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FIELD ANALYSIS : APPROACH TO THE DESIGN OF TELEOPERATOR WORKSTATION.

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ABSTRACT

Following a brief review of theoretical scope this paper will characterize a methodology to the design of teleoperation workstations.
This methodology is illustrated by an example - field analysis of a telemanipulation task in a hot cell. Practical informations are given : operating strategy different from the written procedure, team work organization, different skills.

Recommendations are suggested as regards the writing of procedures, the training of personnel and the work organisation.

INTRODUCTION

The extension of human work in hostile environments such as the nuclear environment calls for very strict safety constraints which have led to the development of new technologies such as "teleoperation". However, the onset of these advanced technologies does not exclude Man from the control loop. On the contrary, Man, provided with ever more sophisticated equipment still plays his role of decisive link. It therefore appears impossible to solve operational problems solely on technical and economical grounds, without taking the physiological and psychological factors related the human contribution into account (LESCOAT, D.A., 1985).

The final aim of a workstation is to enable the operator to carry out his task with a certain efficiency. However, the quality and amount of work done depend largely upon the conditions in which such work is executed. It is therefore necessary to modify the constraints inherent to the tasks such a way that the resultant work load for the operator is minimized while his performance is increased. In terms of systems, it is necessary to optimize the relations between Man and his work through the tools available to him. The adaptability of Man to the working conditions must no longer be relied upon because, if Man cannot or can no longer adapt himself to a task, the situation is a tantamount to fault or accident conditions. The best way of optimizing the system therefore consists in considering that Man functions within certain physiological limits and in adapting the conditions of execution of the task to these limits.

I. A METHODOLOGY : OPTIMIZATION OF THE MAN-MACHINE SYSTEM

A. Theoretical Scope

The relational schema (figure 1) set up within the three components of the usual system, namely : the Man, the Tool and the Task, is always the same, whatever the tool at the operator's disposal and the task to be executed by him. Only the content of these relations is specific to each individual system. The optimization of the Man-Tool interface therefore requires optimization of the content of these relations.

The information is received by the operator (inputs) via his sensory receptors. It is processed at different levels of the nervous system. This processing leads to decision-making associated with a choice of the appropriate strategy to execute the task, which determines the nature and characteristics of the motor response. The motor activities therefore appear as responses to the sensory information.

In return, as the system operates on a closed loop, the motor activities generate a flow of information, either inside Man's body (proprioception) related to the position and the displacements of the different segments with respect to one another, or outside the man (exteroception) and related to the result of the motor action on the work space. The sensory information then appears as the resultants of the motor actions.

Moreover, the Man-Tool-Task system functions within a physical and social environment which act upon him as a positive disturbance (comfort and motivation) or negative disturbance (work load and conflict). All these factors affect the system relations and are therefore to be studied.

The physical environment concerns the ambient conditions to which the system is subjected. The social environment more particularly concerns the operator's relations with his firm and covers many components of an economical and technical order. It applies both to the work organization and to the operator's responsibility.

B. Choice of Relevant Variables

Optimization of the Man-Tool interface, i.e., optimization of the relational content of the system, requires a thorough knowledge of the factors affecting Man's inputs and outputs in each individual system. It is therefore necessary to determine :

- Human capabilities
- Task requirements
- Tool characteristics.

The two latter factors induce the flow of information required and actually available to the operator.

- The optimum social and physical environment for the operator.

The physiological and psychological capabilities of the operator with respect to the work requirements and the population concerned are determined on the basis of the scientific references found in the literature. These capacities concern among others the reach envelope, the articulaltion comfort angles as well as the amount of information Man is able to handle at the same time or the sensitivity threshold of the sensory receptors.

Conversely, the other factors can be only studied by analysing the actual work. This analysis should enable us, in particular, to collect information regarding :

- the use of written procedures
- the actual operating sequences compared with written procedures
- the operating strategy of operators :

. motor activity	Movements
	Displacements
	Postures
	Efforts
	Use of tools
. mental activity	Data acquisition
	Visual strategies
	Speech communications
. relation activity	Organization of team.
	Sharing of tasks
	Inter-individual relations
	Speech communications.

The comparison of all these informations enables a trade-off to be established between the requirements of the three system components, to ensure optimum adequacy of the workstation to the required tasks.

Within the scope of the design of teleoperation workstations, this approach involves a field analysis of several workstations considered as representative.

II. AN EXAMPLE : ANALYSIS OF A TELEMANIPULATION TASK

The aim of our paper is to show, by way of an example, the results which may be obtained from a telemanipulation work analysis by applying the methodology described in the previous paragraph.

A. Description of the workstation

The analyses were carried out in a nuclear plant, during the execution of real tasks. (SAINT-JEAN, T. 1985)

The task studied consists in the dismantling in a hot cell of a device previously irradiated in a reactor.

The principal operations carried out to perform this task were as follows :

- entry of the device into the cell via a lock
- extraction of the irradiated samples from the rigs used for irradiation,
- loading of the rigs with new samples (irradiated or not),
- fractioning of non-recoverable devices
- withdrawal of irradiated samples and radwaste.

This task is performed by a team of 5 people

- two telemanipulation operators. One of them will retire shortly, the other one is being trained,
- two technicians of the Design Offices that have developed the experimental device,
- the engineer who conceived the experiment and the processes and drew up certain written procedures.

The task is performed within a shielded cell provided with an access lock on one side (see figure 2). The top part of the cell has a work space of 95 m^3. The visual access is provided by a window of 0.7 m x 1.04 m, fitted with a periscope. The bottom part of the cell, intended to accommodate the devices, is fully blind.

This cell is fitted with two light telemanipulators of the master-slave type, located above the window, a heavy telemanipulator supported on an overhead bridge, and a lifting crane, both controlled by means of a pushbutton pendant.

B. Purpose of the analysis

During this study, we were essentially interested in the following themes :

- team work : the operating mode of the group, coordination between the different operators, the roles and objectives of each one,
- the use of written procedures,
- the roles of oral exchanges between the different members of the team during the excution of the task.

The themes retained were studied with two approaches deemed as more relevant to the subjects of the study :

- work analysis, usually based on ergonomic methods (OMBREDANE and FAVERGE 1965 ; LEPLAT and CUNY, 1977), has been applied to the study of the team operating mode and use of procedures,
- analysis of the comments exchanged spontaneously between the operators during and after execution of the task has allowed a study of the roles and objectives of each one, as well as of the coordination within the group.

Our presence as observers had been prepared at a meeting of all the staff to whom we have explained the objectives of our research to find applications for the design of new workstations.

The proper analyses were conducted without any recording means other than paper and pencil. Conversely, we have systematically note down the following :

- all the operations carried out,
- by which operator and using what tool,
- the visual means employed,
- the comments exchanged in connection with the current activity.

C. Analysis of the activities : results and discussion

The activities of the operators and functional communications during execution of the tasks were analysed in order to determine :

- group's strategy to cope with the uncertainties of the task and effective role of the procedures,

- specific features of the telemanipulation task: order of operating sequences set up by operators, strategy of use of telemanipulators according to requirements of the different steps of task,
- implicit sharing of the roles and responsibilities between operators possessing different experiences.

The purpose of this analysis therefore is to show the practical organization adopted by the operators.

1. Operating sequences and written procedures. A comparison between the operating sequences observed and the written procedures supplied to the operators shows that the operators often follow an operating logic different from that specified in the procedure. This inadequacy of the procedures results from the fact that they describe objectives rather than operations or instructions. The differences found between the written procedures and the activities performed by te operators are following :

- the procedures indicate the state in which the different devices have to be maintained and do not propose work plans,
- for certain steps, procedure only indicates the type of operation with reference to similar phases previously described, although the device is no longer in the same conditions, which necessarily modifies the course of the operations carried out,
- there is a discrepancy between description of certain steps of the procedures and difficulty and actual time of execution of such steps by the operators,
- the procedures describe the preparatory steps in a succinct manner while the analysis of the operating sequences highlights the importance of these steps both as regards their difficulty and necessity, as well as the time required to execute them (45 % of the total task duration).

Thus analysis of the real activities of the operators shows that a procedure, drawn up on theoretical considerations is not and cannot be the main support of these activites during a task. An operating order is established during the task execution, by modifying the theoretical order and adapting it as and when the operating difficulties and faults occur.

For instance, an operating fault generated three recovery attempts. These three attempts were made at different moments during the sequence of operations. This shows that the operating order is determined by the working conditions and not by the written procedure.

2. Operating strategies

a. Strategy of execution.

The analysis of the activities shows that the operations carried out by means of telemanipulators are not continuous, as in the case of the movements of a Human's arm, but broken down into sequences. The strategy used to execute a task with a telemanipulator differs from that used to carry out the same task hands on. Thus, during a gesture for positioning an object hands on, the tactile information is of prime importance to perfect the positioning, while visual information is used mostly for overall orientation. Moreover, the gesture is corrected according to the tactile informtion.

Conversely, in telemanipulation, the lack of precision in the movements of the manipulator grips makes it necessary for the operator to readjust the position, often by releasing the object to grasp it again in a better position. These readjustments and the search for a more appropriate position account for the breaking down into sequences of the telemanipulation task. This breaking down does not exist in the human arm movement because the gesture is corrected in a more precise and continuous manner and the corrections are integrated throughout the arm's trajectory. The telemanipulation movement highlights all the intermediate readjustements.

Moreover, the lack of tactile information in telemanipulation is compensated for by visual information.

Thus, the mental connections and structures involved in the execution of a telemanipulation task are different from those involved in the execution of a task hands on. In particular, the telemanipultion task activates brain circuits in which vision has to be substituted for touch.

b. Course of operating sequences

Any movement of the irradiated device, either in the access lock to the cell or in the cell itself, is carried out step by step, while checking the position of the whole device at each stage of displacement (forward, backward, upward, downward). This control is carried out even when the device is located in the blind areas of the cell. In this case, the operators take a posture enabling them to observe this blind area, at the cost of a greater work load in order to preserve the postural equilibrium.

Periscope is used when the location of the action cannot be observed by direct vision or when the operator is seeking fine information to ensure the precision of his activities (e.g. position of a valve). In this case, the visual control is carried out at the cost of continuous changes in the posture between the position of action and the position of observation.

In certain steps of the task, the visual control is carried out by several operators located in different places and who therefore observe the device at different angles. Several reasons may explain this strategy, in particular:

- the risks inherent to the task, the lack of details in the procedure, the internal architecture of the cell ;
- the fragility and size of the device are among the essential causes of this strategy. In particular, the rigidity of the device, its length (4.5 m), the length of the cables (6.5 m) and their weight (20 kg), as well as the all over all weight (40 kg immersed) are taken into account by the operator to devise the strategy of displacement ;
- certain phases, such as the entry of the device into the cell are not described in the procedure. The operators therefore have to try to remember

former situations and to analyse the movement of the device in the present situation. The step by step displacement of the device allows the operations to be better controlled and adapted as and when they progress ;

- finally, the fractional displacements enable the operator to make a better use of the space available in the cell, since the dimensions of the device prevent it from being introduced into the cell by a simple translation movement. The operators are therefore obliged to tilt it slowly while introducing it, up to the vertical position. This operation requires the whole space available in the cell, an is very delicate.

The foregoing results demonstrate the objective criteria of the real work condition sought by the operators in executing the task, such as:

- the physical aspects of the device handled (fragility, dimensions),
- the management of the space available in the cell against the physical aspects of the device.

These criteria are not taken into consideration in the procedure.

c- Analysis of speech communications.

The comments exchanged by the operators are closely related to their relevant activities and more particularly to the operating strategy. They can be divided as follows :

- comments to give a general orientation,
- comments on the current activities,
- guidance comments,
- comments on the procedure to be followed.

Although of different character, these comments all concur to the same objective, i.e. the coordination between the operators to find the most adequate operating mode.

In addition, it appears that in the course of the activities, the speech exchanges are an integral part of the operations as an operating sequence ensuring the necessary link between two sequences.

... ...

3. Relational Activities

During the different phases of the task, the five operators always work as a team. This organization is proving necessary for the correct execution of the task. Moreover, it varies with the character of the different steps : the analysis of the activities and comments of the operators has revealed the team leader in the different phases :

- the senior operator often appears as the team leader in the different phases :
  . the execution of the operations,
  . the gathering of information and formulation of a general idea on the situation,
  . suggesting the course of operations,
  . the training of the apprentice operator.

Owing to the lack of precision of the procedure, experience is necessary to draw up the operating mode ; the operator who possesses the greatest experience then becomes the central team leader.

The engineer plays his leading role only in the phases he deems more important, allowing for his own objectives. These are the phases related to the physical principle of the task for which he is the most competent. The written procedure concerning these phases is usually highly detailed.

Conversely, when faced with operating uncertainties the engineer loses his role of team leader for the benefit of the senior operator.

It appears that a strategy of adaptation to the work conditions is continuously elaborated by the operators.

This strategy is related not only to the nature of the task but also to the importance attached by the operators to the team organization as the principal support for working out the operating mode namely : a solution worked out by a team for fulfilling a task in which the security stakes and financial costs are of prime importance. This leads to a strategy of safety measures and prevention where the role of each one seems to be linked with his own prevention criteria and with the way he intends to share the responsibilities.

.../...

It appears that the criterion of the senior operator is the quality of the operations carried out in the hot cell. An analysis of his reasoning shows that he intends to assume this responsibility since he gathers all the information, gives indications to the other team members and even proposes a strategy to the engineer for the subsequent operations. It also seems that he implements mostly the data derived from practical experience. This is evident both in his attitude to cope with difficulties and in the nature of the information he gives to the apprentice operator.

The criterion of the Design Office technicians seems to be essentially the quality of the equipment used in this task and in all cases they assume the responsibility of finding a remedy when the malfunctions seem to result from equipment faults.

The main criterion of the engineer seems to be the execution of the task in due time and without trouble, especially during the phases that condition the continuation of the task. He agrees to the sharing of initiatives and accepts that the team coordination role be played by the most skilled operator. He assumes the reponsibility of the decisions made, after consultations of the team members and evaluation of their opinions in the light of this own technical references.

To conclude, it appears that telemanipulation task requires a veritable groupe strategy which is applied to focalize the objectives of the different members of the team towards a common final aim : the execution of the task in due time and under the required safety conditions.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

It appears that for tasks performed in a hostile environment where uncertainties are aggravated :

- the duration of the preparatory steps, the structure of the operating sequences and the methods of organization of the team, lead to an operating strategy of safety measures and prevention. This strategy is developed as a function of the character of the task, and in paticular of the safety and economical requirements,

- team work is the main support :
  - to explore the widest possible field of the work space in order to control it,
  - to work out operating strategies,
  - to make the decisions to cope with the situation,
  - to share the responsibilities,
  - to execute the task by putting their individual capabilities in synergy,

- the role of each member of the team is different from what might have been expected :
  - the engineer is not always the coordinating member of the team. This role may be devoted to the operator who possesses the greatest expertise and experience,
  - the team organization is not permanent and changes during the execution of the task according to the objectives each one assigns to his own activities,

- the strategy of execution of telemanipulation tasks is different from the execution of gestures hands on for the following reasons :
  - lack of tactile information requiring a visual compensation,
  - lack of precise movements with the grippers leading to long and fractional readjustments of the position of the objects,
  - the necessity for the operator to work out a new body schema including the telemanipulator, to execute the tasks.

This strategy results in the growing importance given by the operators to the visual information and the greater attention which involves multiple visual controls of the gesture effected and entails an increase in work load.

B. Recommendations

The conclusions of this study show that the analysis of the actual work may provide practical information regarding the work conditions which may be applied directly for the design of new workstations and the improvement of existing stations regards :

- the writing of procedures,
- the training of personnel,
- the work organization.

1. Writing of procedures. The results of the analysis of this task as well as of the analysis of other work situations show that in general, the procedures describing the task from a theoretical viewpoint without any operating instructions resulting from practical experience, do not constitute a working aid for the operators.

To provide such a working aid, it will be necessary :

- as the procedure is being written to ask the contribution of the operators who possess the expertise (space control, integration of experience, execution of real telemanipulation tasks: management of the capabilities and limits of the tools and devices, knowledge of the operating difficulties, preferred sequences of certain operations, etc...),
- to carry out tests or simulations of tasks before finalizing the written procedure in order to validate its written formulation.

2. Training of personnel. The difference between the strategies for executing a task hands on or with a telemanipulator shows the necessity of a special training in manipulation. It appears essential to place the operators in conditions suitable for the activation of new mental circuits and the adoption of a new body scheme.

Several recommendations should be made to create these training conditions :

- to simulate the task on a mockup in order to enable the operator to integra-

te the tool in his body scheme,
- to carry out exercises in real conditions during a sufficient period of time to allow activation and consolidation of the mental circuits during the training,
- to provide exchanges between apprentice operator and skilled operators so that he may acquire the know-how which cannot be verbalized.

3. Work organization. The importance of team work and of the role of speech exchanges between the operators explained in the foregoing shows that in the design of new workstations it is essential :
- to consider the telemanipulation tasks as tasks performed by a team and not by a single operator,
- to locate the workstations of the different team members so as to ensure (a) that the telemanipulation operator is not isolated and (b) that the communications within the team, as identified by a preliminary work analysis, may be established,
- to provide the environmental conditions required for speech communications (e.g. surrounding noise).

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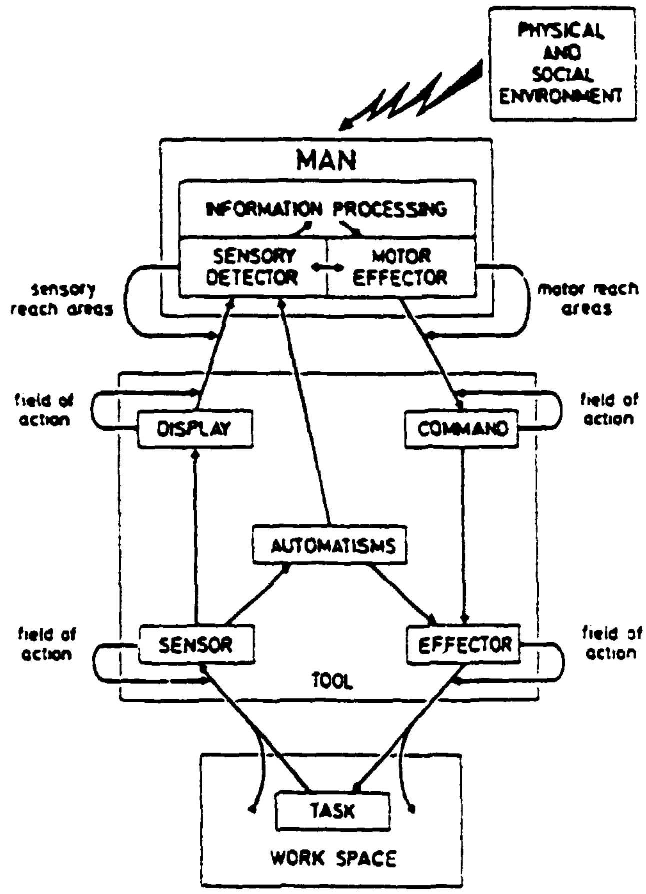

Figure 1

Block Diagram of the Relations Established within the Man-Tool-Task System

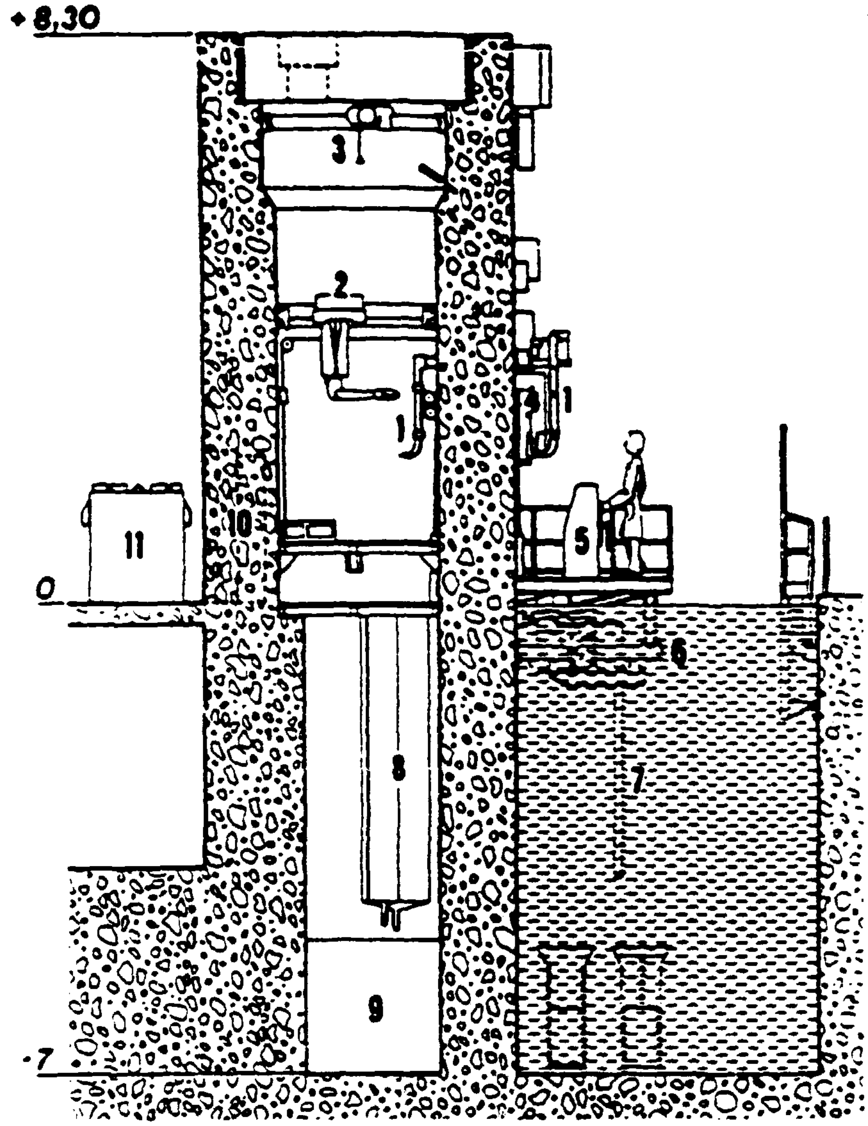

Fig.2 - Diagram of the Hot Cell Structure

1. Ligh TM
2. Heavy TM
3. Lifting Crane
4. Periscope
5. Cell conveyor Control
6. Cell conveyor
7. Device to be Dismantled
8. Clearance Pit
9. Effluent Tank
10. Rear Door
11. Lead Cask

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