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

Report II: ACCOUNT OF LITERATURE AND FIELD STUDY

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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

1.1 PROBLEM DEFINITION

Since a number of years an increasing use has been made of so-called Process Control Systems (PCS*) for the control of processes in the process industries.
Process Control Systems are one of the recent developments in automatic process control, replacing single loop analog control instruments. With PCS are meant control systems usually based on microprocessors, which are characterized by the possibility of a functional and/or physical distributed structure. These systems do not only have a function in the real time automatic control and supervision of the process, but also provide facilities for the exchange of information between process and operator. The information presentation function is provided by means of Visual Display Units (VDU), printers etc. The use of VDU's for monitoring the process, is one of the changes for the operator compared to conventional equipment. The means for intervention in the process are different as well (i.e. keyboards, lightpen, etc.).
The operator has important process control tasks (such as optimalization of the process output, the detection and diagnosis of process disturbances or equipment malfunctions and intervention when critical process states occur), and hence the ways of interaction with the process are essential for a good task-performance. Therefore, the PCS should meet certain ergonomic requirements.
Companies which use PCS (user-companies) as well as companies which manufacture PCS (manufacturer-companies) show a growing interest in ergonomic aspects of PCS. There appears to be a demand from both sides for ergonomic guidelines which apply to the design, implementation and evaluation of PCS. Such guidelines are at the moment only available on certain specific ergonomic aspects of PCS, but not applicable to PCS in general.

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* The abbreviation PCS in this report is used for the singular as well as the plural use of the term.

The International Instrument Users Association (WIB) has initiated a research project that should lead to generally applicable ergonomic guidelines for PCS.
The project has been set up as an international multi-sponsor project, in which both PCS-users and -manufacturers participate. For a list of the sponsors, see appendix 1.
WIB commissioned with the execution of the first phase of the project the Dutch Organisation for Applied Research TNO. The Institute for Mechanical Constructions (TNO-IWECO) formulated the project plan and executed the first phase of the project. The TNO Bureau for Humanization of Work (HUMAR-TNO) was responsible for the project supervision.

1.2 PROJECT PLAN

In the project plan it has been proposed to execute the research in two phases, with the following objectives:

- <u>First phase</u> - the identification of ergonomic keyfactors (aspects which influence the operation of the PCS by the process operator) which are relevant in PCS applications;
- <u>Second phase</u> - the investigation in how far limits of these ergonomic keyfactors can be determined with the ultimate goal to formulate ergonomic guidelines for PCS.

The first phase of the research project has been executed so far, and is reported on in this volume and in report I (see section 1.4). The concrete result of the first phase is a list of ergonomic factors. Besides, recommendations are to be given how to execute the second phase of the research in order to arrive at practically applicable ergonomic guidelines on PCS.

1.3 FIRST PHASE OF THE PROJECT

The objective of the first phase is to identify ergonomic keyfactors of PCS. The term 'ergonomic keyfactors of PCS' has been more specifically defined as: those aspects which, starting from human abilities and limitations, influence the control of processes by the operator using a PCS.* The ergono-

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* In the course of the project the prefix 'key' has been dropped using the term 'factors', reserving the term 'keyfactors' for the most important factors only.

mic factors of PCS for example include the means of the PCS for information-presentation (e.g. displays, printer) and intervention (e.g. touchscreen, lightpen), operator-centered factors (e.g. tasks, training, experience) and environmental influences (e.g. lighting, climate). Specific situation-dependent factors of social or organizational nature are not included.

The first phase shall result in the following items:

- a list of ergonomic factors for PCS;
- priorities for certain factors as indicated by the project sponsors;
- a proposal for further research, including an adjustment of the project plan for the second phase if necessary.

The factors-list shall be based on relevant literature findings and consultation of experts. In the course of the project the sponsors shall be consulted on their opinions considering priorities in the keyfactors list. Finally, the proposal for future research shall be discussed with the sponsors as well as research institutions (universities, TNO).

The first phase shall include the following activities:

1. consultation of relevant information sources (literature, experts) and formulation of a draft factors list;
2. a field study including sponsor-consultation by means of questionnaires and company-visits;
3. formulation of a definitive factors list;
4. formulation of a proposal for further research.

During the project regular meetings are to be held with a working group, consisting of representatives of four PCS user-companies and WIB-members (see Appendix 1 for the names of these representatives).

1.4 CONTENTS OF THE REPORT

The first phase of the project is covered by two reports:

- <u>report I</u> : List of ergonomic factors
- <u>report II</u>: Account of literature and field study

Part II, this volume, is structured as follows. In chapter 2 the formulation of the draft factors list is described, using literature findings and expert opinions. This chapter also contains some remarks concerning the state-of-the-art in the present literature.

Chapter 3 deals with the field study, in which the project sponsors are consulted concerning the factors list, application-aspects of PCS and PCS-demands. The questionnaires used are described, and an analysis of the received answers is given. From these results conclusions are drawn.
Finally in chapter 4, the results of the preceding chapters are discussed. Based on this discussion, outlines of future research needs are identified.
The appendices contain a list of project sponsors, a list of literature references, the sponsor questionnaires as well as the draft and the definitive factors list.

2. FORMULATION OF DRAFT FACTORS LIST

2.1 INTRODUCTION

Because of the broad definition of the term 'keyfactor', it was clear that different types of ergonomic factors were to be identified. Therefore, it was felt that a framework including operator, process and operator-process interface was essential for obtaining a complete factors list. Such a framework stimulates a more systematical identification of ergonomic factors, and should make the factors list more readily accessible for users. Consultation of the literature was meant to investigate whether the available literature offers some kind of structure for the classification of ergonomic factors for PCS, as well as to identify ergonomic factors within this framework. Additionally Dutch experts have been consulted on the occasion of a meeting on May 3rd 1984 of the Scientific Themegroup "Process Control" at the University of Utrecht. These experts came from (Technical) Universities, research institutions etc. (among others prof.drs. J. Moraal, dr.ir. H. Kragt, prof.ir. J.E. Rijnsdorp, prof.dr.ir. H.G. Stassen, drs. H. Zwaga were present). The basic approach of the study as well as preliminary results have been discussed. Many useful comments were given with respect to the set up of the project. Besides, suggestion have been done for additional factors to be included in the factors list. In the report there will be referred to these discussions.

The literature used consisted of the following magazines,, from which the articles published over the last five years were consulted:

- Human Factors (Human Factors Society, Santa Monica, U.S.A.)
- Ergonomics (Taylor & Francis, London, U.K.)
- Applied Ergonomics (Butterworth Scientific Ltd., Guildford, U.K.)
- Systems, Man & Cybernetics (IEEE, New York, U.S.A.)
- International Journal of Man-Machine Studies (Academic Press, London, U.K.)
- Displays (Butterworth Scientific ltd, Guildford, U.K.)
- Regelungstechnische Praxis (R. Oldenbourgh Verlag GmbH, München, B.R.D.)
- Journal A (Kon. Vlaamse Ingenieursvereniging, Antwerpen, Belgium.)

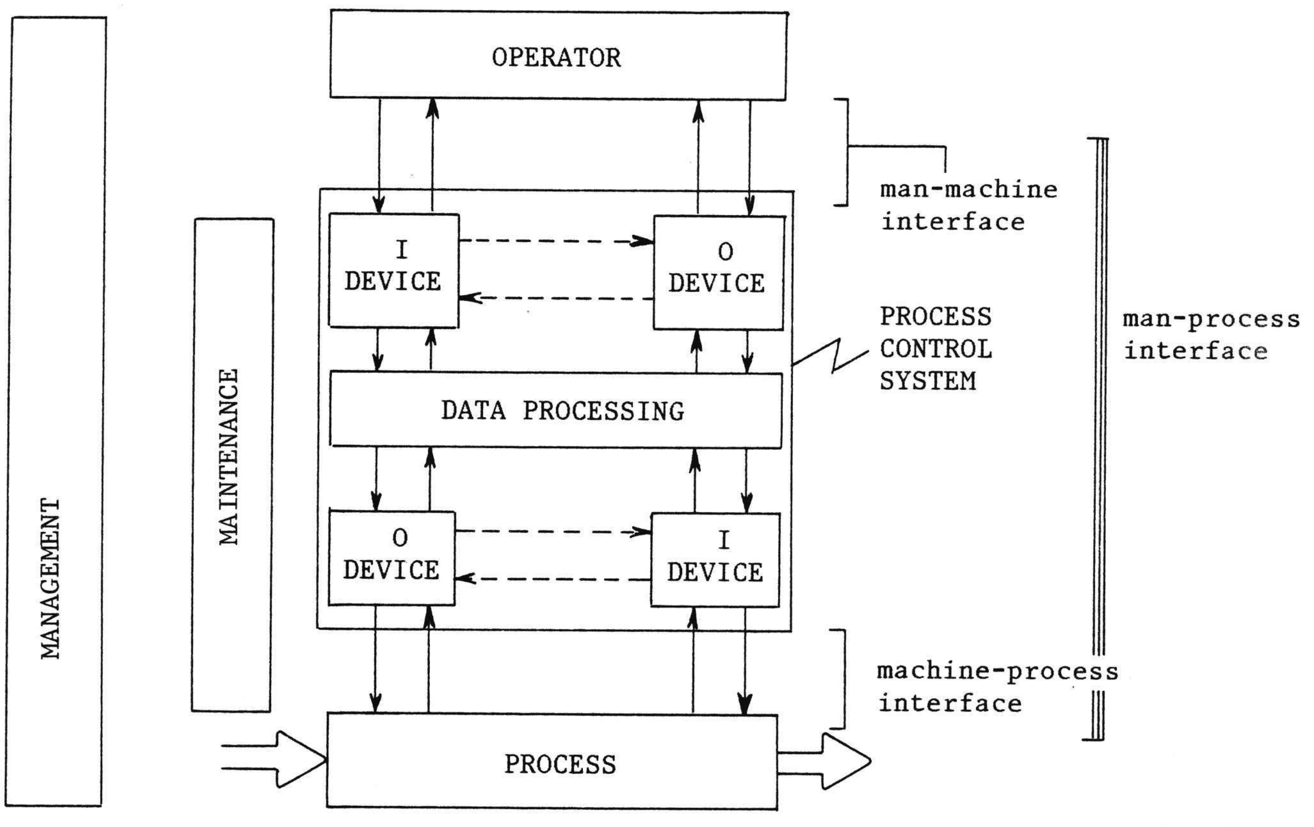

Figure 2.1 The man-process system consisting of the operator, the process control system (machine) and the process.

Furthermore, a number of handbooks and proceedings of conferences or symposia were consulted. In addition a computer survey has been performed by means of the ESA Information Retrieval Service on keywords like VDU, human factors, process control, man machine systems, etc. From experts and sponsor-companies consulted, literature references (e.g. company reports) were received as well.
The results of the literature survey are presented in the next section. In section 2.2.1 the framework for the factors list is described. In section 2.2.2 the ergonomic factors themselves are described in general. In section 2.2.3 some remarks are made about the literature findings. Finally, the meaning of the literature findings for the project is discussed in section 2.3.
In Appendix 2 a list of literature references can be found which are considered to be the most relevant publications for the project. The draft factors list can be found in Appendix 3.3.

2.2 LITERATURE SURVEY RESULTS

2.2.1 Framework for factors list

The system consisting of operator, Process Control System (PCS) and process can be seen as one system: the man-process system (see figure 2.1). This project deals with ergonomic factors which influence the control of processes by the operator using a PCS. Therefore, the most important aspect of the man-process system is the man-machine interface between operator and PCS (see figure 2.1). In order to enable the operator to perform his tasks adequately, the man-machine interface and the working environment (workplace) should meet certain ergonomic requirements. In addition, operator-centered factors like training and taskcontent should meet ergonomic requirements as well. Since all these items are mostly determined in the design of the man-machine system, a considerable amount of attention in literature has been and still is being paid to aspects of the design.
A substantial number of literature references contain proposals for a structured approach towards the design of man-machine systems (see for

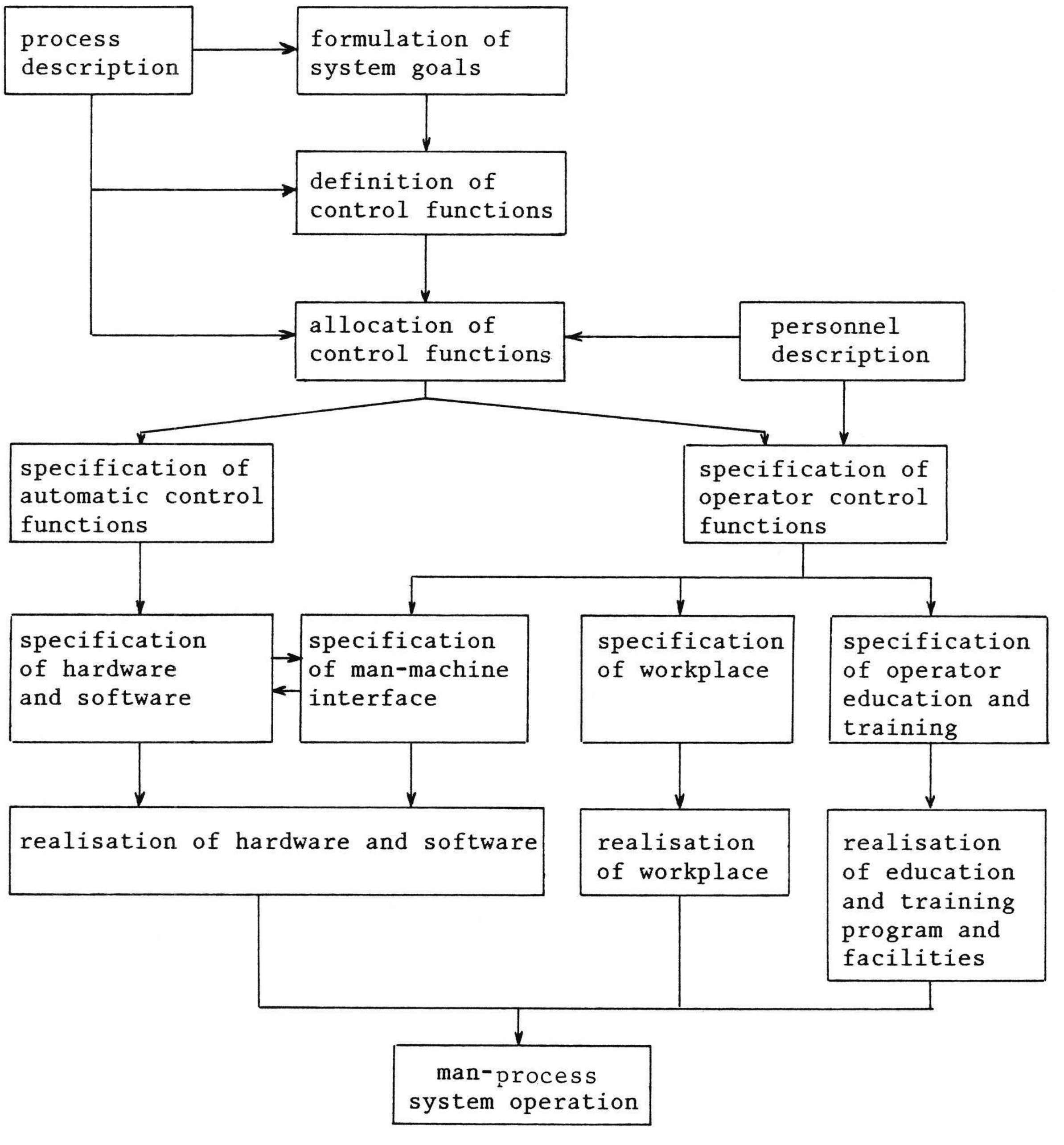

Figure 2.2 A structured approach for design of man-machine systems.

example appendix 2, references [A1] up to [A-13] *). Usually such an approach is presented in a flowchart; an example is given in figure 2.2.
The flowchart shows which activities have to be performed in the design and in which order. Starting from a description of the process, system goals are formulated. These goals not only include economic objectives (e.g. product quantity, energy), but also objectives concerning safety, environmental pollution etc. A following step is the definition of the functions which have to be performed in the control of the process (e.g. continuous or on/off control, monitoring), either by automatic systems or by operators. Next, the control functions defined are explicitly allocated to automatic systems or to the operator, taking process as well as personnel characteristics into account. This allocation of control functions could for example mean that the continuous control of a process variable is allocated to an automatic system, but that on/off switching of an installation component is done by the operator.
Concerning the automatic systems, it is evident that the control functions to be performed have to be specified in order to determine hardware and software requirements. Although less evident, the control functions to be performed by the operator should also be specified. This specification is required for the specification of the man-machine interface, the workplace and for the required operator education and training.
After finishing the specifications, the realisation of all items is started. It is clear that the design of a man-machine system is an iterative process. Although not explicitly shown in figure 2.2, iteration loops will occur in practice.

The flowchart representing the design process has been used as a starting point for the construction of a framework for the factors list. A number of factor-groups are identified, which are considered to be important as far as ergonomic aspects of the man-machine interface are concerned. These factor-groups are:

- System goals (objectives and restrictions);
- Process characteristics;
- (Automatic) control system charactistics;
- Operator task aspects;
- Man-machine interface aspects;
- Workplace aspects;

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*) The given index refers to the literature references in Appendix 2.

Some of these groups can be further subdivided. The group concerning operator task aspects can be separated in a group which contains factors on the tasks contents and a group which concern task performance criteria; this separation is considered to be valuable because of the importance of these criteria.
Furthermore, the group concerning man-machine interface aspects can be subdivided in a group concerning the principals of the interface design (the interface design concept), a group concerning the details of the output device(s) used and a group concerning the details of the input device(s) used.
The subdivision leads to nine factor-groups. It appeared that a tenth factor-group had to be added, which concerns some additional aspects related to the man-machine interface like for example other users of the interface in addition to the operator; this group have been called 'specific system/ situation characteristics'.

It is considered essential to structure the factor-groups in some hierarchical way. This has been done corresponding to the flow-chart of figure 2.2. The result is a hierarchy of factor-groups in four levels which are called clusters. This is shown in figure 2.3.
The clusters 1 and 2 contain factors which refer to the application aspects of a PCS. Therefore, the factors in these clusters can be called together application-centered factors. The clusters 3 and 4 contain factors which concern the PCS itself. These factors can be called PCS-centered factors.
As the framework shows, knowledge concerning the application-centered factors of clusters 1 and 2 is required before something can be said about PCS-centered factors of clusters 3 and 4.

2.2.2 General description of ergonomical factors

In this section a short description of the factor-groups will be given and some remarks will be made about the factors found in the literature; for a detailed account of the factors, the reader is refered to the draft factors list itself in appendix 3.3.

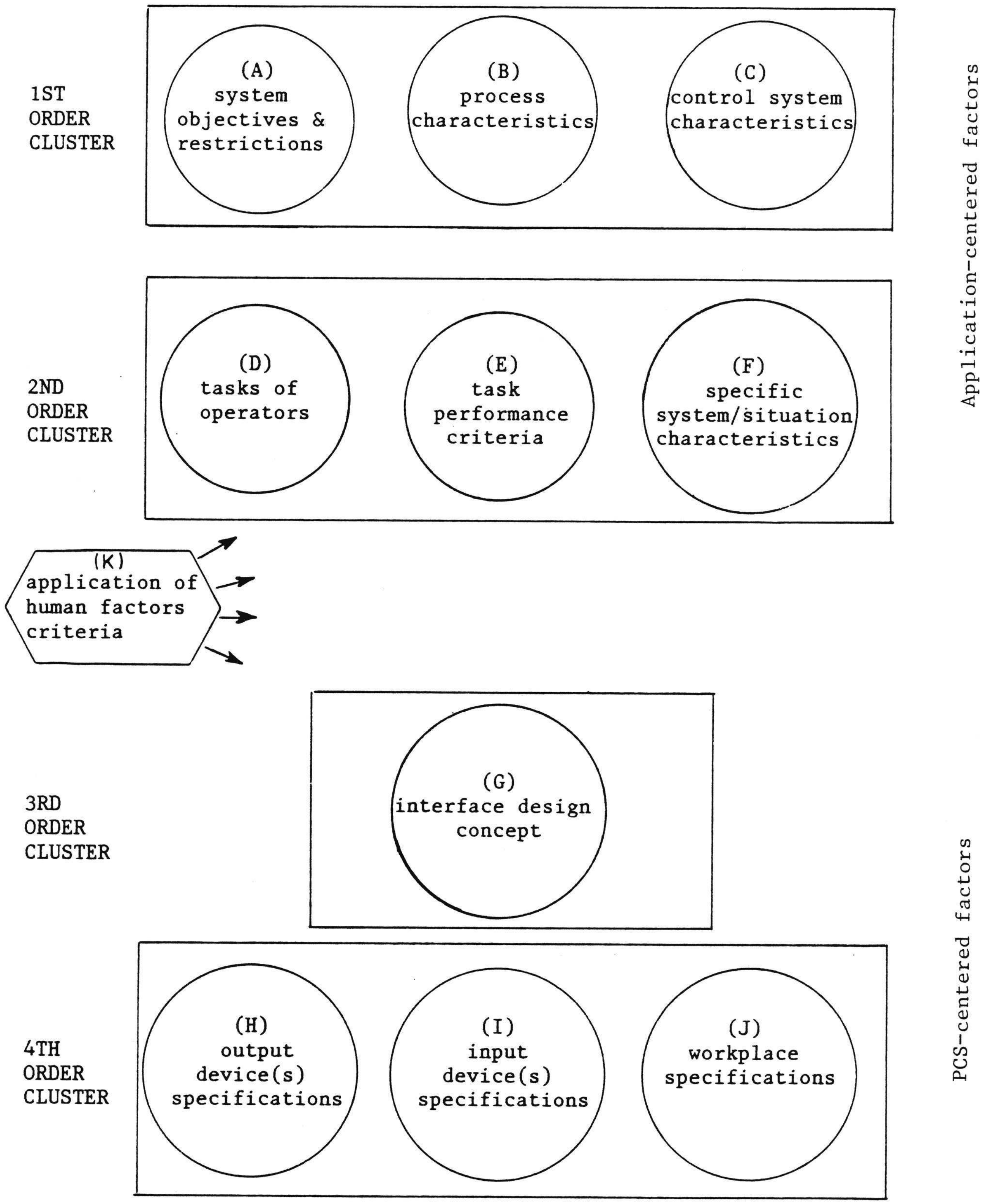

Figure 2.3 Structuring of factors in clusters and factor-groups.

First order cluster

The factor-group 'system-objectives and restrictions' contains factors concerning production-objectives (e.g. product-quantity or -quality) and production-restrictions (e.g. with respect to installation, use of raw materials). On these factors not much literature could be found. Handbooks and general articles usually give some rough descriptions on the subject [A2, D2, E1, E20], but more details about process-objectives for specific processes can only be found in specialized literature.
The factor-group 'proces characteristics' contains factors like for example the process type (batch, continuous) and the proces modes (e.g. start up, changeover). About process-characteristics some literature is available, but this is also limited [A2, C6, D2, D8, D15, E20]. Nevertheless, a number of factors can be clearly identified, which have some influence on the operator's job (for example: process structure and process-type). Also factors concerning dynamical aspects of process behaviour (for example time-constants of subprocesses or the stability of the process) are included. The 'hazard potential of the process' has been mentioned separately, because this factor can have considerable implications for the operator's tasks.
Finally, the factor-group 'control system characteristics' contains factors like the functions performed by the control system (e.g. on/off control, alarm analysis) and control strategies (e.g. cascade or multivariable control) applied. With respect to these factors the literature is also limited. Concerning the functions of control systems some literature is available [A2, D2, D15], in which terms like 'degree of automation' are used [C7]. The factor 'number of control loops' is an example of an empirical measure which is used in practice, but not extensively covered in literature. Factors concerning strategies used are seldom mentioned in literature. Relatively more has been published on alarm systems [C8, E3, E24].

Second order cluster

The factor-group 'tasks of operators' contains factors like the contents of operator control tasks (e.g. tuning of control loops, fault management) and other task characteristics (e.g. frequency of task activities).
On the task of the process operator many articles can be found. Some articles deal with the operator tasks to investigate what he is doing and how he

is doing his work [for example B3, C13], while other publications deal with task-aspects as a starting point for related items such as information presentation [for example E1, E7]. Concerning a description of the operators tasks, the literature does not show agreement on a taxonomy of tasks (i.e. a general applicable structure of the process control activities performed by the operator); different authors come up with task-aspects which agree to some extent [A2, B3, C6, D8, D15, E7, E20, G22], but also contain dissimilarities. The tasks of the operator are sometimes categorised per process mode [E20, D15].
The factor-group 'task performance criteria' contains criteria like required speed and accuracy of task performance, which are demanded from the operator. On task-performance criteria little is known. Mostly the operator-tasks are described in a general way; especially in research studies on operator performance, some performance criteria have been defined, but the validity of applying these measures in a practical situation is not clear.
The factor-group 'specific system/situation characteristics' contains some miscellaneous factors which influence the operator's functioning. Examples of factors are the number of operators, organization structure, and other users of the interface next to the operator (e.g. supervisor, maintenance). Most of these factors can be found in publications dealing with man-machine systems design [A2, D2, D17].

Third order cluster

This cluster consists of the factor-group 'interface design concept'. The interface design concept refers to the basic outlines of the interface like for example the information to be presented (e.g. on process structure, historical information) and input-means (e.g. amount of input information, sequence). Although a considerable number of articles deal with interface design, only a few can be found which deal with the information requirements of the operator. Some publications give a description of these requirements based upon the operator tasks [B2, D2, D8, E20, E22]. Other articles merely deal with factors which influence the information exchange between operator and process, based on ergonomic considerations [A6, D10, D19, D21, E31]. The human-computer dialogue has only recently received special attention [D11, D16, E33]. However, these publications do not deal with the dialogue between the operator and the PCS in particular.

Fourth order cluster

This cluster contains factors which concern specific characteristics of 'output devices' (e.g. screen resolution, use of colors on displays), 'input devices' (e.g. dimensions of keyboard and keys, weight of lightpen) and 'workplace' (e.g. dimension of workstation, lighting).
Many publications can be found concerning these factors. General factors concerning VDU's (i.e. resolution, size, reflections) and workplace can be found in handbooks [A1, A6, A7, G7], review articles or reports [D7, G17, G20] and company or government standards [G2, G3]. More specifically concerning the workplace of the process operator working with VDU's, the amount of literature is limited [G13, G22]. On specific displays for process control few publications are available as well [for example E35, G29].
Concerning the several input devices an extensive number of literature publications is available [F1-F12]. Unfortunately few of these publications concern process control applications, making research results difficult to interprete. Furthermore, since most of these articles deal with specific input devices only, general review articles are needed; few can be found [D12, F2], but again lack process control applications.

2.2.3. Remarks on the literature

Consultation of the literature was meant to identify a structure for the classification of ergonomic factors for PCS as well as these factors as such. Although the literature survey was not meant to assess the state-of-the-art of the literature, nevertheless some insights can be presented here which have been gained during the survey.
Most publications describe research which deals with rather detailed and specific subjects. In terms of the clusters defined this means that most literature describes research on factors which can be placed in cluster 4. In fact more than half of the consulted publications deals with 4th order cluster aspects as input devices, output devices and workplace specifications. The conclusion can be drawn that a lot is known and written down on these factors. However this knowledge can only usefully be applied when the PCS-application is clearly defined. In other terms this means that the relations of these (higher order) factors with the process and task conditions as determined in the lower order clusters have to be known. It seems that the literature on this point shows a lack of insight. As a consequence the literature did not offer a readily available framework or structure to fit in the relevant ergonomic factors. The following concluding remarks sub-

sequently can be made:

- most publications deal with subjects which can be placed in the 4th order cluster (detailed aspects of the interface and workplace);
- in many cases the conditions and criteria for which the results can be applied are not clearly defined;
- relations between factors in the higher order clusters (interface aspects) and factors in the lower order clusters (system goals, process and control system characteristics, operator task aspects) need to be investigated, as literature does not give much insight in this subject.
- it is clear, however, that process and control system characteristics for a great deal determine the tasks for the PCS and the operator(s), the "allocation of control functions" problem in Fig. 2.2. Much effort (not in the scope of this first phase of the project, but in further research and within the sponsor companies during design and implementation processes of PCS) has to be put in the analysis of this allocation function. As soon as the operator tasks and PCS tasks are clearly defined, relevant ergonomic aspects can be formulated. Emphasis should be put in determining in how far these tasks are on strategic, tactical or operational level (personal communication, experts meeting May 3rd, 1984).

2.3 DISCUSSION

The literature does not explicitly offer a framework for the factors list. However, sufficient support could be found for formulation of a framework. From the literature an extensive list of factors could be identified, although these factors differ in level of detail from aspect to aspect.
For the project it is in particular of importance to know <u>which</u> factors of the first two clusters (the application-centered factors) have to be taken into account when dealing with factors of the third and fourth clusters (the PCS-centered factors). This means that knowledge is required on the <u>relations</u> between factors of different clusters. In addition, from an application point of view it is useful to know which factors in each cluster are the most important ones to take into account in general or in particular for a specific process.
Unfortunately, the relations between factors of different clusters as well as factor-priorities are not sufficiently covered in literature.
These findings have some implications for the approach of the field study. From the field study more insight should be gained in the relations between factors and in factor priorities.

3. FIELD STUDY

3.1 INTRODUCTION

A limited field study has been included in the first phase of the project to assure the communication with the sponsors of the project. This communication is considered to be essential in obtaining results that are useful to the sponsors in practice. On the basis of the results of the literature survey some additional aims of the field study have been formulated (see section 2.3.), namely to gain more insight in the relations between factors of the different clusters as well as in the priorities of factors that could be identified in practice. However, because of the limited scope of the first phase of the project, the field study could only be an orientation in practice, rather than being a thorough investigation.

For the field study the following set-up has been chosen.
Firstly, a draft factors list has been sent to all sponsors together with a questionnaire. For each group of sponsors a specific questionnaire has been made (the following sponsor groups are identified: users, manufacturers and the contractors). The set-up and contents of these questionnaires is given in section 3.2; the results are discussed in section 3.3.
Secondly, site visits have been made to two user-companies. These visits served on the one side to support the interpretation of the completed questionnaires. On the other side, a specific process equiped with a PCS was examined in each company to gain insight the procedures and criteria, which were used for the selection and implementation of the PCS. During these visits there have been discussions with the operators using the PCS, as suggested during the experts meeting on May 3rd 1984. Due to reasons of confidentiality, no explicit reporting on these visits has been made. However, the findings of these visits have been taken into account in the interpretation of the completed questionnaires and the formulation of conclusions.

3.2 QUESTIONNAIRES

For the set-up of the questionnaires it appeared to be of importance to distinguish between the different sponsor groups (user, manufacturer, contractor), because of their different roles in PCS use, design and implementation. Taking these differences into account, more specific questions could be formulated, especially with respect to users and manufacturers. The contractors form a special group, as will be discussed later. Despite of the specific nature of the questionnaires, the possibility to compare the answers of the three sponsor-groups has been chosen as a starting point. Hereafter, the specific questionnaires will be described in some more detail (copies of each questionnaire can be found in appendix 3).

PCS-users questionnaire (appendix 3.1)

In order to investigate the relations between factors in different clusters and factor-priorities, insight is needed in actual applications of PCS concerning factors of the first and second cluster (application-centered factors). For this reason the user-questionnaire starts with a part A, which contains questions on two different processes to be chosen by the user. The questions are set up using the structure and contents of the draft factors list. More specifically questions on the following aspects are asked: process characteristics (e.g. continuous/batch, number of subprocesses, time constants, process modes), control system characteristics (e.g. number of control loops, number of measurements) and operator-centered aspects (e.g. number of console and field operators, specific tasks and their frequency). Part A also serves as starting point for the remaining parts B and C of the questionnaire: while completing these parts, the user is asked to use the two described processes as references. With this approach, more specific answers were expected on the questions of parts B and C.
Part B of the questionnaire concerns the draft factors list itself. The user is asked whether in his opinion there are factors missing in the list. He is also asked to indicate a priority between the clusters and factor-groups, according to their relevance for the specific processes of part A.
Finally, part C concerns factors of the third and fourth clusters (PCS-centered factors) and deals with the demands which the user-company has

towards PCS when applied to the processes of part A. In the questions a distinction is made in PCS-demands because of certain process characteristics, certain operator tasks, required types of information to be exchanged via the PCS, required methods for information input and output and required hardware or layout of the PCS (for each case an example is given in the questionnaire). The last question in this part concerns the most important information-sources of the company for identifying the PCS-demands.

PCS-manufacturers questionnaire (appendix 3.2)

The questionnaire to the manufacturers consists of two parts: a part A concerning PCS-demands and a part B with questions on the draft factors list. Part A differs only slightly from part C of the users-questionnaire. The questions are dealing with the demands that users have expressed to the manufacturer concerning PCS. The same aspects of the PCS-demands are distinguished as in the users-questionnaire, for allowing a comparison of user- and manufacturer-answers. The second part of the manufacturers-questionnaire, part B, is the same as part B of the users-questionnaire.

Contractors-questionnaire

In the set-up of the questionnaire, the contractors have at first not been regarded as a separate sponsor group. Because of their experience with selection and implementation of PCS, the contractors have been sent the same questionnaire as the PCS-users. However, in the course of the project it was felt that a distinction between users and contractors should be made, because of their different involvement in PCS-applications. More attention will be paid to this in section 3.3.

3.3 RESULTS

3.3.1 General remarks

The results of the questionnaires are presented in tables in Appendix 4. Before discussing the actual results, first some general information will be given about the completed questionnaires and some problems encountered.

The response on the questionnaires sent was good (see table 1 of Appendix 4). A considerable number of persons were involved in the completion of the questionnaires, differing in the function which they have in the company (see tables 2 and 3).

During the analysis of the results a few problems were identified, which handicapped the interpretation of the results:

- From the given answers on the questionnaires and from the company-visits it became clear that most sponsors had some difficulty with the completion of the questionnaire. The number of persons within a company which had to be involved to cover all relevant aspects, appeared to be one of the reasons for this.

- It became evident that different interpretations had been used by the respondents for terms used in the first part of the users-questionnaires. Although considerable attention had been paid during the formulation of the questionnaire to a clear definition of terms used (including elaborate discussion beforehand with the sponsor working group), it appeared that these differences in applied definitions could not be avoided. From the visits to the two user-companies it was concluded that not only the background or function of the persons involved in completing the questionnaire contributed to the application of different definitions, but also the common jargon in the particular branch of industry. In order to get an idea of these differences, a specific question was included in part A of the users-questionnaire concerning the definition of the term, 'subprocess'.

- On the question when a part of the process is called a subprocess, the respondents for example gave the following definitions:
  - Whenever a distinctly different "process" is applied;
  - When the part of the process is a complete unit on its own with an identifiable feed and product;
  - When it has an independent start-up and process operation;
  - When it does not form a part of the main process;
  - When it is separated by a buffer from other parts of the process or can be operated independently;
  - When there is a certain autonomy for that part of the whole system (separation in time possible by means of tanks, buffers or/either parallel system).

Although the definitions show some similarity, they are not really the same. This finding is not only of importance for the interpretation of the questionnaire-results. Also for the project as a whole, this example shows that a uniform definition of terms like 'subprocess' should be available when general applicable guidelines are strived for.

o The contractor-companies are often involved in the selection and implementation of PCS in user-companies. Especially for user-companies which do not have all the required expertise available within the company, the rôle of the contractor-company is of relatively more importance. In this situation, the contractor-companies should in our opinion be seen as a separate group involved in PCS-applications, next to PCS-users and -manufacturers.
Unfortunately the number of completed questionnaires from contractor-companies was too small to draw valid conclusions. For this reason the analysis of the contractor-questionnaires could only be of very limited scope. However, in our opinion explicit attention should be paid in the follow-up of the project to the needs of the contractors concerning ergonomic aspects of PCS, next to the needs of the users and manufacturers.

In the next sections 3.3.2 until 3.3.4, the results of the users- and manufacturers-questionnaire are discussed. Because of the objectives of the field study and the problems mentioned, this discussion will only concern main points. A description of factors on PCS-applications is given in section 3.3.2. Next, section 3.3.3. concerns ergonomic demands on PCS. In section 3.3.4 the opinions of the sponsors are given with respect to the draft factors list. Finally, conclusions are drawn in section 3.4 on basis of the found results.

3.3.2 Description of PCS-applications

In this section the processes described by the user-companies, are discussed. The following items have been described: process-characteristics (see table 4 of Appendix 4), control system characteristics (table 5), aspects concerning the operator tasks (table 6) and PCS-use by other personnel than the operator (table 7).

From the tables can be concluded that there exist large differences between process characteristics, control system characteristics and operator tasks. Also an indication can be obtained which factors these differences concern and to what extent. The following examples can be given:

- <u>Process characteristics</u>
  - The number of subprocesses in a process ranges from 0 to 6;
  - Time-constants vary from minutes to several hours, not only between processes but also within processes;
  - Some processes only have a start-up twice a year, while others 25 times a year;
  - The frequency of required operator-intervention because of process disturbances and equipment malfunctions varies between once a week up to 15 times a shift.

- <u>Control system characteristics</u>
  - The number of control loops ranges from 10 to 400 per process;
  - The number of measured and computed process variables range from 43 to 2200;
  - In case of batch or partly batch processes the total number of binary variables is much higher than the total number of continuous process variables, although these numbers can vary considerable between processes; for continuous processes this is just the reverse.

- <u>Operator tasks</u>
  - The average number of control loops supervised by one operator ranges from 10 up to 200;
  - The total number of continous process variables presented lies between ca. 50 and 1850;
  - The contents of the operator task differs between processes, for example "tuning of control loops" and "maintenance diagnostics" are not always considered part of the operator's task;
  - The contents of the operator tasks also depends on the process mode (e.g. start up, changeover);

It can be concluded that with the use of the first order cluster of the factors list the processes and control systems can be adequately characterized. Variation in characteristics (complexity (sub)processes, dynamical aspects, etc.) can be expressed in a number of factors.
It is not clear however, in how far these factors are relevant with respect to task execution and subsequently the ergonomic properties of the PCS. Therefore the relation between the first order cluster and the second order cluster has to be known. However the number of processes described is too small in comparison with the number of factors, and the diversity in process and control system characteristics too large to get clear insight in this relation. Furthermore the results of the questionnaire have been influenced by the different interpretation of the users with respect to several terms used.

Although the presented data show much variation, it appears that some factors can be indicated which are relevant and important for all PCS-applications. For example the occurrence of a start up and shut down process mode in each process and the use of PCS by other personnel than the process operator. In section 3.3.3 this subject will be dealt with in more detail.

3.3.3 Ergonomic demands of users on PCS

After the description of specific PCS-applications it is interesting to see what kind of specific ergonomic PCS-demands are formulated by PCS-users. The ergonomic PCS-demands are categorized in the following groups:

a) demands because of certain process characteristics;
b) demands because of certain operator tasks;
c) demands because of different types of information to be exchanged between PCS and PCS-users;
d) demands with respect to methods for information input and output;
e) demands with respect to hardware and layout of the PCS.

This sequence has been chosen according to the structure of the factors list. Examples of the answers given by the user-companies concerning these PCS-demands are presented in table 8 of Appendix 4; also answers of the manufacturers on the question which specific demands users have expressed to them, are presented.

Considering the sponsor opinions on PCS-demands, the following conclusions are drawn. From an analysis of the processes described by the PCS-users and the ergonomic demands mentioned, it appears, that only in a few cases arguments are given in which first or second order cluster (process, control system, operator task characteristics) determine the mentioned ergonomic demands. On basis of this finding, the conclusion is drawn that PCS-users apparently have difficulty with the specification of PCS-demands on basis of the characteristics of their specific PCS-application.
This conclusion was confirmed during the visits to the two user-companies. The company representatives confirmed that they did not systematically specify the PCS-demands for a process to be equiped with a PCS in the way as formulated in the questionnaire. So, the formulation of the required PCS-demands in this way was rather new.

There appears to be a discrepancy between the PCS-demands as mentioned by the manufacturer-companies and the demands mentioned by the users. This discrepancy shows in the number of demands mentioned in the several categories, as well as in the categorization of PCS-demands. For example: the users do not mention many specific wishes concerning the methods for information input/output and hardware/layout; this is in contrast with the user-demands mentioned by the manufacturers, in which specific input devices appear such as joystick, touch screen and voice input.

The questionnaire results and the material presented here do not have the potential to get clear insight in the relations between factors of different order clusters. However, on basis of the questionnaires the following examples can be given:

- Start-up and shut-down modes do more or less frequently occur in different processes. At high frequencies control and monitoring of these process modes will be an important aspect of the operator task. For this purpose the operator needs high-frequent or specific information on the status as well as the actual values of key variables. Therefore the PCS has for example to present fast trends of analog values in some detail (e.q. samples each 2-5 seconds) and has to be equipped with analog and binary values. If the process is very complex, additional text on the VDU with respect to the phase of the process mode can be useful.
- When monitoring the normal operation mode is the main part of the operator task, an adequate alarm summary (in case > 3 alarms per hour

occur) should be presented, supported by effective acoustic alarms (no alarm inflation). In other cases the operator will be responsible for optimization of the process as well. Then on-line calculation and presentation of key variables for the process during normal operation and change-over becomes relevant. The presentation should include live graphic displays and additional alphanumeric information.

- In the control of batch processes, status information and trend information on the batch sequence is important for the operator.
- Many subprocesses support the need for a sufficient number of VDU's to have an overall picture of the process, especially when these subprocesses differ in terms of complexity and dynamics and consequently in actions to be executed by the operator(s). The operator station should have multiple VDU's, useful for different display functions.
- Some processes require very quick and accurate action of the operator in the case of disturbances. Special attention should than be paid to the speed of the PCS with respect to calculation, access to presentation modes etc.

3.3.4 Sponsor opinions on draft factors list

In the questionnaires the sponsors were also asked to give their opinion on the draft factors list. The sponsors were asked:

a) to indicate missing factors in the draft factors list;
b) to indicate the relevance of the several clusters and factor groups;
c) to give general comments on the draft factors list, if required.

The answers to these questions will be dealt with successively.

Sub. a: Missing factors

Concerning the missing factors, the answers of the users and manufacturers are given in table 9 of Appendix 4. All the factors mentioned have been included in the definitive factors list.

Sub. b: Relevance of clusters and factor groups

On the questions concerning the relevance of factor clusters and groups, the answers are summarized in table 10 of Appendix 4.
From these tables we can destillate the following tendencies:

On cluster-level, the users consider the clusters 1, 2 and 3 of equal relevance, but do attach less importance to the 4^{th} cluster (input/output devices and workplace specification). The manufacturers find approximately all four clusters of equal importance.
On group-level, the users indicate the equal importance of the groups A, B, C, D, F and G (table 10b); the other groups H, I, J and E are considered less relevant. In the manufacturers-scores, the group C (control system characteristics) is considered to be the most relevant; furthermore, the groups A, B and J have the lowest scores.

The users score indicating the low relevance of group E (task performance characteristics) is remarkable in comparison with the score on group F (tasks of operators). It might be concluded that users are possibly not familiair with such criteria or the term "task performance" as such. Considering the processes described in section 3.3.2. task performance criteria are certainly relevant for most processes.
The specifications of output device(s), input device(s) and workplace are also indicated as being of less relevance. Users probably consider the factors of clusters 4 as design details of PCS, and they therefore concentrate on the application-centered factors of clusters 1 and 2, as well as on the general factors of the PCS design of cluster 3.

The high manufacturers score of the group factors concerning control system characteristics is understandable since an important function of the PCS is the controlling of the process. On the other hand this result can also be interpreted that the manufacturers consider the functions of the PCS concerning the operator task of secondary importance.
The low score on the group of workplace specification factors from the manufacturers, can be understood since the users of PCS in many cases have clear wishes on the lay-out of the workplace. Nevertheless one can say that some of these factors (e.g. console dimensions) are already determined by the actual technical, basic design of the PCS as well.

Sub. c: General comments

Concerning the general comments on the factors list given by the sponsors, the following answers were obtained.

One of the user-companies stressed that special attention should be given to the question when and under what circumstances a particular input or output device should be selected, and which combinations should be provided. This comment is in line with the more general comment of another user-company, that the combination of the clusters and groups is most relevant for determination of the PCS demands for a specific process and operator task.

From the manufacturers side it was stressed that the study should not dwell on factors that are primarily the 'cosmetics' of the design like anthropometrics, button design, furniture etc. The greater need according to this comment is in the area of understanding the cognitive processes involved in "operations".

In addition some sponsors have made some corrections to the factor list. These corrections have been taken into account in the preparation of the definitive factor list.

3.4 CONCLUSIONS OF THE FIELD STUDY

A limited field study has been executed concerning the sponsor companies. The objective has been to gain insight in the relations between factors of the different clusters as well as in the priorities that could be identified in practice. A questionnaire has been sent to the sponsors (users of PCS, manufacturers, contractors) containing questions on PCS-applications. In addition two sites have been visited to discuss the subject in more detail in the practical situation. The conclusions with respect to the results of the field study are the following:

a) The processes described show a large variety in characteristics, as do the control systems and operator tasks. With the use of the factors list these applications can be characterized.

b) There is a lack of insight with respect to the relations between the different clusters. An adequate description of process and control system characteristics (1st order cluster) as well as tasks of operator and PCS (2nd order cluster) should be the basis for defining ergonomic demands on PCS.

c) The number of processes described in relation to the different factors and the variation in these factors did not make it possible to get additional insight in the relations between the clusters. As a consequence on the basis of the questionnaire results only a few specific examples could be given in how far process and control system characteristics determine task factors of the operator and subsequently require some ergonomic demands to be met concerning PCS specifications.

d) Users are, as can be understood from the above mentioned, especially interested in the clusters 1, 2 and 3. Factors concerning cluster 4 (e.g. input/output devices, PCS hardware characteristics etc.) are judged less relevant, and depend on the outcome of higher order clusters. Manufacturers, judging all clusters equally relevant, seem to over-estimate the relevance of cluster 4 when compared to the user demands on PCS. Our conclusion so far is, that users and manufacturers find it very hard to identify the relevant factors for their specific application, and to set priorities with respect to these different factors. However, this is very important for the actual usefulness of these factors as concluded as well during the experts meeting on May 3rd 1984. In section 3.3.3 some examples of priorities in relation with specific applications of PCS have already been given, and in report I this subject is discussed in more detail.

e) The questionnaire results and site visits yielded many useful suggestions to complete and improve the draft factors list; these suggestions have been worked into the definitive factors list.

f) From the results of this field study, we conclude that the structure and set-up of the factors list can be accepted as a starting point in this project.

g) To increase the benefits of the factors list and of the guidelines based on this list, it is of importance to set up a list with uniform definitions of terms used.

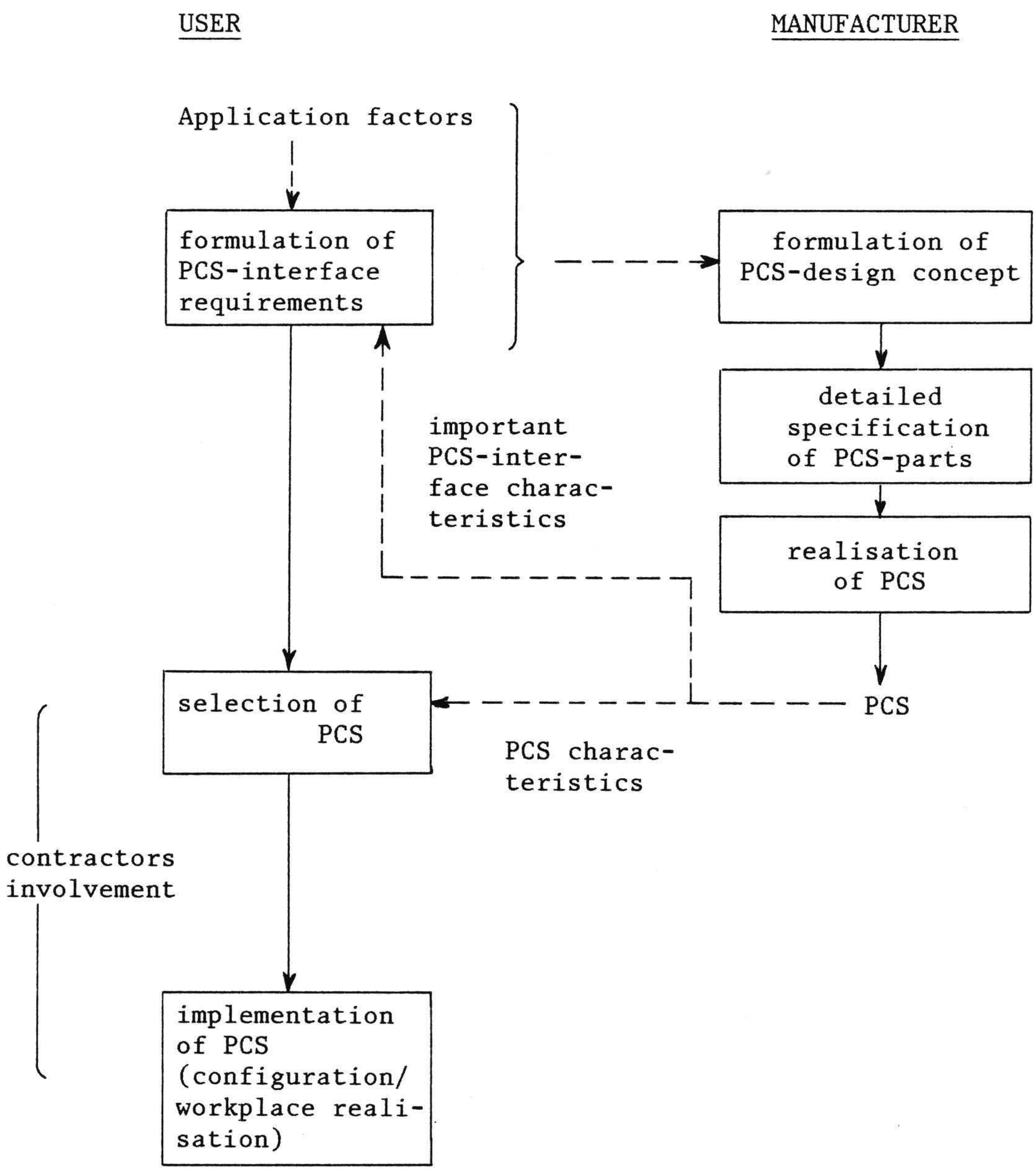

Figure 4.1 Activities in PCS design, -selection and -implementation.

4. DISCUSSION AND FUTURE RESEARCH

4.1 DISCUSSION

From a viewpoint of the objectives of the total project the findings of the literature survey and field study will be discussed.
The discussion will be structured by means of figure 4.1. In this figure the important steps which have to be made in the design and application of PCS are given.

Refering to this figure, we can conclude on the basis of the results of the field study that the actual problems of both users and manufacturers are at the top level. Users have difficulty in formulating PCS-requirements on the basis of their specific PCS-application and manufacturers show that more insight in PCS-applications could contribute to the PCS-design.
The translation from application aspects to PCS-aspects is very important. However, from the literature survey it is clear that little support can be found in the literature on this subject. A cause for the small number of publications available could possibly be the variety in PCS-applications. From the priority the sponsors attach to this translation step should not be concluded that the other steps in figure 4.1 are not important. On most basic ergonomic aspects concerning VDU-hardware and workplace more literature is available; questions with respect to these aspects can therefore be answered to some extent with the use of literature.
Visits to user companies indicated that it is not easy in the practical situation to take into account systematically ergonomic criteria in the selection and implementation of PCS. On the one hand these ergonomic criteria are not easily available with clear guidelines how to apply these; on the other hand insufficient insight exists in the relation between application factors (process, control system and operator task characteristics) and these ergonomic criteria. It is because of this that the sponsors have given priority to the lower order clusters. Steps 2 (selection) and 3 (implementation) by the users require easily available ergonomic criteria as well. Since PCS are expected to be more widely applied in the near future and the flexibility of these systems with respect to configuration and programming will increase considerably, these steps become more important in terms of ergonomic principles to be applied in specifying PCS in practice.

As suggested during the experts meeting on May 3rd 1984 the most promising approach to get clear insight in these relations, though not of a general character, is to analyze thoroughly one specific case (design and/or implementation of PCS for one process) in detail.
Finally, the involvement of contractors in the implementation of PCS should not be forgotten. It is felt that they could be supported by guidelines as well.

When we translate the foregoing to the final objective of the project, namely the ergonomic guidelines, we come to the following conclusions.
Since all steps of figure 4.1 concern important ergonomic aspects, we think that ergonomic guidelines should offer assistance in all these steps. From a viewpoint of effectiveness of the guidelines, it is essential that the guidelines are subdivided in a number of categories which specifically deal with each of these steps. In this way the set-up of the guidelines closely corresponds with the sequence in which users and manufacturers are confronted with ergonomic aspects of PCS in practice. This leads to the following arrangement of the ergonomic guidelines:

I Guidelines which refer to the formulation of ergonomic PCS-requirements on the basis of specific application aspects (process and control system characteristics and operator tasks). These guidelines concern step 1 of both users and manufacturers;

II Guidelines which refer to ergonomic detailed specification and realisation aspects of PCS and which give users support in selection of PCS (step 2 of users, step 2 and 3 of manufacturers);

III Guidelines which refer to ergonomic implementation aspects of PCS, like PCS-configuration and workplace (step 3 of users).

Although as said above all these guidelines are of importance for a successful application of PCS, the field study points out that guidelines mentioned under I are considered to be most relevant by the users.
These conclusions have some implications for the set-up of the second phase of the project. This will be dealt with in section 4.3.

4.2 THE FACTORS LIST

The factors list is the main output of this phase of the project. In appendix 5 the (definitive) factors list can be found. Report 1 contains information for the sponsors with respect to the use of this factors list in practice. The comments given by the sponsors in the field study have been taken into account in finalizing this list.
From the findings of the field study it is concluded that the factors list can be considered as a good starting point, with respect to structure and contents. However, modifications of the contents of the list could occur in the following phase of the project.
The factors list contains a systematical survey of factors which influence the control of processes by the operator using a PCS. The factors of the clusters 1 and 2 refer to aspects of the application (process, operator tasks) in which the PCS has to fuction (application-centered aspects), while the factors of clusters 3 and 4 refer to PCS aspects (PCS-centered factors).
In the second phase of the project the factors list will be used for the formulation of the three categories guidelines as mentioned in section 4.1. Although all categories will use factors from several clusters, each category will focuss on a specific cluster of the factors list. Since the guidelines of category I deal with PCS requirements, these guidelines mainly concern factors of cluster 3. Category II concerns mainly factors of cluster 4, while category III deals with factors of clusters 3 and 4 which are related to implementation aspects of PCS.
All categories refer to factors of clusters 1 and 2. To illustrate this, an example is given for the factors which are used in a guideline of category II concerning the required 'number of displays' on the VDU (factor H.1.2.1 of cluster 4). The guideline would prescribe to take the following factors into account: the number of measured process variables (B.4.6 of cluster 1), the number of subprocesses (B.1.1 of cluster 1) and the number of control loops (C.1.1 and C.1.2);

A last remark should be made about the factors list and the planned guidelines. From both literature survey and field study it became clear that for terms used in the factors list different definitions occur. For an effective use of the factors list a list of definitions is essential. The formulation of this list should be one of the activities of the second phase of the project.

4.3 OUTLINES OF RESEARCH IN THE SECOND PHASE

In this section a proposal will be given for research activities in the second phase of the project.

The main objective of the second phase of the project has been to formulate the ergonomic guidelines. As described in section 4.1 the guidelines should be subdivided in three parts:

I Guidelines which concern the formulation of ergonomic PCS-requirements on the basis of application aspects;
II Guidelines which concern ergonomic detail specifications and realisation aspects of PCS;
III Guidelines which concern to ergonomical implementation aspects of PCS.

The first activity of the second phase should be aimed at an orientation which factors should be dealt with in each of the three categories. A second activity includes a literature survey for the formulation of the guidelines in each category. This survey includes the formulation of a list with definitions of used terms.
However, it might be expected on basis of the conclusions from chapter 2 that the guidelines cannot be formulated on a literature search alone; this can be specifically expected for guidelines mentioned under I. Therefore, a third activity in the second phase should consist of a field study. This field study should in particular be directed at the identifications of the most relevant relations between application-factors and PCS-characteristics. Since the field study should contribute to the literature survey, it should be performed parallel to the second activity. Finally, the guidelines are formulated in a fourth activity.

APPENDICES:

1. LIST OF PROJECT SPONSORS

2. LITERATURE REFERENCES

3. SPONSOR CONSULTATION DOCUMENTS
   3.1 PCS users questionnaire
   3.2 PCS manufacturers questionnaire
   3.3 Draft factors list

4. TABLES WITH RESULTS OF SPONSOR CONSULTATION

5. DEFINITIVE FACTORS LIST

APPENDIX 1 : LIST OF PROJECT SPONSORS

PCS users

AKZO Engineering	Mr. D. v. Droffelaar
DOW Chemical	Mr. M. de Beaumont/Mr. R. v. Gorp*
DSM	Mr. L. de Loey/Mr. E. Piso*
Hoogovens	Mr. H. Radstake/Mr. S. Scholtens*
Gasunie	Mr. G. Reit
Neste Oy	Mr. H. Sunell
Shell	Mr. J.P. Jansen*/Mr. P. v.d. Louw/
	Mr. H. Muller*
Unilever	Mr. J. Wessels

(*member of project working group)

PCS manufacturers

CGEE Alsthom/Controle Bailey	Mr. J.C. Lejon
Eckardt	Mr. G. Eifert
Foxboro	Mr. R.W. Schlunk
Honeywell	Mr. C.M.J. Wilmering
Siemens	Mr. F.A. Stevens
Toshiba	Mr. K. Yoshisaki
Valmet	Mr. G.J.T. Rijgwart
Yokogawa	Mr. Yoshio Tomita

Contractors

Chiyoda	Mr. J. Matsui
JGC	Mr. R. Matsui

APPENDIX 2 : LIST OF LITERATURE REFERENCES

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APPENDIX 3 : SPONSOR CONSULTATION DOCUMENTS

3.1 PCS users questionnaire
3.2 PCS manufacturers questionnaire
3.3 Draft factors list

PROCESS CONTROL SYSTEM USER QUESTIONNAIRE

This questionnaire consists of two parts. Part A contains questions about specific processes which occur in your company; part B deals with questions about the draft factors list. In part C questions are asked about demands of your company to Process Control Systems (PCS).
You are kindly requested to involve several experts of your company in the completion of the questionnaire, as far as possible (process engineer, system or application engineer, ergonomist, design engineer).

Before you fill in the questions of part B and C we ask you to choose two characteristics but divergent processes in your company and to use these processes as a reference while completing the questionnaire. Preferably these processes should be equipped with a PCS, or is planned to be equipped with a PCS in the future. (A PCS is defined as a system for integrated supervision and control of processes by means of a computer and video monitors.
To gain some insight in the actual or planned applications of PCS in your company, some questions about the specific processes are asked in part A.

---

date:

Company:

Filled in by:	Function:
1.	1. ....
2.	2. ....
3.	3. ....
4.	4. ....

PART A: QUESTIONS ON THE PROCESSES

This part consists of two sets of the same questions for each of the two processes.

I FIRST PROCESS

1) Process name or code-name:

2) a) This process is (please mark the correct boxes:

- continuous ☐
- batch ☐
- partly continous/ partly batch ☐

b) In the case of a batch-process, what is the duration of a batch? A: .... minutes/hour

3) a) Can you distinguish subprocesses in this process?
A: Yes/No
(If not, go to question 4).

b) When do you call a part of a process a subprocess?
(If possible give an example as well)
A:

c) How many subprocesses can be distinguished in this particular process? A: (number) ....

d) Can you give a rough estimation of the time-constant for each subprocess? A:

subprocess	time-constant
1	.... minutes/hours
2	.... minutes/hours
3	.... minutes/hours
4	.... minutes/hours
5	.... minutes/hours

4) a) What is the total number of control loops for process control only in the process, based on final control element count (control valve, variable pump, etc.)?
A: (number) ......

b) What is the total number of control loops for plant protection only in the process, based on final control element count?
A : (number) ....

5) a) How many process variables are being measured in the process?
A: (number) ....

b) What percentage of these measurements is being presented to the operators? A: .... %

c) How many process variables are being computed?
A: (number) ......

d) What percentage of these computed values is being presented to the operators? A: ...... %

6) a) How many binary variables are being measured in the process?
A: (number) ....

b) What percentage of these measurements is being presented to the operators? A: ......%

c) How many binary variables are being computed?
A: (number) .....

d) What percentage of these computed values is being presented to the operators? A: ....%

7) a) With how many operators per shift in the central control room is the process being supervised under normal circumstances?
A: (number) ......

b) With how many operators per shift in the field is the process being supervised under normal circumstances?
A: (number) ....

c) With how many supervisors per shift is the process being supervised under normal circumstances?
A: (number) ....

8) a) What is the average number of process disturbances per shift?
A: (number) .....

b) What is the average number of equipment malfunctions per shift?
A: (number) ....

c) How often per shift must the operator intervene in the process because of process disturbances? A: ...... times

d) How often per shift must the operator intervene because of equipment malfunction? A: ...... times

9) a) Is the process controlled with a process control system?
A: Yes/No

b) If so, with which PCS is the process controlled?
A:

10) Which process-modes can be distinguished in the process and in what frequency per year do they approximately occur?

process-mode		occurrence	frequency of occ./year
• start up	- planned	Yes/No	... %
• operation[1]	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• changeover[2]	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• shut down	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• others, viz.		Yes/No	... %

([1]: planned operation = "normal" process conditions;
unexpected operation = disturbed process behaviour;
[2]: planned changeover = planned transition from a process state to another;
unexpected changeover= unexpected transition from a process state to another due to process disturbances.)

11) One of the objectives of this questionnaire is to gain insight in the nature of the console operator tasks in relation to the process characteristics. Underneath a few possible operator tasks are mentioned; we would like you to answer the following question:

Indicate which of the following console operator actions are executed in each of the occurring process modes (see question 10)? Indicate also whether use is being made of the PCS (if applied) by the operator, while executing a task.

Please use the following code for the indication of the operator actions:
F = frequent (more than 5 times per shift)
R = regular (more than once a week)
O = occasionally (in all other cases)

		start up	operation	change-over	shut down	others, viz.	....	is PCS used?
A: a) On/off control actions (example: switching a motor on/off)	A:							
b) Stabilising actions (example: control of a process variable in the desired range)	A:							
c) Tuning of control loops (e.g. adapting control loop gain)	A:							
d) Optimising control (e.g. adjusting setpoints of subprocesses)	A:							
e) Process monitoring (frequent scanning of process variables)	A:							
f) Planning or scheduling of process operations (e.g. determining of necessary supply quantity raw material)	A:							
g) Fault management:								
- fault detection	A:							
- fault diagnose	A:							
- fault correction	A:							
h) Administration (e.g. recording of process information in log book)	A:							

		start up	operation	change-over	shut down	others, viz.	....	is PCS used?
i) Communication (exchanging of relevant process information between people)								
- between console operators	A:							
- between console operators and field operators	A:							
j) Reporting (formal communication e.g. informing management about process events)	A:							
k) Maintenance diagnostics - preventive (e.g. determining when a measuring instrument needs a revision)	A:							
- curative (e.g. diagnosing why a pump has dropped out)	A:							
l) Others, viz.								

12) Please answer the following question for each process mode:
- how much time in seconds may elapse between the occurrence of an abnormal process state and the intervention of the operator before serious trouble occurs?

13) If a PCS is applied to this process, could you roughly describe the functions of the persons next to the console operators who are using the PCS and for what purpose?

A: function / purpose

1. ....
2. ....
3. ....

14) Which specific characteristics of the process do you further consider to have important influence on the controlling of this process by the operator?

A:

II SECOND PROCESS

1) Process name or code-name:

2) a) This process is (please mark the correct boxes:

- continuous ☐
- batch ☐
- partly continous/ partly batch ☐

b) In the case of a batch-process, what is the duration of a batch? A: .... minutes/hour

3) a) Can you distinguish subprocesses in this process?
A: Yes/No
(If not, go to question 4).

b) When do you call a part of a process a subprocess?
(If possible give an example as well)
A:

c) How many subprocesses can be distinguished in this particular process? A: (number) ....

d) Can you give a rough estimation of the time-constant for each subprocess? A:

<u>subprocess</u>	<u>time-constant</u>
1	.... minutes/hours
2	.... minutes/hours
3	.... minutes/hours
4	.... minutes/hours
5	.... minutes/hours

4) a) What is the total number of control loops for <u>process control</u> only in the process, based on final control element count (control valve, variable pump, etc.)?
A: (number) ......

b) What is the total number of control loops for <u>plant protection</u> only in the process, based on final control element count?
A : (number) ....

5) a) How many process variables are being measured in the process?
A: (number) ....

b) What percentage of these measurements is being presented to the operators? A: .... %

c) How many process variables are being computed?
A: (number) ......

d) What percentage of these computed values is being presented to the operators? A: ...... %

6) a) How many binary variables are being measured in the process?
A: (number) ....

b) What percentage of these measurements is being presented to the operators? A: ......%

c) How many binary variables are being computed?
A: (number) .....

d) What percentage of these computed values is being presented to the operators? A: ....%

7) a) With how many operators per shift in the central control room is the process being supervised under normal circumstances?
A: (number) ......

b) With how many operators per shift in the field is the process being supervised under normal circumstances?
A: (number) ....

c) With how many supervisors per shift is the process being supervised under normal circumstances?
A: (number) ....

8) a) What is the average number of process disturbances per shift?
A: (number) .....

b) What is the average number of equipment malfunctions per shift?
A: (number) ....

c) How often per shift must the operator intervene in the process because of process disturbances? A: ...... times

d) How often per shift must the operator intervene because of equipment malfunction? A: ...... times

9) a) Is the process controlled with a process control system?
A: Yes/No

b) If so, with which PCS is the process controlled?
A:

10) Which process-modes can be distinguished in the process and in what frequency per year do they approximately occur?

process-mode		occurrence	frequency of occ./year
• start up	- planned	Yes/No	... %
• operation[1]	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• changeover[2]	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• shut down	- planned	Yes/No	... %
	- unexpected	Yes/No	... %
• others, viz.		Yes/No	... %

([1]: planned operation = "normal" process conditions;
unexpected operation = disturbed process behaviour;
[2]: planned changeover = planned transition from a process state to another;
unexpected changeover= unexpected transition from a process state to another due to process disturbances.)

11) One of the objectives of this questionnaire is to gain insight in the nature of the console operator tasks in relation to the process characteristics. Underneath a few possible operator tasks are mentioned; we would like you to answer the following question:

Indicate which of the following console operator actions are executed in each of the occurring process modes (see question 10)? Indicate also whether use is being made of the PCS (if applied) by the operator, while executing a task.

Please use the following code for the indication of the operator actions:
F = frequent (more than 5 times per shift)
R = regular (more than once a week)
O = occasionally (in all other cases)

		start up	operation	change-over	shut down	others, viz.	....	is PCS used?
A: a) On/off control actions (example: switching a motor on/off)	A:							
b) Stabilising actions (example: control of a process variable in the desired range)	A:							
c) Tuning of control loops (e.g. adapting control loop gain)	A:							
d) Optimising control (e.g. adjusting setpoints of subprocesses)	A:							
e) Process monitoring (frequent scanning of process variables)	A:							
f) Planning or scheduling of process operations (e.g. determining of necessary supply quantity raw material)	A:							
g) Fault management:								
- fault detection	A:							
- fault diagnose	A:							
- fault correction	A:							
h) Administration (e.g. recording of process information in log book)	A:							

	start up	operation	change-over	shut down	others, viz.	....	is PCS used?
i) Communication (exchanging of relevant process information between people)							
- between console operators A:							
- between console operators and field operators A:							
j) Reporting (formal communication e.g. informing management about process events) A:							
k) Maintenance diagnostics - preventive (e.g. determining when a measuring instrument needs a revision) A:							
- curative (e.g. diagnosing why a pump has dropped out) A:							
l) Others, viz.							

12) Please answer the following question for each process mode: - how much time in seconds may elapse between the occurrence of an abnormal process state and the intervention of the operator before serious trouble occurs?						

13) If a PCS is applied to this process, could you roughly describe the functions of the persons next to the console operators who are using the PCS and for what purpose?

A: function / purpose

1. ....
2. ....
3. ....

14) Which specific characteristics of the process do you further consider to have important influence on the controlling of this process by the operator?
    A:

PART B: QUESTIONS ON THE DRAFT FACTORS-LIST

Please answer first the questions of part A and read the explanation to the draft factors list and the draft factor list itself before answering part B.

1) If there are factors missing in the present list, please specify those missing factors.
   A:

2) Could you indicate the clusters corresponding to their relevance to your company? Please use the following code: 1 = most relevant, 2 = relevant, 3 = not relevant.

A:

1st order cluster	
2nd order cluster	
3rd order cluster	
4th order cluster	

3) Could you indicate the groups of factors corresponding to their relevance to your company? (1 = most relevant, 2 = relevant, 3 = not relevant)

A:

A	system objectives & restrictions	
B	process characteristics	
C	control system characteristics	
D	tasks of operator(s)	
E	task performance criteria	
F	specific system/situation characteristics	
G	interface design concept	
H	output device(s) specifications	
I	input device(s) specifications	
J	workplace specifications	

4) Could you indicate those factors on a copy of the factors-list which are the most relevant to your company?

5a) Could you help us with more relevant literature on the subject of this project, especially on internal publications of your company? A: Yes/No

5b) If so, please give title, name of the author, report-number and year of publication. (These reports will be treated confidentially, if requested).
A:

6) If you have further remarks on the draft factor list, please mention these below.

PART C: QUESTIONS ON USER DEMANDS

Please answer first the questions of part A and B.

1) What kind of demands concerning the PCS does your company have because of certain process characteristics? (for example: demands concerning a specific display type for a particular process mode.)

A:

2) What kind of demands does your company have because of certain tasks of the operator(s)? (for example: the possibility of presenting information on the process-structure; the possibility to use the PCS for tasks other than control, such as administration.)

A:

3) What kind of demands does your company have with respect to different types of information to be exchanged via the PCS? (for example: the possibility of presenting historical data, the possibility of presenting production reports.)

A:

4) What kind of demands does your company have with respect to the methods for information input and output? (for example: demands on certain input devices, demands on certain display types.)

A:

5) What kind of demands does your company have with respect to the hardware/layout of the PCS? (for example: demands on the console shape, demands on screen resolution.)

A:

6) What are the most important information-sources for identifying the demands on your company towards PCS?
- consultation of company experts (system engineers, ergonomists)?
  A: Yes/No
- consultation of PCS-users in the company (operators, system engineers, others)?
  A: Yes/No
- formal evaluation of PCS applied processes?
  A: Yes/No
- consultation of experts outside the company (research institutes, consultants)?
  A: Yes/No

PROCESS CONTROL SYSTEM MANUFACTURERS QUESTIONNAIRE

This questionnaire consists of two parts. Part A contains questions about specific demands which users have expressed to your PCS; part B deals with questions about the draft factors list.
You are kindly requested to involve several experts of your company in the completion of the questionnaire, as far as possible (design engineer, system engineer, application engineer, ergonomist).

Before you fill in the questions of part B we ask you to fill in the questions of part A. These questions give us some insight in the demands users have put forward concerning PCS.

---

date:

Company:

Filled in by:	Function:
1.	1. ....
2.	2. ....
3.	3. ....
4.	4. ....

PART A: QUESTIONS ON USER DEMANDS

1) What kind of demands concerning the PCS have users expressed because of certain process characteristics? (for example: demands concerning a specific display type for a particular process mode.)

A:

2) What kind of demands have users expressed because of certain tasks of the operator(s)? (for example: the possibility of presenting information on the process-structure; the possibility to use the PCS for tasks other than control, such as administration.)

A:

3) What kind of demands have users expressed with respect to different types of information to be exchanged via the PCS? (for example: the possibility of presenting historical data, the possibility of presenting production reports.)

A:

4) What kind of demands have users expressed with respect to the methods for information input and output? (for example: demands on certain input devices, demands on certain display types.)

A:

5) What kind of demands have users expressed with respect to the hardware/layout of the PCS? (for example: demands on the console shape, demands on screen resolution.)

A:

6) What are your most important information-sources for identifying the demands of users towards PCS?

- own research in real PCS applications?
  A: Yes/No
- own research in laboratorium set-ups?
  A: Yes/No
- consultation of representatives of user-companies?
  A: Yes/No
- consultation of PCS-users (operator, system engineer, etc.)?
  A: Yes/No
- consultation of independent experts (research institutes, consultants)?
  A: Yes/No

PART B: QUESTIONS ON THE DRAFT FACTORS-LIST

Please answer first the questions of part A and read the explanation to the draft factors list and the draft factors list itself, before answering part B.

1) If there are factors missing in the present list, please specify those missing factors.
A:

2) Could you indicate the clusters corresponding to their relevance to your company? Please use the following code: 1 = most relevant, 2 = relevant, 3 = not relevant.

A:

1st order cluster	
2nd order cluster	
3rd order cluster	
4th order cluster	

3) Could you indicate the groups of factors corresponding to their relevance to your company? (1 = most relevant, 2 = relevant, 3 = not relevant)

A:

A	system objectives & restrictions	
B	process characteristics	
C	control system characteristics	
D	tasks of operator(s)	
E	task performance criteria	
F	specific system/situation characteristics	
G	interface design concept	
H	output device(s) specifications	
I	input device(s) specifications	
J	workplace specifications	

4) Could you indicate those factors on a copy of the factors-list which are the most relevant to your company?

5a) Could you help us with more relevant literature on the subject of this project, especially on internal publications of your company? A: Yes/No

5b) If so, please give title, name of the author, report-number and year of publication. (These reports will be treated confidentially, if requested).
A:

6) If you have further remarks on the draft factor list, please mention these below.

Short explanation on the draft keyfactors list

In formulating the draft keyfactors list the following arguments were used.

A Process Control System (PCS) functions as a link between a process and one (or more) operator(s). In the framework of this project the interface between the operator and the PCS is of importance, as well as the surrounding working environment.
Because the combination operator-PCS has to function in a system operator-PCS-process, this system will make demands towards the functioning of the operator and PCS (see figure 1). On the other hand the operator will make demands to the interface and the working environment, since he is characterized by certain human capacities and limitations. The demands of the system and the operator towards interface and workplace concern specific aspects. As mentioned in the project scope, these aspects are called 'keyfactors' when they influence the use of PCS. For the assessment of the keyfactors the system and operator demands towards interface and workplace should be explored.

This exploration concentrates on the design of the man-machine system operator-PCS-process. Before the actual designing of interface and workplace it first should be clear which tasks the operator has to perform. From the tasks of the operator the requirements to the interface can be derived, taking human factors criteria into account. The tasks of the operators are determined from the system characteristics (system objectives, process and control system characteristics), also in agreement with human factors criteria (see figure 2).
For the project it is important to remark that no significant conclusions can be drawn about the design (or evaluation) of the interface, without taking into account the tasks of the operator and the relevant characteristics of the system. Due to this, a keyfactor-list will also contain keyfactors which concentrate on the operator tasks and the characteristics, in addition to factors concerning the interface and workplace. To indicate the factors, a further investigation of the mentioned items has been performed. Figure 3 is a result of this investigation.

In this figure groups of factors are indicated (by circles) and divided into four different clusters. In the 1st order cluster the system characteristics are divided into three groups: "system objectives & restrictions", "process characteristics" and "control system characteristics".

The 2nd order cluster contains groups of factors which concern the operator directly. Distinguished are the groups "tasks of operator(s)", "task performance criteria" and "specific systems & situation characteristics".
The factors concerning the interface are divided into two clusters (3rd en 4th order).
The 3rd order cluster contains factors which concentrate on the interface design-concept. This means factors which concern questions like: which information does the operator need, what should be on the interface.
The 4th order cluster contains factors concerning the detailed specification of interface and workplace. The factors concerning the interface can be divided into a group of factors concerning the output-devices and a group concerning the input-devices.
The factors of cluster 2, 3 and 4 are influenced by human factors criteria, for example concerning workload and user-acceptability.

A few further remarks will be made on the structuring of factors in groups and clusters.
Due to the objective of the project (formulation of ergonomical guidelines) it is necessary that the list with identified keyfactors is as sufficient and complete as possible. This asks for a systematic and structured approach. The identified clusters correspond with the different levels in the design process of man-machine interfaces. The factors from one cluster influence the factors of higher numbered clusters. The higher the cluster-number, the more detailed and concrete the factors are. Of particular importance is to find out in which way the more detailed factors of cluster 4 are related to the factors in the preceding clusters. By means of a questionnaire to the sponsors more insight on this aspect will be obtained.
It must be remarked that the influence of a certain factor on the use of PCS cannot be stated in absolute terms. This influence can be dependent of situation, time or on other factors. Because of this fact it is suggested to use the word "factor" for the time being, instead of the word "keyfactor". In a later stage of the project the word key-factor could be used for those factors which are considered to be of most importance.

In the draft factors-list enclosed each group of factors has been further specified. At this stage of the project the factors only have been identified on basis of literature research and in consultation with the WIB ergonomics group.

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DRAFT FACTORS LIST - Explanation	date : 6 June 1984
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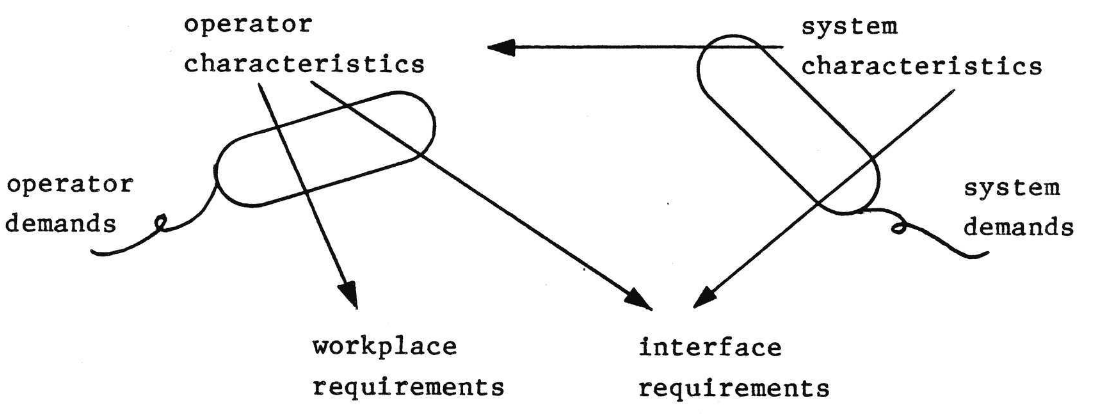

figure 1: relations between system & operator characteristics and the interface & workplace requirements

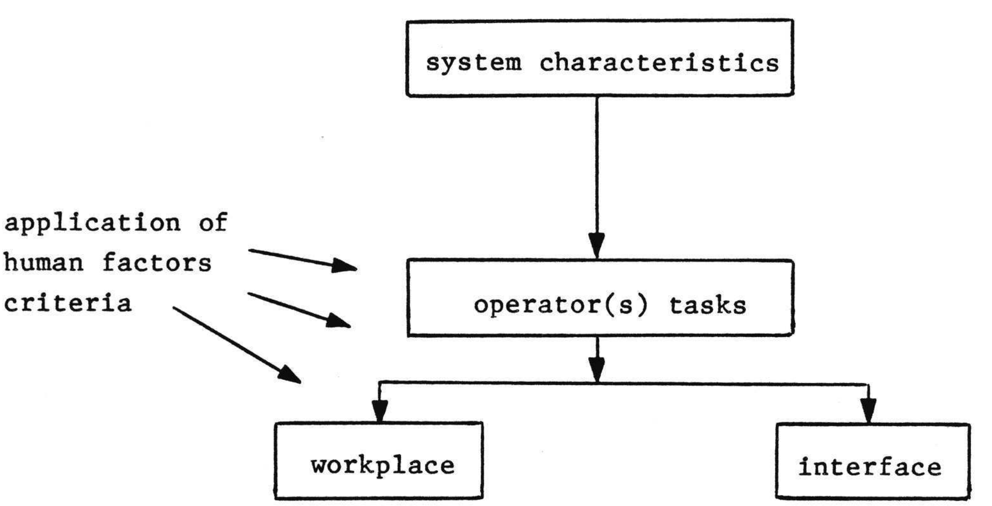

figure 2: global steps in the design process of a man-machine system

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DRAFT FACTORS LIST - Explanation		version: 2 page : iv

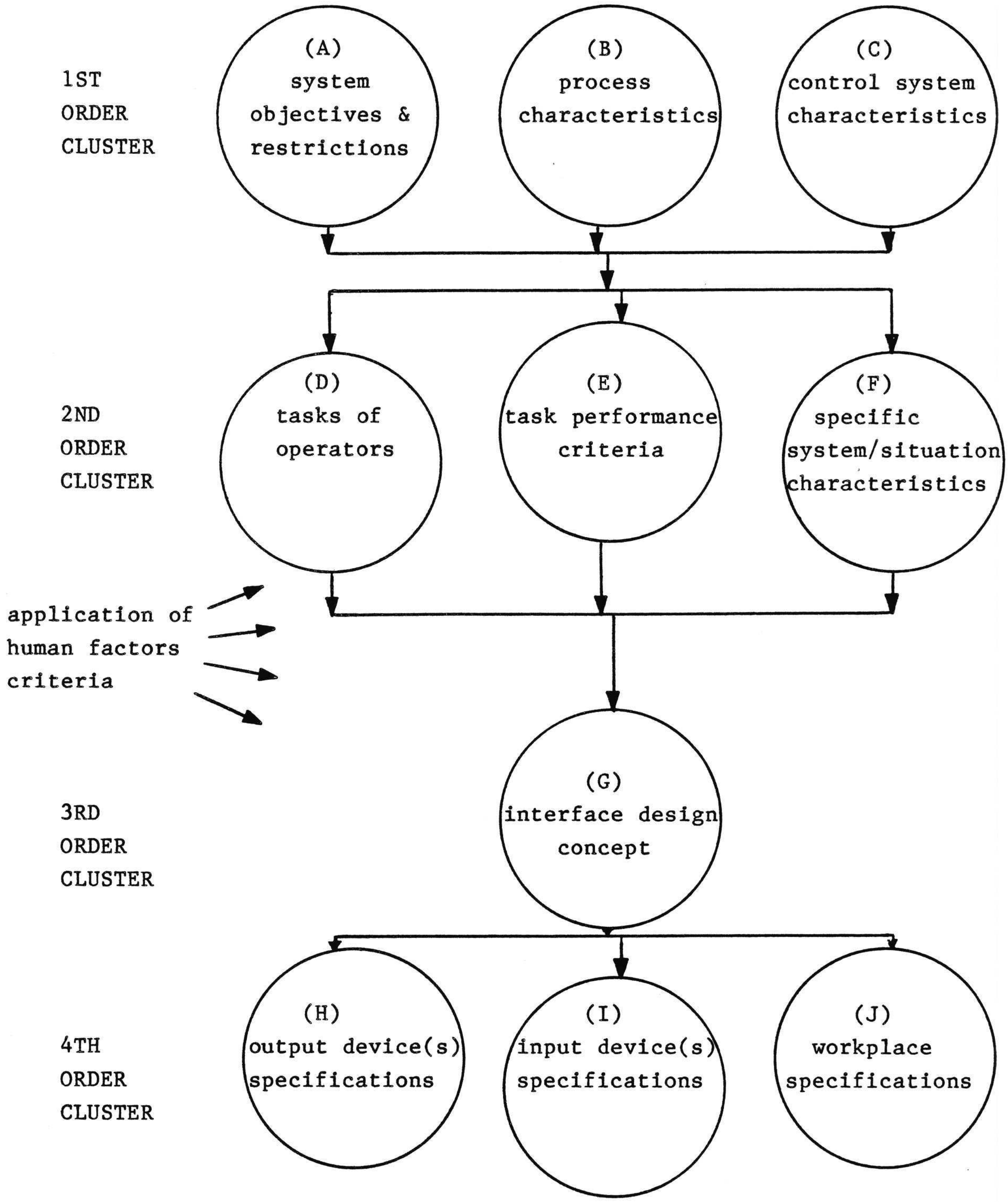

figure 3: structuring of keyfactors in clusters and groups of factors

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DRAFT FACTORS LIST - 1st order cluster		version: 2 page : 1

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:
   - installation (preservation, maintenance)
   - personnel (workload, safety, experience level, availability, etc.)
   - environmental pollution (prevention/limitation of material discharge)
   - energy saving
   - raw materials (use, saving)
   - safety, loss prevention.

B. Factors concerning process characteristics

1) process-structure:
   - functional (subprocesses, integrated operations)
   - physical/geographical structure of process

2) process type (batch or continuous) of subprocesses

3) process modes, e.g.:
   - start up
   - operation
   - change-over
   - shut down.

4) process variables:
   - measurableness
   - controllability
   - mutual interaction
   - disturbances
   - number of process variables
   - number of state variables.

5) process behaviour:
   - dynamical aspects (time constants, time lag, changing characteristics, disturbances)
   - predictability
   - stability.

6) hazard potential of process.

C. Factors concerning control system characteristics

1) functions performed by control system, e.g.:
   - switching actions
   - sequence control (PLC function)
   - stabilising control of process variables
   - process coordination & optimalization
   - upset/emergency control
   - alarm analysis.

2) degree of automation:
   - number of loops controlled by system
   - number of switching actions executed by system.

3) control strategies:
   - single loop control
   - cascade control
   - ratio control
   - adaptive control
   - multivariable control.

4) interaction between control loops.

5) possible malfunctions of control system and effects.

6) required adjustment of control parameters, due to limitations of control system.

7) alarm system,e.g.:
   - number of alarms
   - clusters of alarms (group of alarms which often occur in the same pattern)
   - oscillation of alarms (frequent alarm activation due to fluctuation of a process variable)
   - trip systems (alarms which trigger other alarms).

2ND ORDER CLUSTER

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

1) process control tasks in each process mode, e.g.:
   - on/off control
   - stabilising control
   - tuning of control loop
   - optimizing control
   - process monitoring
   - scheduling/planning of process operation
   - fault management (fault detection, compensation, identification, correction).

2) additional tasks, e.g.:
   - administration
   - reporting
   - maintenance diagnostics (preventive, curative)
   - communication.

3) characteristics of tasks, e.g.:
   - frequency of task activities
   - percentage of time spent on different tasks
   - required number of operator actions.

E. Factors concerning task performance criteria

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.

F. Factors concerning specific system/situation characteristics

1) operator-centered factors:
   - number of operators (field, central control room)
   - background (age, level of education)
   - in-company education and training
   - experience

2) other users of the interface, e.g.:
   - plant or process supervisor
   - operator or operations supervisor
   - maintenance engineer
   - system or control engineer.

3) organisation - centered factors, e.g.:
   - instructions and plant operation procedures
   - authorities and responsibilities (hierarchical organisation)
   - allocation of tasks between field operators and central control room operators
   - authority of interface use.

4) specific demands to interface/workplace:
   - budget
   - operational life cycle
   - applicable standards (plant, company, government)
   - use-objective(s) of control room (process control, training, demonstration)
   - level of interface integration of interface with existing workplace or interface systems.

3RD ORDER CLUSTER

G. Factors concerning interface design concept

1) available process information and accuracy.

2) specific information required in each process mode:
   - overall information on process state and performance
   - information on occurence and location of deviations from normal operation
   - information on important process variables
   - information on functioning of the control system
   - information on process structure (functional, topological, relations with control system)
   - information on historical or expected future process behaviour
   - information on interaction between process variables.

3) general information aspects:
   - amount
   - complexity
   - frequency
   - sequence
   - accessibility
   - coding method
   - redundancy
   - importance, priority.

4) specific input requirements:
   - switching of process plant components
   - changing of setpoints
   - (de)activating control system functions
   - changing of control system tuning parameters
   - acquiring of information.

5) general input-means aspects:
   - amount of input information
   - complexity of input information
   - sequence
   - coding method
   - form.

6) requirements towards input-output dialogue:
   - required skill/experience
   - form
   - consistency and logical design of input method and commands
   - flexibility of input methods/commands (skipping of dialogue-parts, abbreviations of commands)
   - fault tolerance of system
   - user assistance (accompanying text, protection against undesired effect of wrong commands, information on system malfunction)
   - waiting time/system response time
   - required number of user actions before command execution.

4TH ORDER CLUSTER

H. Factors concerning specifications of output devices

1) video monitors

a) general screen-characteristics
- resolution
- refresh rate
- flicker
- contrast
- size
- image sharpness
- luminance
- reflections
- screen profile
- screen orientation
- side-effects (radiation, generated heat, noise)
- number of screens
- allocation of functions between screens
- lay-out of work station.

b) displays, general aspects:
- number of displays available
- accessibility of displays
- allocation of information between displays
- hierarchical structure of displays
- coding of display-structure
- use of colour
- structuring of information on display
- information density on display.

c) specific display aspects:
- overview (presentation method)
- group (number of loops on one display)
- loop (bargraph-presentation method, loop-identification number)
- trend (sample frequency, update frequency, screen resolution, line thickness, number of lines in a graph and coding, scale)
- graphic (level of detail, amount of information in a display, lay-out of graphic)
- alarm (presentation method, number of alarms in one display, accessibility-method to related displays).

d) specific display-elements:
- alpha-numeric signs (size, shape, contrast, colour, matrix-size, spacing between char./rows, columns, distinguishing between characters e.g. 0 and Ø etc., character luminance)
- cursor (size, shape, blinking frequency, control methods)
- menu's (number of levels, access methods)
- tables (number of rows/columns, spacing, lay-out, number of digits per figure, display-switching method e.g. scroll)
- coding methods (underlining, invers video, blinking, different contrast, symbol and style coding).

2) printers:
- position in control room
- character size, shape, spacing, etc.
- page-coding method
- registration/storage methods
- generated noise, heat.

3) acoustic systems
- signal frequencies (fixed or variable)
- duration of signal
- volume of signal (adjustability)
- location of signal source
- voice output.

4) conventional instruments
- recorders
- (single-loop) indicators
- cooperation with PCS.

I. Factors concerning specifications of input devices
----

1) joystick:
- dimensions
- shape
- feedback of cursor-position on screen
- feedback of activation on screen
- feedback method (force- or position feedback)
- ratio joystick movement/cursor movement
- position of enter switch
- handling resistance
- required accuracy of positioning.

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

3) lightpen (with or without enter-key):
   - dimensions
   - shape/profile
   - feedback of activation action
   - feedback of activation on screen
   - frequency of use
   - weight
   - required accuracy for positioning
   - activation method
   - distance between user and screen
   - position of enter-key.

4) touchscreen
   - dimensions of 'key'-area
   - shape of 'key'-area
   - feedback of activation on screen
   - function of 'keys'
   - coding of 'key'-functions
   - grouping of 'keys' on screen
   - required accuracy for finger-positioning
   - activation method
   - distance between user and screen
   - sensitivity of screen to pollution.

5) keyboard (alpha-numerical, fixed-function, variable function or 'soft keys')
   - dimensions of key
   - dimensions and profile of key-board
   - shape/profile of key
   - (tactile) feedback of press-action
   - feedback of key-actions on screen
   - function of keys
   - coding of key-function (incl. grouping)

- number of key-functions
- required key force and travel
- position of key-board in relation to screen
- key-board stability
- surface material (reflection, pollution)
- spacing between keys
- key roll-over (pacing).

6) mouse (with enter-key and/or function keys):
   - dimensions of mouse
   - shape/profile of mouse
   - feedback of cursor position on screen
   - feedback of activation action
   - ratio mouse movement/cursor movement
   - handling resistance of mouse
   - position of mouse in relation to screen
   - sensitivity of mouse to pollution
   - position of enter-key
   - dimensions of key
   - shape/profile of key
   - number of key
   - function of keys
   - position of keys
   - required key force and travel.

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

8) voice input:
   - required volume
   - required clarity of pronounciation
   - number of input commands available
   - allowable speed of input
   - feedback of input command
   - position of input device in relation to screen.

J. Factors concerning workplace realization

1) lay-out of workplace:
   - working posture (standing or sitting)
   - dimensions of workplace
   - distance between user and information sources
   - foot rests
   - amount of workspace (administration)
   - surface of workdesk (texture, reflection)
   - chair.

2) environmental influences:
   - lighting (illumination level, luminance ratio's, contrasts, reflection level)
   - noise (level, frequency)
   - climate (temperature, humidity, speed of air-movement)
   - vibrations (amplitude, frequency)
   - electricity (isolation, anti-static precautions).

3) general control room design:
   - wall material
   - colours
   - contrasts.

APPLICATION OF HUMAN FACTORS CRITERIA

- acceptable physical workload:
  - working posture
  - movements to be executed (limbs, head, eyes)
  - forces to be exercised
  - number 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
  - environmental influences (noise, heat, radiation, climate, lighting, vibrations)
  - social needs.

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

- job satisfaction (motivation).

- individual differences between persons.

APPENDIX 4 : TABLES WITH RESULTS OF SPONSOR CONSULTATION

sponsor group	number of sponsors consulted	number of completed questionnaires received
users	7	6
manufacturers	8	9*
contractors	2	2
	17	17

Table 1: Response on questionnaires (* = from one manufacturer both the European as the US-headquarters returned a completed questionnaire).

function of respondents		number of respondents with this function
on plant site	product engineer	1
	head operator	1
	maintenance engineer	1
	instrument engineer	3
		6
in staff group	instrument or control engineer (process control, computers, PCS)	9
	reliability engineer	1
	ergonomist	3
		19

Table 2: Function of respondents from the user-companies.

specialisation of respondent	number of respondents with this specialization
system application	7
product planning/marketing	5
system design	7
research	1
human factors	3
	23

Table 3: Specialisation of respondents from the manufacturer-companies.

number of processes	process type
7	continuous
2	partly continuous/ partly batch
1	batch

Table 4a: Number of processes with a specific process type.

number of processes	number of subprocesses
3	none
1	3
2	4
1	5
3	6

Table 4b: Number of processes with a specific number of subprocesses.

subprocess	time constants process A	process B	process C
1	30 m	40 m	8 h
2	8-14 h	30 m	12 h
3	1½-2 h	25 m	12 h
4	1 h	50 m	
5	10-15 m	15 m	
6	not clear	20 m	

Table 4c: Indication of the time-constants for each subprocess of three processes (m = minutes, h = hours).

process	batch duration
A	45 m
B	1-5 h
C	12 h

Table 4d: Indication of batchduration for three processes (m = minutes, h = hours)

process mode		occurrence Yes	No	not clear	frequency of occurrence % time per year	number of times per year
start up	planned	6	-	-	0.4 - 2.7	-
		-	1	-	-	-
		3	-	-	-	2 - 25
operation	planned	10	-	-	35-98	-
	unexpected	7	-	-	2-40	-
		-	1	-	-	-
		2	-	-	-	1-50
changeover	planned	2	-	-	1.4-11	-
		-	2	2	-	-
		4	-	-	-	2-1000
	unexpected	1	-	-	0.1	-
		-	4	2	-	-
		3	-	-	-	1-100
shut down	planned	3	-	-	0.08-0.5	-
		-	1	1	-	-
		5	-	-	-	1-25
	unexpected	3	-	-	0.08-0.5	-
		-	1	1	-	-
		5	-	-	-	2-8

Table 4e: Occurrence of specific process modes and the given range of the frequency of occurrence in percentage time or number of times.

disturbance	some mentioned frequencies
process disturbance	1/week, 1/shift, 10/shift, 50/shift
equipment malfunction	2/week, 10/week, 0.3/shift, 15/shift

Table 4f: Some mentioned frequencies of the occurrence of process disturbance and equipment malfunction, which require operator intervention.

parameters	process 1	2	3	4	5	6	7	8*	9*	10*
number of control loops for process control	300	280	190	110	100	10	9	30	100	400
number of loops for plant protection	170	160	50	15	120	20	15	60	40	20
number of continuous process variables										
- measured	2000	1500	1500	300	1200	40	40	150	400	600
- computed	200	250	350	240	24	3	20	20	350	100
- total	2200	1750	1850	540	1224	43	60	170	750	700
number of binary variables										
- measured	700	750	35	800	200	120	50	600	1200	2000
- computed	50	100	17	600	4	30	-	500	700	1500
- total	750	850	52	1400	204	150	50	1100	1900	3500
used PCS										
- conventional	o	-	-	-	-	-	-	-	-	-
- commercial type	-	o	-	o	o	o	o	o	-	o
- own design	-	-	o	-	-	-	-	-	o	-

o = batch or partly batch process

Table 5: Some characteristics of the control system of 10 processes.

aspect	process 1	2	3	4	5	6	7	8*	9*	10*
number of operators										
- central control room	3	2	1	2/3	2	0/1	1	1	2	2
- field	17	7	5	3/4	3	2	1	½	4	7
number of supervisors	2	1	1	1	1	-	1	-	1	1
presented information to the operator(s)**										
- number of control loops	300	280	190	110	100	10	9	30	100	400
- number of measured and computed continuous variables	2200	875	1850	480	not clear	40	60	170	730	150
- number of measured and computed binary variables	750	650	370	1200	200	150	50	220	1900	350
required operator intervention because of:										
- process disturbances	1/s	10/s	2/s	10/s	1/w	not clear	5/s	4/s	10/s	2/s
- equipment malfunctions	0.3/s	10/w	1/s	2/s	2-3/s	not clear	-	2/s	0.5/s	8/s
- time which may elapse, before operator has to intervene (seconds)	not clear	20-60	120	30-60	5-60	not clear	300	60-300	300	10

* batch or partly batch

** note: not all continuous and binary process variables (see table 5) are presented to the operator(s).

Table 6a: Number of operators, presented information and figures on required operator intervention for the ten processes (s = shift, w = week).

operator task-aspect	start up (9)	opera-tion (10)	change-over (6)	shut down (9)
	process mode			
a) on/off actions	8	9	6	8
b) stabilising actions	8	10	6	7
c) tuning of control loops	4	7	2	3
d) optimising control	6	9	5	3
e) process monitoring	9	9	6	9
f) planning/scheduling	6	8	6	6
g) faultmanagement				
- detection	9	10	6	9
- diagnose	7	8	4	7
- correction	6	7	4	4
h) administration	9	10	7	9
i) communication				
- between console operators	8	9	6	7
- between console- & field-operators	8	9	6	8
j) reporting	8	9	6	8
k) maintenance diagnose				
- preventive	4	8	4	4
- curative	7	9	6	7

Table 6b: Number of processes in which the operator performs the specific task aspects in each process-mode, if applicable; between brackets is indicated the total number of processes with the particular process mode.

task-aspect	Frequency	start up (9)	opera-tion (10)	change-over (11)	shut down (12)
		process mode			
On/off actions	frequent	6	1	3	4
	regular	2	6	2	3
	occasional	0	2	1	1
	not at all	1	1	0	1
fault diagnosis	frequent	3	2	1	2
	regular	3	5	2	3
	occasional	1	1	1	2
	not at all	2	2	2	2

Table 6c: Examples of two task-aspects for which the number of processes is given, indicating the frequency of the task-aspect in the occurring process mode (frequent = more than 5 times per shift, regular = more than once a week, occasionally = less than once a week); between brackets is indicated the total number of processses with the particular process mode.

function	purpose
process engineer/ technologist	- check calculation process optimisation - check process data and calculations - optimising - process information
instrument engineer/ control engineer	- measuring instruments calibration, diagnostics - check instrumentation, new configuration - instrument information - control information
plant/production manager or management	- check historical data with respect to quality, quantity, efficiency etc. - optimisation - process management - general process information, daily reports etc. - production reports/administration
(shift)supervisor/head operator	- process control - process information (general information) - observation/information - process monitoring
field operator	- process information
maintenance engineer/ technical support	- testing, alarm setting etc. - configuration changes, preventive maintenance, safety checks - diagnoses, adjustments - test runs, data gathering
research	- data logging, reports

Table 7: Examples of mentioned functions of company-employees other than the operator, which use the PCS for the indicated purposes.

A) What kind of demands concerning the PCS does your company have (have users expressed) because of certain process characteristics? (for example: demands concerning a specific display type for a particular process mode).

Users	Manufacturers
- fast trends; displays with analog and binary values - live graphic displays - better data presentation - graphics/flowscheme's on all screens - start-up procedures on all screens - possibility of connecting/ communicating with other computer system	- sequence control displays - audible alarms and event information when operator is not always in control room - special lay-out of displays in: alarm field, general information field and dialogue field - special displays for batch processes - access from flowsheet to loop - alarm status displays per process unit - alarm priorities - panning for large pipeline system - simple group display - special video display - to get good overview of the process - dedicated push buttons for fast access

B) What kind of demands does your company have (have users expressed) because of certain tasks of the operator(s)? (for example: the possibility of presenting information on the process-structure; the possibility to use the PCS for tasks other than control, such as administration.)

Users	Manufacturers
- calculation and presentation of process keyfactors - alarm summary and first failure detection/print out - sufficient number of screens - PCS speed of response - possibility of limiting information exchange	- calculated data transmission from one station to another - graphic displays - alarm priority levels - (configurable) display for procedures - colorcode for process states - log all operator actions - energy balance - hard copy of any display - assistance for loop tuning

C) What kind of demands does your company have (have users expressed) with respect to different types of information to be exchanged via the PCS? for example: the possibility of presenting historical data, the possibility of presenting production reports).

Users	Manufacturers
- production reports - batch reports - recipe displays - graphics/P&I - status of batch sequence - trend facility - alarm reports	- historical data/production reports - operator assistance data - operator actions recording - circular process units state diagrams - lab results - system control configurations - expert system technology

D) What kind of demands does your company have (have users expressed) with respect to the methods for information input and output? (for example: demands on certain input devices, demands on certain display types).

Users	Manufacturers
- possibility to enter lab. data - multiple screens; operation via one keyboard - operator friendly; robust; quick access to information	- input devices should be simple and robust - good resolution/colour necessary - hardcopy - eliminate keyboards - touch screen, joy stick, track balls - depends on what is current 'hot' topic - process schematics - doing everything with a single button push - voice input/output

E) What kind of demands does your company have (have users expressed) with respect to the hardware/layout of the PCS? (for example: demands on the console shape, demands on screen resolution).

Users	Manufacturers
- more steady displays; higher vertical scan rate - high resolution displays - good readability of alpha-numerical characters - flexibility - coffee-proof	- screen resolution 512x512 or 1024x1024 - separate operator and engineer keyboard - joystick well accepted - operator standing - mention of DIN standards - reduction of "footprint" size of overall console - full graphic - reflections

Table 8: Examples of ergonomic demands on PCS which user-companies have or have expressed to manufacturers.

Missing factors mentioned by manufacturers

1) redundancy of operator stations;
2) information related to system configuration;
3) governmental restrictions to PCS;
4) safety, reliability and availability to PCS;
5) operation of PCS under equipment and system malfunction;
6) guidelines for deciding between operator and automation tasks;
7) operator training on PCS without interfering process;
8) system configuration and programmation factors;
9) interactive scenario's between operator, interface and displays;
10) amount of information to be displayed parallel and serial;
11) operator performance (and its measurement);
12) task allocation between operator and automatic systems;
13) interface criteria for connecting with other computer systems (PCS, host, PLC, office automation system, laboratory system etc.);
14) functional hierarchical structure of total system including management computer, PCS, PLC and so on;
15) system reliability and redundancy;
16) support software.

Table 9b: Missing factors in the draft factors list, specified by the manufacturers.

Missing factors mentioned by users

1) possibility of suppression of characters behind the decimal point;
2) hard copy-, tape-, magnetic- and diskette-unit;
3) desired training facilities, training simulator possibilities;
4) hardware configuration (limitations, possibilities);
5) first-alarm system;
6) alarm-suppression facilities, alarm grouping;
7) interference between operator-jobs;
8) display sets on different VDU's;
9) associated displays (request of pictorial by one dedicated button);
10) robustness and environmental limiting conditions for input/output devices (fall-, coffee-, dustproof, etc.).

Table 9a: Missing factors in the draft factors list, specified by the users.

Cluster	USERS (n=6) total of scores	USERS (n=6) average score	MANUFACTURERS (n=9) total of scores	MANUFACTURERS (n=9) average score
1	9	1.5	13	1.4
2	10	1.7	12	1.3
3	10	1.7	14	1.6
4	13.5	2.3	13	1.4

Table 10a: Totals and averages of scores given by users and manufacturers, indicating the relevance of each cluster to their company (1 = most relevant, 2 = relevant, 3 = not relevant).

Cluster	factorgroup	USERS (n=6) total of scores		USERS (n=6) average score		MANUFACTURERS (n=9) total of scores		MANUFACTURERS (n=9) average score	
1st cluster	A system objectives § restrictions	10	30	1.7	1.7	17.5	42.5	1.9	1.6
	B process characteristics	9		1.5		15		1.7	
	C control system characteristics	11		1.8		10		1.1	
2nd cluster	D tasks of operator(s)	9	32.5	1.5	1.8	13	40	1.4	1.5
	E task performance criteria	13		2.2		13		1.4	
	F specific system/situation characteristics	10.5		1.8		14		1.6	
3rd cluster	G interface design concept	10	10	1.7	1.7	13	13	1.4	1.4
4th cluster	H output device(s) specifications	13	42	2.2	2.3	12	41	1.3	1.5
	I input device(s) specifications	14.5		2.4		13		1.4	
	J workplace specifications	14.5		2.4		16		1.8	

Table 10b: Totals and averages of the scores given by users and manufacturers indicating the relevance of each factor group to their company (1 = most relevant, 2 = relevant, 3 = not relevant).

APPENDIX 5 : DEFINITIVE FACTORS LIST

This list contains a number of factors which influence the control of processes by operators using a Process Control System (PCS).
The factors have been partioned in factor groups, which are hierarchically structured in four clusters. These groups and clusters are shown in the figure below.
The clusters 1 and 2 contain factors which describe the application in which the PCS has to function. Examples of these factors are the number of process variables measured, the functions of the automatic control system and the tasks of the operators.
Clusters 3 and 4 concern the characteristics of the PCS with respect to it's design (cluster 3) and it's specification (cluster 4). The environment of the PCS which serves as the workplace for the operator, is included as well. Examples of factors in these clusters are:
the required information to be presented by the PCS, the number of screens on the PCS and the weight of the lightpen.
The purpose of this list is the identification and structuring of the most important factors which influence the control of processes by operators using a PCS. In a next phase of the project ergonomic guidelines will be formulated based on this list. These guidelines will relate factors and factor-groups to each other and indicate important factors and relations.
It is of importance to remark that not all factors mentioned are expressed on a same level of detail. A further specification could be necessary in the next phase. Furthermore, not all factors are of equal importance; the importance of factors will depend to some extent of specific application aspects.

Some of the terms used in the factors list require (further) definition.
In the next phase of the project these definitions will be made.

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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

3. manual adjustment of control system parameters (automatic/ manual, setpoint, PID-parameters, filters), due to limitations of control system and/or changes process conditions.

5) <u>alarm system,e.g.</u>:
   1. number of alarms
   2. type of alarms (priority levels, frequency of occurrence)
   3. clusters of alarms (group of alarms which often occur in the same pattern)
   4. oscillation of alarms (frequent alarm activation due to fluctuation of a process variable)
   5. trip systems (alarms which trigger trip functions).

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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.

F. Factors concerning specific system/situation characteristics

1) operator-oriented factors:
   1. number of operators (field, control room)
   2. operator background (age, level of education, experience)
   3. interference between operator-jobs
   4. training and education.

2) organisation - centered factors, e.g.:
   1. organization structure
   2. operation instructions and plant operation procedures
   3. allocation of tasks between field operators and central control room operators
   4. authority of interface use.

3) other users of the interface, e.g.:
   1. plant or process supervisor
   2. head operator or operations supervisor
   3. maintenance engineer
   4. system or control engineer
   5. process engineer
   6. administration
   7. research
   8. laboratory.

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.

5) requirements towards input-output dialogue:
   1. required skill/experience
   2. basis structure (dialogue types, language, terminology, consistency, logical design)
   3. commands, codes, abbreviations (construction, spelling, consistency, number, word length)
   4. flexibility of input methods/commands (skipping of dialogue-parts, abbreviations of commands, fault tolerance of system)
   5. user assistance of system (feedback on user actions, prompting on request, error messages, error handling, information on system malfunction, help-function)
   6. waiting time/system response time
   7. feedback on input actions
   8. protection against undesired effects or wrong commands.

6) required training facilities on interface

7) additional demands to interface/workplace, e.g.:
   1. level of integration of interface with existing workplace or other systems
   2. use-objective(s) of control room (process control, training, demonstrations)
   3. applicable standards (plant, company, government)
   4. interface functioning (safety, reliability, redundancy, availability, operation under system malfunctions, connection with other computer systems, system hierarchy, support software).

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)

5. graphic (level of detail, amount of information in a display, lay-out of graphic, coding method)
6. alarm (presentation method, number of alarms in one display, access-method to related displays, filter and grouping facilities according to priorities, first alarm indication)
7. displays for system configuration, programmation and functioning.

4] specific display-elements:
1. alpha-numeric signs (size, shape, contrast, colour, matrix-size, spacing between char./rows, columns, distinguishing between characters e.g. 0 and Ø etc., character luminance, possibility of character suppression behind the decimal points)
2. cursor (size, shape, blinking frequency, control methods)
3. menu's (number of levels, access methods)
4. tables (number of rows/columns, spacing, lay-out, number of digits per figure, display-switching method e.g. scroll)
5. coding methods (underlining, invers video, blinking, different contrast, symbol and style coding).

2) printers:
1. location in control room (frequency of use)
2. character size, shape, spacing, etc.
3. page-coding methods
4. registration/storage methods
5. generated noise, heat
6. acoustic messages/signals (out of paper alarm, changing ribbons).

3) acoustic systems:
1. signal frequencies (fixed or variable, bandwidth, number of frequencies)
2. duration of signal (fixed, variable)
3. volume/intensity of signal (adjustability)
4. location of signal source
5. voice output (volume, intelligibility, language, nature of messages, speed)

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)

8. required accuracy for positioning
9. activation method
10. distance between user and screen
11. position of enter-key.

4) touchscreen:
1. dimensions of 'key'-area
2. shape of 'key'-area
3. feedback of activation on screen
4. function of 'keys'
5. coding of 'key'-functions
6. grouping of 'keys' on screen
7. required accuracy for finger-positioning
8. activation method
9. distance between user and screen
10. sensitivity of screen to dirt.

5) keyboard (alpha-numerical, fixed-function, variable function or 'soft keys'):
1. dimensions of keys
2. spacing between keys
3. dimensions and profile of key-board (thickness, angle)
4. shape/profile of key
5. (tactile) feedback of press-action
6. key force and travel
7. feedback of key-actions on screen
8. functions of keys (number of functions)
9. coding of key-functions (legends)
10. grouping of keys
11. position of key-board in relation to screen (fixed, variable)
12. key-board stability
13. surface material (reflection, pollution)
14. key roll-over (pacing).

6) mouse (with enter-key and/or function keys):
1. dimensions of mouse
2. shape/profile of mouse
3. feedback of cursor position on screen
4. feedback of activation action
5. ratio mouse movement/cursor movement
6. handling resistance of mouse
7. position of mouse in relation to screen
8. sensitivity of mouse to dirt.

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.).

2) <u>environmental influences</u>:
    1. lighting (illumination level, luminance ratio's, contrasts, reflection level, daylight aspects)
    2. noise (level, frequency)
    3. climate (temperature, humidity, speed of air-movement)
    4. vibrations (amplitude, frequency)
    5. electricity (isolation, anti-static precautions)
    6. comfort
    7. dirt/dust.

3) <u>general control room design</u>:
    1. material of wall, floor, ceiling
    2. colours
    3. contrasts.

4) <u>hardware configurations</u>

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.