humanisering van arbeid tno

organisatie voor
toegepast natuurwetenschappelijk
onderzoek

dwarsverband humanisering van arbeid

bureau
wassenaarseweg 56
leiden

postadres
postbus 124
2300 AC leiden

telefoon 071 - 17 04 41
giro 202277 tnv NIPG-TNO
leiden

ERGONOMIC FACTORS OF PROCESS CONTROL SYSTEMS - Phase 1: identification of ergonomic factors

Report I: LIST OF ERGONOMIC FACTORS

A.A.M. Kop [1]
J.A.M. Postmes [1]
with co-operation of C.K. Pasmooij [2]

This research was commissioned and sponsored by the International Instrument Users Association (WIB)

[1] Institute for Mechanical Constructions (TNO-IWECO)
[2] TNO Bureau for Humanization of Work (Humar)

Report no.: HA 295a
Date : August 1985

CONTENTS

		page
	SUMMARY	ii
1.	INTRODUCTION	1
2.	FRAMEWORK FOR ERGONOMIC FACTORS	2
3.	THE FACTORS LIST USED AS A CHECKLIST	6
4.	THE DEFINITIVE FACTORS LIST	9

SUMMARY

The International Instrument Users Association (WIB) commissioned the Dutch Organization for Applied Research TNO to execute a research project with the objective to formulate ergonomic guidelines for Process Control Systems (PCS). The first phase of the project was executed by the TNO Institute for Mechanical Constructions (TNO-IWECO), under responsibility of the TNO Bureau for Humanization of Work (Humar). The objective of this first phase was limited to the identification of ergonomic factors concerning the use of PCS. The study is presented in two reports: report I contains the definitive list of ergonomic factors and report II gives an account of the research project. In the second phase of the project, as far as possible, limits of these ergonomic factors can be determined with the ultimate goal to formulate ergonomic guidelines for PCS. This second phase is to be executed after consultation with WIB.

To identify the relevant ergonomic factors concerning the use of PCS, literature was consulted and the subject was discussed with experts. A field study was done by consulting the project sponsors. Questionnaires were sent to the sponsors, and in addition two plants were visited to discuss the subject at site with local experts.

The study resulted in the attached "Definite Factors List". The factors are grouped on four levels ("clusters") which are hierarchically related. The clusters are:

1 - process and control systems
2 - operator task and environment
3 - interface design concept
4 - human I/O devices and workstation

Within each cluster, groups of factors are distinguished in order to provide a framework in which the ergonomic factors can be arranged. For example, in the first order cluster the three factor groups (A) system objectives & restrictions, (B) process characteristics and (C) control system characteristics are defined. Although this report does neither contain quantitative data nor an indication of priorities, the definite factors list can be used as a tool for design, selection and implementation of PSC.

1. INTRODUCTION

Process Control Systems (PCS) are applied increasingly in the automatic control of industrial processes. PCS are characterized by a functional and/or physical distributed structure. These systems include facilities for the exchange of information between process and users, e.g. human I/O-devices such as Visual Display Units (VDU's), printers, hardcopy units, keyboards and light pens. The application of PCS has consequences for the task of the process operator. To avoid problems in task performance certain ergonomic criteria have to be met, which have to be based on capabilities and limitations of the users of the PCS. The function of PCS in control and monitoring of the process is very important for the PCS users in performing their tasks. These tasks include control actions, monitoring, optimalization of the process, and the detection and diagnosis of disturbances.
The first phase of this research project (an account of this study is extensively covered by report II) has the objective to identify the relevant ergonomic factors. The investigation, of limits of these ergonomic factors, with the ultimate goal to formulate ergonomic guidelines for PCS, will be executed later in the second phase of this research project.

2. FRAMEWORK FOR ERGONOMIC FACTORS

The design and application of PCS shall take into account the capabilities and limitations of the users. Process and control system characteristics largely determine the tasks which have to be performed. Operator and PCS tasks shall be described in terms of activities, information processing characteristics etc. Each task can be judged in terms of ergonomically acceptable or unacceptable elements.
Ergonomic factors are linked to the process-PCS-operator system at different levels:

level (cluster order)	subject
1.	process and control system
2.	operator tasks and environment
3.	interface design concept
4.	human I/O-devices and workstation

At the highest level (1) process and control system characteristics determine via operator tasks (2) and interface design concept (3) the lay-out of human I/O-devices and workstation (4).
This approach has been the basis for the framework to fit the ergonomics factors. The four levels are called clusters. Within these clusters groups of related factors are arranged (see fig. 2.1).

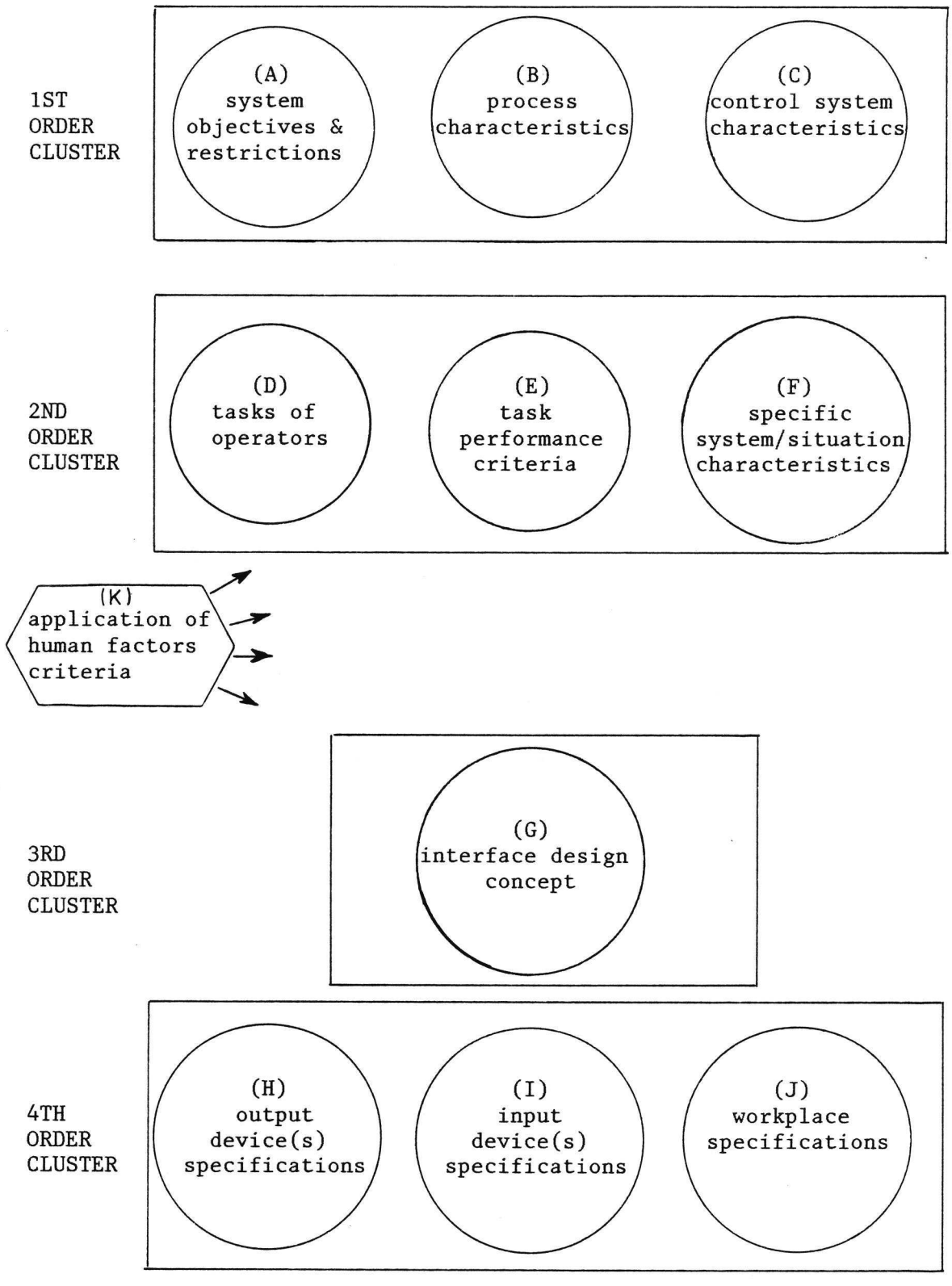

Fig. 2.1 Structuring of keyfactors in clusters and groups of factors.

The groups of related factors are as follows:

1st order cluster:

(A) System objectives and restrictions (objectives and restriction in terms of production aspects).

(B) Process characteristics (structure, type, modes, variables, behaviour, hazard potential).

(C) Control system characteristics (function, degree of automation, strategies, operational aspects, alarm system).

2nd order cluster:

(D) Tasks of the operator(s) (operational tasks, additional tasks, task content).

(E) Task performance criteria (operational criteria).

(F) Specific system/situation characteristics (operator-oriented, organization-oriented, other personnel).

3rd order cluster:

(G) Interface design concept (specific information for PCS-use in each process mode, general information, required human intervention, general human input-means, input-output dialogue, training facilities, additional demands to interface).

4th order cluster:

(H) Output device(s) specifications (VDU, displays - general aspects, specific display aspects and elements, printers, acoustic systems, conventional instruments, other output devices).

(I) Input device(s) specifications (joystick, trackball, light pen, touchscreen, keyboard, mouse, graphic tablet, voice input).

(J) Workplace specifications (workplace lay-out, environmental influences, general control room design, hardware configuration).

In addition to the above mentioned groups of factors, general human factors criteria (K) can be distinguished which have to be taken into account when

assessing PCS in their application. These human factors are the physical and mental workload of the operator, etc.

These groups of factors can be found in the factors list of chapter 4. The purpose of this list is to present a survey of ergonomic factors, which may serve as a starting point for the formulation of ergonomic guidelines for design, selection and implementation of PCS.

3. THE FACTORS LIST USED AS A CHECKLIST

The factors list as presented here identifies relevant ergonomic factors, and gives an arrangement of these factors on the basis of a subdivision in clusters and factor groups. It should be emphasized that consequently the factors can differ mutually in detail, importance for a specific application, knowledge of accepted limits, etc. Nevertheless this "gross" factors list can be of use in the assessment of ergonomic properties of PCS, because it can be considered as a checklist for this purpose. In the following it is described how the factors list in practice can be used as a checklist in practice.

In figure 3.1 the major activities which have to be carried out in the design (by the manufacturers) and application (by the user) of PCS are given.

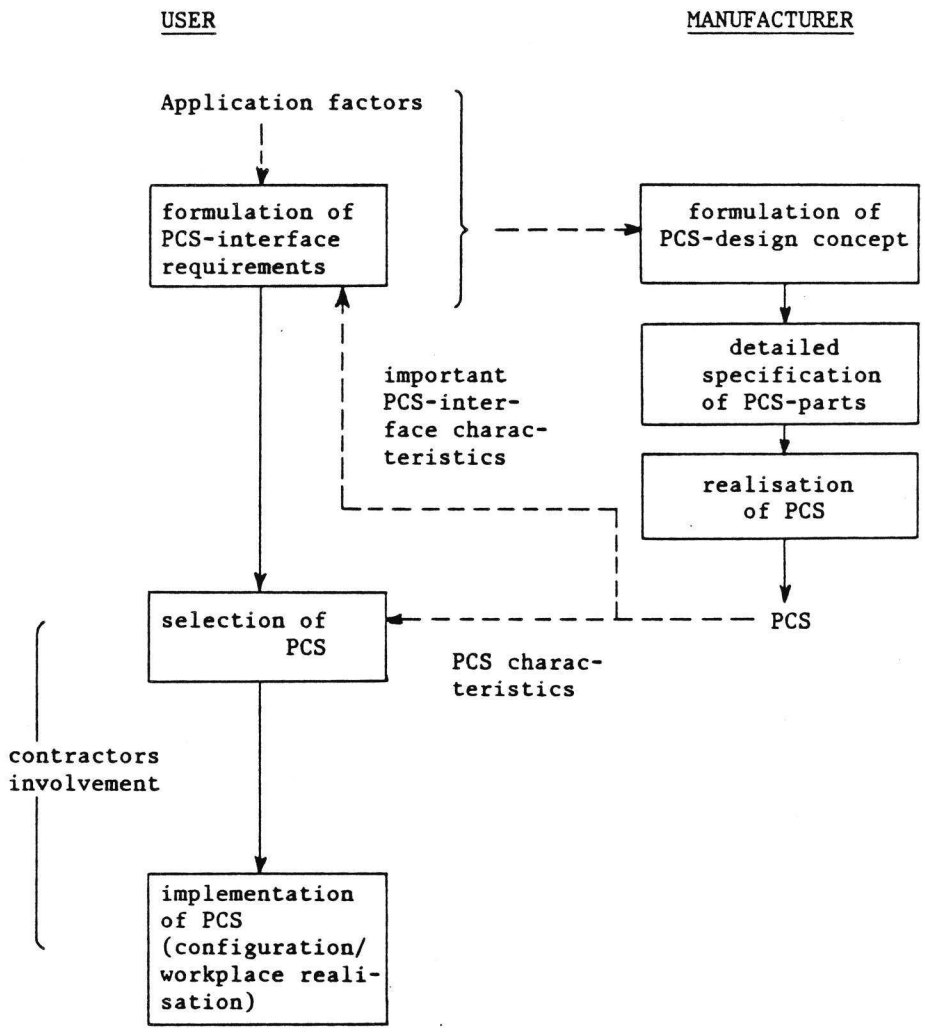

Fig. 3.1 Activities in PCS design, -selection and -implementation.

During these successive activities of manufacturers and users, the factors list can be used as a checklist. The importance of the factors depends on the specific application. Priorities with respect to factors which have to be applied can not be given in general. The results of the literature and field study (see report II) show, that priorities strongly depend on the application of PCS in practice. Users of the factors list therefore should make their own selection.
In all cases, six steps in using the factors list as a checklist can be distinguished:

Cluster 1	Step 1	:	describe system objectives/restrictions and process characteristics (factorgroups A and B)
	Step 2	:	describe control system characteristics (C)
Cluster 2	Step 3	:	describe tasks of operator (and PCS) and task performance criteria (D and E)
	Step 4	:	describe specific system/situation characteristics (F)
Cluster 3	Step 5	:	specify interface design concept (G)
Cluster 4	Step 6	:	specify I/O-device(s) specifications and workplace specifications (H, I and J)

During step 3 and following steps, it is essential to take general human factors criteria (K) into consideration as well. Some examples of the 6 steps are given with regard to the factors concerned (the characters and numbers refer to factor(groups) in the definite factors.

Step 1:
Some factors do or do not apply (e.g. A2.4, B2, B3.3) or have to be specified (e.g. A1, A2.5, B1.1, B4.2).

Step 2:
The same is true for this step (e.g. C1.4, C3 respectively e.g. C2) and is related to the outcome of step 1.

Step 3:
Process control tasks have to be allocated to the operator or the PCS. Here it is important to analyse in how far the resulting operator tasks do meet the general human factors criteria as listed under K. If this is not the case, the allocation of tasks between PCS and operator(s) should be repeated.

Step 4:
On the basis of the outcome of step 3 it is possible to make an assessments of factors in this factor group F (e.g. D1 and D2 relate to F1, E1 relates to F1).

Step 5:
Many of the factors which have to be checked during this step are related to previously specified factors (e.g. G1.1 relates to A1, A2.1-A2.4, A2.7; G1.2 relates to B4.6; G1.3 relates to A1, A2.1-A2.4, A7, B3, B4.5, B5.2, B5.3; G3.1 relates to B3, E1.1-E1.4).

Step 6:
For a number of factors which have to be checked during this step ergonomic criteria are applicable without requiring prior knowledge of factors from previous steps (e.g. H.1.1.1-H.1.1.10). Other factors however do require such knowledge (e.g. H.1.1.11 relates to F1.1, F1.3, F3; H.1.3 relates to G1, G2, G5).

Again it is emphasized that following these steps only helps in recognizing influencing factors in accessing PCS, because no quantitative information on these factors is available from this list.

4. THE DEFINITIVE FACTORS LIST

On the following pages the definitive factors list is presented (see also appendix 5 in report II).

1ST ORDER CLUSTER

A. Factors concerning system objectives and restrictions

1) production-objectives, e.g. concerning:
product-quality, -quantity and -costs.

2) production-restrictions, e.g. concerning:
1. raw materials (use, saving)
2. energy saving
3. safety, loss prevention
4. environmental pollution (prevention/limitation of material discharge)
5. operations (approach, procedures)
6. personnel (workload, safety, experience level, availability, etc.)
7. installation (preservation, maintenance).

B. Factors concerning process characteristics

1) process-structure:
1. functional (number of subprocesses, integrated operations)
2. physical/geographical structure of process
3. physical/chemical nature of process.

2) process type (batch or continuous) of subprocesses

3) process modes (frequency of occurrence, duration):
1. start up (planned, disturbed)
2. operation (planned, disturbed)
3. change-over (planned, disturbed, not-planned)
4. shut down (planned, disturbed, not-planned).

4) process variables:
1. number of continuous and binary measured/calculated process variables
2. accuracy (deviation in %)
3. measurableness/determinability of process state
4. controllability
5. mutual interaction
6. disturbances (frequency, duration)

5) process behaviour:
   1. dynamical aspects (time constants of subprocesses, batch duration, changing characteristics, linear, non-linear)
   2. process disturbances/equipment malfunction (frequency of occurrence, duration, randomness, inside or outside process)
   3. stability
   4. predictability.

6) hazard potential of process (explosion, hazard, toxicity).

C. Factors concerning control system characteristics

1) functions performed by control system, e.g.:
   1. stabilising control of process variables
   2. on-off control (switching actions, sequence control)
   3. process coordination
   4. process optimization
   5. upset control
   6. emergency control
   7. alarming/alarm analysis
   8. monitoring
   9. reporting.

2) degree of automation:
   1. number of control loops for process control (in terms of final control elements, PID-loops, arithmetic functions, analog/discrete)
   2. number of control loops for plant protection
   3. number of switching actions executed by system.

3) control strategies:
   1. single loop control
   2. cascade control
   3. ratio control
   4. adaptive control
   5. multivariable control
   6. other control (free programmable algorithms, etc.).

4) operational aspects:
   1. interaction between control loops
   2. possible malfunctions of control system (hard and software) and effects

2ND ORDER CLUSTER

D. Factors concerning the tasks of the operator(s)

1) process control tasks (frequency) in each process mode:
   1. on/off control
   2. stabilising control
   3. tuning of control loop
   4. optimizing control
   5. process monitoring
   6. scheduling/planning of process operation
   7. fault management (fault detection, compensation, identification, correction).

2) additional tasks, e.g.:
   1. administration
   2. reporting
   3. maintenance diagnostics (preventive, curative)
   4. communication
   5. others.

3) characteristics of tasks in each process mode, e.g.:
   1. frequency of task activities
   2. percentage of time spent on different tasks
   3. required number of operator actions.

E. Factors concerning task performance criteria

1) relevant criteria (and dependance on circumstances):
   1. required accuracy of task performance
   2. required speed of task performance
   3. required response time
   4. allowable operator faults (amount and nature)
   5. task priorities.

3RD ORDER CLUSTER

G. Factors concerning interface design concept

1) specific information required for operators (or other PCS-users) in each process mode:
   1. overall information on process state and performance
   2. information on occurence and location of deviations from required operation
   3. information on essential process variables
   4. information on process structure (functional, topological, relations with control system information)
   5. information on historical or predicted future process behaviour
   6. information on interaction between process variables
   7. information on functioning of the control system.

2) general information aspects:
   1. amount
   2. complexity
   3. update frequency
   4. sequence
   5. accessibility
   6. coding method
   7. serial or parallel presentation
   8. importance, priority
   9. redundancy
   10. relevance.

3) required human intervention actions:
   1. switching of process plant equipment
   2. changing of setpoints
   3. changing of control system tuning parameters
   4. acquiring of information
   5. (de)activating control system hardware and software functions.

4) general human input-means aspects:
   1. input information aspects (amount, complexity, sequence of input actions, coding methods, form, required number of user actions before command execution)
   2. existance/robustness to pollution and wear
   3. failure rate
   4. security against unintentional or accidental operation
   5. frequency of use
   6. flexibility.

4TH ORDER CLUSTER

H. Factors concerning specifications of output devices

1) video display unit:

1] general screen-characteristics

1. resolution
2. refresh rate
3. flicker
4. contrast between symbol/background
5. size
6. image sharpness (of dots, colour convergence)
7. image stability
8. luminance (character, background)
9. reflections (screen filters)
10. screen profile
11. screen orientation
12. side-effects (radiation, generated heat, noise)
13. work station aspects (number of screens, allocation of display functions between screens, redundancy of operator stations, lay-out of work station).

2] displays, general aspects:

1. number of displays
2. accessibility of displays (speed of access and response)
3. allocation of information between displays
4. hierarchical structure of displays (relations between displays)
5. coding of display-structure
6. use of colour (combination of colours, meaning, consistency, total number of used colours, intensity)
7. structuring of information on display
8. information density on display (static, dynamic).

3] specific display aspects:

1. overview (presentation method)
2. group (number of loops on one display, coding)
3. loop (bargraph-presentation method, loop-identification number)
4. trend (sample frequency, update frequency, screen resolution, line thickness, number of lines in a graph and coding, scale)

4) conventional instruments:
   1. recorders
   2. (single-loop) indicators
   3. relation with PCS.

5) other output devices:
   1. hard copy unit (e.g. video copier)
   2. tape unit
   3. mass storage devices (e.g. magnetic, diskette units, solid state memory)

I. Factors concerning specifications of input devices

1) joystick:
   1. dimensions
   2. shape
   3. feedback of cursor-position on screen
   4. feedback of activation on screen
   5. feedback method (force- or position feedback)
   6. handling resistance
   7. ratio joystick movement/cursor movement
   8. position of enter switch
   9. required accuracy of positioning.

2) track ball (with enter key):
   1. dimensions
   2. texture of surface
   3. turning resistance
   4. feedback of cursor-position on screen
   5. feedback of activation
   6. ratio track ball movement/cursor movement
   7. position of enter key
   8. required accuracy for positioning.

3) lightpen (with or without enter-key):
   1. dimensions
   2. shape/profile
   3. feedback of activation action
   4. feedback of activation on screen
   5. frequency of use
   6. weight
   7. resistance (pull of cable)

7) graphic tablet (data or digitizing tablet; with or without keys, lightpen or puck):
   1. dimensions of tablet
   2. shape of tablet
   3. surface characteristics (hardness, reflection, sensitivity to pollution)
   4. position of tablet in relation to screen
   5. input method characteristics (lightpen, keys, pencil, etc.).

8) voice input:
   1. technical means
   2. required volume
   3. required clarity of pronounciation
   4. number of input commands available
   5. allowable speed of input
   6. feedback of input command
   7. position of input device in relation to screen
   8. sensitivity to environmental noise
   9. sensitivity to different voices
   10. language.

J. Factors concerning workplace realization

1) lay-out of workplace:
   1. working posture (standing or sitting, head-position and movement, postural loading)
   2. foot rests/arm support
   3. dimensions of workstation (workspace, desk height, shape, etc.)
   4. distance between user and information sources (reach and reading distance)
   5. amount of workspace (administration)
   6. surface of workdesk (texture, reflection)
   7. chair
   8. documentation, manuals, procedures
   9. resting place
   10. relation of workplace with rest of the plant and personnel (toilet, coffee machine, offices, etc.).

K. APPLICATION OF GENERAL HUMAN FACTORS CRITERIA

- acceptable physical workload:
  - working posture
  - movements to be executed (limbs, head, eyes)
  - forces to be exercised
  - number/frequency of actions (i.e. pressing a key) to be executed
  - physical condition of man.

- acceptable mental workload:
  - memory load (short and long term)
  - required information processing (amount, speed)
  - stress
  - mental condition of man.

- acceptable workplace:
  - attainability of working-tools
  - comfort/well being
  - environmental influences (noise, heat, radiation, climate, lighting, vibrations)
  - social needs (contacts with colleagues).

- user-acceptability of working-tools and -aids:
  - reliability of system operation
  - proper feedback of actions (visual, audible, tactile)
  - accessibility, observability and readability of information
  - compatibility between displays and controls
  - required motoric and mental skills for system operation
  - attainability and managebility of tools
  - learning time.

- job satisfaction (motivation).

- individual differences between persons and shifts.