper does not take into account the organizational circumstances of the errors, or even the temporal aspects of them.
- Even if in all the anesthetic environments, one finds the same generic causes, the form that these errors take in each situation is specific. And the precision of the instant is capital since the main users of the research results are the actors in the situation. Thus, if Cooper denounces the design of certain equipment, it is good to attack the evaluation of the precise instruments.

- The primary objective of the research is not to produce results unknown until now but to bring to light knowledge about their reliability in their domain and the way to transform it. By collecting and formalizing data on human error and the management of incidents, researchers continuously enhance the image of the activity to the actors in order to allow them to better regulate it. It is the very image and the specificity of the precise actors' activity that is suitable to replay – and not those of other persons, in other countries and other situations.
- The supervision of errors and incidents allows external observers, such as public authorities or public opinion, to be vigilant over the evolution of security in the sector.

The starting point of the research consisted in gathering a starting sample of twenty cases of incidents where human error played a part. These cases were first treated qualitatively using a cause-consequence diagram, which allows the visualization of the factors sequence (see Figure 3.5).

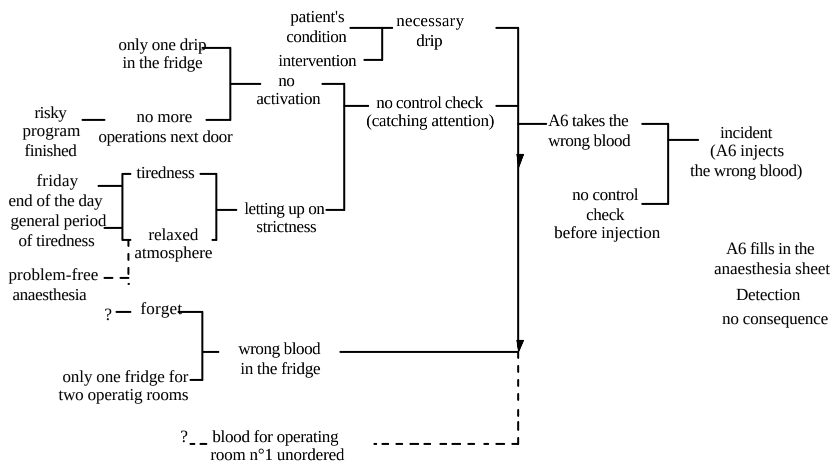

Figure 3.5. Hypothetical causal structure of an incident (De Keyser & Nyssen, 1993). The anesthetist is in his sixth year of training; it is Friday, the end of the week and afternoon. The team has been operating since the morning. The operation program in the neighboring room is over and the nurse has forgotten to remove a bag of blood ordered for the last patient from the refrigerator shared by the two rooms. In the first room, the anesthetist who must transfuse blood into his patient goes and gets the transfusion normally ordered and stored in the refrigerator. Upon his return he injects it without verifying whether or not it is the right blood for his patient. While filling out the anesthesia form, the anesthetist realizes that the number on the patient does not correspond to the number on the routing label. It turned out that no blood had been ordered for the patient. Since the two patients had the same blood type, the error had no consequences.

Then, the data were submitted to a factorial analysis by varimax rotation (De Keyser & Nyssen, 1991). The latter brought to light six factors that contribute to errors. These were:

- *Information management* (principally saturated by a lack of communication, difficult visibility and access to the patient, a lack of adequate monitoring).
- *Supervision* (attitude and prejudices of the beginner regarding the senior anesthetist, late calls, lack of experience and lack of permanent control over the activity).
- *Production and time pressure* (which does not include emergency situations, a factor essentially saturated by organizational variables as the cause of a delay in the planning or a rush).
- *Attention interruptions* (the interruption and presence of distracting elements).
- *Cooperation and decision* (conflicts of authority between the anesthetist and the surgeon, problems of interpersonal relationships in an emergency or during the evolution of a case.
- *Constraints linked to the task* (changes in the material, the end of the week, tiredness).

These results confirm those of the already-mentioned research, but thanks to the classification of the cases by fault trees, they emphasize the ergonomic and organizational factors that are rare in the literature. This is due to the way data were collected which gave a lot of weight to the circumstances of the incident and the antecedents of the error. The anesthetists, circumspect at the outset as to the aims of the study, welcomed the results openly. They immediately tried to modify the factors, which they control. Thus, the supervision, the ergonomics of the equipment, and in an overall way, the training of the anesthetists has been improved. Four initiatives were derived very precisely from this first exploration: 1) the creation of an interdisciplinary team for training the anesthetists on simulators; 2) the evaluation of monitors and computerized equipment during their design; 3) the setting up of monthly hospital security meetings so that incidents and errors would be reported and discussed openly; 4) the evaluation of anesthetists' stress. The next step, which is still a project at the moment, is the creation of a "safety-reporting system" in different Belgian hospitals, at first limited to anesthesia and later extended to other medical subjects such as psychiatry, neonatology, etc.

3.2.4. Training on Simulators and Interdisciplinary Teams

Shortly after the end of the first exploration of errors, the different university anesthesia teams at the national level in Belgium came together to buy a full-scale simulator like the one at Stanford. This simulator would mainly serve to train anesthetists to critical incident cases. The training sessions take place under the supervision of an anesthesia teacher who pilots the case incident and adapts it to the audience. A briefing precedes the session where the case characteristics are presented to the subjects and a debriefing where the subject's performance is evoked. The accent is put on the diagnostic and good application of procedures. A psychologist was integrated into the instructor team. Her role was to video record all the actions and verbal communications which took place during the simu lation and then, in the debriefing session, to comment with the anesthetist and the subjects on the errors committed, their development and their possible recovery. At that time, it was much less the organizational aspects, which were put under the spotlight than the cognitive aspects in the origin and recovery of the errors. In fact, even if the full-scale simulator is functionally and technically reliable, its psychological reliability – that is, the way in which it reproduces the conditions of the action – is far from perfect (De Keyser & Nyssen, 1999a). The reliability of the equipment, the organizational constraints of the hospital, the relationships in the team, the fatigue linked to the previous workload – and many other factors which one has seen play a big role in human reliability – are obviously absent in the simulator.

Besides participating in the debriefing and thus encouraging the subjects to reflect on their own activity – which is of direct didactic use – the researchers used the simulator for research purposes. It appeared interesting to them:

- To check if certain steps in decision-making were more prone to errors than others.
- To check if certain scenarios were more complicated than others, and why.
- To check how the errors were distributed during the training – for example, by comparing the juniors in the first and second year of specialization with the seniors, still in training, but in the third, fourth or fifth year.
- To check if temporal competence could be acquired on the simulator, in spite of time distortions and simplifying temporal constraints generally associated with simulations.

Very briefly, because the results have been shown in other works (De Keyser & Nyssen, 1999a; Nyssen, 1997; Nyssen & De Keyser, 1998), one can say that:

- Contrary to widespread ideas, the diagnostic phase is far from being the most critical: everything which comes before the diagnostic – that is to say the pre-operative information gathering phase and detection of pertinent signs in the incident is decisive. On the other hand, even when a good pre-diagnostic is done by the subjects during the briefing, it is not always taken into consideration in the real situation, the attention of the subjects was taken up by other problems: procedures, maneuvers to carry out on the instruments, etc.
- At this time, the main factors of complexity detected in the scenarios are the rapid rate of the incident, its rarity, and the constraint of making a difficult differential diagnostic from the pertinent clues that may be associated with other pathologies than that of the incident. But these

results must be taken with care: the bank of scenarios is growing only slowly and other factors will certainly come later to complete it.

- The third year of training is a turning point where one sees errors increase. This is the year, in fact, when the anesthetist is given real responsibilities in the management of cases without already having all the experience of the seniors.
- Temporal competence such as that involving a dynamic diagnostic and planning can be acquired on the simulator. But the synchronization of the anesthetist's activity to some contextual constraints (the surgical act, the hospital planning, etc.) cannot be learned on the simulator and remains one of the big problems in the field.

The interdisciplinary team composed of instructors/anesthetists and psychologists worked in perfect symbiosis and this collaboration had immediate repercussions. In fact, the data gathered permitted one to aim the didactic use of the simulator much more precisely. They supplied the instructor with necessary information, first to better understand the difficulties and weaknesses of the subjects and then to focus the training on certain critical points. In this respect, the research is similar to that of Hukki and Norros (1998), which is described in the previous chapter, except that it concerned a nuclear simulator.

3.2.5. The Technological Assessment of the Instruments

The last twenty years have been decisive in anesthesia because of the evolution of the drugs that are used and the technological evolution of the equipment. The clinical signs of the patient – skin color, appearance of the pupils, etc. – are no longer the only source of information for the anesthetist during a surgical operation. Sensors on the patient take data relative to the essential physiologic parameters and report them: in the form of values, curves and graphs usually presented today in an integrated manner on screens that the anesthetist programs as he likes. One more step has been taken, however, along the road towards more complete automation. Automatic intravenous administration systems (pumps) are becoming common. Planned and programmed in advance depending on the patient's characteristics and those of the operation to be done, they order the administration of drugs in a continuous and regular manner and free the anesthetist from unnecessary handling. But the latter continues to take over manually in case of a problem. As Cooper proposed in 1984, these devices are likely to greatly reduce the risk of human error as long as they are adequately designed (Cooper, 1984). Following the first collection of errors, the researchers have thus tried to ergonomically evaluate tools that have already been conceived and those being conceived. The study concerned integrated monitoring and then, automatic intravenous administration systems. It has, each time, permitted them to make modifications in the tools – but it is interesting to see how the method of evaluation has evolved over time – that is, six years.

Integrated monitoring and the new automatic intravenous administration systems have first been evaluated. The assessment methodology is a simplified version of that of De Keyser, Javaux and Haché (1994) and Nyssen and De Keyser (1998). The tools were evaluated in hospital operating rooms and immediately the changes that were introduced were noticeable. In all, 24 anesthetists were observed and two groups of anesthetists, more or less experienced, were trained. The instrument uses a new drug, Propofol, which requires the use of pre-filled syringes equipped with a system of electronic recognition. It appeared very soon that:

- The device transforms the necessary knowledge. A new way of thinking must be developed by the anesthetists. Used to working in terms of dosage (mg/kg/h), the doses having been transformed into flow, from now on, they work in terms of desired plasmatic concentration and the computer linked to the system calculates the circulation flow to reach the target value.
- New knowledge about the functioning of the instrument must emerge: the possible mix-up of syringes, the difficult transition between manual mode and automatic mode, etc.
- New sensory-motor tasks appear: difficult programming at the time of installation on the patient and the checking of all the equipment.
- New planning tasks come up: the length of action of the Propofol is short and the post-operation analgesia must be planned at the time of return to consciousness which means a critical moment for the anesthetist's cognitive care.
- Attention allowances are changed: propofol has a hypotensive effect that requires closer attention by the anesthetist to the patient’s blood pressure.
- The interaction with the surgeon: several surgeons have said that the new protocol of anesthesia has some side effects such as an increase in bleeding, both during the operation and post-operatively.

In any case, the new methods of evaluation are more a guide than a closed method and this generic guide is adaptable to all new instruments. Without reviewing in detail the results of the drip evaluation (Nyssen & De Keyser, 1999a; Nyssen, De Keyser, d’Hollander & Lamy, 1999) one can say that, in general, the instrument seems to be well designed. Compared to a classical push-syringe, it allows the anesthetist to quickly change the level of anesthesia without problem thanks to a roulette that is very easy to use. It can increase, but also decrease, the target concentration that is still not possible with manual drug injection. But it increases the number of programming tasks (age, weight, identification of the patient’s target plasma concentration) before using the new device and this occurs precisely at the beginning of the operation, when the number of acts is high. Furthermore, observations show that in certain emergency situations, the anesthetist gives up using it. The instrument carries a series of new data: length of re-awakening, time needed to eliminate the product, target-concentration, etc. But it is less the instrument than the new anesthetic product, Propofol, which transforms the information gathering strategies of the anesthetist. In fact, its pharmacocinetic characteristics – it is a blood pressure reducer with a short half-life – demands close supervision of the patient's blood pressure and planning of other anesthesia for the re-awakening, thus giving additional work to the anesthetist. The duality between the cognitive aspects, which are more restricting, and the clinical objectives, which are better reached, is reflected in the appraisal that the anesthetists themselves gave for the instrument (see Tables 3.3).

Table 3.3. Answers from anesthetists (n=9) to the questions (Nyssen et al., 1999)

"Do you feel that using such a system has consequences on...? Explain what"		
Perception of the patient's condition	+ + -	Adjustment to the patient Tendency to rely on the system
The plan of action	+ + + + + + +	Avoid re-injection
Memorizing the information	+ -	
Interpretation of the data		
Ability to react	+ + + +	Frees the hands Rapid adjustment
"Do you think that using the system...? Explain how"		
Increases the work load	+ + + + + +	Programming Arterial line Increased vigilance on pressures
Decreases the work load	+ + +	Hands-free =>maintenance
The system's effect on the carrying out the anesthesia		
Increases patient security	__________	Stabilizes the pharamacocinetic model
Changes the induction	__________	Softer for the patient
Changes the maintenance	______	Easier
Changes the re-awakening	________	Quicker

The transition from the automatic mode to the manual mode of the device caused some errors, when there is an incident, but the evaluation took place no later than a month after the first use in service. Many phenomena noticed in the on-site observation (incidents, communication, changed role of the nurses) could be linked to the start-up phase and it would have been useful to repeat the observations later. However, one can consider that this closed loop information constitutes the first step towards more automation in anesthesia and that because of this, it could be the forerunner to more radical changes such as has been found in other procedure checks, such as in aviation. The data from the evaluation of all the instruments, whether it concerned integrated monitoring or the first and second drip, has caused changes and the retrospective effect of the loop between research and designers worked perfectly.

3.2.6. The Setting up of Monthly Safety Meetings

Monthly safety meetings were organized among the wave of other measures destined to reduce the risk of human error. The anesthetists present problems experienced during the month and comment on them. These meetings create a privileged place of exchange and confrontation of expert opinion. However, they are not only for the circulation of knowledge: the spirit in which they are organized allows them, according to the anesthetists, to feel better after an incident. The emotional load can be heavy to carry and the anesthetists are too often left in solitude after the blow. The meetings play a role of "social support" and the psychologists are included, just as with the simulator.

3.2.7. The Evaluation of Anesthetist Stress

The heavy responsibility which is incumbent to anesthetists, the difficult conditions in which they must work, the reported cases of anesthetist suicide after a patient's death, have led researchers to turn their attention to the stress of anesthetists. It is a theme which until now has rarely been studied using a contextual approach, that is, in trying to define the factors which influence the anesthetist's stress: one has rather tried to infer the stress from secondary signs, such as suicide (Seeley, 1996). The second study concerning the causes of stress seems to have been that carried out in 1995 by the Association of Anesthetists of Great Britain (reported by Dickson, 1995), in which the results, obtained thanks to Cooper's OSI (Occupational Stress Indicator) reveal three major sources of stress: lack of control, professional relationships, and work overload.

Our study was based on a sample of 151 anesthetists, of whom 79% were interns and 21% graduated anesthetists. The methodology which was used was that of an exploration, both quantitative and qualitative, of stress, using different instruments, of which two, the WOCCQ (Working Conditions and Control Questionnaire) and the self-collection manual of problem situations, were conceived by our service at the University of Liège (De Keyser & Hansez, 1996; Hansez & De Keyser, 1999). The underlying hypotheses to the WOCCQ, greatly confirmed in the literature, is that the lack of control by the workers over the work situation contributes to the stress they feel. However, contrary to Karasek (1979, 1989) for example, who only represents one scale of control – the degree of latitude – the WOCCQ measures the control that the workers have over six dimensions in their work: control of resources, planning, risks, the future, task-management, and temporal constraints.

The second instrument is qualitative. It is a self-collection manual of problem situations where the subjects bring the problems that they encounter and the frequency and degree of stress produced. The third instrument is a short version of the MSP ("Mesure de Stress Psychologique"), a Canadian questionnaire for the subjective evaluation of stress, conceived by Lemyre, Tessier and Fillion (Lemyre & Tessier, 1988; Lemyre, Tessier & Fillion, 1990). The fourth instrument is a scale of burnout adapted from the MBI of Maslach (1982): the scale of emotional exhaustion.

The results of the WOCCQ bring to light the low level of control over work plans and temporal constraints and, to a lesser degree, the risks: unknown daily planning, the impossibility of taking a break, the fast work pace, overtime; no control over the work pace because of dependency on the pace of their colleagues (see Figure 3.6).

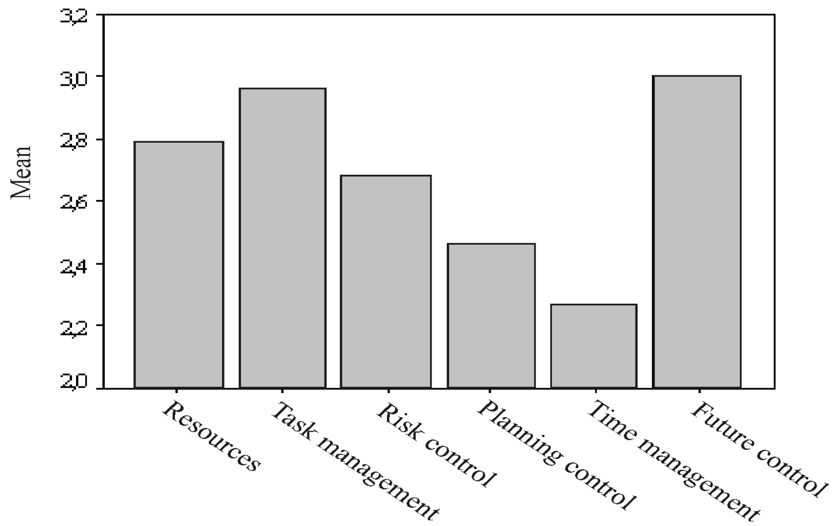

Figure 3.6. Job control mean levels for anesthetists using the WOCCQ (Hansez & Nyssen, 1999).

The analysis of problem situations highlights these results by bringing to light the evidence problems strongly linked to the work-organization (31%). More specifically, the work-organization causes problems concerning the unpredictability of the schedules because of changes in planning and of lack of coordination of work within the medical team, the length of workdays, difficulty in reconciling professional life with private life, overload of work associated with the a multiplicity of simultaneous tasks with no possible time to rest, and bad division of the workload. The anesthetists also list problems linked to responsibility and supervision, notably: missions perceived as too complicated in relation to their competence coupled with inadequate supervision (16%); medical acts reflecting preoperative problems, especially difficult reanimations and intubations (15%); types of activities (especially the organization of duty-periods and lack of time for study) (15%) and relations within the medical corps (conflicts with surgeons, bad comprehension within the team) (14%).

The average level of stress is not alarming in relation to other categories of workers. However, the study of the inter-individual variability of scores is high, testifying to the subjective character of the phenomenon. 18% of anesthetists have high levels of stress. Some of them are extremely stressed (see Figure 3.7).

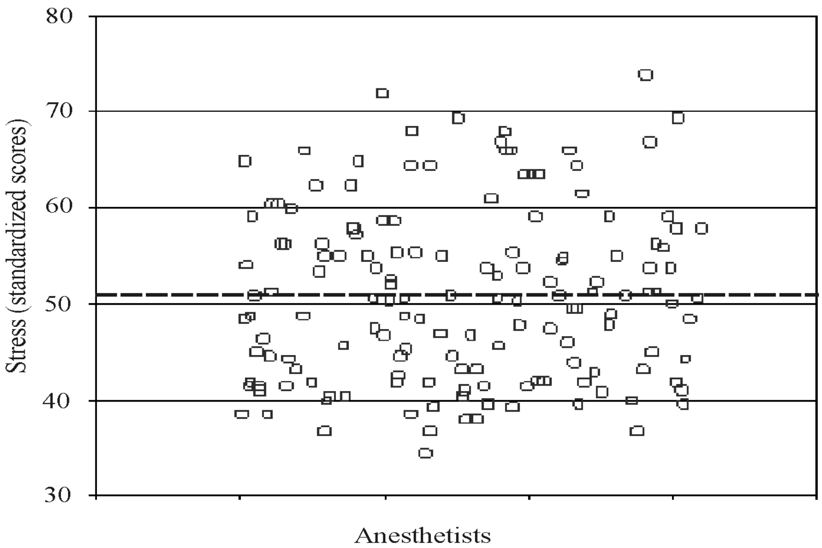

Figure 3.7. Standardized scores of stress for the anesthetists (Hansez & Nyssen, 1999). The figure is very explicit about the high dispersion of the scores among the individuals (MSP).

The results concerning burnout corroborate this idea. One notices an average degree of emotional exhaustion for 44% of the anesthetists and a high level for 40% of them (see Figure 3.8). A deeper analysis shows that the level of stress increases slightly between the first and the third year of training, the year which corresponds to the real taking of responsibility for the act, then has a tendency to decrease at the end of the training and to come into line with that of confirmed anesthetists (see Figure 3.9). In the same way, a high level of burnout affects especially the young anesthetists who are less than 30 years old. Most of them, regardless of their expertise, nevertheless, consider themselves satisfied with their job that gives them a stimulating challenge. The degree of commitment to the job is also high.

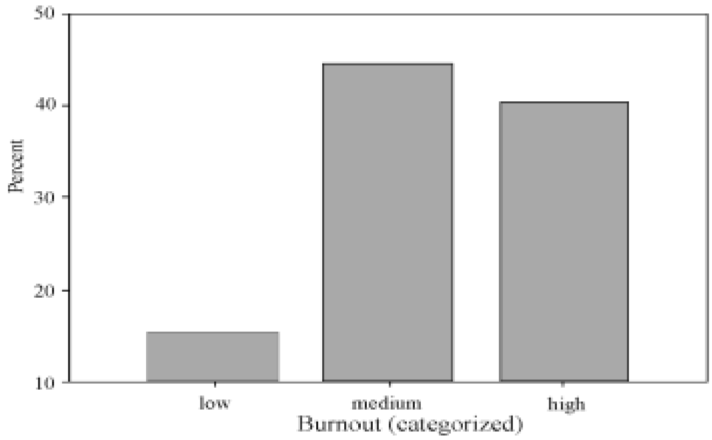

Figure 3.8. Percentage of anesthetist burnout according to Maslach's scale (Hansez & Nyssen, 1999).

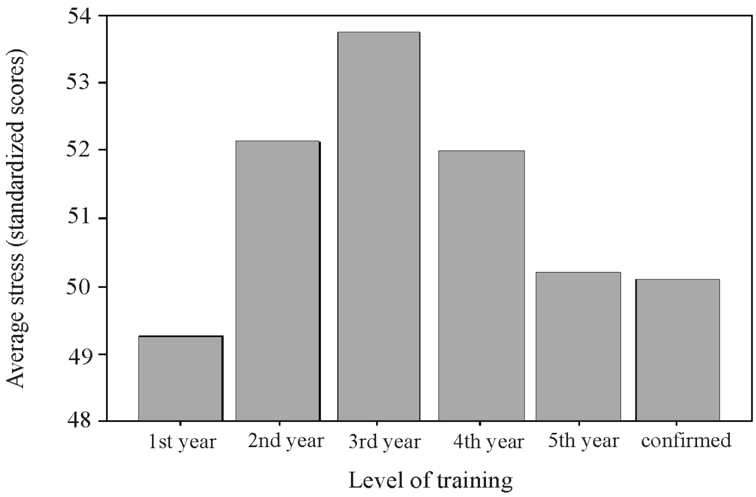

Figure 3.9. Average level of anesthetist stress (MSP) according to the level of training (Hansez & Nyssen, 1999). The figure shows how difficult the third training year seems to be, when new responsibilities have to be taken by young anesthetists.

The results confirm the steps developed until now, especially the training of anesthetist interns thanks to the simulator which allows them to acquire better skills in risky medical acts, and the monthly meetings allowing them to free their emotional load. However, they also put forward the organizational problems not yet solved, such as schedules, long work days and the difficulty of coordinating professional and family lives.

3.2.8. The Safety-Reporting System

At present, the creation of a safety-reporting system is being studied. Bringing together in the beginning the anesthetists who have participated in previous phases of the research, it should extend to other hospital services such as psychiatry, neonatal care, etc. It would not be the first in the world. In fact, for several years a university hospital in Melbourne in Australia has been collecting cases of incidents and errors and has set up a methodology which allies the confidentiality of the incident reports, the retrospective effect of the information to the concerned persons, and the simplicity of the collection of data (Runciman, Webb, Klepper et al., 1993; Runciman, Webb, Lee et al., 1993; Runciman et al., 1998). Once more, one may see a kind of transfer of practices already used in other fields such as aeronautics or the nuclear industry – a transfer already at work in the use of simulators.

3.2.9. The Impact of the Results

The strong points of this research are:

- its duration: the research has been going on for ten years;
- the utilization of crossed methodologies, constantly combining the quantitative and the qualitative;
- the symbiosis of an interdisciplinary team where psychologists and physicians work together constantly;
- the fact that the impact of the research has broadened gradually, and as such has contributed to modifying the way human error is viewed by the field.

This study is still in progress, and actually, is a continuous research process, without any foreseen end. The medical field evolves very rapidly, with extraordinary successes, and some unexpected problems. More than anywhere, in this field, humans are both time reliable and unreliable agents. They save patient lives, but are exposed to errors. But the field has proved to be highly reactive and has changed its prevention practices, in the light of the research results. However, this reactivity had to be supported by a mutual confidence between researchers and practitioners, a mutual confidence, which developed only very slowly. When we began this research, human error was still a taboo at the hospital. It was almost impossible to speak openly about an incident. The fact that psychologists have obtained visible and concrete results, through error analyses, through monitoring device assessments and modifications, has contributed to create a collaborative climate. The introduction of the psychologist into the simulator training was a decisive step. This took time and did not happen without lengthy training of the psychologist in the medical and technical aspects of anesthesia. At present, during the monthly safety meetings at the hospital, people speak openly about errors and incidents - and not only the anesthetists, but all the medical team, including the surgeons. The safety-reporting system will not uniquely be devoted to the collect of anesthesia incidents, but to all types of incidents in hospitals including organizational ones. Another positive impact of the study is that several hospitals in Belgium will participate to this experiment. The enlargement of the topics and the targets, the growing number of actors willing to play a role in this play - these are the general impacts of the study.

From the point of view of the anesthetists themselves, the study was also a success. It relieved them from the unspoken burden of hidden human errors. The first important impact stemmed from the simulator. Even if anyone agrees that a fullscale simulator will never reflect the constraints of naturalistic situations, it helps to face crucial incidents. Two sequential presentations of the same incident scenario have been assessed on the fullscale simulator, with functional and subjective assessments. From a functional point of view, the anesthetists performance criteria such as diagnosis time and accuracy, medical treatment efficiency, etc. show a significant improvement from one training session to another. The subjective assessment of the participants witnesses a real decrease in stress. The same is found for the safety meetings. They are considered to be important from a medical point of view, but they also contribute to relieve people from feeling guilty about the incident. No longer guilty, but more than ever responsible for the prevention measures to be taken collectively.

3.3. PREVENTING HUMAN ERROR IN AERONAUTICS

3.3.1. The Risks in Aeronautics

The risks in aeronautics are also on the front page of the media, even if objectively they are very low. In fact, flying continues to be the safest method of transportation in the world. But the designers are worried about the stagnation of the average number of accidents per million movements (taking off and landing). Until twenty years ago, it had been regularly declining, and the technical progress introduced on aircraft had had a positive impact on the safety (Amalberti, 1996). Since then, it has no longer been the case and the rate has reached a ceiling of around one accident per million movements. The extraordinary technological developments in aviation and its computerization have not led to greater security. The gains in productivity however have been enormous: progress in materials, increased reliability of the equipment, economy of fuel, reduction of personnel, etc. New forms of human error have appeared, linked to the complexity of interactions with these automatic functions. These interactions now come first on the list of risks expressed by the pilots: they are more worried about them than about climatic risks or terrorist attacks (Gras, Moricot, Poirot-Delpech & Scardigli, 1994). The facts seem to prove that they are right: more and more air catastrophes happen without any technical incident and thus evoke human factors. The stagnation in the frequency of aeronautical accidents causes the risk of important commercial repercussions in the war between the transportation companies. In fact, these days, public opinion is confronted with an airplane catastrophe about once every two months. In view of the increase in air traffic, with an equal accident frequency, in five years, it will be confronted by a catastrophe every three weeks – or even every fifteen days. Thus, safety is becoming a commercial stake and the ergonomics of man-machine interaction a prime axis of research. The great efforts deployed to minimize the probability of human error are colliding with the increasing complexity of man-machine interactions in the glass cockpits. In spite of numerous alert and security systems destined to prevent errors as well as to guard against their consequences, air catastrophes happen periodically to remind one that some errors still manage to slip through the net. Investigations, feedback returns and the analysis of certain recent accidents indicate a real difficulty among pilots to understand the logic of technical devices, to have an exact awareness of the situation in which they find themselves and to predict the behavior of the plane. Numerous authors, based on field observations, have stigmatized the complexity of the autopilot-computerized modes, specifically Wiener (1985), Sarter and Woods (1992, 1994, 1995), Billings (1997) and Amalberti (1996). Sarter and Woods' research in particular has had a deep impact because it shows very clearly that highly qualified and proficient pilots have obvious deficiencies in their understanding of automation. The difficulties seem to be situated both at declarative (erroneous or incomplete mental models) and procedural (limits in the ability to modify automation status and behavior) levels. Amalberti who recognizes the impossibility of the pilot having a complete understanding of the plane's automation has made the same type of observation. But this approximate knowledge becomes a risk when the context is modified, and *de facto* the pilot is led to act within an environment that he masters poorly. The context thus appears like a terrifying activator of the effects of the complexity inherent in technical devices.

The research that our department at the University of Liège has led in aeronautics is very targeted: it aims to understand, to describe and to predict the cognitive complexity associated with interaction between the pilot and the autopilot, the principal aim being to simplify the design (Javaux, 1997, 1999; Javaux & De Keyser, 1998a).

3.3.2. The Pilot's Task and the Technological Evolution in the Domain

Flying is not just interacting with the automatic pilot. In fact, relations with air control, with the team, with the exterior and interior environment are all part of the pilot's task and use a part of his resources. But in this chapter we restrict our analysis to the interaction with the autopilot and, within this interaction, to the understanding and the prediction of mode transitions. The autopilot is a system that is taken on board to which may be assigned or delegated certain specific tasks.

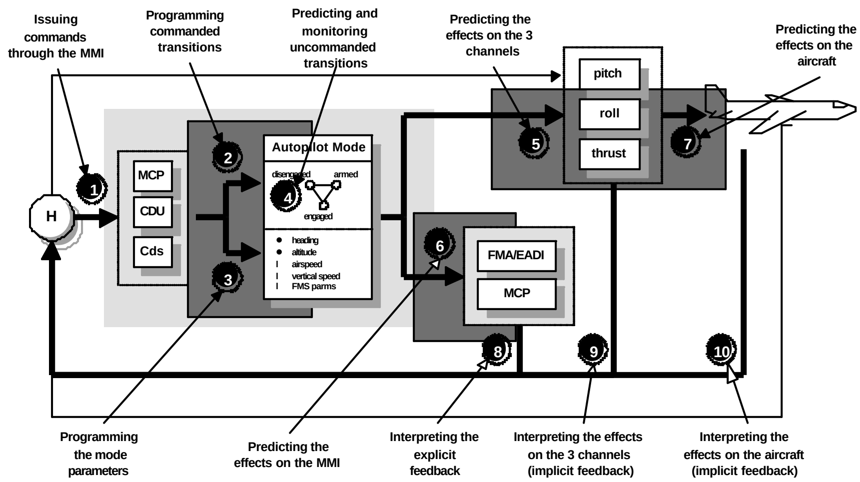

Figure 3.10. The elementary cognitive tasks linked to the interaction with the automatic pilot (Javaux, 1999). Task No. 1 consists of operating the commands through the appropriate interfaces (MCP; CDU; cds[1]) . Task No. 2 is to program the transitions of mode. Task No. 3 is to program the mode parameters (for example a certain rate of descent in the approach mode). Task No. 4 is to predict and monitor automatic mode transitions. Task No. 5 is to predict the effects of these commanded or automatic transitions on the different channels, pitch, roll and thrust and Task No. 7 is to predict the final behavior of the plane. Task No. 6 consists in predicting the effects of these orders on the visualization interfaces (FMA/EADI and MCP[2]) . Tasks Nos. 8, 9 and 10 consist in interpreting the information received from the feedback.

The modes correspond to the basic functions of the automatic pilot. They are each capable of doing well-defined kinds of tasks. To the simplest and most elementary modes which maintain altitude are being progressively added more complicated and more sophisticated modes, in terms of capacity (the tasks they do), of behavior (how they do it) as well as programming (how one tells them what they have to do). The modes called "managed" allow them to do successions of flight segments, respecting a series of altitude and speed constraints with no pilot intervention. The modes called "selected" are generally simpler and accomplish more elementary tasks, but they can also show a certain complexity; thus the approach and landing can be entirely automatic. The modes exercise their effects on certain channels (pitch, roll

[1] MCP: mode control panel; CDU: control display unit; CDS: commands.
[2] FMA: flight mode annunciator; EADI: electronic attitude director instrument.

or thrust) regulating the aircraft's behavior. The state of the mode – engaged, armed, or selected – is displayed on interfaces with the help of one or many symbolic codes. Figure 3.10 shows the set of elementary cognitive tasks linked to the interaction with the automatic pilot.

As illustrated in Figure 3.10, the transition between modes, that is, the passage from one mode to another, can be voluntary or automatic. Intuitively one can understand that an automatic transition of mode is less easily perceived and understood by the pilot than a voluntary transition that he himself has begun; in the case of an automatic transition the awareness of the situation would not be as easy. Otherwise, even for a voluntary transition the conditions of entry and disengagement from a mode may vary from one context to another. Figure 3.11 shows two sequences of action necessary to engage a vertical mode of navigation called ALT HOLD – that is, Altitude Hold. The first one is very common, and well known by the pilots, this is to say "press ALT HOLD switch"; it can be used at any phase of the flight, except during the approach phase. In this approach context "press ALT HOLD" does not work any more, and the pilot has to follow a much more complicated procedure, which he ignores most of the time. He repetitively presses ALT HOLD without any success. One can see, from this example, the importance of the *context* in which the pilot finds himself, and how *approximate knowledge* of the rules for the transition from one mode to another leads to automation surprises.

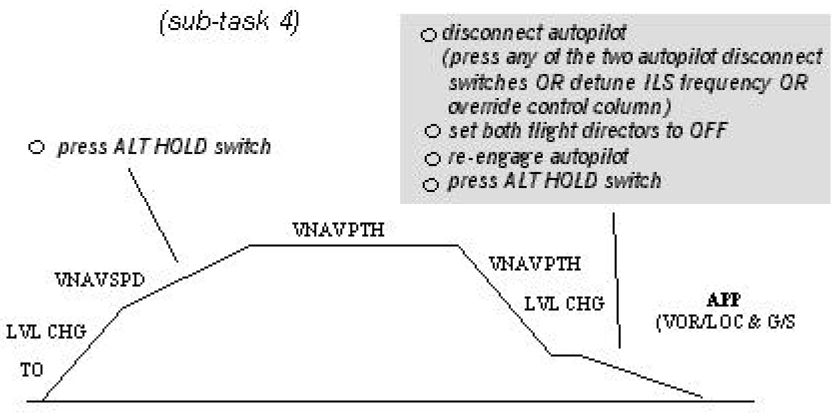

Figure 3.11. The two sequences of action for engaging the ALT HOLD (Javaux & De Keyser, 1998a). During the take off, in the first phase of the flight, the action sequence is very simple: it is enough to manipulate the appropriate ALT HOLD switch. But in the approach (APP), if for one reason or another one must pass into ALT HOLD, the action sequence is very much more complicated. As this transition in the approach is exceptional, the conditions of its application are not well known by pilots. It happens that he pushes, without success, the ALT HOLD switch many times and is surprised and distraught by the plane's behavior.

The objective of the study is to produce a methodology that is predictive of the cognitive complexity associated with the mode transitions. Would one be able to imagine, already at early design stage of a plane, that is to say, ten years before its launch on the market, guiding designers by predicting the cases where the mode transitions will prove to be difficult to master by the pilots and will be sources of potential errors? The project may seem ambitious, but it is crucial from the point of view of prevention. Without going into too many technical details we will illustrate the steps chosen by a study carried out on the mode transitions of the Boeing 737 EFIS (Electronic Flight Instrument System). This plane has 44 modes but until now the analysis has concerned only four pitch modes linked to vertical navigation.

3.3.3. A Reverse Engineering Methodology

The chosen methodology is simple in spirit, but rather long in its many steps. It stems from the assump tion that the knowledge one might have of a system reflects its functional structure, but with a distortion created by the action (Ochanine, 1981) and by natural human limitations. If the system is complex, the operative image is a simplified and distorted reflection of the system, all the while remaining effective in most contexts.

Most research based on this theoretical assumption has been descriptive. Novices' and experts' knowledge has been analyzed in naturalistic situations, common heuristics and bias have been described, empirical studies have collected errors, incidents from which gaps in knowledge have been inferred, and attitudes and opinions about risk in man-machine interaction have been explored (Amalberti, de Montmollin & Theureau, 1991; Gras et al., 1994; de Montmollin, 1984; Sarter & Woods 1992, 1994, 1995). But the challenge is to predict, from the characteristics of a system, and the task to be performed, what kind of approximate knowledge will finally emerge, and what kind of errors could be found in a given environment. Up to know, predictive models of cognitive errors in man-machine interaction do not take the context into account (Polson, Irving & Irving, 1994). Therefore, we have chosen to focus first on this context, with a rather extensive and formal description of the system functionalities. Then and only then, we have applied some simplifications and distortions to this description, which are plausible given the cognitive literature on human limitations and bias. We have deliberately shortcut the building of a new cognitive computational model, and put all the emphasis on the system description - in this case, on the transition modes of the autopilot. The complete *reverse engineerin*g methodology chosen is the following (Javaux, 2000):

- *Step 1.* Make a formal description of the system, its functionalities, and the tasks to be performed in a given environment.
- *Step 2*. Select plausible cognitive distortion mechanisms.
- *Step 3*. Apply these distortions to the system formal description to obtain an approximate knowledge representation.

- *Step 4*. Test the possible consequences of this kind of knowledge in various contexts, and predict human errors.
- *Step 5*. Compare the predicted errors and the observed errors (collected in empirical studies or in incident reporting systems).

Step 1. The formal description of the mode transitions is based on several formalisms (Javaux & De Keyser, 1998b). In this chapter we will only develop the procedural description, which adds to the Boolean description a temporal dimension (see Figure 3.12). The transitions are described by a finite set of rules. The context can be defined, in this case, as the conditions, which must be fulfilled for a transition to be performed at a given moment. For instance in Figure 3.12, the fact that the airspeed is below the minimum speed minus 5 knots and is not increasing are the two relevant characteristics of the environment which are to be taken into account, when an autopilot reverts from Vertical Speed (V/S) to Level Change (LVL CHG), which are two different vertical modes.

It must be noted that the specifications of the autopilot mode transitions do not exist in the airline company where the study was carried out. These transitions are described in natural language in the pilots' operational manual. The process to derive the formal description of the mode transitions from this manual has been very long and only possible with the help of instructors. It contributes to show up some deficiencies and inaccuracies in the manual.

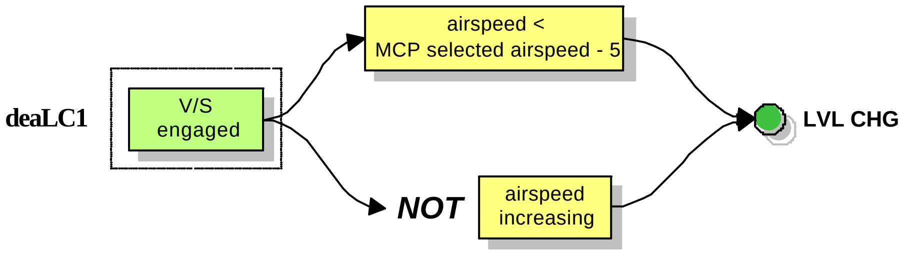

Figure 3.12. Procedural description of the performance limit reversion (Javaux & De Keyser, 1998b). The procedural description concerns the transition deaLC1, that is, the automatic transition (a) of the mode LC (abbreviation for Level Change or LVL CHG). The numerical index, here 1, is added if there is a possible confusion with another rule. The description means: if the mode VS (Vertical Speed) is engaged, and the air speed is lower by 5 than the target speed selected on the MCP interface, and it is not increasing, then VS becomes LVL CHG. This is what is called a "performance limit reversion". This automatic transition is activated when the aircraft is in VS, which is in a vertical mode involving a specific rate of climb, but it does not manage to attain the target speed. The airspeed falls, then, if it reaches a dangerously low threshold which risks the plane leaving its "security envelope", LVL CHG is spontaneously substituted for VS. In fact, in this mode, the plane does not need to reach a specific rate of climb, and as soon as the substitution is made, the plane regains its speed.

Step 2. As to the mechanisms of distortion, we have retained:

- A *frequency simplification* that takes account of the frequency of the transitions as well as the conditional frequency of certain elements of the transition. The idea beyond this selection is that if certain transitions or conditions are not frequently encountered by the pilot, their traces in memory will be very weak. With a lack of practice, even when people have been trained initially to these conditions, the traces will fade, and if these rare conditions were not included in the training, the pilots have little chance to discover them spontaneously through learning by doing. This distortion mechanism is based on the characteristics of the contextual memory.
- An *inferential simplification* that is tied to inferences made from the rules, which are present in certain procedural similarities. This relies on the well known fact that people tend to generalize, to abstract and to categorize their knowledge of the world in order to organize their semantic memory, and to save space in their working memory when reasoning in an economic way. The reliability of inferential simplification will be very sensitive to the coherency in the design of the rules (several hundreds rules for the transitions modes of an autopilot).
- An *incomplete plan of action due to the chaining of rules*. Some plans of action consist in chaining and or embedding transition rules. If these plans are not yet internalized and compiled (from lack of pilot expertise, or because they are very rare) they will require attentional and working memory resources, which could exceed human limitations.

Frequency simplification is sensitive to the occurrence frequency of rules or conditions; inferential simplification is sensitive to the rules design coherency; an incomplete plan of actions is sensitive to the complexity of the task, which sometimes implies the chaining or mixing of several rules. Just as in the first step of the methodology, the frequency, the coherency, and the rule chaining are not directly available in the aviation company. The frequency has been estimated in the study, by the pilots' instructors. The coherency has been derived from a very careful analysis of the mode transitions explored in the study, as well as the rule chaining in action plans.

Step 3. Let us take examples to describe the distortion mechanisms applied to the description of the rules. These examples are extracted from the body of transition rules analyzed in the study and which concern four pitch modes of vertical navigation in the Boeing 737-EFIS.

Frequency simplification. In Figure 3.12 the autonomous transition from Vertical Speed to Level Change is very rare. The trace of this rule in the long-term memory is thus weak; the rule is not well known (i.e. the details of the internal conditions cannot be remembered exactly) and it is sometimes unknown to the pilots. It can also be triggered in operational situations without being detected because it is not expected (and the feed back of the mode status is very weak on the interface). When the detection is made, it produces an "automation surprise", such as is described in Palmer (1995).

In other cases, the rule itself is not infrequent but certain conditions expressed in the rule are either very rare (and thus not memorized) or so constant that one cannot imagine they could not be true. Both aspects lead to a simplification of the rule (see Figure 3.13).

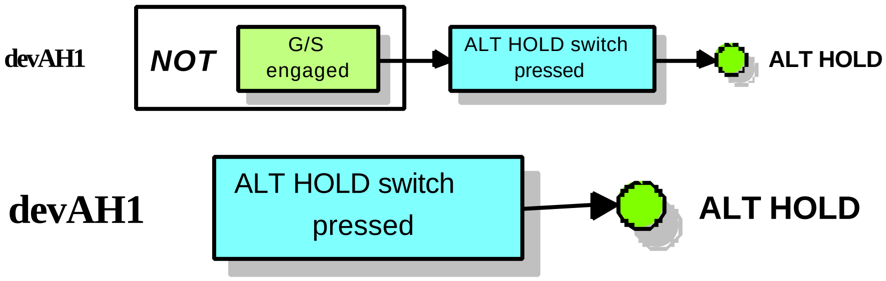

Figure 3.13. Transition rule for the voluntary engagement of the Altitude Hold (ALT HOLD) vertical mode (Javaux & De Keyser, 1998b). Most of the time, the pilot just has to select the ALT HOLD command on the MCP to fly in this mode, for Glide Slope (G/S) is rarely engaged. But when this happens - as in the approach phase - it creates surprises. In fact, the knowledge representation of the rule is simplified, and the G/S condition has disappeared.

Abstraction and generalization. Some rules have similarities between them and the pilot will, for economic reasons, store in his semantic memory only one rule, which is, in some ways, an abstraction of the first rules.

- In this way, for example, the pilot will derive from an ensemble of particular rules concerning the transition of different vertical modes towards the neutral mode CWS, that any vertical mode can be disengaged to reach CWS if enough force is put on the handle in the vertical plan. Sometimes, however, this abstraction mechanism is taken wrongly. In fact, on the same abstraction mode it is possible to think that no matter which vertical mode is engaged (pitch mode) one can go to ALT ACQ (Altitude Acquisition) by putting the ALT ACQ conditions into action. Two problems come up. Firstly, the conditions for the transition to ALT HOLD are not described in the manual. Then, and this is the sensitive point, even if this abstraction holds true for different vertical modes, such as LVL CHG (Level Change), V/S (Vertical Speed) and TO (Take Off), it does not hold true for GA (Go Around). GA is another mixed mode used during gas delivery whose behavior is very close to TO.

From this, once again, arise errors and automation surprises for the pilots.

*Chaining of rules***.** The third distortion mechanism, is linked to the limited span of the working memory, and concerns the chaining of rules in the generation of the plan. To act in a given context, and to produce an appropriate sequence of actions, the pilot does not generally only use one rule of transition. He combines them in a way to produce the desired result. However, he must do a mental check to verify that all the conditions of transition (such as those that may appear in the procedural description) are met for each rule. But some conditions are not terminal and go back to other rules and other actions (see Figure 3.14).

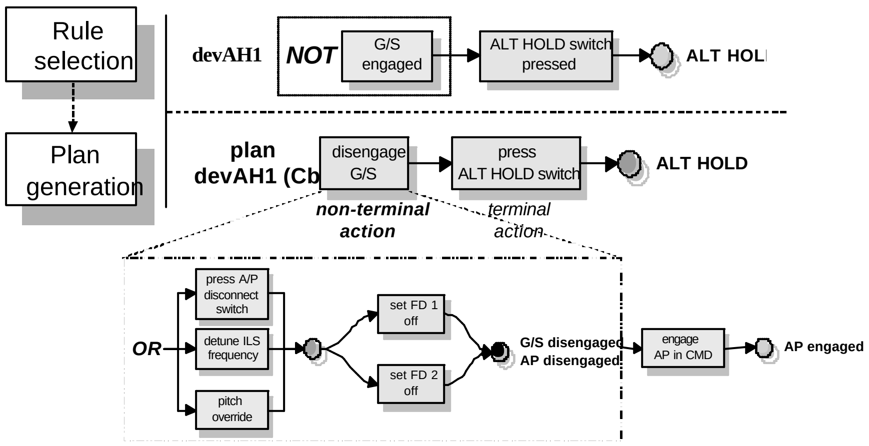

Figure 3.14. The mechanism of generating a plan of action in the case of chaining rules. "Not G/S engaged" is the usual condition. But if exceptionally G/S is engaged, the pilot must disengage it and instantly chose a new rule involving different actions before pressing the ALT HOLD switch (Javaux & De Keyser, 1998b).

It is easy to get lost in the complexity of such an action plan: as it is infrequent, it must be brought into memory in an entirely conscious way and the literature has shown that it is a typical case of error (Sarter & Woods, 1992).

Step 4 and *Step 5*. At this stage of the methodology, the predicted errors should be compared to observed errors, from empirical data. The study is still in progress, and up to now the errors derived from the three distortion mechanisms have been compared to the mode transition errors and the automation surprises described in the aviation literature (De Keyser & Javaux, 1999). At present, this reverse engineering methodology, which derives the approximate knowledge of the pilots from the formal description of the transition modes, succeeds in explaining most of the cases reported in the literature. However, empirical studies are carried out at the University of Liège to compare pilots errors predicted following this model with the observed errors. It is too early to draw conclusions from the preliminary experiments but the first results show how incomplete the pilots' explicit knowledge about the transitions modes is (Olivier, 2000). It does not mean that in a given context they will not act adequately, but their knowledge of the autopilot functioning seems to be almost entirely implicit.

3.3.4. The Impact of the Results

Even though these steps are still in the exploration stage, one can already derive the kinds of impact at the prevention level.

- *An aid in designing and certifying aircraft*. To be able to predict potential errors is important from the beginning of the design of an aircraft. The simplicity of the rules of transition, and their internal coherency should in fact be reviewed. This early management of the complexity is now possible.
- *A training aid.* The proof of the vulnerability of the approximate knowledge in certain contexts will allow better focus in pilot training on certain sensitive points. Additionally the study has also pointed to deficiencies and misunderstandings that must be amended in the training documents.
- *Help in designing the interfaces.* The study has shown the weakness of the feedback that the pilots receive from certain mode transitions as to the necessary conditions to engage or disengage these modes. A real task of cognitive ergonomics is to be directed in this direction. Paths have been suggested in this study, which should be explored.

On the basis of this preliminary study, an important European aviation designer has already made timid steps in these three directions: complexity reduction, training, and interface design. The ideas progress slowly, and not without difficulties. That pilots could be unreliable and must be supported is not questioned in the aviation culture. But that the cause of this unreliability cannot be restricted to the sole “human factor”, but has to be considered in relation to the complexity of the technical aids, is not yet admitted by designers. A significant change in this culture will take time, and will probably need, beside close contacts between human factor researchers and the aviation designers, other significant warning signals, such as incident reports and maybe - unfortunately - accidents.

The context the crew has to be aware of is much broader than the context described in this study. The internal functioning of the plane, the members of the crew and the passengers, the external environment with the air traffic control and the other aircraft: all of them are part of a complex system with its constraints, risks, unexpected behavior, and dynamics. In this case, we have only reported the characteristics of the environment related to the awareness of the transition modes. We have emphasized contexts in which the pilots’ approximate knowledge and modes of control are no longer efficient: infrequent conditions, conditions which need to generate complex and embedded plans of actions, etc.

3.4. DISCUSSION

3.4.1. Context and Approximate Knowledge

Human activity is contextual**.** We have defined the context as "the subset of the environment which is meaningful for the operator" by distinguishing three different facets (see Figure 3.1): one is linked to the task, the other to human limits, and the third to man's approximate knowledge and his control strategies. The study in anesthesia has mainly highlighted facets A & B. It has described the environmental constraints that increase the probability of error and influences stress; it also examines different tools designed to support the anesthetists' activity and has supplied designers with information which may amend them. But until now the study has explored the effects that approximate, incomplete knowledge could have on the anesthetist very little. This question has only been approached indirectly through comparisons of behavior between experts and novices during the unfolding of some incident scenarios on the simulator. One can suppose that if technical evolution, and automation continue to increase in anesthesia the same problems will occur as in aviation - same kind of errors, the same lack of situation awareness, due to the complexity of the aids. To make the field conscious of these risks very early is an important aspect of prevention.

The aeronautic study has not highlighted the two first facets of context. It is, on the contrary, entirely focused on the cognitive complexity associated with exercising approximate knowledge in certain circumstances, on Facet C. The immediate idea that comes to mind when one speaks of approximate knowledge is that the solution is pilot training. This track must not be neglected. In fact, these days the training on this precise point is not optimal: one has seen that the pilots' operation manual contains errors and gaps and additionally the designers do not distribute the formalized specification of the transition rules to the airline companies. Training is, however, far from the whole problem. If one takes only the rules for the transitions of the Boeing 737-EFIS, there are several hundred. One may suppose that explicit training on these rules is practically impossible, and that only implicit learning, favoring repeated confrontations with these transitions can assure a certain maintenance and refreshing. But this implicit learning is greatly dependent on the frequency of occurrence of the rules and especially the conditional rules, and it will be particularly vulnerable to the mechanisms of psychological simplification, and to the effects of internal incoherence. The path for designing and reducing the complexity of the rules must then be followed absolutely; the greater salience of the transitions on the interface in the cockpit is a corollary.

Faced with this observation, some have already reacted: they plan to focus their research less on error prevention than on error management and its recuperation. It is in this line that the error tolerant systems are placed – which signal it to their author and block possible consequences. But what is relatively simple to put in place in the software, for example a word processor, is less so when it concerns controlling dynamic situations such as in anesthesia and aeronautics. We have already seen above the perverse effect surprise automation can have during a performance limit reversion: the transition of an automatic mode aims to put the plane back into a secure configuration, but destabilizes the pilot! Additionally, in critical cases, adequate intervention can go against a usual mode of intervention – because the context is exceptional and requires what would be considered as an error in normal circumstances. To lock all interventions in an envelope of security is thus not the solution. Additionally, too much focalisation on the management of the error could induce the designers to pay less attention to eliminating risks in the designing phase. Management must then be harmoniously combined with prevention.

3.4.2. Interdisciplinary Co-operation

The two research projects that we have evoked were done in strict interdisciplinary co-operation, on the one hand with anesthetists; on the other hand, with pilots, instructors and engineers. However, in the two cases, researchers spent a long time being initiated in the field: at least one year of field observation, lectures, diverse training before reaching a certain understanding of the activity. In both cases, at least three years passed before giving the first results of the research, and four or five years before penetrating into the field, influencing, or reaching true interdisciplinary work with the field workers. An equally long time is demanded for any publication. This research paradigm - completely opposite from the quick steps taken to send questionnaires when the researcher does not even need to go into the enterprise – is thus a long approach and it often has financial ups and downs. The researchers' stability is often acquired only at the cost of feats. But the acquired expertise must be preserved because only this allows the long work of transformation. From the studies, one sees that what makes the difference between applied research and fundamental research is not the hypotheses proposed, nor the methods used, nor the intrinsic value, but much more the loop of the retrospective effect of the results targeted to the field actors.

3.4.3. Researchers as Instruments

In this new research paradigm, researchers follow two objectives: a classic objective of knowledge diffusion by scientific publications and a direct mediation objective towards the field - in the sense of Vygotsky's mediation. Actually, researchers act as instruments; they collect data from the field, they structure them, and build knowledge that will allow, in return, to transform the field and to change its safety culture. This retroaction loop is of crucial importance, and the field becomes a unit of analysis. How the field reacts, what modifications it takes into account, which kind of theory and results are reappropriated or neglected are the reflection of the patient mediation induced by the researchers. Research topics are also transformed. They follow life cycles that are often thirty or forty years long and evolve under the influence of political, economic, technical and cultural factors. At a given moment, the research seems to stutter. Suddenly, a mutation occurs, a new topic emerges, and new fields appear. This was the case for human error. After decades of research on occupational accidents, human error took off in the 80’s, and was first analyzed in the nuclear industry and in continuous processes. Today it is exploding in transportation and the medical world. Many researchers have participated in and followed these slips, both in the topics and in the field. Their role of mediator drags them into the changes that they provoke.

CHAPTER 4

PRACTICES

V. DE KEYSER

Research and instruments can only make their way as part of a movement, carried by social dynamism capable of both guiding and regulating an industrial course, too exclusively concerned with competition and profit. At the end of the last century Western Europe witnessed the ravages of a brutal form of capitalism, which, according to the incisive expression of Neuville (1976), "afforded lower life expectancy to an industrial worker than to a soldier on the battlefield of Waterloo". A century of social conflict, of workers' gains, the progressive development of a legislative arsenal, the awakening of public opinion ever more concerned by industrial catastrophes and sensitized by the ecology movement, trade union pressures and occupational medicine have all reduced risks. The European Commission through its various structures has given a decisive push to this generalized improvement in working conditions. However, vigilance remains necessary. The increase in unemployment combined with the requirements of the industrial world engenders new risks that are even more difficult to detect and combat. Safety, in the sense of reducing industrial accidents, and today, stress in the workplace, which we can consider as a kind of occupational disease - though not recognized as such - preoccupy States and find their way into legislative texts. This is not the case for human error. Although too often the subject of top news stories though it is part of the judicial domain, the subject remains vague. Whose mission is it to be concerned by human error? On whom and on what does it depend? What are the current practices? All these questions are so many areas for reflection. The practices toward error prevention and well being at work in Europe seem to be influenced by cross-firing policies at different levels: European, national, local, field and enterprise levels. But inside these levels, there is a large diversity of dynamics and sources of pressure.

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

4.1. THE IMPULSION AND INTEGRATION ROLE OF THE COMMISSION AT THE HEART OF THE EUROPEAN UNION

The European Commission has played a major role in the areas of health and safety at work through its multiform approach. It has done so in different ways: by supporting European directives, by launching comprehensive research programs, by creating methodological tools and diffusing knowledge. All these means of action have contributed to make national policies and structures converge towards a common vision of health and safety in the workplace and to harmonize European research on these topics. The European Community has also supported researcher mobility in Europe, which explains the widespread diffusion of the ideas invoked in Chapter 1. The legal mechanism through which the Commission influences national legislation is as follows.

> Primary and secondary law can be distinguished. Primary law consists of the legal norms that are contained in the treaties such as the protocols and the accession treaties. Secondary law concerns the legal norms that derive from the above-mentioned documents and which are contained in the decision taken by the European institutions pursuant to the powers that the treaties have conferred upon them. In the above mentioned framework of legislation also fit occupational safety and health legislation. When Europe was formed from the Economic Community of Steel and Coal (ECSC), the European Economic Community and Euratom, only the Euratom Treaty contained some explicit provisions regarding safety and health: Chapter III of Title II of the Euratom Treaty, Articles 30 and 31 oblige the Community to lay down basic standards to protect the health of workers and the general public against the dangers arising from ionizing radiation (Kanse, Malaise, De Keyser, Kuznetsova & Leonova, 1996). Initiatives could then be taken, based on the power conferred upon the Commission by the legal obligation of the Treaty. Each Member State had to lay down the appropriate provisions to comply with the basic standards established and was obliged to take the necessary measures with regard to teaching, continuous education and vocational training. Note that as of the 1960s vast research programs on safety in mines and in steelworks were launched by ECSC (Kanse et al., 1996). Notwithstanding the fact that Community institutions had only limited competence in the area of health and safety, quite a number of important initiatives were taken in the framework of Article 100 of the EC Treaty regarding the approximation of laws. In its resolution of January 21, 1974, concerning a social action program, the Council confirmed the necessity to establish an action program for workers aimed at the humanization of their living and working conditions with particular reference to improvement in health and safety conditions at work. It was pointed out that protective measures differed from country to country and that those national measures which have a direct influence on the functioning of the common market had to be harmonized and improved upon, in view of a harmonious economic and social development in the Community. The Single Act of 1986 introduced Article 118A into the EC Treaty and thus clearly affirmed the competence of the Community in relation to health and safety. Within the framework of co-operation among the Community institutions and in order to achieve the objective laid down in the first paragraph of Article 118A, the Council, acting by a qualified majority

on a proposal from the Commission in co-operation with the European Parliament, adopted, by means of a directive, minimum requirements for gradual implementation, with regard to the conditions and technical rules existing in each of the Member States. Such directives were imposing administrative, financial and legal constraints in a way that would hold back the creation and development of small and middle-sized firms. Finally, the provisions adopted pursuant to Article 118A were not to prevent any protection of working conditions compatible with the Treaty. Health and safety is a shared responsibility and both the Member States and the Community are competent for their improvement. The Community institutions lay down minimal requirements upon which the Members States can improve, not derogate to the detriment of the workers. These requirements would gradually be implemented over a period of time. For instance, since December 31, 1992, the "Cadre" directive 89/391/CEE has been in force. It defines the essential principles to be respected covering the main safety and health aspects in the workplace. These are thus far the basic legal provisions. In fact, these legal provisions frame national policies and strategies, which are sometimes ahead of, or even go beyond European directives.

However, legislation is far from being the Commission's only means of action. In the research framework programs that it draws up every four years, health and safety are closely linked to various specific themes, within an applied, pre-competitive research framework, oriented towards technology and conquering an economic market. Human error is treated in such research, though somewhat tangentially, as one of the elements that can lead to accidents, or as a factor affecting product commercialization. A good example is the program Telematics for Transport Services of the General Direction XIII (DG XIII) of the Commission. Part of this program concerns different computerized devices used to facilitate mobility throughout Europe. These devices concern various users: drivers, road authorities, pedestrians, automobile designers, etc. So one finds an assortment of tools, still at the prototype stage, but that have strong chances of one day being diffused in the market: driving assistance systems, electrical road sign devices, guidelines, etc. (Telematics Applications for Education and Training, 1995; Nicolle & Burnett, 1998). To avoid Europe developing along purely technological lines, while forgetting social needs, the Telematics and Transport program imposes constraints on project directors. For example, if the project deals with a computer application, the needs of potential users must first be analyzed. This must to be done through an analysis of activity in the field.

Research teams have to be interdisciplinary and they very often include both designers and specialists in human factors, like ergonomists and psychologists. So, well before marketing, at the pre-conception step, European influence is already felt. Moreover, the Commission has targeted its efforts towards high-risk domains, where means are still poorly structured: for example, small and medium-sized enterprises, Construction, Fishing and Agriculture. The Commission has attempted to give small entities in these sectors, isolated until now, those methods, programs and at times the telematic means indispensable to structure safety organization (Figure 4.1).

Adapting work to people (ergonomics)
(8) In your enterprise, do you take into consideration the following elements:

	Yes	No
• As a priority, selecting material in which safety actively participates in productivity?	O	O
• Take into account the experience and/ or former training of concerned workers?	O	O
• Take into account the height of the workers when selecting equipment and material? (protection integrated in design)	O	O
• Make sure that the organization, choice of materials, products and procedures attenuate work monotony?	O	O

0 1 2 3 4 5

NUL AVERAGE EXCELLENT

Figure 4.1. Auto-audit manual. This method allows small and medium-sized enterprises to assess themselves the level of safety of the company (European Commission, 1995).

Finally, besides legislation and research, Europe also benefits from European institutions which, through transnational surveys and indicator collections touching on health and safety, serve as observatories for the evolution of practices and their continued evaluation. These institutions diffuse information quickly and efficiently through their Internet sites. The young European Agency for Safety and Health at Work of Bilbao was created in 1966. One of its first missions was to draw up a table comparing safety and health at work among the Member States of the European Union (European Agency for Safety and Health at Work, 1998). The diverse means used in Europe, including both supervision and incentives to promote health and safety, have been compared. One finds there, among other things, a table noting those risks, that according to Member States, will draw their attention in the coming years (see Table 4.1).

First are psychosocial risks, including sexual harassment, stress, exhaustion, violence at work and psychosocial intimidation. Ergonomic risks take second place, at the same level as chemical agents and lead. The Internet site of the Agency in particular gives access to European Health and Safety Database (HASTE), provided by the Finnish Institute of Occupational Health, which gives summaries of descriptions of national systems for monitoring health and safety at work in Europe.

The drive by the European Commission to give the Union a social face and to watch over the health and safety of workers in promoting research, promulgating directives, providing methodological guides and searching for reliable, standardized indicators has been decisive throughout the past 40 years. This effort has enabled the convergence of practices in Member States. But if the integration factor is encouraging, it cannot hide the threat posed by the appearance of new risks, as attested to in all the European surveys.

Table 4.1. Risks that will probably draw attention in the near future within the European Union (European Agency for safety and health at work, 1998)

14	*Chemical agents*	*11*	*Psycho-social*
7-9	Chemical agents (general)	>9	Psycho-social (general)
7-9	Carcinogens	<4	Sexual harassment
4-6	Asbestos	<4	Stress
4-6	Organic solvents	<4	Burn-out
<4	Lead	<4	Violence at work
<4	Heavy metals	<4	Psycho-social intimidation
<4	Benzene		
<4	Vinylchloride	*9*	*Ergonomic risks*
<4	Pesticides	7-9	Physical strain / manual handling
<4	Mineral fibers	4-6	Ergonomic risks (general)
<4	Dust	<4	VDU
<4	Cytostatics	<4	Repetitive movements
10	*Physical agents*	*11*	*Organization/management*
4-6	Noise	4-6	New work patterns
<4	Ionizing radiation	<4	Time pressure
4-6	Vibration	<4	Aging workers
<4	Physical agents (general)	<4	Night work
<4	Thermal stress	<4	Economic incentives
4-6	EMF	<4	Small firms
<4	Indoor climate	<4	OSH organization
		<4	Quality management system
7	*Biological agents*	<4	Monotonous work
		<4	Risk assessment
12	*Safety*		
4-6	Machine safety	*4*	*Allergies*
4-6	Risk of falling	<4	Allergies (general)
<4	Electrical risks	<4	Respiratory
4-6	Safety (general)	<4	Skin
<4	Falling objects		
<4	Traffic in the workplace		
<4	Fire risks		
<4	Use of work equipment		
<4	Burial		
<4	Explosions		
<4	Sveso-II/Major Hazards		

4.2. NATIONAL INFLUENCES

Member States may have an influence on the national level in four main manners: practices relative to health and safety in the workplace, legislation, its control, research and information diffusion. The opinion of Member States on the role played by legislation varies.

Many agree that it should be simpler, more intelligible, taking into account the latest scientific knowledge, targeting objectives, rather than finicky obligations. Obsolete legal provisions should be abrogated, thus enabling actors in the field to decide how to resolve specific problems. But all recognize its role as a safeguard and worry about its applicability. When new questions arise, they must be able to address them.

> In 1996, Belgium was one of the first European country to promulgate a law concerning well-being at work whose aim is to reduce stress and workload. This law was an adjustment to the Directive 89/391/CEE of the Council of the European Communities of June 12, 1989. This law renews safety measures and the role of occupational medicine, broadening their missions, and requires that they be based on five types of expertise: in ergonomics, psycho-sociology, in work hygiene, in safety, toxicology and occupational medicine. There is a strong emphasis on stress, which is explicitly designed in the law, as well as in the joint agreement between unions and employers signed after this law[1]. One of the ideas of this reform is to continuously gather those indicators that enable checking worker well-being, morbidity, accidents, work dissatisfaction, stress, etc., and to intervene immediately when a problem occurs. Parallel to this social watchdog effort, the Belgian Ministry for Work and Employment promotes research programs aimed at creating instruments and methodologies for this surveillance As this legislation is very recent, its effects cannot yet be measured. Its adoption met a strong resistance among employers, and could only be implemented with assurances that additional financial burdens would not be placed on the enterprises. This lack of financial means slows down regulation implementation, but awareness of stress is manifested. Unlike human errors and work accidents that happen only periodically, and that can be easily ignored, new working conditions are declining all the time and feelings of discontent and dissatisfaction at work are shared by many.

Legislation can only have an impact if its implementation can be checked by inspection services. In most European countries, these services are insufficient for the enormous task at hand. Moreover, if safety can be easily verified, this is not the case for psychosocial risks that are more difficult to detect like stress or moral harassment. It is rather in the field that such risks need to be combated. Thus, the importance of the nation's policies of communication and information diffusion. Well-targeted campaigns aimed at both a particular audience and sector seem to have found favor among Member States. But such campaigns are both expensive and short-lived. Few countries are able to evaluate their impact, and in particular, to

[1] Collective agreement CCT 72, December 1999.

verify if their effects are lasting. Specialized institutes at the national level and European agencies and foundations already cited can intervene efficiently and over time: diverse agencies for improving working conditions, transport safety centers, worker health observatories, etc. Though such institutes can have a research vocation, they act more as indispensable links, conveying research results to the public. They help make the results operational, diffusing information through debates and lectures and by providing the impulsion for pilot projects. Such relays are remarkable. They exist in every Western European country, and without them numerous new ideas and studies would lack practical significance. As far as health and safety research is concerned, it exists all over Europe.

4.3. FIELD DYNAMICS

Human error attracts enormous media attention today, obviously because of potential consequences. Current efforts to control it have little to do with legislation on worker protection, which, to our knowledge, does not mention human error anywhere in Europe. But public opinion pressures, the reactivity of the field where it occurs and research efforts in the area are, on the other hand, quite decisive. Risk sectors such as nuclear industry, chemical industry, transport have developed since decades policies to reduce human errors by different means: safety-reporting systems, training, human-centered design, operators assistance devices, etc. They tend to react after a catastrophe or an accident, and even to adopt forecasting approaches, specially when they plan to introduce new technologies.

> In January 1992, there was an air catastrophe involving an Airbus A320 of the company AirInter in France. The plane crashed over Mount St. Odile, near Strasbourg, with 87 victims. This was the last event in a bad luck series for the French airline, which had experienced several other catastrophes, with no detection of technical causes. So human error was blamed. This was both paradoxical and embarrassing for the airline. When the A320 was first put on the market, the advertising campaign stressed its automated functions which simplified the pilot's work, thus reducing training time and increasing safety. The *Direction de l'Aviation Civile* (DGAC) in France reacted quickly. It set up and financed a research network on human error. The network included about ten teams from universities or specialized research centers, and covered a broad range of problems: fatigue and alertness, intercultural aspects, interactions with automated devices, communication between the crew and air traffic controllers (ATC), training, etc. This immediate reaction was not surprising. Even if the French airline was not the only one to be targeted, the aeronautics industry, traditionally a safe sector, would be confronted in the coming years with three main types of problems having an impact both commercially and on safety: the increasing complexity of piloting, the saturation of air space and the competition created by low-cost companies that offer discount rates (Amalberti, 1999; Dorigo, 1997; Stuchlik, 1999). In fact, air traffic doubles every ten years. So, even if the average number of accidents per million movements remains stable, the frequency and thus the visibility of accidents increases. This might even discourage the

> public from using this means of transportation. Thus, the necessity, as in the DGAC human factors network, to have both a forecasting and a global research approach becomes crucial. Technological evolution in the field and economic pressures continue to leave the door open for new risks, in spite of intense efforts to increase human and technical reliability, as is illustrated in aeronautics. The entire arsenal of usable instruments to increase safety has been deployed there. From a human factor viewpoint, selection, training, plane ergonomics, scrupulous study of procedures and experience gained from safety-reporting systems, piloting aides with a safety objective have been installed. Advanced research today is looking at technologies of the future. Interdisciplinary teams that include human factor experts, plane designers and pilots are working in this direction. Undoubtedly it would be impossible to better optimize commercial objectives and safety, but tension between the two poles remains. It has always existed, but has become even more acute, given the current framework of international competition.

Aeronautics is surely not the only example of a field where this kind of effort has been deployed. This dynamics is found anywhere that error can have tragic consequences on the social level and threatening consequences for the economy. We have seen it in the nuclear industry in Europe after the alarm given by Three Mile Island. The same scenario is found: safety procedures, operator training, safety-reporting systems, efforts made in ergonomic control room, etc. And the results are conclusive. But the nuclear industry undoubtedly has the advantage over aeronautics of not having to face unbridled competition. There is computerization, but nothing resembling the automatic pilot man-machine co-operation is to be found in control rooms. Operators are still in the verification circuit, and if there is a serious incident, the risk of their making a wrong diagnosis is not mitigated by machines, but rather by human organization. On the basis of the same data, other experts both inside and outside the power plant in fact reformulate the hypotheses and verify the conclusions

In the production of chemicals, petroleum-chemical products, in steelworks and in continuous processes in general, there have been analogous efforts. Sometimes with less regulation, less external visibility, less public opinion pressure, less insistence on errors than on accidents, but within procedures aimed at introducing safety systems within the organizations. Medicine, as we have seen in the example of anesthetists, has slowly begun to take this direction as well. Emotions aroused by legal actions associated with medical errors urge this on. However, we must also take into account the movement regarding the quality of care. Indeed, throughout Europe, health care costs have exploded in recent years, while unemployment has increased, endangering Social Security funds that usually depend on work revenues. The idea of greater control over expenses, questioning as to how hospitals are managed, putting a ceiling on, or at least monitoring medical prescriptions is accompanied by concerns about improving the quality of patient care. The medical field is dominated by the powerful medical profession, comprised of strong personalities and some hospital departments are veritable baronies. If the necessity of improving the quality of care is uncontested, as everywhere patient health is the primary objective, opinions as to the means to reach that goal and particularly the idea of any type of supervision are far from being unanimous. The quality of care has become a widespread movement among the nursing staff and in hospital management, with the setting up of indicators, procedures, etc. On the other hand, for doctors, it is more of a personal matter, often linked to carrying out technical acts, and is rarely thought of in terms of systems or organizations. That is why the steps taken in anesthesia today are remarkable. One could think, though, that the massive entry of new technologies in hospitals would arouse new doubts.

> Minimal invasive surgery procedures such as laproscopy and endoscopy are probably among the most significant innovations in the past ten years (Satava, 1993). In these two techniques surgeons use minute cameras and surgical instruments that are inserted into the body using small metallic rods that slip through a cannula. Surgeons visualize the intervention on a TV monitor to guide and control their actions. This transforms the medical act in that the surgeon loses all contact with tissues and the degree of freedom of movement is limited. Robotization of surgery prolongs this progressive loss of contact with the human body. The surgeon tele-manipulates the robot from a console that gives a three-dimensional view of the surgical site. The army is particularly interested in this technique which allows tele-surgery. Such systems have already begun to mobilize interdisciplinary teams of doctors, technicians and human factor specialists for their design and evaluation. We would expect this evolution to continue in the future[2].

National legislation has been centered on work safety and today, in several countries, is timidly approaching the question of stress. But human error as such is taken into account in the field. The combination of risks linked to its possible consequences, market constraints and increasing technology motivate efforts to control human error. The arsenal of prevention methods used is very similar. However, one does find variations in the regulations, the prescriptive nature of procedures and control systems used by the authorities, depending on the case.

4.4. THE POPULATION AND LOCAL DYNAMICS

Certain industrial sites present major risks that, in the event of a crisis, cannot be contained within the walls of the enterprise. Everyone surely remembers the tragic example of Chernobyl. But in Western Europe, it is especially the Seveso catastrophe that left an impression on people. Indeed we remember that an entire region in Italy was devastated by dioxin pollution, due to a leak at a chemical factory. This accident led the European Commission to promulgate the Seveso directive which obliged high-risk enterprises to have increased transparency, better external communication and rigorous planning for all critical incident (Zwetkoff, 1994). New awareness by the local authorities of their vulnerability has created a

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[2] A interdisciplinary research project is in progress at the University of Liège and the University of Brussels in Belgium, co-ordinated by Professors De Keyser and Barroy. It concerns the analysis of transformations of knowledge and of action strategies that occur in the use of minimal invasive surgery with a view to reducing the risks of error and medical accidents.

rather interesting dynamism around certain industrial sites. The idea is that in the case of a crisis, collective risk management would help prevent the following types of errors: lack of planning for the scenario encountered, poor identification of the problem, poor management and resource allocation, absence of communication and co-ordinations between the actors, etc. These are all errors encountered elsewhere. They are not very different from those one can encounter in the operating room, when an incident occurs and the anesthetist has to manage the crisis, using all the resources the medical team has at its disposal. But in this case the problem is broader and more complex, the probability of risk is very weak and the involvement of different actors intervening in the emergency varies widely. Moreover, certain actors, such as the public, hesitate to enter into a catastrophe view and prefer to ignore it, leaving the responsibility to local authorities and the enterprise. Thus it seems interesting to see how the dynamics is created locally, to avoid creating panic in the public, while leading it to enter the debate. This debate usually regroups local authorities, military and civilian forces, scientists, representatives of the local population, the directors of the enterprise at risk and its workers. It deals with inside-prevention in order to avoid a crisis, as well as the management of the problem, should it occur (Gilbert, 1993).

The issue of respecting the environment and the political success of the green parties certainly contribute today to reinforcing this dynamics. Though the “to err is human” remains a common saying, responsibility for its prevention and control do, in fact, exist. If local responsibilities can be shared, others cannot. The population is now aware that henceforth dangers do not only come from those industrial sites classified as at risk. The adulterated oil scandal in Spain several years ago, contaminated blood in France, mad-cow disease in England and, more recently, the dioxin affair in Belgium, have all increased worries about the rapid propagation of risks throughout Europe due to market globalization. The problem of transparency of decisions taken, the specific responsibility of the authorities, product traceability, supervisory organisms and external communication are today all part of the public debate.

4.5. THE ENTERPRISE SAFETY CULTURE

Undoubtedly, prevention and supervision practices are the most efficient in the field. In the industrial world throughout Europe, safety and health at work are managed within a triangle: the manager of safety, the company work physician and workers’ representatives. Depending on the country and the enterprises and activity sectors, these functions are more or less structured and developed. In Belgium, for example, the function of head of safety is fully regulated, and those who aspire to the position must undergo complementary training. If the enterprise is large or if risk is high, the initial training required is the level of an engineer. Complementary training is postgraduate university training, which includes technical courses as well as courses in psychology, ergonomics, etc. Occupational medicine is highly developed and equal representation committees are found in all companies with more than 50 employees, giving trade unions decisive incentive and watchdog roles in these problems. These structures have enabled occupational safety and health to evolve favorably, and now confront problems related to stress and even mobbing, but they do not deal with human error as such. It is only in high risk environments that error is considered from a safety angle. In other sectors, there are attempts to analyze and reduce it because of its impact on product quality. Organizational movements such as quality control and Total Quality have contributed to diffuse analysis methods and incident analysis in which the fight against human error is part of a general zero-fault policy. Operating in a much less dramatic context than the crisis scenario, its approach is pragmatic: worker training, workers' access to information, ergonomic study of their work posts and availability of instruments permitting self-checking of work quality are no longer the exception. This vulgarization and de-dramatization of error is undoubtedly one of the most positive evolution factors today. The fact that error appears in certain circumstances, but that it can be easily found and corrected by the person himself, by a technical device or by a nearby team, is a lesson that many enterprises have integrated. In the Total Quality movement, the combination of error prevention and its management have come about quite naturally. The new culture is industrial in nature, but it has slowly begun to penetrate other sectors including administrations, hospitals, schools, etc.

It is because they are so widespread that new phenomena like stress, mobbing and insecurity at work have been met with so much interest in all work sectors in Europe. Though the interventions rarely deal with profound causes, particularly in the case of stress, diverse approaches, such as individual psychological counseling, relaxation techniques and the creation of social support groups, have appeared (Murphy et al., 1996). Chronic stress, burnout and post-traumatic stress after an aggression are all taken into account. Violence is increasing in schools and teachers are looking for new rules for functioning with students. It is not rare to see social support groups created spontaneously in schools after an aggression, as well as a demand for psychological assistance. Other assistance for post-traumatic stress victims has appeared: post office employees, bank clerks, department store cashiers and bus drivers have increasingly become victims of aggressions.

> The best and the worst are found among theses practices. Often it is the high performance enterprises require from their staff that leads to concern for their well-being, as part of a purely commercial logic. Some call-center operators thus receive relaxing massages while they talk on the phone in order to maintain performance levels! Other firms offer mountain holidays, where work teams relax and solve problems at the same time. The most amazing practices are developing, with no efficiency evaluation to speak of. Consultants have thus found a very promising market there and their creativity has gone wild. Le Goff (1995) well described these ad-hoc practices, where gurus promise to cure everything, from discontent to lack of faith in the enterprise.

Because the phenomena we have mentioned are linked to profound organizational causes, they can only be treated over time, using a crossfire of methodologies and influences. Such is the case for safety, of which we have long been aware, but it also holds true for human error and will be found to be so for stress, moral harassment and all the other psychosocial risks noted by the European Agency of Bilbao (see Table 4.1). To change safety culture is difficult and time-consuming, but still feasible. It might still take a few years. We define very pragmatically safety culture as those aspects of the organizational culture which impact on attitudes and behaviors related to increasing or decreasing risk (Guldenmund, 2000; Hofstede, 1991; Schein, 1992[3]). It requires, from the organizations, strategic priorities and the means associated with them, practices, training systems, personnel valorization, communication and procedures. It also requires valorization of knowledge as such, through research and development, critical incident gathering and its use in prevention and educational purposes, the continuous confrontation and sharing of interdisciplinary and inter-hierarchy knowledge. We also find participation and negotiation, since many problems are the result of diverging interests. Such a policy can only be constructed slowly, where the results, far from being miraculous or spectacular, only appear after the fact. And like all policies, it must be thought through, desired and supported at the highest level of the enterprise. Beyond the cross-crossing influences of the European Commission, national structures, the terrain and public opinion, there indeed remains an open space which enterprises can invest. They can do so in order to control and limit the risks due to technology and the market competition they have to manage.

> We can cite the exemplary effort made by a steelworks company in Belgium, prior to the installation of the non-stop production line at some of its mills. It asked a team of work psychologists and ergonomists to study, prior to the change, all the risks linked to the human factor that could occur because of the following technical modifications: organizational modifications, transformations of workers' knowledge, increased time pressure linked to increased machinery speed, changes in maintenance, in the planning of work posts, etc. The study, carried out with the participation of personnel and trade unions, gave rise to a number of measures to accompany the planned technical changes: in ergonomics, training and work organization (De Keyser & Malaise, 1992).

Such actions are the result of a policy decision by the firm to combine quality, performance and safety. Indeed, the direct impact of such policies is impossible to evaluate as the measures are preventive ones. The enterprise can, however, measure the long term effects through comparison with its competitors. This type of investment is sometimes out of reach for small and medium-sized enterprises that function in the short term and are particularly vulnerable at both the commercial and safety levels. This is where the most acute problems arise and where today certain risks are concentrated. As a result, we see the efforts made by the European Commission and public authorities of the different Member States to help them.

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[3] For a state of the art of this concept, see Guldenmund, 2000.

4.6. DISCUSSION

4.6.1. The Role of the Commission

The Commission of the European Community has often been criticized because of its slow functioning, its technocratic bureaucracy, its market economy view of Europe, etc. However in the health and safety domain, the EC has played a remarkable role. It has been a key element in health and safety policies developed at the level of Member States. And this, thanks to European legislation, research and concentration and information diffusion. Moreover, it has done so more subtly as well, through a determined policy, targeting the most threatened sectors of activity and involving the less developed countries in the same vision of health and safety. The EC has also constantly attempted to get closer to the terrain. For example, the ergonomics research conducted in the 1960s by the ECSC in mines and steelworks was often confided to university research teams. Though the latter did not hesitate to work in the field, the involvement of the host enterprises was but superficial. In the 1970s the question of research results was posed. What was its real impact? In order to guarantee enterprises the feedback and benefit of these studies, the roles were inverted. Henceforth, in most cases, enterprises would themselves constitute their own research network in partnership with universities. In most programs today this type of partnership remains the rule. As we have stressed, at the heart of an enterprise-university partnership there is interdisciplinarity, and it is no longer uncommon to see human factor specialists sitting at the table with engineers. Moreover, associative movements, municipalities – in fact, citizens as such – are regularly associated with the studies. This occurs when a city is host to a pilot project or when the subject is a particularly sensitive one at the social level. Obviously, such research structures often prove cumbersome to co-ordinate, but they clearly indicate the will of the Commission not to have scientific, economic and social concerns coincide. This dynamics is peculiar to Europe, and is a positive factor with no equivalent on the same scale in the United States.

4.6.2. The Elusive Error

When we introduced human error in Chapter 1, we spoke of invention, so ambiguous is its status, so important are the hindsight bias and causal attribution mechanisms in its definition. Indeed, if everyone admits making mistakes, compared to one's own norms and intentions, as soon as we abandon the individualized reference, things become less clear. An outside observer or legislator would consider as an error an act that resulted in negative consequences, but which was perhaps caused by external circumstances that made the error quasi-inevitable. When a train-driver goes through a switch at 100 km per hour instead of 30, and the train derails, everyone will surely blame human error. But what are we to think if the sign was poorly indicated or illogical? The error, in fact an organizational error, was made before. So what happens to the train-driver? In such cases, the justice system does not hesitate to condemn the last link in the chain, the train-driver (De Keyser, 1989, 2000). Faced with such a case, one might well feel the shock of injustice. Work situations, given their technology and prescriptive organization, are not situations where there is free-will, where each does what he wants. The influence of the context is obvious. Not only is error relative, but whatever norm we refer to in judging it, error is, in fact, extremely commonplace. It is not by chance that national laws on work in Europe do not directly take it into account. Error is elusive and constantly present. So, not taking it into consideration is merely hiding.

In spite of all the difficulties involving definition, collection and classification that we meet, taking human error into account is crucial from a pragmatic point of view. And the different fields at risk and enterprises have perfectly understood this. Because error is closely tied to the notion of control and the mastery of a situation, its appearance signals a flaw in this regulation. The person who, either implicitly or explicitly, is considered as the last rampart able to block risk, suddenly becomes deficient. It is this very role as a rampart against risk that is constantly questioned in environments where danger exists or where human lives are endangered. So, knowing why the dike broke becomes capital. Is it because of fatigue? Stress? Poorly designed technology? Absence of adequate training? A shaky communication system? Insufficient financing? The analysis of error questions the organization rather than the person. It is, in fact, a concentrate of the entire organization. So its non-recuperation poses identical problems: Why was not it noticed? Why was help so late in coming? Why did not the alarms go off? We, therefore believe that the study of error is a privileged means of obliging a society to reflect on its future. Within the concept of sustainable development dear to ecologists, there is also the concept of *sustainable technological evolution* which means that technological complexity should continue to be mastered, from a human point of view. Are we heading towards a sustainable mastery of our own technological evolution, knowing full well that for every risk that is under control, another emerges? To increase the different technical defenses against human errors may just produce the opposite result: Amalberti (1999) has described in aviation the side effects of an ultra safety evolution. Human error poses the question of the automation limits, though does not provide a definitive answer.

4.6.3. Propagation of Risks and their Transformation

It is more and more difficult to decree what is the enterprise’s domain and what corresponds to the social domain in matters of human error and well-being at work. First of all, because the notion of the traditional enterprise itself is collapsing. The concept of the virtual enterprise has entered into our mores, tele-commuting is gaining ground and atypical forms of work like self-employment are developing. However, prevention is still based on the old models. How can these new workers be protected? Legislation finds it difficult to integrate these changes, as do trade unions. Then, like all highly-integrated systems, globalization of commerce makes it particularly sensitive to incidents. Moreover, while occupational illness is declining and safety throughout Europe is improving, the risks are being displaced. Stress, insecurity, discontent and suffering in the workplace as well as new forms of human error are appearing. One cannot deny that in recent years the intensification of work has been substantial and that unemployment has only stabilized slowly. And this at the price of determined employment policies in most European countries. These phenomena of risk propagation and displacement worry public opinion, and rightfully so. In fact, it has created a new, but not totally unambiguous role. Public opinion has become a powerful instrument that can thwart commercial interests that go against safety. However, in the medical domain it can also have perverse effects. As we can see in the United States, where indemnities to victims of medical errors are on average ten times higher than in Europe, error is a bonanza for lawyers. As far as physicians are concerned, they can no longer get insurance, and refuse to take the slightest risk. They also multiply laboratory analyses in order to cover themselves in case of a complaint. Pregnant women sometimes find it difficult to find a gynecologist still practicing childbirth. At the other extreme of this manipulation of public opinion that incites to reject all responsibility for an incident onto someone else, we must encourage local dynamics which associates local actors and scientists in risk prevention in enterprises through a collective management of the risks. It will probably be thanks to this type of action, that in the future we shall be able to limit the appearance of some of these new and harmful effects.

4.6.4. The Difficulty of Evaluation and Indicator Observatories

We can deplore the general lack of evaluation of measures taken to prevent human error or to combat stress, for example[4]. In this area we have, at times, seen the best as well as the worst. Many reasons explain this deficiency. When these practices emanate from external consultants, we rarely see any evaluation other than the one based on the very ephemeral satisfaction of the subjects. Evaluation is expensive and neither the enterprise nor the consultants are ready to launch it (Murphy et al., 1996). However, in applied technology projects, evaluation, both at the design stage and at the end of the project, has become more frequent, as witnessed by the experience of Commission research programs. But unless there is a data gathering system, like a safety-reporting system, once the product is launched on the market, we lose track of its long term effects. Moreover, even if we wanted to do a long-term evaluation in an enterprise, after a campaign against human error, it would be necessary that all other factors remain the same a year before and a year after. As we well know, such conditions can hardly be met today. Who, in any work situation today, can claim to have a stability for a certain number of factors, at, say, a six-month interval? In most cases, the organization has changed, people have been

[4] Professor Anna Leonova's team is one of the few to have evaluated the positive influence of stress reduction techniques in the long term (see Chapter 7).

transferred, new machines have been introduced, a consultant or two may have been hired or there may be a fear of restructuring in the air, etc. Even public administrations suffer from the same unsettling phenomenon. This is why evaluation today can rarely measure the efficiency of a given intervention. But selective evaluation could be replaced by continuous evaluation of certain indicators, collected at repeated intervals, similar to what is done in the large European observatories. We would be exaggerating if we were to say that many enterprises have already advanced in this direction. However, we note that consultations with personnel on indicators concerning morale, work satisfaction, stress, etc. are, in fact, spreading rapidly.

PART 2

HUMAN ERROR PREVENTION IN A RUSSIAN PERSPECTIVE

CHAPTER 5

METHODOLOGY OF WORK SAFETY AND HUMAN ERROR RESEARCH IN RUSSIA

A. LEONOVA, M. KAPITSA AND I. BLINNIKOVA

5.1. HISTORICAL BACKGROUND: EMPIRICAL FOUNDATIONS AND METHODOLOGICAL SEARCH

For our Western colleagues the history of Russian psychology is mostly associated with the names of Vygotsky, Leontiev, Luria, and Galperin, the founders of famous and unique schools in world psychology. A more detailed picture of the development of psychology in Russia is less familiar to the scientific audience, and the history of Russian applied psychology remains virtually unknown even to specialists working in the field. This is understandable: Russian/Soviet psychology was hidden for a long time from the rest of the world. Nevertheless, despite the lack of international representation, Russian applied psychology and its main branch – *work and engineering psychology* – is relatively well developed (for a review see Klimov, 1988; Leonova, 1994, 1995; Zinchenko & Munipov, 1979).

The features of Russian history and many tremendous changes in social and economical life during the past century seriously affected the destiny of Russian applied psychology. The most important events, like World War I and the consequent Russian Revolution, Stalin's purges in the 1930s and late 1940s, World War II and the restoration period, the so-called perestroika and the collapse of the Soviet Union at the beginning of 1990s, and the modern reformation processes in the country led to the cardinal changes in the social status and research context of our science. Such transformations often looked like a series of dramas and catastrophes. In spite of this, the work of Russian psychologists on different aspects of professional life has never completely stopped. After each crucial stage the studies were renewed enthusiastically, sometimes under new titles and methodological "banners" (Lomov, 1966; Munipov, 1983a; Noskova, 1997; Petrovsky, 1985).

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

If one looks more closely at the history of Russian applied psychology, a general conceptual line of research on work safety and human error prevention can be distinguished that to some extent defines the specificity of the East European approaches to this problem. Traditionally it was one of the central research topics over the all stages of the development of Russian applied psychology.

Stage 1. "Initiation" (late 1890s – mid-1910s) witnessed the first steps of institutionalization of psychology in Russia as a separate scientific discipline, including its main fields of application – industry, medicine, and pedagogy (Noskova, 1997; Petrovsky, 1985). Russian psychology has common roots with European psychology, stimulated first of all by prospective development of experimental psychology (Yaroshevsky, 1985). Some well-known Russian psychologists were trained in Western Europe, mainly in Germany and France; collaboration with European colleagues was the standard of Russian scientific life. So it is not surprising that the main directions in the development of Western applied psychology – *psychotechnics* and *pedology* – were assimilated by Russian psychologists and used for creating a methodology for applied research. The books of Muenstenberg, Marbe, Krepelin, and Stern gave a great impetus to studies on professional testing, individual predisposition to accidents, skilled performance indicators, etc. (Petrovsky, 1985; Zinchenko, Munipov & Noskova, 1983).

At the same time, the intention to elaborate an "objective" methodology for analysis of human behavior was supported by advanced research of the famous Russian physiological schools of Sechenov, Pavlov, Vvedensky, Ukhtomsky. The models of conditioned/unconditioned reflectory acts, descriptions of the central-nervous mechanisms of fatigue and monotony, methods and techniques for the registration of different organic responses in parallel with performance indicators were used for practical purposes to explain such phenomena as traumatism, professional accident rates, fluctuations of workability during working shifts, and "risky" work conditions (Leonova, 1984; Nechaev, 1929; Zolina & Izmerov, 1983). According to this line of investigation the first research laboratories of work safety and professional health appeared, both in scientific institutions and in different applied areas – in industry, traffic, military service (Noskova, 1997; Petrovsky, 1985).

The wave of empirical and research activities at the initiation phase gave a good harvest. New experimental methods and test batteries (e.g., Rossolimo's Personality Profiles, Nechaev's methods for professional ability evaluation) and methodological approaches to field studies (e.g., the principles of "natural experiment" by Lazursky) were elaborated (for details see Petrovsky, 1985; Yaroshevsky, 1985). Sometimes naive and simplified, sometimes anticipatory and fruitful, these inventions provided a basis for extensive growth of Russian applied psychology immediately after the Revolution (1917).

Stage 2. "Romantic Marxism" (1920s – mid-1930s) was a period of intensive development of Russian applied psychology under the banner of Marxist philosophy, due to the new socio-political conditions in the country. From the beginning of this stage the enthusiastic move to "materialist psychology" was directed not only by ideological pressure but also by the dominance of behaviorist schools in Western psychology and the above-mentioned prospective influences of Russian physiology. The first attempts to implement this ideology in the studies of work activity were made in the early 1920s, in the form of so-called "reactology" by Kornilov and "reflexology" by Bekhterev (for a review see Petrovsky, 1985). Very soon dissatisfaction with such vulgar materialist approaches arose, especially in the fields of scientific organization of labor, professional education and personnel assessment (Gellerstein, 1926; Vygotsky, 1930/1983). Soviet work psychology turned again to the problems and methods of *psychotechnics* and *pedology*, which became the most powerful branches of Russian psychology for a decade, until the mid-1930s (Noskova, 1997).

The awe-inspiring surge of experimental and practical research in different areas of utilization of labor resources and professional activities coincided with a radical transformation of the economic and political situation in Russia, which was building a "new socialistic world". So these scientific directions had great support from state institutions and the government. Many of the subsequently famous Russian psychologists began their professional life in such applied units: Bernstein in the laboratory of ergotechnics at the Central Institute of Labor in Moscow, 1921; Myasishchev in the laboratory of work psychology at the Institute of Brain Research in Leningrad, 1919; Teplov in the laboratory of visual camouflage at the military department of the Central Institute of Labor in Moscow, 1923; and Gellerstein in the laboratory of industrial psychotechnics at the Institute of Work Safety in Moscow, 1922. Dozens and dozens of less familiar scholars worked intensively in applied psychological units in industry and other areas all over the country (for a review see Zinchenko et al., 1983; Noskova, 1997).

Besides re-establishing contacts with Western specialists, the Soviet psychotechnic school tried to construct its own research methodology according to the postulates of Marxist philosophy. This search led to the application of Vygotsky's cultural-historical approach even to the analysis of professional activities (Vygotsky, 1930/1983). As the founder of a new conceptual paradigm for psychotechnics and pedology, Vygotsky stressed the necessity of considering any form of human labor as the coordination of highly synthetic mental functions which are mediated by (1) technology, technical equipment and job situation specifics (including the social context) and (2) individual goal-oriented intentions and voluntary control over one's own behavior (Vygotsky, 1978). This idea was in contradiction with elementary analysis of single performance acts and separate professional abilities. It stimulated the development of a more complex method of detailed job analysis – so called *professiographia* – which included both objective and psychological "portraits" of professions (Gellerstein, 1926).

The implementation of professiographic methodology paved the way for intensification of research in practice. Besides the problems of professional selection, traditional for psychotechnics, there was an increasing number of studies on professional training and retraining, professional adaptation, design of a healthy work environment, prevention of fatigue and other negative human states (Spielrein, Kekcheev, Kogan, etc., see Noskova, 1997). Many investigators of traumatism, industrial injuries and accidents, human errors and unreliable job performance turned to psychology. These issues started to be interpreted in a wider context of job safety, elimination of risk factors in work environments, individual reliability and well-being of the personnel (for examples of field studies see Zinchenko et al., 1983). Since that time, this way of considering the problems has become typical for Russian applied psychology.

During this period Soviet psychotechnics was well represented on the international scene. Russian psychologists participated regularly in the most important scientific events, for instance, at the international conferences on psychotechnics in Paris, 1926, Utrecht, 1928, and Barcelona, 1928; and in the 9th International Congress of Psychology, New Haven, USA, 1929. The 7th International Conference of the Psychotechnics Association (now the International Association of Applied Psychology, IAAP) took place in Moscow in September 1931. Stern, Pieron, Lipmann, and other famous Western psychologists were among the organizers and participated in this conference. It was evidence of the rising international authority of Russian applied psychology at that time.

Stage 3. "Psychology in Underground" (late 1930s – mid-1950s) was a long and difficult period in the history of Russian/Soviet Psychology. The rapid development of both experimental and applied psychology was broken by Stalin's purges (Noskova, 1996). Psychology shared the fate of some other promising scientific disciplines in the USSR, like genetics and cybernetics, and paid a heavy price, measured in hundreds of human lives, as a potential "danger" to official Soviet ideology.

On July 4, 1936, the sadly famous Decree of the Soviet Government "On Pedological Perversions in the System of Public Education" was published. It was a dark day in the history of our science. Almost all psychological practice was forbidden, and subsequently a storm of administrative and political persecutions overwhelmed psychology and psychologists (Noskova, 1996; Petrovsky, 1985). Most research and applied psychology centers were closed or re-oriented to non-psychological issues. Only few scientific units with academic status were maintained, though in a reduced form – a small chair of psychology at the Moscow State University Department of Philosophy, the Research Institute of Psychology and Pedagogy in Moscow, and the laboratory of clinical psychology at the Leningrad Psychoneurological Institute. Yet this does not mean that psychology was totally liquidated in the Soviet Union.

Very slowly, fragmentarily and with significant divergence, applied psychology continued to develop under the protection of related and less afflicted disciplines – medicine, psychopathology, physiology and hygiene. As examples of such research, that are of special interest for the subject of our book, one can mention the studies of workability dynamics and divergent human states by Myasishchev (1935-1948), the issues of motor skills and job performance in aviation by Schwarz and Platonov (1936-1940), psychophysiological studies on sensory adaptation and masking by Luisov (1942-1950), and some others (for details see Leonova, 1995; Petrovsky, 1985).

The scope of applied psychological studies widened during World War II. They dealt mainly with the treatment and rehabilitation of people after brain injuries, traumas, psychological shocks and asthenia states. It is notable that Vygotsky's brightest students (Luria, Leontiev, Zaporozhets, Galperin), as well as other famous Russian psychologists (Ananiev, Myasishchev, Teplov, Zeigarnik) directly participated in this work. New objects of analysis, a large volume of original findings and empirical facts stimulated the development of some innovative theories and methodological approaches. The best example was *neuropsychology* founded by Luria on the basis of his rich empirical practice in several neurosurgical clinics. Besides the great impact upon world psychology, other original concepts started to be developed at this time: *Activity Theory* by Leontiev, the *psychology of attitudes* by Ananiev, *differential typology of temperaments* by Teplov, the *voluntary actions development concept* by Zaporozhets and co-workers. Although these theories had no direct relation to work safety and error prevention research, they predetermined the applied psychologists' mode of thinking in the future decades.

In parallel, progress in physiological research provided an important breakthrough of the dogmas of the classical Pavlovian theory. This resulted in the development of such well-known systemic concepts as the *physiology of activity* by Bernstein (1967) and the *theory of functional systems* by Anokhin (1980). On many general points these concepts replicated the above-mentioned lines of methodological search in psychology. As studies in work-related areas were mainly produced in the framework of labor physiology and hygiene, empirical studies on the efficiency of job performance and optimization of work conditions were greatly influenced by organic paradigms (Vinogradov, 1958; Zolina & Izmerov, 1983). Since that time, the role of physiological and psychophysiological interpretations has been very strong in the field studies of work safety and error prevention.

In spite of such brilliant but isolated achievements, direct continuity in the development of Russian/Soviet applied psychology was lost. Useful experience and scientific standards of research, especially in practical work, were nearly "forgotten" due to the destruction of the regular system of professional psychological training at the universities. In addition, the lack of publications and the breaking of almost all international contacts produced a "vacuum" in psychological research in the middle of the 1950s. So the next period of development of Russian/Soviet applied psychology was defined by the need for recovering the scientific potential and re-establishing the organizational structure of science after the long interruption.

Stage 4. "Restoration and Expansion in Practice" (late 1950s – mid-1980s). The situation improved in the late 1950s. This was the time of "resuscitation" of psychology in the eyes of the public thanks to the rapid technological development and growth of skilled professions in the postwar period, as well as initiation of democratic processes in the country in Khrushchev's time. During the first decade of this period specialized research units appeared both at academic institutions and in practical areas (industry, medicine, professional education, sport). Several departments of psychology at universities were opened – the first ones at Moscow State University and Leningrad State University in 1966, only 30 years after Stalin's Decree Soviet psychology again appeared on the international scene. The 18th International Congress of Psychology took place in Moscow in August, 1966; it was made highly representative by the participation of such outstanding scientists as Piaget, Fress, Pribram and many others. From that time on, contact with Western colleagues and contemporary Western scientific literature began to be available to Soviet psychologists, although with strict limitations.

At that stage, Soviet psychology resumed its rapid development in the context of progress in applied psychological disciplines – *engineering psychology* and *ergonomics*. Studies of human factors in modern technological systems that had become established in the West just after World War II (see Chapanis, 1965), began in the Soviet Union with a 10-15 year delay. Initially they were inspired and financially supported by the Soviet military-industrial complex, which determined the specificity of the main topics of applied research. Space research, flight control and operators' jobs in highly automated systems were the "privileged" fields of psychological practice for a long time. The first engineering psychology laboratories were organized by Zinchenko in 1959 (in Moscow) and by Lomov in 1960 (in Leningrad). During the following two decades the number of such research units increased rapidly. They began to appear in civilian areas, such as industry and the social services (Munipov, 1983a; Zinchenko & Munipov, 1979).

Very soon the attempts to build an essential methodology for large-scale empirical research exceeded the bounds of technocratic ideology, which predominated at the outset of the development of engineering psychology (Gubinsky, 1967; Zinchenko & Munipov, 1979). As a result, *ergonomics* as a multidisciplinary approach to design and optimization of work activity in complex man-machine systems was founded. Work and engineering psychology was considered a substantial part of this approach. A network of ergonomic laboratories and departments was set up in industry and the services from the beginning of the 1970s. At the beginning of the 1980s more than 200 applied ergonomic units worked in most important industries: energy production, transport and civil aviation, microelectronics, the manufacturing industry, etc. (Fedorov & Leonova, 1987;

Gubinsky, 1982; Nersesian & Konopkin, 1983; Strelkov, 1989). An association of ergonomic institutions of East European countries was also established, which functioned within the framework of COMECON's coordination programs. General recommendations for organization of work in ergonomic units at enterprises and even the system of state legislative norms and ergonomic standards were drafted on the basis of this cooperation (Munipov, 1983a; Zinchenko & Munipov, 1979).

Like many other scientific areas, the contextual development of engineering psychology and ergonomics in the countries of "developed socialism" had many specific features. The strict limitation of relations between Eastern and Western psychologists led to differences in dominant concepts and research paradigms. However, the barriers to communication of scientific data to the West did not completely prevent the transfer of information in the opposite direction. The classical works by Chapanis, Fitts, McCormick, de Montmollin, and many other famous specialists in "human factors" were translated into Russian and widely discussed in special studies (see, for instance, Lomov, 1966; Lomov & Zabrodin, 1983; Zinchenko, Leontiev & Panov, 1964).

At the same time, the unilateral links caused specific assimilation of this knowledge within the original theoretical framework, which had no exact correspondence, either in terminology or methodology, to the Western approaches applied in this field. Different versions of system analysis of man-machine interactions (Gubinsky, 1982; Lomov & Zabrodin, 1983), descriptive schemes of Activity Theory (Leontiev, 1981a), and psychophysiological models of the theory of functional systems (Anokhin, 1980) were used for developing a methodology for practical research as the most relevant to the demands of materialist ideology.

It has to be mentioned that until the beginning of the 1980s, research in several important applied areas (e.g., psychological assessment and psychodiagnostics, psychological consulting, psychotherapy, etc.) was still under official prohibition. That limited the opportunity of practical psychologists to work in organizations but, at the same time, stimulated the use of experimental psychology methods and psychophysiological techniques in field studies (see, for instance, Frolov, 1987; Gurevich, 1970; Sereda, Bocharova, Repkina & Smirnov, 1976; Zabrodin, 1983). Furthermore, the development of sociology and social psychology was delayed[1] and quite isolated from the other branches of the humanities in the Soviet Union. It looks like one of the paradoxes of the officially proclaimed "collective" orientation of Marxist philosophy and the real practice of political control over scientific life. For this reason, studies in work and engineering psychology mostly dealt with different aspects of individual behavior, and only rarely with the problems of interactions within professional groups and organizations.

[1] The first department of social psychology was organized in Moscow State University in 1972, and the first faculty of sociology – only in 1989 in the same university.

As the central theme of engineering psychology and ergonomics, research on work safety and human error prevention rapidly developed during all this time (Kotik, 1981; Strelkov, 1989). According to the above-mentioned restrictions the investigations mainly concerned an individual operator's activity in complex man-machine systems. Since the pioneering space-flight research (Gorbov & Lebedev, 1975) and studies on industrial automated systems (Oshanin, 1999; Pushkin, 1965), these subjects were considered within the framework of the more general concept of human reliability (Lomov, 1966; Nebylitsyn, 1964). This directed empirical studies to a more in-depth analysis of risk factors to efficient job performance, both objective and psychological, which could provoke errors and inadequate behavior of personnel. Since that time the accent on analyzing the mechanisms of activity regulation in concrete work situations, the mode of actualization of individual resources and dynamics of workers' states has become the most significant trend in Russian/Soviet research on work safety and human error prevention (Gorbov, 1964; Kotik, 1981; Leonova, 1984, 1993; Zarakovsky & Pavlov, 1987).

Stage 5. "Recent Development" (since the late 1980s). The contradictions between restrictions of ideology-controlled Soviet science and the viable tendency of applied research towards turning to wider areas of professional practice led to a critical situation in Soviet psychology at the beginning of perestroika (mid-1980s). The following tremendous changes in all aspects of economical and political life in East Europe and Russia have not helped to improve the situation up to now. The development of applied research in Russia during the last decade looks chaotic and ambivalent. Research on traditional issues in the field of work and engineering psychology has almost stopped. On the other hand, there are many signs of continuation and resumption of psychological research in practical areas. Initially these attempts were made for extremely pragmatic purposes dictated by the need "to survive" during the transition to the market economy.

New pragmatics provoked a rapid revision of the dominant research topics in applied psychology. The psychology of management, retraining of professionals, personnel assessment, organizational consulting, marketing, and computerized psychodiagnostics became the main areas both in psychological research and practice. These tendencies resulted in the foundation of new psychology disciplines for Russia: organizational and personnel psychology. Over the past five years such departments have been established in Russia's leading universities, business schools and academic institutions. Within the framework of these new disciplines the problems of human error prevention and personnel well-being regained prominence (Kabachenko, 2000; Leonova & Burmistrov, 1997; Lepsky, 1999; Munipov, 1986).

To a large extent the progress in these fields is determined by the revision of traditional approaches and acceptance of the rich experience of Western colleagues. An open door to the West helps Russian researchers to obtain information on different, especially previously "forbidden" or "unknown" subjects. Moreover, it provides a chance for a wide exchange of ideas and knowledge, which have more than just a pragmatic value. It seems that the healthy traditions of Russian psychology, which helped us to survive in previous dramatic stages, are still alive and could be comprehensively integrated into the full-scale panorama of international psychological research.

5.2. THE CONTEXTUAL FRAMEWORK OF HUMAN ERROR RESEARCH

5.2.1. Errors and Work Safety

In the traditions of Russian work and engineering psychology human errors were considered in connection with the problems of *work safety* and *reliable job performance* (Kotik, 1981; Lomov, 1966; Zinchenko et al, 1964; Zinchenko & Munipov, 1979). As a more general category work safety is ensured by such working conditions and characteristics of job execution that exclude any dangerous or harmful influence of industrial/organizational factors on the worker (Kotik, 1981). Consequently, work safety depends on the environmental and functional parameters of technical systems, as well as on different characteristics of worker activity.

According to statistics, human error causes 40-80% of all accidents in industry and transportation systems, and 50-75% of all accidents in aviation (Legasov, 1987; Lomov, 1964; Vasin & Sakach, 1989). It should be mentioned that the relative contribution of the human factors to the total volume of accidents is constantly increasing, while the role of the technical factor is decreasing (see Figure 5.1).

In the early 1930s, the Soviet psychotechnic Gellerstein (1932) first used the term “personal factor” for analyzing the causes of accidents. He defined it as a general combination of all psychological and physical characteristics of an acting person which are somehow connected with the accident.

Within this interpretation the personal factor included only the individual’s negative characteristics that contributed to the accident. It is clear that worker errors or inadequate actions may also be provoked by objective factors (e.g., low level of man-machine adaptation) or organizational causes (e.g., abnormal conditions and work regimes). So later, in line with the Western tradition, the term “human factor” began to be widely used (see, for example, Lomov, 1964; Zinchenko & Munipov, 1979). This concept took into consideration not only the psychological and physiological characteristics of individuals, but also the technical and organizational conditions which could produce serious difficulties or breakdowns in the functioning of technological systems.

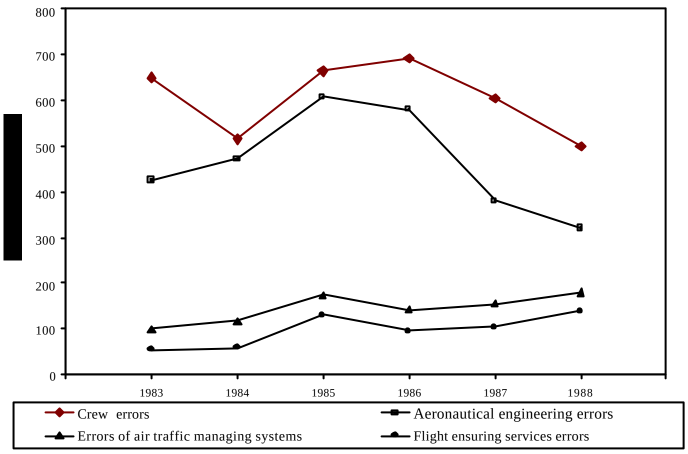

Figure 5.1. Distribution of aircraft accidents following different technical and personnel errors (after Vasin & Sakach, 1989).

5.2.2. Errors and Performance Accuracy

Originally, errors were considered as a direct indicator of work quality and *performance accuracy.* From the psychological point of view, performance accuracy could be considered as the correspondence between worker actions and the given task's execution program. No automated technological system can function absolutely faultlessly. The system's design determines a certain tolerance in its work. If some parameters exceed the fixed tolerance limits, this means that an error has occurred. These considerations, typical for a traditional engineering paradigm, led to the development of a mathematical approach to the study of human error (Krylov, 1972; Lomov, 1964; Zarakovsky et al., 1974). This approach was based upon classical works by Chapanis (1965), who developed the principles of mathematical estimation of operator errors and their contribution to the final fault of the system.

In Russia most studies within this approach were carried out in the 1960s (Lomov, 1964). Many new terms were introduced: accidental error, systematic error, absolute error, relative error, positive error, negative error, constant error and variable error. They supplemented the set of criteria for evaluating system reliability in systemotechnic design (Krylov, 1972; Tsibulevsky, 1979). Besides detailed mathematical analysis, the findings demonstrated that the accuracy of man-machine systems depends upon such psychological factors as the operators' remuneration, punishment for mistakes, the subjective significance of errors, feedback in the system, etc. Three ways to increase the accuracy of man-machine systems were proposed: (1) selection and training of operators; (2) man-machine adaptation; (3) elimination of mistakes through the duplication of actions by several operators (Lomov, 1966).

The problem of performance accuracy was also experimentally examined in relation to three main aspects: the task accuracy or faultlessness, the spatial accuracy of actions, and the temporal accuracy (Zarakovsky & Medvedev, 1971). In more integrative studies the relationship between task accuracy and performance speed was analyzed. As an example of the most precise analysis of the speed/accuracy trade-off, we mention the study by Shadrikov (1972). He considered the problem in connection with professional training of operators. The execution of signal detection tasks was used as a model of an operator’s job. In different experimental sessions the subjects were instructed to perform tasks (1) as quickly as possible (speed), (2) as correctly as possible (task accuracy), or (3) maintaining both a high speed and high accuracy. They demonstrated the effects of different sets of instructions on the increase of speed versus task accuracy (see Table 5.1).

Table 5.1. Effects of different instructions on performance accuracy (after Shadrikov, 1972)

Performance accuracy (means per session)	*Sets of instructions in different sessions*		
	speed	*task accuracy*	*speed and task accuracy*
Number of errors	1.9	1.1	2.2
Reaction time (in sec)	4.06	4.82	5.04

Obviously, the simultaneous instruction to work fast and accurately is less efficient for both performance aspects – speed and task accuracy. The author drew the conclusion that it is better to give the instruction to work accurately. In a more profound experiment, modeling emergency situations, different dynamics of performance indicators were observed depending on the level of operator expertise. The more experienced operators started to work slowly but very accurately, and after reaching a high level of accuracy they maintained and began to increase speed. The less experienced operators tried to perform tasks quickly from the very beginning. Generally, it appears that as a rule more experienced operators work more slowly than less experienced ones in emergency situations, but their slow actions are more adequate. Less experienced operators make more mistakes and have no time to correct them when time is limited (Shadrikov, 1972).

5.2.3. Errors and Individual Differences

Psychological research on errors and accident risk factors always concerned the problem of individual differences and a psychological predisposition for inadequate work behavior. The results of such studies were widely used in Russian work and engineering psychology (Gurevich, 1970; Kotik, 1981; Strelkov, 1989). Even the first attempts at personnel selection of pilots in the early 1920s were based upon a thorough analysis of their psychophysiological features (Minz: see Kotik & Yemelyanov, 1993). Then Burluk and Gellerstein (1930) examined a hypothesis about accident proneness. They confirmed that there may be some individual characteristics that make people more predisposed to errors. Later on, the traditions of the Pavlovian school had a great impact on the study of individual differences (Gurevich, 1970; Nebylitsyn, 1964; Teplov, 1961). Patterns of central nervous system (CNS) characteristics were identified in their correspondence to the basic temperament traits (Nebylitsyn, 1966). Further development of this line of investigation led to distinguishing two major groups of individual characteristics that could be important for the prognosis of professional efficiency – psychophysiological and psychosocial factors (Klimov, 1969; Kotik & Yemelyanov, 1993; Merlin, 1986).

At first, the group of *psychophysiological factors* was represented by the set of basic CNS characteristics: strength, balance, mobility of nervous processes (Nebylitsyn, 1966; Rozhdestvenskaya, 1980), and the level of anxiety (Kitaev-Smyck, 1983; Kotik, 1989). Adequate diagnostic methods for practical use were developed: both instrumental tests (Nebylitsyn, 1966; Nersesian & Konopkin, 1983) and questionnaires (Marishchuk, Platonov & Pletnitsky, 1969; Rusalov, 1992).

Besides distinguishing the patterns of basic temperament traits, individual differences in highly developed psychological functions were analyzed as predictors of errors and incorrect job performance. Attentional resources (mostly abilities for selection, distribution and switching of attention), emotional stability as a resistance to extraordinary events, and different parameters of sensory-motor coordination were considered most important (Kitaev-Smyck, 1983; Mileryan, 1974; Naenko, 1976).

Another line of investigation concerns the *psychosocial characteristics* of individuals who may be "risky" for job performance. Three groups of factors were systematically analyzed: (1) social behavior and communicative habits, (2) intellectual abilities, (3) demographic characteristics (Berezin, 1988; Strelkov, 2001). The following set of individual characteristics was distinguished as having the most negative impact on a worker's behavior from the side of the first group of factors: difficulties in communication and social contacts, disrespect of social norms and rules as well as of colleagues; tendency to conflicts; tendency to aggression; irresponsibility; suspiciousness, and an increased level of egocentrism and arrogance; and risky behavioral styles. According to this list, concrete programs of socio-psychological training for the personnel of different industrial objects were elaborated (Lepsky, 1989; Zhuravlev, Kudryavy, Lomakin & Sakov, 1993).

The group of intellectual factors was considered in a more constructive way as providing an individual predisposition for correct and efficient job performance. Such general intellectual abilities as generalization, anticipatory and prognostic functions, adaptability, abilities for transferring knowledge and for re-education, and self-control were identified as most important for the individual predisposition (Merlin, 1986; Strelkov, 1989; Zavalova, Lomov & Ponomarenko, 1986). Application of these findings led to the introduction of standard intellectual tests into the practice of personnel selection (Bodalev & Stolin, 1987; Marishchuk, Bludov, Plakhtienko & Serova, 1990).

Among the demographic characteristics (age, sex, level of education, etc.) special attention was paid to such indices as age and length of service. In several studies the relationships were analyzed between these indices and error probability (Kotik & Yemelyanov, 1993). For instance, it was shown that operators achieved maximum efficiency at the age of 35-40 years (Reshetuk, 1989). Nersesian and Konopkin (1983) provided empirical data confirming that the age of 50 is the limit for engine-driver professions: they account for 10-23% of all errors and failures registered on railroad transport. A deeper analysis of the relationships demonstrates more complicated tendencies. As the length of service and age of professionals in various occupational groups increases, the probability of some types of errors (mainly related to performance speed, switching of attention and short-term memory processing) rises, while the probability of some other errors (contextual decision-making, prognostic problem solving) systematically decreases (Kotik & Yemelyanov, 1993).

5.2.4. Errors, Work Efficiency and Human Reliability

From the origin of Russian/Soviet engineering psychology the studies of human error were integrated into the research on work efficiency. In a general sense, this concept was defined as the fulfillment of a certain number of job tasks or technological functions at the required level during fixed time intervals (Krylov, 1972; Lomov, 1966). Reliability and quality of performance were considered as the two main components of work efficiency. Initially the concept "reliability" was borrowed from technology where it defined the ability of a technical system to keep the required characteristics of task execution within the given working conditions (Zarakovsky et al., 1974). As regards the specificity of psychological studies of man-machine interactions, the content of this concept was revised within the framework of the problem of human reliability (Firsov, 1996; Nebylitsyn, 1964).

Nebylitsyn was among the first Russian/Soviet psychologists who applied the term "reliability" to the analysis of an operator's job (Nebylitsyn, 1964). In his opinion *human reliability* is a set of individual characteristics which ensures his/her ability to maintain the qualitative and quantitative parameters of performance at the required level. Later this set was described in terms of "basic reliability", as distinct from "pragmatic reliability", which could be evaluated by the results of performance of a task in concrete job situations (Gubinsky, 1967; Nebylitsyn, 1966). In general it was supposed that an operator's reliability is determined by three main factors: (1) the level of adaptation of technical equipment to the human psychophysiological and psychological capacities; (2) the level of the operator's expertise and training; (3) the operator's individual psychophysiological characteristics and personality traits.

According to the above-mentioned postulates, human reliability had begun to be considered as an integrative function of the available pool of individual resources, on the one hand, and objective job requirements and facilities, on the other (Nebylitsyn, 1964; Zarakovsky et al., 1974). Initially in experimental studies attempts were made to demonstrate the dependence of certain professionally important abilities on the basic psychophysiological characteristics of a worker. The following relationships were selected as the principal ones (see Gorbov, 1964; Menshov, 1971; Nebylitsyn, 1964; Teplov, 1961):

- reliability is a monotonically decreasing function of the time of active work, the gradual changes of which depend on the endurance of the CNS;
- reliability of work in emergency situations depends on the strength of the CNS and the balance of nervous processes;
- hindrance resistance is a function of the strength of the CNS;
- spontaneous distractibility is also a function of the strength of the CNS;
- reactions to unexpected signals are determined by the balance of nervous processes;
- switching of attention depends on the mobility of nervous processes;
- resistance to environmental factors (temperature, pressure, noise, humidity, etc.) is connected with the strength of the CNS.

In later investigations the accent on revealing direct links between the psychological components of human reliability and the basic CNS characteristics weakened. But the intention to develop an adequate structural model of human reliability still remained strong (Milman, 1983; Osetrov, 1987; Ponomarenko, 1990; Zarakovsky & Pavlov, 1987). In contemporary studies the psychological structure of human reliability is described in terms of several most important constituent factors: (1) work efficiency; (2) professional motivation; (3) emotional stability; (4) cognitive strategies; (5) hindrance resistance; (6) self-regulation habits; (7) professional skills (Firsov, 1996; Milman, 1983). Appropriate methods of job analysis (so called professiographic analysis, Klimov, 1988; Kotelova, 1986) are used for the contextual description of these components and elaboration of assessment tools.

It should be mentioned that the term "reliability" does not allow attention to be concentrated only on the analysis of errors, mistakes or technical failures. Evaluation of the probability of negative outcomes, as well as prediction of risk factors for human or system functioning is the central point of the research. It has created a more general framework for psychological studies of human errors in which the focus of interest shifted to *error prevention* ideology. The efficiency of utilization of human resources, the level of "internal costs" of activity, the adequacy of short- and long-term adaptation of the personnel to critical situations were traditionally considered as the important criteria of human reliability (Berezin, 1988; Leonova & Medvedev, 1981; Medvedev, 1982; Zarakovsky et al., 1974; Zavalova et al., 1986).

To a great extent human reliability depends on the subjective sense or the significance of the errors or accidents to the acting person, the people around her/him, and society as a whole. Psychological interpretation should provide not only an analysis of factors which caused certain errors or critical situations, but also the process of their apprehension by a worker, subjective attitudes towards this event, the emotional experience of going over the difficulties, and other personal factors. Using the method of expert evaluation, Kotik (1989) found a strong correlation between subjective perception of the gravity of a probable accident and appraisals of the potential danger of the situation. The possibility of a fatal outcome makes the situation subjectively very dangerous, even if its probability is less than 2%. In contrast, the probability of getting a light injury makes the situation subjectively dangerous if its probability is near 45%. Recently the problem of subjective appraisal of situations that could provoke strong stress reactions (Cox & Mackay, 1981; Lazarus, 1966) was elaborated in empirical studies on human reliability in high-risk occupational groups (Leonova, 1996; Maryin & Lovchan, 1993; Tarabrina, Lasebnaya & Zelenova, 1994).

5.3. PSYCHOLOGICAL CLASSIFICATIONS OF HUMAN ERRORS

5.3.1. Terminology and Basic Definitions

In the Russian language errors are defined as incorrect actions or statements. The scientific definition is somewhat different. For example, the most popular psychological dictionary (Davydov et al., 1983) defines an operator's error as:

> "a failure which is not connected with a cessation of activity" (p. 242).

However, for the purpose of special psychological studies such a vague interpretation is not enough. That is why the elaboration of this notion was a special task for specialists working in the field (Lomov, 1966; Nosov, Piskoppel & Shchedrovitsky, 1986; Tsibulevsky, 1979; Zarakovsky & Medvedev, 1971).

Initially, in Russian/Soviet engineering psychology the concept of error was developed in the framework of the "man-machine" paradigm (Lomov, 1966; Zarakovsky et al., 1974). Researchers introduced the term "operating system error" defined as departure of operator-regulated parameters beyond allowed deviation limits (Lomov, 1966). The specificity of *human error* is considered from the point of view of operator actions, either performed or lacking, which could result in lapses of technical functioning or deviations of the system's controlling parameters beyond allowed limits (Firsov, 1996; Zarakovsky & Medvedev, 1971; Zarakovsky & Pavlov, 1987). Errors were also regarded as a particular case of *failure*:

> "an accidental event amounting to partial or complete loss of workability of a system or individual when performance of functions becomes impossible" (Sereda et al., 1976, p. 189).

More psychologically oriented studies referred to the concept of human error as any incorrect human actions which may cause failures and accidents (see, e.g., Genes & Madiyevsky, 1974). In the definition of human error by Nosov (1994) the idea of subjective improvidence of human actions is stressed. He defines errors as intentional deviations in workers' actions, when it is known that he/she had the ability, opportunity and desire to perform the task correctly. Many specific types of human error are considered in the contextual analysis of job situations. They are described in terms of illusions, distortion of consciousness, pseudo-hallucinations, etc. (Gorbov & Lebedev, 1975; Nosov, 1994; Strelkov, 2001). Such errors often take place during flights on modern aircraft, space flights, or work in extraordinary environmental conditions (Denisov & Onishchenko, 1972; Marishchuk et al., 1969; Medvedev, 1982; Nersesian & Konopkin, 1983). For instance, in a wider sense "illusions" are errors of sensation or distorted perception. They manifest themselves in subjective deformations of spatial or visual images, incorrect detection of speed or directions of movement, and other abnormal feelings (Gorbov & Lebedev, 1975; Kitaev-Smyck, 1983).

Several classifications of human error were built on the basis of the above-mentioned definitions. All of them tried to analyze the psychological background of different forms of incorrect actions, mistakes or failures.

5.3.2. Classification on the Basis of the Algorithmic Approach

One of the first and most general classifications of human error was proposed by Zarakovsky (1966) in the framework of the algorithmic approach to human performance (see also Munipov, 1983a; Zarakovsky & Pavlov, 1987). The algorithmic approach, borrowed from information theory, was used for analysis of operations as parts of the general logical scheme of the executed activity. Both the logic of technological processes and the prescribed consequences of human actions are present in the structure of algorithms describing man-machine functioning. The author developed a method of studying errors which may appear in different sections of the algorithm, including elementary acts and the connecting logical conditions. In general this method includes criteria for distinguishing errors as well as a psychological classification of errors and a mathematical model for error prediction. Even now modified versions of this method are used by ergonomists, especially for the purpose of system design and prevention of technical accidents (Golikov & Kostin, 1996; Ponomarenko, 1992).

In the proposed classification of errors Zarakovsky stressed that a human error could be identified only if the acting person knows what an adequate action would be. In view of this, two criteria were used for distinguishing types of errors: (a) external manifestation of errors as results of execution of a certain algorithm, mostly related to the reliability indicators; (b) psychophysiological determinants of errors, mostly related to the indicators of work effectiveness and the internal price of activity (Zarakovsky, 1966). This classification is described in Table 5.2 in more detail.

5.3.3. Contextual Classification of Errors

Later some elements of the algorithmic approach were included in a more contextual-oriented analysis of industrial accidents or personnel failures. The first attempt to create a contextual classification of errors was made in the analysis of air crew members' mistakes (Zarakovsky & Medvedev, 1971). This was supplemented with results of studies on locomotive-drivers, electric power plant operators and some other high-risk professionals (Gubinsky, 1982; Nersesian & Konopkin, 1983; Venda, 1982). This classification includes the following blocks of error descriptors:

- type of error: incorrect action, failure to perform an action, rearrangement of actions, execution of an unpredictable action, violation of temporal intervals, skill interference, and so on;
- consequences of errors: effects on reliability and effectiveness of system functioning, effects on an operator's performance, the individual "cost" of an error (physical or mental disturbances, personal and/or social losses, etc.);
- personal attitudes to errors: awareness, material and moral responsibility;
- factors which can cause errors: direct (necessity to do with enhanced job demands), principal (deficiency of the job design as a whole) and mediating (individual disabilities and/or social risk factors).

Table 5.2. Classification of human error on the basis of the algorithmic approach (after Zarakovsky, 1966)

External manifestations of errors	*Psychophysiological determinants of errors*
I. Missing elements in the work process • loss of sensory stimulation • loss of motor components of actions • loss of logical connections between operations • loss of a certain sector of an algorithm • improper ending of the work process *II. Quantitative errors* • deviation from the required level of control parameters • inappropriate reduction or increase of performance speed • incorrect calculations *III. Qualitative errors* • misunderstanding of a signal • violation of the sequence in algorithmic operations • logic failures (in working with concepts, data comparisons, making conclusions, etc.)	*I. Motivation* • intentional errors • involuntary actions as a result of: (1) a negative attitude to work or (2) overstrained positive motivation *II. Awareness* • errors of which an operator is aware • accidental errors due to loss of attention *III. Information load* • errors as a result of overloading • errors as a result of underloading *IV. Informational interference* • errors which are relevant to interfered information • errors which are irrelevant to interfered information *V. Human functional states* • errors as a result of fatigue, monotony, boredom • errors as a result of emotional tension and stress • errors as a result of distortion of physical and mental health • errors as a result of individual sensitivity to environmental factors

In general, this classification looks like a program for empirical research on concrete occupational groups rather than a scheme for error specification. It stimulates the introduction of the job analysis methodology to case studies of accidents or human reliability risk factors.

5.3.4. Classification of Factors which Cause Errors

Shifting the accents in empirical research from error description to error prevention ideology emphasizes the need to analyze causal determination of errors. On the basis of the model of operator activity Tsibulevsky (1979) proposed classifying errors according to the main groups of factors which provoke them. Among the most common and significant factors he distinguished the following groups:

(1) input characteristics: modality of signals, coding of information, temporal characteristics of informational flow, spatial presentation of information;
(2) type of response: verbal or motor, the level of a skill's complexity, temporal duration of actions;
(3) compatibility of input information and the required types of response through their spatial, temporal and contextual characteristics;
(4) individual fitness of the job to the worker's psychophysiological resources: individual abilities, the level of education and training, age, gender, actual psychophysiological state, physical and mental disorders;
(5) job arrangement and work conditions: characteristics of technical devices, work place design, work schedules, task interference, environmental risk factors.

Some criteria and normative values for error-free task performance, especially for points 1-3, were elaborated within the framework of this classification. They are used to regulate the operator's interface design and the ergonomic expertise of operator work places (Lomov & Zabrodin, 1983; Munipov, 1983a).

5.3.5. Behavioral Classification of Errors

Attempts to put in order and coordinate different forms of inappropriate performance (mistakes, omissions, delays, etc.) have produced several behavioral classifications of errors (Kotik & Yemelyanov, 1993; Nosov et al., 1986; Strelkov, 1989). The classification proposed by Sereda and co-workers (1976) was often used as a prototype for such issues. The authors tried to identify different kinds of deterioration in the process of man-machine functioning, but only for the cases of personnel faults (so-called accidental errors). Any type of performance deterioration that depends on technical causes or job design deficiency (so called regular errors) was excluded.

A hierarchy of accidental errors is constructed based upon two sets of factors: (1) their predictability or unpredictability for the acting person, and (2) the possibility of correcting an error (see Figure 5.2). Both predictable and unpredictable errors may be of three types. In some cases, a worker can correct himself/herself (correctable errors). If this happens on time, they are called "save failures", since there are no serious effects on the task performance or final results. If errors are corrected but not on time, they are qualified as delays. Another case is when a worker does not make a correction at all. These are non-reversable or "fatal" errors. They may be either omission (the loss of a necessary action), or an incorrect action. Also, a subject could do everything correctly but it may take too long a time. This particular case is considered as a form of inopportune service. Together with delays, this type of error produces operative refusal.

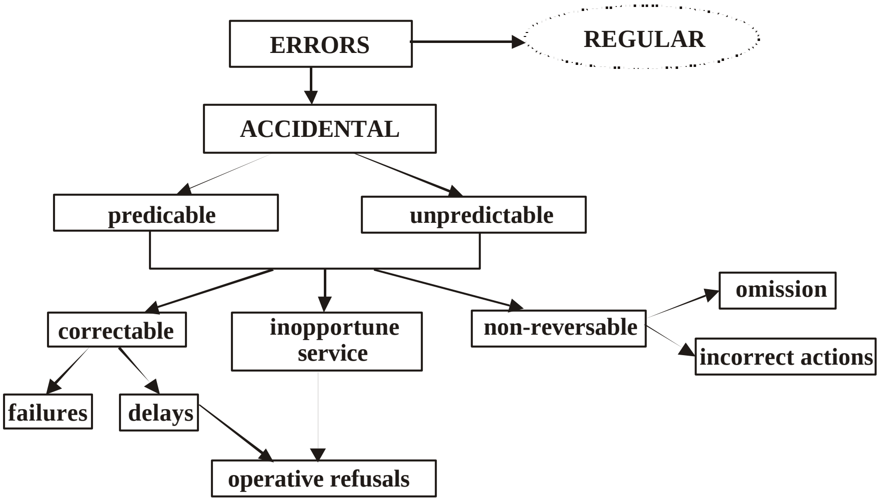

Figure 5.2. Behavioral classification of errors (after Sereda et al., 1976).

Besides an interpretation of different kinds of inappropriate performance, this classification provides a deeper phenomenological analysis of different personnel faults. For instance, Nosov (1994) tried to specify the nature of unexplainable errors by using Leontiev's Activity Theory. He considered errors on three levels of the structure of human activity: (1) normative, fixed in norms and regulations, (2) behavioral, and (3) mental. Through the analysis of typical incorrect actions at different levels of activity and their coordination, a new category – "pseudo-actions" – was introduced. Pseudo-actions are defined as normative actions that are accomplished only on the mental level but are not realized in behavior. Such actions usually arise in situations of high time pressure when an operator has to perform several actions and some of them are more significant or difficult than the others. In this case the completion of a more difficult action can influence a less important or more automatic one. As a result a "simple" action remains incomplete, although subjectively it has been included in performance scenarios. This is a rather specific type of omission but a very frequent cause of industrial and traffic accidents (Nosov, 1994; Strelkov, 2001; Zavalova et al., 1986).

5.4. ACTIVITY THEORY AS A METHODOLOGICAL FRAMEWORK FOR HUMAN ERROR RESEARCH

5.4.1. Activity Theory and Professiographic Issues

Among different methodological approaches Activity Theory (Leontiev, 1981a) played a special role in the development of Russian/Soviet applied psychology (Munipov, 1983b; Zinchenko et al., 1964). This happened not only because the "materialist surface" of this theory has helped it to remain resistant to ideological pressure for decades (see Section 5.1). Activity Theory made an essential attempt to discover the basic psychological determinants and constituent factors of human activity. The elaborated theoretical constructs were highly relevant to the analysis of work activity and associated phenomena of professional life (Munipov, 1983b).

According to Activity Theory, any kind of psychological function or mental process can be regarded as a specific form of internal activity developed in order to achieve goals important to the subject. Central to this theory is the idea about the structural identity of external (behavioral) and internal (mental) planes of human activity. This identity emerges in consequence of the process of interiorization[2]. On this basis an analytical paradigm for analysis and coordination on both external and internal planes of activity was elaborated (Leontiev, 1981b). It was proposed that any kind of human activity, including work activity, should be described on three hierarchical levels:

(1) as *activity generally*: representing coordination of objective purposes of activity and actualized subjective motives;

(2) as a set of *distinct actions*: outlining relations between particular objective tasks and subjectively accepted task-oriented goals;

(3) as a set of *operations*: specifying how an action is executed in concrete circumstances.

It seems that the application of these ideas to the practice of job analysis can help to overcome a barrier in the descriptions of objective reality demands and responses of an acting person (Hacker, 1986; Zinchenko et al., 1964; Zinchenko & Munipov, 1979). Following the traditions of the Soviet psychotechnics (see Section 5.1) such an attempt was realized on the basis of professiographic analysis of work activity or, to use a shorter term, professiographia (Ivanova, 1987; Klimov, 1988; Zinchenko et al., 1983). Professiographia is a complex methodology of job analysis, which includes a full-screen description of a profession in the light of human factor

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[2] In this theory the concept of interiorization concerns a complex process of transformation of objective, mainly socio-cultural norms and ways of activity realization, to elements of psychological functioning: subjective values, motives, perceptual and cognitive acts, mental operations, and other internal means of activity (cf., Piaget, 1946; Vygotsky, 1978; Wertch, 1981).

requirements. It consists of detailed studies of the organizational and technical aspects of a concrete job, as well as professional and psychophysiological attributes of the employed personnel (Gellerstein, 1926; Ivanova, 1987; Kotelova, 1986). Two principles define the specificity of this approach: (1) differentiated analysis of any concrete job with an emphasis on the practical problems that need to be resolved; and (2) professional stipulation of those individual resources that support and regulate the process of work execution. As a result, a detailed psychological description or a "psychological portrait" of the profession should be worked out. The core part of this description includes a set of professionally important functions and abilities of the specialist that are needed for efficient or normative job realization.

The hierarchical structural model presented in Activity Theory supplies professiographia with a methodology. If one looks at a concrete job, the three mentioned levels of activity can easily be delineated. Analysis on each level corresponds to filling up the slots of the model with necessary information by: (1) adequate job/profession descriptors and (2) all the requisites of a working person. Therefore, a variety of data have to be collected and considered within the hierarchy in two directions: vertical ("activity – actions – operations") and horizontal ("job/profession descriptors – working person"). A general scheme of professiographia, presented in Table 5.3, outlines a way of accomplishing this paradigm in applied studies.

It is a question of the concrete applied study how detailed the professiographia must be. Furthermore, the types of professiographic issues can be different. So-called normative profesiographia stresses the target characteristics of work activity and the obligatory requirements set on the personnel. As a result, a general description of a profession and a portrait of the "standard specialist" are elaborated. Dozens of such descriptions for different occupational groups have been worked out. They are widely used in psychological consulting and professional assessment practice (see, for instance, Altukhov, 1977; Klimov, 1988; Ponomarenko & Vorona, 1992). In another type of professiographic issue, so-called analytical professiographia, more attention is paid to analysis of the work at concrete workplaces (Ivanova, 1987). Fitting the man to the real job setting is evaluated in different respects. It helps to identify the weak points in the general structure of the work. A comparison of these findings with the data of normative professiographia makes a good basis for the detection of potential "zones of risk" to work efficiency, as well as to organizing the process of psychological expertise when an accident or another negative event has already taken place (Kotik & Yemelyanov, 1993; Leonova, 1984; Maryin, 1992; Strelkov, 1989).

Table 5.3. A general scheme of professiographia in coordination with the levels of activity analysis

Job / Profession descriptors	*Levels of activity analysis*	*Working person*
Job objectives	← *ACTIVITY* →	*Motives and attitudes*
social context and job content, general job design, objective norms and requirements, professional demands on personnel, job remuneration		dominant job motivation, social and professional attitudes to job, personal responsibility, level of professional expertise, professional achievements, age/gender/educational impacts
Job tasks	← *ACTIONS* →	*Subjectively accepted goals*
sets of job tasks, time and space allocation of tasks, technology and technical equipment, task demands, mental loads		goal orientations, professional abilities, individual capacities, sets of professionally important psychological functions, required physiological mobilization
Work conditions	← *OPERATIONS* →	*Internal tools and regulators*
sets of job operations, work process design, work algorithms/procedures, workplace design, work flow control, environmental factors, work-rest schedules		mental habits and skills, cognitive and sensory-motor strategies, ways of utilization of psychophysiological resources, dynamics of workability, subjective feelings

INTEGRATIVE CHARACTERISTICS

↙ JOB PRODUCTIVITY ↓ WORK EFFICIENCY ↘ HUMAN RELIABILITY

5.4.2. Human Information Processing and Functional Organization of Activity

Substantial ideas about mental regulators of work activity were developed in the studies of informational models and operator performance (Oshanin, 1999; Zinchenko & Munipov, 1979; Zavalova et al., 1986). In highly automated systems an operator is distant from real objects and technological processes. As a rule, he deals only with informational flows and imitative representations of the object's transformations. In applications of Activity Theory, the specificity of such types of work was defined as:

> "an activity with informational models of the situation" (Zinchenko & Munipov, 1979, p. 244).

It is stressed that an informational model *per se* is not a mental regulator or an "internal instrument" of activity although it provides the necessary background for the initiation of appropriate psychological processes. An operator's performance is built upon a conceptual model of the situation that includes representations of incoming information as images.

Such a conceptual model is developed in coordination with the subject's intention to act according to general knowledge about the system, evaluations of concrete task demands, preferable individual goals, available tools for task execution, etc. (Gordeeva & Zinchenko, 1982; Venda, 1982). Different mental regulators of activity can be depicted as constituent factors of the conceptual model. They were partially described in the concept of dynamic operative images by Oshanin (1999), in the model of adaptive informational interactions by Venda (1982), and in some other methodological studies (Lepsky, 1999; Strelkov, 2001; Zavalova et al., 1986), although not all of these authors are advocates of Activity Theory.

These findings were of great value for system interface design (Munipov, 1983a). Evaluations of the congruity/incongruity of both informational and conceptual models are widely used in ergonomic practice as criteria of optimal organization of indicator boards and operators' work places (Golikov & Kostin, 1996; Lomov & Zabrodin, 1983). The risk factors of errors and incorrect behavior have also been revealed by looking for the discrepancy between these models and the job reality. Errors may occur if a conceptual model is not adequate to the parameters of the controlled object and its forms of representation (Gordeeva & Zinchenko, 1982), or if the images of anticipated results and the data of actual task processing do not correlate (Oshanin, 1999; Zavalova et al., 1986). Elimination of such a discrepancy can help to develop promising ways of human error prevention.

Another application of Activity Theory to studies of operators' work resulted in the *microstructural approach* to cognitive and motor actions (Zinchenko & Munipov, 1979). To a large extent, the development of this approach was inspired by Western research in cognitive psychology (Velichkovsky, 1988). It deals with the functional organization of mental processes that underlie the execution of typical operator tasks, such as signal detection, coding, recognition, image rotation, the shadowing of dynamic objects, etc. The microstructure of these processes was examined and represented by structural models of relevant mental actions (Gordeeva & Zinchenko, 1982; Leonova, 1984; Velichkovsky, Blinnikova & Lapin, 1986; Velichkovsky & Kapitsa, 1980; Zinchenko, Leonova & Strelkov, 1985). Modifications of well-known models of human information processing (Atkinson & Shiffrin, 1971; Baddely & Hitch, 1974; Sternberg, 1975) and allocation of human resources (Broadbent, 1984; Hockey, 1993; Kahneman, 1973) were often used in these studies. A microstructure of different cognitive and motor actions was presented as a specific composition of mental operations. It helps to define the prevalent cognitive strategies of task execution, the types of utilization of psychophysiological resources, the role of automatic and conscious control functions (e.g., parallel vs. sequential modes of information processing) in the solution of different cognitive tasks (Leonova, 1993, 1998; Zinchenko, Velichkovsky & Vuchetich, 1980;).

Microstructural changes under the influence of different work-related factors were investigated in experimental and field studies (Gordeeva & Zinchenko, 1982; Leonova, 1984, 1993; Velichkovsky & Leonova, 1978; Zinchenko et al., 1985). It was shown that the effects of these factors may be rather specific and selectively affect different stages of human information processing (cf., Broadbent, 1985; Eysenck, 1982). For instance, the effects of prolonged job performance, i.e. fatigue effects, on the processing of symbolic information in short-term memory (according to the multistore memory model, Atkinson & Shiffrin, 1971) seem to be mainly related to distortions in such control operations as rehearsal, verbal coding, simple serialization, and interactions in working memory. Other factors have distinct effects on the same processing system. Monotonous conditions or routine work affect the operations of masking information in sensory memory, phonologic encoding, and the preparation of a motor response. Intensive emotional pressure, for instance, a heightened level of responsibility, influences retrieval operations and organization of motor responses (Leonova, 1984, 1998; Zinchenko et al., 1985). These findings demonstrate the possibility of localizing deterioration in blocks of mental operations that can be "risky" for reliable job performance in certain work conditions.

Changes in the microstructure of mental actions can be also described in terms of shifts in cognitive strategies and the required effort under the dynamics of situational demands. It is known that the most "economical" cognitive strategies of task execution are usually realized by automated mental operations (Hockey, Gaillard & Coles, 1986; Kahnemann, 1973; Sternberg, 1975; Zinchenko et al., 1980). A complication of the situation leads to an increasing role of reflexive evaluations of activity flow. In particular, it requires more conscious or voluntary control of an information processing system (cf. "supervisory controller" in the Broadbent demand-management model, cit.: Hockey, 1993). In consequence of this, the degree of mental effort increases, and task performance becomes more "costly" from the point of view of applied psychophysiological resources.

Such a method of evaluation of the "internal costs" of activity can be demonstrated, for instance, by applications of the Sternberg model of recognition processes in short-term memory (Sternberg, 1975). This was realized in field studies of desk-top operators, telegraphists, operator-microscopists, and university students under examination stress (Leonova, 1984, 1998). The dominance of different memory search strategies was analyzed depending on changes in the work loads and the workers' abilities to cope with them. It was shown that the optimal strategy of sequential exhaustive search (Sternberg, 1975) is typical for normal work conditions in all occupational groups. More complex work situations (e.g., too long working periods, increased informational interference) result in systematic shifts to the use of a more costly and less efficient strategy of exhaustive self-terminating search (Tenushev, 1986; Yaroshetskaya, 1982). Unbearable emotional tension (e.g., examination stress) can even lead to a distortion of regular cognitive strategies. Positive emotional mobilization in the same situation helps to cope with difficulties by strengthening the optimal search strategy or generating a more efficient, parallel processing mode (Gordon, 1988).

As these examples suggest, both structural and energy aspects of activity regulation can be merged in microstructural analysis of task performance. This provides answers to two questions: "Where are the deficiencies or break points in the structure of performance of mental actions localized?" and "How costly and efficient are cognitive strategies that are developed to compensate for such impairment?" For this purpose, computerized test batteries were elaborated for evaluating changes in the microstructure of different cognitive and sensory-motor actions (Gordeeva & Zinchenko, 1982; Kolodeznikova & Leonova, 1980; Leonova, 1993; Velichkovsky & Leonova, 1978). All the tests have been validated in practice, and are in use for the prediction of the level of human reliability in concrete types of job (Fedorov & Leonova, 1987; Leonova, 1984; Munipov, 1983a). The points of interest in these studies are not so much direct error prognosis as potential risks and negative consequences of insufficient regulation of activity.

5.4.3. The Concept of Human Functional States and Activity Regulation

A more general way of analyzing the human potential that underlies the process of job realization is proposed in the concept of *human functional states*. It is one of the central research subjects in Russian/Soviet work and engineering psychology (Dikaya, Semikin & Shchedrov, 1994; Leonova, 1994; Leonova & Medvedev, 1981; Zabrodin, 1983). The meaning of the term "human functional state" (HFS) is quite distant from its traditional physiological interpretation (cf.: Bernston, Cacioppo & Quigley, 1991; Danilova, 1985). It is broadly used in the studies of a variety of human states that typically develop during work: fatigue, monotony, different types of stress reactions, physical and emotional overstrains, "optimal" or "productive" inspiration, and so on. The spectrum of concrete types of HFS is practically boundless since at any time a person is in a certain state of mood.

Contemporary research clearly indicates that changes in human states cannot be explained only by shifts in the level of energetic mobilization or psychophysiological activation (Hockey & Hamilton, 1983; Medvedev, 1982; Sudakov, 1987). Transformations of dominant worker drives, motives and subjectively accepted goals should be considered as the most important regulatory factors in the dynamics of human states (Cox & Fergusson, 1994; Hockey et at, 1986; Klimov, 1988; Leonova, 1994; Marsella, 1994). These postulates are similar to the basic ideas of Activity Theory. This gives an impetus to the development of the *activity regulation approach* in applied studies of worker states (Chirkov, 1983; Leonova, 1998; Medvedev, 1982; Zabrodin, 1983).

As distinct from the other interpretations of human states (e.g., in terms of psychophysiological states, emotional or motivational states, conscious and unconscious states), the concept of HFS concentrates on revealing the relations between work efficiency and individual resources utilized in a concrete work situation. HFS is defined as:

> "an integrative set of those activated worker functions and abilities which directly or indirectly determine the efficiency of job performance in actual circumstances" (Zarakovsky et al., 1974, p. 94).

Work efficiency evaluations play the central role in this interpretation. They are regarded more widely than just listing individual parameters of work results or productivity. Two groups of criteria – *reliability* of job performance and *internal costs of activity* – are taken into consideration. Their relationships make a basis to answer the question "Was a job performed efficiently or not?" (see Section 5.2). Both actual and postponed indicators of work outputs, well-being and health are examined in order to identify the level of work efficiency (see Table 5.4; cf.: Leonova, 1994; Marsella, 1994; Warr 1994). This does not mean that the whole range of possible measures or indicators of work efficiency have to be estimated in one concrete study. Only the most crucial of them are distinguished by professiographic data. As a rule, several measures of work efficiency are selected that correspond to different groups of indicators, for instance, measures of "work output" and "well-being", or "work output" and "workers' health". The correlation between them shows how far the achieved results are sufficient for achieving pure pragmatic goals and a permissible level of individual expense.

An integrative pattern of actualized worker functions and abilities helps to clarify the way individual resources are utilized in the process of activity regulation. These patterns cannot be presented only by a simple collection of various symptoms or manifestations of a worker's state (see Cox & Fergusson, 1994; Frankenhaeuser, 1986; Simonson & Weiser, 1976). The set of various HFS measures has to be coordinated and structuralized in order to reconstruct changes in the functional structure of activity as a result of adaptation to various job demands. For this purpose the following principles of HFS analysis were elaborated.

- Among the variety of HFS manifestations, it is important to select those which are most relevant to *the job content*, dominant workloads and subjective attitudes to work. Being highly sensitive to changes in job demands, they can be interpreted in terms of actualized regulatory mechanisms and coping strategies.

- The composition of *the functional structure of activity* has to be identified on different levels of job realization: (a) energetic components of activity, measured by physiological and psychophysiological indicators; (b) operational components of mental activity, represented by indicators of cognitive functioning and sensory-motor coordination; (c) reflexive components, including evaluations of dominant motives and drives, subjective feelings, affective reactions, and self-estimations; (d) characteristics of job performance and overt behavior.
- *Integration of multilevel assessment* should provide a comprehensive interpretation of HFS in terms of syndromes of concrete workers' states and their effects on work output, well-being and health. Different practical tasks modify the accents on the required diagnostic solution. For instance, it may be a simple comparison of the states, or an outline of their dynamics, or an in-depth specification of each state's syndrome. Therefore, different strategies of data integration can be applied in order to give a proper answer to a pragmatic request. In all cases a structural representation of HFS in the form of an integrative pattern is needed. This is obtained by using such statistical procedures as pattern recognition algorithms, correlation and factor analysis, multidimensional scaling, and so on (for more detail see Leonova, 1994, 1998).

Table 5.4. Main groups of work efficiency indicators

Work output	*Well-being*	*Mental and physical health*
Productivity: *task results, quality of production, temporal characteristics of performance, errors and faulty actions*	Subjective comfort Job/life satisfaction Dominant motivation Level of responsibility Social integration	Borderline states Professional deformations (e.g., burnout syndrome) Personality accentuation Workers' sick rate
Strategies of work behavior	Professional competence	Psychosomatic disorders
Accident rate	Health risk behavior	Injuries and traumas
Turnover and absenteeism	Recovery periods after intensive work	Organic diseases
Team work: *coordination between team-members, conflicts, organizational climate, etc.*		Professional morbidity/ mortality rates

Traditionally, negative workers' states are treated as one of the most important sources of human error and risk factors for human reliability (see Section 5.3). The development of negative states is usually considered in its time-scale dynamics, from short periods of intense work of the worker to extended observations of different occupational groups (Appley & Trumbul, 1986; Gaillard & Wienjes, 1994; Kotik & Yemelyanov, 1983; Leonova, 1996; Siegrist & Peter, 1994; Simonson & Weiser, 1976). This enables researchers not only to indicate the appearance of a state that could undermine performance, but also to make a prognosis about "risky" stages by analyzing the general trends in HFS dynamics (Frolov, 1987; Zarakovsky & Pavlov, 1987). This approach is of great value for the development of specialized methods in human error research (see Section 6.2).

According to the activity regulation approach, HFS dynamics are associated with the stages of transition from optimal to non-optimal types of activity regulation. The data obtained in different work settings demonstrate the actual process of transformation, from (1) a strongly specialized and cooperative functional structure of activity (cases of optimal HFS), to (2) more diffuse structures with additional compensatory links (cases of sufficient or deficient compensation), and even up to (3) complete disintegration of the structure (cases of "breakdown" or dismissal HFS) (see, for instance, Berezin, 1988; Dikaya et al., 1994; Leonova, 1994, 1998; Maryin, Lovchan & Efanova, 1992). Besides the qualitative specification of the HFS syndromes, it is also a way to identify individual coping strategies and their vulnerability as potential risk factors for human reliability. Also, the selection of adequate correction procedures might be more reasonable in this context.

The realization of the described approach is illustrated by two case studies presented in Chapter 7. Both emphasize a preventive outlook on the problem of human error and well-being at work (see also Chapter 8). The characteristics of well-being and mental health are becoming the most significant among the work efficiency criteria. This is because in recent times an error in high-risk occupations may turn out to be much too destructive and "bloody" from the economic and social points of view, a price too high both in the East and in the West (Caplan, Cobb, French, Van Harrison & Pinneau, 1975; Kitaev-Smyck, 1983; Legasov, 1987; Levi, 1981; Ponomarenko, 1995).

CHAPTER 6

METHODS OF ASSESSMENT AND PREVENTION OF HUMAN ERROR

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The investigation and prevention of human error took on great significance during the past hundred years, when the issue was recognized not only as a problem of interpersonal relations between the worker and his boss, but one of a broader context of industrial and public safety. From the beginning of the 20th century special methods of human error prevention were elaborated in Russia. The first methods confined themselves to the accumulation of event reports about traumas, technical failures and human errors. The content of these reports was used for the statistical analysis of incidents and accidents. In this period restrictive precautions prevailed among preventive measures: workers had to follow safety rules and the equipment had to have protective devices, barriers and safety signals. Later, along with growing complication of machinery, special selection of personnel, and optimization of the conditions of work and rest were added.

Subsequent development of production, technology and means of transportation revealed the necessity of elaborating more advanced methods. Computer technologies permitted the modeling of processes of production, as well as probable errors and failures. At first the modeling took into consideration mostly physical factors which could influence the technological process. Later, the psychological characteristics of workers and social factors, which are hard to formalize and cannot be predicted, were supplemented. Gradually the modeling became more complicated, that allowed emergency situations to be foreseen and prepared for. At this time ergonomic design, the training of workers and careful personnel selection became the most significant preventive measures. More attention was paid to individuals at their workplaces and these changes provoked the development of techniques of human functional states management.

However, technical systems were still considered out of touch with human activity. The two separate modes – man and machine – needed mutual adaptation.

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

From one side there were attempts to adjust machines to human capabilities, and at the same time it became obvious that some professional skills must be cultivated.

Nowadays we are the witnesses of a new stage in the analysis and prevention of human error, when the process of production is analyzed as a complicated socio-technical system. Such a system includes technological, organizational and psychological units. This approach puts human activity or the functioning of an organization into the focus of analysis, which demands the elaboration of special methods and instruments for investigation of the levels and substructures of activity. From this point of view technical devices and organizational parameters can be described as external means, or the context of human activity and they must be analyzed along with the mental means of activity and internal human states. Detailed investigation of activity forms the basis of effective and safe running of a socio-technical system and here the issue of mutual adaptation of man and machine is replaced by human-centered design and advanced professional training. Not only workers, but also machines are provided with means of self-education, self-regulation and self-adaptation.

Although we have underlined certain stages in the development of methods of investigation and prevention of human error, one should keep in mind that each successive stage does not abolish previous experience. All the elaborated methods are widely used and the choice depends on the complexity of the task and the type and peculiarities of industrial activity.

6.1. TRADITIONAL METHODS OF ASSESSMENT OF HUMAN ERROR AND ACCIDENTS

Traditional methods for error assessment can be subdivided into the following main groups: (1) statistical analysis of accidents and professional trauma, (2) causal analysis of errors and failures, and (3) modeling of accidents. Besides these directions of analysis, today increasing attention is paid to organizational aspects of error assessment. Special methods of detection of weak spots in the organization of work at enterprises have been elaborated.

6.1.1. Statistical Analysis of Accidents

The statistical analysis of accidents and professional injuries has a long history - the first statistical report on accidents was published in Vienna in 1756. Before 1917 Russia had one of the most progressive statistical systems of professional trauma analysis, which was a part of the general ambulance statistics. The system even received the recognition of the International Exhibition on Hygiene held in Dresden in 1911.

The main purpose of the method of statistical analysis is to define the quantitative regularity that describes the appearance of various negative work outcomes related to inadequate job performance and workers' health. The realization of this method is based mostly on the investigation of a large number of accidents. To find out the psychological origins of human error and incorrect actions, the collected data must include information about the individual specificity of those persons who have made mistakes. In this case the psychological data (like any other) must be strictly standardized in order to be processed using methods of mathematical statistics. The statistical approach emphasizes quantitative analysis of accidents first of all. But if the accumulation of data is strictly regulated, they can also be used for qualitative analysis of root causes. The results obtained by this method make it possible not only to identify the objective causes of accidents, but also to predict the occurrence of human error in the future.

Unfortunately, in the Soviet Union all the information about accident statistics in industry was often hidden from the public. Psychologists tried to use indirect ways to better understand human error. Kotik (1981) proposed a scheme for the collection and analysis of data about industrial injuries and microtraumas. This procedure significantly enlarged the volume of data and improved the models of statistical analysis.

6.1.2. Methods of Analysis of Root Causes

Investigations of incidents and accidents are based on a study of all possible factors, both objective and subjective, that could provoke human error. This study includes an analysis of registered technical parameters and human actions as well as testimony of witnesses and participants of an accident. Causal analysis often uses the biographical method and the method of expert evaluation based on strict rules and procedures (Gubinsky, 1982; Strelkov, 1989). A special commission, which consists of engineers, medical staff and psychologists, examines the results of causal analysis so as to pass a decision about those guilty of an accident.

The first scheme of causal analysis of aircraft accidents was elaborated in Russia in 1921 (see Kotik & Yemelyanov, 1993). This scheme consisted of three branches of investigation: the search for guilty parties, the examination of the aircraft hardware, and the investigation of the circumstances of an accident. Later the procedure of accident analysis was developed on the basis of Activity Theory. One of the examples illustrating this tradition is the scheme for the investigation of aircraft accidents offered by Nosov (1994). As was mentioned above (see Section 5.4), he suggested analyzing different levels of operator activity: normative, behavioral, and mental. In his opinion, the analysis of human error requires separate consideration of professional instructions, actually accomplished actions and mental representations of actions. The investigation of a particular aircraft accident gave the author an opportunity to reveal the psychological causes of erroneous actions by the crew, which were actually connected with a discrepancy between the level of automatic operations and the level of conscious actions.

Specialists investigating an accident feel the strong pressure of public opinion, which forces them to find guilty persons and root causes as soon as possible. The power of this pressure is more pronounced at the beginning of the investigation. Often, the possibility to look for objective and indirect circumstances of an accident appears only after some time. The Rasmussen survey (Rasmussen, 1980) is one of the best-known examples of such secondary analysis. Rasmussen analyzed the compilation of significant event reports at nuclear power plants and defined omissions as the most frequent type of human error. He also revealed the dependence of omissions on the kind of task and the type of mental activity. Another example of secondary analysis of accidents on the basis of event reports can be found in Reason's research (Reason, 1990). He chose five major accidents at complex high risk systems which were well documented and investigated for his analysis. Examination of the chain of events, active errors, contributing conditions and latent failures from the reports of the selected accidents allowed him to propose a "resident pathogen" theory of accident causation and identify some of the system factors involved in unsafe acts (errors and violations). In Russia the similar approaches were also realized in the practice of accident analysis on a regular basis (Isakov, 1981; Nosov, 1994; Strelkov, 1989).

In the 1970s there were several attempts to elaborate rigid schemes of causal analysis of accidents, which made it possible to automate and computerize the analysis (see Leplat, 1982; Venda, 1982). One such method is the "INRS method" elaborated by the Institute National de Recherche et de Securite in France (Quinot, Meric, Monteau & Szekely, 1977). In the Soviet Union computer programs for automatic analysis of accidents were developed and widely applied in practice (Kvintitsky, Wilson & Melnichenko, 1976; Sinilo & Rumyantsev, 1973; Venda, 1982). One example of an efficient realization of this approach is the Yemelyanov model (Kotik & Yemelyanov, 1993), which consisted of the following blocks: (1) data collection, analysis, and classification; (2) diagnostics of the causes of error; (3) recommendations on error prevention; (4) organization of databases of operator errors and sources of error. This method implies unification of formal/statistical and contextual descriptions of operator activity, which makes possible the use of computer technologies in the complex analysis of inappropriate human actions and decisions.

6.1.3. Modeling of Failures and Accidents

To better evaluate the probability of different types of accidents and their possible consequences special efforts for modeling extreme situations are constantly undertaken. Besides creating extreme situations on simulators and in virtual plans, they can be set up at a concrete working place in the course of training procedures (Kotik & Yemelyanov, 1993; Nosov, 1994; Zavalova et al., 1986). Some interesting attempts to provoke false accidents were made at the end of the 1960s. They helped to reconstruct the operator activity, the dynamics and quality of his reactions, and the specificity of the decision-making process in crucial situations.

Kotik studied the work of aircraft crews in the situation which pilots call "beyond the line-of-sight range", or "over-the-horizon" (see Kotik & Yemelyanov, 1993). In the experiment, a gyrohorizon[1] failure was provoked. It lasted for two minutes and manifested itself in a 10-15 degree deviation. The pilot did not know that a "failure" had been planned and controlled. The investigator photographed the instrument panel and the pilot's face reflected in the mirror; an automatic recorder fixed the dynamics of the aircraft's position in relation to the horizon. After the flight all pilots gave self-reports. Flight analysis revealed the different patterns of behavior and strategies demonstrated by pilots in emergency situations. The data obtained showed that 15% of pilots did not detect the failure; they even did not realize that they were on the verge of a serious accident. The pilots who managed to detect the failure either used the reserve gyrohorizon or other indicators, such as the directional indicator and turn-and-slip indicator. These actions enabled the pilots to take control of the situation and escape an accident.

A similar experiment was carried out by Zavalova et al. (1986), who investigated the situation of "directive flight control". This is a kind of automatic piloting mode, when the aircraft computer gives directive instructions to the pilot. They only supplement the basic piloting signals, but in most cases the pilots use these alone because it simplifies piloting and decision-making. In one experiment the investigators provoked a failure of the computer commands in real landing conditions while the basic signals were not changed. The data obtained showed that it took pilots 15-80 seconds to realize that something was wrong with the computer. This period was 10 times longer than for manual (non-automatic) piloting. Pilots did not collate the computer commands with the readings of other instruments. In about 30% of cases they did not recognize the errors in the computer commands and the probability of incorrect actions was very high - about .52 (see Table 6.1).

Table 6.1. Pilot's actions in the situation of false information loading (after Zavalova et al., 1986)

False information detection parameters	*Quantitative characteristics*
Duration of flight control on the basis of false signals	15-80 sec
Probability of detection of false signals	.69
Probability of an unacceptable decrease of piloting quality	.52

These results demonstrated the shortcomings of automated piloting: in the case of failure of an automated system, pilots were slow in switching to piloting on the

[1] A gyrohorizon is an instrument used for detecting the deviation of an aircraft from the horizontal level.

basis of readings of the main instruments. The pilots' ability to make correcting judgments decreased, and the probability of errors and accidents rose.

In another experiment, relations between the efficiency of an operator's job and the volume of operative information were investigated in field studies involving the personnel of energy production facilities (Venda, 1982). In this experiment an accident situation was also modeled. The investigator unexpectedly switched off one of the main aggregates (for example, a blow fan or smoke exhaust) for the operator. The duration of emergency signals, technological deviations and all the operator's actions were controlled. The data obtained helped classify the most typical recovery strategies and determine the time necessary for their implementation.

It is clear that the method of accident provocation cannot be widely used because it interrupts the technological process. It is more convenient to model extreme situations on simulators, especially full-scale simulators, which are used for training operators in emergency situations (Nosov, 1994; Strelkov, 1989). Nowadays simulators and accident modeling is becoming mostly virtual (Bashlykov & Yeremeev, 1994).

Computer virtual modeling of accidents and extreme situations and probabilistic risk assessment have been actively used since the beginning of 1970s in Russia, as well as in the West. Reason (1990) in his book "Human Error" reviewed 9 models for predicting human error probabilities, which underlie the various techniques: human reliability databases, time-reliability curves, mathematical models, or expert judgments of human reliability. All these models presume that human activity is influenced by so-called performance shaping factors. Most models analyze such factors as work environment, ergonomic parameters, the criticality of the situation and operator qualities. Recent models pay more attention to organizational factors and the type of human activity, particularly to high level mental functioning.

Traditionally for Russian research, computer modeling of the situation builds up the structure of human activity. Gubinsky (1982) was the first to propose identifying the degree of reliability of an operator's work through analyzing the hierarchical levels of job performance. These levels correlated with the structure of human activity represented in Activity Theory. The highest level of activity determined the general structure for all tasks. The next level - the level of actions - was connected with the goals and algorithms of a concrete task. The lower level was represented by functional blocks of operations. The lowest level corresponded to particular psychophysiological acts (or operations) that supported the execution of the task. The author demonstrated the effectiveness of this model for the detection of incorrect job performance by operators working at energy production facilities.

A more general model was proposed by Yemelyanov (Kotik & Yemelyanov, 1993). This model took into consideration various technical and psychological characteristics (see Figure 6.1). Particular attention was paid to the analysis of the impacts of the social environment and organizational structure of labor on an operator. The model included the following blocks: operator characteristics, parameters of the control system, technical equipment and means of control, the material environment, the close social environment (family, colleagues, friends) and the distant social environment (upper managers, mass media, public organizations). All the connections between these factors were identified and their parameters could be changed. This model simulated different conditions of functioning of the whole system.

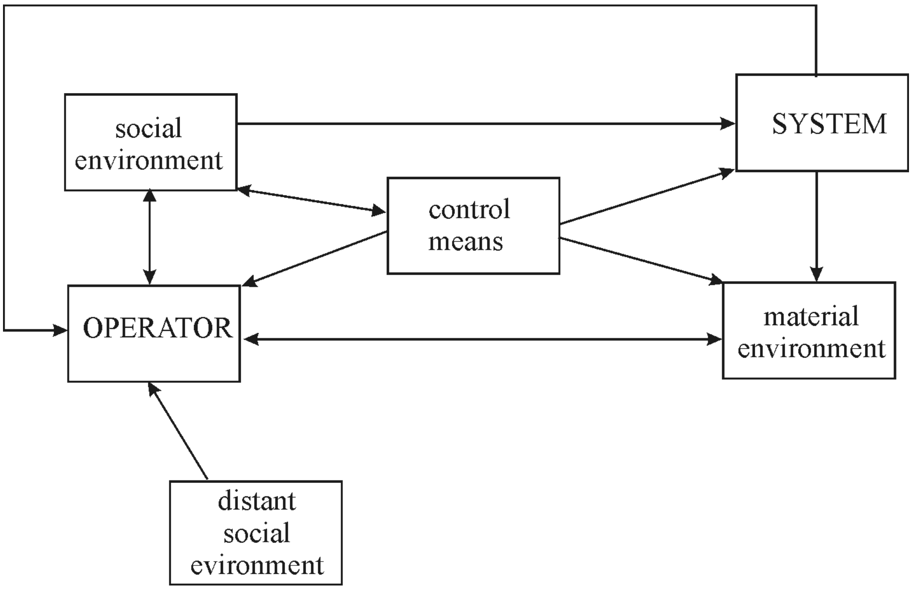

Figure 6.1. Representation of operators' activity in the form of a frame (after Kotik & Yemelyanov, 1993).

6.2. COMPLEX PSYCHOLOGICAL METHODS OF ERROR ASSESSMENT

6.2.1. On-Line Analysis of Work Activity

The majority of Russian assessment and human error prevention methods are based upon a detailed examination of the structure of human activity and evaluation of utilized human resources. They make it possible to understand the basic reasons for failures, disturbances and mistakes which cause accidents. For this purpose it is necessary to analyze the interactions between various characteristics of work and the worker which correlate with different levels of work activity. This integrative diagnostic approach cannot be realized using any simple or "universal" tool (Bodrov, 1985; Leonova, 1984; Zinchenko & Munipov, 1979).

To carry out this analysis it was necessary to elaborate precise procedures for the investigation of the execution of work activity in real life situations. These procedures should include methods of explication of minor mistakes, determination of all essential operations, workers' attitudes to work in general and at the given moment, and the identification of the most difficult elements of activity which provoke errors.

The study of the dynamics in the process of work execution includes two directions of analysis (Ivanova, 1987; Klimov, 1988). The first is the registration of *job performance indicators*, such as the productivity, speed and quality of performance. Productivity can be measured by the number of working cycles performed per shift. The average time of a single working cycle corresponds to the speed of performance, and the number of errors or false decisions to the quality of performance. Various schemes for evaluation of these indicators and their coordination were elaborated in the framework of professiographic analysis of activity (Ivanova, 1987; Lomov & Zabrodin, 1983; Zinchenko & Munipov, 1979). The second direction is connected with *job motivation and satisfaction* of the workers. Job satisfaction can be evaluated directly and indirectly through the estimation of the following factors: material prosperity and income; job content; work conditions; career development prospects; personal interests, attitudes and self-realization. For the assessment, a whole variety of checklists and specialized questionnaires are used (Fomicheva, 1982; Kabachenko, 2000; Munipov, 1983a).

6.2.2. Evaluation of Activated Human Resources in the Work Process

The utilization of human resources during the work process is evaluated by the analysis of HFS dynamics (see Section 5.4). The assessment methods and techniques used for this purpose can be classified into four main groups (Leonova, 1994): physiological, cognitive, subjective and behavioral (see Table 6.2). This classification is similar to that described in relevant Western research (Gopher & Kimchi, 1989; Hockey et al., 1986).

Physiological methods. Various characteristics of the functioning of the vegetative and central nervous systems are considered to be indicators of functional state dynamics. Among them are electrophysiological indicators such as EEG, EMG, EOG, event-related potentials and skin conductance. Parameters of brain electrical activity are traditionally connected with the levels of activation and energetic mobilization. Skin conductance parameters are widely used for the diagnostics of emotional tension (Chainova, Goncharenko & Munipov, 1980; Danilova, 1985; Rozhdestvenskaya, 1980; Rusalov, 1979). The most sensitive and informative indicators of HFS dynamics include various cardio-vascular system parameters, such as the heart rate, heart rate variability, blood flow and blood pressure. They help to understand the development of the states of fatigue and physiological and emotional overstrain, which are connected with an increase of consumed energy. The dynamics of other vegetative parameters, for example body temperature and sweating, is used as characteristics of changes in physiological activity during the day (Baievsky, 1979; Frolov, 1987; Zolina & Izmerov, 1983).

Another important source of information about overloads and other negative impacts on work activity is the registration of biochemical shifts (Kitaev-Smyck, 1983; Meerson, 1989).

Table 6.2. The most popular methods of HFS diagnostics used in Russian applied studies

Set of methods	*Measures*	*Methods and techniques*
Physiological	Electrophysiological	EEG, EMG, EOG, event-related potentials, skin conductance
	Vegetative	Heart rate, heart rate variability, blood flow, blood pressure
	Hormonal	Corticosteroid excretions
Cognitive	Sensory	CFF, detection thresholds, visual persistence/after-images
	Visual perception and attention	Vigilance tasks, attention span, switching of attention, the Burdon test and its modifications
	Memory	Identification and recognition tests, short-term memory tests, working/operative memory, semantic coding
	Intellectual	Machine paced computing, mental arithmetic, semantic classification and alteration, decision making tests
Subjective	Acute and chronic subjective states	Well-being scales, state-trait anxiety scales, Izard differential emotion scale, mental effort scales, specialized checklists for acute and chronic fatigue, monotony, and stress reactions
	Mediating personality traits	MMPI, Luscher test, questionnaires for type A behavior, locus of control checklists
Behavioral	Motor characteristics	Simple/complex reaction time techniques, tapping test and modifications of it, compensatory tracking, tremor, psychomotor tonus
	Speech	Complexes of acoustic parameters, intonation and semantic characteristics of speech, projective verbal tests
	Overt behavior	Lists of mimic, gesture and pantomimic manifestations, checklists for general overt behavior characteristics, photo/video recording of eye and body movements

Cognitive methods. Many attempts have been made to use cognitive models of human information processing to construct batteries of microstructural tests sensitive to HFS dynamics. Unlike traditional cognitive tests, which are based on overall speed and accuracy parameters, these methods take into consideration detailed changes in the functional structures and strategies of cognitive processing (Broadbent, 1984; Zinchenko et al., 1985). Some results of the application of these assessment means in field studies were discussed above (see Section 5.4).

Subjective methods comprise a number of self-estimation techniques, such as subjective scales, checklists and questionnaires (Chirkov, 1983; Marishchuk, Bludov, Plakhtienko & Serova, 1990). Typically they include several groups of symptoms reflecting certain aspects of subjective attitudes and feelings. In spite of the differences in actual HFS manifestations, it is possible to identify some common factors in the structure of subjective evaluations: symptoms of well-being and physiological discomfort, the dominant affective tone, main motivational trends, and personality attitudes to a current situation. These groups of symptoms are concerned with two principle types of reflexive acts which insure activity regulation at the most general level. They refer to (1) analysis of the state of affairs in a current situation, and (2) reflection of the results of actions and construction of programs of prospective behavior (Kuhl, 1983; Leonova, 1993).

Different subjective characteristics can be analyzed in connection with the following aspects of psychological states: (a) subjective feelings of current psychological states (actual well-being, emotional strain, acute fatigue, and subjective feelings of monotony); (b) subjective manifestations of negative chronic states (prolonged stress reactions, chronic fatigue or asthenia, trait anxiety); (c) psychosomatic symptomology and disorders (negative cardio-vascular symptoms, gastric disorders, hormonal dysfunction, symptoms of depression and neurotic reactions).

Behavioral methods are based upon analysis of the micro- and macrostructure of human motor activity. Several patterns of changes in the microstructure of single motor acts have been explored, directly corresponding to both low and moderate levels of monotony, compensatory mental fatigue, physical exertion and noise conditions (Kolodeznikova & Leonova, 1980). Relevant assessment indicators are implemented in standard motor techniques, such as the tapping test, choice reaction time and compensatory tracking, and are used in applied studies of operators' work (Fedorov & Leonova, 1987).

More traditionally, concrete qualitative changes in overt behavior are analyzed at the macrostructural level. There have been attempts to represent sensitive behavioral features in the form of specific expressive "portraits" or "images" of different HFS. Appropriate diagnostic techniques have been developed to aid HFS analysis through complex parameters of speech (Alekhina, 1990; Nikonov, 1985; Nosenko, 1981) and physiognomic aspects of behavior (Olshannikova & Potsyavichus, 1981). For example, patterns of acoustic characteristics received during radio- and telecommunication contacts with workers make it possible to assess HFS according to sensitive changes in moods and work efficiency levels (Nikonov, 1985). Besides being a necessary supplement to the quantitative analysis of job outcomes, these methods help to confirm subjective HFS expressions in verbal form.

Analysis of the diagnostic properties of each considered group of methods shows that different sets of data should be combined. While the observed changes of cognitive and behavioral indicators help us to understand the specificity of task performance from operational point of view, subjective measures are highly useful in analyzing the psychological nature of the changes, as well as in providing a more comprehensive interpretation of the observed state. Physiological parameters characterize the cost of activity for the organism. Thus, the integrative approach, which relies on qualitatively different sources of information, gives a more coherent picture of HFS.

After decades of debate it was shown that an integrative diagnostic solution cannot be found by any single or some universal “formula” (Frankenhaeuser, 1986; Hockey & Hamilton, 1983; Leonova, 1984; Simonson & Weiser, 1976). It seems that a more constructive approach involves a classification of the different types of diagnostic tasks, i.e., (a) identification of a state as optimal or non-optimal, or (b) definition of the main tendency of the HFS dynamics over time, or (c) in-depth characterization of a concrete state’s syndrome by explaining the relationships between different symptoms. For each task an adequate formal procedure and statistical methods suitable for integrating the initial sets of indicators can be selected. This approach is being elaborated in the framework of “strategies of data integration” (Leonova, 1994, 1998; Medvedev, 1982). An example of its practical application will be described in Chapter 7.

6.2.3. Evaluation of Organizational Factors in the Work Process

The examination of human errors and accidents which have already occurred is a very important part of job optimization, but it is not exhaustive. Error prevention is impossible without the detection of weak spots in the organization of work at enterprises. Besides a detailed professiographic analysis of occupations (see Section 5.4), it is necessary to outline the general structure of social and organizational factors that affect the work. For this purpose, different methods of social psychology, such as questionnaires, checklists and survey studies, are widely used (Andreeva, 1996; Kabachenko, 2000).

This approach can be exemplified by the study of risk factors for work safety at power plants (Zhuravlev et al., 1993). The checklist consisted of four groups of questions: (1) observance of safety rules by workers and managers; (2) availability of special technical means that provide safe functioning; (3) administrative support of workers; and (4) responsibility of the personnel. The study was carried out in Russia, at two departments of a large power plant, sequentially in 1991 and 1993. Mean values were compared with the data obtained on a similar power plant in the USA.

The findings showed significant differences between the Russian and American sets of data. These differences could be determined by such factors as cultural specificity, the level of technical equipment, and the organizational structure. For instance, Russian workers declared that they did not always conform to safety rules. Moreover, the managers often forced them to violate instructions. In the most general way these facts can be explained by the faults of the Soviet work safety system, particularly by its excessive formalization (for a discussion of this problem, see Chapter 8). The results obtained also revealed the weak points in the organization of the job process and labor protection tools at the Russian power plant. Most workers were upset by the lack of administrative support, as well as by the low technical level of information panels and communication systems.

6.3. SUBJECT-ORIENTED METHODS OF HUMAN ERROR PREVENTION

6.3.1. Basic Approaches to Human Error Prevention

In Russian applied psychology different methods have been developed for human error prevention (Kotik, 1981; Munipov, 1983a; Strelkov, 2001). They originate from two basic approaches: (1) reduction of potential risk factors by optimization of the work environment, and (2) error prevention through direct influence on a working person.

The most typical approach for engineering psychology and ergonomics is the reorganization of the objective job structure and the normalization of work conditions (Kotik & Yemelyanov, 1993; Krylov, 1972; Lomov, 1966; Munipov, 1986; Zinchenko & Munipov, 1979). It seems obvious that the most radical method of work optimization is to minimize or to eliminate, if possible, the causes of negative events. That is why any procedures and activities designed to improve the main objective job components may be considered as a potentially powerful prophylactic work. This "objective optimization" approach includes:

- technical modernization and redesign of work processes;
- modification of the work place and working postures;
- normalization of work-rest schedules;
- enrichment of job content;
- socio-psychological evaluation of workers' mutual compatibility and the composition of working groups.

The effectiveness of these methods has been proven by many experimental and field studies carried out in different work fields (Aseev, 1974; Kotik & Yemelyanov, 1993; Krylov, 1972; Leonova, 1994; Munipov, 1983a; Zinchenko & Munipov, 1979, and many others).

The second basic approach is oriented towards the people who participate in the work. Such traditional methods as professional training, use of simulators, personnel selection, and the monitoring and control of the personnel in highly demanding professions are widely used in psychological practice (Abramova, 1993; Altukhov, 1977; Butov, Kurgansky & Suslov, 1984; Kluev, Kachalkin, Didenko, Ovcharov & Gorbach, 1997; Kotik, 1981; Nersesian & Konopkin, 1983; Ponomarenko, 1990; Zavalova et al., 1986; for more examples see Section 8.1).

At the same time, real work situations often leave no opportunity to achieve effective error prevention using these methods alone. The reasons are various. The most important among them are as follows: a low level of technology, objective difficulties of work in so-called “complicated work conditions” (work at high altitudes, in a hot climate, with long social isolation, etc.), and highly demanding jobs in specific occupational groups (in aviation, aeronautics, fire-fighting, and others). Moreover, while fulfilling any task a person could encounter difficult situations of any character: emergency events, the necessity to work intensively over too long a time, etc. That is why it is not enough to use only the described preventive strategies - total elimination of work complications, or impeccable training or selection of personnel. Increasing the individual’s resistance to different job stressors and the development of special abilities to cope with them is also of great importance for efficient error prevention.

Accordingly, a specific method of error prevention should be accepted: the finding of ways to influence the mechanisms of activity regulation by correction of negative HFS. In Russian psychology this is called the psychoprophylactic approach, and is traditionally used in different areas of psychological practice (Grimak & Khachaturiants, 1981; Leonova & Kuznetsova, 1987, 1993).

The application of direct methods of HFS management as a way of error prevention seems to be fruitful because the roots of certain types of errors are related to specific HFS types (for instance, several types of “fatigue errors” or behavioral stress disturbances). Thus, the direct influence on HFS provides an opportunity to cope efficiently with the negative consequences of workloads and to prevent human errors which are related to non-optimal HFS.

6.3.2. Classification of Methods of HFS Management

In Russian psychological research there are several classifications of direct methods of HFS management. The basis of some classifications is the level of human activity influenced by specific psychoprophylactic means (Dikaya & Grimak, 1983). Here all methods are differentiated according to the special activating or regulatory systems, namely specific and non-specific arousal, cognitive and motivational. For example, three levels of prevention tools are identified (Chugunov, Yeremeev, Timofeev & Kornev, 1986):

- biological: reflexotherapy, massage, hydrothermoprocedures, relaxation and respiratory training, aerobics, diets, oxygen barotherapy;
- psychological: autogenic training, hypnosis, different techniques of psychotherapy;
- socio-therapeutic: music therapy, work therapy, therapy by means of culture.

This classification can be recommended for the development of a complex psychoprophylactic and correction system with respect to some borderline states that are close to neurosis. The authors also suggest that it is useful for general orientation in HFS optimization strategies for people who permanently work under strong emotional tension.

Another type of classification is based on the methodical specificity of different means (Nekrasov, Khudadov, Pikkenhein & Frester, 1985). It is proposed to differentiate between verbal and non-verbal methods, methods based on special technical equipment, and methods which could be used without them.

Several authors suggest differentiating between methods according to the type of prevention influence (Leonova & Kuznetsova, 1993). These classifications include the following prevention means: methods of introducing and studying unusual work experiences; psychotherapeutical ways of regulating human states; pharmacological means; physical training; methods of non-specific emotional influence through the use of music and color. To organize practical work, it is important to take into consideration the psychological position of a subject who is involved in the recovery or prevention programs. From this point of view the proposed classification (Leonova & Kuznetsova, 1993) takes into account how a subject can participate in the prevention process: will it be only passive acceptance of an influence, or can the subject actively take part in HFS correction. Accordingly, it was proposed to differentiate between two principal groups of HFS management methods: external and internal recovery procedures (see Table 6.3).

Table 6.3. Methods of direct prevention of negative HFS used in applied optimization work

External recovery methods	*Internal recovery methods*
• Rational nutrition, vitamin therapy • Pharmacological agents • Reflexotherapy and physical therapy • Functional music, multimedia means • Bibliotherapeutical means • Verbal suggestion and hypnosis	• Self-regulation techniques: - progressive (neuro-muscular relaxation) - ideomotor training - autogenic training • Breathing/respiratory gymnastics, special physical exercises • Behavioral psychotherapy • Group training for stress management

What is common to all *external* recovery methods is the subject's relatively passive position in the recovery process. This means that during the use of these procedures the subject does not intend to work out any special internal skills to support the process of management of his/her own state.

Internal, or active, recovery methods include different self-regulation and self-management techniques. The subject's active position during the use of these means is crucial for this type of prevention. Unlike external recovery methods, the specificity of self-regulation methods consists in the following: all self-regulation techniques are targeted to the development of internal regulatory skills (or so-called mental habits), which a subject can actively use to manage his/her state in different life situations. Practicing self-regulation techniques helps the subject to relax, to improve recovery processes and to achieve the required or desirable types of HFS.

6.3.3. Methods of Self-Regulation Training

There are several well-known methods that may be considered as *psychological self-regulation*: progressive relaxation techniques (Jacobson, 1978), autogenic training (Schultz, 1983), and various modifications of them. These two methods have been widely used in work processes for more than 30 years. There are also some other methods, which are not so widely used but quite efficient (Leonova & Kuznetsova, 1987, 1993). They are based on the principles of *ideomotor training* and *imaginative training*.

Self-regulation methods differ as regards the type of self-management exercises. But what is common to all of them is the specific dynamics of human states during their application: psychological and physiological transformations from initial non-optimal HFS (e.g., fatigue, physiological or emotional tension, etc.) to a special relaxation state, and after it to optimal HFS, which meets the standards of efficient work (see Figure 6.2).

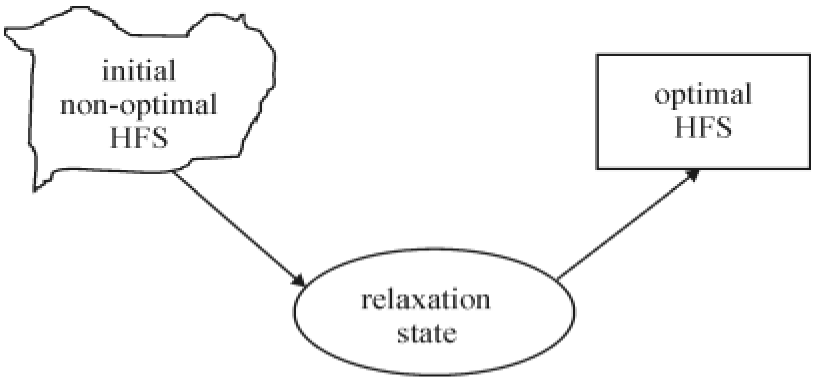

Figure 6.2. Dynamics of HFS during self-regulation training.

There are various data concerning the physiological mechanisms of the process of transformation from initial non-optimal HFS to a relaxation state (Lobzin & Reshetnikov, 1986; Luthe, 1969-1974; Nikiforov, Filimonenko & Polshin, 1986). These physiological data were obtained by on-line registration, following the process of state transformation. Typical physiological changes rake the direction of deep muscular relaxation, decrease the level of consciousness, and intensify recovery processes in the main functional systems of the human body.

At the same time there has not been so much experimental research on the psychological mechanisms of changes while being in such states. The main reason consists in the objective difficulties of registration of psychological parameters. It is impossible to study the specificity of psychological functions when a subject remains in a state of relaxation. A typical feature of the relaxation state is that one deeply plunges into oneself and the attention is concentrated on ones own state. It should be stressed that as opposed to hypnotic states, when it is possible to contact with a person, for instance, to speak with him, non-interrupted communication with a person during the relaxation process is impossible[2]. Nevertheless, empirical results show a strongly pronounced improvement in psychological functioning after relaxation training, as well as an improvement of mood and well-being (Dikaya & Semikin, 1991; Leonova, 1988; Nikiforov et al., 1986).

Practical application of self-regulation methods requires additional time for mastering self-regulation skills. Any method should be used as part of a whole training course consisting of a number of self-regulation sessions. In each session a person learns exercises intended for changing his/her state from a non-optimal to an optimal mode. The types of exercises differ depending on the specificity of the self-regulation method: they could be physical relaxation exercises (various progressive relaxation techniques) or different mental exercises, like autogenic formulae (in autogenic training), and also different image manipulations (in ideomotor training and in imaginative training).

During training a person learns how to recognize and to differentiate between the feelings aroused by exercises and related to the stage of physical and mental relaxation, i.e., learns to experience the relaxation state. Then he or she has to study how to activate recovery processes and achieve an optimal HFS. From session to session, external training transforms into internal self-regulation skills. It is, therefore, necessary to include in each training session the following HFS transformations stages: the initial stage, the stage of relaxation, the stage of internal activation, and the stage of external activation. The sequence of stages is presented in Figure 6.3.

The duration of a session usually depends upon the type of self-regulation method: training by progressive relaxation exercises requires more time than training by autogenic suggestions. So, at the beginning of self-regulation training the duration of a session can vary from 30 to 45 minutes. For advanced sessions the time is shorter, around 10-15 min. This becomes possible because the developing internal self-management skills start the process of HFS transformation without support in the form of external exercise.

During the process of interiorization of self-regulation skills, a re-allocation of time in the session takes place. When a person learns self-regulation skills, he begins

[2] That is why self-reports and instrumental investigations become possible only in a retrospective way, when the person leaves the relaxation state. As a result, any conclusions concerning psychological changes can be obtained only by a comparison of different HFS indicators before and after a self-regulation session.

to reach a relaxation state more quickly. As a result, it becomes possible for a subject to stay in the relaxation state as long as necessary, and to use additional self-management procedures aimed at improving the current HFS.

Self-regulation programs adapted for practical use have been implemented in different branches of industry and organizations (Leonova & Kuznetsova, 1993). As the basic principle a combination of different self-regulation methods within the framework of one training program is used. This is done for the purpose of training people in a wide range of self-regulation techniques. This idea proved to be fruitful: people get a chance to choose the most suitable types of self-regulation skills for self-recovery during work hours.

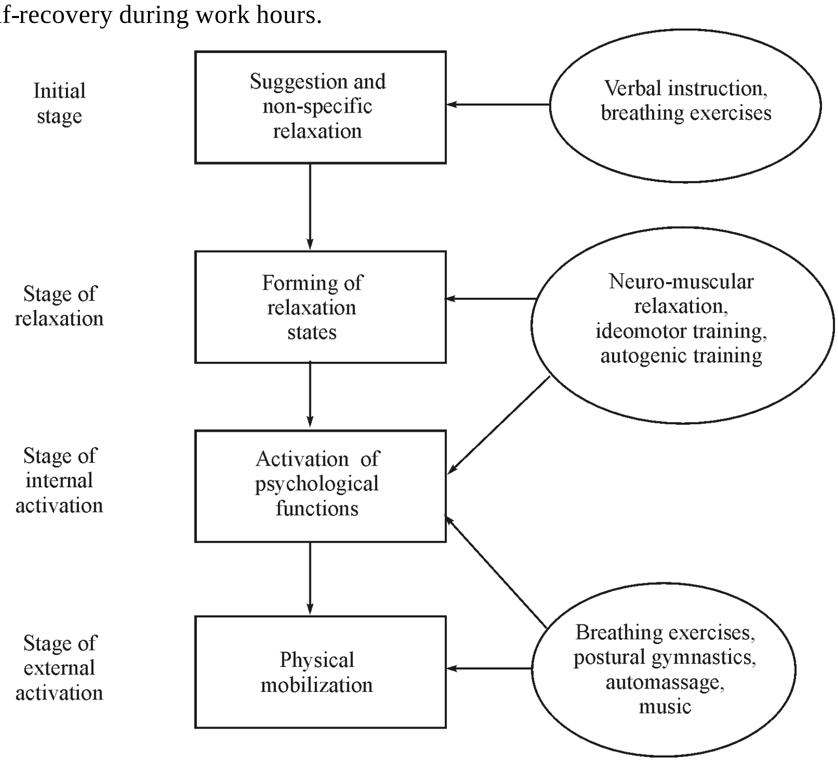

Figure 6.3. Scheme of a relaxation session.

Examples of such complex self-regulation programs will be discussed in Chapter 8. Methods of practical implementation of self-regulation methods in real work conditions will also be discussed with an accent on evaluating the efficiency of HFS self-management application.

CHAPTER 7

THE ACTIVITY REGULATION APPROACH IN CASE STUDIES OF HUMAN RELIABILITY

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The application of the described methodology of human error research is exemplified by two case studies. They were carried out on specific occupational groups: (1) operator-managers of a highly automated system, and (2) personnel of fire-fighting troops, working in an extraordinary job environment (dealing with the consequences of the Chernobyl Accident). The choice of such unlike samples allows us to consider the sets of risk factors for human reliability in principally different types of job - mental information work, and physically overstrained and risky professions. At the same time, comparison of the general results of these studies demonstrates the great importance of such psychological factors as subjective appraisals of the work situation and individual coping strategies that play the central role in maintaining reliable job performance in various professional activities.

7.1. RISK FACTORS OF OPERATOR RELIABILITY IN A HIGHLY AUTOMATED SYSTEM

7.1.1. Technical Innovations in the Operators' Job

The expansion of modern information technologies has lead to rapid changes in the content of professional work (Blackler, 1988; Roe & Meijer, 1990; Salvendy, Sauter & Hurrel, 1987). Even traditionally computerized professions, such as different types of operators' jobs, are strongly influenced by this process. The increasing role of mental information work, the intensification of the cognitive workload accompanied by a reduction of physical effort, a radical transformation in the organizational structures of work (i.e., work in virtual environments), as well as the necessity of quick personnel adaptation to innovations are mentioned among the most important sources of stress in modern occupations (Johanssen & Gardell, 1988; Karasek & Theorell, 1990; Khananashvili, 1978; Lepsky, 1999; Roe & Meijer, 1990). Accordingly, the problem of relations between objective job changes and the

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dynamics of work efficiency, personnel well-being and health is of great importance for research in human reliability.

Risk factors for human reliability in such jobs were investigated in our longitudinal study on operator-managers of highly automated systems. The personnel of the central control node of a telecommunication system participated in a study over six years, 1985-1991 (for more details see Leonova, 1993, 1996). These specialists were responsible for the functional control of remote technical equipment (satellites, radiolocation sets, etc.) and ensured reliable technological functioning of the system as a whole. The price of operator error or incorrect action was very high, since they could lead to serious damage or even the loss of the controlled objects. So impeccable task performance was one of the most important job requirements.

The operators' jobs consisted of monitoring and assessing the technical reliability of objects using different types of cognitive operations (control of telemetric data, decision making about an object/system deficiency, modeling of correction regimes, etc.). Since the controlled objects were remote from the observers, the latter had to work with informational models of technological processes without prompt feedback. However, each operator was personally responsible for the final decision on the technical reliability and safety of all operations.

Although the observed group of operators is quite unique and not large, the requirements on their job are typical for a wide range of top-level technical managerial positions in complex industrial systems (Lepsky, 1999; Zinchenko & Munipov, 1979; Salvendy et al., 1987). As in our case, intensive cognitive and emotional overstrains – the processing of massive information flows, decision-making when dealing with complex tasks, time shortages, a high level of personal responsibility with respect to work results - become the most important sources of stress in this occupational group. To a large extent, the ability to cope efficiently with such high job demands depends on the capacities of computerized tools that correspond to different levels of work automation.

In the course of the study we took a chance to analyze the effects of different stages of work automation on the operators, including the characteristics of job performance, personnel well-being and health. A radical modernization of the operators' workplaces took place in the middle of the study. More efficient program tools and technical devices were installed in order to optimize the human-computer interface. This produced substantial changes in the operators' jobs. *Before* the modernization, computerized tools provided only a display of long lists of telemetric data that had to be screened and analyzed by the operator. Here, the operator played a role of an integral part of the on-line data processing system. This was the stage of semi-automation of work. *After* the modernization, a more comprehensive informational control model supported the operators' activity, in which the majority of routine operations were done automatically. The operator used computerized facilities for work in modeling regimes that helped him to plan and implement different testing strategies and correction procedures for technological processes in the whole system. The modernized job design was closer to the stage of complete work automation.

Other organizational aspects of the operators' job did not seriously change after the technical innovations. The same operators worked at modernized workplaces after intensive retraining courses organized during the installation of the new equipment. This gave an opportunity to compare the effects of job demands on human reliability at different stages of work automation.

Three sets of data corresponding to the critical periods of the study were collected: *Stage 1* – before modernization (9-12 months before the innovations); *Stage 2* – adaptation to the innovations (6-8 months after the installation of new equipment); *Stage 3* – after modernization (18-20 months after the completion of automation).

A group of 31 male operators participated in the study on a regular basis over the six-year period of investigations. At the beginning of the study they were 28-49 years old, and had been professionally employed in the organization for 6-19 years. All operators were tested three times by the same set of assessment methods.

As indicators of operator reliability the following were used: (1) job performance parameters in the form of work outputs; (2) *job satisfaction* indices; (3) characteristics of *current psychological states*; (4) characteristics of *chronic psychological states*; (5) *psychosomatic symptoms* and health disorders. The data on performance parameters were picked up by instrumental observations and analysis of technical protocols. All psychological indicators (job satisfaction, current and chronic psychological states) were evaluated by standard psychodiagnostic methods for Russian applied research (see Section 6.2). The presence of psychosomatic symptoms and health disorders was identified by the results of systematic medical examinations. The list of assessment measures consisted of 15 different indicators (see Table 7.1). All of them were estimated at each stage of the study. The following data processing procedures were used:

(1) Analysis of variance for detecting the main trends in the dynamics of measured indicators depending on the stages of job modernization (the one-way ANOVA model);

(2) Factor analysis for description of the patterns of relationships between job performance indicators, different aspects of operators' psychological states and health at Stage 1 and Stage 3, before and after complete automation (the method of principal components with varimax rotation);

(3) Analysis of correlation between the number of errors and individual operators' characteristics, such as age, length of service, and all measured assessment indicators (the Pearson coefficient of correlation).

*Table 7.1. Effects of work automation on indicators of task performance, psychological states and health (Significance levels: *** - $p<.001$; ** - $p< .01$; * - $p<.05$)*

Indicators	*Mean scores for the stages of modernization*			*F-value*	*Direction of significant changes*	*Interpretation*
	Stage 1	*Stage 2*	*Stage 3*			
Work outputs						
Productivity	16.5	27.6	28.9	101.75***	increase	strong improvement of productivity, speed and quality of task performance
Time of task execution	23.7	15.2	17.4	57.31***	reduction	
Number of errors	7.8	5.6	4.1	89.22***	reduction	
Job Satisfaction (general index)	4.9	5.9	5.7	4.89**	increase	strong increase of job satisfaction
Current psychological states						
Subjective comfort	45.1	51.3	53.2	2.67	no changes	decrement of subjective feelings of monotony and strong increase of emotional strain
Acute fatigue	21.3	18.9	19.6	1.07	no changes	
Monotony	6.1	3.9	4.4	5.19*	reduction	
State anxiety	42.7	46.8	45.7	7.84**	increase	
Chronic psychological states						
Prolonged stress reactions	48.4	53.6	56.1	4.32*	increase	accumulation of chronic stress reactions and increasing trait anxiety
Chronic fatigue	21.3	24.8	27.2	3.07	no changes	
Trait anxiety	41.3	43.7	45.3	5.09*	increase	
Psychosomatic symptoms						
Cardio-vascular	26.2	38.5	33.1	3.98*	increase	deterioration in physical and mental health: increased number of cardio-vascular symptoms and increasing manifestations of depression and neurotic states
Gastric	14.6	19.3	18.7	2.61	no changes	
Hormonal	6.7	7.1	8.9	1.85	no changes	
Depression, neurotic states	10.3	17.7	21.4	3.59*	increase	

7.1.2. Effects of Modernization on Job Performance and Well-Being

The effects of workplace modernization are clearly presented in the dynamics of all groups of indicators. The directions of the observed significant trends and their interpretations are summarized in Table 7.1. As can be noted, some of these changes appear contradictory. This reflects the contrast of improved performance and job satisfaction associated with the accumulation of chronic negative effects.

All job performance parameters significantly improved after the workplace modernization. The number of operative tasks performed per working shift (productivity) strongly increased. The time spent on one working cycle (the task performance time) decreased 1.4-1.6 times, so the speed of performance increased. The quality of performance did not suffer at all because of this job intensification - the number of operator errors even progressively reduced.

At the same time, the dominance of the specific types of operator errors changed at different stages of automation. Qualitative analysis of the protocols made it possible to subdivide the total number of errors into several groups: (a) *omissions* or simple loss of attention; (b) *false alarms* or subjective perception of defects when in reality they were absent; (c) *communication errors*, e.g. contacts with inappropriate colleagues during task execution; (d) incorrect *decision making* or *wrong qualification* of technical defects in controlled objects; (e) *incorrect choice* of task performance strategy; (f) rare lapses or *other untypical actions*. Although the overall rate of errors was relatively low at all stages, there was a clearly observed tendency towards a redistribution of the types of errors typical for an operator's job at Stage 1 and Stage 3, before and after complete automation (see Figure 7.1). Work intensification and the increased complexity of performed tasks in Stage 3 could explain the increasing number of "cognitive" errors, such as failures in decision making, strategic planning, etc.

Motivational attitudes to work, measured by job satisfaction indices, also improved after modernization. This pertains mainly to the job satisfaction indices connected with the enrichment of job content and better work conditions, accompanied by increasing personal interest in the work. Two relatively "superficial" indices – material prosperity and, to a lesser degree, career development prospects – decreased during the stages of modernization (Leonova, 1996). However, this effect cannot be derived only from job changes since the study period overlapped the extraordinary transformations in social and economic life in the country. Nevertheless, the general index of job satisfaction increased significantly.

The effects of modernization on the characteristics of current and chronic psychological states are not so positive and harmonized. Some positive tendencies are observed in the manifestations of current psychological states after complete automation: a decrease of monotony and a slight improvement of the feeling of subjective comfort. A stable level of acute fatigue, despite an objective increase of cognitive loads after modernization, corresponded with these positive trends.

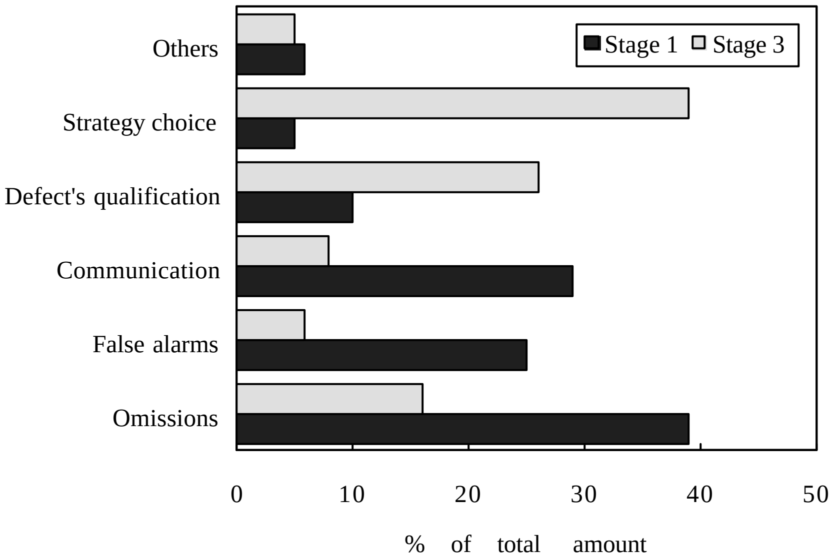

Figure 7.1. Distribution of types of errors depending on work automation stages.

At the same time, a strong increase of emotional tension represented by a rising anxiety index is in contrast with the above-mentioned effects. It might be the evidence of changes in the psychological mechanisms of activity regulation at different stages of work automation. A more passive inclination to spend available psychophysiological resources in semi-automated work is replaced by continual emotional hypermobilization which stimulated job performance after complete automation.

Intense feelings of emotional tension corresponded with increasing manifestations of negative chronic states after modernization. First of all, they were displayed by the growth of prolonged stress reactions and increasing levels of trait anxiety. There was also an accumulation of manifestations of chronic fatigue. These negative trends could be considered as a signal of the development of borderline states that are potentially dangerous for operator well-being and mental health.

The negative impacts of work automation on the operators' health were revealed by the increasing number of psychosomatic symptoms and disorders. This negative tendency is significant for the group of cardiovascular diseases. The most frequent among them were hypertension and coronary deficiency. After modernization more than 30% of operators had these medical problems. The frequency of neurotic reactions and symptoms of depression also rose after modernization. These were manifest in sleeplessness, lowered mood, communicative difficulties and intensification of aggressive reactions.

The peak of psychosomatic symptoms appeared during Stage 2, just after modernization, and remained at a high level in the subsequent Stage 3. So it cannot be qualified only as a response to the difficulties of the transient stage of adaptation to a changing work environment. In terms of medical control, all these symptoms had the status of health deterioration that need to be treated. From the psychological point of view, these findings can be considered as a result of the intensification and complication of the operators' jobs after complete automation. They also demonstrate a real decrement of human abilities to cope with job demands, relating to increasing risk factors for operator reliability.

The data were integrated by means of factor analysis, and discussed as patterns of relationships between the measured operator reliability indicators. The factor structures obtained for Stage 1 ("before modernization") and Stage 3 ("after complete automation") are presented in Table 7.2.

A comparison between factor structures demonstrates that work automation leads to a noticeable transformation of the patterns of assessment indicators. The transformation of the initial factor structure (Stage 1) to the final factor structure (Stage 3) demonstrates that each job performance indicator starts to correspond more closely with certain indicators of work attitudes and psychological states. The main job intensification indicator (the speed of task performance) is strongly connected with the increase of emotional tension or state anxiety. The growth of productivity (the number of performed tasks) is more closely associated with the increased level of trait anxiety accompanied by the development of cardiovascular symptoms. The rising work quality (a lower number of errors) is connected with reduced levels of fatigue and monotony.

Such changes began to appear at the transitional stage just after modernization, and were consolidated at the stage of complete automation (Leonova, 1996). Therefore they could be explained mainly by the changes in job content. The execution of work after complete automation needed to be regulated in a different way than in the case of semi-automation, since the intensity of work flows and cognitive complexity of the tasks increased. The presence of some constant factors in both factor structures can be probably related to some common features of the operators' jobs independently of the stages of work automation.

7.1.3. Changes in the Quality of Performance Depending on Personnel Characteristics

Relationships between the quality of performance, measured by the number of errors, and the individual characteristics of the operators were also analyzed at different stages of work automation. A list of observed significant correlations is presented at Table 7.3.

The data suggest that relationships between the number of errors and other assessment indicators are quite different at Stage 1 and Stage 3. However, in both cases such personnel characteristics as age, length of service and deterioration

Table 7.2. Factor structures of diagnostic indicators at different stages of work automation

Stage 1 (before modernization)				
Factor 1 *(21.7%)*	Factor 2 *(19.6%)*	Factor 3 *(12.3%)*	Factor 4 *(10.5%)*	Factor 5 *(9.3%)*
Cardio-vascular s. (.75) Trait anxiety (.72) Subjective comfort (-.68) State anxiety (.61) Chronic fatigue (.53) Monotony (.50)	Job satisfaction (.78) Acute fatigue (-.75)	Job performance: productivity (.83) speed (.76) errors (.63) State anxiety (-.57) Acute fatigue (-.51)	Gastric s. (.89) Monotony (.58) Depression (.52)	Hormonal s. (.82) Prolonged stress reactions (.56)

Stage 3 (after complete automation)					
Factor 1 *(23.3 %)*	Factor 2 *(15.2%)*	Factor 3 *(13.3%)*	Factor 4 *(13,2%)*	Factor 5 *(9.0%)*	Factor 6 *(7.2%)*
Job satisfaction (.84) Subjective comfort (.68) Acute fatigue (-.62)	Errors (.66) Chronic fatigue (.60) Monotony (.58)	Speed (.89) State anxiety (.66)	Productivity (.65) Trait anxiety (.77) Cardio-vascular s. (.50)	Gastric s. (.61) Depression (.85) Monotony (.49)	Hormonal s. (.80) Prolonged stress reactions (.51)

in health are not directly linked with the number of errors. The quality of performance significantly correlates with the parameters of job performance, job satisfaction, and psychological states.

In Stage 1 the number of errors significantly correlates with the productivity and speed of performance and different indicators of current psychological states (positive correlation with monotony and acute fatigue, negative correlation with subjective comfort). This shows that before modernization, the quality of performance was related to the intensity of the work flow and the exhaustion of internal resources matching this intensity.

*Table 7.3. Significant correlations between the number of errors and other diagnostic indicators at different stages of work automation (using the Pearson correlation coefficient, n=31; Significance levels: ** - p<.01; * - p<.05)*

Stage 1 (before modernization)	*Stage 3 (after complete automation)*
Productivity (r = .457)**	Job satisfaction (r = -.393)*
Speed of performance (r = .376)*	State anxiety (r = .395)*
Subjective comfort (r = -.475)**	Chronic fatigue (r = .452)**
Acute fatigue (r = .482)**	
Monotony (r = .356)*	

In Stage 3, after complete automation, the number and type of correlation links change. Only three indicators significantly correlate with the number of errors: there is an observed negative correlation with the index of job satisfaction, and a positive correlation with the levels of state anxiety and chronic fatigue. All these indicators belong to the class of subjective appraisals of the situation. The increased emotional tension might be strengthened by physical and mental exhaustion, which is represented by the level of chronic fatigue. This is a direct risk factor for the quality of performance. Also a lower level of job satisfaction relates to a growing number of errors. This should be seen as a manifestation of the role of motivation in regulating the quality of performance.

It could be mentioned that in Stage 3 the indices of state anxiety and chronic fatigue have a branched structure significantly correlating with the other personnel characteristics and indicators of psychological states. State anxiety correlates with the length of service (r=.364, p<.015, job satisfaction (r=.377, p<.05), subjective comfort (r=-.636, p<.01), trait anxiety (r=.390, p<.05, prolonged stress reactions (r=.357, p<.05), and gastric disorders (r=.423, p<.05). Chronic fatigue correlates with age (r=.397, p<.05), length of service (r=.362, p<.05), well-being (r=.399, p<.05), trait anxiety (r=.367, p<.05), and cardio-vascular diseases (.361, p<.05). Therefore those two indicators can be regarded as intermediate variables that reflect the influences of different individual factors on the quality of job performance.

7.1.4. General Trends in Operator Reliability in the Process of Work Automation

The transition from routine service operations (e.g., information monitoring and transferring) to more creative functions (decision-making and management) was the main substance of change in the operators' jobs after the complete modernization of the workplace. It provided a sufficient improvement in job performance but had a rather ambivalent influence on different components of the operators' well-being and health. Besides the increase in job satisfaction (mainly in terms of subjective attractiveness of the work) some indicators of current psychological state also improved.

At the same time, consolidation of prolonged stress reactions and an appropriate accumulation of psychosomatic symptomology were observed. The increased level of emotional strain, both in its acute and prolonged influences, can be mentioned as the main reason for such negative effects. This factor may play the most important role in the genesis of errors and incorrect actions when an operator is dealing with a completely automated system.

The pattern of stress-related reactions mentioned differs from the fatigue-boredom syndrome, as in Stage 1 in the presented study, which is typical for more traditional types of operator job (Cooper & Payne, 1988; Leonova, 1984; Salvendy et al., 1987). For these circumstances the deficiency in the mechanisms of emotional regulation appears a more adequate explanatory principle than simple exhaustion of psychophysiological resources.

The observed phenomenon of intensive emotional hypermobilization was often considered in the literature as a spontaneously formed coping mechanism of adaptation to complicated job conditions (Siegrist & Peter, 1994). Its prolonged exploitation leads to damage of activity regulation processes and the development of mental and physical diseases. Thus, the overuse of emotional and motivational resources during working cycles due to the specificity of the operators' subjective attitudes to their job can be regarded as the principal risk factor for operator reliability.

This assumption is supported by observed changes in the relations between the quality of work (number of errors) and other characteristics of job performance and subjective feelings. After complete automation, the number of errors lost the almost direct connection with increased job intensity, as well as with manifestations of acute mental exhaustion. It became directly correlated with such psychological factors as reduction of job satisfaction and increased emotional strain. Thus, in the case of "total" automation, the appearance of errors and incorrect actions depends mostly on the growing emotional strain which makes it difficult to cope with cognitive overloads.

So, the long-term adaptation of the personnel to the changing work environment is a controversial process. It depends both on job requirements and demands, which could rise during technical innovations, and individual modes of dealing with them. In general, it leads to an increase of the emotional and cognitive costs of activity, which is a weak point regarding reliable job performance. Relatively rare but contextually important operator errors present a potential danger for the functioning of the automated system as a whole.

A high professional standard and a strong job-oriented motivation help operators to support efficient performance in cognitively overloaded job conditions. But intermediate accumulation of chronic borderline states and psychosomatic symptoms reveals the inadequacy of spontaneously formed coping strategies based on non-specific generalization of emotional strain.

The acquisition of more systematized self-regulation habits in special relaxation training can promote an improvement of the recovery process and help develop more adequate individual techniques for coping with human reliability risk factors (see Section 8.3).

7.2. RISK FACTORS OF HUMAN RELIABILITY IN FIRE-FIGHTING JOBS

Among the most catastrophic consequences of human errors and negligence are fires and explosions. Fire accidents at industrial objects and energy production facilities are especially dangerous because they increase the risk of human deaths and injuries many times, may lead to irretrievable material damage and become the cause of ecological disasters. Such a disastrous event as the explosion at the Chernobyl Nuclear Plant on April 26, 1986 shows how harmful and protracted the consequences of such accidents can be for the social and economic life of several countries - Ukraine, Russia, the Baltic Republics, to say nothing of the countless dramas of individuals and families. This unfortunate experience also emphasizes the necessity of dealing with various psychological and medical problems. One of them is the analysis of the specificity and better organization of the work of people who are professionally involved in dealing with such accidents (Alexandrovsky, Lobastov, Spivak & Shchukin, 1991; Maryin et al., 1992; Reshetnikov, Baranov & Muchin, 1990).

The occupational group *of fire-fighters* plays the most important role when an emergency occurs. The risks of this job are very high even in the case of an “ordinary fire”, and they increase greatly in extreme situations. During their work fire-fighters “have no right” to be careless or make mistakes: any false action can lead to deaths, including the loss of their own lives and serious damage to human health, as well as to further complication of the critical situation. So the factors which might influence human reliability are of great significance for efficient performance in this profession.

The intensity and liability of fire-fighting jobs have been growing in the past decade. From 1992 till 1998, the number of fires in the Russian Federation has increased by 11%, the number of people lost in accidents - by 56%, and the number of people injured in such situations - by 36%. This means that throughout the country fire brigades receive more than 1500 emergency calls per day. That is, they rush to accident sites 60-65 times per hour; on average, two people are lost in each major accident and more than 20 receive injuries and burns (Maryin, 1996). Fire accidents are also becoming more serious. More than 70% take place in big cities and at industrial facilities. The consequences could be quite serious for the normal functioning and ecological safety of densely populated regions. Therefore fire-fighters are responsible not only for saving people and the damaged object but also for keeping the environment intact.

The reliable performance of fire-fighters does not only depend on the level of professional training and physical endurance. Many psychobiological and social factors influence the efficiency of their work (Alexandrovsky et al., 1991; Maryin, 1992). The present study makes an attempt to identify the main psychological risk factors for human reliability in the special group of fire-fighters, those who dealt with the consequences of the Cherbobyl Accident. Fire-fighters worked systematically in the Chernobyl Zone for several years after the accident in order to keep the situation under control, including the regular extinction of local explosions and fires[1].

The initial set of empirical data was collected directly in the Chernobyl Zone from 1990-1993 by the Psychological Unit of the All-Russia Research Institute for Fire Fighting under the guidance of M. Maryin. Later the data were processed by A. Leonova at the Laboratory of Work Psychology, Moscow State University. The project consisted of three parts:

(1) a professiographic study, including a survey of job attitudes to the work of the personnel of the fire-fighting squads;
(2) a diagnostic study of the dynamics of fire-fighters' HFS during a regular working shift in the Chernobyl Zone;
(3) a study of the development of stress syndromes in a difficult work situation based on the data of the enduring accident at the Chernobyl Nuclear Plant in October 1991.

7.2.1. Work Stressors in Fire-Fighting Jobs

The results of professiographic analysis of fire-fighting jobs show that two groups of factors constrain the body of main stressors typical for this profession:

- *extraordinary environmental conditions and job demands*: the intensity and variety of operative tasks; physical overloads; severe time pressure; extreme temperature regimes and humidity levels; intensive pollution of the atmosphere; various sources of harmful radiation; intensive noise; shift work and prolonged work duration;
- intermediate psychological factors that lead to *a high level of mental tension and overstrain*: the constant awareness of risk and lethal danger;

[1] The teams worked in a watch regime: 1–1.5 months at the Chernobyl Zone with a subsequent vacation of up to two months. There was rotation of the personnel in the teams, but on average the fire-fighters spent four – eight watches in the Chernobyl Zone.

the strong social expectations and control over the quality of work; a high level of responsibility and personal involvement; the necessity of performing a variety of operative tasks at the same time, of being ready to react immediately to solve problems in rapidly changing circumstances; to cope with obscurity and unpredictability in the development of the situation, and the strong affective components in the execution of operative tasks.

It may seem that extreme job demands exceed the capacity of personnel to maintain efficient work. A variety of concomitant stress manifestations are typical for different fire-fighter groups. The data of occupational reports show that more than 90% of fire-fighters feel strong emotional tension and subjective discomfort just after receiving an alarm signal, and it does not abate until the work is accomplished. Nearly 25% have symptoms of a divided conscious state and space disorientation during the working shift. Fifteen percent of fire-fighters have a residual feeling of overstrain and fatigue until the beginning of the next shift (Maryin, 1992; Maryin et al., 1992).

An intensive experience of job-related stress has a negative impact on the fire-fighters' health. This objectively manifests itself in a high sick rate and a wide spectrum of health disorders among these professionals. It directly correlates with such parameters as length of service and job complexity (Alexandrovsky et al., 1991; Maryin & Sobolev, 1990). Different forms of behavioral and social dysadaptation as well as mental health deterioration have to be mentioned as the greatest danger to reliable job performance (Maryin et al., 1992). These disorders range from short-term behavioral deviations (impulsive actions, affective reactions, stupor, etc.) and borderline states (chronic fatigue, asthenic syndrome, "frozen" states) to clinical norms of mental diseases, mainly depression and reactive psychosis (see Alexandrovsky et al., 1991).

An example of the negative impacts on fire-fighters' mental health depending on different types of fire-fighting jobs is presented in Table 7.4. The data were collected during a regular medico-psychological screening of fire-fighter brigades just after the resolution of fire accidents (Maryin et al., 1992). The personnel of two brigades were observed: (1) fire-fighters who systematically participated in large-scale accidents (n=53); and (2) fire-fighters who usually participated in "ordinary" fires (n=40). The findings demonstrate a really menacing tendency in both groups, especially in Group 1. More than 90% had mental health problems, 66% of which could be qualified as a malady that ought to be under medical or psychotherapeutic control. The level of this contingent's reliability is more than problematic.

A subjective representation of dominant work attitudes and job difficulties was investigated in a special survey. The survey comprised the following groups of questions: (a) work motivation, (b) job satisfaction/dissatisfaction, (c) subjective experience of negative moods and HFS, (d) attitudes of families and friends to fire-fighters' work in the Chernobyl Zone.

Table 7.4. Mental health deterioration according to the type of fire-fighting jobs

Type of fire-fighting jobs	*Rates of mental deterioration (in %)*			
	Behavior accentuation, borderline states	*Neurotic reactions, psychosomatic disorders*	*Clinical forms of mental diseases*	*Total*
Large-scale accidents (n=53)	28.3	52.8	13.2	94.5
"Ordinary" fires (n=40)	22.5	15.1	2.5	40.1

The data were collected from 1990-1992 among the personnel of fire-fighting squads who systematically worked in the Chernobyl Zone over the three years. Ninety-three male subjects, professional fire-fighters with 2 to 10 years of service, participated in the study. The main results of the survey are summarized below:

(1) *Work motivation*. Almost all respondents (97%) indicated that they had a high personal involvement in the job. It should be mentioned that only 22% of the sample were volunteers. The others were sent to the Zone under orders. Nevertheless, all respondents agreed about the necessity and high social value of their job.

(2) *Job satisfaction/dissatisfaction*. 70% of the subjects noted that, in general, they were satisfied with their job, especially from the point of view of its great importance and the obvious "usefulness" of the results. Among the main causes of job dissatisfaction were mentioned:
   (a) high risks and difficult work conditions: unpredictability of work situations - 52%; intensive ionizing radiation - 45%; high work pressure and time limits - 34%; danger of explosions - 31%; long working shifts - 24%;
   (b) negative social and psychological factors: the necessity of living apart from the family - 59%; social isolation - 43%; low or inadequate material remuneration - 28%; low level of social protection - 18%.

(3) *Subjective experience of negative moods and HFS*. In the total sample of subjects, 72% had constant feelings of subjective discomfort during their work in the Zone. Among the most typical negative symptoms they mentioned: feelings of high anxiety - 69%; feelings of permanent threat - 53%; symptoms of unremitting fatigue - 45%; high emotional strain - 41%.

(4) *Attitudes of family and friends*. Approximately 50% of the sample noticed that they had serious family problems due to their work in the Zone (the number of divorces among the personnel doubled during the period under

consideration); 43% had little contact with friends and relatives; 37% had problems with alcohol consumption, or manifested social disintegration in other ways.

The results obtained suggest that the heightened level of job demands, both physical and psychological, is reflected adequately in subjective appraisals of the work situation. Also, despite the conflicting structure of job attitudes, the majority of fire-fighters named the dominant motivation as "work at any price". In this case, the direct and most common way to cope with difficulties consists in the extreme mobilization of psychophysiological resources that helps to maintain performance at a fairly high level (Hockey, 1993; Medvedev, 1982). The answer to the question "How close are the effects of such mobilization to the limits of human capacities?" was the purpose of the subsequent experimental study.

7.2.2. HFS Dynamics During a Working Shift in the Chernobyl Zone

The first part of the experimental study deals with evaluation of HFS changes during a regular working shift in the Chernobyl Zone. The data were collected from 1992-1993, more than five years after the accident. By this time the work of special fire-fighting teams became relatively "routine": the inspection of the territory of the Station (especially near the notorious Block 4), the detection of flare-ups and pollution, and the elimination of these hazardous events. Still, the danger of radioactive contamination, as well as the effects of other job-related stressors, remained at a high level.

A group of 25 fire-fighters systematically participated in the study. All subjects were tested twice - at the beginning (8.00 - 8.30 a.m.) and at the end (8.00 - 8.30 p.m.) of the shift, by a set of assessment methods. The diagnostic set consisted of several standard tests frequently used in Russian applied studies (see Chapter 6):

(1) physiological measurements: heart rate; blood pressure; EKG parameters; electrodermal response parameters;

(2) subjective tests for evaluating actual well-being and emotions: the multiple well-being scale; the projective Luscher Color Test;

(3) performance tests: sensory-motor coordination and dynamometry.

A list of concrete measures and indicators is presented in Table 7.5. The significance of changes between two diagnostic cuts was evaluated by the Student t-test, separately for each single indicator. The results of statistical analysis and their interpretation are also presented in Table 7.5.

The negative dynamics in the subjects' states during the shift is clearly manifested for the majority of HFS indicators. Significant changes in *physiological indicators* indicate the symptoms of intensive energetic overstrain and imbalance in the vegetative regulation system, depicted by the effects of increasing parasympathetic activation (strong increase of heart rate and diastolic blood pressure, disintegration of EKG parameters, raising of skin resistance level).

Table 7.5. Changes in HFS indicators from the beginning to the end of the fire-fighters' working shifts
(by Student t-criteria, n=25; significance levels: ** $p < .01$; * $p < .05$)

Methods/ measures	*Indicators*	*Beginning of the shift mean (s)*	*End of the shift mean (s)*	*t-value*	*Interpretation*
Heart rate	Pulse (beats per min.)	68.5 (8.9)	87.0 (13.3)	5.5**	negative strong increase
Blood pressure	Systolic (mm Hg)	120.2 (11.1)	122.0 (10.5)	.54	no changes
	Diastolic (mm Hg)	75.8 (7.8)	83.9 (8.9)	3.81**	negative strong increase
EKG	P -interval amplitude	2.1 (.5)	1.8 (.8)	2.2*	negative decrease
	T -interval amplitude	4.9 (1.5)	5.7 (1.2)	3.83**	negative strong increase
	Vago-symphathetic coefficient	42.8 (10.9)	31.6 (14.0)	3.99**	negative strong decrease
Electrodermal response	Skin potential amplitude (mV)	34.2 (16.4)	34.5 (16.8)	.06	no changes
	Skin resistance level (K/Ohm)	3.2 (1.1)	4.4 (.9)	2.3*	negative increase
Well-being scale	Subjective comfort (subjective scores)	5.6 (1.1)	4.1 (1.2)	3.72**	negative strong decrease
	Activity (subjective scores)	4.8 (1.2)	4.1 (1.3)	2.40*	negative decrease
	Mood (subjective scores)	4.8 (1.1)	4.4 (1.1)	2.53*	negative decrease
Luscher color test	Anxiety/ depression aggravation index	14.6 (6.6)	18.5 (6.9)	2.54*	negative increase
	Emotional mobility index	10.6 (3.7)	13.1 (4.1)	1.18	no changes
Dynamometry	Muscular strength in right hand (kg)	52.9 (10.8)	53.4 (9.4)	.27	no changes
Simple sensory-motor reaction	Reaction time (msec)	315 (92)	361 (82)	2.33*	negative increase

Negative tendencies in the *subjective self-estimation* of experienced mental states are manifested by: (1) an intense decrease of subjective comfort and reduction of the general intention to act, and (2) a growth of emotional tension, represented by high anxiety and depression indices. In *performance characteristics* the negative change consists in a decreased performance speed as shown by a longer reaction time in the sensory-motor test.

In a more general way, the described negative dynamics can be demonstrated by the differences in integrative HFS patterns at the beginning and at the end of the shift (see Figure 7.2). The data integration procedure was based on transformations of raw scores of single indicators into relative scores[2], and after that into standard z-scores. Then, the intergrative z-score's coefficients for each group of indicators were computed by linear regression analysis. It should be mentioned that the coefficients below -2.5 correspond to a range of inadmissible values of HFS indicators, risky for mental and physical health. The data show that integrative scores of physiological and subjective indicators exceed this limit of normal psychophysiological functioning.

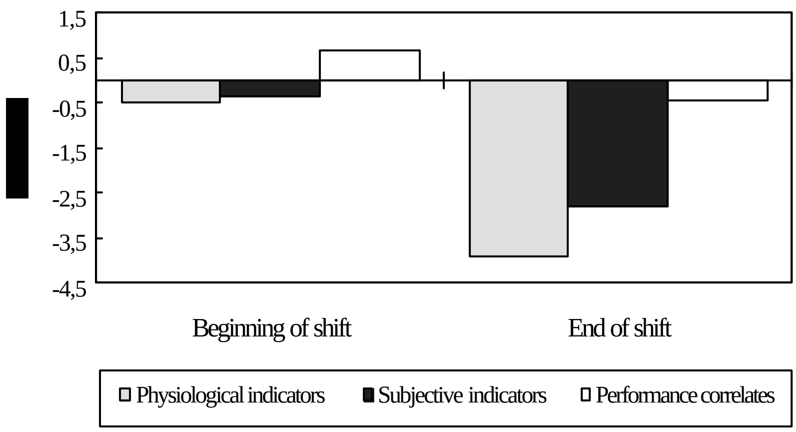

Figure 7.2. Integrative patterns of HFS indicators at the beginning and at the end of the fire-fighters' work shifts.

Qualitative characteristics of observed HFS at the beginning and end of the shift were obtained on the basis of the results of factor analysis processed by the method of principal components with varimax rotation. Although in both cases the obtained

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[2] A relative score for each indicator is calculated using the formula [(Xi - Xbg)/(Xmax -Xbg)], where Xi is the current indicator value, Xbg - the "background" indicator value, i.e. the sample norm in a neutral situation, and Xmax - the maximal positive indicator value (see Leonova, 1994).

factor solutions consisted of three main factors, their component structures were quite different.

At the beginning of the shift the factor structure of HFS indicators could be described as follows[3]:

- Factor 1 (24.4% of variance) - “emotional mobility and performance activization” (emotional mobility index (.503); reaction time (.468); depression/anxiety index (-.416));
- Factor 2 (16.2% of variance) - “subjective involvement in job” (self-estimations of mood (.589); activity (.554); subjective comfort (.437));
- Factor 3 (12.7% of variance) - “intensive energetic mobilization” (P-R interval amplitude (.568); heart rate (.523); vago-sympathetic coefficient (.464).

This factor structure corresponds to *the state of high alertness* with intense components of emotional and physiological mobilization.

At the end of the shift the content of the factor structure radically changed:

- Factor 1 (19.3% variance) - “subjective exhaustion and fatigue” (subjective discomfort (.621); lowered mood (.519); increased reaction time (.467);
- Factor 2 (16.1% variance) - “physiological exhaustion and imbalance” (P-R interval (-.565); diastolic blood pressure (.531); systolic blood pressure (.472);
- Factor 3 (14.2% total dispersion) - “dominance of inhibitory processes and emotional tension” (vago-sympathetic coefficient (.573); anxiety/depression index (.499); skin resistance level (.447).

By this factor structure *a state of deep physical and mental exhaustion* can be identified. It correlates with the stage of complete activity disorganization (Gaillard & Wientjes, 1994; Leonova, 1984; Simonson & Weiser, 1976).

Radical HFS changes from high level of alertness to deep exhaustion during one working cycle is an everyday experience for fire-fighters at the Chernobyl Zone. Both acute negative effects (a high degree of fatigue, intensive physiological and emotional tensions) and their accumulation over time are genuinely dangerous to work efficiency. As the considered data suggest, the deep involvement of cardiovascular parameters in the process of activity regulation induces the development of psychosomatic disorders. Strong emotional tension and the development of a variety of physical and mental health deterioration processes seems to be a natural result of this job even in relatively “routine” work situations (Alexandrovsky et al., 1991; Reshetnikov et al., 1990).

[3] Here and below, the description of each factor includes the three most loading diagnostic indicators.

7.2.3. The Development of Stress Reactions in Extreme Job Situations

The second part of the experimental study analyzed the development of negative stress reactions when the same occupational group had to work in an extreme situation. This was carried out during the handling of recurrent emergencies at the Chernobyl Nuclear Plant in October 1991.

The use of instrumental assessment methods was limited in this case for objective reasons. Therefore, the data were collected using the checklist elaborated for evaluation of stress-related reactions typical for different fire-fighting jobs (Maryin & Lovchan, 1993). The checklist includes three groups of symptoms: (a) physiological, mainly vegetative, reactions (e.g., dizziness, thirst, headaches, tachycardia); (b) moods and emotions (e.g., agitation, anxiety, irritation, fear of radiation); (c) behavioral symptoms (unwillingness to work alone, automatism in actions, careless behavior, disintegration of skills). In general it consists of 26 symptoms which characterize the variety of stress-related reactions.

A team of 30 fire-fighters working at the place of the accident participated in the study. All of them completed the checklist three times during the extreme shift: (1) just *before* the beginning of work, the "initial stage"; (2) in a short break *during* their work (after 4-5 hours of work), the "execution stage"; and (3) 1-1.5 hours *after* the work was completed, the "recreation stage". The dynamics of stress experience intensity over the shift and the differences in the types of stress reactions were analyzed (see Figure 7.3).

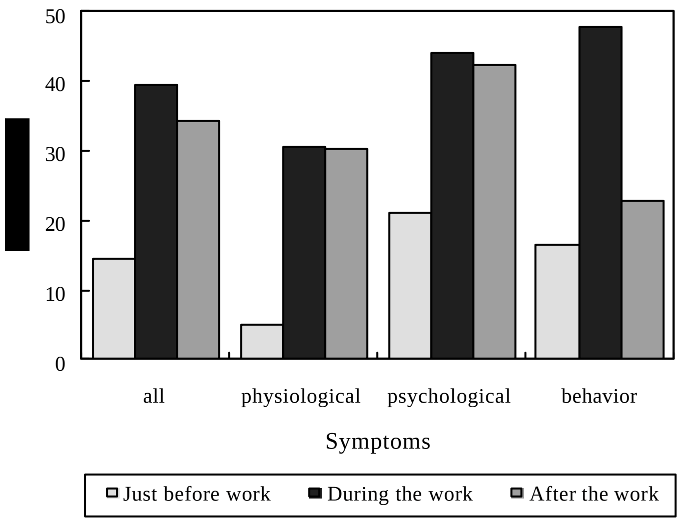

Figure 7.3. Dynamics of stress-related symptoms at different stages of extraordinary fire-fighting shifts.

In general, a strong increase of negative stress feelings during the work shift was observed for all groups of symptoms. The dynamics are characterized by an abrupt and highly significant growth of the number of mentioned symptoms (two-three times) from the "initial" to the "execution" stages of the work. Except for the group of behavioral symptoms, the high level of stress manifestation did not significantly change after the work. This corresponds to the high intensity of subjectively experienced stress reactions even at the "recreation stage".

In the dynamics of particular symptoms two types of stress syndromes can be differentiated. Some of the symptoms arise just before the outset of the work and increase at the stage of execution. Soon after the end of the work almost all these symptoms weaken or disappear. Other symptoms become more pronounced or remain at the same high level. Accordingly, the types of stress syndromes could be qualified as (a) *acute stress* which includes reactions to actual situational demands, and (b) *post stress* which is represented by delayed reactions and residual effects (see Table 7.6). It should be emphasized that almost all symptoms that are most representative for the described stress syndromes are different. Only the symptoms of "fear of radiation" and "careless behavior" were observed in both cases.

Table 7.6. Subjective manifestations of the acute stress and post stress syndromes

Stress syndromes	*Most common symptoms*		
	Physiological	*Psychological*	*Behavioral*
Acute stress (just before and during the work)	Thirst Parched mouth Tachycardia Trembling	Agitation Emotional tension Anxiety Fear of radiation	Unwillingness to work alone Automatic acting Careless behavior
Post stress (after the work completion)	Buzzing in the head Headaches Nausea	Fatigue Fear of radiation Depressed mood General weakness	Disintegration of motor skills Careless behavior Loss of control

Interesting data about relationships between stress experience intensity and individual job motivation levels were also demonstrated. Four grades were identified in the strength of experiencing stress syndromes: strong, moderate, light, and absent. Alongside, using the method of expert evaluations the sample of observed fire-fighters was divided into two groups - with a high and a low level of motivation to work in the Chernobyl Zone. The data presented in Table 7.7 show that stress intensity is different in the groups with a high and a low job motivation. Highly motivated subjects displayed more intense stress reactions: 100% gave subjective estimates of stress corresponding to strong and moderate intensity, both for acute and post stress syndromes. The picture is not the same in the group of lowly motivated subjects: 45% of them indicated a light degree or the absence of acute stress syndrome, and 20% - a light degree or the absence of post stress syndrome. The greater intensity of stress experience in highly motivated vs. lowly motivated groups is statistically significant, and the difference is especially strong in the case of acute stress syndrome.

These findings show the paradoxical effect of high job motivation on stress resistance. Those workers who had a stronger individual orientation to perform the job well were more affected by negative stress factors. Consequently, the influence of job-related risk factors on their reliability could be greater than in the group of more indifferent workers. It may be a result of the aggravating conflict between basic safety motives and a deep personal involvement in the work.

Table 7.7. Intensity of stress experience depending on the job motivation of fire-fighters in the Chernobyl Zone

Stress syndromes	*Level of stress experience*	*Number of fire-fighters*		*c^2 (df = 3)*
		Highly motivated	*Lowly motivated*	
Acute stress	Strong	7	4	
	Moderate	11	2	13.29
	Light	-	2	p<.01
	Total	18 (100%)	8 (66%)	
Post stress	Strong	10	3	
	Moderate	8	5	7.86
	Light	-	3	p<.05
	Total	18 (100%)	11 (93%)	

7.2.4. A Transactional Model of Fire-Fighters' Stress

A fire-fighting job as work *in fire* and *against fire* is hard and risky by its nature. The variety of extraordinary work conditions and intensive job demands constitute a body of risk factors affecting reliable job performance. Each of these factors taken separately can be viewed as a potential danger or a serious obstacle to work activity. But the problem of human reliability in fire-fighting jobs cannot be reduced to enumerating and summarizing the effects of these factors. The principal point is that the job performance of fire-fighters has to be highly productive and errorless. This strongly conflicts with the highly demanding work situations, producing an additional set of risk factors, such as enormous expenditure of psychophysiological resources, strong motivational conflicts, behavioral deviations, social dysadaptation, and disorders in mental and physical health.

As the data presented above demonstrate, the personnel of fire-fighting teams experienced high level of stress and other negative HFS during all periods of their work in the Chernobyl Zone. In the light of the contemporary approaches to occupational stress (Cox & Fergusson, 1994; Leonova, 1998) different types of stress responses have become the most important intermediate variable that defines the specificity of potential risk factors upon human reliability. To analyze such influences in fire-fighting, the transactional stress model by Cox was used (Cox & Mackay, 1981). A modification of this model is presented in Figure 7.4.

The basic components of the model are represented by descriptions of (a) job demands; (b) situational or environmental demands; (c) the level of activated human resources; and (d) individual motives and values. Each block of the model lists the most important demands and constraints that were identified on the basis of empirical results. The conflicting nature of the fire-fighting job is displayed by an *imbalance* in-between almost all factors demanded and resources available for their realization. For instance, the requirements of high quality and the "taboo" of errors are in conflict with the urgency of work, scarcity of time, and unpredictability of the situations (the block of job demands). The extraordinary mobilization of physiological and mental capacities (the block of activated human resources) conflicts with the need to maintain a high level of resource activation during long periods. The block of situational demands consists of extremely dramatic characteristics that are often opposite to human survival norms. This leads to insoluble conflicts in the motivational block: deep involvement in work is almost incompatible with the maintenance of individual safety.

The conflict nature of the job is clearly displayed in subjective appraisals of work situations. Results of the job attitudes survey (see Section 7.2.1) show that the main job objectives and constraints are perceived adequately by fire-fighters. This helps to maintain job performance at an adequate level but cannot reduce objective difficulties. At the same time, the potential dangers of situations are also reflected. Therefore, subjective appraisals are represented by two opposite groups of feelings: (1) job-oriented attitudes and emotions, i.e., high responsibility, personal involvement in the job, dominance of goal-achievement orientations; and (2) anticipation of vital dangers, such as "evil radiation", anxiety, awareness, and fears. A permanent contradiction between them gives rise to intense stress responses. It results in specific forms of behavioral, mental and health deterioration, which may deeply impair human reliability.

Both the intensity of stress experience and the impossibility of softening the conflict nature of the job emphasize the importance of different stress management tools in the occupational group considered. The traditional methods of increasing of human reliability, such as procedures of personnel selection, professional training, optimization of work-rest schedules, etc., are widely employed in this profession,

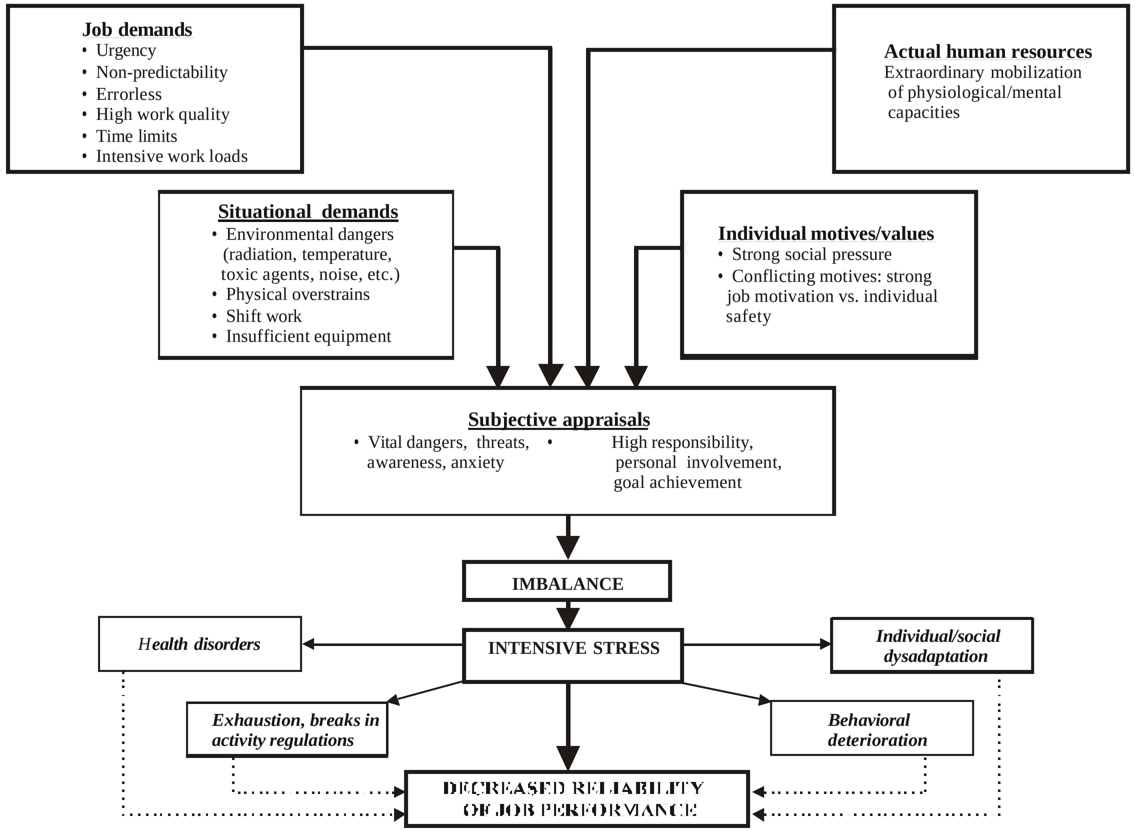

Figure 7.4. General model of risk factors for human reability in fire-fighting jobs.

but they are not sufficient for solving the problem as a whole (Maryin, 1996; Reshetnikov et al., 1990). Specialized self-regulation training programs could be also of great value (see Section 6.3). The application of these techniques in several empirical studies shows that this approach is extremely promising (Maryin, 1996; Maryin & Lovchan, 1993).

CHAPTER 8

PSYCHOLOGICAL SUPPORT OF WORK SAFETY AND LABOR PROTECTION

A. KUZNETSOVA, M. KAPITSA, I. BLINNIKOVA,
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8.1. WORK SAFETY AND LABOR PROTECTION SERVICES: LEGAL BASIS AND ORGANIZATIONAL STRUCTURE

The state labor safety system, established in the Soviet Union over 70 years, developed strict control over all enterprises in the country, from industrial giants to boiler houses, gas stations, universities, hospitals, museums, schools, etc. This system was based on national labor safety laws and spread from the so-called state committees and industrial ministries to enterprises and their branches. The general principles of the work safety system were contained in the "Foundations of the Labor Laws of the USSR and the Soviet Republics" and were approved by the Supreme Soviet, the country's parliament, in 1970 (Dvornikov, Livshits & Rumyantseva, 1971).

Responsibility for the execution of this basic law was placed with the State Labor Committee at the Soviet Government and the All-Union Trade Union Central Council. The principles of the law were specified in national and branch labor safety standards, general and branch labor safety rules, and sanitary and hygienic norms, which regulated work safety. The elaboration of these standards and rules was carried out by two research institutes: the All-Union Central Research Institute for Work Safety (under the All-Union Trade Union Central Council) and the Institute for Labor Protection and Occupational Diseases at the Academy of Medical Sciences.

Enterprises were obliged to introduce all necessary labor protection measures. In order to fulfill this task, each enterprise had a labor protection or work safety department. Their staff members were mostly engineers or technicians. They were responsible for elaborating and observing the technical requirements, as well as for instructing and training workers in work safety.

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

The concept of work safety was one of the declared principles of the communist paradigm. Official Soviet ideology emphasized the care lavished on the people of the Soviet Union as opposed to the exploitation of workers in the capitalist countries. Therefore, officials did a lot to control work safety issues. Top managers of plants, factories and power stations were personally responsible for observing work safety rules and ensuring the safety of their enterprises. After any serious accident, particularly if there was a death involved, the manager, shop superintendents and sometimes even the local party leader could be fired or penalized. A punishment followed even if inspectors detected shortcomings in the observation of labor protection rules. That is why managers of all levels feared these inspectors like death itself.

It would seem that this strict state organizational system could have ensured effective and safe functioning for all enterprises. But numerous accidents and disasters demonstrated its vulnerability. At the end of the 1980s, industry became more complex and the weakness of centralized management became obvious. The Chernobyl tragedy exposed this problem to the whole world.

The disintegration of the Soviet Union in 1991 was followed by radical economic and political changes in Russia, which led to the collapse of the state labor protection system. The Soviet trade unions lost their influence and government financial support for work safety programs was radically reduced. Enterprises found themselves face to face with work safety tasks, but they could not handle them without legal, financial and organizational support. Work conditions and labor protection during that time in Russia started to deteriorate and were not taken seriously by the officials who had previously been in charge of this matter. As a result, the number of industrial accidents and occupational diseases increased (Krylov, 1999).

To improve this situation the Government of the Russian Federation took certain steps. In 1994 President Yeltsin signed the Decree on State Supervision and Control of the Observance of Labor and Labor Protection Legislation of the Russian Federation, which set up the State Labor Inspection Agency as the chief institution in this field. This decree gave impetus to the elaboration of normative legal acts containing general labor protection requirements. But these measures were not effective enough. One of the weak spots was their failure to consider the new economic and labor relations: nothing obliged managers and owners of private enterprises to follow labor protection requirements.

In 1997, in view of the new economic realities the RF Government approved the Federal Program for the Improvement of Labor Conditions and Protection. This document confirmed that work safety remains extremely important for the Russian authorities. It formed the new legal base and determined the organizational structure of labor protection regulation. The top of this organizational structure was occupied by the Ministry of Labor and Social Development, the All-Russia Center for Labor Protection and Work Efficiency and the Joint Labor Protection Committee. They were instructed to implement the Program. In the lower level interdepartmental and branch documents, standards and sanitary rules and norms were to be developed. This work was under the authority of ministries and local governments. Enterprises, institutions and organizations at their level were to draft and approve concrete rules and instructions for particular types of work. Workers and trade unions obtained the right to participate in the drafting and coordination of normative legal acts on labor protection. The Federal Program determined the mechanisms of state control over labor protection. These mechanisms include obligatory regular registration of all enterprises and official examination of technical equipment and work conditions. The government also undertakes to implement educational programs in work safety and training in labor protection management.

An essential task of the Federal Program is to ensure the safe functioning of enterprises having a high probability of industrial or ecological accidents. The legal base for solving this task is the Federal Law “On Industrial Safety of Highly Hazardous Industrial Facilities” adopted by the Russian Parliament in 1997. It defined the legal, economic and social basis for the safe running of hazardous industrial facilities and the powers of their top managers in localizing and eradicating the consequences of accidents.

The Law contains a list of different categories of hazardous facilities and defines such concepts as industrial safety (the protection of the vital needs of personnel and society from accidents); accident (the destruction of structures or uncontrolled explosion of exhaust or poisonous substances); incident (the failure or damage of technical installations, a deviation from the normal technological process, or violation of labor protection legal laws and technical requirements). The Law determines the safety requirements set on technical equipment and conditions of work, as well as the general approach to personnel management in highly hazardous plants. It also defines the procedure of accident investigation. This procedure includes both the analysis of technical conditions and personnel behavior which could have caused the accident.

The organization of the safety service in the gas and oil industry is a good example of effective application of the new approach to work safety. The Department of Inspectors in the gas and oil industry has elaborated a guide for the process of safety management and risk analysis at highly hazardous industrial plants (Rukovodstvo po analizu riska na opasnykh promyshlennykh predpriyatiyakh, 1996). In the guide one can find definitions of a hazard (a source of potential damage or a situation which generates a possibility of damage), risk (the combination of the probability and consequences of a certain dangerous event), quantitative indices or types of risk, individual risk (the probability of loss of life or less serious injury to workers as a result of the impact of hazardous factors), collective risk (the expected number of mortally wounded persons in possible accidents), potential territorial risk (the spatial distribution of the probability of a certain negative effect), social risk (the probability of damage to the social and natural environment). The guide describes the main procedures, goals and methods of the risk analysis, and contains recommendations for planning and organizing risk analysis, hazard identification and minimizing risks.

In the Soviet Union the state system of work safety was formal and forced upon lower-level organizations. It was perceived by workers and managers not as caring for people and their health, but as an additional strict requirement, and caused constant resistance. At present in Russia the situation has radically changed. People feel unprotected in the new economic situation and try to provide for their safety. The government is trying to find a way to regulate work safety in these new conditions. The conceptual approach to work safety has also changed: it implies not only the technical functioning of enterprises, but also a complex model of a worker - his/her motives, attitudes, goals, skills, knowledge and states. This approach is reflected in laws, where such tasks as personnel selection, professional training and control over HFS are defined.

8.2. THE ROLE OF PSYCHOLOGISTS IN WORK SAFETY SYSTEM

Up to the 1980s psychologists did not actively work in labor protection departments. But on the whole their impact on solving the tasks of work safety was significant. It was mainly connected with such issues of human reliability as personnel selection, the training of psychologically important qualities, the elaboration of ergonomic requirements and control over the HFS.

Traditionally psychologists participate in the *selection* of applicants for specialized colleges and schools (military, flying and air traffic control schools), as well as candidates for work in highly demanding conditions such as in aeronautics, polar expeditions and other occupations where unique human qualities and high compatibility are needed. Detailed selection methods of psychological assessment and diagnostics have been elaborated (Bondarev, Diakonov & Zagriadsky, 1981). By the beginning of the 1980s these methods were standardized and from that time the opinion of psychologists was considered very seriously (Bodrov, 1985).

In flying schools four different types of personnel selection are used: medical, educational, social and psychological. Psychological selection comprises group and individual assessment by qualified specialists with the help of standard and verified tools and procedures (Korchemny, 1986). Psychophysiological indices, cognitive abilities, the peculiarities of emotional reactions and motivation to flight work are tested. The results of the testing are kept secret from the applicants and are passed on to a competent commission. Conclusions made by psychologists are often crucial for the future of applicants: those who get the highest grades in psychological tests are admitted *hors concours*, and those who fail in psychological tests are not admitted at all.

Another sphere of the application of psychological knowledge in the work safety domain is *professional training and education*. Psychologists are involved in the process of professional training at simulators, which are widely used in flying and air traffic control schools. Simulators enable psychologists to create models of real activity and to provide practice in psychologically important qualities (Altukhov, 1977). They also make it possible to evaluate the level of professional skill (Isakov, 1981).

Russian flying schools use a special system of "psychological monitoring" of students. It includes a wide range of regular social, psychological and psychophysiological assessment and psychological counseling of students. Psychological monitoring starts with the analysis of the results of psychological selection of applicants. After this a more profound investigation of personality characteristics begins. These measures are designed to enhance academic results and the efficiency of future professional activity. Psychologists try to predict the potential capacities of each student and their behavior in regular and abnormal or crucial situations. This prognosis forms the basis of an individual training program. Psychologists also take part in the formation of crews, trying to provide optimal social compatibility and psychological climate, which increases the efficiency of training and the students' resistance to flight difficulties. Special psychological support is available to those students who cannot easily adapt to the requirements of military training and service. This support consists in social-psychological training, counseling, psychophysiological correction, group and individual psychotherapy, and training in self-regulation (Ponomarenko & Vorona, 1992).

The principle of psychological monitoring is used not only in education but also in control over various professional activities. It consists of regular *assessment and correction of the HFS* and has been carried out on space stations (Beregovoi, 1974), warships (Butov et al., 1984), nuclear power stations (Dyakov, 1993) and in "more civilian" occupations (see Chapter 6 and Section 8.3.1).

Psychological knowledge is widely used in *ergonomic design*. Ergonomists and engineering psychologists have done much to adjust complicated technical devices and installations to human parameters (Zinchenko & Munipov, 1979). Their main contribution in this field is connected with the elaboration of psychophysiological, psychological and social-psychological standards. In the beginning, these standards defined the demands set on technical devices and work places, which had to correspond to sensory, motor and energetic human parameters (psychophysiological standards), as well as to the characteristics of cognitive processes and the development of professional skills and work efficiency rhythms (psychological standards). Later ergonomic standards began to take into consideration variations of human behavior in different work conditions and HFS. They also identified optimal conditions for group work (social-psychological standards).

In the 1970s psychological research in ergonomics was devoted mostly to the optimization of information displays. These studies examined different features of visual information: physical parameters such as brightness, visual contrast, size, critical frequency of flicker, shape and color, spatial and temporal characteristics, and quantitative parameters (Velichkovsky & Kapitsa, 1980). On the basis of the data obtained, in-depth recommendations on the coding of information on displays and visual indicators were elaborated. Particular attention was paid to signals used in emergency situations. The tradition of these experiments was continued in modern research connected with the development of user-friendly interfaces (see Section 8.4.3).

Gradually the tasks suggested to psychologists at enterprises became more complicated and extended to a broader range of industrial activities. Psychologists participated in accident analysis, evaluation of potential risk and prediction of human behavior in emergency situations. At the end of the 1970s this led to the establishment of the official structure of psychological services in Russia. Psychological services had to cover different human aspects and levels of the functioning of enterprises. Such a complicated and diverse task demanded special training for the professionals working in psychological services. At the beginning of the 1980s the Moscow State University Department of Psychology proposed a special program for psychologists working in industry, which included combined training in ergonomics, work and social psychology.

In 1995 the RF Government decided to set up the Commission and the Research Center for Occupational Counseling and Psychological Support. This center supervises research in applied psychology and drafts official documents which regulate the work of psychologists at enterprises and define their rights, obligations and tasks. In a very short period psychological services were organized at ministries, banks, large companies, schools, enterprises, etc. Psychological services at enterprises have to solve a wide range of tasks, which can be divided into three modes. The first mode is analytical. It includes job analysis, investigation of factors influencing the effectiveness of human activity, causal analysis of the violation of work safety regulations, discipline and labor fluidity. The next mode is practical. It consists of personnel selection, psychological monitoring of professional activity (assessment and control of the HFS of workers) and professional training. The third mode includes recommendations for the optimization of work processes, personnel management and social climate in work groups.

Within the framework of labor protection and psychological support of people who are engaged in high-risk and hazardous work, it would be interesting to examine the organization of psychological services in the Air Force, the Ministry for Emergency Situations and the State Customs Committee.

The psychological service in the Air Force of Russia is one of the oldest and most diversified systems with branches at flying schools, air regiments, Air Force headquarters and test-flight institutes. This service has the most elaborate structure and regulations, and a large staff of psychologists. It extends to all main directions of psychological work such as professional consulting, selection, training, psychological support, personnel management and HFS management, analysis of errors and flight accidents, and ergonomic analysis of aircraft.

Psychologists face different tasks depending on the aspect of the pilots' work and training. At flying schools they are mainly engaged in the selection and educational training of would-be pilots. At this level psychologists take into consideration the human qualities that are important for proficiency in a pilot's work and reaching the professional peak in this job. Work with experienced pilots in air regiments focuses the psychologists' attention on the issue of psychological reliability[1] and the qualities which underlie it. Recent research has defined these qualities and elaborated special instruments for their selection and cultivation (Firsov, 1996). It was shown that reliability includes several components, which can be divided into six groups on the basis of factor analysis.

The first factor is connected with flight experience (age, length of active service, total number of flight hours and types of aircraft mastered by a pilot). This factor is important at the stage of selection. The second factor – the factor of high professional level - includes the ability to work in non-standard situations and to mobilize internal resources. This factor cannot be formalized and cannot, therefore, be predicted at the early stages of training. The third factor is emotional stability. As opposed to the previous one, it can be diagnosed and used in psychological examination. The fourth factor is professional motivation: being a very important quality, it is of special interest for psychologists at the stage of expertise and individual counseling. The last two factors – the stability of cognitive functions and self-regulation skills - often become objects of psychological training. Besides individual psychological reliability, it is also possible to analyze and train group reliability. To deal with this task psychologists have to work with crews and pay attention to the process of interaction between them and air-traffic control services (Kluev et al., 1997). These measures make it possible to raise work efficiency and resistance to negative work conditions, stress and hazard in pilots.

In the field of test flights the issues of reliability of pilots and crews are closely connected with ergonomic analysis of new aircraft. At the Air Force headquarters psychologists are mainly engaged in the analysis of flight accidents and the elaboration and implementation of psychological recommendations that provide a high flight safety level. The structure of the psychological service in the Air Force is often used as an example for organization of psychological services in other fields of human activity.

The psychological service at the Ministry for Emergency Situations was officially established in 1995. Two federal laws, "On Rescue and Life-Saving Services and the Status of Rescuers" and "On the Protection of Residents and Territories in Emergency Situations Caused by Natural or Technological Factors" formed the legal base for the functioning of the Ministry for Emergency Situations and the All-Russian Center for Disaster and Emergency Medicine. This medical center has a laboratory of psychophysiological support, which has branches in many regions of Russia.

From the very beginning the psychological service of the Ministry for Emergency Situations has been working very intensively and productively. It has

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[1] Psychological reliability is defined as a complex structure of individual psychological abilities that is actualized in order to support the efficient execution/regulation of work activity depending on the specific professional demands and requirements (Firsov, 1996).

assimilated methods and approaches used in the psychological support of fire-fighters. The psychological characteristics of the work of rescuers are very similar to the work of fire-fighters. Both activities involve intensive physical loads and a high level of psycho-emotional stress, which result in various abnormalities in mental health and social adaptation and determine the main directions in psychological work in this field. Psychophysiological selection for work in rescue crews is not crucial for the applicants; psychologists can only give some recommendations. Much more important is regular assessment of the rescuers, which helps provide an early diagnosis of psychological troubles. Of primary significance in this work is functional rehabilitation of those who have already participated in the handling of emergency situations. It includes self-regulation training of rescuers.

In 1997 a psychological service was organized within the framework of the RF State Customs Committee. The work of customs officials has become complicated and even dangerous: the borders of Russia and some former Soviet republics are still quite transparent and have become an easy route for illegal drug and arms traffic. Customs officials have to possess special skills and abilities, which are difficult to formalize, including intuition, attentiveness and skills of deep personality analysis. They often suffer from a shortage of time and pressure from clients. An exhaustive job analysis of this occupation does not exist. This task is still a focus of attention of psychologists. Fulfilling it would help provide effective professional training and selection.

The state work safety system in Russia has a long and rich history. Although it has been in development for over seventy years, the last decade has seen a crucial turning point. Recent socio-economic changes in the country have weakened the overall work safety system and necessitate new mechanisms of state regulation of labor protection. During this transition period, Russian society has developed a feeling of subjective instability and a pervasive lack of safety. In this situation, workers and lower-level managers are changing their attitudes towards the observance of labor protection regulations leading to a radical increase of work safety motivation among them.

In response to growing demand for safety, psychologists have elaborated support methods for use during work which tend to be effective among a variety of professions. Among a broad range of practical tools and instruments, two relatively new trends in preventative practice are of special interest. The first trend grows out of the Russian invented HFS management. The second trend makes it possible to create computerized means for user support within the framework of Activity Theory.

8.3. HFS MANAGEMENT IN THE WORK SAFETY SYSTEM

8.3.1. Organizational Principles of HFS Management

For many decades in Russia and in some former Soviet republics an important part of the policy of error prevention in work-site settings was HFS control. Maintenance of the optimal HFS is one of the directions of prevention policy at the individual level (see Section 6.3). As is shown in Table 6.4, there are two principal ways to directly influence HFS: external recovery procedures and internal recovery procedures. Self-regulation techniques are classified as internal recovery means; their specificity lies in two main characteristics: first, the subject's active conscious participation in managing his/her own state and, second, the development of so-called internal (mental) HFS regulation skills.

Internal regulation skills are widely presented in the psychological structure of all human beings, otherwise one would not be able to maintain one's existence in the world. A new point in self-regulation training with respect to HFS management in work is the elaboration of special skills which may be developed and then used by the subject himself to manage his/her HFS in an optimal way. Understanding the optimal way implies such characteristics as high probability of reaching the required HFS level with respect to the work tasks, the limited time for the usage of HFS management procedures, full conscious understanding by a subject of the necessity and the targets of HFS management, and full conscious control of the techniques of HFS regulation.

Thus, the main goals of self-regulation training usually were as follows: higher work efficiency, normalization of workers' HFS, prophylactic treatment of work-related diseases, and fewer work errors. With respect to error prevention strategies, self-regulation training seems promising because of the possibility of preventing and/or reducing the errors which occur when non-optimal HFS starts to emerge (Dikaya & Semikin, 1991). The history of practical implementation of self-regulation is to a certain extent in accordance with the stages of work and engineering psychology expansion in our country (see Chapter 6).

Originally, HFS control and correction means were implemented in aviation and aerospace at the beginning of the 1960s. Self-regulation training, including mostly programs based on autogenic training and progressive (neuro-muscular) relaxation, was used as part of a pilot's professional training and also as part of different rehabilitation programs (Grimak & Khachaturiants, 1981; Marishchuk et al., 1969; Reshetnikov, 1978). The reasons for the introduction of self-regulation training in this field were both work specificity-related and financial. In aviation and aerospace, people usually do their work under extreme conditions and face emergency situations, and this makes it necessary to reach and maintain high work reliability and efficiency, because the "price" of work errors is too high. Also, government financial support was traditionally stronger here.

Some time later, self-regulation methods were extended to certain types of operator occupations, where a broad range of means of stress and fatigue reduction were traditionally used (Dikaya & Grimak, 1983; Grimak & Khachaturiants, 1981). Then the practical implementation of self-regulation spread to other fields where the ordinary working conditions are classified as extreme: the mining and fishing industries (Filatov, 1984; Golubov & Tabachnikov, 1980; Repin, 1973). In the early 1970s, self-regulation training programs were extended not only to occupations with extreme working conditions but also to other industries: metal-working, the manufacturing industry, microelectronics, etc. (Fedorov & Leonova, 1987; Margolin & Chukovich, 1983). From that time, self-regulation methods such as HFS management tools became quite common in many industrial companies.

The rapid practical implementation of self-regulation training could be explained by its double effect. First, it raises the level of HFS after each training session, so it is possible to eliminate the negative consequences of work tension. Second, self-regulation training helps a person to develop new internal habits that could be used where and when this seems to be necessary without any additional help from another person, either a psychologist or anyone else. So, after a complete course of self-regulation training a worker develops a relatively well-established habit of helping himself to cope with poor well-being, control emotional reactions at work, and prevent work fatigue.

Self-regulation training was conducted in work settings in different organizational forms. As was shown in Section 6.3.3, self-regulation skills are developed during special self-regulation training, so in all cases it was necessary to conduct training courses which consisted of several sessions. Self-regulation methods were implemented in two ways: at the stage of occupational training (for instance, in aviation), and directly in work conditions.

Organizational aspects of work in many enterprises made it possible to conduct self-regulation training courses not only before or after work shifts, but also in the course of work shifts during special breaks in the work process. This proved reasonable because of the specific feature of self-regulation training mentioned above: the positive effects on the HFS may be reached during each individual training session, so even primary training helps to reach the required HFS level.

From the middle of the 1970s HFS management programs in work settings were applied as a special organizational form - in so-called “relaxation premises” (RP). Relaxation premises are the places used for rest and self-regulation training during work shifts under the professional guidance of qualified psychologists, and specially equipped for the purpose of supporting the relaxation and self-regulation process. According to the publications, the first RP were opened in 1974 at a metallurgy plant in Odessa (Leonova & Kuznetsova, 1993). In the mid-1980s, the development of RP concentrated more and more on the idea that self-regulation training is an effective way of improving individual resistance to stress, to raise reliability, to maintain a high level of work efficiency, and to increase work satisfaction. In consequence, it was considered useful in protecting physical health and preventing mental disorders.

By the end of the 1980s the accumulated unique experience of practical implementation of psychoprophylactic means helped to transform RP into complex relaxation centers, which included a variety of premises to suit different purposes. Usually there were two main purposes: rest and improvement of recovery processes during work breaks supported by listening to music programs and/or watching relaxation slides and video films, and the development of habits of HFS management using self-regulation training. In addition such centers included fitness cabinets, rooms for reflexo-therapy, massage, etc. (Leonova & Kuznetsova, 1993; Margolin & Chukovich, 1983).

RP had different interior design concepts determined by their functional specificity. When the premises were used as resting places, the design was elaborated in order to stress the contrast between the working space and the resting space. This contrast is constituted by sound isolation, color schemes, and the range of accessories. For instance, it was quite popular to build fountains with colored lighting, to hang pictures and install colored dynamic panels on walls and ceilings, to put in plenty of plants and flowers, etc. For example, the RP at the Kishinev TV-assembly plant were designed as a picturesque grotto by the seaside. In those cases when the RP were used mainly as places to practice self-regulation skills, the design concept was different, because it was subordinated to the task of developing maximum concentration by the subjects on their own state without any distraction of attention. As was said above (see Section 6.3), self-regulation training requires full concentration of attention on the characteristics of one's state and on the dynamics of the state during training sessions. That is why colorful and unusual details in the RP could interfere with the training process, so the design was more restrained, there were not many striking accessories. The main achievements of psychological work on the basis of RP in work settings were showed at an exhibition of RP held in 1986 in the main Russian Exhibition Center in Moscow (Sayushev, 1986).

A variety of different self-regulation training methods and techniques were practiced in work settings: progressive relaxation, autogenic training, imagination training, and various programs based on different combinations of these methods (Leonova & Kuznetsova, 1987, 1993). According to practically all publications, the positive effect of self-regulation training on the HFS and work efficiency was observed. In spite of the proved efficiency of all self-regulation programs, the following main problem remains - “the problem of choice” of the most adequate self-regulation method: which self-regulation method should be chosen for implementation in particular work conditions, for a particular occupational group? In other words, how should a self-regulation program be arranged taking into account the specificity of each occupational group?

Between the mid-1980s and early 1990s, the Laboratory of Work Psychology at Moscow State University conducted a wide range of empirical studies in order to identify and to confirm the main principles of self-regulation implementation in work conditions. Section 8.3.2 presents the main results.

8.3.2. Efficiency of Self-Regulation Training in Different Occupations

The main purpose of these studies was to ascertain and evaluate the efficiency of different self-regulation techniques for HFS management and error prevention in different occupations. The dynamics of the manifestation of workers' states was taken as the main object of this research. This means that the sets of physiological and psychological functions were evaluated before, during and after the implementation of self-regulation programs.

In general, the research involved nine occupational groups: blue-collar workers, industrial managers, operators of high automated systems, air-traffic controllers, booking office operators, accounting workers, medical doctors, school teachers and students (Leonova & Kuznetsova, 1993). The dynamics of HFS in the process of self-regulation training was evaluated by a complex of diagnostic indicators for measuring the changes at physiological, cognitive and subjective levels of activity regulation. In each group, this complex was assembled according to the set task, and assessment of the most important psychophysiological functions for each type of job based on the results of job analysis. The combination of indicators was chosen on the basis of the HFS research methodology and in accordance with two main principles: a) the indicators should be adequate to the job content in particular occupations, and b) the experimental results obtained for different occupational groups should be comparable. The diagnostic complex included some general physiological indices and indicators (blood pressure, heart rate, vegetative Kerdo index), psychophysiological and cognitive performance tests (critical frequency of the flicker test (CFF), the modified Burdon checking test[2]) and tests of self-estimation of HFS (well-being scale, Spielberger's state-anxiety scale, acute fatigue scale).

During the study three self-regulation techniques were used. They formed the complex system of self-regulation training (Leonova & Kuznetsova, 1987, 1993): (a) *progressive relaxation training;* (b) *sensory-motor imagination and image reproduction* in a special combination; (c) *a modified version of autogenic training*. The general description of this system is presented in Table 8.1**.** The number and content of stages could differ depending on the occupational group, but their sequence was always the same.

In the special study we compared self-regulation techniques and their efficiency. First, the specific effects of using self-regulation techniques in each of the occupational groups were identified, and the main tendencies in the background level of HFS with respect to prolonged use of self-regulation techniques were evaluated. Second, a comparison of self-regulation efficiency in different occupational groups was made. In correspondence with that the influence of self-regulation training was evaluated on two levels:

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[2] The modified version of the Burdon test was used as a correlative measure for the assessment of probability of attention errors during task performance.

- *Actual effects* of self-regulation training. These effects can be evaluated by comparing the data before and after each self-regulation session.
- *Prolonged effects* throughout training. These effects can be revealed by a comparison of background data gathered before the training sessions at different stages of the self-regulation program realization.

It was possible to make the following predictions: (1) application of different self-regulation techniques leads to HFS optimization immediately after each training session (actual effects) and cumulating of stable positive changes of HFS throughout the training course (prolonged effects); (2) the efficiency of self-regulation techniques may vary in dependence on the specificity of job loads in different occupations; (3) self-regulation methods based on the active utilization of mental skills (sensory-motor imagination training and autogenic training) have more clear positive effects on those manifestations of negative workers' states which are strongly affected by psychological factors.

Table 8.1. The program of self-regulation training

Self-regulation technique	*Content of stages*	*Additional procedures*	*Duration of session*
Progressive relaxation	Development of subjective feelings of a relaxation state, deep muscular relaxation	Verbal instructions, general and postural gymnastics, breathing exercises	20 min.
Sensory-motor imagination training	Transition to the voluntary relaxation of main muscular groups and body as a whole	The same	20 min.
Autogenic training	Self-ordering by verbal formulas and auto-suggestion	The same	15 min.

The obtained data show that in all occupational groups strong positive results can be achieved while using all self-regulation techniques. As an example, the main results of self-regulation training in the two occupational groups are presented in Figure 8.1 - the group of booking office operators and the group of accounting workers. In this figure the integrated relative scores of HFS were calculated[3] on the basis of the following indicators: accuracy and productivity of the Burdon test; CFF parameters; general indices of well-being, state-anxiety, and acute fatigue scales. The background scores before the progressive relaxation training were taken as a starting point and evaluated as the background "zero level", so the other integrated scores can be viewed as deviations from this position. Increased integrated scores

[3] The procedure of calculation was the same as described earlier (see Section 7.2.2).

manifest positive changes in HFS, decreased integrated scores - negative changes in HFS.

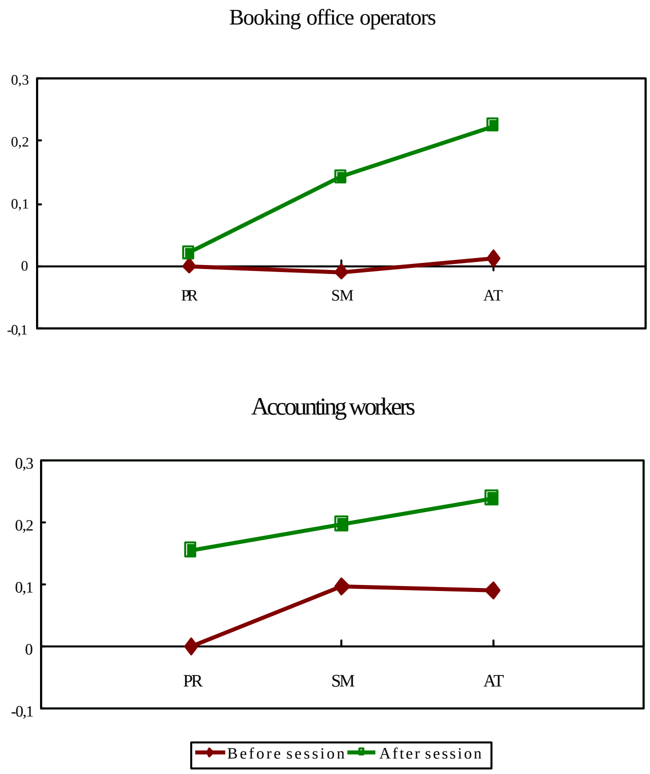

Figure 8.1. Actual and prolonged effects of self-regulation training (data are presented in total integrative relative scores calculated for whole sets of indicators; PR - progressive relaxation; SM - sensory-motor imagination training; AT - autogenic training).

The positive actual effects of the self-regulation sessions are clearly pronounced in all groups of indicators of a worker's state. The type of workers' states achieved after the self-regulation training sessions can be qualified as "activity mobilization". This is manifested in an improvement of physiological, cognitive and subjective HFS indicators.

At the same time there are some specific effects which depend upon differences between occupational groups. The changes in HFS indicators show that in each group the mental and psychophysiological functions more sensitive to the influence of self-regulation training are those that are more involved in the process of job execution, i.e. the most important professional functions.

The specific positive effects were also observed in the indicators of the Burdon test in the groups of booking office operators and accounting workers (see Figure 8.2). After applying different self-regulation procedures both indicators of the test (accuracy and productivity) increase - in parallel with the reduction of the number of errors the workers begin to perform task faster. This result could be interpreted in terms of the minimization of so-called attention errors and activation of a more efficient strategy of visual information processing.

Concerning the prolonged effects of self-regulation training, the following results were obtained (see Table 8.2 and Figure 8.1). When subjects were trained systematically, positive results were reached with respect to all indicators of HFS. The physiological indicators of blood pressure and heart rate change towards general normalization: from negative background positions (either too high or too low) the scores reach the level of an optimal range; at the same time the background normal scores remain the same. The psychophysiological and cognitive performance indicators, as well as the indicators of self-estimation of HFS, are also transformed positively.

Positive prolonged effects were obtained in all occupational groups, but their grades were different. For instance, in the group of accounting workers the positive changes of the background HFS level before training sessions started to be quite explicit by the middle of self-regulation training period (see Figure 8.1). At the same time, in the group of booking office operators these changes were not so obvious. This result in this particular group reflects that the period of the training course implementation accidentally coincided with a high increase of workloads; nevertheless, by the end of the training course the background HFS level improved.

In general, the observed prolonged effects manifest the improvement of such components of a worker's state which suffer more from the job loads in the ordinary course of work activity. Such functional "weaknesses" are not the same in different occupations. As the result, the dominant effects of the training course are professionally specific (see Table 8.3). Data show that in the group of industrial managers, the most explicit positive changes manifest themselves in normalization of physiological functioning; in the group of air-traffic controllers - in the improvement of both attention indicators and increasing feelings of subjective comfort; in the group of booking office operators - in the decrease of emotional tension and increase of the speed of visual information processing; in the group of accounting workers - in the decrease of acute fatigue and increase of the quality of information processing.

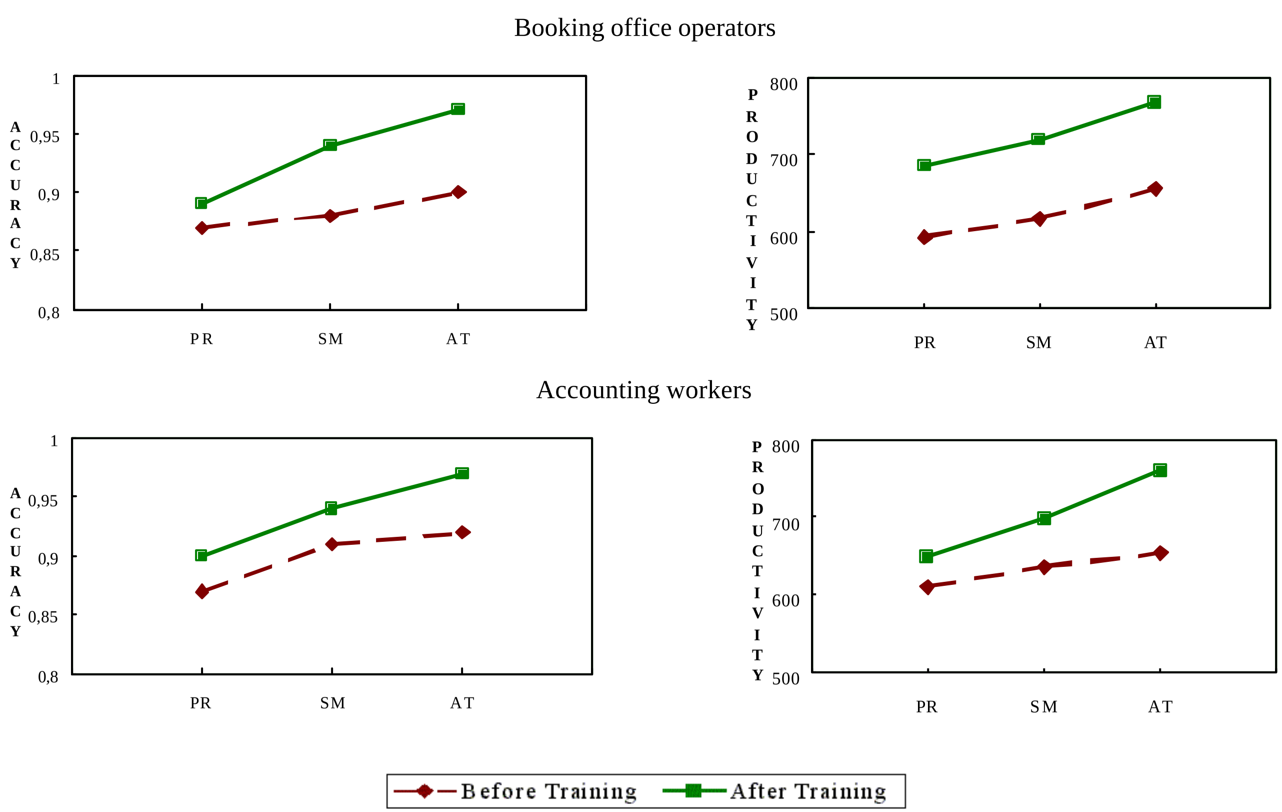

Figure 8.2. Effects of self-regulation training on the indicators of visual information processing – accuracy and productivity of the Burdon cheking test (PR - progressive relaxation; SM - sensory-motor imagination training; AT - autogenic training).

The comparison of actual and prolonged effects demonstrated the cumulative character of self-regulation exercises. While after the first sessions, mostly in all occupational groups, the indicators showed a slight tendency towards positive changes, at the end of the training course this effect became more clear and stable (for the most evident example, see the results of booking office operators, Figure 8.1). This result could be interpreted as a demonstration of the gradual transformation of overt execution of self-regulation exercises at the stage of progressive relaxation into special mental skills, or a self-regulation habit, at the stage of autogenic training.

The obtained results could be summarized as follows. The positive effect of self-regulation training on human well-being and mental functions is distinctly manifested in all occupational groups. It can be achieved by all self-regulation techniques used in the study. Concerning the problem of error prevention, the results showed the possibility of developing self-regulation skills as a good basis for the prevention of attention errors.

In the last part of the study we tried to compare *the efficiency of different self-regulation techniques*. For the comparison, four occupational groups were taken: industrial managers, air-traffic controllers, booking office operators, and accounting workers. These groups can be differentiated by the intensity of emotional and cognitive workloads. The main results show that the efficiency of the distinct self-regulation techniques is not equal. For instance, in the group of industrial managers the most positive dynamics was observed after using the progressive relaxation technique. In the air-traffic controllers group the most positive effect was reached after sensory-motor imagination and autogenic training. In the group of booking office operators and in the group of accounting workers, the most positive effect was achieved after autogenic training.

The following general tendencies in manifestations of the efficiency of different self-regulation techniques can be distinguished. First of all, the most significant positive effect is always observed for some, but not for all indicators of HFS dynamics, while the trend towards a general optimization is the same for all self-regulation techniques. Secondly, the most "psychologically-oriented" techniques, such as sensory-motor imagination and autogenic training, have a stronger effect on the emotional and cognitive components of task execution, while progressive relaxation procedures make it possible mostly to normalize the indicators of psychophysiological functioning and to minimize negative psychosomatic effects.

The results of the study provide an opportunity to elaborate general recommendations and basic principles for the implementation of self-regulation training according to professional specificity. Systematic self-regulation training leads to a wide range of immediate and cumulative positive effects: the HFS improves and the number of human errors decreases. It is recommended that self-regulation training courses be conducted during work shifts in order to prevent the negative consequences of workloads and avoid high-pressure job environments. The application of self-regulation techniques is also recommended as a means of short

Table 8.2. The prolonged effects of self-regulation training in different professional groups. Positive effects: +! ($p < .01$); + ($p < .05$); +? ($p < .1$). No effects: 0. The measure was not used:space is not filled

Occupational groups	*Blue collar workers*	*Industrial managers*	*Operators of highly automated systems*	*Air-traffic controllers*	*Booking office operators*	*Accounting workers*	*Medical doctors*	*School teachers*
Blood pressure	+!	+	+	0	0	+?	+	+?
Well-being score	+	0	+?	+!	0	+!	+	+
State anxiety score	+	0	+	0	+	0	+	+
Acute fatigue score	+1		+		0	+!	+?	+?
Critical Fusion Frequency					+?	0		
Accuracy in Checking Test				+!	0	+!		
Productivity in Checking Test				+!	+	+		
Trait anxiety score	+?	+?	+?				+	+
Chronic fatigue score	+	+?	+				+?	+

and intensive active rest and effective controlled recovery. Self-regulation methods are the most efficient in respect to those components of HFS that suffer more from intensive physical and mental loads in the ordinary course of work activity.

The level of optimization can be varied depending on the type of self-regulation technique. Their application should correspond to the dominant type of complication or deterioration in the activity regulation process in particular occupational groups. Besides occupational specificity, it is necessary to take into consideration individual characteristics of workers. The choice of an adequate self-regulation technique is also based on the causal analysis of typical errors. If errors are caused by physical and mental exhaustion during prolonged work without rest, self-regulation techniques, which normalize psychophysiological exertion and improve feelings of subjective comfort, will be more helpful. Progressive relaxation is an example of such a technique. If errors are caused by psychological difficulties at work, such psychologically enriched techniques as autogenic training or sensory-motor imagination will be preferable.

Table 8.3. The specificity of prolonged effects of self-regulation training in different occupational groups

Industrial managers	*Air-traffic controllers*	*Booking office operators*	*Accounting workers*
Normalization of physiological functions	Improvement of attention Increase of subjective comfort	Decrease of emotional tension Increase of the speed of visual information processing	Decrease of acute fatigue Decrease of attention errors

The observed programs and implementation results are examples of the well-developed psychoprophylactic approach in Russian work and health psychology. They aim at a systematic acquisition of new psychological skills for HFS management. Specially organized self-regulation training programs enrich the existent sets of spontaneously formed coping skills and increase the ability of individuals to maintain an optimal level of HFS during the work process. Because of the generalized nature of these coping skills, they are always at the disposal of a person, and the programs of self-regulation training fit well in any organization and in any work environment.

Today the share of computerized work activities is rapidly increasing. Computers have become the main instruments of work in almost all types of professions, and thus, to some extent, this instrument is also always on hand. Thinking along these lines, could it be possible to use a computer not only as a tool for work, but also as a tool of psychological support? One of the possible ways to realize this approach involves the installation of computerized relaxation and self-regulation programs at the work place. The content and duration of the programs can differ. During fixed or individually preferred breaks, a worker can choose a program and run it in order to support his or her rest or to facilitate recovery processes.

8.4. PSYCHOLOGICAL SUPPORT OF COMPUTERIZED PROFESSIONAL ACTIVITY

Intensive development of computer technology in Russia started only at the beginning of the 1990s. Before this "computer boom" computers were available mostly in large research and information centers, laboratories and leading business institutions. For these privileged users a computer was not the *means*, but rather the main *object* of activity: all their efforts and attention were directed to the computer itself, its software and options. Most of the faults in the process of computer usage were explainable by the low level of user competence (Donskoi, 1998). The users themselves were made responsible for all difficulties, and nobody cared about the ergonomic aspects of the information system.

For a long time, the software market in Russia was lacking. At the end of the 1980s Russia became open to foreign products, and its market was flooded with Western software. Russian developers had to compete with international companies when their financial interests and copyrights were not protected. They mostly spent their time trying to promote their products and to protect them from unauthorized usage rather than on user support.

At the beginning of the 1990s the situation in the market began to change. Russian software companies which offered products for such branches of business as banking, trade and industry flourished. By this time the computerization level of some occupational groups increased so much that basic and advanced computer training became necessary. To answer this need, software companies started to organize some sort of support service for end users.

8.4.1. Different Paradigms of Support for Computer Users

Nowadays computer users can obtain different kinds of support, such as training courses, hot-line support services and usability engineering.

Training courses. New software training is provided by the established companies for all personnel. During the classes employees get detailed instructions and information, learn basic operations and get initial experience in software handling. Of course, students can ask questions, but they do not yet know all the coming difficulties and cannot foresee their future needs. This is one of the reasons why training courses are not effective enough. They could have helped developers to raise the usability of their product, but inadequate feedback prevents them from doing that.

Hot-line support groups. Today almost every software company has its own technical support center, which provides hot-line services for users. Programmers or advanced users who have already taken a special training course become operators of the technical support group. A user can ask for help in case of emergency or when having difficulties in mastering the software and its options. Help is provided in real time, but it is not effective. Very often the technical support group lacks adequate skills in providing the necessary support if operators are unaware of possible professional problems and the level of user competence. The two sides speak different languages: the user thinks of the software in terms of the work at hand and his professional tasks, while the operator thinks in terms of abstract functionality, discrete operations and commands implemented in the software. The resulting misunderstanding negatively affects work efficiency and the well-being of both.

Apart from user support groups, there are analytical groups, which are responsible for the development of new versions of software and bug-fixing. Only in a few companies do these two groups work in close contact, because developers do not consider the opinion of users as valuable input. As a rule, users report only disadvantages and are not able to give any constructive ideas about the realization of software options. The development of new software versions is dragged out.

Software usability. In contrast to training and hot-line support, usability engineering makes it possible not only to abolish software faults, but sometimes to avoid them. This task is extremely important for computer systems in high-risk technological processes, such as nuclear power plants, air-defense and air-traffic control. Trading in financial markets is probably less dangerous, but the stakes involved sometimes make mistakes very hard to swallow. The users (software operators) of these systems have to work in real time and cannot take time off from their main activity to perform routine auxiliary operations (for example, manipulate the file system). It is necessary to create high usability information systems which could support the process of decision-making in real-time conditions (Bashlykov & Yeremeev, 1994).

Positive tendencies in the development of user-centered technologies have recently appeared. Market mechanisms play an important role in this process. After the domestic market had been flooded with software, competition among companies became more aggressive; they started to fight for customers. In turn, users became selective and fastidious (Donskoi, 1996). They try to avoid routine operations and minimize wasted time, and refuse to work with an inconvenient and uncomfortable software interface. Participation of Russian software companies in the international market has dramatically increased the ergonomic demands set on software products.

The development of information technology gave birth to such activities as Internet browsing and tele-working, which need psychological support (Velichkovsky, 1995). Internet and the virtual office paradigm have changed the psychological structure of professional activity in different occupations. In addition, the World Wide Web provides many new opportunities. Users can easily look through and evaluate software. They can just download several demo versions from different developers and decide which is the most suitable. Therefore, the users' opinion is becoming more important for software developers.

One crucial task for software usability is providing reliability and safety in large industrial settings. Operators must have easy access to all the necessary information. The form of information presentation must enable an operator to quickly analyze a problem situation, identify deviations from the norms and control the technological process.

Owing to these positive tendencies in psychological support, users feel more comfortable in the situation of rapid development of information technology. The technical paradigm of the users' adaptation to the requirements of information technology has been gradually but inevitably replaced by a more human paradigm - the adaptation of information technology to user requirements.

8.4.2. Error Prevention in Computerized Clerical Work

As a rule, usability engineering includes administration of questionnaires and interviewing end users, as wells as empirical psychological research of their computerized activities. It reveals the cognitive mechanisms underlying these activities and makes it possible to design an ergonomically adequate software interface. One example of such psychological investigation, which reveals the characteristics of computer-mediated activity in conditions of external interference, is an experimental study of interruptions in computer-mediated mental work. This study was conducted jointly by the Laboratory of Work Psychology, Moscow State University, Russia and the Work and Organization Research Center, Tilburg University, The Netherlands (Burmistrov & Leonova, 1996; Burmistrov & Leonova, 1997; Roe, Zijlstra, Leonova & Krediet, 1999).

Interruptions were chosen as the study topic for a number of reasons. First, since computerized intellectual work places high demands on the cognitive system, it is likely that this type of work is very sensitive to interruptions. Frequently interrupted work presents an important concern for work system designers. With the advancement of integrated computerized support, such technologies as broadband communication networks and multi-tasking environments, multiple task work has grown in importance as a design issue. Secondly, interruptions appear to be typical for the working conditions of many occupations in which computerized mental work predominates (e.g., office workers and secretaries). This makes it interesting to find out how people deal with them while carrying out their duties. Thirdly, interruptions may negatively affect a person's state and performance, thereby exerting an influence on workers' well-being and productivity. Finally, a practical consideration is that interruptions present an aspect of mental work with relatively high accessibility. Interruptions can be observed in practice, but they can also be evoked and studied under controlled conditions in a laboratory setting. This opens the possibility of doing laboratory research with great ecological validity, and testing the methods and findings used in the laboratory under real-life conditions. The ultimate study goal was to suggest usability engineering recommendations to the user interface design of human-computer work systems aimed at preventing the negative consequences of interruptions.

In an experimental study 30 subjects performed a computer-assisted task (text editing) highly similar to real-life office tasks during two pairs of experimental sessions over two days. The experimental task was to make corrections in a computer file based on a hard-copy version of a text that contained handwritten corrections. During the experimental sessions the subjects' work activity was disturbed by a number of interruptions (phone calls). The interruptions were made according to a certain scheme, which had been designed in such a way that the effects of the presence (vs. absence) and complexity of interruptions could be ascertained. Interruptions affected three types of editing operations: (a) regular editing (making simple corrections); (b) typing in new text; (c) moving a block of text to a new location. Interruptions were made at predefined points, e.g. the operation "move a block of text" (which consists of several sequential actions: select block – cut block – find its new location in the paper-printed brochure – find the same in the computer file – paste block) was interrupted after cutting the block of text but before pasting it from the clipboard. During a telephone call the subject was asked to perform another task, referred to as an "interruptive task".

The independent variables were the presence/absence of interruption and the complexity of interruption (two interruption complexity levels were investigated: simple and complex interruptions). An example of a simple interruptive task was to find a telephone number in the telephone book. A complex interruptive task was to correct all the typing faults in a short article. Among others, a dependent variable was the editing latency (the time to complete a particular editing operation, such as typing in new text or moving a paragraph to a new location).

The experiment took place in a simulated office environment. The 40 m^2 laboratory was divided into two rooms by a wall. One room was equipped as an office workplace (with furniture, a personal computer and an intercom telephone), while the other was used as a control room. In the office location, a movable tripod video camera was placed to monitor the subject. The video signals from the camera and from the computer screen were routed to a video mixer in the adjacent control room. From this room the experimenter controlled the experiment and watched the mixed video signal (a view of the subject plus the contents of the subject's computer screen) via the video monitor. The mixed video signal was also recorded on a VCR. An intercom phone was used for communication between the control room and the office location.

Statistical analyses revealed the significant effects of both the presence/absence of interruptions and the interruption complexity on the editing latencies for cognitively complex editing operations (e.g. moving a paragraph to a new location), while the performance indices for cognitively simple editing actions (e.g. typing in a new paragraph) were not affected by interruptions. A probable explanation of this fact may be that the operation "typing in a new paragraph" is the simplest one in text editing. It neither involves the search and location of some point in the text (as in regular editing) nor includes complex sequences of actions and additional mental load caused by the necessity to track the contents of the clipboard (as in moving a paragraph to a new location). The latter operation is an example of a "functional thread", i.e. a series of commands and actions; the effects of interruptions on this class of operations were more serious, e.g., subjects might have forgotten about and lost text transferred to the clipboard.

Results also suggest that an additional orientation activity, which appears after completing the "interruptive" task, is responsible for the increase in net operation time if an operation is interrupted. Additional compensatory activities (referred to as "strategic activities") caused by interruptions and directed at either immunization (removing the influence of the disturbance) or recovery (resuming the work activity at an appropriate point) were observed in the experiment. The analysis of the videotaped behavior of the subjects allowed the proposal of an empirical classification of interruption handling strategies.

Based on the analysis of interruption handling strategies, a number of recommendations for the user interface design for frequently interrupted work conditions were developed:

(1) The interface should give an opportunity to instantaneously "freeze" the current state of the system in order to prevent accidental damage to the information while working on interruptive tasks.

(2) The interface should perform complex operations (functional threads) as guided step-by-step operations. For example, "Select – Cut – Find new position – Paste", the sequential group of actions for moving a paragraph to a new location should be organized as a single command "Move paragraph" producing an appropriate support tool which guides the user in performing the necessary steps.

(3) Frequently interrupted work conditions require a more apparent indication of the presence of information in the clipboard (e.g., in a small floating window). Otherwise users may lose clipboard information when their attention is occupied by interruptive tasks.

(4) The metaphor "cooling down text" or "drying up ink" was also suggested. Authors recommended using color coding for indicating recently changed or inserted information on the screen, the colors "cooling down" during document-specific time from a hot color (most recently changed information) to a cold color (old or unchanged information). This improvement could reduce the time of orientation in the main task after completing an interruptive task.

8.4.3. Elaboration of a Human-Centered Interface for the Russian Trading System

An example of active participation of ergonomists and psychologists in industrial software systems development is the Technical Center of the Russian Trading System. The Russian Trading System (RTS), launched in July 1995, is Russia's largest fully electronic system for over-the-counter (OTC) trade in securities. Today, the RTS consists of over 1000 workstations, throughout the country and abroad, connected to servers which link to the central processing complex in Moscow. The RTS Technical Center (RTS TC) was also founded in October 1995 as a technical support center to operate the RTS. Its main objective is to provide financial market operators with technological tools to perform trading, manage front office and back office activities, organize data transmission among the trading system, broker-dealer firms, clearing and settlement institutions, control authorities and the public. RTS TC is a service-oriented company. Its customers do not "buy" a product required to solve a problem, they rather "entrust" the solution of the problem to the company, complete with the task of updating the solution according to the modification of stock market regulations and new developments in the stock market infrastructure.

The Analytical Department (AD) functions as a specialists' support group within the RTS TC. The main goals of the AD are: (1) to perform efficient analysis and monitoring of the current situation on the Russian stock markets by accumulating and analyzing the opinions of professional market agents in order to create recommendations for the RTS management, and (2) to conduct usability engineering activities and user interface design for the software development departments of the RTS TC. AD research is usually initiated by requests from other RTS departments: committees and commissions, the software development division and trading system's managers. The AD uses both qualitative and quantitative research methods to guide RTS products and service development.

The AD's most prominent work is the development of the user interface for the stock trader workstation, *RTS Plaza* (Burmistrov, 1999). From the very beginning, the building of an on-line trading system became the focal point of the RTS TC activities. Initially, RTS traders used Portal™ software developed by NASDAQ, an obsolete character-based system with heavy keyboard operation. Later, RTS started the development of a stock trader workstation "from scratch" for the Microsoft Windows™ environment. In 1998, after two years of analysis, prototyping, usability evaluation, software engineering and coding, the new RTS Plaza workstation was launched.

The AD began with field studies of stock traders' tasks and the organizational structure of their work. To elicit the users' task structure and formulate system requirements, dozens of user interviews employing an ethnographic interview approach were conducted (Wood, 1997). Each interview was accompanied by detailed observations in actual dealing rooms. Using the data from videotaped interviews and observation, a comprehensive task analysis was executed.

The main difficulties in AD work were (a) that many users of a very high social status – in many cases, it was impossible to employ conventional requirements gathering and usability testing procedures, and (b) the very high level of secrecy in users' work – many of them treated the AD team members as collectors of insider information on their firms. These difficulties were overcome mainly through painstaking analysis of massive recordings of traders' negotiations via a chat facility. A supplementary method of information gathering was the administration of questionnaires conducted via the Internet.

After formulating the general principles of the new system, the AD team developed paper prototypes of the new user interface and collected feedback from its prospective users. Then, the programming team developed the first executable prototype of the system, which was installed in about twenty broker-dealer firms. Feedback from beta-testers was collected and used for refining the user interface.

The OTC market has no trading centers. Instead, it consists of hundreds of brokerage firms located throughout the country and doing business via the computer network and telephone. Firms in the OTC market are generally referred to as "broker-dealers", because they can sell and buy securities either as brokers (agents) or as dealers (principals). OTC trading is performed by traders in dealing rooms of broker-dealer companies.

Of all the white-collar professions, modern stock trading is one of the most complex and stressful. Traders must absorb and analyze huge amounts of news and market information received simultaneously from different news agencies and different trading floors. They must extensively communicate with other traders in their own companies and counterpart firms. On this basis, they must make immediate decisions, at their own risk and taking full responsibility.

The analysis of users' activities showed that, in many aspects, they are similar to those of plant operators in control rooms in continuous process industries, air traffic controllers, and high-ranking officers in command of combat operations. The RTS Plaza design is based on electronic warfare techniques. In the "trading war", the adversaries are primarily the counterparts – other broker-dealer firms. This understanding determined the development of the trader workstation and the choice of user interface standards and guidelines. In the military environment, the systems are designed to receive, filter, and generate information based on large volumes of different inputs, and to provide decision support for crucial actions. RTS Plaza has similar functions – it filters stocks, receives price inputs and reports the outcome of trading sessions, alerts traders to market movements, maintains peer-to-peer communication between counterparts, and broadcasts financial and political news coming from the information agencies.

The AD developed their own set of user interface guidelines differing from the conventional guidelines for windowing applications in "office" work environments. In particular, many elements usual for desktop-oriented environments, such as overlapping windows and pop-up dialogues were banned in the guidelines, because they are extremely navigationally loaded and may hide important information. Instead, a fixed screen arrangement of information and control areas was recommended. The main reason behind this decision was that the speed of interaction with the system is a crucial factor in trading. A fixed arrangement of screen areas supports sensory-motor coordination, speeds up visual search, and minimizes the time wasted during window navigation activities, such as window selection, pressing the buttons or scrolling.

The RTS Plaza interface is not a “windowed”, but a “frame-based”, or “tiled” interface. In contrast to the windowed interface, the tiled interface is a display environment in which users do not lose their view of the process or alarm status, even while they access and view data in multiple screen areas from a number of sources. They have complete control over every tile in their system and interact with permanent windows that can never be hidden or overlaid.

Some of the distinguishing features of the RTS Plaza user interface are as follows:

- The RTS Plaza interface provides the optimal balance between the representation of a huge information feed and limited screen space.
- The primary interaction style in RTS Plaza is drag-and-drop operation via the mouse. About 90% of data input and manipulation can be performed with the mouse and, therefore, with one hand, thus releasing the other hand for other activities, e.g., holding a telephone handset.
- Special never-covered screen areas are used to inform traders about important news and events on the market and the necessity of performing urgent actions.
- The system provides text-based chat facility via the Communications tab. This facility is an important low-pace communication supplement to extensive conventional phone communication, which allows traders to maintain long-term contact with multiple counterparts throughout the trading session.

The RTS Plaza user interface received very positive feedback from actual traders. When Plaza replaced the previously used software, Portal™, one of the leading traders said that he felt as if he had “exchanged an old Lada for the latest model of Mercedes Benz”.

The case of RTS is only one of many examples of active participation by psychologists and ergonomists in the design of software products that are mainly adapted to the actual needs and interests of real users. Today industry leaders, both in the West and East, have begun to fully grasp that in order to succeed in the market place, products and services must offer not only technological excellence, value, and aesthetic quality, but also, and most importantly, usability. Many experts believe that Russia is currently on the verge of a “usability boom.” Although the concept of usability comes from the West, methodologies applied by Russian usability specialists appear to differ from those in the West in that they are more concentrated on the contextual analysis of jobs as a whole. Attempts to apply the principles of Activity Theory to human-computer interface design underpins the methodological framework of this work (Kaptelenin, 1996; Lepsky, 1999). A search in this direction is now at the initial stage. Nevertheless, this framework could eventually make the design of computerized products not only “friendly”, but also truly supportive.

CONCLUSIONS

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A variety of psychological traditions and methodological approaches has formed a body of human error research in different parts of Europe. As we have tried to show in the materials presented above, these traditions are closely related in many respects - sometimes by saying the same things in different languages, sometimes stressing a specific vision of the situation and therefore having a complementary character. It seems to be a natural result of the intensive search for principals that can help to explain the specificity of human behavior in complex technological systems. We believe that working people have to be considered first of all as *human beings* that can adopt different social and cultural norms of behavior. The nature of basic human reactions has many more common features than differences all over the world, and similar psychological regulators of activity can be promoted or suffer in consequence of the corresponding changes in working life. New trends in the development of modern societies (such as globalization of the economy, the increase of human capital mobility, the flexibility of contemporary types of work and organizations, the total computerization of workplaces, etc.) unify the demands on people living in different countries. This stresses the necessity of paying more attention to the discussion of general lessons that come from the history of error prevention studies.

Following the above-mentioned, we do not want to present in the Conclusions the results of a step-by-step comparison of established research traditions in different parts of Europe. This was partially done in parallel with discussing the materials in each chapter. For a deeper investigation of this problem it seems more productive to give a competent reader the freedom to create his or her own vision of the situation. Here we would like only to highlight some *convergent lines* of research which have recently been presented both in Russian and West-European studies. This may be useful for understanding how the traditional facets of error prevention practices are changing towards the new realities of a modernized world of professions.

V. De Keyser and A.B. Leonova (eds.), Error prevention and well-being at work in Western Europe and Russia, 1-263.

A convergence of the Western European and the Russian approaches becomes apparent first of all in forming more complex and structurally integrated strategies of error prevention and error management. From a historical perspective these approaches were clearly differentiated because they were mainly oriented to the different levels of preventive action implementation (individual, technological, or organizational levels). Over the last decades the accents have shifted. Recently the common point for both lines of research consists in linking together different levels of preventive practices:

- A shift from concentration on separate technological units or man-machine systems to analysis of their functioning on the organizational level is typical for the Western European studies. The essence of modern approaches emphasizes the necessity of creating different programs that could help to arrange and maintain efficient work in an organization as in a single whole organism (De Keyser, 1995). Accordingly, a core part of the appropriate prevention methodology concerned the problems of organizational design/redesign. Gradually the researchers started to stress the role of minimizing potential risk factors and latent failures (De Keyser, 1987; Reason, 1990). Many of those factors cannot be so easily eliminated on the levels of technical innovations or organizational redesign. They relate to understanding the means of utilization of personnel resources, indications of worker's abilities, well-being and health. Therefore the research interests turn to the individual level that provides better personnel adaptation. In contemporary studies such individual orientation is examined from the viewpoint of an organizational improvement perspective.
- In the Russian tradition the error prevention methods are mostly implemented on the individual level and the level of man-machine interactions. Two main groups of error prevention methods were used. The first one concerns the elimination of discrepancies between objective job demands and individual psychophysiological resources or abilities of a worker. The means of technological innovation and reorganization of jobs at concrete working places (Munipov, 1983a) is mainly used for these purposes. The second group refers to the in-depth analysis of activity regulation processes and individual coping strategies (Leonova, 1994). In this case error prevention and health protection programs were elaborated for increasing an individual's resistance to demanding work conditions. Under the influence of new social and economic conditions the broader organizational context of these studies started to develop. Recently the implementation of individual prevention tools has constituted a special branch of organizational policy.

Developing in opposite directions ("from organization to individuals" in the Western tradition, and "from individuals to organization" in Russia), both lines of research are meeting now at the same point. The important feature of the up-to-date situation is focusing again on individuals and their needs but by taking into consideration the broad organizational context of professional activities. Enrichment of organizational design by subject-oriented methodology seems to be a major perspective for future progress in the error prevention domain. Within this trend a new vision of work safety culture has to be developed. Exceeding the bounds of the traditional technocratic orientation, new types of safety systems in organizations are beginning to include special programs for personnel adaptation, professional training, well-being support and health promotion as necessary components.

In a general sense, by safety systems we mean the group of practices, explicit rules, internal norms, structure of set-ups and valorization systems that contribute to work safety in an organization. Although the global international institutions such as the European Commission and the national governments make great efforts for the development of common regulation norms in this area, the differences between countries and industrial/professional sectors remain still strong. To a large extent this depends on the field dynamics and organizational philosophy of the enterprises. Nevertheless, both in the West and the East, effective safety systems have been developed in traditional risk sectors (like aeronautics, energy production industries, public transportation systems, and today, medicine). Recently they have consisted of modules of preventive tools that are almost identical in each of the mentioned sectors:

- Developing *databases of incidents*, human errors and dysfunctions for statistical and didactic use. They are used to constitute professional "memory systems" in order to prevent a repetition of similar incidents. The elaboration of safety-reporting systems (for instance, like those borrowed from aeronautics) provides continuous gathering of data with guarantees of anonymous reports.
- Programming *regular surveys* for indicators of well-being, job/life satisfaction, moral climate, stress at work, etc. These data, when combined with classic safety indicators (productivity, incident rates, sick rates, occupational traumatism, etc.), become a real social watchdog for potential dangers.
- *Professional training programs* that go far beyond the classic framework of safety training programs. The latter were formerly limited to accident risk prevention, for instance, by showing subjects how to use appropriate means of protection, how to avoid dangerous behavior, etc. Today they provide a representation of the whole context of activity where different forms of personnel behavior can be required.
- *Simulators* are used more and more often for developing safe work behavior. We indeed see a multiplication of training simulators: from screen simulators to full-scale simulators that guarantee technical and functional faithfulness with regard to the referent situation. We also see a profitable application of virtual realities, when their use is justified by economic and risk factors – like in the training of surgery interns who

learn to operate without using cadavers, and without endangering the life of a patient. Such practices are increasing. They do pose certain questions about the psychological validity of modeling conditions and knowledge transferring, but they imply a different relation regarding training.

Besides those described above, *health promotion* and *stress management* programs have recently become a substantial part of safety systems. This area is not limited only to investigations of physical health and psycho-hygienic aspects of health protection. As sensible predictors of human reliability different indicators of *mental health* and worker *well-being* are used in assessment practice (examination of critical incidents, diagnostics of latent risk factors, etc.). Also, such indicators often play the role of the target criteria for work optimization in the process of organizational design/redesign. Moreover, numerous examples of job stress interventions in different fields of practice show the high economic and social effectiveness of their implementation (Murphy et al., 1996). Here again the development of Western and Russian approaches have become consolidated:

- In the Western research the concepts of mental health and personnel well-being formed in the framework of occupational stress research, which initially had a strong pragmatic orientation. Systematic epidemiological studies showed how costly an increase of psychosomatic pathology and manifestations of social/professional desadaptation among different occupational groups is for the society. The development of the person-environment-fit approach and transactional models of occupational stress shifted the attention of researchers to the analysis of the intermediate processes of stress initiation and its resolution, both in positive and negative forms. Appropriate psychological methods have been elaborated for the evaluation of an individual's vulnerability to stress as well as for enhancing stress management procedures with the accent on the acquisition of adequate coping strategies by concrete people. Recently, besides the consideration of stress as an organizational phenomenon, an individualized approach to the correction and prevention of different stress syndromes (burnout, personality deformations, patterns of risky behavior, etc.) has been grounded in work-site health promotion practices.
- In Russia, and more widely - in many East-European countries - the HFS concept plays the central role in work safety research. Within the framework of this concept the notions of human reliability and work efficiency are defined in terms of mechanisms of activity regulation and human resources that are actualized by a worker in specific work conditions. A similar development is observed now in some Western research, which is established on the basis of the state-regulation approach to occupational stress (Hockey, 1993). Grounded on integrative evaluations of individual abilities to work efficiently in given conditions, the methodology of HFS assessment is widely used for the purposes of technical and organizational design. The results of such research help to

show how efficient innovations are, and where the "weak-points" for reliable job performance or personnel well-being are situated. Furthermore, the development of the HFS concept facilitates the practical implementation of psychological methods of stress management and the prevention of health disorders. First of all, this concerns the techniques of self-regulation training. A specification of these methods for the needs of concrete occupational groups and work settings provides a better correction of negative stress syndromes and improves human reliability.

Progress in the practical implementation of error prevention tools and programs depends not only on the level of social sensitivity to this problem but to a great extent on the existing sets of legal norms and regulations that may differ from country to country. If we compare, from a very broad perspective, the nature and the influence of the Russian and Western European legislation systems related to human error prevention and well-being at work, several points should be mentioned:

- In the past, Russia, as well as Western Europe, had a strong body of laws and regulations to protect workers from potential hazards of the work environment. This body was solidly anchored in the social history of both parts of the world. It aimed to enhance safety at work and occupational health. Many actors and structures have played a major role in implementing these regulations and controlling their application: occupational medicine, trade unions, work inspection, prevention committees inside companies and organizations, etc. Even if they are not shaped in exactly the same way all over Europe, and even if they do not have the same power everywhere, their roles are rather similar. In Russia and in Western Europe, the initial concepts of safety at work and occupational health have gradually evolved to include the prevention of psycho-social risks: stress, mobbing, burnout, etc. Actually, well-being at work is a shared concern all over Europe, and psychological concepts and findings are incorporated into the legislation.
- In Western Europe, the integration influence of the European Commission has been decisive. By the means of European directives, adapted by each Member State to take into account its own specificity, the national regulations are now convergent. This impulse has also contributed to reduce inequalities in the concern for safety at work and occupational health in Europe. In the past, Southern European countries had weaker traditions in work safety. Poorer and less industrialized than the rest of Europe, some of them were isolated by authoritarian regimes (Spain, Portugal, Greece) and did not develop a very strong safety culture. In contrast, the North of Europe had solid regulations, good prevention structures, and a very old and strong tradition in safety at work. Actually, the discrepancies between the North and the South of Europe have tended to diminish, thanks to the major political changes in the South of Europe in combination with a new economic prosperity. In this political

landscape, the policy of the Commission which mixes a top-down approach (by enacting European Directives) with a bottom-up approach (by adjustments to the national peculiarities of the Member States) has had long term beneficial effects.

For decades now, the highly developed countries in Western Europe have tried to modify and to simplify their occupational legislation. For most of them, this legislation is rather heavy, very complex and despite this complexity, still incomplete. Rapid technological evolution, new typical forms of work, and new psycho-social risks make the task of the legislators very hard. The tendency is to replace the old normative regulations, which assigned norms, standards, etc. to be strictly observed, by a framework of recommendations to be followed. For instance, there would be no stress standard, giving the maximal level of stress tolerated in a company, but a recommendation to detect and to reduce the stress at work in any company of the country. In this case, what the law could sanction would be a lack of adequate stress detection procedures and subsequent ad-hoc interventions.

The present situation in Russia is still deeply influenced by the collapse of the Soviet system. As has been already mentioned, the level of protection of the workers was high in the past. This protection was inherent in the ideology of the Communist regime, which set a very high value on work. Workplaces had to respect strict ergonomic standards elaborated during the 1970s. There was, for instance, a set of standards for human reliability, for work complexity, fatigue, etc. However, at the end of the 1980s, just before the fall of the Communist regime, these strict regulations were frequently respected only formally. It was just a facade to be maintained, but this facade was not supported by real prevention practices, for obvious economic reasons. After ten difficult years of political changes, economic collisions, and total deregulation under the pressure of the new emerging market economy, there are signs that Russia is starting to rebuild its regulations and prevention standards adapted to a totally new work environment. Even if the economy is still far from prosperous, and even if the working conditions suffer from this situation, the fact that legislation and standards are being rebuilt and reconstructed is a positive sign. Moreover, psychological concepts and applied research find an audience in this landscape, and we can expect a growing concurrence with Western European legislation and practices in the future.

The tendency for the unification of legislation and standards in different parts of Europe is not the only important feature of modern development in the error prevention domain. Another significant trend is the humanization of work which is common for different cultures and economic environments. The clearest sign of that is the changing focus of error prevention studies. The majority of them overstep the limits of the traditional technocratic ideology, even to a form of complex socio-technical design, and direct attention to the needs and problems of the people acting in a situation. This puts a challenge of high quality psychological instrumentation of preventive work. As has been shown by practical examples coming both from the West and the East, modern psychology is ready to answer this request. Real progress has been achieved in the development of psychological tools for on-line support and off-line training error prevention systems as well as in the implementation of new organizational and management safety regulations. What is more important, these attempts have helped to revise the old tradition of seeing the worker as only the culprit or victim of an error. The new vision of the problem concentrates on the person, who has to be supported and well-equipped to overcome the difficulties of modern working life.

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GLOSSARY

Action for design: design aimed not only at facilitating the user's action but also at regulating it. The design comprises not only the achievement of certain objectives of the action but also the fact that the user can control it. This concept was introduced by Roe (1984, 1988) and taken up by Arnold (1988) within the allocation of function between human and computer. "The task structure, as determined by the computer software and work procedures should not interfere with the activity plan that the user considers as optimal" (Arnold, 1999, p.16).

Action: the basic unit of human activity, that corresponds to the relations between a particular objective task and a subjectively accepted task-oriented goal. A realization of an action is directed by a conscious goal and is voluntarily controlled. These goals are steps towards fulfilling an individual motive, i.e. goals have not only social, but also personal meanings. An action consists of a set of operations, and an operational structure of an action is defined by the conditions of the task (see also *Activity Theory*).

Activated human resources: the level of physiological and psychological resources, which ensures the required characteristics of task/job performance.

Activity: in the most general sense, any kind of active interaction between a living being and its environment; it is regulated by needs important to the subject. According to Activity Theory, subject-environment interactions are presented in a variety of activities that include both external (behavioral) and internal (mental) components. Each activity is driven by specific individual motives and builds up a more or less structuralized hierarchy of actions and operations. The basic component of human activity is an action. The goal-directed activities of human beings proceed in a biophysical as well as in a social (cultural-historical) environment (see also *Action*, *Activity Theory*, *Operation*).

Activity regulation: the process of actualization of human functions and abilities in order to reach the goal. Two principle types of reflexive acts ensure activity regulation at the most general level: (1) analysis of the state of affairs in the current situation, and (2) reflection on the results of actions and construction of programs of prospective behavior (see also *Activity*).

Activity Theory: a general methodological framework for psychological research developed in Russian/Soviet psychology (Leontiev, Luria, Rubinstein). According to the main postulates of Activity Theory, mental functions mediate the process of interaction between a subject and his/her environment. Any kind of mental (or psychological) function is described as a specific form of internal activity in order to achieve goals important to the subject. Leontiev emphasized structural identity as well as plastic transformations between external (behavioral) and internal (mental) modes of human activity. He also introduced principles of hierarchical structure of activity: the coordination of objective goals and individual motives as a whole (the highest level) consists of sets of goal-directed actions (the middle level) and resource-dependent operations (the lowest level).

Approximate knowledge: a concept linked to cognitive complexity associated with interactions with technical systems. This complexity is such that it becomes impossible for the users of these technical systems to be completely acquainted with them in every detail. They have only a rough knowledge, sufficient in certain contexts, but which may prove dangerous in others (see also *Compensatory strategy*; Amalberti, 1996; De Keyser & Javaux, 1999; Hollnagel, 1998).

Artifact: the envelope, either material or symbolic, of the instrument. The instrument refers to the person's use, the appropriation and adaptation of the artifact when doing a task, which can be very different from the formal use prescribed by the designers (Rabardel, 1995).

Automation: "The use of advanced technical resources in entirely or largely self-regulating processes or subprocesses, thus eliminating to a large extent the human intervention in the direct production process" (Algera, 1988, p. 134).

Clumsy automation: automation that is inappropriate in certain contexts. For example, an aid to the operator, aimed at reducing the work-load, which proves effective when the situation is normal and the load light, but inadequate during an incident, when the work-load increases (Bainbridge, 1987; Woods et al., 1994).

Cognitive complexity: complexity associated with the cognitive resources to be used in performing an action in a certain context. Often evaluated from a quantitative estimation of these cognitive resources, attention constraints and work memory (Kieras & Polson, 1985).

Cognitive compromise: the way the subject uses his limited cognitive resources within the constraints of the complexity linked to the task and/or context. In certain cases, this approach can give satisfactory performance; in others it fails. We then speak of human errors linked to a breakdown of cognitive compromise.

Cognitive engineering: engineering of artifacts and technical systems, taking into account present-day knowledge of human cognitive functioning in a given context (Hollnagel, 1998; Hollnagel & Woods, 1983). This concept relies on two basic assumptions: 1) the interactions between the human agent and automated control systems are best viewed in terms of a joint cognitive system, 2) the behavior of the human agent is seen as being shaped primarily by the socio-technical context in which the behavior occurs rather than by the peculiarities of an internal information processing system.

Cognitive strategy: a way of performing cognitive tasks, it reflects the specific composition of elementary mental operations and their temporal organization (e.g.

sequential or parallel modes of information processing, exhaustive or self-terminating search in short-term memory, etc.). The choice of cognitive strategy in concrete circumstances depends on situational demands, individual capacities, and training. Changes in cognitive strategies correspond to transformations in activity regulation mechanisms. The microstructure of coping strategies and compensatory mental tools has also been investigated in this framework (Broadbent, 1984; Leonova, 1988; see also *Activity regulation*, *Coping strategy*).

Common performance conditions (CPC): concept used by Hollnagel (1998) to describe the general determinant of performance in a context. The CPC are defined in terms of adequacy, thus as a relational property of the system. There are 9 CPCs: the adequacy of organization, the working conditions, the adequacy of the man-machine interface and operational support, the availability of procedures/a plan, the number of simultaneous goals, the time of day, the adequacy of training and experience, and the team collaboration quality.

Compensatory strategy: a strategy, which compensates for possible weaknesses in the subject's knowledge by greater prudence and more frequent verifications of the results of the action. This is a means of maintaining satisfactory performance (Masson et al., 1993). The subjects try to remain within a "security envelope" where they are sufficiently sure of themselves.

Complexity: the property of an object or relationship - artifact, technical process, sphere of knowledge, man-machine interaction, etc. A distinction has often been made between objective complexity, which can be derived from the objective description of an object or a domain, and subjective complexity, seen through the interpretive view of the subject (Pederson, 1990) The position taken up in this work is that of describing complexity as a relational property, a man-machine interaction in a given context (De Keyser & Javaux, 1999). It demonstrates a certain mismatch between the subject's internal or external resources and the constraints of action in this context.

Context: a subset of the environment, which is meaningful for the operator. Three acceptances of the context may be found. They are not mutually exclusive. On the one hand there is the context created by the subject in respect of the action, together with whatever is involved in this action: objectives, constraints and means. On the other hand there is the context in relation to human limits: emotional, cognitive, perceptional, and psychomotor. Finally, the context, which proves pertinent when taking into account the subject's approximate knowledge; this is the subset of the environment that constitutes an error-trap, for what is usually true or valid suddenly ceases to be so for the operator (see also *Approximate knowledge*).

Control modes: the strategy set up by an operator for controlling a process. Hollnagel (1998) distinguishes four control modes, introduced as more or less extensive temporal planning of the action. The scrambled mode is completely disorganized. It frequently occurs when the situation is unfamiliar and changes in unexpected ways, when the task demands are very high, and when the time to react is very short. The opportunistic mode takes place when the next action is determined by the salient features of the current context, rather than by more stable intentions or goals. The tactical control mode reflects planning, but with limited scope, and sometimes ad-hoc actions. In strategic control mode the person considers the global context and uses a wide time horizon. The choice of the mode depends on the characteristics of the situation and on the operator's characteristics (expertise, emotional state, etc.) Thus highly dynamic and variable situations will not fit easily into a strategic or even a tactical mode and will be more likely to be managed using an opportunistic or even scrambled mode. Strong links between control modes and human reliability were assumed by Hollnagel (1998; see also *Compensatory strategy*, *Human reliability*).

Coping: efforts, both action-oriented and intrapsychic to manage environmental and internal demands and conflicts among them, which tax or exceed person's resources.

Coping strategy: an individualized strategy of dealing with difficult situations or heightened demands which exceed a person's capacity or are subjectively appraised as a threat. "Appraisal and coping are closely related parts of a complex process. When a situation is appraised as potentially harmful - that is, where the discrepancy between load and carrying capacity exceeds acceptable levels - coping strategies are developed and pursued to reduce that discrepancy" (Appley & Trumbull, 1986, p. 318).

Correct action: an action whose goal is achieved without any deviation from the prescribed parameters of its execution.

Costs: "Hidden and unwanted consequences of actions which achieved some primary goal. They may be subjective, physiological or performance-related" (Chmiel, 2000, p. 441).

Cultural-historical approach: a conceptual paradigm for understanding the development of highly synthetic mental functions, according to which all specific human mental functions emerge and develop on the base of social structures of different signs and means (including language, writing, counting) through the process of interiorization. The founder of this approach Vygotsky stressed the necessity of considering any form of human labor as coordination which is mediated by (1) technology, technical equipment and job situation specifics (including the social context) and (2) individual goal-oriented intentions and voluntary control over one's own behavior (Vygotsky, 1983).

Delay: a type of error connected with the execution of activity until later than planned.

Distributed cognition: the contextual theory of cognition taking as its unit of analysis the system composed of natural agents (i.e. human), and artificial agents (i.e. intelligent machines). Natural and artificial agents are on the same footing; they cooperate, have a memory, form representations, make decisions, correct each other and recognize their reciprocal intentions. The cognitive mode underlying this vision is a classic symbolic model extended to a set of natural and artificial agents. The myth is clearly that of a joint cognitive system in which men and machines would work in harmonious synergy (Nardi, 1996a).

Domain: an ensemble of more or less structured rules, procedures, and facts that form the basis of knowledge (Csikszentmihalyi, 1996).

Efficiency: the achievement of required or desired results of an activity at a minimal cost. "Efficiency is not to be equated with absolute achievement but rather with the relation between activity (regarded as psychological costs) and performance outputs such as gains ... Eysenck (1979) proposed as an index of efficiency the ratio between performance and effort" (Schoenpflug, 1983, p. 303). The criteria of quality of performance and human reliability are the principal measures of work efficiency (see also *Cost, Human reliability, Work efficiency*).

Erroneous act: term used by Hollnagel (1998) to characterize the manifestation of error from the phenomenological point of view. Indeed, he shows as opposites the phenotype of error, the visible side, and the genotype, its deeper cause (see also *Human error*).

Error management: management of error from the moment it appears. This management covers correction of the error and/or limitation of its consequences, for example, by technical systems tolerant of error. The concept of error management often conflicts with error prevention. Indeed its supporters point out the difficulty of preventing error, it being so common and widespread, and the practical advantage of preventing it from leading to nasty consequences (see also *Error prevention*).

Error prevention: reduction of the probability of error appearing. Different techniques are in use at the present time within the setting-up of a safety culture: the exploitation of safety-reporting systems, training on simulators, improvements in organizational communications, action facilitation design, etc. (see also *Action for design*, *Safety culture*, *Safety-reporting systems*).

Error recovery: early detection and correction of error, which prevents its potential consequences. Some kinds of errors as slips are very often spontaneously recovered by the subject. Other ones, as mistakes, are rarely detected by the subject him/herself. They need to be detected by a "fresh observer" or a technical system (see also *Error management*, *Mistake*, *Slip*).

Error tolerant system: a technical system that foresees error and/or prevents its consequences. It can prevent the error having an effect, for example, by refusing an action that would endanger it, encourage its detection by the subject, or limit and even neutralize its consequences.

Failure: a type of error typified as “an accidental event amounting to partial or complete loss of workability of a system or individual when performance of functions become impossible” (Sereda et al., 1976, p. 189). Those errors which are corrected on time are called “save failures”, since they do not seriously affect the task performance.

Fatal error: a non-reversible error, which cannot be corrected on time.

Field: a set of actors linked by a common objective and sharing the same domain of knowledge.

Functional structure of activity: a certain organization of behavioral, physiological and mental components of activity that is established in order to achieve important goals for the subject or results in a concrete situation. The components of the functional structure of work activity are described in terms of professionally important functions that supply a process of activity. An analysis of the coordination of those functions and their transformations under the influence of changing conditions helps to reveal actualized mechanisms of activity regulation. The basic principles of this analysis (compensatory adaptation, anticipation of desired results, feedback correction) are elaborated in the theory of functional systems (Anokhin, 1980; Bernstein, 1967; see also *Activity*, *Activity regulation*, *Human functional state*).

Heuristics: a means of achieving a goal or solving a problem that is never certain but is lighter and more flexible than the usual algorithmic procedure. Heuristics are always a short cut, a rule of thumb, which may be unreliable in certain contexts.

Human centered design: design, which includes human characteristics and limits in its specifications and throughout its conception cycle.

Human error: discrepancy in relation to a reference recognized as correct (norm, model, theory, established knowledge) although the subject intended to conform to it. Degrees of freedom must exist to think or to act with respect to this reference (Reason, 1990). It is widely accepted that (1) human errors should not be conceived as merely due to the incompetence of the operators, since in many cases they are the result of persons’ best attempts towards the accomplishment of desired and sensible goals; (2) human errors are multifaceted events; (3) human errors should be considered as man-machine mismatches, where the two components of the whole man-machine system enter a state of conflict partners in the system, it is crucial to find what has gone wrong (i.e. the potential conflicts between the two partners in the system), rather than to assess who has to be blamed for an error (Bagnara et al., 1990).

Human functional state (HFS): the concept that is developed and widely used in Russian applied psychology to study a variety of work-related human states (fatigue, monotony, stress responses, states of optimal or productive inspiration, etc.). The meaning of the term HFS is quite distant from the traditional physiological interpretation, and concentrates on revealing the relation between work efficiency and the individual resources utilized in a work situation. From an operational viewpoint HFS was defined as “an integrative set of those activated workers’ functions and abilities which directly or indirectly determine the efficiency of job performance in actual circumstances” (Zarakovsky et al., 1974, p. 94).

Human functional state management: maintenance of the optimal level of HFS; one of the directions of error prevention practices on an individual level (also see *Error prevention, Human functional state*)

Human reliability: a set of individual capacities and abilities of a worker that can be actualized in order to maintain efficient execution and regulation of job performance which depends on specific professional demands and requirements.

Human reliability assessment: a movement, deriving from engineering preoccupation, which attempted to liken human reliability to that of an element in a technical system (Hollnagel, 1998). It was therefore concerned with classifying errors, and particularly estimating the probability of appearance in order to come to certain decisions about the appropriateness of building or maintaining a mechanism or a procedure. Recently human reliability assessment is intensively developed in the area of nuclear energy, because of the sensitivity of public opinion towards the risks involved.

Internal costs of activity: the volume of human resources, both physiological and mental, which is utilized during the process of a task/job performance. Different indicators of work efficiency, worker well-being and health are used for evaluations of the internal costs of activity (see also *Activated human resources, Work efficiency*).

Lapse: a type of error mentioned by Reason (1990) typified by a failure of memory. The subject does or says one thing “instead of another”. The recovery of a lapse by the subject is usually easy and almost immediate (see also *Human error*).

Latent failure: fault or deficiency in the technical or organizational system, which is present even in the absence of error or incident, but which fosters their appearance. This is the prime target of error prevention. It was Reason (1990) who introduced this term, very analogous to the “black spots” of Faverge’s concept of reliability (1970).

Microstructural approach: the Russian version of a methodology used for analysis of a functional organization of mental processes that underlie the execution of typical operators’ tasks such as signal detection, coding, recognition, image rotation, the shadowing of dynamic objects, etc. The microstructure of these processes is examined and represented by a structural model of relevant mental (mainly cognitive) actions (Velichkovsky, 1988; Zinchenko et al., 1985). The development of the microstructural approach was inspired by Western research in cognitive psychology and adopted the principles of Activity Theory (see also *Actions*, *Functional structure of activity*).

Mistake: a type of error of planning mentioned by Reason (1990), typified by a failure at a knowledge-based behavior (see also *Human error*).

Omission: a type of human error typified as the loss of a necessary action in the execution of activity.

Operation: the smallest unit in the analysis of human activity. Operations are defined as behavioral and mental tools, which are used for achieving a goal in concrete circumstances. As a rule, operations are executed in automatic mode but can also become conscious in the case of difficulties. This changes their status from background involuntary processes to focal actions (see also *Action*, *Activity Theory*).

Orientation (or orienting activity): one of the basic concepts of Galperin's theory of stage-by-stage formation of mental actions. Describes the manner in which a subject investigates a situation that includes new elements or slight shifts in habitual conditions. In the process of orienting activity the subject creates new functional meanings for objects and reorganizes the chain of actions (Galperin, 1992).

Performance shaping factors: factors, which influence the operator's behavior and performance. In classical human reliability assessment, a distinction is made between extemal (contextual) factors, and internal factors (see also *Common performance conditions*, *Human reliability assessment*).

Productivity: a rate of production, such as the number of manufactured articles, performed tasks, or achieved results per unit time. Productivity also includes qualitative characteristics of products, which are based on standards, type and number of errors, loss of time, etc.

Professiographia: a complex method of job analysis that is used in Russian applied psychology and includes a full-screen description of a profession. Two principles define the specificity of this method: (1) differentiated analysis of any job or practical problem that needs to be resolved; and (2) a professional stipulation of those individual resources that support and regulate the process of work. A professiographic description includes a set of professionally important functions and abilities of specialists that is required for efficient (or normative) job performance.

Refusal: the act of refusing or denying the execution of human activity or the functioning of a system.

Reliability: in systemotechnic design and ergonomics, a fulfillment of a certain number of job tasks or technological functions at the required level and during fixed time intervals. The main criteria are faultlessness, timeliness, and minimized risks of breakdowns and accidents in job performance (Lomov, 1966). In West Europe, the concept of reliability was introduced in the 1960s by Faverge (1967), to characterize a man-machine system functioning without any errors, accidents, breakdowns or failure during a given time.

Responsibility: a legal, moral, or mental accountability for fulfilling, executing or planning an action. In psychological research, responsibility is considered one of the main sources of stress at work. Two different sorts of responsibility are differentiated: "first, responsibility for the people, for their work, welfare and promotion, and second, responsibility for things, for buildings, machinery, money. Responsibility for things often implies a responsibility for people" (Cox, 1978, p. 164).

Safety culture: those aspects of the organizational culture, which will impact on attitudes and behaviors related to increasing or decreasing risk (Schein, 1992).

Safety envelope: domain of knowledge and actions controlled by the subject, in which he/she feels confident and where he/she masters his performance. The subject often develops strategies to avoid going outside this domain. This "territory" varies according to his specialization (De Keyser & Javaux, 1999; see also *Compensatory strategy*).

Safety-reporting systems: a method of reporting of incidents or errors, which is becoming more and more common today in risk-prone environments. It is based on voluntary action and confidentiality. Exploitation of the data is primarily aimed at accident and disaster prevention.

Self-regulation: a type of activity regulation performed by a subject on the basis of psychological means of apprehension and the modeling of reality. The acquisition of special self-regulation skills (behavioral and mental) as well as voluntary control over automated physiological functions, are built on the mechanisms of productive feedback (see also *Activity regulation*).

Self-regulation training: a systematic development of self-regulation skills that increases an individual's tolerance to stress and helps to manage negative reactions when they arise in demanding conditions. The basic self-regulation procedures used in practice of stress management include: progressive neuro-muscular relaxation, sensory-motor imagination, and autogenic training (see also *Human functional state management*).

Situated cognition: a contextual cognitive theory, which postulates emergence from the context in relation to the subject's interaction with the environment. This context cannot be described *a priori*. Each situation is unique and singular. The subject's behavior is not predetermined by a plan or a preliminary representation of the action but reacts to the particular circumstances of the moment, and its finality becomes clear during the course of the action (Nardi, 1996a).

Situation awareness: a concept used to describe whatever understanding a subject may have of the context in which he finds himself, of its possible evolution and its significance. The term has been mainly used in aeronautics in contrast, to describe states of non-awareness: the fundamental surprise in the face of the plane's behavior when on automatic pilot, an air disaster happens without the pilot even realizing its imminence, etc. (Dusire, 2000; Sarter & Woods, 1991). Growing automation and the complexity of information modes prescribed in some technical devices increase the risk of the subject's losing awareness of the situation.

Slip: term adopted by Reason (1990) to qualify an error of execution linked to a failure in attention mode. The subject clearly intended to do something but failed in the accomplishment of this intention: some distracting element disturbed him, or former automatism took over without his knowing. Unlike mistakes, slips, exactly like lapses, are fairly easily corrected by the subject (see also *Human error*, *Lapse*).

Stress: (1) In the classical theory, stress is defined as a non-specific adaptive reaction of the whole organism to any noxious or aversive stimulus (Selye, 1956). (2) In the person-environment-fit models, stress is treated as a result of imbalance between environmental demands and individual resources to cope with them (Cooper & Payne, 1988). (3) In the Lazarus theory "psychological stress refers to a relationship with the environment that the person appraises as significant for his or her well-being and in which the demands tax or exceed available coping resources" (Lazarus & Folkman, 1986, p. 63). (4) In the transactional approach stress is defined as a process of interaction between the person and the situation, when cognitive appraisal of the situation is evaluated by a subject as threatening in any respect (Cox, 1978).

Total quality: an organizational movement, which was taken up by European enterprises during the 1980s in the wake of the Japanese quality control circles. This time, however, the concern for quality is not limited to a few circles of volunteers but becomes a global policy, manifest throughout the enterprise. Total quality aims at the elimination of every type of defect or incident, whether technical, organizational or linked to working conditions, etc. In the Total Quality Movement, the idea of the customer is essential. The quality to be attained is the one the customer wants and pays for. Moreover, the customer idea can be extended: it is considered that within the enterprise each service is at the same time both provider and customer of the other services. This movement is important for the prevention of human error since it militates against error because of its potential impact on the quality of production and not only for reasons of safety.

Violation: a deliberate transgression of procedure or safety norm. Its deliberate nature distinguishes a violation from an error.

Work efficiency: the fulfillment of a certain number of job tasks or technological functions at the required level during fixed time intervals. Reliability and quality of performance are considered as two main components of work efficiency. Besides work outputs, the criteria of work efficiency include indexes of well-being and mental health (see also *Efficiency*, *Internal costs of activity*, *Productivity*, *Reliability*).

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