Alarm Information in Fault Diagnosis

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Introduction

The transcript from a recent incident (Times, 7.6.91) suggests that operators originally disbelieved alarm information (attributing it to a trivial problem), subsequently they were unable to interpret the message and finally they could not recover the situation before disaster struck. This calls into question the way in which the fault was communicated to them. A number of studies by the author have led to the conclusion that the presentation of alarm information is not always compatible with the response required by the operator. For instance, an examination of the presentation of an alarm announcing: "Oxygen in flue high/low"; reveals first of all the alarm reports the effect, rather than the cause, and second this particular example would require two different recovery strategies depending upon whether the level was high or low. It was therefore considered necessary to find out what operators do with alarm information. These investigations took the form of interviews, questionnaires and observations (Stanton;1990a, 1990b, 1991a, 1991b). The findings suggest six identifiable stages in alarm handling, namely: observe, accept, analyse, investigate, correct and monitor. Each of these stages have different information requirements, and some of these may be in conflict with each other. It is proposed that better definition of 'alarms' coupled with improved presentation of alarm media could offer substantial benefits to the operator. These benefits should ideally be measurable in terms of:

- time to diagnosis
- mental workload
- number of control actions
- success of control actions
- quality of diagnosis
- output performance.

This approach is counter to alarm reduction techniques, which have successfully reduced the number of alarms present, but have not always produced corresponding improvements in the operator's performance (Sanquist & Fujita, 1989). This is because the apparent redundancy of the information may hide its usefulness in keeping the operator abreast of the state of the process and developments therein, as well as aiding the diagnosis task.

Design of alarms

The design of alarms needs to be considered together with the nature of incidents within which they are likely to be used. Woods (1987) suggested that operators dealing with incidents need to track their development, rather than requiring a single diagnosis of the situation. He further proposed that whilst initial assessments are often accurate, as the incident develops, subsequent assessments can become less realistic. As Reason (1988) suggests, incidents may start out in a familiar way, but they rarely develop along predictable lines. Hale & Glendon (1987) proposed that erroneous action or diagnosis may initially produce confirmatory feedback, and this can become progressively harder to ignore, even in the light of subsequent data. It has been further noted that the initial alarms may be insufficient for diagnosis, and the 'window' for accurate diagnosis may be very limited and time dependent (Herbert, Jervis & Maples, 1978; Zwaga & Veldkamp, 1984). After this window has closed, a new recovery strategy must be sought (from another window) but there may be a time after which the situation becomes unrecoverable. Therefore, we may view the operator's task as one where a process plant with up to 24,000 alarms (Singleton, 1989) needs to be controlled in situations of uncertainty (Bainbridge, 1984) and complexity, with poor tracking of events (Woods, 1987) and in any case where diagnosis has limited windows of opportunity (Herbert et al, 1978). It is a credit to the adaptability of operators and the robustness of plant design that such systems manage to operate at all. However, it is clear that fault diagnosis is a topic that is worthy of further attention.

Landeweerd (1979) contrasts fault diagnosis with control behaviour, proposing that the latter focuses attention on the forward flow of events, whereas the former calls for a retrospective analysis. Wickens (1984) widens the contrast by suggesting that the two tasks may be in competition with each other for attentional resources, and that the two phases of activity may be truly independent. However, whilst diagnosis certainly does have a retrospective element in defining the problem space, it almost certainly has a forward looking element of goal directed behaviour in correcting the fault. Research from the domain of problem solving illustrates this clearly. Hoc (1988) sees problem solving as involving two interrelated components: problem understanding (the construction of a coherent representation of the tasks to be done) and procedure searching (the implementation of a strategy to find or construct a procedure). This suggests that there is an 'executive controller' of the problem solving activities which directs the choices that are taken (Rouse, 1983). Planning is the guiding activity that defines the abstract spaces and is typically encountered in problem solving. Hoc believes that planning combines top-down components (creating new plans out of old ones) with bottom-up components (elaborating new plans or adapting old ones). Thus he suggests an information representation that supports the shift between these components would result in more efficient strategies.

There are at least five methods of presenting alarm information: text, mimics, annunciators, speech and tones. Each has inherent qualities that support different activities. For instance; text lists favour temporal tasks, mimics favour spatial tasks, annunciator favour pattern matching tasks, speech favours semantic classification tasks and tones favour attraction and simple classification tasks. The author is currently conducting research into the intrinsic characteristics of the media for alarm handling tasks. Preliminary findings are presented below.

Laboratory studies

In laboratory studies conducted at Aston on a process control simulator, it was possible to compare the three visual alarm media directly (text, annunciator and mimic). The findings suggest that for initial detection of faults, text and mimic alarm systems are superior to annunciator systems; whereas for fault diagnosis, text and annunciator systems are superior to mimic alarm systems. Finally for compensation behaviour, text and annunciator conditions produced superior performance to the mimic alarm condition. The reason that text alarm condition led to better performance overall may be in part due to three factors. First, the text alarms always appear in the same place on the screen, whereas the spatial arrangement of the other two systems is largely dependent upon the plant layout. Second, the text message is unambiguous. Whilst this second feature is also true of the annunciator panel, the annunciator panel requires an independent scan to see if new alarm have occurred, whereas the mimic alarms are located within the plant diagram. Finally, text lists provide an 'order of events' which may be useful in diagnosis. However, it has been noted that the spatial arrangement of annunciators may also provide useful information. This was recounted to the author in a 'tale of myopia'. A short-sighted operator was able to learn the names of regular annunciators by their position, even though he was unable to read the message. Whilst this practice cannot be recommended, it does indicate that positional information can be of additional use to operators. This may be in the form of pattern recognition for assessment of system states or maybe even fault diagnosis. This kind of information is not available in alarm lists.

An investigation into speech as a possible alarm medium also undertaken at Aston compared human with synthesised speech output of alarm messages for four tasks: recording of message, rating of urgency, identifying location of signal and choosing appropriate corrective action. It is an attractive medium for presentation of alarm information because of its apparent 'naturalness' and 'eyes-free, hands-free' nature which may be an important consideration in alarm handling. The results suggest that speech is an acceptable medium for simple linguistic tasks, such as recording or word spotting depending upon the quality of the speech. However it is not recommended for spatial tasks, or tasks that require interpretation or retention of information.

The use of tones has not yet received our attention, although this position is likely to change in the future. However, auditory warnings has been quite well researched by others (for example Patterson, 1989; Edworthy, 1990). The consensus is that discrimination is generally limited to about seven auditory warnings, and that the medium is best suited to transmitting information about urgency of intervention.

Observation studies

The representation of plant presented to operators tends to be in the form of a plant mimic via pages on a Visual Display Unit (VDU). The use of VDUs has replaced large plant mimics presented on wall panels. The transfer was seen as one of utilising modem technology by the operators, although one operator expressed the sentiment that he found the wall-based mimic easier when explained to external agents (such as myself) the nature of the process. The VDU provides a window on process which is rather like using binoculars with two fixed focus points; either they are able to see all of the process in very coarse detail or part of process in very fine detail, but nothing in between, or even both at same time, however*"with big plant mimic it was possible to see the whole and follow through, this system only allows us to see part of the plant at a time"*. This introduces new kinds of problems in process operation, for example *"I've spent maybe 3/4 of an hour struggling to get something right, only to find a more important problem when I've finished, but I've not noticed the new problem develop because I've been concentrating on the other problem"*. This type of problem has been called 'cognitive lockup' by Moray & Rotenburg (1989) who noted that people prefer to deal with faults serially rather than concurrently.

From a series of observation studies in a manufacturing plant, other features of the operators task became apparent. For instance, operators are in and out of central control room (CCR) all of time, perhaps only 50% of their time is spent in CCR. This is probably in part due to the close proximity of the plant (operators can see plant from CCR), and in part due to the nature of the information that is provided. One operator expressed the sentiments that*"sometimes it would be better to give us no information than confuse us"* and *"there are some alarms that even we do not know what they mean"* to indicate that the information might not always be as useful as it was intended. Sometimes the information is unreliable, either reporting a state that is not present (e.g. alarm: its empty!; operator: its not!) or not reporting a state that needs to be reported (e.g. according to VDU the plant was still running, but the operator noticed that it was not by looking out of the CCR window onto the plant: noise of machinery stopped, no movement of machinery not product passing on conveyer belt). This state of affairs fits in with the comment,*"you can't beat 'mince pies'* (eyes)" which highlights the importance of the operator's role in checking the state of the plant independently of the control system.

The plant also requires the operator to possess both 'process knowledge' and knowledge of how to use the control system. They are required to integrate this knowledge for effective operation, but this can take a considerable amount of time, as highlighted by one operator who reported that*"after 12 months we are still learning the plant"*. However there may be some difficulties in operation that are never resolved, for example,*"sometimes if we cancel an alarm from the control desk it may still remain on the screen, then we have to get an electrician to cancel the alarm in GEM. It can take up to 20 minutes to get the electrician, during which time the line could be stopped"*. The final irony is the alarm that is not an alarm, as one operator put it: *"a lot of alarms are irrelevant, so we ignore them."* This brings into question the purpose of the alarm system. If the information is being ignored, then it is no longer an 'alarm' system. From the observational studies undertaken, the author can conclude that only one percent of the signals presented may be defined as genuine alarms, i.e. that they were not predicted, were gents for action, and that inaction would have been detrimental to plant and/or product. However, the information might be useful in other ways, e.g.:

- as an indication that they may proceed with, or stop, a course of action;
- to complement the associated instrumentation;
- to provide information not available by other media.

For these reasons pursuing the 'darkboard' philosophy relentlessly may not always result in the performance improvements expected, as indicated in the introduction.

Future Research

The model of alarm handling mentioned at the beginning of the paper is proposed as a framework for research. It is proposed that the 'observe' stage could benefit from research in detection and applied vigilance, 'accept' could benefit from work on group versus single acknowledgement, 'analyse' could benefit from work on classification and decision making, 'investigate' requires work from problem solving and diagnosis, 'correct' needs work on cognitive affordance and compatibility, and 'monitor' needs work on operational feedback. However it is proposed that best method of presenting alarm information will be dependent upon: what the operator is required to do with the information and the stage of Alarm Initiated Activity (AIA). Therefore the alarm types need to be considered in terms of the AIA. This may be undertaken though a systematic comparison of a combination of alarm message across task types to empirically investigate the effect of message type and content on performance.

In summary, it is proposed that the alarm system should support the AIA. Observation may be supported by drawing the operators' attention, but not at the expense of more important activities. Acceptance may be supported by allowing the operator to see which alarm has been accepted. Analysis may be supported by indicating to the operator what they should do next. Investigation may be supported by aiding the operator in choosing an appropriate strategy. Correction may be supported through compatibility between the task and the response. Finally, monitoring may be supported by the provision of operational feedback. The design of alarms need to reflect AIA as the purpose of an alarm should not be to shock operators into acting, its should be to get them to act in the right way.

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