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REDESIGNING AND EVALUATING VDU GRAPHICS FOR PROCESS CONTROL:

cognitive ergonomics applied to the operator interface

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SUMMARY

In the control rooms of the chemical process industry panel instrumentation is gradually being replaced by visual display units (VDU's) as the interface between process and operators. After discussing the consequences of this trend for the operator task it is concluded that a serious "interface mismatch" often exists: the way of presenting information on the VDU's does not fit the mental model of the operators. Therefore a procedure was developed to enable plant employees themselves to redesign the existing VDU graphics. So far favorable results have been obtained in several case studies indicating an efficient and effective way of user participation.

INTRODUCTION

Since the end of the 1970's many process automation projects have been started in the Dutch chemical industry. The application of process-control computers was usually followed by the introduction of VDU interfaces in the central control room to replace the conventional panel instrumentation located along the walls.

This change in type of interface has had enormous effects on the task of the control-room operators. Such employees are responsible for monitoring and controlling a very complex process and for managing its incidental faults, disturbances and sometimes even plant shut-downs (Wickens, 1984).

PANEL VERSUS VDU

Some of the most important differences between panel- and VDU interfaces in terms of information processing by the operator may be characterized as follows:

With panel instrumentation operators had all available process information at their disposal on a permanent basis. They could use their own search-strategy...
to select parts of that massive amount of information in order to monitor and interpret the process status. Thanks to the fixed location on the panel of every individual piece of information they could often quickly recognize a pattern in the many parallel data flows. When studying a small part in detail, its relation with other process parts remained clear. The large surface of the wall panels also enabled operators to get information from it without disturbing their colleagues or to discuss part of it with many others at the same time.

When this same information is presented on a limited number of VDU screens operators are forced to request the information needed sequentially. Faced with prepackaged groups of information they then have to select and memorize only the relevant parts. Finally they have to integrate all of this to arrive at an interpretation of the process status. The levels of detail and the groupings of process information have been decided upon by relative outsiders: software- or process engineers who are only vaguely familiar with the actual operator task. Their view of the process is dictated by wiring schemes and their knowledge of physical chemistry. As a last point the concentration of all this potentially available information within a few VDU screens severely hinders the discussions with colleagues.

Summarizing, we may predict that it will be easier for operators to obtain an overview of the process status by means of panel interfaces than with VDU interfaces. Also with panel instrumentation operators may adapt their search strategies in a more flexible way to changing process conditions and to individual preferences for certain groupings, orders and levels of detail when processing information.

A SURVEY OF OPERATOR VIEWS

In three different chemical plants so far these expectations have been checked in questionnaires with control-room operators who had extensive experience in controlling the same chemical process with both types of interfaces. As an example the results for one of the key questions ("How do you rate the degree of overview of the process with each type of interface and under three different disturbance conditions?") are given in Table 1.

It appears that the operator's evaluation of the panel interface remains relatively constant as the disturbance gets worse. On the VDU's however it quickly becomes difficult to obtain a sufficient overview of the process situation.
Table 1: Degree of overview of process information under different disturbance situations, judged by operators from 3 different chemical process plants (A, B, and C), for both panel instrumentation and VDU-based systems.

N.B.: The averages as shown above have to be interpreted as gradings on a 10 point scale (10 = perfect), so that the outlined part of the table represents situations in which the interface is judged to be inadequate.

<table>
<thead>
<tr>
<th></th>
<th>panel</th>
<th>VDU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>one small</td>
<td>7.4</td>
<td>6.9</td>
</tr>
<tr>
<td>disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>one major</td>
<td>6.9</td>
<td>6.9</td>
</tr>
<tr>
<td>disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>multiple major</td>
<td>6.6</td>
<td>6.4</td>
</tr>
<tr>
<td>disturbances</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In other questions of the same questionnaire operators indicated that their appreciation of the VDU interface was mainly caused by the way information had been grouped and by the level of detail in which it was shown. Especially the "graphics" or "mimics" were heavily criticized for lacking in overview. The possibilities of these graphics however in terms of showing both graphical, structural aspects of the process (like product-flow schemes) and numerical, dynamic information (like pressures, flows or temperatures) was highly thought of.

INTERFACE MISMATCH

It may be concluded that operators are often faced with bad process overviews on their VDU's. This decreases the efficiency of their monitoring task while the probability of costly mistakes increases, especially during severe disturbances.

A cognitive interpretation of this hypothesis is that the actual information need of the control-room operator is not sufficiently taken into account in the present informal design procedures for VDU information. We might call this an "interface mismatch": the mental model of the operator task as held by the designer differs too much from that of the user, that is the operator.

A REDesign PROCEDURE

A possible solution for this problem is to systematically integrate the real information need of the operators in a (re)design procedure for VDU-based process control information.
Our approach distinguishes two phases: for each control room first the General Procedure is applied to a representative sample of existing VDU graphics or process parts. On the basis of these results this timeconsuming extensive General Procedure is then reduced to a set of simple, straightforward Specific Guidelines. These guidelines are stated in such a way that the operators themselves may use them to (re)design the remaining VDU graphics. The General Procedure consists of four steps which are summarized in Figure 1.

<table>
<thead>
<tr>
<th>Step</th>
<th>Goal</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>functional grouping (user-defined functional relationships between process parts)</td>
<td>structured discussions within shifts</td>
<td>description of total process consisting of main groups, each containing many sub-groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>consensus seeking between shifts</td>
<td>optimal &quot;paging&quot; sequences of main groups and of sub-groups</td>
</tr>
<tr>
<td>Step 2</td>
<td>process information needed for the purpose of overview:</td>
<td>priority ratings by operators and by process engineer</td>
<td>relative necessity of each case of dynamic information and its required precision</td>
</tr>
<tr>
<td></td>
<td>- numerical information</td>
<td>questionnaire for operators on screen lay-out, colour coding, abbreviations, et.c</td>
<td>specifications for graphical display of structural information (process schemes)</td>
</tr>
<tr>
<td></td>
<td>- graphical information</td>
<td>guidelines from step 2 (e.g. spatial separation of dynamic and structural process information)</td>
<td>proposal for VDU graphic, and its configuration on the process control system</td>
</tr>
<tr>
<td>Step 3</td>
<td>integration of results from steps 1 and 2</td>
<td>questionnaire for operators performance tests by operators with the proposed VDU picture (search-, comparison- and interpretation tasks)</td>
<td>final version of VDU graphic</td>
</tr>
<tr>
<td>Step 4</td>
<td>evaluation, after a minimum period of experience with the proposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. A summary of the General Procedure.
The General Procedure is directed at answering the following questions:
1. How do the operators view the process from a control point of view; which main- and subsections do they distinguish and how are these interrelated?
2. Which numerical and graphical information is absolutely necessary for the operators in order to establish and maintain a good overview of the process status; how detailed should this information be and how should it be depicted on the VDU?
3. How should the results obtained above be integrated into a working prototype?
4. How do operators evaluate the prototype of the (re)designed graphic compared to the old situation; what is their level of performance on a set of basic interactive tasks using both the new and the old graphic.

The process of applying the General Procedure and then transforming it into a set of Specific Guidelines will be illustrated by two extensive case studies in the chemical industry.

In both cases the starting point was a combination of panel and VDU interfaces in the control room, with many operator complaints about the latter.

**CASE ONE**

In this plant the control-room interface of panels was very gradually being replaced by VDU's. The operators used the VDU graphics very frequently, but had not been involved in the design process in any way. From this set of existing graphics four representative examples were chosen to be the subject of the General Procedure.

Step 1 resulted in a user-defined grouping which deviated on several essential points from that of the VDU-graphic designer.

In step 2 it appeared that a large proportion of the numerical information (process values) was really unnecessary for a good overview of the process status and was thus removed from the graphics.

In step 3 all of the operators preferred to separate the structural part from the dynamic data in the graphic. The process scheme could thus be depicted in a much simpler way while the level of detail in the dynamic values could be adapted to their relevance for the operator much easier.

The evaluation in step 4 consists of three independent ways of comparing the old graphics with the newly designed prototypes:
1. **Objective checklist** for graphics design: in this way it is checked whether the prototypes score better on a number of objective criteria (like the number of crossing lines or bends, total length of all connecting lines) than the original graphics. This was the case for all of the criteria.
2. **Subjective evaluation**: more than three quarters of the operators preferred the prototypes to the original ones. After taking into account a few remarks for improvement in the design of the final version this preference rose to 100%.

3. **Performance tests**: all control-room operators performed a set of five basic interactive tasks with the original and prototype versions. The results are depicted in Figure 2, along with the results on a control group of non-redesigned graphics to check for motivational differences. After having worked with the prototypes for only a few days operators performed faster with these than with the original graphics, in spite of at least three years of experience with the latter.

![Figure 2: Results from performance tests with 28 operators from plant I.](image)

(“old” = original graphics; “new” = redesigned versions of these same graphics; “control group” = original graphics, which were not redesigned; t1 = before implementation of the new graphics; t2 = after several days of experience with the new graphics).

**CASE TWO**

The starting situation, the methods used and the main results for the second plant were almost identical to those of the previous case, with a few important exceptions:

1. In this second control room it was not possible, according to the operators, to reduce the amount of numerical information in the graphics. Therefore the prototypes contained essentially the same dynamic information as the original ones and differed "only" from these in the presentation of this information.
2. The performance test was organized in a different manner, giving a better insight into the important question of adaptation to the new prototypes.

![Figure 3: Results from performance tests with 13 operators from plant II (t1 = no experience with the new graphics; t2 = several days of experience with the new graphics; see also Figure 2).](image)

As shown in Figure 3, operators were, at the time of the first test, confronted with prototypes which were then totally new to them. As expected, they performed better with the familiar graphics because they knew exactly where to look for certain information on those. After a few days of experience with the prototypes however this advantage was clearly reversed in favor of the newly designed graphics. Because in this experimental setup the original graphics acted as their own control group, we may conclude that motivational differences (experimental fatigue, combined with a stressful production phase at the time of the second test) probably explains the absolute differences between the first and second test results with the original graphics.

CONCLUSIONS

After two extensive case studies the General procedure seems to give the results it was developed for: this intensive method of user participation produces better graphics, which are also accepted by the operators as such.

The Specific Guidelines have been applied for almost two years now in plant one. An informal evaluation early 1989 confirmed their usefulness and more recent questionnaire results corroborate this conclusion.
The best test of course would be to monitor operator behaviour during disturbance situations because at that time the interface may mean the difference between a timely recovery and a complete shut-down. Such disturbances however are not only relatively rare but also always different in one or more important aspects from a similar previous one. In a "live" plant therefore it is almost impossible to make such a controlled comparison between types of interfaces; the present trend of introducing highly realistic simulation facilities into the control rooms will however give us more opportunities to validate our ideas.

REFERENCE