Ergonomics in the struggle against 'alarm inflation' in process control systems : many questions, few answers

Ergonomics in the struggle against "Alarm inflation" in process control systems - Many questions, few answers

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SUMMARY

This article deals with process alarm systems which are in use in the control rooms of chemical plants. The signal flows in process alarm systems are discussed. Conventional and advanced process alarm systems are considered from an ergonomic point of view. Some results of an open-ended interview concerning process alarm systems with operators in a high pressure plant are presented. An outline for further research is given.

1. INTRODUCTION

A lot of research has been carried out on the operator in process plants [1,2]. A few years ago the group that studies Man-machine systems at the University of Technology Eindhoven together with the DSM decided to carry out research on the operator-process situation in *chemical* plants [3]. One research topic was the design of control rooms; the place where the human operator controls the processes. From an ergonomic point of view the design of such a control room is very important. The questions which arise are : 'Wat is a good design ?', and 'What criteria does one use for the design of control rooms ?'
In order to obtain 'guidelines' which will be of use for project teams in the future, a field study was started at the end of 1976. In this study five different kinds of control rooms were fully described from an *ergonomic* point of view. These descriptions included evaluations of the man-mache interface, the consoles, the lighting etc.
From the evaluations, it appeared that the design of the process alarm system which is a very important system in a central control room could be improved. Such a system should be adapted to the capabilities of the human operator.

The process alarm system is concerned with *monitoring* and one of the activities which are essential constituents of the job of the operator is also monitoring [4].
Inside the control room, monitoring has a clear meaning for the operator : a regular watch must be kept to ensure that the process variables remain within predetermined limits.
Outside the control room, he must inspect the plant system two or three times per shift for any possible leakage, blockage, etc.

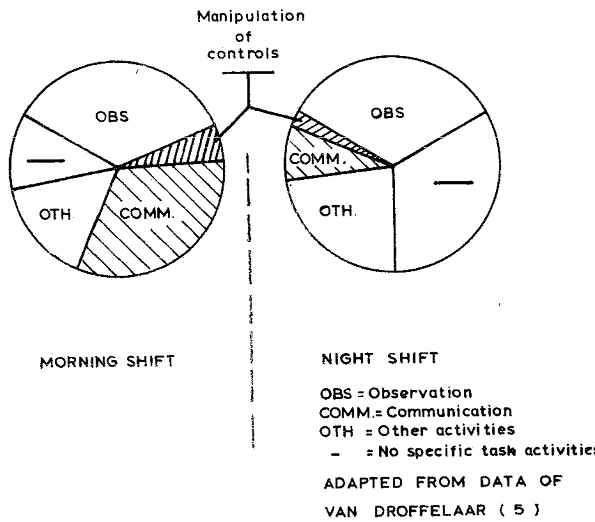

Fig. 1. Operator activities.

In a field study carried out by Van Droffelaar [5] it was found that the human operator spent about 1/3 of the time on display monitoring (see figure 1). We think this time is more or less representative of the operator-process situation in chemical plants.
With Edwards & Lees [1] we expect this fraction will increase in the future; this stresses the need for a carefully designed process alarm system in order to help the human operator in performing this task.
As said before, we found in our field study that the design of the process alarm system could be improved. The same was the opinion of Andow & Lees [6] and of the Purdue-Europe Technical Committee no. 6 on Man-Machine Communications [7]. This committee made a study in 32 process industries on the continent (DSM included) and in the UK by means of a questionnaire. The objective was to gather information from designers and plant engineers on control rooms. (However they

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did not interview the control room operators.) With regard to the process alarm system, the above-mentioned committee noticed two problem areas :
1. the growth in the number of alarms;
2. the lack of confidence of the operator in the system.

At the end of this paragraph we would like to quote Edwards & Lees [2] and Williams [8].

Edwards and Lees (page 418):

'Alarm systems are often one of the least satisfactory aspects of process control system design. There are a number of reasons for this, including lack of a clear design philosophy, confusion between alarms and statuses, use of too many alarms, etc. Yet with the relative growth in the monitoring function of the operator, and indeed of the control system, the alarm system becomes increasingly important. This is therefore another field in which there is much scope for work !'

Williams (page 63):

'Alarm systems in general are unsatisfactory, particular those in computer systems which rely on typewriter print out. Alarms will mushroom after a system is installed; and a better alarm hierarchy strategy is needed. Everyone shudders at the analysis job required to plan and rationalize such systems.'

2. PROCESS ALARM SYSTEMS

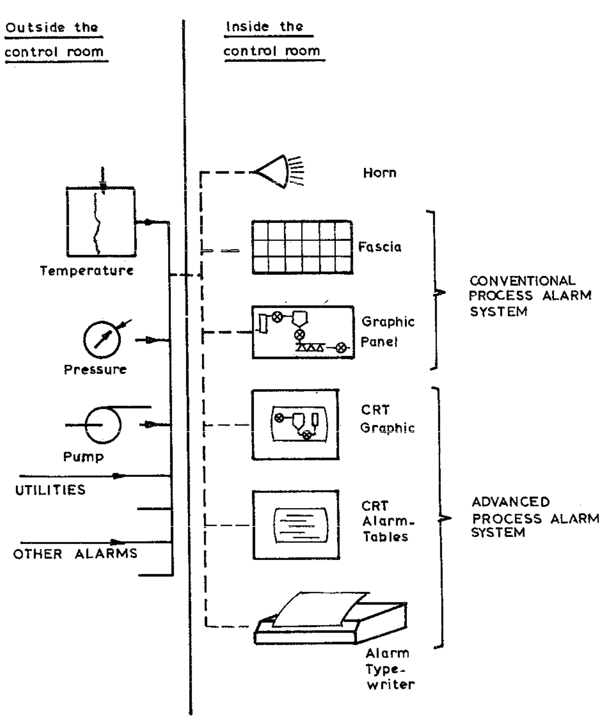


Fig. 2. Signal flows in a process alarm system.

In figure 2 an overview is given of the signal flows in a process alarm system. We distinguish between signals outside the control room and signals within the control room.
From outside the control room binary information comes from the process, from the utilities and from other apparatus.
The original information is usually available as an analogue signal which is digitized by a special instrument, e.g. a temperature switch or a pressure switch.
In some cases, there are special variable limits available at an analogue instrument, e.g. a temperature instrument with an adjustable limit setting. In the control room, the signals are presented audibly and visually.
The way in which these signals are presented to the human operator is interesting for ergonomists; we will discuss it in this article.
The acoustical signal is presented by means of a horn and the visual signal can be presented in different ways, namely :
- on a fascia;
- on a graphic panel;
- on a CRT (cathode ray tube; graph or alarm table);
- on an alarm type-writer.

In this article we distinguish between *conventional* and *advanced* process alarm systems (see figure 2). It is relevant to deal with both, because in the future, conventional process alarm systems will still be used as well as the advanced systems.
In each process alarm system, the visual signal has three states :
1. a normal state (light off);
2. an unacknowledged state (flashing light);.
3. an off-limit state (light on).

The off-limit state occurs when the incoming alarm signal is acknowledged by the operator. In the conventional alarm system (see paragrah 3), this means a steady light on the fascia. In the advanced alarm system (see paragraph 4), it means a text on a CRT or a text on an alarm type-writer.
Let us consider the information processing tasks which the human operator should perform when a single alarm signal comes up. (For the definition of each activity we refer to [9].)
First of all, he has to *detect* the audible signal as well as the visual signal. Generally, it is possible to hear the audible signal above the control room noise, particularly, when the number of audible signals is limited to one or two.
Problems can arise when the human operator has to detect the visual signals, e.g. at the fascia. In our opinion, the detection process of the operator is not optimal if the visual signals are not presented to him in a hierarchical way.
System designers should realize that the time in which the operator tries to detect the visual signal has to be minimized. With hierarchical information presentations this can be realized and the more advanced process alarm systems are based on this principle.

After having detected and *discriminated* the visual signal, the operator has to *interpret* the flashing light. After the interpretation, he will acknowledge the signal by pushing a button; consequently, he has to decide whether to take the action or not.
Normally this should be the procedure in case of a single alarm signal; however, it is possible that several alarm signals are presented in a rapid sequence, for example with a time difference between two signals of less than ten seconds. In such a situation the operator has to acknowledge each of the alarm signals in the above-mentioned way, but this can involve problems. In that case, the human operator can react theoretically in two different ways :

a. he neglects the visual signals which could mean a deterioration of his task performance, but by doing this he equalizes his mental load;

b. he tries to react to all the visual signals which means an increase of his mental load. This can have serious long-term effects :
deterioration of the human being in the future (e.g. stomach ulcer, high blood pressure, chronical headache).

3. CONVENTIONAL PROCESS ALARM SYSTEMS

In paragraph 2, we put forward the thesis that the visual signal in a process alarm system should be presented *hierarchical* in order to be effectively and efficiently detected by the human operator.
Let us consider the hierarchy concept in more detail. In figure 3 an overview is given of what happens when an alarm signal comes up. If a process contact switches from the normal state to the alarm state an audible signal sounds in the control room. At the same moment a visual signal at one of the fascias is flashing. It keeps on flashing until the operator has acknowledged the signal by pressing the fascia-button concerned. The acknowledgement takes place after the so-called *visual detection period* (t_d). After such a period, the audible signal stops and a steady light comes on at the fascia concerned.
In the next two examples, we will illustrate with regard to the conventional process alarm systems, the relation between the way in which the visual signal is presented and the above-mentioned detection time t_d.

Example 1

In some control rooms the alarm signals consisted of one auditive signal and many specific light signals on fascias which were decentralized at the panels. In those cases, the operator had to scan the panels after hearing the audible signal. During this scanning process, the operator could fail to detect the visual signal quickly,

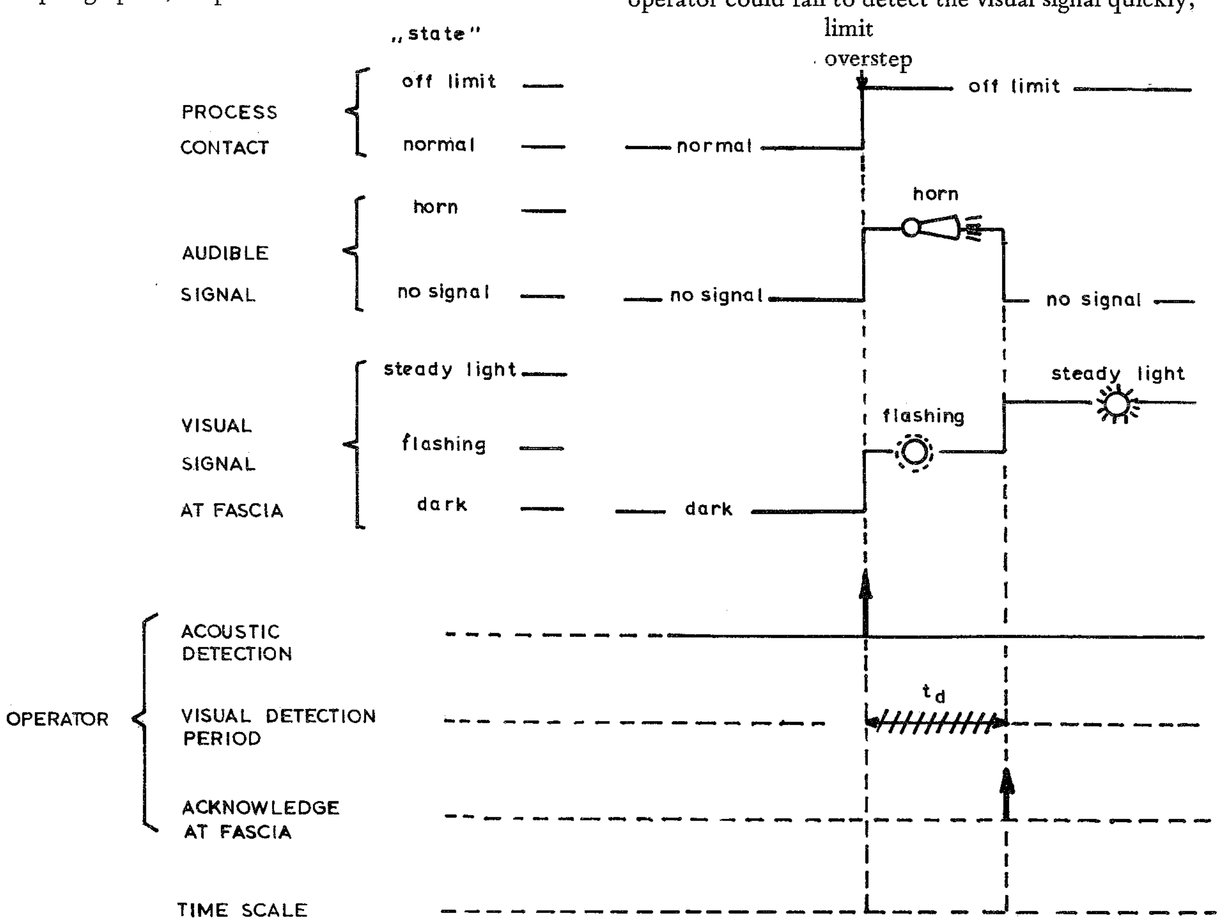


Fig. 3. Time sequence of a process alarm system.

or he could simply overlook it during the first scan. In that case, the visual detection period took longer than necessary which meant an extra stress on the operator.

Example 2

In some control rooms, the visual signal was presented in two steps :

1. At a *central* fascia which showed the number of the panel on which the alarm had occurred.

2. At a *local* fascia placed at the panel concerned.

If these two fascias were not adapted to each other, the visual detection period would take longer than necessary.
In figure 4, an illustration is given of a lay-out which can lead to a detection problem at the local fascia.
If system designers tackle this problem by making each panel consisting of a fascia with a limited number of alarm lights (e.g. 2 x 9), they have to realize that a detection problem could arise at the central fascia.
On the other hand, if local fascias with the dimensions as given in figure 4 have to be used it is advisable to divide the fascia into a number of small fascias (e.g. 3 x 9 alarm lights). Such a group can be supplied with a common alarm light and, by doing so, the visual detection period can be minimized (see figure 5).

In this context we would like to put these questions :

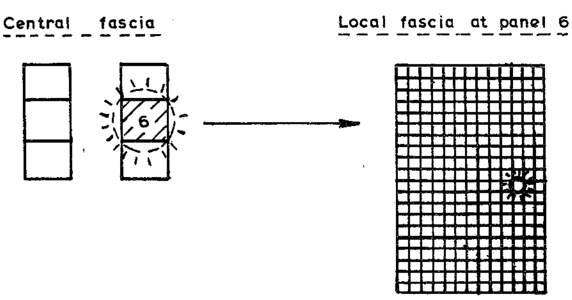


Fig. 4. Hierarchical conventional alarm system (two levels).

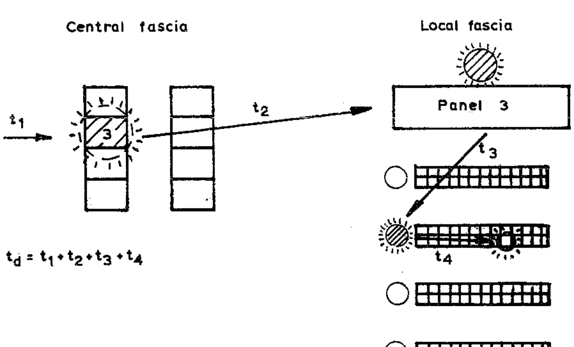


Fig. 5. Hierarchical conventional alarm system (three levels).

- Is it necessary to present to the operator a change from the alarm state to the normal state (see figure 3)?
- What is the maximum number of different audible signals which can be used in a control room ?
- Which demands (visibility, legibility) do we have to make upon the central fascia ?
- How many different colours can be used in a conventional process alarm system ?
- Where should the acknowledge button be placed (local, central) ?
- How many alarm lights should be allowed in one control room ?

Naturally each control engineer has his own answers to the above-mentioned questions, but not all answers will be supported by ergonomic principles.

4. ADVANCED PROCESS ALARM SYSTEMS

The introduction of more advanced techniques in process control such as process computers, integrated instrumentation systems and programmable logic controllers gives a wide range of possibilities for designing an alarm system which is better adapted to human capabilities than the conventional process alarm system.
In this chapter, special attention will be given to the alarm presentation in integrated instrumentation systems, such as the Honeywell TDC 2000, Foxboro Videospec and Taylor Mod. III.
As there are few of these systems in use at present we did not have the opportunity to evaluate the ergonomic aspects of these systems in practice. Nevertheless, we give our opinion with regard to some special ergonomic features of these systems. First of all, we will mention some advantages and disadvantages in general :

Advantages

- *Combination of the alarm information with the instrument- and process-information*

This is a real improvement over the conventional approach in which the alarm systems with their fascias are physically separated from other process information.

- *Hierarchical procedure in locating alarm signals*

Most integrated instrumentation systems have a very simple procedure for locating an individual alarm signal. A section of the keyboard, or a special alarm light panel, starts flashing when a predetermined limit is exceeded. The button or the alarm light shows where to look for further information about each individual alarm signal. Acknowledging, or asking for this information, by the operator results in a display of the alarm group concerned automatically.

Disadvantages

- Overloading the display with information

As there are so many demands on the design of an alarm system, the instrument designer can overload a system by including too many special features. Such features can be provided with little extra costs, but they can cause an overloading of the system.

- Too many alarm signals

As it is easy to design an alarm signal for an integrated system, the control engineer can include an alarm limit for every measurement. Usually it is just a matter of using the standard software of the system. But this can lead to the installation of too many alarm signals for the operator to control.

When we look in more detail at available CRT displays of integrated systems, we find the following kinds of alarm information presentation (see figure 6) :
- alarm tables (chronological sequence);
- alarm tables (alarm group display);
- alarm signals combined with instrument information;
- alarm signals combined with process graphics.

(The alarm signals in the form of alarm tables can be recorded on type-writers; the CRT information can be recorded on hard-copy units. In this article, we will not deal with the specific ergonomic problems which could arise in using CRT's. See for instance Kraiss [10].)

Each of the above-mentioned presentations will be discussed in more detail :

4.1. Alarm tables (chronological sequence)

Description

Alarm tables (fig. 6a) are presentations in text of alarm signals.
Every new alarm signal is introduced at the table, every alarm signal that returns to normal again is removed from the table.

Comments

It is important to use a separate CRT, or a separate part of the CRT screen, or a special alarm type-writer for all the alarm messages, otherwise the alarm information will be drowned by the process or other messages.
With Zwaga [11] we doubt of the effectiveness of alarm tables with more than three or four items.
If these tables are presented on a CRT, the operator usually remembers only the last alarm signal. He will not use the screen to examine the tables nor make his decision on that information, but he will use other information to decide his action.
Alarm tables on an alarm type-writer can be used in a simular way by the operator. The only advantage here is the possibility to check at ease in a particular situation by examining the different alarm signals.

12.05	Ratio reactor	Low
11.45	Temperature 3	High
10.00	Pressure	Low
10.00	Temperature 12	High
09.59	Flow B	Low

a) ALARM TABLES CHRONOLOGICAL SEQUENCE

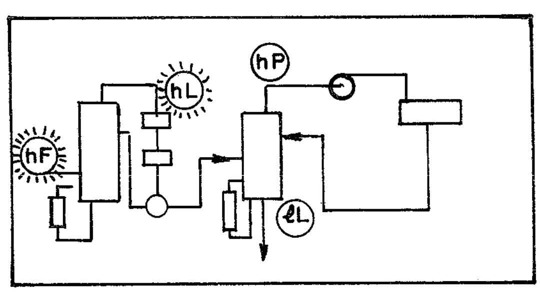
REACTOR GROUP
Ratio
11.45 Temperature 3 High
Temperature 1
Pressure

b) ALARM TABLES (Process) GROUP DISPLAY

A – – MV A –	A – – MV	– MV	– MV
Equivalent of one panel instrument	– MV A –	A – – MV A –	A – MV

c) ALARMS COMBINED WITH INSTRUMENT GROUP

MV = Measured Value
A = Alarm limit



d) ALARMS COMBINED WITH PROCESS GRAPHICS

Fig. 6. Different levels of CRT presentation with integrated instrumentation systems.

However, the second category of alarm tables, i.e. alarm tables as a group display, are more appropriate for this purpose.

Questions

- How many items on an alarm table with a chronological sequence can be remembered ?
- Are the above-mentioned alarm tables used in practice to pinpoint the alarm signal concerned, or are they used in checking a situation before action is taken ? Or is the alarm table an aid to provide an overview of the alarm situation ?

4.2. Alarm tables (alarm group display)

Description

The alarm group display (alpha-numerical) presents an overview of all those process variables which are defined in a specific group concerning one process unit (fig. 6b). A special indication (colour, special sign, etc.) is given for those process variables which are in an alarm state. (Temperature 3 in figure 6b.)

Comments

This special feature of a modern integrated instrumentation system is very important to the operator, because he is able to compare off-limit situations within one process group. Combination of several off-limit situations makes it possible for the operator to decide the importance of each alarm signal, which is much more difficult in case of a chronological alarm table.

Questions

- Is it better to describe an alarm signal than to use a tag number ?
- How many process variables should be maximal in a group alarm display ?
- How many alarm signals of a group alarm display can be remembered ?
- Which presentation should be used in order to discriminate between process variables in normal state and process variables which are in an alarm state ?

4.3. Alarm signals combined with instrument information

Description

The CRT presentation is equivalent to a conventional control panel section consisting of e.g. eight controllers or indicators (fig. 6c). Usually it is also possible to display one controller or indicator of this group.

Comments

Essentially, alarm settings on control loops and indicators should give a warning to the operator. In the case of indicating instrument displays this is no problem, but the use of alarm settings at controllers is a contradiction because, when the control loop functions correctly, there is no reason to expect an alarm call.
On the contrary, if the control loop is not functioning correctly, one should rely on an independent alarm signal. In conclusion, it is inadvisable to use alarm settings on control loops unless there is a special reason. Excluding alarm settings on control loops can be the first stage of winning the battle against 'alarm inflation'.

Some other opinions on ergonomic aspects of alarm signals integrated with instrument information are :
- the use of alarm pointers at the scale is an important visual aid to the operator and makes it possible to compare at a glance alarm limits and measured values (see figure 6c);
- digital information is needed for *setting* the alarm limits by the operator or the control engineer;
- usually, digital information for alarm limits is not needed by the operator;
- digital information for alarm limits causes overloading of alpha-numerical information on the screen.

4.4. Alarm signals integrated with process graphics

Description

Alarm signals integrated with process graphics are either alpha-numerical or pictorial signals which are presented together with a graphic display of a part of the process (fig. 6d).

Questions

- Does the operator use a graphic display for an overview of the situation mostly, or as a check before taking action, or for diagnosing a special situation ?
- If colour coded CRTs are used, is one colour code enough to indicate an alarm situation ?
- Does a graphic display give better information than an alpha-numerical display ?

5. PROPOSED RESEARCH ON PROCESS ALARM SYSTEMS

As said in the introduction, ergonomic workplace analyses were carried out in five different control rooms.
As a result a questionnaire with 56 items was developed. This questionnaire was used in the analysis of a control room in a high pressure plant and nineteen items on the questionnaire referred to the process alarm system. We mention some of the items of the open-ended interview in which twenty operators were involved (4 shifts x 5 operators) :
- group opinions about the alarm system itself;
- the number and kind of alarm signals;
- the kind of reactions of the operator to the alarm signals;
- the problem of alarm limits;

- the problem of false alarm signals;
- the kind and number of human errors in using the alarm system;
- computer alarm systems versus conventional alarm systems.

In the following paragraphs, we would like to present some results :

Number of alarm signals

During normal process operation the operators were satisfied with the way in which the alarm signals were presented to them. In that situation the number of alarm signals were less than ten per hour.
Some of the operators remarked that one of the great advantages of the computer print-out was that with the aid of the hard copy there existed the opportunity to analyse the events afterwards. This is very important, particularly in the case of a shift change; however, during a breakdown or when starting up the process, there was talk of what we call 'alarm inflation'. In such situations, too many messages were presented to the operator; however, most of these messages gave no extra information to the operator. Subsequently, there is the risk that in case of starting up the process the alarmprinter will be hardly noticed, with the consequence that a single (= real) alarm signal is not noticed either. (Operator : '... pressing the button without looking, because the displays on the panel requires all my attention...'.)

Kind of operator actions

In fewer than ten percent of acknowledged alarm signals the operator seemed to interfere with the process. (Some operators believed that 'action' included communication necessary with the field operator.)

Note :

During one of the interviews, it became apparent that it was sometimes better to speak about 'messages after an action' than about 'action after a message'.

False alarm signals

In the control room in question, it was said that the operator rarely noted false alarm signals; however, false alarm signals can only be discovered after a normal check procedure and that is exactly what the operator did. Although in some cases with a smiling face, e.g. when a temperature was indicating -2000°C. Nevertheless in such cases, the normal check routine was carried out and the staff concerned were consulted.

6. RESEARCH IN THE FUTURE

In an explorative study to be subsidized by the Commission of the European Communities, we intend to interview the operators of each shift in three control rooms with the aid of the developed questionnaire. Moreover, we want to describe the alarm situations quantitatively.
A number of relevant magnitudes can be recorded, such as :
- the elapsed time between successive process alarm signals;
- the average number of alarm signals per unit of time;
- the elapsed time before acknowledgement by the operator;
- the number of alarm signals followed by an action;
- the number of alarm signals not followed by an action;
- the number of false alarm signals.

From this study, we expect to be able to formulate specific design rules which we could discuss with production staff and instrument manufacturers.

In order to illustrate what is meant by design rules, we give the following two examples of rules used nowadays in the design of process alarm systems :
- all alarm systems with fascias will be designed as unlit panels, e.g. in the normal situation no lamps are lit. (Note : in the case of status signals it will sometimes be impossible to define a 'normal' situation.);
- if there is a demand for an important action by the operator within 5 minutes after the first alarm call, one should realize that this may be unreliable, therefore, such an alarm signal should be included in the trip system (automatic shutdown system).

Finally, we mention some of our assumptions which should be investigated.:
- status information should be physically separated from alarm signals;
- there would be a need for a hierarchical procedure when locating a flashing alarm signal if there are more than 2 panels of 36 alarm lights;
- alarm systems should be able to suppress part of the system at special times (start up, etc.) in order to prevent irrelevant alarms;
- the listing of a print on an alarm type-writer or a CRT should not have a time sequence base, but should be based on the clustered information of the process unit in question.

As a result of our study, we hope to make a priority listing for further research in this field, as well as defining design rules.

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