Alarm Initiated Activities:
matching visual formats to alarm handling 'tasks'.

Neville A. Stanton*
Department of Psychology
University of Southampton
Highfield
Southampton
SO17 1BJ
UK

Robert B. Stammers
Psychology Group
Aston University
Aston Triangle
Birmingham
B4 7ET
UK

*Corresponding author

KEYWORDS: Alarm displays, Alarm handling, Alarm design

Running title: "Matching formats to tasks"

This paper addresses the selection of visual alarm formats for different 'alarm initiated activities'. The activities under examination were alarm handling tasks. Seven such tasks have been identified, namely: observe, accept, analyse, investigate, correct, monitor and reset. One of the most important stages is the initial analysis of the alarm information as this determines the subsequent manner in which the information is processed. It was hypothesised that the format in which the information is presented will determine the success of the alarm handling task, hence the proposal to match *formats* to *tasks*. The findings suggest that text-based formats are best suited to tasks requiring time-based reasoning, mimic formats are best suited to tasks requiring spatial location and annunciator formats are best suited to tasks requiring recognition of spatial patterns. The importance of considering both reaction time and accuracy of response in consideration of task match was also noted. In summary, it is suggested that care needs to be taken to determine the appropriateness of the medium for any given task and the demands it places on the human operator.

1. Introduction

This paper addresses the use of different formats as means of displaying visual alarm information. The use of visual displays is common to most control rooms and they often are employed for conveying alarm information. Indeed, as Stanton, Booth & Stammers (1992) illustrated, visual alarm information can be presented in a variety of formats, including scrolling text messages, plant mimics and annunciator panels. These three presentation formats will serve as the focus for this paper. Examples where central control rooms are found include power stations, manufacturing and the process industries. Control rooms are characterised by the centralisation of data collection and display. Data from plant sensors are transmitted to control rooms and either displayed directly (in hard-wired systems) or via a central computer. The data may either be displayed on backpanels or at the operators desk, or both. This information is assimilated by operators to maintain an awareness of the state of the plant or to respond to changes in the plant. Venturino & Eggemeier (1988) characterise the control room environment in their introduction to a special issue of Human Factors:

"*Although advanced control and display technologies significantly enhance the capability of modern systems, such technologies can also impose very heavy demands on the information processing systems of the human operator. Large volumes of information are often presented at rates and in different formats, forcing operators to select, integrate, and interpret information from numerous sources.*" (p. 535)

Alarm information enables operators to be kept aware of changes in the status of the plant and may indicate that intervention is necessary. How timely and effective the intervention is will depend upon the nature of the alarm information displayed. Whilst there are many issues that could be tackled with respect to alarm information, the medium for displaying the information is certainly a pertinent one, especially when the trend toward scrolling text-based displays is questioned (Stanton & Baber, 1995).

In brief, Stanton & Baber (1995) argue that consideration of both alarm initiated actions and the objections from control room operators lead one to suppose that other alarm formats may be better than text for some activities. One quote presented by Stanton & Baber (1995) highlights frustrations with text-based systems:

"*Using a computer to display alarms in a written form is an easy way of displaying a lot of alarms, but it can be confusing or useless.*" (p. 2415)

One of the possible problems associated with text-based alarm systems seems to be the translation of the written code into spatial reference and relating pieces of alarm information to one another in order to determine the nature of the problem. For the purposes of this paper, and the study contained within, we will be focusing upon the classification activities associated the initial analysis of alarm information in order to determine if different activities are supported by different alarm formats.

1.1. *Text-based alarm displays*

The text display provides the operator with a list of events that have occurred on a plant. Typically, the events are time-tagged and the order of events may give some clue as to the nature of the fault. However, the configuration of the plant components and the specified alarm thresholds can change the behaviour of the alarm system quite dramatically to make 'first up' (i.e. the order in which alarms are presented to the operator) virtually useless.

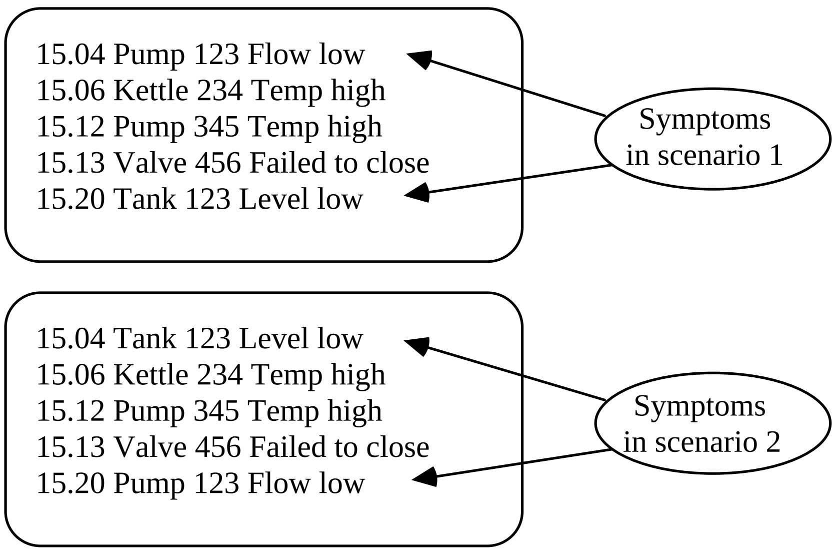


Figure 1. Text based alarm presentation for scenarios 1 and 2.

For example, consider the two scenarios presented in figure 1. Due to the nature of the leak in the tank, the size of the tank or the sensitivity of the alarm thresholds, the tank level alarm could be presented either before or after the pump flow alarm.

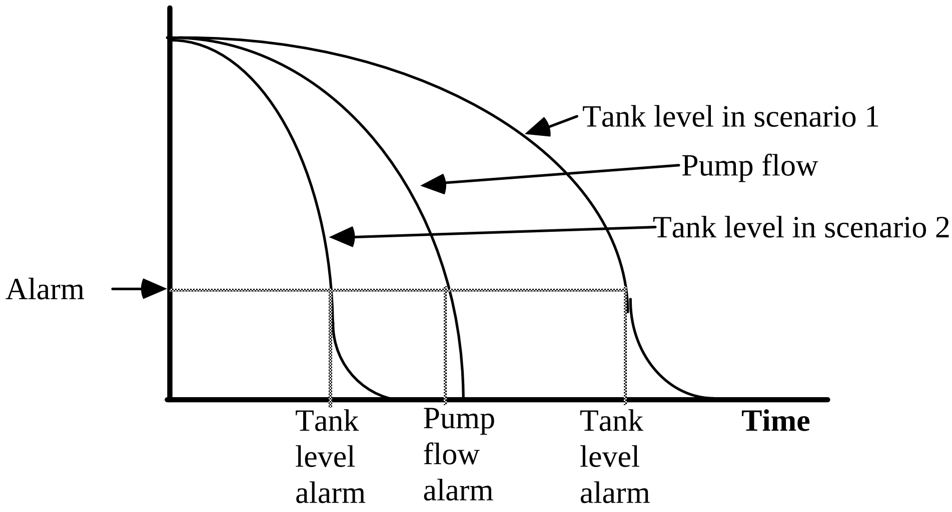


Figure 2. Two possible scenarios for alarm presentation.

In scenario 1 the pump flow alarm is presented before the tank level alarm, but in scenario 2 the reverse occurs. This order of alarm presentation is illustrated in figure 2. This leads to one questioning the usefulness of order of events information, as it could lead to possible faulty diagnosis. Control room operators have first to identify which alarm events are linked and then to determine the meaning behind the sequence of events. The problem of linking information that is embedded in other information is far from a trivial exercise. It can be likened to the jigsaw puzzle analogy, where there are several jigsaw puzzles to solve and all the pieces are mixed together and presented in a sequential order. First you have to work out which parts of the jigsaw belong to the same set and then you have to work out how they fit together! It is little wonder that control room operators find text-based alarm displays difficult to use.

1.2. *Annunciator-based alarm displays*

Annunciator alarms typically have no means of presenting order of events information. The operator is required to determine the nature of the failure based on the presentation of a lit annunciator panel. However, the failures are embedded within other non-failure information (see figure 3).

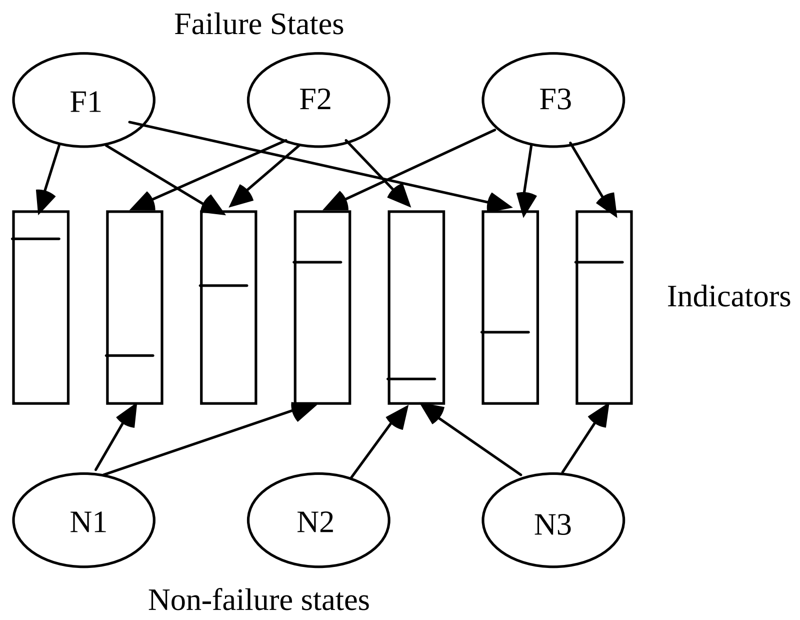


Figure 3. Annunciator alarm presentation (from Wickens, 1992)

Over time, the operator may come to associate certain patterns of lit annunciators with certain types of fault. Thus frequent and familiar failures are likely to be readily recognisable. However, the display does not appear to be conducive to aiding the operator in discovery of infrequent and novel failures, due to the way in which the information is embedded.

1.3. *Mimic-based alarm displays*

Plant mimic alarm displays attempt to provide the operator with a pictorial representation of the plant in the form of a diagram with information overlaid. As operators may be promoted to control room work after serving several years on the plant, this kind of representation serves to keep them in touch with the physical layout of the plant (see figure 4).

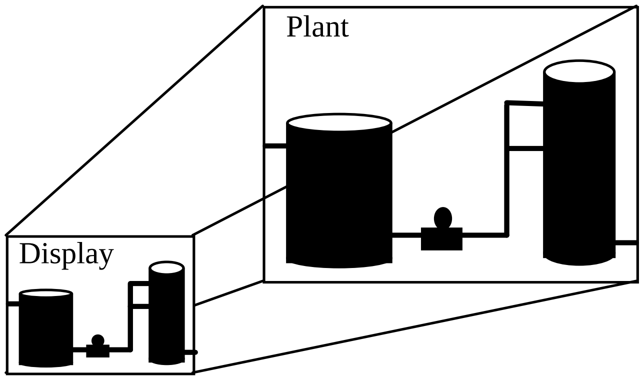
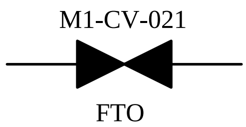


Figure 4. Plant mimic representation.

The plant mimic has the advantage of providing a more direct spatial mapping between the control room and the plant. This may allow operators to see the propagation of faults through the plant, and trace back to the source of the failure.

1.4. *Properties of visual alarm formats*

It is worth considering the linguistic and pictorial properties of different visual alarm representations. For example, consider three presentations of the same information: picture in the form of a plant mimic, language in the form of a text display and a mixture of both in form of an annunciator display, as shown in figure 5. Each of these will be considered in turn.



A. Plant mimic representation

MOULDING 1 CONTROL VALVE 021 FAILED TO OPEN

B. Text display representation

M1-CV-021 FAILED TO OPEN

C. Annunciator representation

Figure 5. Visual alarm representations.

In order to provide the basis for comparison, the three different representations are communicating the same fault: that control valve 021 has not opened. The plant mimic consists of a representation of a valve which would be within a larger diagram of plant pipe work (see item A in figure 5). Thus the operator would have some spatial context of the failed valve. The tag number above the valve may also be used for reference and the letters "FTO" below are an abbreviation for 'failed to open'. Whether this abbreviation is of much use is open to question as it may easily be confused with the very similar abbreviation "FTC" which stands for 'failed to close'. It is the picture that primarily provides the information to the operator. Typically, the colour of the valve would change to indicate the fault. The text alarm contains the alarm information within the following syntax: <plant area> <plant unit> <problem> (see item B in figure 5). This is fairly typical of text based alarms (Stanton & Baber, 1995). On presentation of the message, the operator has to interpret it and determine the severity of the fault. The annunciator alarm provides some spatial information and some textual information. The spatial information is its presentation within a panel of tiles relating to a particular plant area. The textual information is the description of the fault (see item C in figure 5). Typically, annunciator boards present short messages due to the restricted space allocated to individual tiles.

Despite this brief consideration of the characteristics of the different approaches to alarm representation and presentation, it is not possible to offer a 'best' method. That all three methods of presenting visual alarm information are presently used in industrial settings suggests that no one particular method has been found to suit an application better than any other. There is no clear guidance as to which method of alarm presentation is applicable, and designers often find themselves constrained by the graphical and textual facilities that the control system allows them to present alarm information. In fact, none of the alarm systems investigated by Stanton, Booth & Stammers (1992) appeared ideal. Thus it is the remit of the studies presented in this paper to conduct investigations into visual alarm displays within the context of human supervisory control activities.

2. Visual alarm presentation

The main benefits of presenting alarms using the visual channel are that they do not impose loads on operator memory because there is either a permanent or semi-permanent record, and they are presented at a fixed point (either VDU or annunciator board) so that they may be accessed with some ease. Stanton *et al.* (1992) presented a classification of alarm media. The presence of alarms within a visual display also offers consistency with display of general status information, which is generally presented visually. This may be related to Wickens (1984) notion of 'SCR' compatibility. If the alarm information is considered by the operator in conjunction with status information, one might postulate that from an information processing viewpoint it might be desirable to present all the information in the same format (see figure 6). This, one might hypothesise, would lead to the most efficient processing of information.

		Code	
		Verbal	Spatial
Modality	Auditory	Speech	Sound Localization and Pitch
	Visual	Annunciator displays Text displays	Annunciator displays Mimic displays

Figure 6. Four display formats (adapted from Stokes, Wickens and Kite, 1990)

If, however, there is an incompatibility between the information display and the task the operator is required to perform, one might predict that this will lead to poorer performance, e.g. slower reaction times and greater errors. Further consideration of the literature on human information processing may give clues to the suitability of different implementations of display media and their suitability to support different tasks. From this, implications about the method of alarm presentation may be drawn.

Mental representations may similarly be divided in the same way as these two external classes of representations (pictorial and language) to consider analogical (like visual images) and propositional (like language) representations. Eysenck & Keane (1995) assert that the properties associated with linguistic and pictorial representations may be applied to their mental correlates. That is to say, propositional representations are; discrete, explicit, combined according to rules and abstract. Whereas analogical representations; are nondiscrete, represent things implicitly, have loose rules of combination and are concrete (in the sense that they are not tied to any particular modality). Easterby (1984) suggests seven psychological processes used by the human operator that should be considered in design of displays. He suggests that these processes determine the limits of the display formats. These have been adapted to consider the implications for the design of visual alarm displays, as illustrated in figure 7.

Psychological process	**Implications for design of visual displays**
Detection	Determining the presence of an alarm
Discrimination	Defining the differences between one alarm and another
Indentification	Attributing a name or meaning to an alarm
Classification	Grouping the alarms with a similar purpose or function
Recognition	Knowing what an alarm purports to mean
Scaling	Assigning values to alarms
Ordering & Sequencing	Determining the relative order and priority of alarms

Figure 7. Psychological processes and implications for design of visual alarm displays (adapted from Easterby, 1984).

From figure 7 we may consider aspects of display design in relation to a taxonomy of psychological process of the human operator. This serves to illustrate the different nature of the three types of visual alarm presentation methods. For example: scrolling text displays are temporal in presentation, whilst annunciators and mimics are spatial; scrolling text displays are not grouped by plant area, whereas annunciators and mimics are; finally scrolling text displays can contain a complex message, annunciators tend to contain a simple message and mimics contain a plant item that may or may not be annotated in some way. Obviously, these facets are largely dependent upon the presentation mechanisms. Therefore, rather than the information requirements being defined in terms of operator needs, they are restricted by the limitations of the media. This is contrary to the philosophy of a human-centred approach, which posits that one needs first to define the requirements of the operator in the supervisory control task, before designing the alarm to support that task. In this way it should be possible to design alarm systems that are driven by human factors rather than technical capabilities.

2.1 *When are visual displays useful?*

Due to the dynamic nature of human supervisory control tasks it is necessary to keep the human operator informed about the status of the system being monitored. Stanton (1993) suggested that auditory alarms are inappropriate for tasks that incorporate the following demands:

- some memory component;
- a delay before the fault is attended to;
- more than one alarm is presented at the same time;
- information has to be drawn from several sources using spatial reference.

However, visual display formats do appear to be suited to these task demands. The main benefit offered is the longevity of the information presentation. This reduces the memory load by allowing the human operator to refer to the information as frequently as necessary. This is not to say that simply presenting alarm messages in the visual medium solves the problems of alarm presentation. Easterby (1984) points out that the visual display of information reflecting the current status of the system indicates when the human operator should intervene. It is the effectiveness of the displays in communicating the relevant information that is of prime importance, because if the intervention is to be effective it must be appropriate and timely. As Easterby (1984) notes, the display should "*give some clues as to what to do [...] and when*" to do it.

In summary, it seems that the visual display is best suited to tasks which are characterised by the use of information in 'parallel' rather than a 'serial' manner. This is similar to the activities in human supervisory control. Woods (1983) discusses the topic of 'visual momentum' in process control. He suggests that it is important that the relationship between displays and the 'big picture' is made clear to preserve 'visual momentum' as operators make transitions between displays and extract information.

2.2. *The selection of visual alarm displays*

There are many technical possibilities afforded the designer of visual alarm displays. The presentation of visual alarm information is usually restricted to backpanels, lights, annunciators, printers and VDUs. Ergonomists have offered advice on the physical design parameters of such devices, e.g. the benefit of reverse video over high intensity highlighling to attract attention and aid search in alphanumeric displays (Spoto & Babu, 1989); the importance of consistency, readability, position and priority in design of annunciator systems (Benel, McCafferty, Neal & Mallory, 1981); and the design of symbolic display formats for alerting and guidance (LaLumiere-Grubs, Berson, Boucek & Summers, 1987). For example, Corlett & Clark (1995) provided guidelines for the design of annunciators. These guidelines are useful when designing such panels, but they are rather vague in indicating when the presence of such panels is appropriate. Singleton (1989) suggests that the alarm system must support the operators in their search for meaning, and this could be aided by the design of the visual display. The usefulness of the information will be context-dependent, but in order to evaluate its potential, the human operator will have to determine the context in which the information presented. Information that assists this assessment could be: the position of an alarm in an array, an illuminated legend, the colour status of the alarm, an alarm within a plant mimic, the alarm associated with other plant data, the alarm associated with an emergency procedure (Singleton, 1989). Until we have some understanding of how to support these activities, and what information is optimum under particular circumstances, we cannot offer the designer sensible advice of how to present the visual alarm information.

One approach may be to base research and development on an understanding of human alarm handling activities. For example, the Alarm Initiated Activities (AIA) framework (Stanton *et al*, 1992, Stanton, 1994; Stanton and Baber, 1995) illustrated by figure 8.

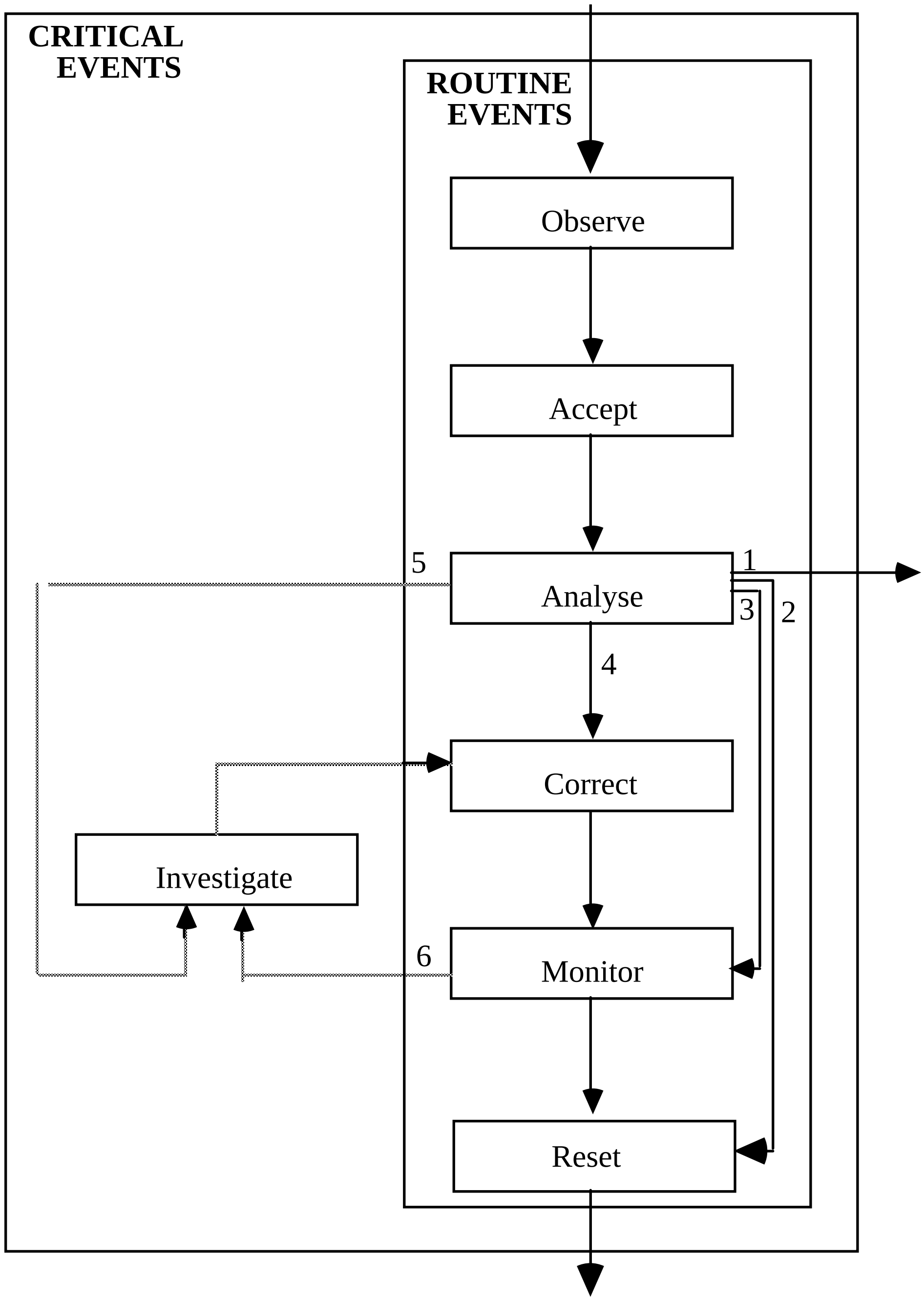


Figure 8. Alarm initiated activities

AIA defines seven stages through which alarm handling can progress. The initial stage (observe) involves the operator detecting the alarm. Stanton and Baber (1995) argue that, in this stage, the operator can be either active, i.e., searching for alarm information, or passive, i.e., receiving alarm information as it is displayed. At this stage, it might anticipated that there will be differences in the speed with which an operator will respond to different kinds of alarm display.

The second (accept) stage of AIA involves the operator accepting the alarm and hence, changing its status. Following the accept stage, the operator then proceeds to the third (analyse) stage. In this stage, the operator decides on the appropriate course of action. Often accept and analyse occur simultaneously, i.e., a 'nuisance alarm' occurs, the operator analyses the alarm and accepts it to turn it off. If necessary, the operator will proceed to the fourth (investigate) stage, in which the source of the alarm will be sought and its cause diagnosed. Once an alarm has been diagnosed, the fifth stage is to perform some corrective action on the process in order to remove the alarm condition, and then to monitor the change in the process, before resetting the alarm.

This brief discussion of AIA has indicated that there may be differences between alarm media at specific stages in alarm handling. This means that an alarm medium may be useful for one stage, but less useful than another. In a study of verbal alarm displays (comparing speech-based with text-based alarm displays with the AIA framework), Stanton & Baber (1996) found that speech-based displays led to longer 'acceptance' times when compared to text-based displays. They argued that the reason for slower responses in the speech condition may be due, in part, to the interference of speech with tasks being undertaken when the speech was presented. However, the differences in media had little effect upon the 'investigative' activities of the participants. Thus, in summary, only routine alarm handling is degraded when using speech-based alarm displays.

From the earlier discussions, it is possible to draw the conclusion that there is likely to be some differences in the way in which textual and graphical information is processed. This has implications for the appropriateness of the type of information that is used to support different types of alarm initiated activities (Stanton, 1994). This is one of the fundamental tenets of this paper and the main purpose of the study presented. Although much has been cited on guidelines for the design of alarm displays, little has been suggested as to the appropriateness of one display format over another.

The results of an earlier study, using a simple simulation, suggest that the performance of the participants in a text-based and a mimic-based alarm condition were better than participants in an annunciator condition (Stanton, 1992). This finding seems counter-intuitive to our hypothesis, given that the annunciator condition would, in theory, seem potentially to exploit both processing codes in terms of multiple resource theory. We suspect that participants probably use text, annunciator and mimic information in different ways. We explore these differences with regard to the different kind of alarm handling tasks introduced earlier.

3. Matching Formats to Tasks

From section 2, a number of experimental hypotheses may be developed. Textual and graphical information may actually support different types of task. The experimental hypotheses can be defined as follows:

i.) Text based alarms may be best suited to temporal tasks.
ii.) Mimic alarms may be best suited to spatial tasks.
iii.) Annunciator alarms may be best suited to pattern recognition tasks.

These hypotheses may be stated in figure 9, where the filled cells (in black) represent the hypothesised matching between display format (condition) and task type.

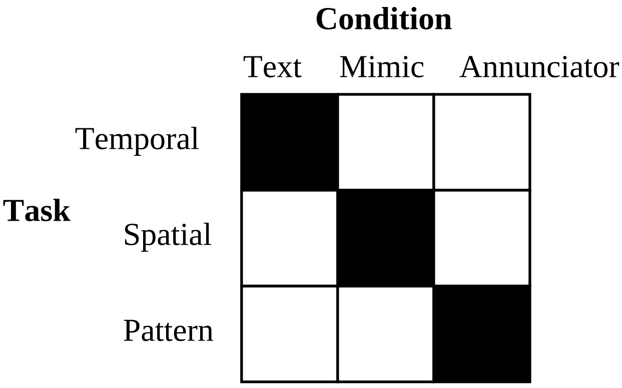


Figure 9. Hypothesised task-display format match.

3.1. *Participants*

54 psychology undergraduates participated in this study. The participants in the experimental groups were matched for age and sex as closely as was possible.

3.2. *Design*

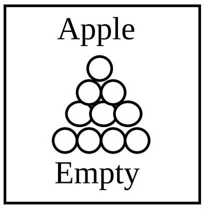
The participants were randomly allocated to one of 9 cells as illustrated in figure 10. Participants were first allocated to an experimental condition, and then assigned a task within that condition.

		Condition		
		Text	Mimic	Annunciator
Task	Temporal	6	6	6
	Spatial	6	6	6
	Pattern	6	6	6

Figure 10. Cell matrix of experimental design.

3.3. *Experimental Task*

Participants were assigned to one of three experimental conditions: text, annunciator or mimic. The scenario was kept very simple in order to reduce the training requirements and draw on participants' experience in a highly familiar situation. For this reason, participants were asked to imagine that they were control room operators in an automated supermarket. The supermarket had automatic shelf filling plant that would keep the shelves topped up. This experimental paradigm has been used successful before in the investigation of alarm media for process control tasks (Baber, Stanton & Stockley, 1992). However, under fault conditions alarm messages would be presented. Figure 11 gives examples of mimic (11a), text (11b) and annunciator (11c) based alarm messages. We accept that the task is artificial, but the objective was to reduce the training requirements of participants and also keep the information consistent between the formats. The messages consisted of three pieces of information about each fault: the <product>, the <container> and the <problem>, in keeping with a previous study comparing speech and text-based alarm formats (Baber et al, 1992).



A. Plant mimic representation

Apple Loose Empty

B. Text display representation

Apple
Loose
Empty

C. Annunciator representation

Figure 11. Comparison of experimental alarm formats

Each condition (text, annunciator and mimic) was further subdivided into groups performing either temporal, spatial or pattern matching tasks. The temporal task required the participants to record the order in which the 'alarm' messages were presented. The spatial task required the participants to record the location of the 'alarm' that was presented. The pattern matching task required the participants to select the current alarm(s) being presented from 16 alternative sets on a record sheet. The display of information was controlled by the experimenter. The task became progressively harder as the session proceeded as the number of alarm presented in each set increased.

3.4. *Procedure*

The procedure was as follows:

1. Participants were allocated to experimental groups and materials.
2. Participants were presented with a practice item via an overhead projector.
3. Participants were in the 'temporal' group were required to list the order in which the 'messages' were presented on a record sheet.
4. Participants were in the 'spatial' group were required to mark the location of the message on a map.
5. Participants were in the 'pattern' group were required to mark the corresponding template from 16 alternative sets.

6. After completing each task in turn, the participants' recorded their own response time, taken from a stop watch. When the whole group was ready, the next 'alarm message' was presented.
7. When all the messages had been presented, participants were thanked for their involvment and the response sheets were returned to the experimenter.

3.5. *Statistical analysis*

Data for the number of items correctly assigned were first analysed using ANOVA followed by a Mann-Whitney if appropriate (as these were non-parametric data). Time data were analysed by ANOVA followed by Scheffe F-test if appropriate (as these were parametric data).

4. Results

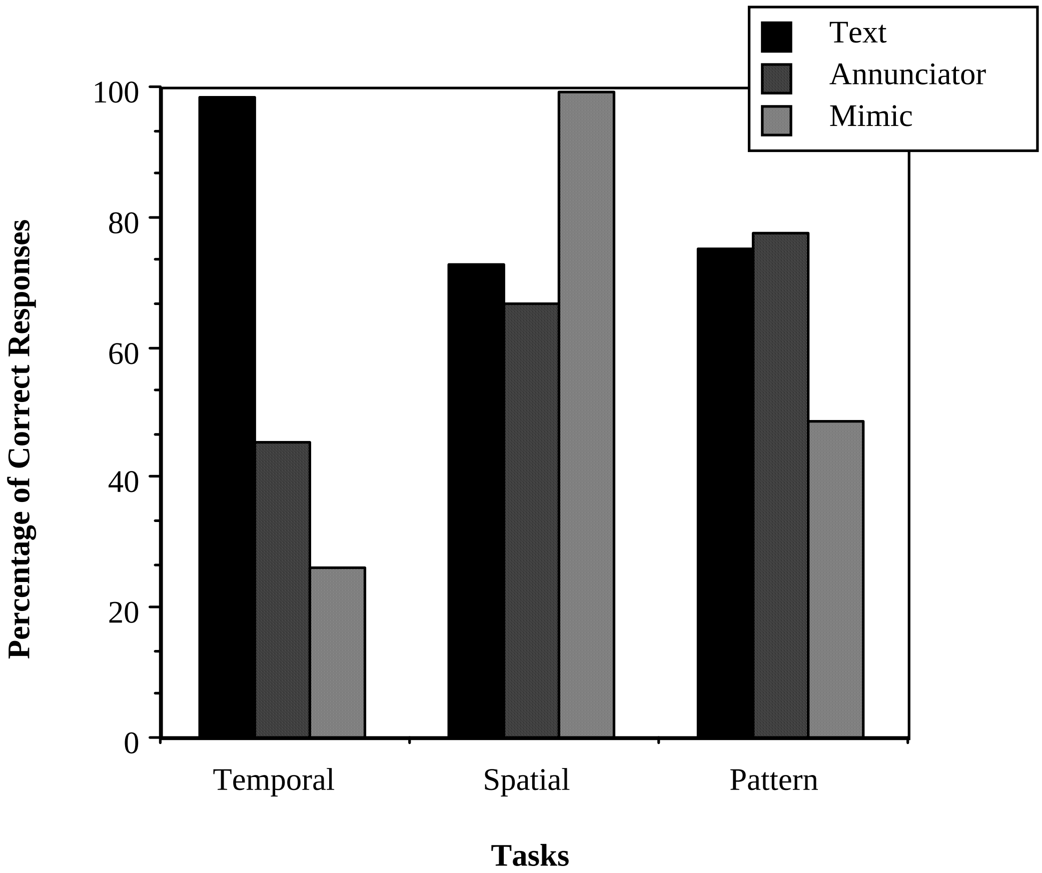
4.1. *Percent Correct*

The results of the ANOVA show statistically significant differences for alarm display formats ($F_{2,45} = 16.953$, $p < 0.0001$) and display tasks ($F_{2,45} = 13.783$, $p < 0.0001$). The summary of results also reveal a statistically significant interaction between the alarm formats and tasks ($F_{4,45} = 26.145$, $p < 0.0001$). This suggests that different alarm formats produce different errors for different tasks.

Post hoc analyses for the temporal task show significant differences between text and mimic (Z [corrected] = -2.903, p<0.003) and between text and annunciator (Z [corrected] = -2.903, p<0.003). However, there was no significant difference between annunciator and mimic (Z [corrected] = -1.524, p=NS). These results suggest that participants in the text condition performed significantly better at the temporal task than participants in the other two conditions, as is illustrated in graph 1.

Post hoc analyses for the spatial task show significant differences between text and mimic (Z [corrected] = -2.934, p<0.003) and between annunciator and mimic (Z [corrected] = -2.934, p<0.003). However, there was no significant difference between text and annunciator (Z [corrected] = -0.722, p=NS). These results suggest that participants in the mimic condition performed significantly better at the spatial task than participants in the other two conditions, as is illustrated in graph 1.

Post hoc analyses for the pattern task show significant differences between text and mimic (Z [corrected] = -2.209, p<0.02) and between annunciator and mimic (Z [corrected] = -2.589, p<0.009). However, there was no significant difference between text and annunciator (Z [corrected] = -0.164, p=NS). These results suggest that participants in the text and annunciator conditions performed significantly better at the pattern task than participants in the mimic condition, as is illustrated in graph 1.



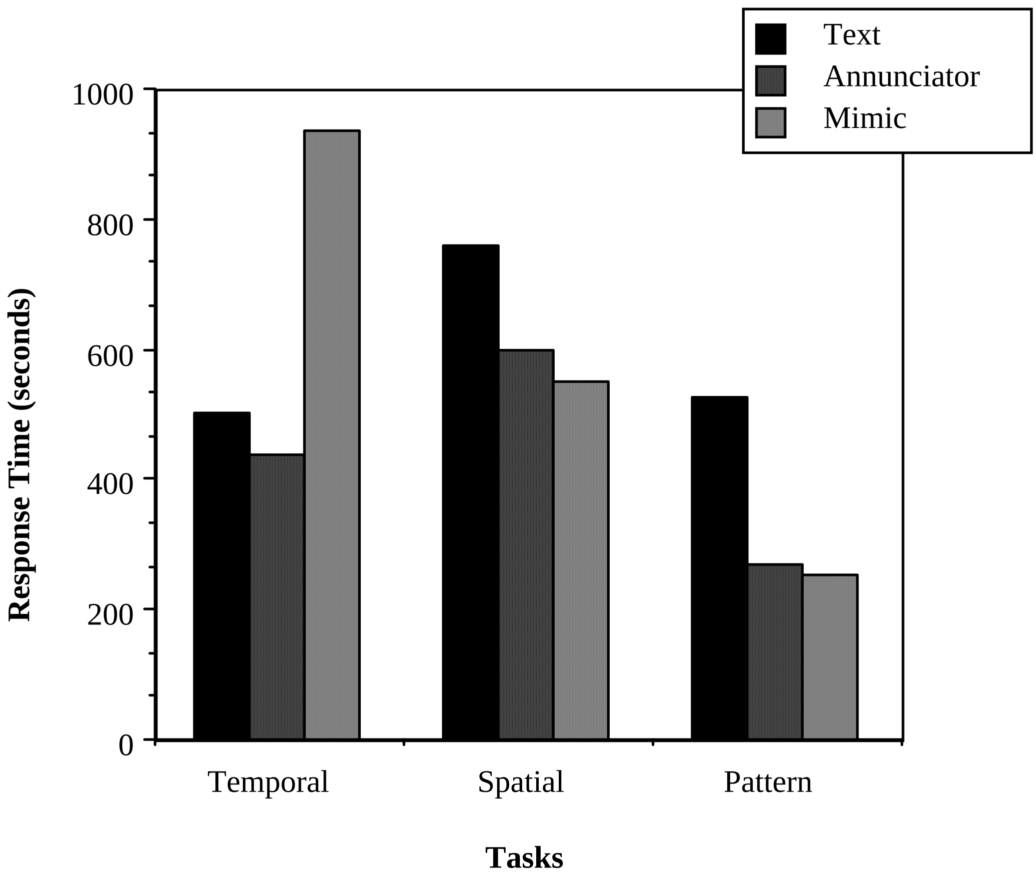
Graph 1. Percentage of correct responses for the experimental conditions

4.2. *Response Time*
The results of the ANOVA show statistically significant differences for alarm display formats ($F_{2,45} = 6.268$, $p < 0.005$) and display tasks ($F_{2,45} = 20.657$, $p < 0.0001$). The summary of results also reveals a statistically significant interaction between the alarm formats and tasks ($F_{4,45} = 11.054$, $p < 0.0001$). This suggests that different alarm formats produce different reaction times for different tasks.

Post hoc analyses of the temporal task show significant differences between text and mimic (Scheffe F = 9.405, p<0.05) and between annunciator and mimic (Scheffe F = 12.492, p<0.05). However, there was no statistically significant difference between text and annunciator. These results suggest that participants in the text and annunciator conditions were significantly quicker at the temporal task than participants in the mimic condition, as is illustrated in graph 2.

Post hoc analyses of the spatial task show no significant differences between the text, annunciator and mimic conditions. Mean response times for the groups are shown in graph 2.

Post hoc analyses of the pattern task recognition task show significant differences between text and annunciator (Scheffe F = 6.84, $p<0.05$) and between text and mimic (Scheffe F = 7.632, $p<0.05$). However, there was no significant difference between annunciator and mimic. These results mean that participants in the annunciator and mimic conditions were significantly quicker at the pattern task than participants in the text condition, as is illustrated in graph 2.



Graph 2. Response time for tasks in the three experimental conditions.

5. Discussion

Although the results of the an earlier study has suggested that there is little to choose between alarm media, the results of this study suggest that there is good reason to suppose that different types of presentation methods do support different types of alarm task. Consideration of the two figures independently may give rise to some incongruence between the experimental hypotheses and the results. For example, participants in the text and annunciator conditions do almost as well as each other in the pattern task (see graph 1), and perform almost as quickly as each other in the temporal task (see graph 2).

However, by comparing the results from both the 'percentage of correct responses' and the 'response time' it is clear that performance of the participants in the text condition is superior to the participants other two conditions for the temporal task, even if they are not significantly quicker than participants in the annunciator condition. Similarly, the performance of participants in the mimic condition is superior to the other two conditions for the spatial task, even if they do not complete the task significantly quicker than the other two conditions. Finally, although participants in the annunciator condition do not get significantly more correct responses than participants in the text condition, they do manage to perform the task significantly quicker. This relationship is illustrated in figure 12, where white boxes mean poor performance, grey boxes mean good performance on one of the evaluation criteria (either reaction time or percentage correct) and black boxes mean good performance on both evaluation criteria (both reaction time and percentage correct).

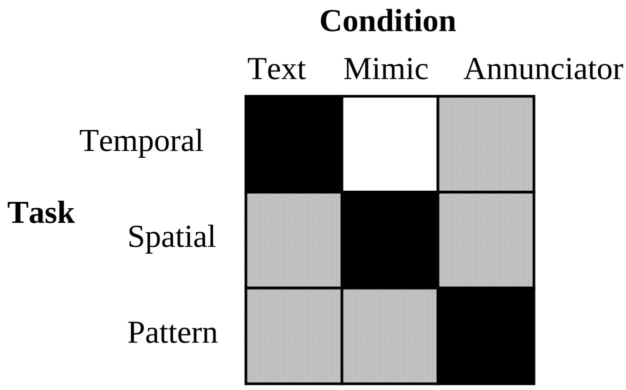


Figure 12. Overlap of task-display format match.

These data highlight the need to consider both speed and accuracy when conducting studies on task type and display format. The experimental hypotheses are supported, as comparison of figure 10 (the hypothesised task-display format match) with figure 12 (the overlap of task-display format match) illustrates. A study by Selcon, Taylor & McKenna (1995) indicated that combining verbal and spatial information leads to faster response times than when either are presented alone. It could have been anticipated therefore, that participants in the annunciator condition were likely to respond faster to the alarms presented as annunciators contain both verbal (i.e. the text message on the annuciated display) and spatial (i.e. the relative position in the annunciator grid) information. The results seem to lend some support to this proposal as the participants responses in the annunciator condition were always one of the fastest for all three tasks. This would appear to be encouraging for proponents of the Parallel Distributed Processes paradigm.

The results also seem to lend support to the spatial-verbal dichotomy described by dual-coding theorists (Wickens, 1984; 1992). The verbal information contained in the form of text messages supported the task that required information to be represented in a sequential form. Whereas the 'mimic' and 'annunciator' information might be better considered in spatial terms. Although the annunciator information contained textual information, it appears that it was the spatial information that was being used as the superiority of the annunciator to the text condition for pattern recognition task demonstrates. The spatial arrangement of the mimics was also clearly superior to other forms of message presentation in the map-based task. Thus, it could be concluded that in essence the classification of display formats proposed by Stokes, Wickens & Kite (1990) has been substantiated by this study. Despite this optimistic stance, the ecological validity of the study might be called into question as the task was of contrived nature. For the purposes of the investigation reported in this paper, the experimental design was focused upon the relationship between visual format and some abstractions of the alarm handling task. Experimental studies of this nature always attempt to strike the balance between a tightly controlled investigation and research into applied phenomena.

Despite these difficulties, this study has demonstrated the suitability of text, mimic and annunciator display formats for temporal, spatial and pattern recognition tasks respectively. As the study in this paper suggest, suitability of the display format is highly dependant upon the tasks the operator is required to perform. One alarm display can only be considered to be superior to another in the context of the activities an operator might be required to perform. It was not possible, at this stage, to consider combinations of alarm media within this study, but this must be an important goal for future research. There may be potential problems from inappropriate formats, for example using text-based displays for a spatial task may lead to problems as the results from this study have shown, or using mimics for a temporal task. The results also suggest that annunciator display formats may be a useful compromise design. This finding concords with the arguments put forward by Stanton & Baber (1995) in favour of annunciator formats over text-based formats for alarm displays.

6. Conclusions

From this study, a number of conclusions may be drawn, which can be used to inform decisions concerning the implementation of visual displays in control room operations. These are as follows:

* Text messages are recommended for tasks requiring presentation of sequential information to be used.

* Annunciator displays are recommended for tasks that require patterns of alarms to be identified.

* Embedded mimic alarms are recommended for tasks that require spatial reference.

* Combination of alarm presentation methods and media needs to be further investigated.

Further studies should aim to investigate other aspects of the alarm initiated activities model on the alarm format. A taxonomy of alarm handling identified by Stanton & Baber (1995) indicates where the efforts may be best focused.

Acknowledgement

The authors would like to thank Dr Chris Baber for his comments on earlier drafts of this manuscript.

References

Baber, C; Stanton, N. A. & Stockley, A. (1992) Can speech be used for alarm displays in 'process control' tasks?. Behaviour and Information Technology. 11, 216-226.

Benel, D. C.; McCafferty, D. B.; Neal, V. & Mallory, K. M. (1981) Issues in the design of annunciators. Proceedings of the Human Factors Society 25th Annual Meeting. Santa Monica, CA.: Human Factors Society, 122-126.

Corlett, E. N. & Clark, T. S. (1995) The Ergonomics of Workspaces and Machines: A Design Manual (2nd edition). London: Taylor & Francis

Easterby, R. (1984) Tasks. processes and display design. In: Easterby, R. & Zwaga, H. (eds) Information Design. Chichester: Wiley, 19-36.

Eysenck, M.W. & Keane, M.T. (1995) Cognitive Psychology (3rd edition). Hove: Lawrence Erlbaum Associates.

LaLumiere-Grubbs, L.; Berson, B. L.; Bourcek, G. P.; Anderson, C.; Summers, L. G. & Metalis, S. (1987) An assessment of display formats for crew alerting and guidance. Proceedings of the 31st Annual Meeting of the Human Factors Society. Santa Monica, CA.: Human Factors Society, 1077-1081.

Selcon, S. J.; Taylor, R. M. & McKenna, F. P. (1995) Integrating multiple information sources: using redundancy in the design of warnings. Ergonomics, 38, 2362-2370

Singleton, W.T. (1989) The Mind at Work. Cambridge: Cambridge University Press.

Stanton, N. A. (1992) Comparing alarm media in a simulated process control task. Aston University: Applied Psychology Group.

Stanton, N. A. (1993) Speech-based alarm displays. In: Baber, C. & Noyes, J. (eds) Interactive Speech Technology. London: Taylor & Francis.

Stanton, N. A. (1994) Alarm initiated activities. In: Stanton, N. A. (ed) Human Factors in Alarm Design. London: Taylor & Francis.

Stanton, N. A. & Baber, C. (1995) Alarm Initiated Activities: an analysis of human alarm handling. Ergonomics, 38, 2414-2431.

Stanton, N. A. & Baber, C. (1997) Comparing verbal alarm displays: speech versus textual systems. Ergonomics (in press)

Stanton, N. A.; Booth, R. T. & Stammers, R. B. (1992) Alarms in Human Supervisory Control: A Human Factors Perspective. International Journal of Computer Integrated Manufacturing. 5, 81-93.

Stokes, A.; Wickens, C. D. & Kite, K. (1990) Display Technology: Human Factors Concepts. Warrendale, PA: Society of Automotive Engineers Inc.

Venturino, M. & Eggemeier, F. T. (1988) Special issue preface. Human Factors, 30, 535-538.

Wickens C D (1984) Engineering Psychology and Human Performance. Columbus, Ohio: Merrill.

Wickens, C.D. (1992) Engineering Psychology & Human Performance. New York: Harper Collins.

Woods, D. D. (1983) Some results on operator performance in emergency events. Ergonomic Problems in Process Operations. I. Chem. E. Symposium Series No. 90. Oxford: Pergamon Press, 1983, 21-32.