HUMAN PERFORMANCE AND ERRORS IN CONTROL OF NEW COMPLEX AND RELIABLE TECHNOLOGY

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Abstract

Human performance has significantly changed in recent years in interaction with new technologies. Employees through the whole human society had to acquire a new set of skills and abilities. There is a fundamental change of human performance dynamics and efficiency. Operators of various operations and maintenance personnel are now able to affect more parts of the system and more system parts' functions in a shorter time. They are able to remotely control the system, which previously had to be reached manually in a specific position or by a larger number of workers. Hand in hand with that, new types of human errors have occurred. To face that, we have to find new ways to analyze human performance. We have to deal with more complex and reliable systems, whose reliability brings new paradoxical phenomena in relation to humans.

Introduction

Operators around the world can feel a shift to a new way of performance, different tasks and actions. These actions not only bring different mental requirements, but also accelerated dynamics. This change in the dynamics of human performance in interaction with the new systems had never been scientifically studied. For many performances it has not been assessed whether the new interaction involves an increased likelihood of human error, or new types of human errors and consequences. The main question is - are the current methods of assessing human performance and errors in this changed environment still valid?

1 Classical Approach to the Analysis of Human Performance

Efforts to describe and analyze human activities can be seen in virtually all areas of human society. People within the social hierarchy assess each other on the basis of interactions they enter into. This way of human performance analysis covers the whole continuum from totally intuitive and based on education and social habits (used in everyday life) to very specific methods used only for certain types of human activity.

The most sophisticated analyses provide fields in which human performance is the correct critical element in a complex interaction with technology.

1.1 HRA

Human Reliability Analysis (also frequently used term: Human Reliability Assessment), shortly HRA is an important part of risk management.

The beginning of the development of HRA methods is dated back to the 50s of the 20th century. This area has always been a hybrid discipline touching the reliability assessment, system design and psychology [1]. HRA is therefore inherently interdisciplinary. The first reason is that it requires knowledge of the nature of human errors, their psychological basis and mechanisms. Certainly it is necessary to know the related factors such as training, interfaces, communication and psychological description of other factors that affect human performance. The second reason is the need to understand the system design, so that forced and unforced human interactions could be explored for their potential for error, their potential impact and evaluation of the reliability and risk. HRA should therefore be integrated into an overall "risk picture" system [1].

The development of HRA was relatively slow over many decades and on the edge of interest. Since the accident at Three Mile Island (1979), a lot of effort has been thrown into this sector, which has brought many HRA tools into existence, most of them applicable in the nuclear industry.

1.2 Classification of HRA Methods

The classification (sorting) of the methods is an individual matter, and so each one can introduce its own approach. However, at present, we received two kinds of widely accepted classifications which are essentially complementary. According to one wide-spread sorting, we classified HRA to [2]: task-related (THERP, HEART), time-related (HCR, TRC) and context-related (ATHEANA, CREAM, MERMOS, and CAHR). The second classification (which is currently the most widely used) sorts methods into generations. Roughly speaking, the methods that are context-related can be described as methods of the second generation. Task-related and time-related are methods of the first generation.

1.3 First-Generation Methods

The development and introduction of the first generation methods can be dated back to the eighties and nineties of the twentieth century. The methods are often referred to as task methods. The main representatives are THERP and HEART. Their general application was based on the traditional PSA/PRA (Risk Management) framework. The methods were at first focused mainly on quantifying activities associated with the use of already installed equipment, while much less seeking the real causes of failures, and not offering tools to reduce errors and optimize the system. Everything was focused on HEP. The human error probability (HEP) was simply defined as follows:

$$HEP = \frac{number\ of\ errors\ occurred}{number\ of\ opportunities\ for\ error} \tag{1}$$

After the Three Mile Island accident and other more recent accidents, there was a shift of emphasis from quantifying HEPs to understanding the causes of errors and deeper psychological levels of human behavior. Also, there was a need to reduce human errors. The first-generation methods responded to that and brought some helpful tools. But they were still built on the foundations of the old techniques of assessing machine reliability.

2 Necessary Changes in the Approach to the Analysis of Human Performance

If we try to correctly model human performance in operating new complex and reliable systems, the use of the first-generation HRA methods is problematic in many cases, or worse, completely misleading. For the correct prediction of human interactions with such technology, it is necessary to use all the new knowledge of the second-generation methods.

2.1 Second-Generation Methods

The second-generation methods are sometimes called context-related HRA methods. They are quite different from the task or time related HRA methods. For the context-related methods, the context under which the action takes place is more important than the task or time. It should be stated that the context is directly related to the task [2]. The second generation methods' HEP is determined by each of the influential context elements. Some of these are the quality of training of the crew, the quality of the procedures, the quality of the man-machine system, the quality of the communications standards, and so forth. The important context elements depend on the situation being considered [2].

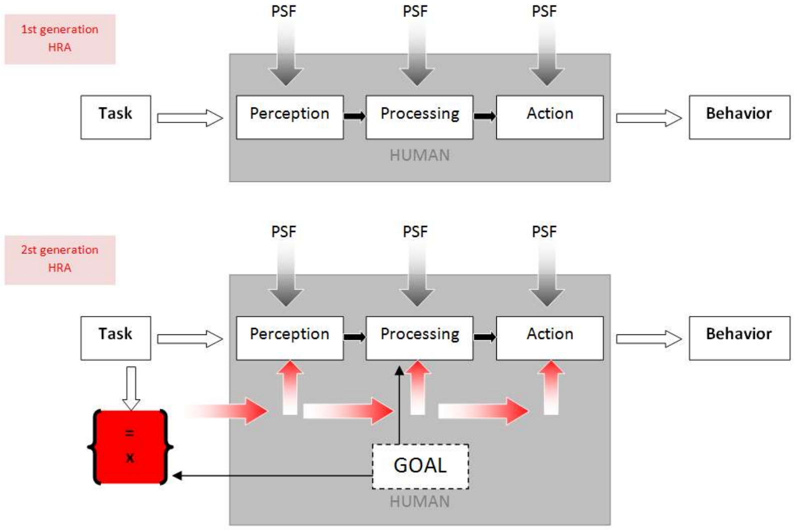

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Fig. 1: *Model of human information processing - differences between generations*

2.2 Errors of Commission

Errors of commission (EOCs) are those actions that can increase the severity of an accident [2]. They are often presented as a complement to errors of omission, which are usually considered as a failure to react appropriately. Errors of commission are described as inappropriate and dangerous actions, actions with disproportionate intensity, at a wrong time, etc.

Some of the first-generation methods also deal with this kind of errors – but as a secondary problem. With the second generation techniques, we can see that this kind of behavior and errors is embedded in the very foundations of methods. The main representatives are ATHEANA, CREAM, MERMOS, CESA and CAHR. Others are SPAR-H (Standardized Plant Analysis Risk HRA) and HDT (Holistic Decision Tree Method).

One of the most promising methods of the second-generation is CAHR (Connectionism Assessment of Human Reliability). This method uses the connectionism algorithm which is a term connected to human cognition modeling on the basis of artificial intelligence models. It refers to the idea that human performance is affected by the interrelation of multiple conditions and factors (internal and external) rather than by singular ones [3].

An interesting new tool of CAHR is the use of the assumption that the human brain collects information and compares it permanently with the internal representations of the world. This is sometimes conscious, but most of the time it is an unconscious process. This process is called the cognitive mill [3].

The method is based on similar psychological foundations as CREAM. Some of its elements have been picked up by other authors, and are evolving in a further development of new HRA methods. The method tries to deal with the cognitive aspect of human performance. Like other methods, CAHR is mainly interested in the role of human interaction with technical systems. The exchange of information between a man and a machine happens under certain circumstances and certain psychological conditions of the situation. The same idea is valid for the exchange of information among multiple people. The theoretical background of the CAHR method works with the idea of cognitive performance, which is largely influenced by the inner world of a worker. Figure 2 shows the exchange of information.

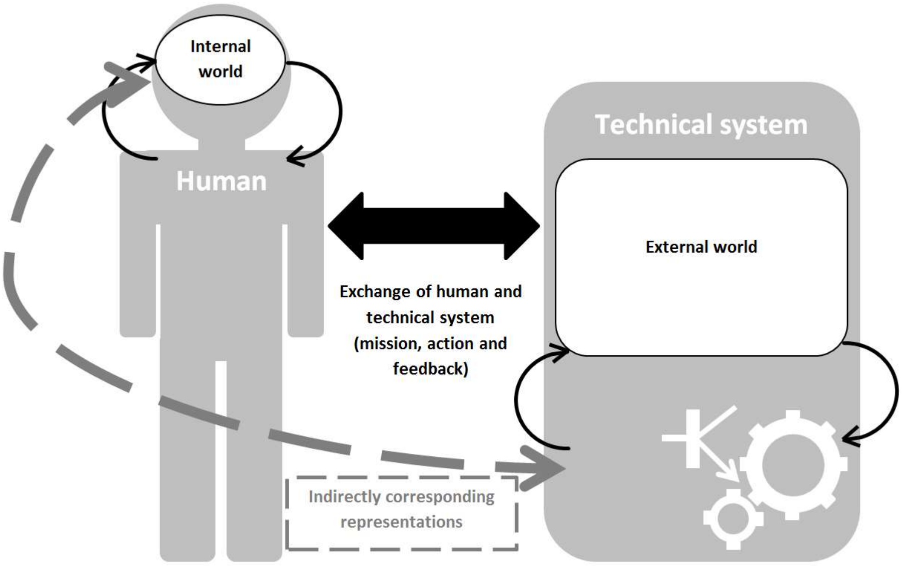

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Fig. 2: *Model of man-machine system of HRA second generation method CAHR*

CAHR uses quite a different type of task analysis in contrast with the first-generation methods. The important part is that we can decompose the whole task to particular MMS (man-machine system) components. It is a flow diagram that shows different MMS components in blocks and information flow, and cognitive coupling with human performance. CAHR uses its own ergonomic approach to describe the cognitive load (which should determine associated cognitive coupling according to the cognitive mill theory). It is associated with a MMS and is given separately for each identified MMS within the description of an event. For every MMS block with the decided determining cognitive load we can try to find MMS that interact with the same load in the method's database. This database shows us two pieces of basic information – the number of occurrences and the number of errors resulting from this type of interaction. These two pieces of information are then converted into probability. The database also gives us information on the occurrence of the EOC. You can use it for the analysis of different possible scenarios resulting from the EOC.

A detailed description of the method is beyond the scope of this article - this brief summary of the basic CAHR features shows how today's methods approach the human performance.

2.3 Human Performance and HRA

HRA methods can identify different types of human errors (and not only the previously observed), and quantify their probability. They can also simulate the course of accidents and show the possible scenarios. These new methods can also explain various psychological reasons why these events happen at a very detailed level. In all of these activities the second-generation methods show their high utility.

3 Problems with New Reliable Technology

Ivergård [4] describes a paradigm shift in human performance with human society development. Industrial revolution and ever increasing application of automation in the western society has been changing the nature of work performance. Hard manual labor is constantly replaced by machines. People are increasingly operating machines either individually or in the control rooms. In recent years we can see a strong effort to increase the aggregation of more control rooms to one control center.

Moray [5] describes an interesting phenomenon in handling of instruments in the control room – the influence of degree of confidence in the instruments in dependence on their service reliability. With the paradigm shift caused by the advancing human performance and automation systems autonomy, the role of people is increasingly shifted to supervising. A key component of this oversight is the trust. People in such situations tend to create a "humanizing" relationship to devices based on trust. In essence, the natural behavior patterns apply when the devices are highly reliable and when they had no serious failures in the past - they are seen as credible and are rarely checked. People also lose their subjective ability and willingness to deal with their eventual failure. So this phenomenon (and its resulting problems) occurs when people handle highly reliable systems. A paradoxical example is the control of the A340 aircraft, which is so sophisticated that it allows a very little experienced pilot to control it. On the other hand, it is recommended by pilots themselves to allow this to only most experienced pilots, since only they are able to recognize what and why the automated systems try to do, and whether they are successful in that effort [5].

Our industrial society will have to cope with this new phenomenon of highly reliable and automated systems. It is very difficult to understand their behavior and deal with their problems, which occur in intervals of years or more.

We are faced with many problems: Loss of self-confidence in handling of technology which is most of the time controlled by automatic systems. Excessively clinging to goals, even when the diagnostics shows a clear indicator that it is dangerous to continue. These situations can be explained by the knowledge of the second-generation methods.

3.1 Preventive Tool - Simulators

One of the biggest grey areas in the field of human factors is the use of simulators in real practice. By simulators we mean a copy of a control room capable of modeling all essential characteristics (physical, chemical, etc.) of the controlled processes and important external factors contributing to the overall system behavior (including safety). Real results show daily that the use of simulators (in aviation or in nuclear power plants) significantly reduces the likelihood of human errors and improves the overall reliability and safety of a system. Yet, outside these industries, where simulators are required by legislation, simulators are far from making a real breakthrough.

Simulators are used especially in training of new employees and periodic training of safety procedures. They can also be used for verification and implementation of improved procedures and internal equipment in the control rooms as well as for collection of statistical information on human performance for the purposes of HRA.

The knowledge of major industrial accidents in recent decades shows that most of them were caused by poor performance of an operator during an abnormal event. Practically in most of these poor performances, we can say that the operators were not properly trained for this kind of an event with the simulator equipment. A human factor expert Shepherd [5] attached using simulators for training of safety procedure response the central and critical role in the overall reliability and safety of process control in such rooms. Experts' experience of real accidents casualty shows that a large part of accidents could be prevented by a proper use of simulators, or at least it would not have such critical consequences. Unfortunately, managers do not have enough support for the economic rationale for investing in simulators yet. Accidents resulting in consequences in amounts of tens of millions Euros and humans' lives at risk have not been sufficient arguments for investing hundreds of thousands Euros in simulators.

The use of simulator techniques obviously reaches wider areas beyond the control rooms. Different types of simulations and models can be used in the preparation for maintenance shutdown, practicing complex human performance, etc. In situations where an extension of the periodic shutdown of one hour means an economic loss in amounts of tens of thousands Euros, it is not too difficult to calculate whether the simulator techniques pay off or not. Still the use of these instruments in maintenance and similar areas is more distant than in the control rooms. This is one of the reasons why a regular maintenance shutdown and time to repair after a failure have been much longer in central European practice than with similar technologies in the more developed world.

4 Results

For understanding the human performance associated with the new complex systems, we have to apply new important tools of the second generation HRA methods. Especially in dealing with new phenomena like goal reduction, information fixation, etc. The use of simulators will probably be necessary for ensuring safe operations of many processes. Sometimes it would be probably necessary for a useful data support of the HRA analysis. The use of all of these instruments will also encounter the resistance zone. This border can be described as follows:

There is a limit of a complex system size that can be controlled by a single operator.

There is a reliability limit at which the system becomes very difficult to control after a failure. If we want a person to respond adequately to a failure that occurs every few tens or hundreds of years on average, we can only prepare him or her by training and simulations. However, if the ratio between simulations and real human performance (feeling of technology nature) is inadequate, it can be very dangerous.

At present, we are approaching this boundary and vaguely sense it somewhere ahead. We can see some indicators that confirm it (some of them were described above). Our next scientific effort should be the specification of this boundary, conditions and factors influencing it, etc.

Conclusion

A new complex and reliable technology brings new types of human behavior. Human interaction with the new technology is changing and so is its reliability. We can see new human stereotypes and different error modes. Under these conditions, we can use the philosophy of cognitive performance and the tools based on this knowledge. The new methods based on those inputs allow us to understand these events better, prevent accidents and improve safety. These new findings should also change the design of control systems and their interface to make them more user-friendly and less confusing. This is a process that needs to respond to a new, constantly changing technology with new impacts and opportunities, although the technology is always one step ahead.

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LIDSKÝ VÝKON A CHYBY PŘI ŘÍZENÍ NOVÝCH KOMPLEXNÍCH A SPOLEHLIVÝCH TECHNOLOGIÍ

Lidský výkon se v posledních letech výrazně proměnil pro nutnou interakci s novou technologií. Pracovníci napříč celou společností si museli osvojit nový soubor znalostí a schopností. Zásadně se také změnila dynamika lidského výkonu a jeho efektivita. Operátoři různých provozů i pracovníci údržby jsou dnes schopni v kratším čase ovlivnit mnohem více částí systému a jejich funkci. Jsou schopni vzdáleně ovládat části systému, které musely být dříve kontrolovány ručně na specifické pozici, případně i ve větším počtu pracovníků. S touto novou dynamikou se objevily i nové typy lidských chyb. Abychom mohli čelit těmto novým prvkům, musíme najít nové způsoby, jak analyzovat lidský výkon. Musíme se také vypořádat s více komplexními a viz výš spolehlivými systémy, jejichž spolehlivost přináší nové paradoxní fenomény v lidském chování.

MENSCHLICHE LEISTUNGSFÄHIGKEIT UND FEHLER BEI KONTROLLTÄTIGKEITEN IN NEUEN KOMPLEXEN UND ZUVERLÄSSIGEN TECHNOLOGIEN

Die Leistungsanforderungen an die Mensch-Technik-Interaktion mit neuen Technologien haben sich in den letzten Jahren grundlegend verändert. Diese Entwicklung hat dazu geführt, dass Angestellte in der ganzen Gesellschaft sich neue Qualifikationen und Fähigkeiten aneignen mussten. Daher hat sich die Dynamik und Effizienz der menschlichen Leistungsfähigkeit fundamental gewandelt. Sowohl Bedienpersonal in der direkten Systeminteraktion als auch Personal mit Instandhaltungsaufgaben können weite Teile und Funktionen des Arbeitssystems innerhalb kurzer Zeitintervalle beeinflussen. Weiterhin können sie das Arbeitssystem über Fernzugriff kontrollieren, eine Tätigkeit, die vorher manuell an einer festgelegten Position oder durch eine hohe Anzahl an Mitarbeitern durchgeführt werden musste. Mit dieser Entwicklung einhergehend, haben sich neue Typen von menschlichen Fehlhandlungen entwickelt. Um dem entgegenzuwirken, müssen neue Ansätze zur Analyse der menschlichen Leistungsfähigkeit entwickelt werden. Es ist daher erforderlich, dass wir uns mit neuen komplexen Systemen auseinandersetzen, deren weitere Zuverlässigkeit davon abhängig ist, inwieweit auch scheinbar paradoxales Verhalten von Menschen berücksichtigt werden kann.

PRACA CZŁOWIEKA I BŁĘDY POPEŁNIANE PODCZAS STEROWANIA NOWYMI KOMPLEKSOWYMI I NIEZAWODNYMI TECHNOLOGIAMI

Na przestrzeni ostatnich lat praca człowieka przekształciła się w dużym stopniu w konieczną interakcję z nowymi technologiami. Pracownicy niemal wszystkich branż musieli przyswoić sobie dużą wiedzę i nowe umiejętności. W wyniku tego w istotnym stopniu zmieniła się dynamika pracy człowieka i jej efektywność. Obecnie operatorzy różnych procesów i konserwatorzy urządzeń potrafią w krótkim czasie wpływać na większą liczbę elementów systemu i ich funkcje. Mają oni możliwość zdalnego sterowania elementami systemu, które dawniej można było kontrolować tylko ręcznie, czasami nawet tylko w większych grupach osób. Wraz z tą nową dynamiką pojawiły się też nowe typy błędów ludzkich. Aby sprostać pojawiającym się wyzwaniom, należy znaleźć nowe metody analizowania pracy człowieka. Należy jednocześnie uwzględnić bardziej kompleksowe i niezawodne systemy, których niezawodność rodzi nowe paradoksalne zjawiska w zachowaniu człowieka.