AN ABSTRACT OF THE THESIS OF

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TITLE: AN EXPERIMENTAL EVALUATION OF TWO PROCESS CONTROL DISPLAYS

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This study was designed to compare two types of process overview displays for a distributed process control system. The two types of formats included in the study were an alphanumeric type (letter) and an analog type (bar). The study required the subjects to perform check reading and search tasks.

Thirty-six subjects were tested on both types of display. The results indicated that the analog display was superior to the alphanumeric display. The results reported are based on speed (response time) and accuracy (percent correct).

# AN EXPERIMENTAL EVALUATION OF TWO PROCESS CONTROL DISPLAYS

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# CHAPTER I

## INTRODUCTION

Human factors engineering is an interdisciplinary specialty concerned with influencing the design of equipment systems, facilities, and operational environments to promote safe, efficient, and reliable operator performance [Edwards and Lees, 1973; McCormick, 1982].

The initial focus of human factors was mainly on designing military equipment for human use. Later it has been widely recognized in nonmilitary areas such as the design of control centers for process control systems, transportation equipment, communication equipment, and many other areas. In recent years, human factors has been applied to the design of virtually all man-made things. The central concern of this thesis is with the application of human factors in the design of operator interfaces in process control systems.

In the past decade the trend in the development of process control equipment has been to replace conventional control panels which consist of multi-colored push buttons, large meters, moving scales, etc., by a CRT station called a console. This console usually consists of one or more CRTs through which all process variables can be supervised and controlled. This new CRT approach to process interfacing has brought several advantages to industrial control.

These consoles provide a level of detailed information presentation unavailable with conventional control panels (e.g., flow diagrams, tables, graphic symbols and bar graphs). The versatility of these new techniques allow greater freedom in structuring information. They put the control room on a desk. One of the applications of this technique is the use of several CRTs in the console. The use of multiple CRTs has the added advantage that more than one operator can use the console.

Dallimonti [1975] emphasized that the future operator interface will be microprocessor driven CRT consoles. This point is supported by several authors working in this area. These new devices give rise to innovative displays. Common examples of displays are graphic symbols, tables, bar graphs, and alphanumenric information.

Bar graphs are usually used for showing trends (past values). The display of a trend is shown on a graph in which the horizontal axis represents one variable and the vertical axis a second variable. This is especially common when the horizontal variable is time and the second is some parameter which will vary in some manner over time.

Schutz [1961] conducted an experiment to determine the human performance differences between line graphs and bar graphs for predicting the direction of trends. He concluded that line graphs are preferrable to bar graphs.

Bar graphs are also used as analog indicators to show present values. The current generation of control consoles continue to use analog representations on their CRT formats. Dallimonti [1975] has suggested that the bar graphs can be used to show present values of a series of variables similar to conventional analog indicators. He has also suggested that this type could be used as a process overview display in which an array of bars shows the plus and minus deviation from set points (Figure 1-1).

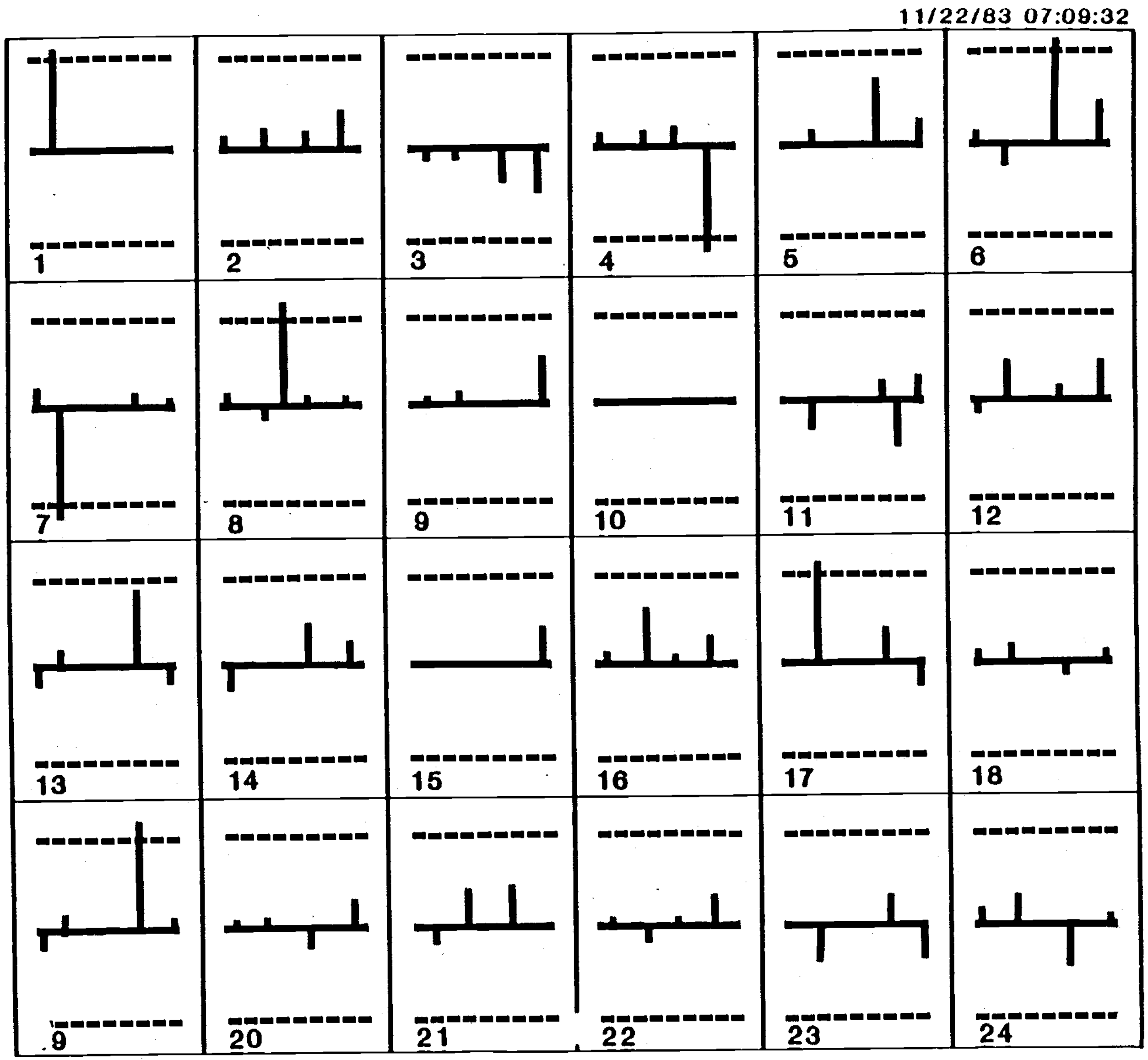


Figure 1-1 Overview display (bar type)

Historically speaking, the use of alphanumeric methods for presenting information in a process overview display is fairly recent (Figure 1-2), but it was always used as one of the abstract coding methods for representing targets on visual displays. Hitt [1961] conducted an experiment to ascertain the relative effectiveness of selected abstract coding methods. He compared five different coding methods (numeral, letter, geometric shape, configuration, and color). He concluded that numeral coding and color coding are the two best coding methods.

In the design of a process overview display, one of the first decisions the designer must make concerns the type of format to be used. The problem with, for example, format design is that it is application specific and with current display technology can lead to an infinite variety of designs. Although for some applications one type of format may be preferred over the other, the choice is often difficult. Furthermore, the necessary guidelines are not available in the literature. Experimental evaluations have, therefore, tended to be adhoc and lacking in generality. There is a need for the study of process control displays especially computer generated displays. This thesis is a contribution towards this study.

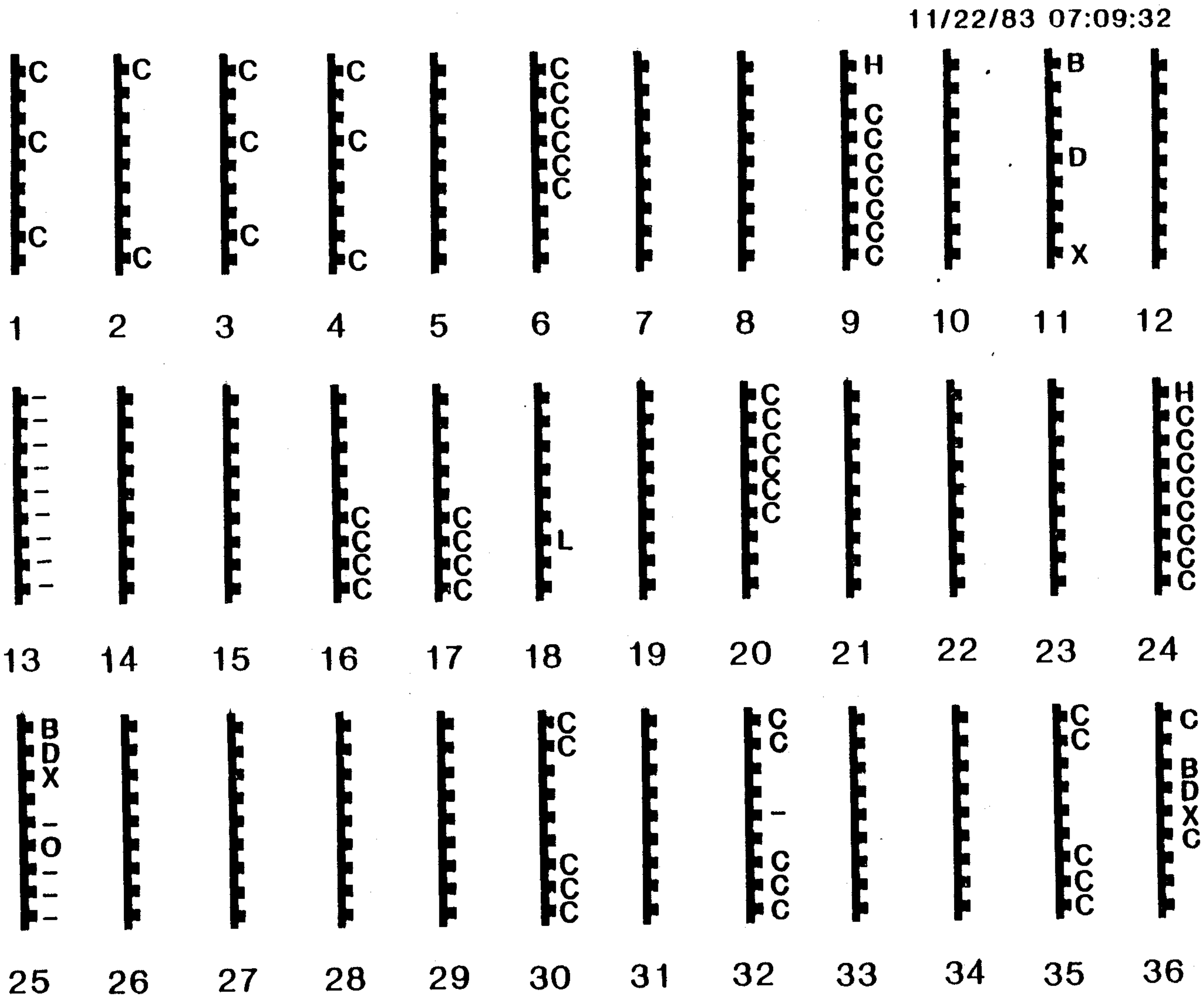


Figure 1-2 Overview display (letter type)

The present research is designed to yield information to aid design engineers in selecting the most compatible display format for process overview displays by answering some questions such as:

1. How do display formats affect performance?

2. How much time does it take to identify a system's status using a given overview display?

3. How much time does it take to identify the status of a particular process variable?

4. How many errors are made?

The overview of the thesis is as follows. First, Chapter II provides an introductory account of process control. Along with this, an introductory review of human factors and in particular of those aspects which are most relevant to process control is given. This is a very general description which is intended primarily to provide a background to the field.

This is followed by Chapter III which describes the methodology used to achieve the objective of the present study. Here the experiment itself is described in detail. In this chapter are introduced many of the terminology which recurs throughout the thesis. Next, the results of the experiment are analyzed in detail in Chapter IV. There follows an account for the discussion of results which are presented in Chapter V. The conclusions and directions for future research work are presented in Chapter VI.

Finally, the area of man-machine interfaces in process control constitutes a significant portion of present research in human factors engineering. A large amount of work has appeared in the literature to date. A detailed annotated bibliography is therefore provided in Appendix G.

# CHAPTER II

# BACKGROUND

## INTRODUCTION TO PROCESS CONTROL

Process control has existed in nature since the first living creatures appeared on Earth. We can recognize natural process control as an operation that regulates some internal physical characteristic important or critical to a living organism. Common examples of naturally regulated quantities are body temperature, body fluid flow rate and many others. As civilization developed, it became necessary for humans to regulate parameters in their environment in a way which superceded their natural control levels. This initiated artificial process control. This regulation was accomplished by observation of a parameter, comparison with some desired value and action to bring the parameter to that desired value. Examples of such control are found in fires for light and heat, cooking of food, and so forth. [Encylopedia of Science and Technology, 1982; Johnson, 1982]

## AN EXAMPLE OF PROCESS CONTROL

Let us consider a simple example which illustrates the essential features of a process control system. Consider a human operator controlling the temperature in a room by watching a thermometer and adjusting the valve on a radiator. The variable is the temperature of the room, and the regulation is the maintenance of the temperature level at some desired level. Here the control of temperature is by the regulation of steam flow using a valve on the radiator. Operationally, the valve on the radiator controls the rate of temperature loss in the room. If the system is left alone, the steam flow will simply adopt any value commensurate with inward and outward flow. If steam flow or some other parameter affecting inlet changes, a new temperature level occurs. This is an open-loop system. That is, the output is not fed back to the controlling element. To have a closed-loop system we must feed the information on the steam flow back to the controlling element, in this case the human operating the valve on the radiator. Thus the human operator provides the required feedback to close the loop. The thermometer permits the operator to make visual measurement of the temperature level in the room.

The operator makes an evaluation about whether the temperature level is high or low or just right. Whenever it is incorrect, the operator adjusts the valve to correct the temperature level. Measurement, evaluation and control form the basis of a process control loop [Johnson, 1982].

## HISTORICAL DEVELOPMENT

Traditionally in process control plants, the control system was based on a single loop with an analog controller (Figure 2-1). In such a system the analog controller receives from the measuring instrument a measured value of the controlled variable, and compares this with a desired value or set point to obtain an error value (set point - process variable). This controller then sends an output signal to the control valve, which then adjusts the regulated variable.

Analog control generally means that each loop employs a controller which continuosly monitors the process variable. It also implies that determining the error and computing the controller output is done on an analog basis. This means that the signals within the controller are all analog variables: continuous

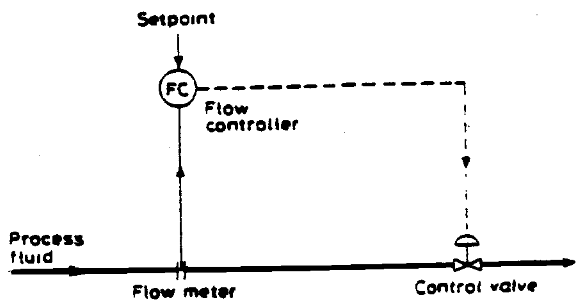


Figure 2-1 Analog control
(Source: Edwards and Lees, 1973)

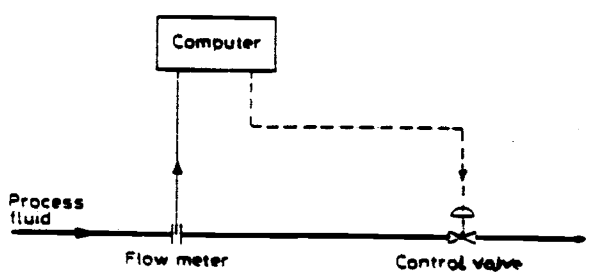


Figure 2-2 Digital control
(Source: Edwards and Lees, 1973)

variables such as voltage, current and pressure.

In a digital control system, all information carried in the process control loop is encoded into a signal that is binary in nature. This usually means that the process variable is sampled periodically and controller output is updated at discrete time intervals. In a direct digital control system this function is performed by a digital computer. This is shown in Figure 2-2 [Edwards and Lees, 1973]. Such a system generally possesses the following characteristics:

1. High processing power located in the central computer.

2. centralized data base.

3. concentrated interface between the computer and the human operator.

4. large centralized power supply.

This is shown in Figure 2-3.

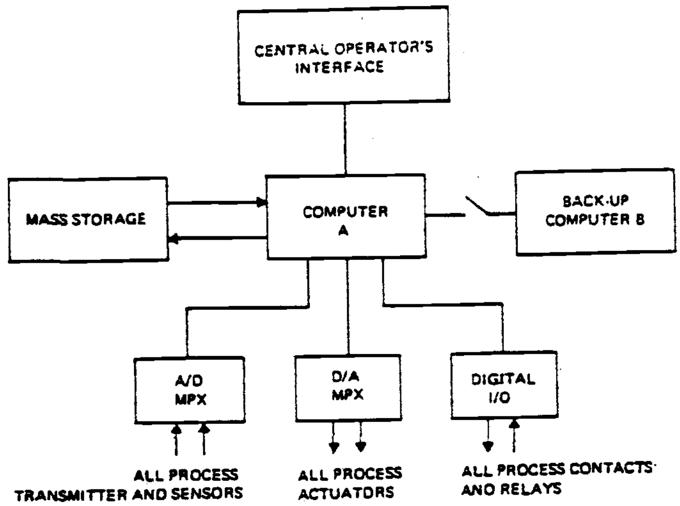


Figure 2-3 Conventional control system
(Source: Stella, 1976)

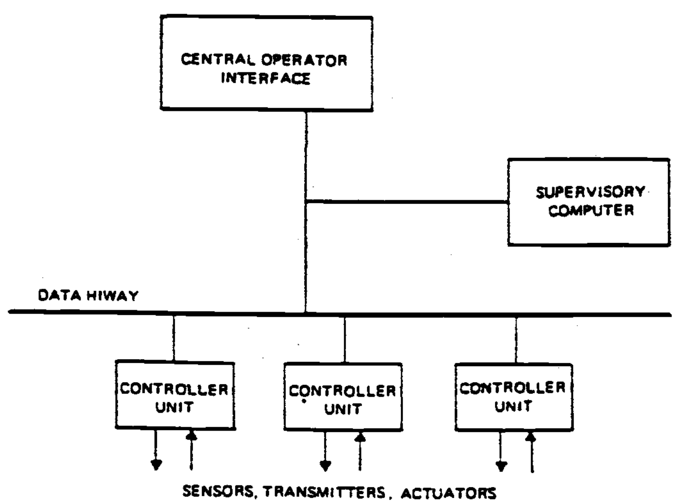


Figure 2-4 Distributed process control system
(Source: Stella, 1976)

## PRESENT SITUATION

The present trend in process control is to replace conventional control system and instrumentation by a distributed architecture. In a distributed process control system, the control instruments are mounted in racks which can be located anywhere and connected to the console by a system bus. The CRT stations, process controllers and supervisory process computers are integrated via a high speed digital highway. This type of arrangement is also called a Microprocessor Based Distributed Computer Control System [Mamzic, 1981]. A very general configuration of such a system is shown in Figure 2-4.

The current trend for the operator interface in a distributed system is to use CRTs as the main interface device. The word interface is associated with hardware most of the time. In a broader sense, however as a common boundary between different types of elements, "interface" means everything which makes possible communication and interaction between the various elements. Translated into process control terminology, the different types of elements are the man, the process and the process control computer; the interface is the hardware, the software, and the procedures which make possible interaction between the elements [Berta, 1971].

## INTRODUCTION TO HUMAN FACTORS

Traditionally, mans' tools and working methods have evolved slowly over long periods of time such that without conscious attention being paid to design, reasonably satisfactory solutions emerged. When, however, technological evolution was accelerated into revolution, and systems of considerable complexity were produced very quickly, the process of natural development was far too slow-moving to bring about a state of harmony. Conscious attention to design factors must be given if man is to achieve a satisfactory relationship with his occupational environment.

Largely as a consequence of studies carried out during the Second World War, a substantial technology has emerged concerned with the role of man at work. Human Factors is concerned with optimizing the relationship between man and his work by the systematic application of data from the human sciences, integrated within the general framework of systems engineering [Edwards and Lees, 1973].

## HUMAN FACTORS AND PROCESS CONTROL

The introduction within the last decade of process control computers for chemical plants, power generation plants, etc. has made it possible to obtain a high degree of automation of the control functions. However it is impossible in most plants to achieve complete automation and there remains an area in which the human operator appears to retain an essential role. This situation has led to an increasing interest in the operator and the functions which he performs [Edwards and Lees, 1976].

A certain amount of research has been carried out upon the task of the human operator engaged in process control. In the practical world of process control, the research approaches tend to be somewhat pragmatic and unscientific. A great deal of emphasis is given to the hardware aspects of the problem: choice of CRT; shape, size, and color of the console; and kind and arrangement of keyboards and other supplementary input devices.

While the importance of these studies should not be minimized, there is significant evidence that says the real challenge in design lies elsewhere. It lies in a better appreciation of the role of man in the system and his information processing capability. Therefore, the first important requirement of a project should be a very thoughtful definition of the role to be played by the human being in the system. The operator responsibilities should be well delineated, the scope of his mission should be clear, and the means of measuring his performance shuld be established [Dallimonti, 1975].

In process control, the operator's role generally falls into the categories of receiving, evaluating and controlling. His primary task, therefore, is comprised of receiving information about the process, making broad decisions concerning its required control parameters, and communicating these requirements to the hardware which provides the moment to moment control.

In the receiving category, vision and audition comprise the two principal input channels. The differing properties of human vision and audition dictate certain general rules regarding the selection of sensory modality for different types of input. Visual communication tends to be more appropriate for long complex messages to which man may wish to refer on several occasions. Auditory signals tend be used in the case of short, simple messages and for signals which are to be communicated to mobile personnel. Therefore human vision provides the predominant channel of communication in most situations. Huchingson [1981] says that eighty percent of human knowledge is acquired visually. Hence, most of the material presented here onwards will deal with visually displayed information.

In process control the operator's input receiving capacity is easily saturated and overloaded which results in mental stress, confusion and operational errors. An example of sensory overload in control systems may be illustrated in an analysis of control panels commonly found in industry. Typically large control consoles are designed with control and display instrumentation arranged in rows or columns on the panel surfaces. Display instrumentation may include stripchart recorders, current status moving scales and digital displays. Lights and colors are also used in various combinations to transmit information to system operators. Large multi-colored pushbuttons with stick-on name plates above, below or between are common. Although designed with the best of intentions, these types of panels do not match basic man-machine communication criteria. Each display system, pushbutton grouping, labelling scheme, and color on the console adds to the figure-ground sensory stimulation or "visual noise" the operator must filter out to receive the necessary system data. Too much data is displayed at one time and the whole suffers [Sublett, 1976].

The above discussion can be supported by the unfortunate historical experience of the Three Mile Island nuclear generating station. It was human error that created the worst part of the accident, but it also took humans to analyze what was wrong and regain control before the accident became a public disaster. It is clear from the events at Three Mile Island that the operators were faced with a great deal of information to digest, much of it scattered around the control room and some obscured or accessible only with great difficulty. During the accident, hurried operators had problems in finding and analyzing critical information about the reactor. It was concluded from the information available that the historical evolution of control center design has not generally emphasized strong application of known human factors design principles [Sugarman, 1979; Hanson et al, 1982]. It can be noted that one of the main causes for the above accident was the poor operator interface.

The essential requirement of any operator interface is that each system component should communicate effectively with other system components. Communication takes place between components by means of an interface, which in the case of a man and machine consists of displays through which information passes from the machine to man. The design of a man-machine interface (MMIF) is made particularly difficult because of the fundamental differences in the performance characteristics of men and machines. The problem can be divided into a number of categories which correspond approximately to various stages of the human information processing system. The objective in designing an effective MMIF for a given task is to ensure that the characteristics of the human information processing system at these various stages is matched by the characteristics of displays so that the flow of information is neither inhibited nor corrupted. Therefore it can be remarked that the displays are one of the predominant components of the operator interface.

The physical nature of the MMIF will depend on the type of man-machine system and the technology employed. As discussed earlier, the development of microprocessor technology has resulted in the replacement of large control panels by distributed architecture with CRTs as the main operator interface. These devices have tremendous flexibility in display of information, and have brought about significant reductions in the size of operating centers [Umbers, 1981].

They have several advantages over conventional panels because they have the capability to display information in many different forms. They do, however, have a limitation in the amount of information which they can display at one time. The solution to this problem is met by organizing the displays in a logical hierarchy that permits quick and easy access to any desired display within the hierarchy (Figure 2-5).

The number of levels in a display hierarchy can vary, but the multilevel display can usually be identified with one of the following types of format under such names as [Emcon-D, 1982]:

1. Overview display

2. Group display

3. Detail display

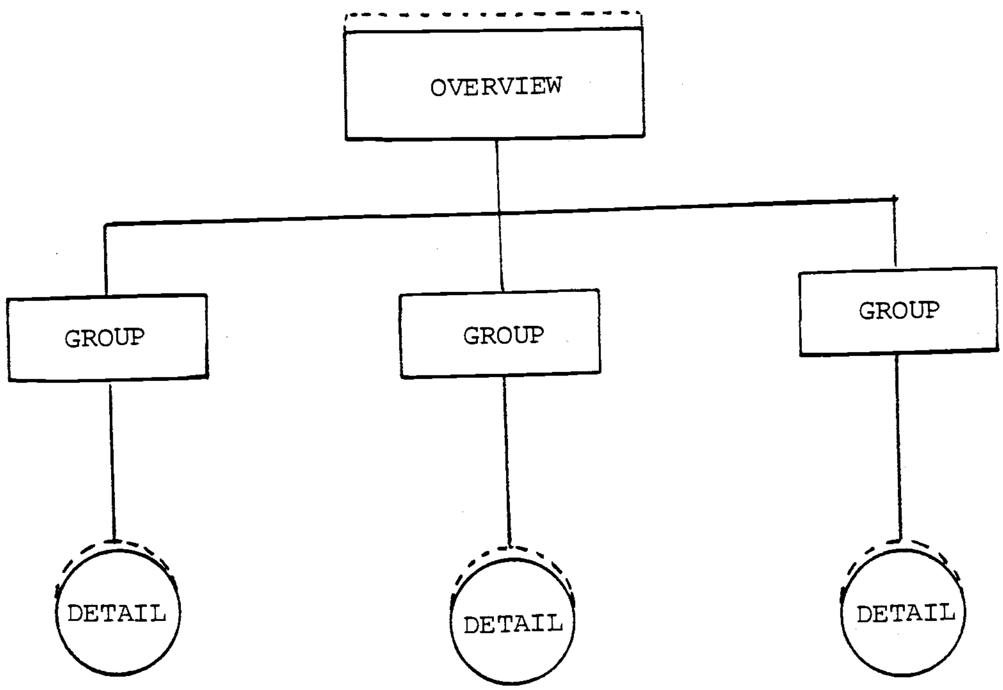


Figure 2-5 Display hierarchy

OVERVIEW DISPLAY

As the name implies these displays give an overview of the behaviour of the whole plant or major plant area on a single screen .

In our case consider the example of the campus heating system. Here the operation associated with process control is the maintenance of a desired temperature level in various buildings on campus. Measurement, evaluation and control is done by the operator using a process control computer. In a typical process control situation like this, an overview display would show the status of the various buildings on campus keeping the operator informed about the temperature levels in all the buildings. Figure 1-2 shows one kind of overview display. This type of overview display allows the operator to view the individual status of eight rooms per building, for a total of 288 rooms per display. During normal periods of operation this might be the only display that needs to be monitored. Should an abnormal condition or malfunction such as failure of a hot water pump occur, then the operator might choose to go to a lower level for detailed information. The overview display is periodically updated to show real time changes in the buildings as they occur.

GROUP DISPLAY

This shows as much information as an operator usually needs to know about a limited number of closely related variables (quite often eight) for control purposes. The group display is used to observe process variables and to operate controls in a particular area of the plant.

In our case, this display might be used to observe the temperature in a particular building on the campus. This display is constructed to resemble a collection of conventional controller face plates. Process variables, set point, and controller outputs are displayed in both analog and digital form. The operator has direct access to these parameters at this level.

DETAIL DISPLAY

If more information is needed, this display can be requested by the operator to present a particular control loop in further detail. In our case, this display is used to obtain more information about a particular room in a building. This display carries most of the detail data about control and measurement points in the system.

From the above discussion we can say that the displays help the operator to :

1. Monitor- Plant overview displays provide this capability by keeping the operator informed about the status of the whole plant or a major plant area.

2. Operate- Group level displays provide this capability by allowing the operator to operate controls in a particular area of the plant.

3. Tune- Detail displays provide this capability by presenting the control loop with more information. For example the operator can change the upper limit of a particular room temperature.

To perform the above functions, the operator has to call the appropriate display. This method is usually called "operation by exception" which proposes that during normal operating conditions the operator only needs to be informed of the parts of the process which are not functioning as specified.

One of the greatest challenges facing human factors specialists concerned with process control systems is the design of appropriate displays. There have been number of studies conducted on the role of the human operator in computer based control systems. As discussed by Smith [1976], there has been considerable interest in the human component in control systems [e.g., Rasmussen 1974; Edwards and Lees 1974], particularly with respect to the design of displays and controls. There is considerable evidence available to demonstrate the importance of suitable coding schemes in the design of displays [McCormick, 1964].

Both traditional and current recommendations for display applications where check reading and rate of change of information are important evaluation criteria have supported analog display formats, but many computer process control interfaces have adopted digital formats for their programming ease. To reinforce the design recommendations preferring analog over digital display formats in CRT applications, Hanson and his colleagues [1981] recently conducted some experiments to compare analog versus digital CRT displays in error detection monitoring. The first experiment examined the degree to which check reading and rate of change of information are more appropriately displayed in an analog format. This experiment was designed to consider the performance differences between basic analog versus digital display formats. The results of this experiment showed that the analog displays were significantly better than the digital displays. This finding is consistent with design recommendations and other research of Tullis [1980] and McCormick [1976]. They concluded that the digital display led to poorer overall performance than the analog format.

Umbers [1981] conducted a survey of distributed process control systems. During his survey, he found that the group display was laid out in two fashions. An examination of these two types showed that information was presented both in analog and digital form (Figure 2-6). The analog versions were of the Bar type. They were arranged either in a vertical or horizontal fashion. All the information for a control loop was laid out either in one or two rows. Thus, all the group type displays were classified as one of four types: vertical bar in or two rows, or horizontal bar in one or two columns. For a complete evaluation of

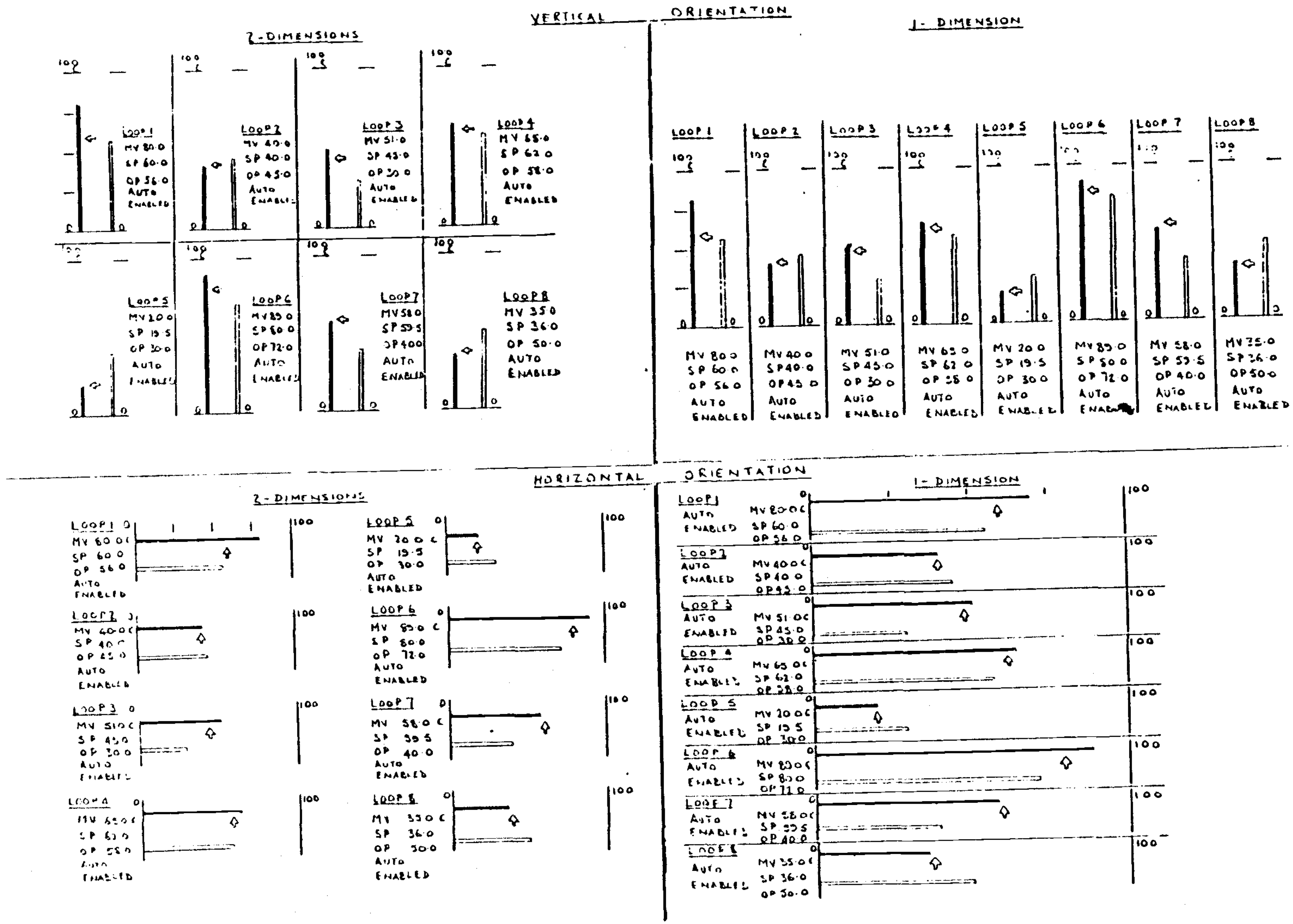


Figure 2-6 Group display (Source: Umbers, 1980)

these four types, a study might be conducted involving the four main tasks (quantitative, qualitative, check reading,and comparison). Umber conducted a study which considered only the performance on a quantitative reading task. The results obtained indicated that there were no significant effects on performance due to the two main factors, vertical bar in one or two rows and horizontal bar in one or two columns. In addition the results suggest that arranging digital or analog information in columns or rows does not affect the quantitative reading task.

To demonstrate that excessive information may degrade peformance on a specific task, Murrel [1971] cites a study by Connel in which the effect of reading performance of increasing the number of digits on a numerical display was investigated. The results showed a linear increase in time and errors for each addition of a number beyond two digits. This suggests numerical information should only be presented to the precision required for a given task [Umbers, 1981].

Overview displays in several current process control systems are of of alphanumeric type (Figure 1-2) in which all the status conditions are represented by letters (e.g., H-high absolute alarm, L-low absolute alarm, and so on). Dallimonti [1975] suggests that in process control the operator does not require any quantitative information at the first level of the process. Data should be presented in graphic form to be most effective for the human operator. As an illustration one technique for process overview display is shown in Figure 1-1 [Dallimonti, 1975]. In this type of process overview display, a row of bars shows the plus and minus deviations of a variable from a set point.

Apparently, no emperical study has been performed which compared these two types of overview displays. Therefore to help the designers of hierarchial distributed control systems, a study was designed to investigate the differences between these two overview displays. The two overview displays considered for this experiment are shown in Figures 2-7 and 1-1.

The first type (Figure 2-7) consists of twenty-four vertical bars arranged in four rows, each with a number beneath it. Each of the tick marks represents a controller in the system. For simplicity, consider that each vertical bar represents a building and each tick mark represents a room in that particular building. Next to each tick mark is the status of that

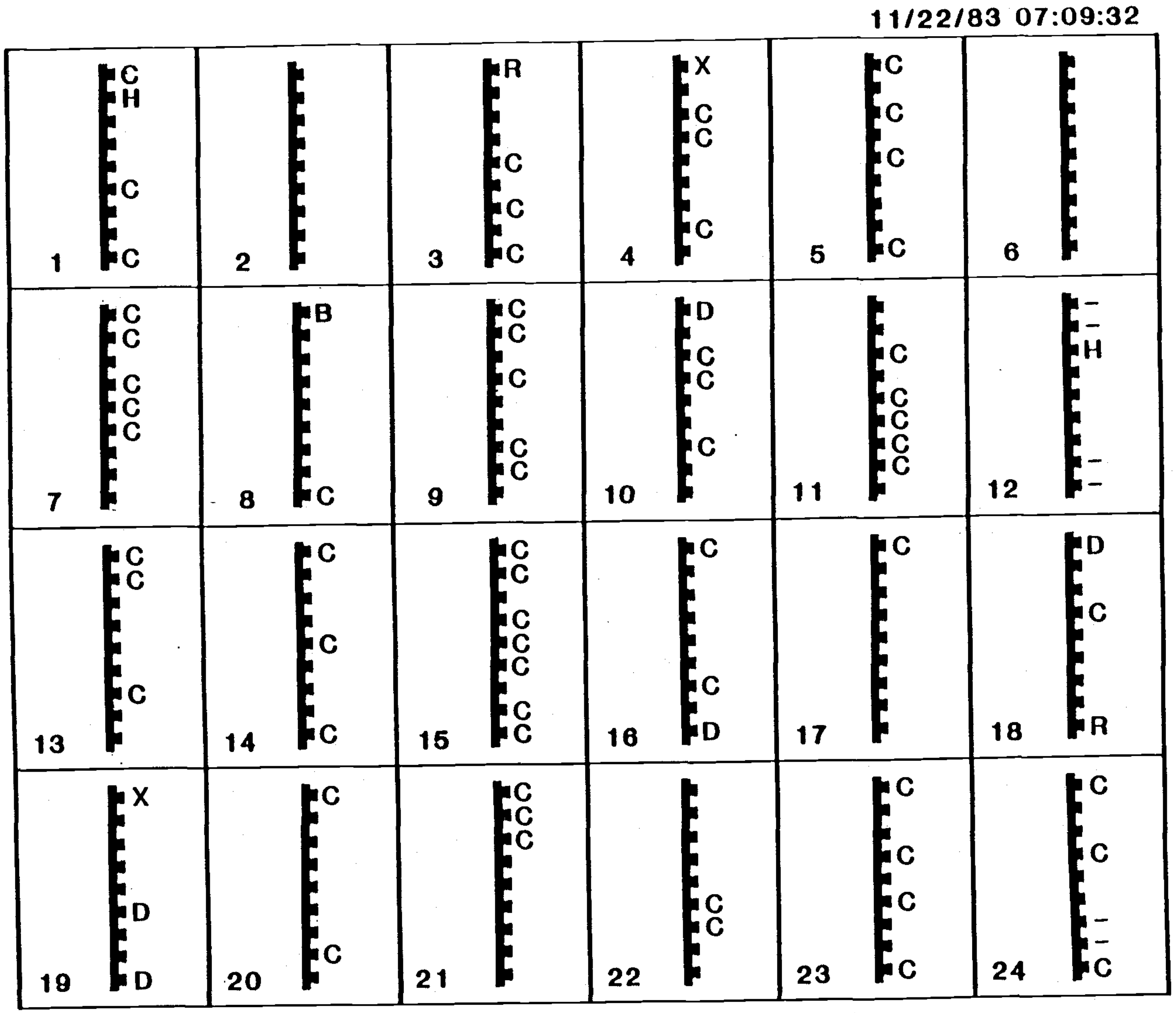


Figure 2-7 Overview display (letter type)

particular room.

Figure 1-1 shows a twenty-four bar graph display arranged in four rows, each with a number beneath it. Here each horizontal bar corresponds to a building . Each vertical bar shows the plus or minus deviation of an individual room temperatures from a set point.

For simplicity, let us refer to the first type as the Letter type display (since the abnormal states are represented by status letters) and the second type as the Bar type display (since the each bar shows the deviation of a controller from its set point). From here onwards these displays will be referred to as either the Letter type display or the Bar type display respectively.

## RESEARCH HYPOTHESIS

The purpose of this experiment is to compare two types of plant overview displays. A distinguishing characteristics of the research method is the formulating and testing of a hypothesis. Hypothesis-testing procedures should be viewed as tools that aid an experimenter in interpreting the outcome of research. Thus in order to answer the questions mentioned above the following hypothesis can be stated.

> HO: Display type (Letter or Bar) does not affect operator performance.

The experiment is described in the next chapter.

# CHAPTER III

## EXPERIMENTAL METHODOLOGY

In order to compare the Letter type display and the Bar type display an experiment was designed in which the subjects utilized the two types of displays in the following tasks:

1. Check reading: determining whether all the room temperatures in all the buildings are NORMAL or some ABNORMAL (NORMAL means that the room temperature lies between upper and lower limits and ABNORMAL means that the room temperature has crossed an upper or lower limit).

2. Search: determining the status of a particular building (e.g. what is the status of building # 157)

The experiment was divided into two phases. Phase I involved the check reading task where the subject was required to determine the status (NORMAL/ABNORMAL) of the display shown. Phase II of the experiment involved the search task. In this case the subject was required to find the status of a particular building.

## SELECTION OF INDEPENDENT AND DEPENDENT VARIABLES:

Three independent variables were manipulated. They were:

1. Display type (letter type and bar type)

2. Exposure duration (short, medium and long)

3. Subject Nationality (Americans and Foreigners)

Both accuracy and speed of performance are important in process control. The two dependent variables selected as the measures of operator performance were:

1. Accuracy of response (percent correct)

2. Response Time (speed)

## EXPERIMENTAL DESIGN

The design used was a split-plot factorial design with each subject as his own control. In this design each subject was tested with every combination of treatments. Using Kirk's [1968] terminology this experimental design can be designated as an SPF-p-qr design, where

1. SPF= split-plot factorial design.

2. p= two levels (blocks) of nationality (Americans and Foreigners). Each has n(=18) levels of subjects, therefore N (overall subjects)=np=36 subjects.

3. q= two levels of display (Letter type and Bar type).

4. r= three levels or two levels according to the task i.e. three levels of durations for the check reading task, two levels of durations for the search task.

The reason for using this design was to increase the precision and efficiency of the experiment by eliminating intersubject differences as a source of error. In this case only one criterion measure is usually recorded for each subject for each treatment. In this experiment this criterion was the mean of a number of independent observations. Another reason for using this design was to permit a study of the interaction of treatments and subjects, in order to determine if the relative effectiveness of the treatments differs from subject to subject.

It should be noted that a very important assumption was made. The effect of each treatment was assumed to have been entirely dissipated before the next treatment was administered.

## SUBJECTS

Thirty-six subjects participated in the experiment. All subjects were from graduate and undergraduate schools at Oregon State University. These subjects included eighteen Americans and eighteen Foreigners. Thirty-three of the thirty-six were males. All participated voluntarily and without remuneration. The subjects had no experience in process control tasks.

Subjects were required to have normal visual acuity (20/20), either naturally or with glasses. Vision was tested by requiring each subject to perform a reading task using a standard Snellen chart just before the session.

## EQUIPMENT AND MATERIALS

The stimuli used in the experiment were 35 mm transparencies. The set of test slides was divided into equal groups of NORMAL and ABNORMAL slides. The NORMAL slides showed all the room temperatures to be normal. In the ABNORMAL slides some of the room temperatures were shown beyond the permissible range. The abnormal parameters in these slides ranged from one through six. The positions of these abnormal parameters were randomized for each slide. For example in a slide in which three abnormal parameters were showed, the positions of these abnormal parmameters were determined using a random number sequence genarated on the HP-85 computer. For example if the random numbers obtained were 3, 8, and 18, the abnormal parameters were located in those buildings. All the displays were drawn up and photographed to produce slides. These slides were back-projected onto a screen using a dual channel tachistoscope.

The stimulus-presentation subsystem consisted of the following components:

1. <u>HP-85 computer</u>: This controlled the display presentation (slide advance and slide interval time). All the control programs were written in BASIC. Listings of the programs are contained in Appendix E.

2. <u>Tachistoscope controller</u>: This console was used to control the exposure duration time of the display presented.

3. <u>Relay Circuit</u>: A special relay circuit was built in order to interface the tachistoscope to the HP-85 computer. The design of the circuit can be found in Appendix F.

The response timing device was the HP-85. This computer has four function keys. In this experiment three of these keys were usedas subject response keys. The first was marked 'START' and was used to start the experiment. The second and the fourth key were used for recording NORMAL and ABNORMAL responses. These keys were color coded. The right (red) key represented the ABNORMAL condition while the one on the left (green) represented the NORMAL condition. A 11 in X 4 in sheet of metal (Figure 3-2) was used to cover the keyboard to prevent inadvertant activation of other keys.

## TASK AND PROCEDURE

The subjects were tested individually. The test for each subject was divided into two sessions, each taking about twenty to twenty-five minutes.

In the first session (Phase I) the subject performed the check reading task and in the second session (Phase II) he† performed the search task. The experiment took a total of just under an hour for each subject.

## PHASE I

In this phase of the experiment, the subject was

---

† I hope that all the shes and hers in this world will understand that the hes and hims in this thesis are used only for consistency. Until our society develops a neuter term, that's the best I can do.

required to view twelve slides for each type of display at three different durations. He was shown four slides for each exposure duration.

The subject's task in this experiment was to determine the status of the display shown. This required the subject to view the display and to report whether all room temperatures were NORMAL or some ABNORMAL. The three different durations were:

1. SHORT: The display was presented for a fixed duration of 1 second.

2. MEDIUM: The display here was presented for a fixed duration of 2 seconds.

3. LONG: In this case the display was shown until the subject responsed.

The subject's response as well as the time to respond (reaction time) were recorded.

The reaction time performance was chosen as an indication of the amount of processing required to make a decision. It is believed that when the information in a particular display is more difficult to extract then more processing time will be required to make a decision [Petersen, 1982]. Therefore, one way of assesing ease of information extraction is to measure the time required to respond to the different displays. We can assume that the decision and the response related components of reaction time remain constant provided the task and the response remain constant across all the experimental conditions. Hence, any change in response time can be attributed to a change in the amount of perceptual processing required to extract information from the different display configurations. [Smith, 1962; Petersen, 1982; Estes, 1975]

Testing was conducted in a small quiet room. First the subject's vision was examined using a Snellen eye chart to verify the normal acuity. Then he was seated at a desk 29 in high with the center point of the screen at a height of 13.5 in above the desk. These dimensions were chosen to be consistent with the standard equipment design recommendations [Vancott and Kinkade, 1972]. Viewing distance was 22 in (Figure 3-3).

Next the subject was familiarized with the procedure using detailed written instructions. Then he

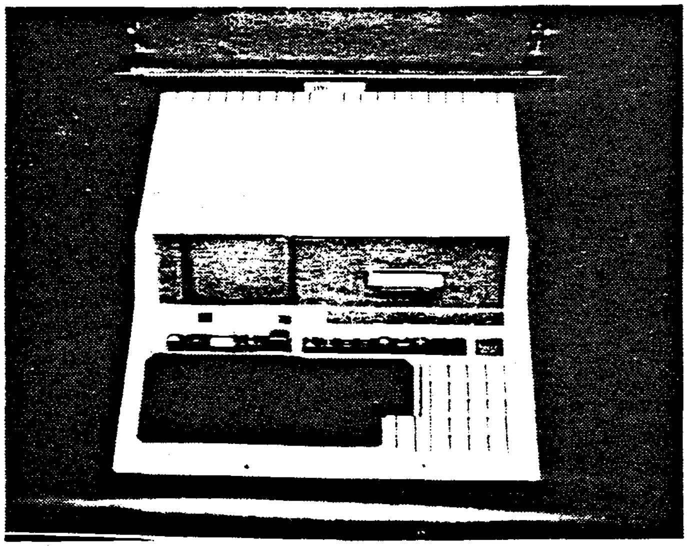

Figure 3-2 HP-85 Computer

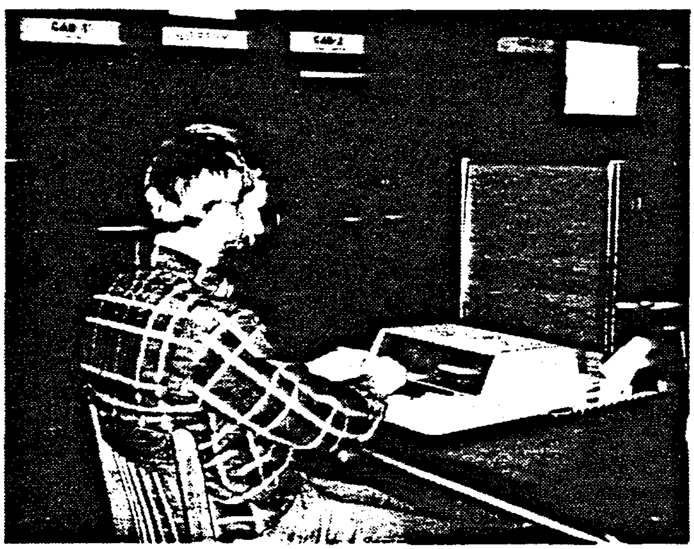

Figure 3-3 Experimental set up

was given oral instructions. A copy of these instructions is contained in Appendix A. When the subject indicated that he understood the task, he was given twelve warmup trials for each type of display. Four warmup slides were presented for each duration.

After the detailed instructions and warmup trials, the testing began for the first display type (Letter or Bar). Each subject was tested under three different durations. Each response was recorded. The procedure was then repeated for the other display type.

A visual mask was presented between every slide to eliminate the possibility of retina memory. This mask, shown in Figure 3-4, consisted of a random black and white pattern.

Upon the completion of the experiment the subject was given a questionnaire to fill out. The purpose of this questionnaire was to gather opinion and preference from the subjects. Responses were used to perform the subjective evaluation of the displays which is discussed in Chapter V. A copy of the questionnaire can be found in Appendix B.

The order of presentation of slides, type of

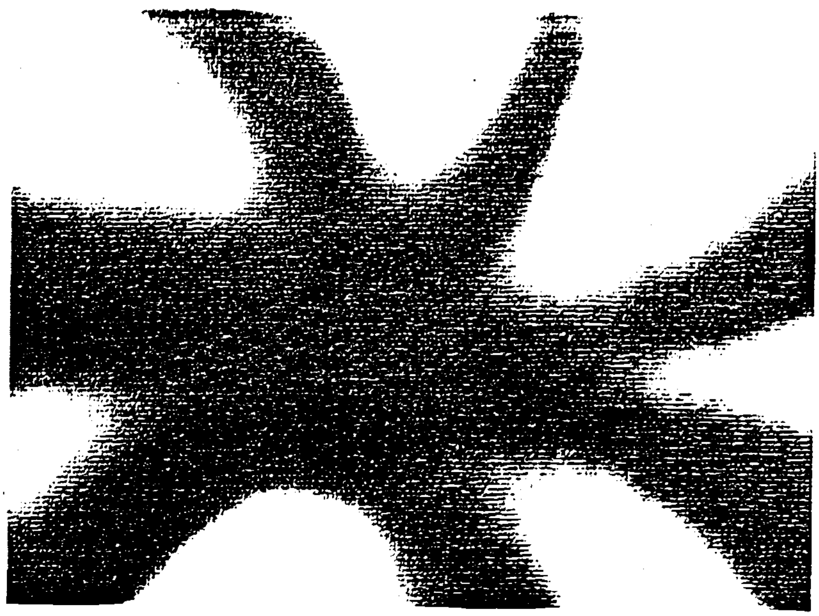

Figure 3-4 Visual mask

display format and the exposure duration times were randomized across the subjects.

PHASE II

The second phase of the experiment utilized essentially the same procedure as the first phase. The following changes were made.

The subject viewed twelve slides for each type of display at two different duration times: one and two seconds.

The subject's task was changed from the check reading task to a search task. Now instead of merely reporting the overall status of the display, the subject was required to find a particular building in the display and report its status. This required the subject to view a display, make a decision regarding the display, and make a response as quickly as possible.

Here also the subject was given an appropriate set of instructions to read. When the subject indicated that he understood the task, he was given twelve warmup trials for each type of display. He viewed six slides in each duration. The rest of the procedure followed was exactly the same as in Phase I of the experiment.

## SOURCES OF VARIATION

In addition to independent and dependent variables, all experiments include undesired sources of variation. These sources of variation may affect the dependent variable provided proper care is not taken. An experimenter would like to obtain non-biased results. In this experiment the approach taken was to attempt to hold the sources of variation constant for all subjects. Care was taken in this regard with the following:

1. AGE: Only subjects whose ages ranged from 18-29 years were selected.

2. TIME: No early morning or late evening sessions were conducted. All subjects performed the experiment between 9:00 am and 6:30 pm.

3. ILLUMINATION LEVEL: The illumination level of the room was kept at 2.5 lux throughout the experiment.

4. INSTRUCTIONS: Each subject received the same written and oral instructions.

5. OTHER ENVIRONMENTAL FACTORS: All testing was conducted in the same small, quiet room.

A second approach used to control unidentified sources of variability was to assign the experimental conditions randomly to subjects. This was done to distribute any bias evenly over the entire experiment.

The results of this experiment are presented in the following chapter.

# CHAPTER IV

# EXPERIMENTAL RESULTS

The results reported here are based on both speed (response time) and accuracy (percent correct) of responses. Raw data for the thirty-six subjects who participated in the experiment are contained in Appendix C and will be referred to as required.

## DATA TRANSFORMATION

A transformation is any systematic alteration in a set of scores whereby certain characteristics of the set are changed and other characteristics remain unchanged. The reason for using transformation was to meet the assumptions of homogeneity of variance and normality of distribution. In this experiment the accuracy data were converted to angular scores in the manner described by Kirk [1968]. This involved substituting arcsin (1/2n) for an incorrect response and arcsin (1-1/2n) for a correct response, where n is the number of observations. For example, for an incorrect response, substituting n=4 we get arcsin(.125)=0.7075. Similarly for a correct response with n=4 we get arcsin(.875)=2.4 [Kirk, 1968;

Chapanis, 1965].

The raw data were divided into two basic categories according to check reading task and search task.

ANALYSIS

The analysis of variance of these data was conducted in four separate parts. In all four parts the statistical model used was a split-plot factorial design.

The design included three main factors. They were as follows:

1. The first factor was the display type (DIS) which contained the levels Letter type and Bar type.

2. The second factor was the duration (DUR). This factor had three or two levels according to the experimental task. In the case of the check reading task there were three durations denoted by the letters S(Short), M(Medium), and L(Long). In the case of the search task

there were only two fixed durations of 1 second and 2 seconds.

3. last factor was the nationality (NAT). This contained the level Americans (18 subjects) and Foreigners (18 subjects).

The display-duration level combinations were randomly assigned within each nationality block. Four sets of error terms were used in this design. They are as follows:

1. Subject within (w.) Groups

2. Display * Subject w. Groups

3. Duration * Subject w. Groups

4. Display * Duration * Subject w. Groups

The data categories discussed earlier were analyzed statistically, with graphic representations as required. The analysis also included regular and paired t-tests. Most of the calculations were done using the statistical Interactive Programming System

(SIPS) developed at Oregon State University. All analysis will be presented in the same sequence as the previously established experimental tasks. All computer output is contained in Appendix D.

## PHASE I (CHECK READING)

For this phase, the analysis of variance was conducted in two separate parts. The first part of the analysis considered the accuracy of the subjects' responses in terms of percent correct. Table 4-1 presents results from the analysis of variance to show which factors were statistically significant.

The analysis revealed that effect of exposure duration was significant at the 1 percent level. This showed that longer exposure times produced more correct responses. This can be easily seen in Figure 4-1 , where exposure duration versus percent correct is plotted. The nature of this graph indicates that as the length of time the display was shown increased, the number of correct responses also increased correspondingly. This is not surprising, since the amount of information available for making a decision would increase the time to respond with a longer exposure.

Table 4-1. Analysis of variance for Phase I (percent correct).

| | SOURCE OF VARIATION | SSE | DF | MSE | F |
|---|---|---|---|---|---|
| 1. | NATIONALITY (NAT) | 0.00048 | 1 | .0004 | 0.002 |
| 2. | SUBJ. W/N GROUPS (SUB) | 7.05400 | 34 | 0.207 | - |
| 3. | DISPLAY (DIS) | 0.53410 | 1 | 0.534 | 2.380$^{+}$ |
| 4. | NAT * DIS | 0.01800 | 1 | 0.018 | 0.080 |
| 5. | DIS * SUB | 7.62500 | 34 | 0.224 | - |
| 6. | DURATION (DUR) | 5.10000 | 2 | 2.550 | 28.650$^{++}$ |
| 7. | NAT * DUR | 0.12620 | 2 | 0.063 | 0.709 |
| 8. | DUR * SUB | 6.05200 | 68 | 0.089 | - |
| 9. | DIS * DUR | 0.10180 | 2 | 0.051 | 0.754 |
| 10. | NAT * DIS * DUR | 0.00340 | 2 | 0.002 | 0.002 |
| 11. | DIS * DUR * SUB | 4.59000 | 68 | 0.067 | - |
| | TOTAL | 31.205 | 215 | | |

$+\ P < .25$

$++\ P < .01$

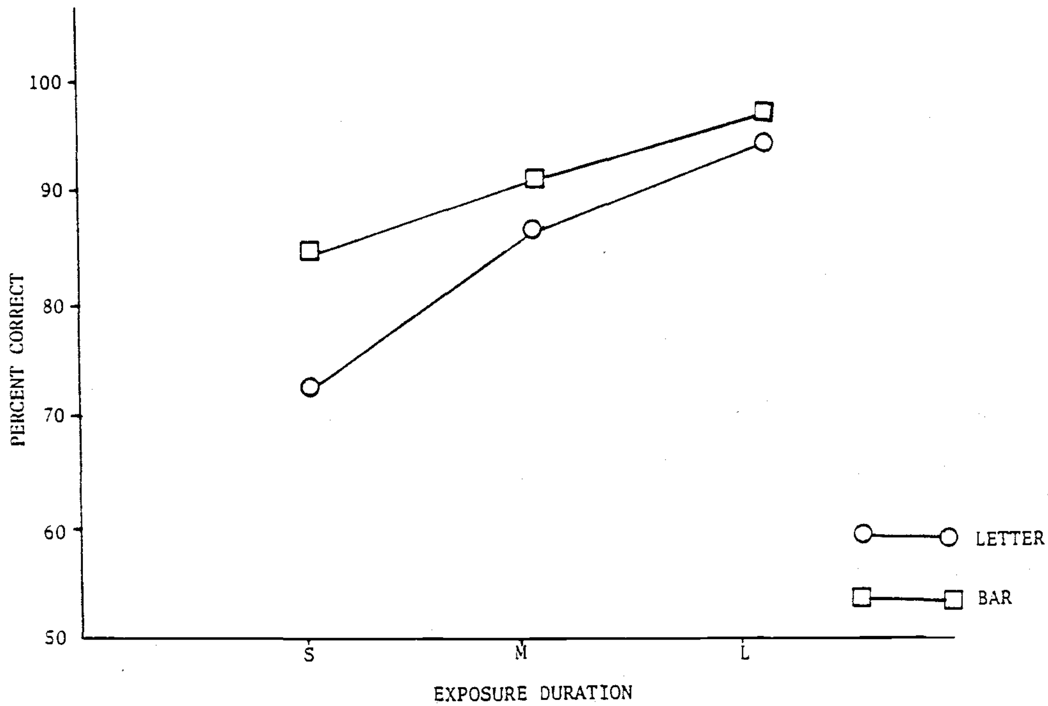


Figure 4-1 Percent correct for three exposure duration times (Phase I)

The effect of display type on response accuracy was significant at the 25 percent level. A bar graph of percent correct aginst display type was drawn (Figure 4-2). The bar graph shows that the subjects made fewer errors when viewing the Bar type display. The effect of nationality and the interaction between display type and exposure duration were not statistically significant. Therefore we can assume that the check reading task is not influenced by the differences in nationality.

The second part of the analysis considered the subject's response time. The results of this analysis, presented in Table 4-2, indicated that the effects of both display type and exposure duration were significant at the 1 percent level. In addition, a significant interaction was shown for the display type and exposure duration level. A graphical plot of mean detection time against the exposure duration level is shown in Figure 4-4. A grahical plot of mean detection time against display type showed that the subjects were faster in responding to the Bar type display (Figure 4-3).

Since the main objective of this research was to evaluate the two display formats, mean comparisons of

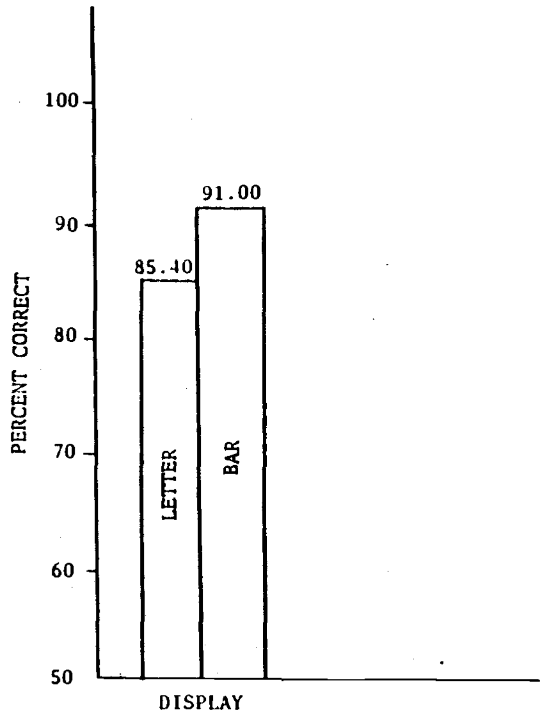


Figure 4-2 Percent correct for the Phase I experiment

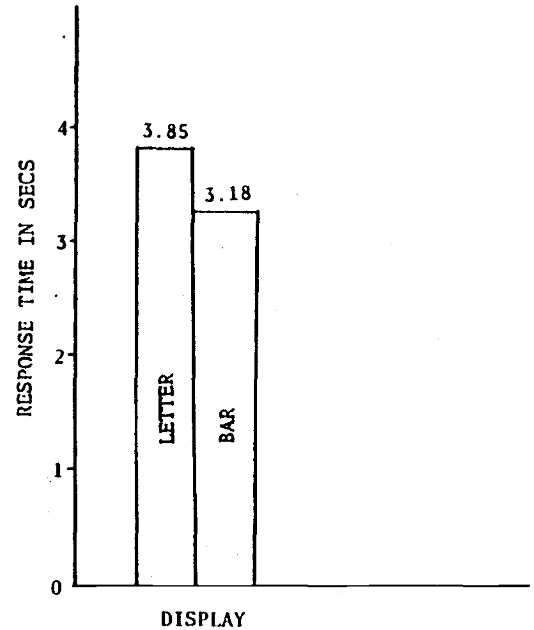


Figure 4-3 Mean response time for Phase I experiment

Table 4-2. Analysis of variance for Phase I (response time).

| SOURCE OF VARIATION | | SSE | DF | MSE | F |
|---|---|---|---|---|---|
| 1. | NATIONALITY (NAT) | 0.3791 | 1 | 0.379 | 0.310 |
| 2. | SUBJ. W/N GROUPS (SUB) | 41.1400 | 34 | 1.210 | - |
| 3. | DISPLAY (DIS) | 24.3000 | 1 | 24.300 | $85.320^{+}$ |
| 4. | NAT * DIS | 0.1170 | 1 | 0.117 | 0.410 |
| 5. | DIS * SUB | 9.6800 | 34 | 0.285 | - |
| 6. | DURATION (DUR) | 64.6900 | 2 | 32.345 | $81.260^{+}$ |
| 7. | NAT * DUR | 0.2560 | 2 | 0.128 | 0.321 |
| 8. | DUR * SUB | 27.0640 | 68 | 0.398 | - |
| 9. | DIS * DUR | 5.2960 | 2 | 2.648 | $9.180^{+}$ |
| 10. | NAT * DIS * DUR | 0.2476 | 2 | 0.124 | 0.383 |
| 11. | DIS * DUR * SUB | 21.9300 | 68 | 0.322 | - |
| TOTAL | | 195.100 | 215 | | |

+ $P < .01$

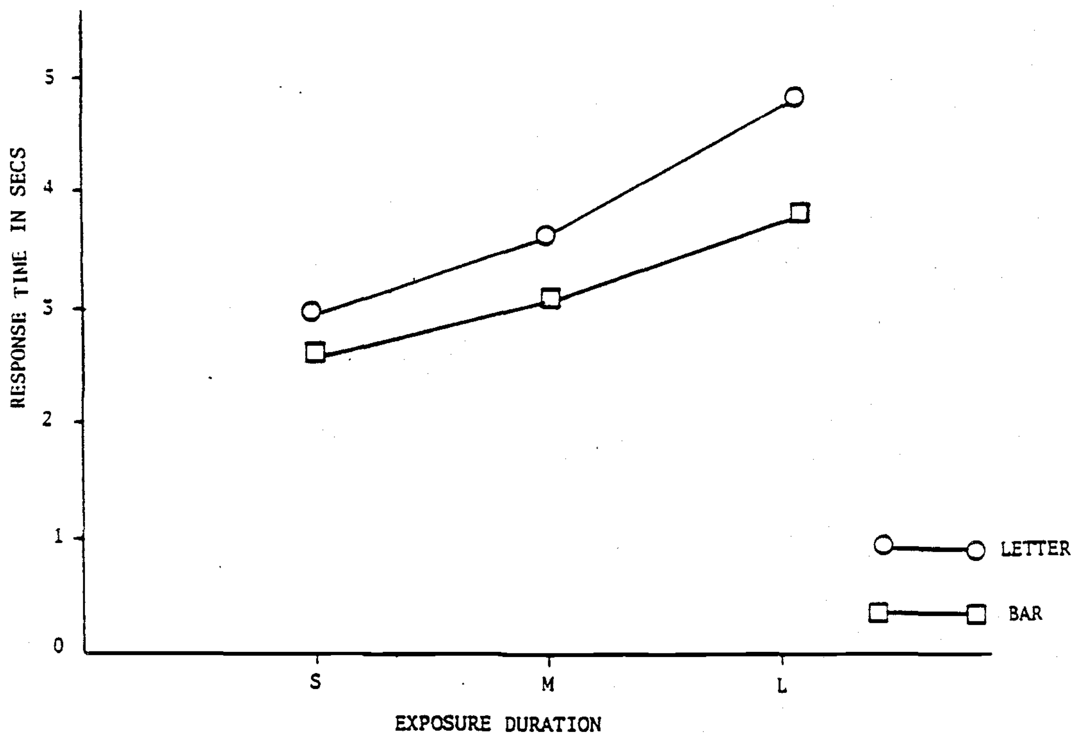


Figure 4-4 Mean response times for three exposure duration times (Phase I)

the dependent variables were conducted using t-tests. The t-values for each of the two dependent variable are presented in Table 4-3.

Table 4-3. T-values for the two dependent variables.

| SOURCE | tvalue | d.f. |
|---|---|---|
| PERCENT CORRECT | - 2.349 | 35 |
| RESPONSE TIME | 5.44 | 35 |

Table t-value (95%) = +/- 2.030

The above calculated t-values suggested that the null hypothesis (H0) should be rejected for the dependent variables at a 95 percent confidence level. This showed that the mean value of the observations for the Letter type was different from that of the Bar type. This can be easily seen in Figures 4-2 and 4-3. A copy of the computer output can be found in Appendix D.

Mean response times with respect to display condition (NORMAL or ABNORMAL) were calculated for both kinds of display and displayed graphically in Figure 4-5. The analysis suggested that there was considerable difference in the response times. Mean response times for correct and incorrect responses for both kinds of display were calculated and are shown in Figure 4-6.

Paired t-tests were also performed on the mean values of NORMAL and ABNORMAL conditions, and correct and incorrect responses. The t-values for each of these variable are presented in Table 4-4 and Table 4-5. In both cases the dependent variable was the response time.

Table 4-4. T-values for NORMAL and ABNORMAL conditions (dependent variable: response time).

| SOURCE | t-value | d.f. |
|---|---|---|
| NORMAL | 6.232 | 35 |
| ABNORMAL | 5.46 | 35 |

Table t-value (95%)= +/- 1.697

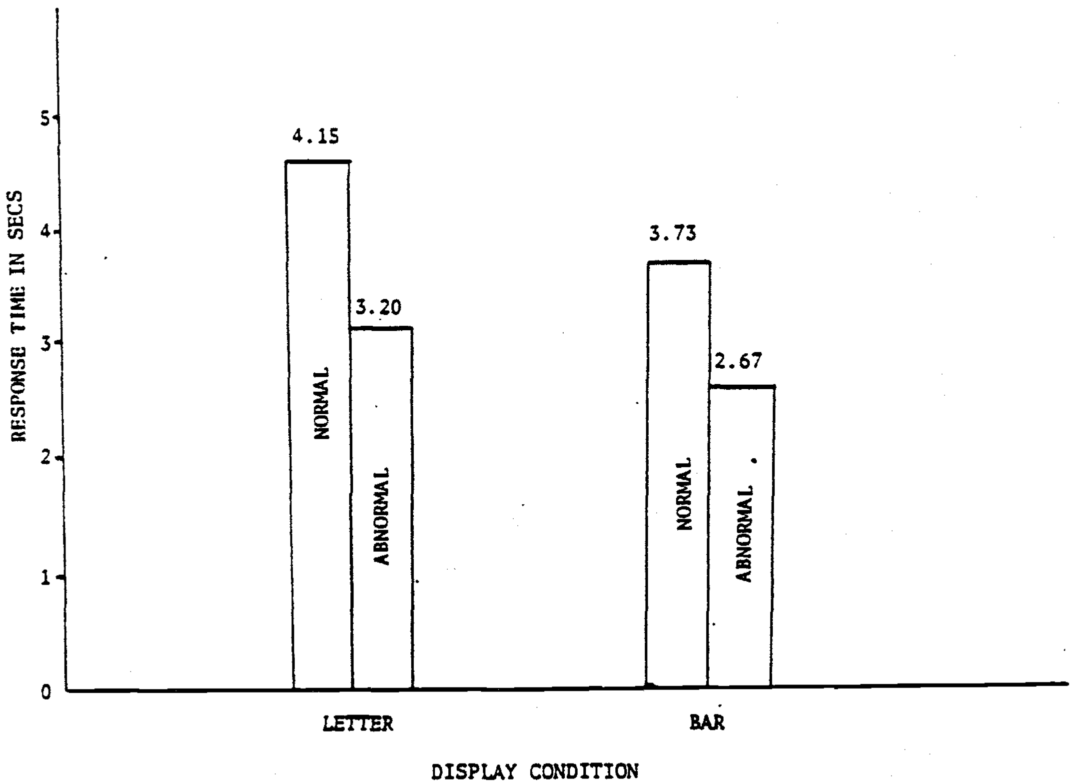


Figure 4-5 Mean response times for NORMAL and ABNORMAL conditions (Phase I)

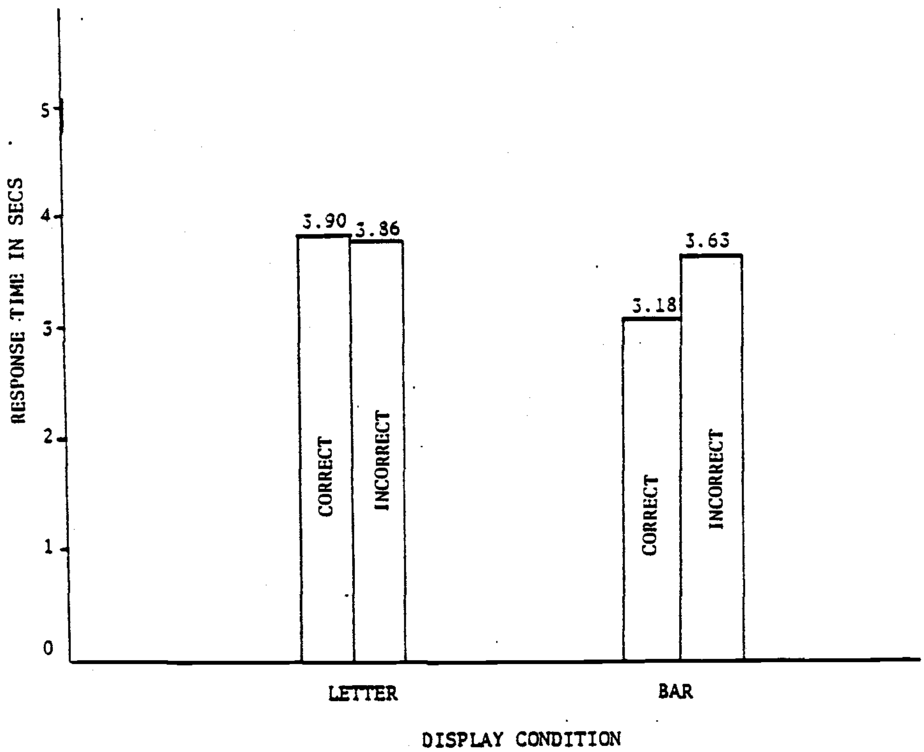


Figure 4-6 Mean response times for Correct and Incorrect responses (Phase I)

Table 4-5. T-values for Correct and Incorrect responses (dependent variable: response time).

| TYPE | CORRECT AND INCORRECT | d.f. |
|---|---|---|
| LETTER | .2139 | 19 |
| BAR | -2.9865 | 21 |

Table t-value for 19 df (95%) = +/- 2.08

Table t-value for 21 df (95%) = +/- 2.07

The t-values suggested that the null hypothesis (H0) should be rejected for all of the variables except for correct and incorrect response (letter type only) at a 95 percent confidence level. This showed that the mean value of the observations for the Letter type was different from that of the Bar type.

## PHASE II (SEARCH TASK)

For this phase of the experiment an analysis of variance was conducted in two separate parts as in Phase I. The first part of the analysis considered the accuracy of the subjects' responses in terms of percent correct.

Table 4-6 presents the results from the analysis of variance to investigate which factors were statistically significant. A copy of the computer output is contained in Appendix D.

The analysis revealed that the exposure duration was statistically significant at the 1 percent level. This showed that subjects made fewer errors for the long exposure duration. This can be easily seen in Figure 4-7 where exposure duration versus percent correct is plotted. The reason is the same as mentioned in the discussion of Phase I. Display type and nationality were not significant, however a plot of percent correct against display type showed a slight advantage for the Bar type display. This difference was not statistically significant. This is shown in Figure 4-9. The interaction effects of 1) Nationality and duration 2) Display and duration 3) Nationality and duration and display were not statistically significant at the 10 percent level.

The second part of the analysis considered the subject's response time. The results of this analysis presented in Table 4-7 indicated that none of the independent variables have any effect on this dependent measure at a significance level of 10 percent. The

Table 4-6. Analysis of variance for Phase II (percent correct).

| SOURCE OF VARIATION | SSE | DF | MSE | F |
|---|---|---|---|---|
| 1. NATIONALITY (NAT) | 0.1204 | 1 | 0.120 | 0.880 |
| 2. SUBJ. W/N GROUPS (SUB) | 3.9400 | 34 | 0.116 | - |
| 3. DISPLAY (DIS) | 0.0061 | 1 | 0.006 | 0.075 |
| 4. NAT * DIS | 0.0087 | 1 | 0.009 | 0.090 |
| 5. DIS * SUB | 2.7710 | 34 | 0.081 | - |
| 6. DURATION (DUR) | 0.3110 | 1 | 0.311 | $5.650^{+}$ |
| 7. NAT * DUR | 0.0400 | 1 | 0.040 | 0.720 |
| 8. DUR * SUB | 1.8700 | 34 | 0.055 | - |
| 9. DIS * DUR | 0.0390 | 1 | 0.039 | 0.640 |
| 10. NAT * DIS * DUR | 0.0070 | 1 | 0.007 | 0.110 |
| 11. DIS * DUR * SUB | 2.0500 | 34 | 0.060 | - |
| TOTAL | 11.163 | 143 | | |

$+ \ P < .05$

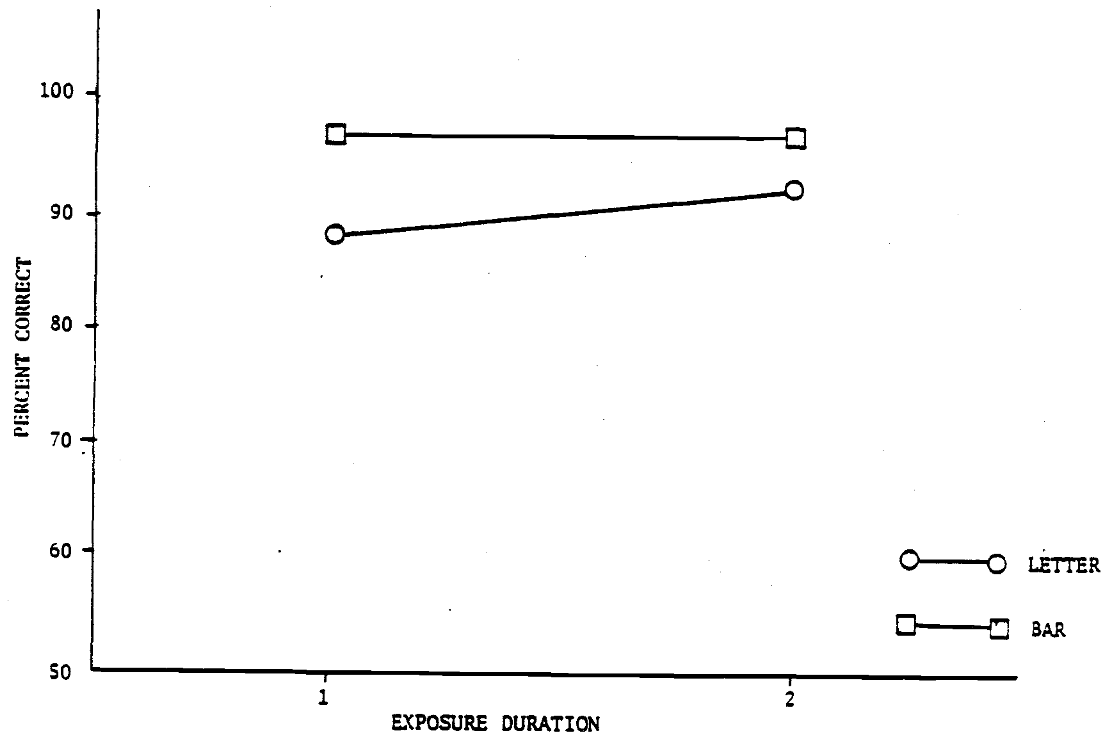


Figure 4-7 Percent Correct for two exposure duration times (Phase II)

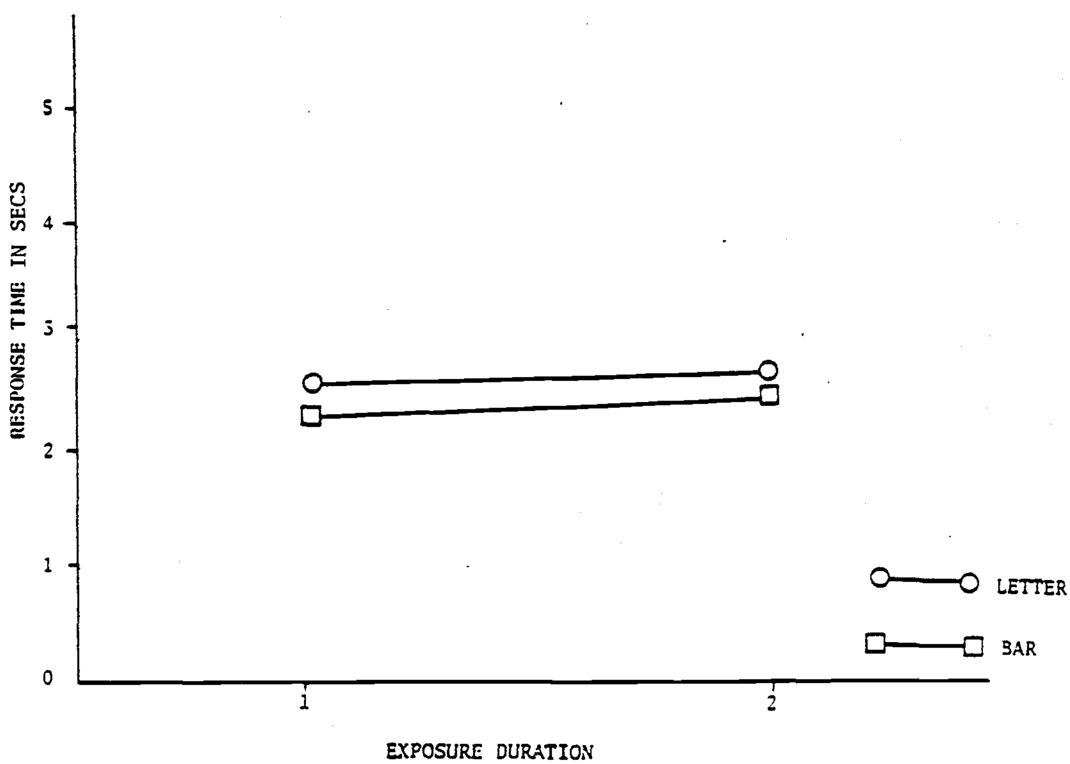


Figure 4-8 Mean response times for two exposure duration times (Phase II)

Table 4-7. Analysis of variance for Phase II (response time).

| SOURCE OF VARIATION | SSE | DF | MSE | F |
|---|---|---|---|---|
| 1. NATIONALITY (NAT) | 14.350 | 1 | 14.350 | 0.773 |
| 2. SUBJ. W/N GROUPS (SUB) | 529.040 | 34 | 15.560 | - |
| 3. DISPLAY (DIS) | 7.620 | 1 | 7.620 | 0.436 |
| 4. NAT * DIS | 18.750 | 1 | 18.750 | 1.073 |
| 5. DIS * SUB | 593.980 | 34 | 17.470 | - |
| 6. DURATION (DUR) | 25.410 | 1 | 25.410 | 1.459 |
| 7. NAT * DUR | 17.730 | 1 | 17.730 | 1.010 |
| 8. DUR * SUB | 596.700 | 34 | 17.550 | - |
| 9. DIS * DUR | 16.740 | 1 | 16.740 | 0.940 |
| 10. NAT * DIS * DUR | 18.020 | 1 | 18.020 | 1.018 |
| 11. DIS * DUR * SUB | 601.460 | 34 | 17.690 | - |
| TOTAL | 2439.800 | 143 | | |

interaction effects of 1) nationality and duration , 2) display and duration, and 3) nationality and duration and display were not statistically significant at the 10 percent level. The associated mean values of other variables are graphed in Figure 4-9 and Figure 4-10.

To evaluate the two display formats in this task, mean comparisons of the dependent variables were conducted using t-tests. The t-values for each of the two dependent variable are presented in Table 4-8.

Table 4-8 T-value for the two dependent variable.

| SOURCE | t-value | d.f. |
|---|---|---|
| PERCENT CORRECT | -.36 | 35 |
| RESPONSE TIME | 3.690 | 35 |

Table t-value (95%) = +/- 1.684

The t-values suggest that the null hypothesis (H0) for the response time would be rejected at a 95 percent confidence level. This showed that the mean value of the observations for the Letter type was different from that of the Bar type. This can be easily seen in

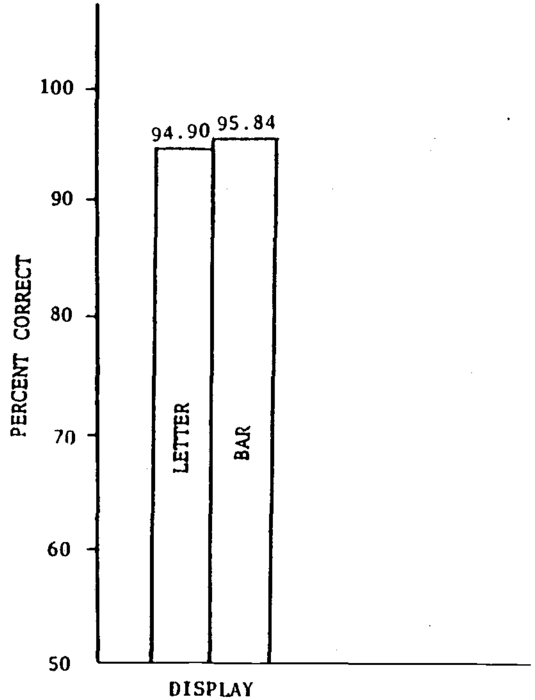


Figure 4-9 Percent correct for Phase II experiment

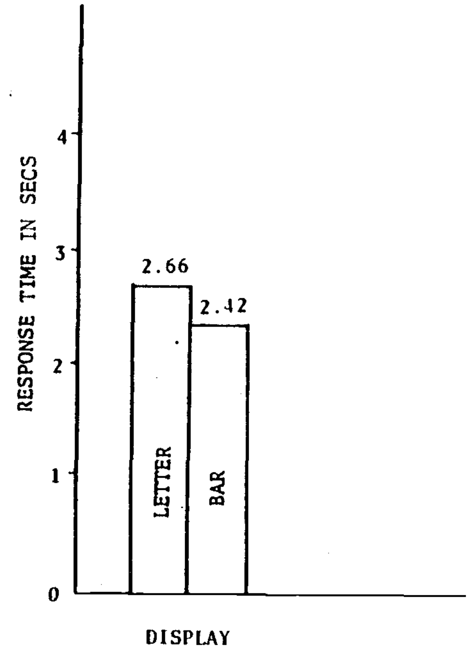


Figure 4-10 Mean response time for Phase II experiment

Figure 4-10. The nature of the graph indicates that less time was required to locate and determine the status of a particular building in the Bar type display.

Mean response times with respect to display condition (NORMAL or ABNORMAL) were calculated for both kinds of display. They are presented graphically in Figure 4-11. Also, mean response times for correct and incorrect responses for both kinds of display were calculated and are shown in Figure 4-12.

Paired t-tests were also performed on the mean values of NORMAL and ABNORMAL conditions and correct and incorrect responses. The t-values for each variable are presented in Table 4-9 and Table 4-10.

Table 4-9. T-values for NORMAL and ABNORMAL condition.

| SOURCE | t-value | d.f. |
|---|---|---|
| NORMAL | 5.7092 | 35 |
| ABNORMAL | 4.724 | 35 |

Table t-value (95%)= +/- 1.697

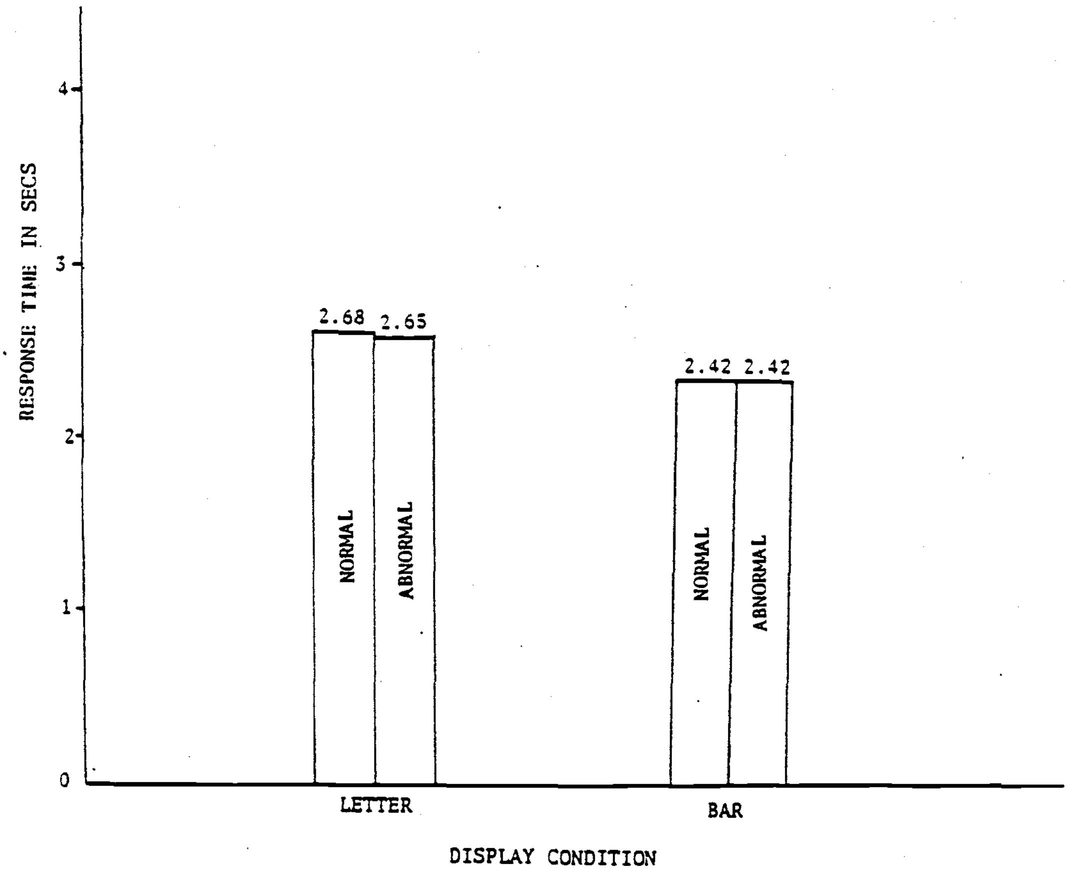


Figure 4-11 Mean response times for NORMAL and ABNORMAL conditions (Phase II)

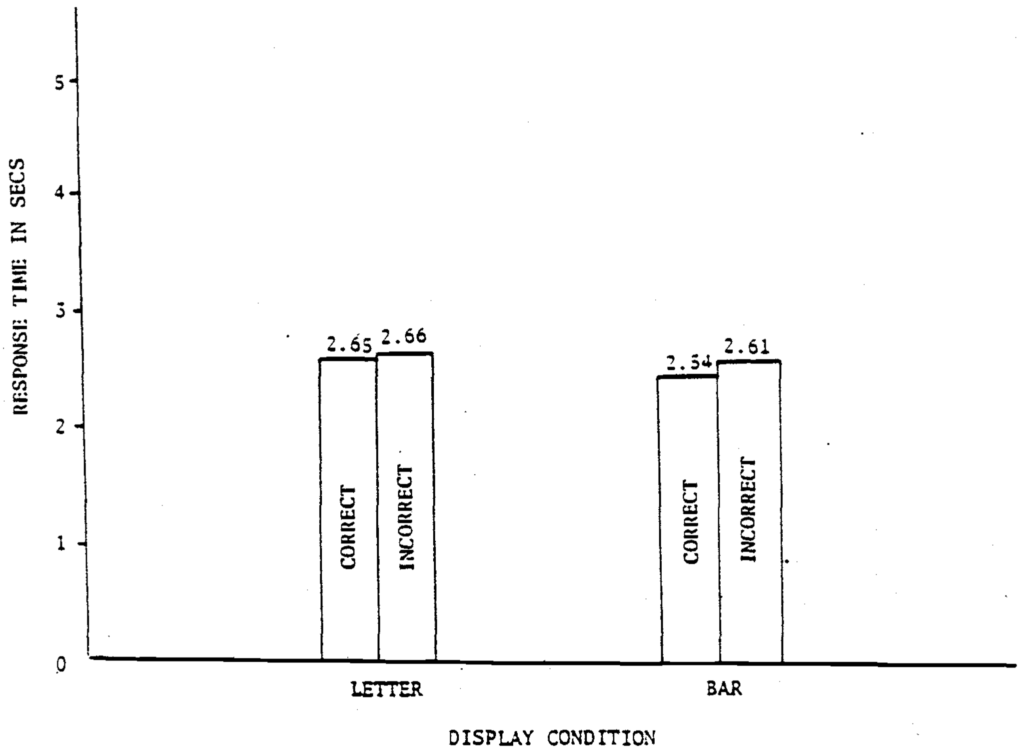


Figure 4-12 Mean response time for Correct and Incorrect responses (Phase II)

Table 4-10. T-values for correct and incorrect responses.

| TYPE | CORRECT AND INCORRECT | d.f. |
|---|---|---|
| LETTER | -.36 | 20 |
| BAR | -.5346 | 7 |

Table t - value for 20 df (95%) = +/- 2.08

Table t - value for 7 df (95%) = +/- 2.36

In both cases the dependent variable was response time.

The t-values suggest that the null hypothesis (H0) should be rejected for all variables except for correct and incorrect responses. This showed that the mean value of the observations for the Letter type and Bar type were *not* the same.

## SUMMARY OF RESULTS

A summary of results is presented in Table 4-11. This table gives the statistical significance for the analysis of variance for all levels of treatments in

Table 4-11. Summary of Significance.

| SOURCE OF VARIATION | PHASE I %CORRECT | PHASE I RESPONSE TIME | PHASE II %CORRECT | PHASE II RESPONSE TIME |
|---|---|---|---|---|
| 1. NATIONALITY (NAT) | NS | NS | NS | NS |
| 2. SUBJ. W/N GROUPS (SUB) | – | – | – | – |
| 3. DISPLAY (DIS) | P < .25 | P < .01 | NS | NS |
| 4. NAT * DIS | NS | NS | NS | NS |
| 5. DIS * SUB | – | – | – | – |
| 6. DURATION (DUR) | P < .01 | P < .01 | P < .05 | NS |
| 7. NAT * DUR | NS | NS | NS | NS |
| 8. DUR * SUB | – | – | – | – |
| 9. DIS * DUR | NS | P < .01 | NS | NS |
| 10. NAT * DIS * DUR | NS | NS | NS | NS |
| 11. DIS * DUR * SUB | – | – | – | – |

NS = NOT SIGNIFICANT

– = ERROR TERM

all categories considered for this experiment.

The discussion of these results is presented in the following chapter.

# CHAPTER V

# DISCUSSION

In the experiments performed in this research project, the evaluation of displays consisted of two experimental tasks and the data was analyzed with respect to the following dependent variables:

1] Percent correct

2] Response time

## PHASE I (CHECK READING)

The fact that the exposure duration was significant and the display type was not (at the 10% level), does not rule out the superiority of the Bar type display. In retrospect, Figure 4-2 and Figure 4-3 support the stastical results obtained from the ANOVA table (Table 4-1).

In the last (long) duration the subject took as much time as desired before he made the decision regarding the status of the display. This is the main reason for the exposure duration to be a significant factor. This is shown in Figure 4-1.

In the second part of the analysis the dependent variable was the response time. The reason for the display type to be significant is simple. To make the picture clear let's take a look at the mean response time for both kinds of display.

Table 5-1. Mean response times for two displays.

| DISPLAY TYPE | MEAN TIME |
|---|---|
| LETTER TYPE | 3.85 s |
| BAR TYPE | 3.81 s |

There is a difference between the two means. This suggests that the subjects were faster in responding to the Bar type display. The reason is that the Letter type display violates one of the basic human factors design principles i.e. it fails to consider the population stereotype which is important in designing displays. people are used to scanning from left to right rather than from top to bottom. Comments from the post experiment questionnaire indicated that scanning the buildings from left to right (in the Bar type display) was easier than scanning from top to bottom (in the Letter type display). This is the main reason for the display type factor to be significant. This finding made us reject the original hypothesis that display type does not affect operator performance.

The findings of the Letter type inferiority is consistent with the results of Hitt [1961] who compared letter with numeral, shape, and configuration. He concluded that the numeral coding and color coding are the two best coding methods.

The other reason for the Letter type display inferiority is that it imposes an additional transformational load that the operators have at their disposal to deal effectively with unexpected system alarms. This result represents a useful application of human information processing methodology to human factors concerns [Hansen, 1981; Kantowitz, 1981].

The exposure duration was significant at the one percent level. To explain the significance let us take a look at Figures 4-1 and 4-4. The first figure where exposure duration versus percent correct is plotted, indicates that as the length of time the display was shown increased, the number of correct responses also increased. Consequently Figure 4-4 indicates that the time to respond also increased correspondingly. This result supports the experimental evidence of Hyman [1953] and the analysis of Fitts and Posner [1967] that the performance would be better solely on the basis of the subject having more time to consider his decision.

Another significant result was the interaction between duration and display type. The explanation for this significance was mainly due to one of the exposure duration times. For the long exposure duration, where the diplay was shown until the subject responded, considerable difference in the speed with which individuals perform was found. In the Letter type, the fastest response time was 2.32 secs and the slowest response time was 7.98 secs. Comments from the post experiment questionnaire indicated that more time was required to inspect all the letters. In the Bar type, the fastest response time was 2.19 secs and the slowest time was 5.77 secs. Table 5-2 shows the pattern of response times for the two displays .

Table 5-2. Pattern of response times for two displays.

| DISPLAY TYPE | FAST | SLOW |
|---|---|---|
| LETTER TYPE | 2.32 s | 7.98 s |
| BAR TYPE | 2.19 s | 5.77 s |

The last significant result in this experiment was the mean response time for the display conditions shown in Figure 4-7. A possible explanation for this significance is that , in the case of a NORMAL display the subject needs to scan the entire display before he makes any response whereas in the case of an ABNORMAL display all that he has to do is to find just one abnormal parameter to make a response. Table 5-3 shows the pattern of response times for both displays for different display conditions.

PHASE II (SEARCH TASK):

In this Phase, the display type was not significant in both the analyses (percent correct and

Table 5-3. Pattern of response times for two display conditions.

| TYPE | NORMAL | | ABNORMAL | |
|---|---|---|---|---|
| | FAST | SLOW | FAST | SLOW |
| LETTER | 3.09 | 6.95 | 2.20 | 4.48 |
| BAR | 2.94 | 4.57 | 1.88 | 3.95 |

response time). The reason is due to the ability of subjects to estimate the position of buildings in the display before the slide was shown.

To compare both displays effectively in this task, the experiment should be conducted with several different time durations. Here the time durations correspond to the time between the question asked to search for a particular building and the display shown. In the short duration times the display type would probably be significant.

THE PREFERENCE OF THE SUBJECTS

At the end of the test, the subjects were asked to comment on the two types of display that they had seen. All the thirty-six subjects preferred the Bar type display to the Letter type display. Comments also indicated that, for Letter type, it takes more time to inspect the letters.

In summary, the superiority of the Bar type display may be due to the following reasons.

1. Bar type display considers population stereo type.

2. Bar type display imposes less transformational load.

3. In the Bar type display it was easier to scan the whole display than inspecting every letter as in the Letter type display.

# CHAPTER VI

## CONCLUSIONS

The objective of this thesis was to compare two kinds of process overview displays for a distributed process control system. This objective was accomplished using two separate experimental tasks as data sources for stastical analysis. The conclusions are naturally limited to the types of the variables included, to the measure of performance employed in the study, and to the population of subjects represented by those participating in the study.

The significant effects of format on both speed of performance and accuracy of performance showed that the Bar type was superior to the Letter type display.

The above experiments reinforce design recommendations preferring analog displays (Bar type) over alphanumeric (Letter type) display formats in general as well as in CRT applications. The first experiment indicated that the Letter type displays require longer detection times and a visual examination of Figure 4-1 reveals that the Bar type contributes to better performance. This finding alone strongly supports the use of Bar type displays over Letter type displays.

In addition, the results from Phase I of the experiment tend to support the use of Bar type displays in situations where the control environment requires quick response times for the monitoring of numerous variables. That control environment is typical of process control in general.

There are many applications for Bar type displays in process control systems, because the data collected in process control systems often represent values for some parameter at various points in time.

One possible advantage of the Bar type display over the Letter type display for process supervision is its superiority for prediction. It is possible by extrapolation to estimate when a variable will reach some pre-determined critical value. Letter type displays do not facilitate this type of extrapolation.

Another advantage of the Bar type display is that two or more variables may be readily compared. For instance the operator's task might be to determine which of two room temperatures is increasing at a faster rate. This also would be a more difficult task with a Letter type display.

Although some authors [Tullis, 1980; Hanson, 1981] have suggested that the performance differences can be overcome by extended training on different displays, it must be remarked that the most critical moments in process control are during infrequent multiple alarm conditions outside highly practiced training situations [Goodstein and Pederson, 1975]. The present research shows the superiority of Bar type displays in such critical circumstances because it can be argued that the short exposure durations in this experiment simulated critical events in process control.

Dallimonti [1975] says that, since the operator's role is primarily one of monitoring a large data base for low probability perturbations, the process operation should be presented as a graphic pattern that clearly indicates to acceptable and non acceptable plant states. He also suggests that, at the first level of process monitoring, operators do not use quantitative information if some form of analog display exists. That is, they establish certain visual patterns from the displays which they associate with good operation.

If we consider the above points, we can conclude that the Bar type display satisfies the following requirements.

1. Prediction: By using the past values the operator can estimate when a variable will reach some pre-determined critical value.

2. Comparison: The operator can compare two room temperatures.

3. Acceptable- Unacceptable: The Bar display clearly distinguishes between two states e.g., acceptable(NORMAL) and unacceptable (ABNORMAL).

4. Pattern Perception: Bar display establishes visual pattern.

5. Transformational Load: Bar type display impose less transformational load. e.g., in Letter type one needs to remember the meanings of different abstract letters.

In summary, this study has shown the Bar type display to be the superior display format and should be implemented in process control interfaces. However, the caution of Chapanis [1967] should still be considered with respect to this or any other experimental finding that has not been examined in the glare of real world applications. It is hoped, though, that the results of this study will provide process control system designers with information useful in the selection of appropriate display formats.

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# APPENDIX

# APPENDIX A

## INSTRUCTION TO SUBJECTS

## INSTRUCTION TO SUBJECTS

The purpose of this experiment is to compare the value of two types of displays. The type of displays you will be viewing now are the plant overview displays for a process control system.

In this case, the display represents temperatures in various buildings on campus. Here the temperature in every room of a building is set to a certain desired level which is usually referred as the set point. Associated with this set point is an upper limit as well as a lower limit. The Overview display serves as a status (NORMAL/ABNORMAL) display , keeping the operator informed of the room temperatures of several buildings on campus. The Status of a building may be either Normal-which indicates that all room temperatures are normal (temperature lies between upper and lower limits) or ABNORMAL-which indicates that some room temperatures are not normal (temperature has reached/crossed the upper or lower limit).

When the experiment starts, you will view twelve slides as fast as you can; at the same time you will be asked to hit the corresponding key i.e. NORMAL/ABNORMAL (Green and Red keys on the computer) when you identify the state of the display. Your main task is to identify the state the display represents i.e. all Normal or some Abnormal room temperatures and to hit the corresponding key on the computer (green or red).

The two types of displays considered for this experiment are as shown in the slides. At this time please hit the 'START' key (Brown key on the computer) once and refer to the next page for a description of the display......

If you look at this display, you will notice that it consists of twenty-four vertical bars arranged in four rows, each with a number beneath it. For simplicity consider that each vertical bar represents a building on campus and each 'tick mark' represents a room in that particular buiding. Next to each 'tick mark' is the status of that particular room.

Note that all the abnormal states are represented by either the character 'H' (which indicates that the corresponding room temperature is too high) or 'L' (which indicates that the corresponding room temperature is too low). For example in building #2 look at room #7. Here the presence of 'H' indicates the state of display as abnormal, in building #14 look at room #1. Here the presence of 'L' indicates the state of the display as abnormal. Therefore presence of either at least one 'H' or at least one 'L' will indicate the state of the overall display as abnormal. The presence of other characters will not affect the state of the display.

You will now refer to the second kind of overview display considered for this experiment. At this time please hit the 'START' key and refer to the next page for a description of the display......

As you can see, this display shows a twenty-four bar graph display arranged in four rows, each with a number beneath it. Each horizontal bar corresponds to a building on campus. Each vertical bar shows the plus or minus deviation of individual room temperatures from the desired temperatures. In this case the abnormal states are those in which the vertical bar has reached/crossed the threshold limit [upper or lower]. For example in building #2 look at room #7. This has reached the upper limit and in buiding #10 look at room #7. This has reached the lower limit. Note that even a single vertical bar touching/crossing a lower or upper limit will indicate the state of the overall display as abnormal.

For each type of display you will be given a series of practice trials in which to familiarize you with the equipment and the correct responses to various slides. The displays will be shown to you for only a brief period of time. If you cannot determine the state of the display i.e. NORMAL/ABNORMAL, make your best guess. The display will then be shown to you for a different duration of time.

For each type of display you will be required to view twelve slides at three different duration times. You will be viewing four slides in each duration time. Following is an explanation of how to view the slides.

To start the experiment, you should press the start key once then you should wait for the beep to show the slide on the screen; at that time you should view the slide and press the corresponding key [Normal (green)/Abnormal (red)] as soon as you identify the state of the display. For subsequent slides you are to wait for the beep to show the slide and to press the corresponding key just as you did for the first slide. This will continue for four slides.

The experimenter will then change the duration time. You should follow the same procedure for all the duration times as you did for the first duration time. Your response will be recorded for each slide.

You will now familiarize yourself with the equipment and the correct responses to different slides. Please note that the displays here will be shown for a long period of time. This is to develop a genuine understanding of the displays.

At this time please hit the 'START' key once and go to next page.......

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: 'ABNORMAL'

REASON: There ARE 'H' AND 'L' CHARACTERS. FOR EXAMPLE LOOK AT BUILDING # 1.

Hit the 'START' key and go to next page........

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: 'NORMAL'

REASON: THERE IS NO 'H' OR 'L' CHARACTER IN THE DISPLAY.

Please hit the 'START' key and try to answer the question below before seeing the answer on the next page.

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: GO TO NEXT PAGE.............

A: NORMAL

REASON: NO 'H' OR 'L' CHARACTER IN THE DISPLAY.

Hit the 'START' key and try to anwer the question below before seeing the answer in the next page.

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: GO TO NEXT PAGE............

A: ABNORMAL

REASON: PRESENCE OF 'H' AND 'L' CHARACTERS IN THE DISPLAY.

You will now familiariaze yourself with the second kind of Overview display considered for this experiment. At this time hit the 'START' key and refer to the next page .......

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: 'ABNORMAL'

REASON: IN BUILDING #1 THE ROOM TEMPERATURE HAS CROSSED THE UPPER LIMIT.

Hit THE 'START' key and refer to the next page for a description......

Q: WHAT IS THE CORRRECT RESPONSE TO THE DISPLAY SHOWN?

A: 'NORMAL'

REASON: NONE OF THE ROOM TEMPERATURES HAS CROSSED THE UPPER/LOWER LIMIT.

Hit the 'START' key and try to answer the question below before seeing the answer on the next page.

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: GO TO NEXT PAGE............

A: 'ABNORMAL'

REASON: IN SOME BUILDINGS THE TEMPERATURE HAS TOUCHED/CROSSED THE UPPER/LOWER LIMITS. e.g. IN BUILDING #1 LOOK AT ROOM #3.

Hit the 'START' key and try to answer the question below before seeing the answer on the next page.

Q: WHAT IS THE CORRECT RESPONSE TO THE DISPLAY SHOWN?

A: GO TO NEXT PAGE............

A: 'NORMAL'

REASON: NONE OF THE ROOM TEMPERATURE BARS HAS CROSSED THE UPPER/LOWER LIMIT.

You will now have a series of warmup trials before the actual experiment begins. Note that you will be responding similarly to an actual test. If you have any questions please feel free to ask the experimenter. At this time tell the experimenter that you are ready for the warmup trials. Also repeat your task to the experimenter before you start the actual test. Remember that the displays will be shown to you for only a brief period of time (similarly to actual test). I would like to remind you once again that the object of this experiment is to hit the desired key in the least possible time.

# REACTION TIME EXPERIMENT

In this part of the experiment, you will participate in a reaction time experiment. Now, instead of merely reporting the detection you must find a particular building in the display, then your task will be to determine if the building is 'NORMAL OR ABNORMAL'. If the building is normal, then you should press the green button otherwise you should press the red buttton for abnormal. Therefore your main task is to search for a particular building and identify whether it is normal or abnormal and to hit the corresponding key i.e. NORMAL/ABNORMAL in the least possible time.

The two types of displays considered for this part of the experiment are the same as in the first part of the experiment.

GOTO NEXT PAGE.......

For each type of display you will be required to view twelve slides in two different duration times. You will be viewing six slides in each duration of time. Following is an explanation of how to view the slides.

To start the experiment, you should press the start key once then wait for two beeps before you hit the appropriate key on the computer. At the first beep , the computer will ask you to find the status of a particular building. The second beep will show the slide on the screen. At that time you should view the slide and find the status of that particular building before you hit the corresponding key on the computer.

Your main task would be to find the status of a particular building asked by the computer and to hit the corresponding key as quickly as possible. Therefore the object of the experiment is to hit the desired key in the least possible time.

For each type of display you will now have practice trials. At this time please hit the start key once and try to answer the question asked by the computer before seeing the answer in the next page.

Q. WHAT IS THE STATUS OF THE BUILDING # 6 ?

A. NORMAL

Hit the 'START' key once and try to answer the question asked by the computer before seeing the answer in the next page.

Q. WHAT IS THE STATUS OF THE BUILDING # 8?

A. ABNORMAL

You will now familiarize yourself with second kind of display considered for this experiment. At this time hit the 'START' key and try to answer the question asked by the computer before seeing the answer in the next page.

Q. WHAT IS THE STATUS OF THE BUILDING # 10?

A. NORMAL

Hit the 'START' key once and try to answer the question asked by the computer before seeing the answer in the next page.

Q. WHAT IS THE STAUS OF THE BUILDING # 12?

A. 'ABNORMAL'

You will now have a series of warmup trials before the actual experiment begins. Note that you will be responding similarly to actual test. If you have any questions please feel free to ask the experimenter. At this time tell the experimenter that you are ready for the warmup trials. Also repeat your task to the experimenter before you start the the actual test.

## ORAL INSTRUCTIONS TO SUBJECTS

1. In Letter type look for 'H' or 'L' characters

2. In Bar type look whether any room temperature has crossed/touched upper/lower limit.

3. You need to hit the start key only once, it shows four slides for that duration for only a brief period of time.

4. I change the duration time after every four slides.

5. Do not hit the key twice. If you hit twice please inform the experimenter.

6. Object of the experiment is to hit the desired key in the least possible time.

## SEARCH TASK EXPERIMENT

7. When once you hit the START key it shows six slides. For every slide it will ask you to find the status of a particular building. Then you need to look for that particular building only.

8. In letter type look for only 'H' or 'L' and in bar type see whether any room temperature has crossed/touched the upper/lower limit.

9. After six slides I change the duration.

10. Do not hit the key twice. If you hit the key twice please tell the experimenter.

11. Object of the experiment is to hit the desired key in the least possible time.

# APPENDIX B

## DATA SHEET AND POST EXPERIMENT QUESTIONNAIRE

DATA SHEET

SUBJECT #

DISPLAY TYPE L OR B

| DURATION | S | | | | M | | | | L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SLIDE # | | | | | | | | | | | | |
| RESPONSE | | | | | | | | | | | | |
| ARC SINE | | | | | | | | | | | | |
| MEAN SCORE | | | | | | | | | | | | |

DISPLAY TYPE L OR B

| DURATION | S | | | | M | | | | L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SLIDE # | | | | | | | | | | | | |
| RESPONSE | | | | | | | | | | | | |
| ARC SINE | | | | | | | | | | | | |
| MEAN SCORE | | | | | | | | | | | | |

CLASSIFICATION OF RESPONSES

| TYPE | HIT | MISS |
|---|---|---|
| L TYPE | | |
| B TYPE | | |

# SEARCH TASK EXPERIMENT (PHASE II)

SUBJECT #

DISPLAY TYPE L OR B

| DURATION | 1 SEC | | | | | | 2 SECS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SLIDE # | | | | | | | | | | | | |
| RESPONSE | | | | | | | | | | | | |
| ARC SINE | | | | | | | | | | | | |
| MEAN SCORE | | | | | | | | | | | | |

DISPLAY TYPE L OR B

| DURATION | 1 SEC | | | | | | 2 SECS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SLIDE # | | | | | | | | | | | | |
| RESPONSE | | | | | | | | | | | | |
| ARC SINE | | | | | | | | | | | | |
| MEAN SCORE | | | | | | | | | | | | |

## CLASSIFICATION OF RESPONSES

| TYPE | HIT | MISS |
|---|---|---|
| L TYPE | | |
| B TYPE | | |

CHECK LIST

SUBJECT #

SUBJECT TYPE

SEX M OR F

VISION (20/20)

TIME AND DATE - FEB-84

POST EXPERIMENT QUESTIONNAIRE

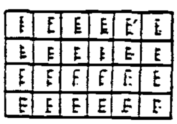
NAME

STATUS GRAD OR UNDER GRAD

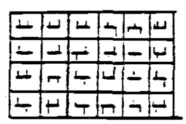
AGE

PLEASE ANSWER THE FOLLOWING QUESTIONS:

1] WHICH ONE DID YOU LIKE BETTER ? WHY ?



LETTER TYPE



BAR TYPE

2] WHICH ONE WAS EASIER TO READ ?

LETTER TYPE

BAR TYPE

I ONCE AGAIN THANK YOU FOR YOUR KIND CO-OPERATION

# APPENDIX C

## RAW DATA FOR PHASE I AND PHASE II EXPERIMENTS

# LEGEND FOR RAW DATA TABLE

SHORT = Exposure duration of 1 second.

MEDIUM = Exposure duration of 2 seconds.

LONG = Display was shown until the subject responded.

A/B = A- Percent correct, B- Response time in seconds.

## RAW DATA FOR PHASE I EXPERIMENT

| SUBJECTS | LETTER TYPE | | | BAR TYPE | | |
|---|---|---|---|---|---|---|
| | SHORT | MEDIUM | LONG | SHORT | MEDIUM | LONG |
| 1 | 1.87/2.32 | 2.40/3.54 | 2.40/4.67 | 1.87/2.43 | 2.40/3.20 | 2.40/3.64 |
| 2 | 1.30/3.04 | 1.87/3.23 | 1.30/5.10 | 2.40/2.49 | 2.40/2.73 | 2.40/2.87 |
| 3 | 1.30/3.67 | 2.40/3.75 | 2.40/4.10 | 1.87/2.79 | 2.40/3.10 | 2.40/3.95 |
| 4 | 1.87/2.84 | 1.87/3.67 | 2.40/4.15 | 2.40/2.19 | 2.40/3.83 | 2.40/3.89 |
| 5 | 2.40/2.86 | 2.40/2.97 | 2.40/3.02 | 2.40/2.38 | 2.40/2.59 | 2.40/2.75 |
| 6 | 1.87/3.32 | 2.40/3.51 | 2.40/3.60 | 2.40/2.81 | 2.40/2.80 | 2.40/3.46 |
| 7 | 1.87/3.45 | 2.40/3.46 | 2.40/4.03 | 2.40/2.92 | 1.87/2.85 | 2.40/3.77 |
| 8 | 1.87/3.52 | 1.87/4.18 | 2.40/4.32 | 1.87/2.81 | 2.40/3.35 | 2.40/3.90 |
| 9 | 2.40/3.24 | 2.40/3.34 | 2.40/4.57 | 2.40/2.38 | 2.40/2.89 | 2.40/4.17 |
| 10 | 1.30/2.82 | 1.30/2.85 | 2.40/3.32 | 1.87/2.92 | 2.40/2.56 | 2.40/3.81 |
| 11 | 2.40/2.82 | 1.87/3.18 | 1.87/7.20 | 1.87/2.33 | 2.40/3.48 | 2.40/4.24 |
| 12 | 2.40/3.06 | 2.40/3.89 | 2.40/4.58 | 2.40/2.66 | 2.40/2.97 | 2.40/3.13 |

| | SHORT | MEDIUM | LONG | SHORT | MEDIUM | LONG |
|---|---|---|---|---|---|---|
| 13 | 1.30/3.64 | 2.40/3.84 | 2.40/4.57 | 1.87/3.05 | 1.87/3.90 | 2.40/3.99 |
| 14 | 1.87/3.68 | 1.87/4.01 | 2.40/4.42 | 2.40/3.05 | 2.40/3.90 | 2.40/3.99 |
| 15 | 1.87/2.61 | 2.40/4.11 | 2.40/7.98 | 1.30/3.63 | 1.87/4.18 | 1.87/4.23 |
| 16 | 2.40/2.72 | 2.40/3.26 | 2.40/6.11 | 2.40/2.78 | 1.87/2.85 | 1.87/2.60 |
| 17 | 2.40/2.92 | 1.87/3.62 | 2.40/4.68 | 1.30/2.77 | 1.87/2.85 | 2.40/2.91 |
| 18 | 1.87/3.58 | 2.40/3.69 | 2.40/5.15 | 1.87/3.10 | 2.40/3.76 | 2.40/3.77 |
| 19 | 1.87/3.06 | 1.87/3.64 | 2.40/5.29 | 2.40/2.51 | 1.87/2.80 | 1.87/2.99 |
| 20 | 1.87/2.35 | 2.40/4.16 | 1.87/5.99 | 1.87/2.79 | 2.40/3.09 | 2.40/3.83 |
| 21 | 1.87/2.99 | 2.40/3.69 | 1.87/3.83 | 1.87/2.84 | 2.40/3.10 | 2.40/3.95 |
| 22 | 1.87/2.58 | 1.87/2.88 | 2.40/3.43 | 2.40/2.27 | 2.40/2.67 | 2.40/2.94 |
| 23 | 1.87/2.74 | 1.87/4.18 | 1.87/4.70 | 1.87/2.40 | 2.40/2.93 | 2.40/3.35 |
| 24 | 1.30/3.14 | 2.40/3.91 | 2.40/4.04 | 1.30/2.96 | 2.40/3.44 | 2.40/4.53 |
| 25 | 1.87/3.67 | 1.87/4.26 | 2.40/4.88 | 1.87/3.07 | 2.40/3.89 | 2.40/3.93 |
| 26 | 1.87/3.49 | 1.87/3.65 | 2.40/4.85 | 2.40/3.01 | 1.87/3.61 | 2.40/4.94 |

| | SHORT | MEDIUM | LONG | SHORT | MEDIUM | LONG |
|---|---|---|---|---|---|---|
| 27 | 1.30/4.44 | 2.40/4.69 | 2.40/6.99 | 2.40/2.94 | 2.40/3.74 | 2.40/5.77 |
| 28 | 1.30/2.75 | 1.87/2.82 | 1.87/3.00 | 1.87/2.46 | 2.40/2.96 | 2.40/3.50 |
| 29 | 1.30/3.04 | 1.30/4.00 | 2.40/7.60 | 1.87/2.88 | 1.87/3.44 | 2.40/5.69 |
| 30 | 1.87/3.54 | 1.87/3.62 | 2.40/3.79 | 1.87/2.55 | 2.40/2.79 | 2.40/3.03 |
| 31 | 1.30/3.24 | 2.40/4.86 | 1.87/5.88 | 2.40/2.88 | 2.40/2.94 | 2.40/3.61 |
| 32 | 2.40/2.92 | 2.40/3.04 | 2.40/3.62 | 2.40/2.43 | 2.40/3.28 | 2.40/3.28 |
| 33 | 1.87/2.72 | 2.40/3.26 | 2.40/6.11 | 1.30/2.78 | 1.87/2.05 | 2.40/2.60 |
| 34 | 2.40/2.80 | 2.40/3.35 | 2.40/3.52 | 1.87/2.51 | 2.40/2.54 | 2.40/3.52 |
| 35 | 2.40/3.47 | 2.40/3.91 | 2.40/6.17 | 1.87/2.74 | 2.40/3.15 | 2.40/3.27 |
| 36 | 2.40/3.58 | 2.40/4.09 | 2.10/4.54 | 2.40/3.10 | 1.87/3.48 | 1.87/3.44 |

RAW DATA FOR PHASE II EXPERIMENT

| SUBJECTS | LETTER TYPE | | BAR TYPE | |
|---|---|---|---|---|
| | 1SEC | 2SECS | 1SEC | 2SECS |
| 1 | 2.53/2.40 | 2.53/2.59 | 2.53/2.15 | 2.13/2.29 |
| 2 | 2.53/2.91 | 2.53/3.30 | 2.53/2.45 | 2.53/2.84 |
| 3 | 2.53/2.41 | 2.53/2.46 | 2.13/2.04 | 2.53/2.16 |
| 4 | 2.53/3.30 | 2.53/3.38 | 2.53/2.78 | 2.53/2.90 |
| 5 | 2.53/2.56 | 2.53/2.88 | 2.53/2.70 | 2.53/2.86 |
| 6 | 1.74/2.52 | 2.53/2.58 | 2.53/2.19 | 2.53/2.23 |
| 7 | 2.13/2.37 | 2.53/2.42 | 2.53/2.27 | 2.53/2.23 |
| 8 | 2.53/2.59 | 2.13/2.74 | 2.53/2.33 | 2.53/2.44 |
| 9 | 2.13/2.33 | 2.53/2.64 | 2.53/2.19 | 2.53/2.29 |
| 10 | 2.13/2.89 | 2.53/3.51 | 2.53/2.46 | 2.53/2.49 |
| 11 | 2.53/2.40 | 2.53/2.51 | 2.53/2.13 | 2.53/2.21 |
| 12 | 2.53/3.27 | 2.53/3.29 | 2.53/3.13 | 2.53/3.65 |

| | 1SEC | 2SECS | 1SEC | 2SECS |
|---|---|---|---|---|
| 13 | 2.53/2.37 | 2.53/2.66 | 2.53/2.69 | 2.53/2.38 |
| 14 | 2.53/2.58 | 2.53/2.73 | 2.53/2.33 | 2.53/2.45 |
| 15 | 2.53/2.37 | 2.53/2.72 | 2.53/2.12 | 2.53/2.28 |
| 16 | 2.53/2.43 | 2.53/2.43 | 2.53/2.36 | 2.13/2.41 |
| 17 | 2.13/2.52 | 2.13/2.25 | 2.53/1.96 | 2.13/2.42 |
| 18 | 2.13/3.22 | 2.13/3.30 | 1.17/2.91 | 2.53/2.69 |
| 19 | 2.13/2.81 | 2.13/2.36 | 2.13/2.03 | 2.53/2.15 |
| 20 | 2.53/2.34 | 2.53/2.81 | 2.53/2.06 | 2.53/2.12 |
| 21 | 2.53/2.45 | 2.53/2.53 | 2.53/2.15 | 2.53/2.32 |
| 22 | 2.53/3.18 | 2.53/3.11 | 2.53/2.82 | 2.53/2.58 |
| 23 | 2.13/2.73 | 2.53/2.97 | 2.53/2.39 | 2.53/2.59 |
| 24 | 1.74/2.58 | 2.53/2.59 | 2.53/2.40 | 2.53/2.71 |
| 25 | 2.53/2.29 | 2.53/2.50 | 1.17/2.31 | 1.74/2.39 |
| 26 | 2.53/2.55 | 2.53/2.69 | 2.53/2.29 | 2.53/2.45 |

| | 1SEC | 2SECS | 1SEC | 2SECS |
|---|---|---|---|---|
| 27 | 2.53/2.75 | 2.53/2.95 | 2.53/2.62 | 2.53/2.73 |
| 28 | 2.13/2.57 | 2.53/2.67 | 2.53/2.20 | 2.53/2.61 |
| 29 | 2.53/2.57 | 2.53/2.75 | 2.53/2.43 | 2.53/2.49 |
| 30 | 2.53/2.41 | 2.13/2.47 | 2.53/2.35 | 2.13/2.37 |
| 31 | 2.53/1.92 | 2.53/2.27 | 2.53/2.35 | 2.13/2.37 |
| 32 | 2.13/2.49 | 2.53/2.79 | 2.53/2.17 | 2.53/2.36 |
| 33 | 2.53/2.89 | 2.53/2.95 | 2.53/2.52 | 2.53/2.77 |
| 34 | 2.13/2.35 | 2.53/3.15 | 2.53/2.43 | 2.53/2.46 |
| 35 | 1.17/2.54 | 2.13/2.56 | 2.13/2.37 | 2.13/2.48 |
| 36 | 2.53/2.50 | 2.53/2.54 | 1.17/2.29 | 2.53/2.77 |

# APPENDIX D

## COMPUTATION OF SUM OF SQUARES (SIPS OUTPUT)

## Legend for Anova Tables

A - NATIONALITY (NAT)

S - SUBJECTS (SUB)

B - DISPLAY TYPE (DIS)

C - DURATION (DUR)

ANOVA FOR CHECK READING EXPT (for percent correct):

1 SIPS LOG.X.43 03/09/84

ANALYSIS OF VARIANCE FOR Y

| | LINE | SOURCE OF VARIATION | DF | MEAN SQUARE |
|---|---|---|---|---|
| ( | 1) | A | 1 | 0.477040E-03 |
| ( | 2 | S | | |
| + | 3) | A*S | 34 | 0.208133E 00 |
| ( | 4) | B | 1 | 0.534116E 00 |
| ( | 5) | A*B | 1 | 0.185000E-01 |
| ( | 6 | S*B | | |
| + | 7) | A*S*B | 34 | 0.224291E 00 |
| ( | 8) | C | 2 | 0.255256E 01 |
| ( | 9) | A*C | 2 | 0.639791E-01 |
| ( | 10 | S*C | | |
| + | 11) | A*S*C | 68 | 0.894660E-01 |
| ( | 12) | B*C | 2 | 0.509207E-01 |
| ( | 13) | A*B*C | 2 | 0.173546E-02 |
| ( | 14 | S*B*C | | |
| + | 15) | A*S*B*C | 68 | 0.675936E-01 |
| | | TOTAL | 215 | |

ANOVA FOR CHECK READING EXPT (for response time):

ANALYSIS OF VARIANCE FOR Y

| | LINE | SOURCE OF VARIATION | DF | MEAN SQUARE |
|---|---|---|---|---|
| ( | 1) | A | 1 | 0.379178E 00 |
| ( | 2 | S | | |
| + | 3) | A*S | 34 | 0.121075E 01 |
| ( | 4) | B | 1 | 0.243412E 02 |
| ( | 5) | A*B | 1 | 0.117134E 00 |
| ( | 6 | S*B | | |
| + | 7) | A*S*B | 34 | 0.284801E 00 |
| ( | 8) | C | 2 | 0.323451E 02 |
| ( | 9) | A*C | 2 | 0.128839E 00 |
| ( | 10 | S*C | | |
| + | 11) | A*S*C | 68 | 0.398157E 00 |
| ( | 12) | B*C | 2 | 0.296130E 01 |
| ( | 13) | A*B*C | 2 | 0.123825E 00 |
| ( | 14 | S*B*C | | |
| + | 15) | A*S*B*C | 68 | 0.322500E 00 |
| | | TOTAL | 215 | |

ANOVA FOR SEARCH TASK EXPT (for percent correct):

ANALYSIS OF VARIANCE FOR Y

| LINE | | SOURCE OF VARIATION | DF | MEAN SQUARE |
|---|---|---|---|---|
| ( | 1) | A | 1 | 0.102400E 00 |
| ( | 2 | S | | |
| + | 3) | A*S | 34 | 0.111595E 00 |
| ( | 4) | B | 1 | 0.613611E-02 |
| ( | 5) | A*B | 1 | 0.871110E-02 |
| ( | 6 | S*B | | |
| + | 7) | A*S*B | 34 | 0.815074E-01 |
| ( | 8) | C | 1 | 0.311736E 00 |
| ( | 9) | A*C | 1 | 0.400000E-01 |
| ( | 10 | S*C | | |
| + | 11) | A*S*C | 34 | 0.559989E-01 |
| ( | 12) | B*C | 1 | 0.393361E-01 |
| ( | 13) | A*B*C | 1 | 0.711121E-03 |
| ( | 14 | S*B*C | | |
| + | 15) | A*S*B*C | 34 | 0.604604E-01 |
| | | TOTAL | 143 | |

ANOVA FOR SEARCH TASK EXPT (for response time):

ANALYSIS OF VARIANCE FOR T

| LINE | | SOURCE OF VARIATION | DF | MEAN SQUARE |
|---|---|---|---|---|
| ( | 1) | A | 1 | 0.143578E 02 |
| ( | 2 | S | | |
| + | 3) | A*S | 34 | 0.185655E 02 |
| ( | 4) | B | 1 | 0.762220E 01 |
| ( | 5) | A*B | 1 | 0.187561E 02 |
| ( | 6 | S*B | | |
| + | 7) | A*S*B | 34 | 0.174711E 02 |
| ( | 8) | C | 1 | 0.254100E 02 |
| ( | 9) | A*C | 1 | 0.177311E 02 |
| ( | 10 | S*C | | |
| + | 11) | A*S*C | 34 | 0.175509E 02 |
| ( | 12) | B*C | 1 | 0.167486E 02 |
| ( | 13) | A*B*C | 1 | 0.180271E 02 |
| ( | 14 | S*B*C | | |
| + | 15) | A*S*B*C | 34 | 0.176945E 02 |
| | | TOTAL | 143 | |

$END

1 SIPS LOG.X.43 03/16/84

$=T-TEST FOR CHECK READING EXPT (for percent correct):

```
 SAMPLE SIZE                                36
 MEAN OF     1                  2.076944
 MEAN OF     2                  2.193611

 MEAN DIFFERENCE                     -0.116667
 STD. ERR. OF DIFFERENCE              0.052412

 T-VALUE                             -2.225967
 DEGREES OF FREEDOM                         35

BT-TABLE VALUE AT (.95)              2.030147
BT-TABLE VALUE AT (.99)              2.724004

B95% CONF. INTERVAL (-0.223070    ,-0.102632E-01)
B99% CONF. INTERVAL (-0.259436    , 0.261029E-01)
```

T-TEST FOR CHECK READING EXPT (for response time):

```
 SAMPLE SIZE                                36
 MEAN OF     1                  3.850278
 MEAN OF     2                  3.179444

 MEAN DIFFERENCE                      0.670833
 STD. ERR. OF DIFFERENCE              0.082180

 T-VALUE                              8.162977
 DEGREES OF FREEDOM                         35

BT-TABLE VALUE AT (.95)              2.030147
BT-TABLE VALUE AT (.99)              2.724004

B95% CONF. INTERVAL ( 0.503996    , 0.837671      )
B99% CONF. INTERVAL ( 0.446975    , 0.894692      )
```

T-TEST FOR SEARCH TASK EXPT (for percent correct):

| | |
|---|---|
| SAMPLE SIZE | 36 |
| MEAN OF 1 | 2.076944 |
| MEAN OF 2 | 2.193611 |
| MEAN DIFFERENCE | -0.116667 |
| STD. ERR. OF DIFFERENCE | |
| T-VALUE | 0.35123 |
| DEGREES OF FREEDOM | 35 |
| BT-TABLE VALUE AT (.95) | 2.030147 |
| BT-TABLE VALUE AT (.99) | 2.724004 |

B95% CONF. INTERVAL (-0.223070 ,-0.102632E-01)
B99% CONF. INTERVAL (-0.259436 , 0.261029E-01)

T-TEST FOR SEARCH TASK EXPT (for response time):

| | |
|---|---|
| SAMPLE SIZE | 36 |
| MEAN OF 3 | 2.669167 |
| MEAN OF 4 | 2.425278 |
| MEAN DIFFERENCE | 0.243889 |
| STD. ERR. OF DIFFERENCE | 0.032488 |
| T-VALUE | 7.507150 |
| DEGREES OF FREEDOM | 35 |
| BT-TABLE VALUE AT (.95) | 2.030147 |
| BT-TABLE VALUE AT (.99) | 2.724004 |

B95% CONF. INTERVAL ( 0.177934 , 0.309843 )
B99% CONF. INTERVAL ( 0.155393 , 0.332385 )

T-TEST FOR CHECK READING EXPT (for display conditions):

a] NORMAL CONDITION:

| | |
|---|---|
| SAMPLE SIZE | 36 |
| MEAN OF 1 | 4.511111 |
| MEAN OF 3 | 3.734306 |
| MEAN DIFFERENCE | 0.776806 |
| STD. ERR. OF DIFFERENCE | 0.124630 |
| T-VALUE | 6.232889 |
| DEGREES OF FREEDOM | 35 |
| BT-TABLE VALUE AT (.95) | 2.030147 |
| BT-TABLE VALUE AT (.99) | 2.724004 |
| B95% CONF. INTERVAL | ( 0.523788 , 1.02982 ) |
| B99% CONF. INTERVAL | ( 0.437313 , 1.11630 ) |

b] ABNORML CONDITION:

| | |
|---|---|
| SAMPLE SIZE | 36 |
| MEAN OF 2 | 3.207694 |
| MEAN OF 4 | 2.672778 |
| MEAN DIFFERENCE | 0.534917 |
| STD. ERR. OF DIFFERENCE | 0.097892 |
| T-VALUE | 5.464343 |
| DEGREES OF FREEDOM | 35 |
| BT-TABLE VALUE AT (.95) | 2.030147 |
| BT-TABLE VALUE AT (.99) | 2.724004 |
| B95% CONF. INTERVAL | ( 0.336181 , 0.733652 ) |
| B99% CONF. INTERVAL | ( 0.268258 , 0.801575 ) |

$END

T-TEST FOR CHECK READING EXPT

(for correct and incorrect responses):

a] LETTER TYPE:

| | |
|---|---|
| SAMPLE SIZE | 20 |
| MEAN OF 1 | 3.749000 |
| MEAN OF 2 | 3.719350 |
| MEAN DIFFERENCE | 0.029650 |
| STD. ERR. OF DIFFERENCE | 0.138564 |
| T-VALUE | 0.213981 |
| DEGREES OF FREEDOM | 19 |
| BT-TABLE VALUE AT (.95) | 2.093066 |
| BT-TABLE VALUE AT (.99) | 2.861156 |

B95% CONF. INTERVAL (-0.260373 , 0.319673 )
B99% CONF. INTERVAL (-0.366803 , 0.426103 )

b] BAR TYPE:

| | |
|---|---|
| SAMPLE SIZE | 22 |
| MEAN OF 1 | 3.187727 |
| MEAN OF 2 | 3.635864 |
| MEAN DIFFERENCE | -0.448136 |
| STD. ERR. OF DIFFERENCE | 0.150126 |
| T-VALUE | -2.985061 |
| DEGREES OF FREEDOM | 21 |
| BT-TABLE VALUE AT (.95) | 2.079656 |
| BT-TABLE VALUE AT (.99) | 2.831577 |

B95% CONF. INTERVAL (-0.760348 ,-0.135925 )
B99% CONF. INTERVAL (-0.873231 ,-0.230420E-01)

T-TEST FOR SEARCH TASK EXPT (for display conditions):

a] NORMAL CONDITION:

| | |
|---|---|
| SAMPLE SIZE | 33 |
| MEAN OF 1 | 2.683030 |
| MEAN OF 3 | 2.424545 |
| MEAN DIFFERENCE | 0.258485 |
| STD. ERR. OF DIFFERENCE | 0.045271 |
| T-VALUE | 5.709735 |
| DEGREES OF FREEDOM | 32 |
| BT-TABLE VALUE AT (.95) | 2.036973 |
| BT-TABLE VALUE AT (.99) | 2.738682 |

B95% CONF. INTERVAL ( 0.166269 , 0.350700 )
B99% CONF. INTERVAL ( 0.134502 , 0.382467 )

b] ABNORMAL CONDITION:

| | |
|---|---|
| SAMPLE SIZE | 33 |
| MEAN OF 2 | 2.659697 |
| MEAN OF 4 | 2.428788 |
| MEAN DIFFERENCE | 0.230909 |
| STD. ERR. OF DIFFERENCE | 0.048876 |
| T-VALUE | 4.724355 |
| DEGREES OF FREEDOM | 32 |
| BT-TABLE VALUE AT (.95) | 2.036973 |
| BT-TABLE VALUE AT (.99) | 2.738682 |

B95% CONF. INTERVAL ( 0.131349 , 0.330469 )
B99% CONF. INTERVAL ( 0.970524E-01, 0.364766 )

T-TEST FOR SEARCH TASK EXPT

a] LETTER TYPE: (for correct and incorrect responses):

| | |
|---|---|
| SAMPLE SIZE | 21 |
| MEAN OF 1 | 2.651429 |
| MEAN OF 2 | 2.667857 |
| MEAN DIFFERENCE | -0.016429 |
| STD. ERR. OF DIFFERENCE | 0.065299 |
| T-VALUE | -0.251590 |
| DEGREES OF FREEDOM | 20 |
| BT-TABLE VALUE AT (.95) | 2.086005 |
| BT-TABLE VALUE AT (.99) | 2.845559 |
| B95% CONF. INTERVAL | (-0.152642 , 0.119785 ) |
| B99% CONF. INTERVAL | (-0.202240 , 0.169383 ) |

b] BAR TYPE:

| | |
|---|---|
| SAMPLE SIZE | 8 |
| MEAN OF 1 | 2.540000 |
| MEAN OF 2 | 2.617500 |
| MEAN DIFFERENCE | -0.077500 |
| STD. ERR. OF DIFFERENCE | 0.144960 |
| T-VALUE | -0.534630 |
| DEGREES OF FREEDOM | 7 |
| BT-TABLE VALUE AT (.95) | 2.364633 |
| BT-TABLE VALUE AT (.99) | 3.499287 |
| B95% CONF. INTERVAL | (-0.420277 , 0.265277 ) |
| B99% CONF. INTERVAL | (-0.584757 , 0.429757 ) |

# APPENDIX E

## PROGRAM LISTINGS FOR PHASE I AND PHASE II EXPERIMENTS

These programs were used to advance the slide projector and also to record the response.

PROGRAM LISTING FOR PHASE I EXPERIMENT

```
10   ! PROGRAM CHECK READING
20   ! N IS A NORMAL ARRAY
30   ! A IS AN ABNORMAL ARRAY
40   ! S IS A CHARACETER ARRAY
50   ! DIM A(50),N(50),S$[50]
60     I=1
70     CONTROL 4,8 ; 1
80     CONTROL 4,4 ; 192
90     CONTROL 4,3 ; 1
100    OUTPUT 400 USING "#,B" ; 1
110    OUTPUT 400 USING "#,B" ; 0
120 ! SELECT ALLOWED KEYS
130    ENABLE KBD 1+32+128
140    CLEAR
150    DISP "PROGRAM BEING INITIALIZED"
160    DISP "-------------------------"
170    DISP "THANK YOU FOR PARTICIPATING"
180    DISP "IN THE EXPERIMENT"
190    DISP "PLEASE READ AND FOLLOW THE"
200    DISP "INSTRUCTIONS"
210 ! DEFINE KEYS
220    ON KEY #1, "START" GOSUB 1000
230    ON KEY #2, "NORMAL" GOSUB 2000
```

```
240   ON KEY #4, "ABNORMAL" GOSUB 3000
250   ON KEY #5, "HELP" GOSUB 4000
260   ON KEY #8, " " GOSUB 5000
270   KEY LABEL
280   GOTO 280
1000 !SUBROUTINE FOR START
1010  BEEP 2,150
1020  CLEAR
1030  KEY LABEL
1040  L=0
1050  WAIT 3000
1060  L=L+1
1070  IF L>4 THEN 3070
1080  CONTROL 4,8 ; 1
1090  !SELECT HAND STROBE
1100  CONTROL 4,4 ; 192
1110 !INVRT CONTROL
1120  CONTROL 4,3 ; 1
1130  BEEP 10,1000
1140 !START CLOCK
1150  SET TIME 0,0
1160  OUTPUT 400 USING "#,B" ; 1
1170  OUTPUT 400 USING "#,B" ; 0
1180  WAIT 10000
1190  GOTO 1060
1200  RETURN
```

```
2000 !SUBROUTINE FOR NORMAL RESPONSE
2010  BEEP 2,150
2020  N(I)=TIME
2030  S$[I]="N"
2040  I=I+1
2050  WAIT 3000
2060  RETURN
3000 !SUBROUTINE FOR ABNORMAL RESPONSE
3010  BEEP 2,150
3020  N(I)=TIME
3030  S$[I]="A"
3040  I=I+1
3050  WAIT 3000
3060  RETURN
3070  BEEP
3080  DISP "PLEASE CALL THE EXPERIMENTER"
3090  DISP "----------------------------"
3100  WAIT 5000
3110  CLEAR
3120  KEY LABEL
3130  GOTO 3130
4000 !SUBROUTINE FOR HELP
4010  DISP "K5:HELP"
4020  DISP "EXPLANATION OF KEYS"
4030  DISP "-------------------"
4040  DISP "K1=PRESS TO START THE EXPERIMENT"
```

```
4050 DISP
4060 DISP "K2 & K4: NORMAL AND ABNORMAL TASK"
4070 DISP "BY HITTING THE DESIRED KEY IN LEAST"
4080 DISP "POSSIBLE TIME"
4090 RETURN
5000 !SUBROUTINE FOR RESULTS
5010 FOR I= 1 TO 50
5020 IF S$[I,I]= "N" THEN GOTO 5050
5030 PRINT I; "ABNORMAL TIME= ",N(I)
5040 GOTO 5060
5050 PRINT I; "NORMAL TIME= ",N(I)
5060 NEXT I
5070 RETURN
```

## PROGRAM LISTING FOR PHASE II EXPERIMENT

```
10    !   PROGRAM SEARCH TASK
20    !   N IS A NORMAL ARRAY
30    !   A IS AN ABNORMAL ARRAY
40    !   S IS A CHARACTER ARRAY
50    !   B IS A BUILDING ARRAY
60        DIM A(50),N(50),B(50),S$[50]
70        I=1
80        CONTROL 4,8; 1
90        CONTROL 4,4; 192
100       CONTROL 4,3; 1
110       OUPTUT 400 USING "#,B;1
120       OUTPUT 400 USING "#,B;" ; 0
125       INPUT R
130   !   SELECT ALLOWED KEYS
140       ENABLE KBD 1+32+128
150       DISP "PROGRAM BEING INITIALIZED"
160       DISP "------------------------"
170   !   DEFINE KEYS
180       ON KEY  1, "START" GOSUB 1000
190       ON KEY  2, "NORMAL" GOSUB 2000
200       ON KEY #4, "ABNORMAL" GOSUB 3000
210       ON KEY #8, " " GOSUB 4000
220       KEY LABEL
```

```
230      GOTO 230
1000 !   SUBROUTINE FOR START
1010     BEEP 2,150
1020     CLEAR
1030     KEY LABEL
1040     L=0
1050     WAIT 3000
1055     L=L+1
1060     IF L>6 THEN 3080
1070     BEEP 10,1000
1080     DISP "WHAT IS THE STATUS OF BUILDING #";R
1090     DISP "--------------------------------"
1100     DISP "LOOK FOR THAT BUILDING ON THE SCREEN"
1110     DISP "NOW AND HIT THE CORRESPONDING KEY!"
1120     WAIT 3000
1130     CLEAR
1140     KEY LABEL
1150     CONTROL 4,8; 1
1160     CONTROL 4,4; 192
1170     CONTROL 4,3; 1
1180     BEEP 10,1000
1190     SETTIME 0,0
1195     OUTPUT 400 USING '#,B" ; 1
1196     OUTPUT 400 USING '#,B" ; 0
1200     WAIT 15000
1210     GOTO 1055
```

```
1220      RETURN
2000 !    SUBROUTINE FOR NORMAL
2010      BEEP 2,150
2020      N(I)=TIME
2030      S(I)=R
2040      M$[I]="N"
2050      R=R+L
2060      I=I+1
2070      WAIT 3000
2080      RETURN
3000 !    SUBROTINE FOR ABNORMAL
3010      BEEP 2,150
3020      N(I)=TIME
3030      S(I)=R
3040      I=I+1
3045      M$[I]="A"
3050      R=R+L
3060      WAIT 3000
3070      RETURN
3080      DISP "PLEASE CALL THE EXPERIMENTER"
3090      BEEP
3100      WAIT 5000
3110      RETURN
4000 !    SUBROUTINE FOR RESULTS
4010      FOR I=1 TO 50
4020      IF M$[I,I]="N" THEN GOTO 4050
```

```
4030    PRINT I; "ABNORMAL TIME FOR";S(I);"=";N(I)
4040    GOTO 4060
4050    PRINT I; "NORMAL TIME FOR ";S(I);"=";N(I)
4060    NEXT I
4070    RETURN
```

# APPENDIX F

## RELAY CIRCUIT DIAGRAM

## RELAY CIRCUIT

A relay circuit was built as shown in Figure F-1. The circuit consisted of following items.

1. Two NPN transistors

2. Two relays (SPST) rated 5V DC AND 120 AC.

3. One 5 volts power supply to operate the relays.

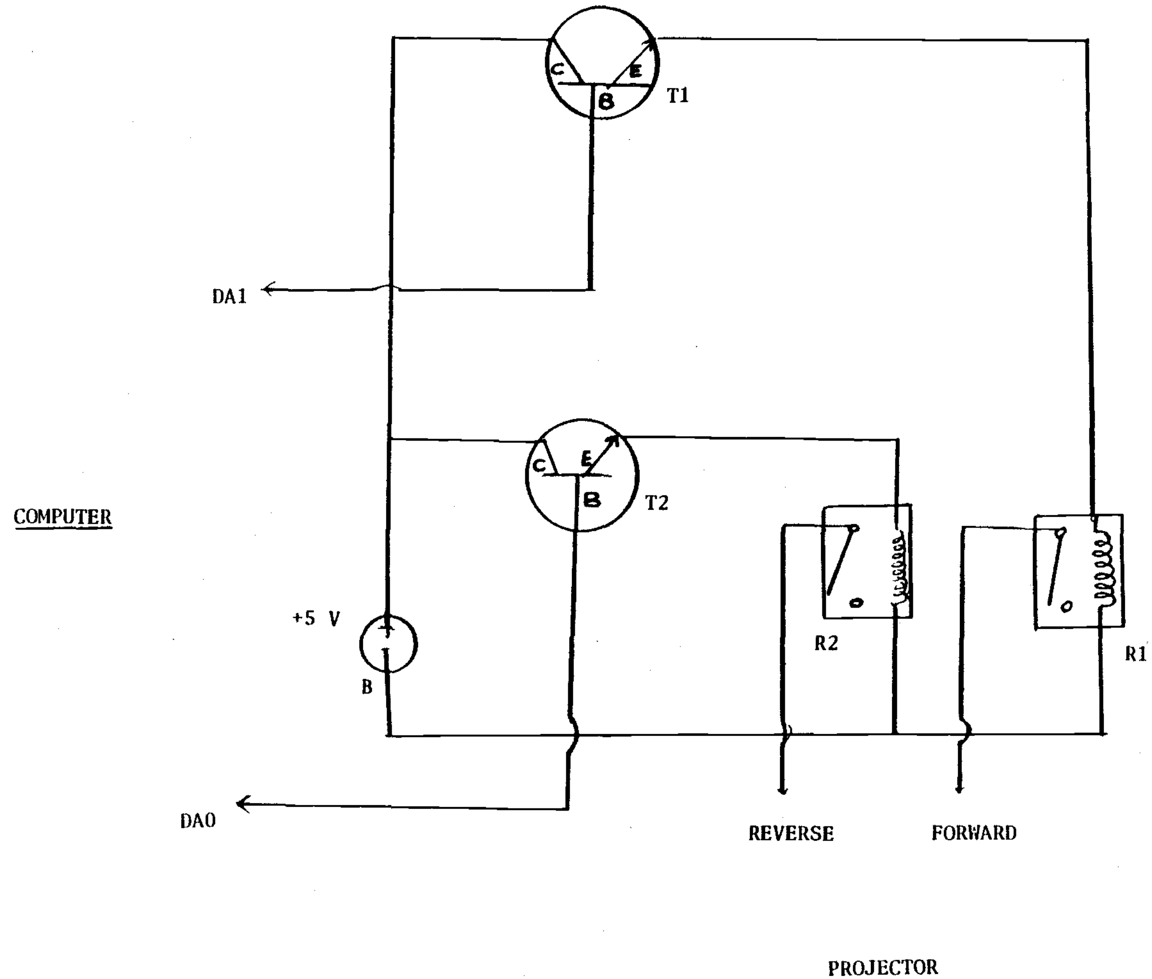



Figure F-1 Relay circuit

# APPENDIX G

# ANNOTATED BIBLIOGRAPHY

# AN ANNOTATED BIBLIOGRAPHY OF ARTICLES ON HUMAN FACTORS IN PROCESS CONTROL

COMPILED BY:

KRISHNARAJA R. HOLLA

SUBMITTED TO:

DEPARTMENT OF INDUSTRIAL AND GENERAL ENGINEERING

OREGON STATE UNIVERSITY

# CONTENTS

## ACKNOWLEDGMENTS

I wish to express my sincere gratitude and thanks to Dr. Kenneth Funk for his interest, assistance, and encouragement throughout the preparation of this annotated bibliography.

This bibliography would not have been feasible without the resource of the library of the Oregon State University at Corvallis and the cooperation of the library staff.

I would especially like to thank Mr. Hugh Franklin, engineering librarian for his help in preparing this bibliography.

I am also grateful to the staff of interlibrary loan service, Mrs. Doris Tilles, Mrs. Nancy Powell, and Mrs. Debbie Remmington, for their helpful service.

## INTRODUCTION

The area of Man-Machine interfaces in Process Control constitutes a significant portion of present research in human factors engineering. In the last decade the literature related to this field has increased most dramatically. The current trend in the development of microprocessors for a distributed system that is destined for the supervision and control of an Industrial process has a definite impact on the interface between the system, the human operator and other major equipment. Also the current development of Industrial Control equipment is to replace physically large conventional control panels and instrumentation by a small console having one or more CRTs at which all variables can be seen. Progress in this direction is inevitable because this technique promises tremendous flexibility in the display of information, significant reduction in size of operating centers, and increased operator effectiveness. A large amount of work has appeared in the literature to date. This has made it extremely difficult for most researchers to keep abreast of recent advances in areas outside their own.

Concurrent with this development, there has been an increased need for survey, tutorial, or review articles that summarize recent research in a given area and reflect the state of art in that area. This need has been recognized by the leading journals in Control Engineering and Human Factors resulting in the more frequent appearance of review articles.

The aim of constructing this annotated bibliography was to prepare a well-organized listing of literature that has appeared in the leading Control Engineering, Human Factors, and Process Control journals, relating to Human Factors in Process Control.

The following sections define the scope of the bibliography and discuss the selection guidelines used in its construction.

1. Literature included:

This collection consists of review articles appearing in the journals listed in Table I. It also includes conference proceedings, symposia, colloquia, and special issues as listed in Table II. The journals serving as my primary source material were chosen on the basis of direct, practical relevance to Human Factors in Process Control. This bibliography is restricted to English language journals only. No attempt has been made to include the large amount of theoretical material on subjects such as modelling, estimation techniques, control theory, direct digital control algorithms or optimization.

Abstracts written by the author of each reference were used where possible. For some references, formal abstract was not available. A brief summary written by the compiler of this bibliography accompanies these references. The bibliography is arranged alphabetically by author name.

2. Categories:

Many papers can, of course, be classified under a number of headings. Here most papers appear under one entry only. Table IV

TABLE I

| JOURNALS |
|---|
| 1. Advances in Instrumentation |
| 2. Applied Ergonomics |
| 3. Brown Boveri Review |
| 4. Canadian Controls and Instruments |
| 5. Computer |
| 6. Computer and Control Abstracts |
| 7. Computer Design |
| 8. Control Engineer |
| 9. Control and Instruments |
| 10. Chemical Engineer |
| 11. Chemical Engineering |
| 12. Datamation |
| 13. Electronic Engineer |
| 14. Electronic Progress |
| 15. Human Factors |
| 16. Hitachi Review |
| 17. IEEE Transactions on Human Factors Electron (HFE) |
| 18. Instrument and Control |
| 19. Instrument Technology |
| 20. InTech |
| 21. International Journal of Man-Machine Studies |
| 22. Measurement and Control |

23. New Electron
24. Process Automation
25. Process Engineer
26. Telecommunications
27. Toshiba Review

## TABLE II

Important conferences, symposia and special issues of journals on process control and on human factors are listed below. Throughout the bibliography, the abbreviations given in Table II are used in order to conserve space.

| Abbreviation | References |
|---|---|
| CE/68 | Special issue on 'Displays'. Control Engineering, Vol. 15(6), 1968. |
| CE/80 | Proceedings of Sixth Annual Advance Conference on Man-Machine Interfaces for Process Control. Control Engineering, 1980. |
| CHEMECA/70 | Proceedings of CHEMECA Australia. Chemical Engineering Conference Australia, Sydney, 1970. |
| ERS/67 | The human operator in complex systems. Ergonomics, Vol. 10(6), 1967. |
| HF/64 | Proceedings of the Human Factors Society. 8th Annual meeting Santa Monica, California, Oct 20, 1964. |
| HF/70 | Special issue on 'Human Factors in information processing systems'. Human Factors, Vol. 12(2), 1970. |
| HF/77 | Proceedings of the Human Factors Society. 21st Annual meeting San Francisco, California, Oct 17, 1977. |
| HF/78 | Proceedings of the Human Factors Society. 22nd Annual meeting Detroit, Michigan, Oct 20, 1978. |
| HF/79 | Proceedings of the Human Factors Society. 23rd Annual meeting Cambridge, Massachusetts, Nov 23, 1979. |
| HF/80 | Proceedings of the Human Factors Society. 24th Annual meeting Los Angeles, California, Oct 19, 1980. |
| HF/81 | Proceedings of the Human Factors Society. 25th Annual meeting Rochester, New York, Oct 23, 1981. |

| | |
|---|---|
| HF/82 | Proceedings of the Human Factors Society. 26th Annual meeting Seattle, Washington, Oct 25, 1982. |
| IBM/68 | Special issue on interactive graphics in data processing. IBM Syst. J., Vol. 7(3-4), 1968. |
| IChE/67 | The application of Automation in the Process industries. Institute of Chemical Engineers, 1967. |
| IEE/69 | Direct Digital Control Processes. Institute of Electrical Engineers (IEE), Colloquium Digest No. 19/2, 1969. |
| IEE/70 | Man-computer interaction. Institute of Electrical Engineers (IEE), Conf. Pub. No. 68, 1970. |
| IEE/71 | Conference on Displays. Institute of Electrical Engineers (IEE), Conf. Pub. No. 80, 1971. |
| IEE/71(1) | Symposium on Centralized control systems. Institute of Electrical Engineers (IEE), London, 1971. |
| IEE/79 | Trends in on line computer control systems. Institute of Electrical Engineers (IEE), Conference, March, 1979. |
| IEE/82 | Trends in on line computer control systems. Institute of Electrical Engineers (IEE), Conference, April, 1982. |
| IEEE/70 | Special issue on 'Computer in Industrial Process Control'. Proceedings of IEEE, Vol. 58(1), 1970. |
| IFAC/64 | Digital Computer Application to Process control. International Federation of Automatic Control (IFAC), Stockholm, 1964. (New York: Plenum Press). |
| IFAC/67 | Digital Computer Application to Process control. International Federation of Automatic Control (IFAC), Menton, 1967. |
| IFAC/71(1) | Digital Computer Application to Process control. International Federation of Automatic Control (IFAC), Helsinki, 1971. |
| IFAC/71 | Interfaces with process control computer - The Operator, Engineer, and Management. International Federation of Automatic Control (IFAC), Pittsburg, PA:ISA, 1971. |

| | |
|---|---|
| IFAC/77 | Digital Computer Application to Process Control. International Federation of Automatic Control (IFAC), June, 1977. |
| IMC/71 | Data reduction, communication and presentation for the process operator, Institute of Measurement and Control (IMC), London, 1971. |
| ISA/58 | First symposium on Instrumentation in chemical and petroleum industries. Instrument Society of America (ISA), 1958. |
| ISA/68 | Computer impact in Engineering Management. Instrument Society of America (ISA), PA, USA, 1968. |
| ISA/73 | Advances in Instrumentation. Instrument Society of America (ISA), Vol. 28, Texas, 1973. |
| ISA/76 | Interfaces with Process Control. Instrument Society of America (ISA), Niagara Falls, NY, 1976. |

TABLE IV

| CATEGORY<br>DISPLAYS: a) CRT displays | | | | | |
|---|---|---|---|---|---|
| Aronson | 1970 | Jervis | 1970 | Zey | 1978 |
| Bishop | 1970 | Jervis | 1971 | IEE/71 | 1971 |
| Bitticker | 1976 | Konaka | 1980 | IFAC/71 | 1971 |
| Bond | 1977 | Lauher | 1970 | CE/68 | 1968 |
| Braddock | 1973 | Lauher | 1972 | IMC | 1969 |
| Bryden | 1971 | Lecocq | 1977 | ISA/76 | 1971 |
| Bryden | 1979 | O'hare | 1971 | | |
| Crowder | 1971 | Parish | 1971 | | |
| Crowe | 1976 | Mohan Rao | 1971 | | |
| Cundall | 1968 | Schmittroth | 1968 | | |
| Cundall | 1970 | Selig | 1968 | | |
| Cundall | 1971 | Weiseberg | 1968 | | |
| Dallimonti | 1972 | Sheffield | 1972 | | |
| Dallimonti | 1973 | Shephard | 1977 | | |
| Danchak | 1977 | Stradler | 1973 | | |
| Danchak | 1977(1) | Stoddard | 1975 | | |
| Dolkart | 1980 | Suret | 1971 | | |
| Foley | 1978 | Vartabedian | 1971 | | |
| Hurd | 1972 | Vartabedian | 1970 | | |

| DISPLAYS: b) General | | | | | |
|---|---|---|---|---|---|
| Coffey | 1961 | Kishi | 1975 | Myers | 1980 |
| Corkindale | 1971 | Kwarham | 1977 | Reynolds | 1976 |
| Durham | 1983 | Liss | 1973 | Rooney | 1971 |
| Edwards | 1971 | Martino | 1975 | Sharpe | 1971 |
| Freer | 1982 | McLaughin | 1973 | Umbers | 1978 |
| Friedwald | 1980 | Merrit | 1979 | Watts | 1979 |
| Gillenson | 1975 | Muckler | 1965 | Wilder | 1974 |
| Hitt | 1961 | Myers | 1979 | Williams | 1971 |

| HUMAN OPERATOR: | | | | | |
|---|---|---|---|---|---|
| Bitticker | 1976 | Dickinson | 1979 | Kelley | 1968 |
| Caplan | 1975 | Edwards | 1972 | Rasmussen | 1971 |
| Carbonell | 1968 | Edwards | 1974 | Sublett | 1976 |
| Carlo-stella | 1976 | Edwards | 1976 | Umbers | 1979 |
| Carter | 1972 | Galitz | 1969 | Lees | 1972 |
| Chubb | 1970 | Good | 1971 | | |
| Dallimonti | 1974 | Julian | 1976 | | |

| MAN-COMPUTER INTERACTION: | | | | | |
|---|---|---|---|---|---|
| Bainbridge | 1970 | Burnett | 1972 | ERS/69 | 1961 |
| Bishop | 1970 | Butler | 1971 | IBM/68 | 1968 |
| Baker | 1966 | Dallimonti | 1976 | IEE/71 | 1971 |
| Brown | 1970 | Gould | 1968 | | |

| MAN-MACHINE INTERFACE (DESIGN + GENERAL): | | | | | |
|---|---|---|---|---|---|
| Berta | 1971 | Duncanson | 1971 | Lagana | 1981 |
| Brown | 1970 | Engel | 1975 | Purdue | 1977 |
| Crawley | 1976 | Foley | 1974 | Rijnsdorp | 1977 |
| Crooks | 1974 | Geiser | 1980 | Rouse | 1975 |
| Dallimonti | 1980 | Handler | 1968 | Umbers | 1981 |
| Dallimonti | 1982 | Kuschnerus | 1971 | Webers | 1982 |

| GENERAL: | | | | | |
|---|---|---|---|---|---|
| Alden | 1972 | Jossi | 1981 | Ryan | 1981 |
| Cowley | 1978 | Kawabe | 1981 | Schlatter | 1982 |
| Deutsch | 1977 | Kompass | 1983 | Sperandio | 1974 |
| Ficarro | 1979 | Kornstein | 1978 | Suzuki | 1980 |
| Gopalkrishna | 1981 | Martin | 1973 | Uyetani | 1978 |
| Gray | 1982 | Masucci | 1977 | Wiercinski | 1981 |
| Hampel | 1980 | McMorris | 1971 | Williams | 1977 |
| Janes | 1983 | Ostmeier | 1980 | Yamaguchi | 1978 |
| Johnson | 1976 | Pluhar | 1980 | Yates | 1971 |
| Jong | 1971 | Ramaker | 1976 | | |

provides this information.

3. Sections:

a) Section A: This section gives a list of References which are arranged according to author names. These references were gathered during the project and as time did not permit finding all of the articles, it was decided that it would be valuable to include them. Some of the earlier articles which are not in the main body are deliberately included in this section as more recent articles supersedes them. In a few exceptional cases, when this is not true, I have included them in the main body.

b) Section B: This section gives a list of major books to supplement the articles and help to fill whatever gaps in coverage that would otherwise exist. In this section, books are arranged alphabetically by author name.

Conclusions and Recommendations:

This annotated bibliography will be useful in facilitating both research and teaching. Apart from serving as a valuable tool for researchers, certain tutorial articles form an excellent introduction to a body of knowledge for the student.

Periodically, this annotated bibliography should be updated to include current research documents.

Alden, D.G., Daniels, R.W., and Kanarick, A.F. Keyboard design and operation: A review of the major issues. Human Factors, 1972, 14, 275-293.

A search of the physchological, Technical, and promotional literature was conducted to compile information relevant to key, keyboard, and operator characteristics. The most recent and significant articles were discussed and evaluated. Where possible, general conclusions have been drawn to aid the keyboard designer.

Andreiev, N. Versatility in color - a look at industrial graphic CRT displays. Control Eng. vol. 22, no. 8, (August 1975) 30-2.

Describes the graphic c.r.t. display, with alphanumeric and graphic capabilities coupled with color and microprocessor supplied 'brains', are making the c.r.t. a serious contender for a growing percentage of all future control displays.

Aronson, R.L. CRT terminals make versatile control computer interface. Control Engng. (USA), vol. 17, no. 4, (April 1970) 66-9.

Cathode ray tubes are being adapted to industrial process control, and are capable of displaying piping and other process diagrams, tabulations of process data, trouble shooting charts, startup and procedural flow charts, signals of alarm conditions with recommended corrective actions, and even operator training material, if desired. Some of these techniques are described and illustrated, their potential for specific types of process is considered, and some early actual installations are cited. Different types of crt terminals with widely varying capabilities and costs (hardware and programming) are considered, with advantages and tradeoffs.

Aust, J. The Touch Display Simplifies the Man Machine Interface , Instrum. & Control Vol. 12, no. 5, Oct. 1971 109-111.

This touch display has been developed as a simple method of interaction between man and machine. Basically it can be considered as a means by which a computer presents a list of choices which are available to an operator at any given instant and as a means by which the operator indicates his choice to the computer. Each choice is made from a list displayed on a visual display unit and the content of each succeeding list similarly displayed, is determined by the previous choice.

Bainbridge, The Influence of Display on Decision Making IEE/70

This analysis suggests various influences on the process by which an operator makes control. Computation all of which require further test. The computations may be digital or analogue. And this is influenced by the type of display on which the relevant variables are presented. In addition computations may not be made using a continuous analogue but using a few discrete steps, or category values, where the aim is to identify a discrete setting or qualitative category.

Berta, Kornel 'New Possibilities for the Operator, Engineer, and Management Interface with the Process Control Computer and Process IFAC 1971 (1), 180-187.

The essential needs of communication and interaction between the process and the operation, engineering, or managing personnel are summarized. The conventional interface between the process control computer and the operator, engineer, and management is briefly reviewed in the light of their needs. It is shown that some recently developed devices can function better than the conventional ones as an interface between the process and the operating and engineering personnel as well as a communication device between the process or several processes and management.

Bishop, P.G. Display and Input Software for On Line Control IEE/70.

For on-line control, a software package is needed which enables the general user to produce displays without needing a specialist understanding of input/out programming. Display programs should be separate from the main control programs so that the display can be easily and safely changed when the computer is operational. The display programs should be compatible with any of the program languages in use in the installation, the input programs should be written in a way which makes the display and input device compatible.

Bitticker, William R. The Process Operator - Heart of Production ISA/1976.

This paper reviews operator communication requirements from a practical viewpoint based on experience with process computer systems, and discusses basic principles that should be included in the design of computer/operator communications. Typical computer display and data input functions found in an industrial process environment and in meeting the requirements of the operator. Hardware interface, computer system design, and programming considerations are presented.

Bond, A. At Last, a Real VDU Alternative to Giant Control Panels Control and Instrum. (BG) Vol. 9, No. 5, May 1977, 33.

CRT-based display systems have so far failed to achieve a high level of acceptance as replacements for conventional control panels. The author looks at a new system that might tip the balance in favour of the color VDU.

Braddock, B.D. Characteristics of visual display terminals, Telecommunications (USA) vol. 7, no. 11, Nov. 1973, 31-35.

Advances in technology have made VDT's economical for use in low speed/hard copy applications. The article discusses user parameters of alphanumeric display terminals.

Brown, M.F. Man-computer control interface (General Electric Co., NY, USA) Centralized control, looking forward to the seventies, New Brunswick, N.J. USA 23-25 March 1970 (Pittsburgh, PA, USA: Instrum. Soc. America 1970), 7-14.

This paper reviews the methods and concepts currently being used as communications tools with process computers. It covers the application and features of cathode ray tubes, alphanumeric displays, light box matrices and special purpose operator's consoles. It is primarily the operator's consoles which determine the flexibility of control and the maximum operator work load. The paper also reviews some of the advantages to the user of high level software packages such as BICEPS. These types of programs allow plant personnel at the engineering level to develop their own operating control programs.

Brown, R.M. An experimental study of an on-line man-computer system. IEEE Transactions on Electronic Computers, February, 1965, EC-14, 82-85.

One of the more promising areas of computer use involves the coupling of a man to a computer system for real-time problem solving where the procedure for solution of the problem is either unknown or involves complex tasks, such as pattern recognition, that can best be performed by humans . Unfortunately, a straightforward approach to such use commits significant amounts of computer time most of which is spent idling. The imbalance in operating costs, assignable to the human and the computer, argues against computer use unless the total gain over strictly manual operations is sufficiently great. The technique of computer time-sharing, currently under development in several institutions (2), attempts to divide the computer costs among a number of users by interweaving the execution of their programs so as to share the operations time while also minimizing mutual conflicts. The success of this technique rests on a number of assumptions concerning the characteristics of the programs if run alone. This paper defines some properties of on-line programs useful in predicting their performance under time-sharing. It then describes a specific man-machine program and gives experimental measurements on this program. While at this stage of understanding, no man-machine program can be described as "typical," this program, containing both operator-controlled data measurement and typewriter dialogue between a computer program and an operator, is sufficiently illustrative of interactions that can occur so that the data on such a program are felt to be of help to system planners.

Bryden, J.E. Design considerations for computer driven CRT displays , Comput. Design (USA) vol. 8, no. 3, (March 1979) 38-46.

A display should match the characteristics of a computer to the visual system of man. Important relationships, together with some of the practical limitations of a CRT display and its auxiliary equipment, are reviewed, concluding with a short review of design trends.

Bryden, J.E. Visual displays for computers , Comput. Design. vol. 10, no. 10, October 71, 55-60.

Discusses visual displays for computers with regard to selection of equipment. Systems discussed range from single alphanumeric read-only displays to high capability, interactive, dynamic-graphics displays capable of multimode operation. Consideration is given to versatility, image content, operator display interface and user application software.

Bryden, J.E. Visual display systems, Electron. Prog. (USA), vol. 13, no. 3, (Fall 71) 2-10.

A visual display may provide a communications link between man and machine. The machine may be almost any device; it could be a radar system, a communications link, a computer or clock. A display subsystem may include data processing and facilities for the operator to enter or edit data. The advancement of display engineering is occurring on four separate fronts. New applications, processing data, hardware design, and human engineering. Each of these areas is discussed and an attempt is made to indicate the trend of development.

Burnette, K.T. Evaluating the man-display interface. Electron. Eng. (USA) vol. 31, no. 7, (July 1972) 64-67.

Progress to determine the most effective information presentation form at the man-display interface has been very slow. One technique to solve the interface problem has been the development of 'display quality factors', which are highly complex functions of both the human perception and the display environment. Among these quality factors are flicker, display element resolution, visual acuity, and constrast-luminance requirements. Also affecting the choice of a display are factors involving legibility, information coding, and size which vary greatly with the individual situation and must be handled statistically.

Butler, H.S., B.L. Hartway, D.R. Machen, T.M. Putnam. An operator's console for the LAMPF accelerator. IEEE Trans. Nucl. Sci. (USA) vol. no. 18. no.3, (June 1971) 419-21.

The control system for the Los Alamos Meson Physics Facility (LAMPF) accelerator is organized around an on-line digital computer. The computer's versatility in acquiring and arranging data for presentation to the operator made a strong impact on the design of the operator's console, and the central control room. The racks full of lights, meters, and knobs so typical of a conventional control system were replaced at LAMPF by a compact console in which the prominent device is a graphic display scope with a light pen. This paper traces the evolution of the present LAMPF operator's console.

Caplan, S.H. Guidelines for reducing human errors in the use of coded information. HF/75

This paper presents code design and display guidelines intended to make it difficult to generate a code-related error and easy to detect errors that still occur. Principles governing immediate memory and rules for making erroneous codes easily recognizable combined to form guidelines for code design. Design factors include various dimensions of code configuration length, the kind of characters, their location and grouping. These guidelines minimize the common errors of substitution, transposition, ommission, and addition of characters. Besides the code itself, errors are also affected by the way the code is displayed. To further enhance reliability, additional guidelines are included for the size, style, and contrast of characters. A reliable code system requires a structure which is compatible with human recognition and short-term memory capabilities. These abilities have been extensively explored in the experimental psycology literature. The particular studies used as a basis for the coae guidelines in this paper are those where recall follows perception by only a few seconds and no intervening information is processed in the interim. These experimental conditions correspond to usual transactions in which transcription or keypunching closely follows visual perception of the code.

Carlo-Stella, Guido R. and Keiles, Yoel. Process, operator and computer interface for a distributed microprocessor-based system. ISA/1976.

The distributed organization of a microprocessor based system offers a considerable potential for enhancing the performance and the reliability of the system interfaces with the human operator and the process.

A specific example of how this may be accomplished is given.

Carter, R.J. On-line digital control systems - the role of the process operators. London England: Inst. Measurements & Control 1972 19-23.

This paper stresses that greater emphasis on people achieves the dual results of making firms much better places in which to work and also of increased efficiency, profits and benefits all round. It describes features of commercially demonstrated systems which meet the needs of the process operators and which, in turn, are necessary for the effective utilisation of the system itself.

Clarke, J. and Welbourne, D. Display systems for use on line power situations. IEE/1970.

A typical nuclear power station reactor-turbine unit involves about 2500 contact signals for alarms and state indications, together with a similar number of analogue signals from thermocouples, pressure, flow and position tranducers and other measurements. Practice on current C.E.G.B. stations in that these signals be processed and displayed by an extensive on-line computer system. The systems for Wylga and Hartle pool stations are described in this paper.

Coffey, J.L. A comparison of vertical and horizontal arrangements of alpha-numeric material-experiment. 1. Human Factors, 1961, 3, 93-98.

The objectives of this study was to determine the relative effectiveness of visual display containing alpha-numeric material displayed in vertical and horizontal arrangements. Variables included in the experimental design were: types of arrangement of display material, density of material, composition of material, and operator tasks. The major finding in the study was the non-significance of the purposes, the differential effects of vertical and horizontal arrangement of alpha-numeric materials on operator performance are negligible.

Corkindale, K.G.G. The evaluation of visual displays. IEE/1971.

The history of research on display evaluation over the past thirty years is briefly described. Any evaluation programme depends on the establishment of suitable criteria. Methods of developing criteria based on an analysis of the function of a display are outlined Such an analysis also determines the choice of subjects and the environment in which the evaluation programme is undertaken.

Cowley, P. Remote Plant Monitoring. New Electron (GB) vol. 11, no. 24, Dec. 12, 1978, 100-1.

Describes RPMC (Remote Plant Monitoring and Control) which is a software system whose primary functions are to continually monitor the state of remote plant and to provide operator and process control supervision of industrial environments.

Crawley, J.E. Simulation studies of interface design. ISA/1976.

The methodology used in this research is an examination under similation conditions of the information interface between the computers and the human decision-maker. Areas covered by this technique so far include certain aspects of basic oxygen steelmaking, the scheduling activity associated with the operation of soaking pits and an examination of computer based order entry systems. Results of the simulation work associated with these activities are reported and the plans for validating the information treatments developed under simulation are also reviewed.

Crooks, W.H., Artof, M., Weltman, G., and Freedy, A. Man/machine interaction in adaptive computer aided control: Analysis of automated control allocation. Woodland Hills, California, Perceptronics, Report No. PATR-1008-74-12/30, December, 1974.

Control allocation between the human operator and an intelligent control element is becoming an important part of advanced Navy systems, which place increasing emphasis on decision making as compared with manual control. The present research focuses on human factors criteria for the man/machine interactions in such shared decision and control systems. The research effort includes evaluations of task allocation methods, information feedback, decision risks, and operator indoctrination. This report presents the results of a series of experimental investigations of adaptive computer-aided control and task allocation.

Crowder, R.S. CRT interfaces for a continuous plant . Instrum. Technol. v. 18, n. 1, June 1971, 58.

Computer control technology opens up possibilities for better plant information systems. Dupont now uses a console with three graphic and alphanumeric CRT displays to monitor and control a batch plant, and selected a similar system for a new continuous process. The author describes how three consoles will be applied in an integrated plant that has control corps.

Crowe, J.E. A microprocessor based CRT operator display system for process control. IEEE/1976.

An operator station is discussed which condenses the physical area a process control operator must monitor and manipulate while presenting him with additional information to that which is available at the panel instrumentation.

Cundall, C.M. CRT Display Systems. Electronics and Power (GB) v. 14, March 1968, 115.

Automation systems become more complex, so it becomes more necessary to adopt technically sophisticated methods of communicating with the operator, more by simplifying his task. CRT displays now forms the basis of many such man-machine communication systems.

Dallimonti, Renzo. Advanced Design of a Central Operator Console for Process Control, II. ISA/1973

Modern computer and display technology already provide the tools for implementing bold and exciting innovations to the man/machine interfaces of the future. The communication of plant operating personnel with their processes requires serious analysis of the role of people and machines. A central operator's console for all plant unit control and monitoring is rapidly becoming feasible as a practical replacement for the large instrument panel. This paper describes the design of an advanced prototype console which has been built to explore the operational and economic practiality of plant unit-operation from such a single, "desk-type" control center.

Dallimonti, R. New Designs for Process Control. Consoles, I. Instrum. Technol. (USA), vol. 20, n. 11, Nov 1973, 48-53.

Modern computer and display technology already provides the tools to implement exciting innovations in the man/machine interfaces of the future. The communication of plant operating personnel with their processes requires serious analysis of the role of people and machines. A central operator's console for all plant unit control and monitoring is rapidly becoming feasible as a practical replacement for the large instrument panel. The author describes a prototype built to evaluate operational, economic, and human engineering factors in the design of such a console.

Dallimonti, R. Future Operator Consoles for Improved Decision-making and Safety. Instrum. Technol. vol. 19, n. 8, Aug. 1972.

Considers limitations of computer linked complete control systems on a desk. The main constraint is considered to be operator's capabilities.

Dallimonti, R. The Human Operator in Process Control Systems, European Conference on Electrotechnics, Euro Con-74 Digest, A3-6/ 2.

The author alludes to the elimination of large instrument panels by small desk sized consoles using CRT displays in conjunction with computer systems. This paper describes a prototype design of such a console which has been built to explore operational; technical and economic feasibility.

Dallimonti, R. Human Factors in Control Center Design, Instrum. Technol. vol. 23, n. 5, May 1976 62-70.

As more and more industrial processes are becoming automated, human operators are being required to digest more and more data. Instead of using every display feature built in to CRT's, the author suggests that more attention be given to generating displays which are meaningful to human operators. The author explored the human factors and psychological side of man/machine interface, and offers a continued number of new display formats designed to make the best use of an operator's talents.

Dallimonti, R. Principles of Design for Man-Machine Interfaces in Process Control . C.E./1980.

Methodology and principles are collected for guidelines to the design of man-machine interfaces for process control applications. The importance of establishing a human factors basis for design is stressed. The premise is made that future operator interfaces will be entirely CRT console-based and principles are discussed within that context. The subject is covered in four categories - Plant structure, human behavior , display design and control center environment.

Dallimonti, R. Challenge for the 80S: Making man-machine interfaces more effective (Process control). Control Eng. (USA) vol.29, n.2, Jan. 1982 26-30.

The introduction of digital control systems, based on microprocessors and serial data highway communication, brought with it the CRT console as the operator's new 'window' to the process. As a result, hundreds of control centers have since been designed without the traditional panels full of individual instruments-instead they are replaced by multiple CRT consoles. The instruments in operator performance which this development offers are discussed.

Danchak, M.M. CRT Displays for Power Plant, Instrum. Technol. (USA) vol. 23, n. 10, (Oct. 70) 29-36.

Discusses color CRT display design for effective human response with particular reference to monitoring and diagnosis of power generation systems.

Danchak, M.M. Effective CRT display creation for power plant applications. Computer and Control Abstracts vol. 12, no. 135 (August 1977).

Sophisticated information display tehcniques are being used to improve man-machine communications in the control of nuclear power generating stations. Creation of effective CRT displays requires a detailed knowledge of the process, display techniques, and the operator. A methodology has been devised for display creation that identifies the purpose of a display and the primary task required of the operator. Guidance is then provided for determining the appropriate type of display, format, density, and coding method. The methodology and examples of its application are presented as well as human factors problems pecular to process control displays.

Deutsch, L.-S., Engelse, W.A.H., Zeelenberg, C, Van Der Voorde, F., and Hugenholtz, P.G. The United Patient Monitoring System: A New Approach for a New Technology. Med. Instrum. (USA) vol. 11, no.5, Sept.-Oct. 1977, 274-7.

The unibed system represents a new approach to the design of medical instrumentation based upon recent advances in microcomputer and related large-scale integration technology. The system is intended to replace an entire range of traditional monitoring devices with a single general-purpose unit capable of recognizing the nature of the signal source and performing appropriately. All of the usual switches, knobs, dials, and meters have been replaced by a touch-sensitive character display. The hardware responsible for physiological signal analysis, information display, and user interaction is actually a set of firmwave modules implemented in terms of microcomputer programs. This firmware gives the system its functional personality and transforms it from a compact process-control system into a useful medical instrument.

Dickinson, A.B. Remember Operator Needs When Selecting CRT Displays. It's the Best Way to Ensure the Success of Your System. Instrum. and Control Syst. (USA) vol. 52, no. 3, Marcn 1979 37-41.

In any process control system, the operator is one of the keys to success. Whether the system is large-case pneumatic, miniature electronic or computer-based with CRTs, the system's success will depend upon how well the operator interfaces with the instrumentation. both visually and manually. The author discusses the selection of CRT displays for control systems based on the operators' needs.

Distributed System Provides PID and Logic Control. Can. Controls and Instrum. (Canada) vol. 20, no. 1 Jan. 1981 106-7

Describes a new microprocessor-based distributed control system from Bailey controls. The Network 90. The system is based on process control units which can each control up to 50 loops individually or connected via a data communications highway to conventional or CRT-based operator displays and control panels and to computer interfaces. It can provide modulating (i.e., PID) and/or sequential logic control in industrial and utility power generation applications. Particular advantages are said to be flexibility for growth and adaptation as control needs of a plant alter, simplicity of use and economy.

Distributing the Operator's Panel Adds to Distributed Process Control. Control Eng. (USA) vol. 26, no.3, March 1979 56-7.

A description of Fischer and Porter's new distributed process control system. It is unique in that, in one configuration, it provides a local CRT-terminal operator's panel for independent dedicated unit control, or as backup for a central operating console located at some distance on a data highway.

Dolkart, V.M.; Pure, R.R.; Kramfus, I.R.; Lurie, V.V.; Munday, C.W. (editors). Colour CRT data dispaly system for process control applications. Automatic Control in Space. IFAC/80

The problem of process computer control implementation is that of providing high reliability of control functions rather than the probelm of providing high reliability of computer hardware itself (so called fault-tolerance). Apart from architecture and computer hard-ware performance, process to operator interface is becoming of ever increasing value for higher system efficiency. Process-operator interface and data display facilities must meet human engineering and fault-tolerance requirements. The display system consists of colour displays and one or two function key boards connected via colour monitor interface, Key board interface and two link remote units interface. Images are described by sets of tables and are coded using the graphic image language. The language is a graphic macro-assembler of an interpreting type. The design of the display system gives a user necessary flexibility and enables him to tailor the system according to different applications.

Don't Forget the Operator: He's Only Human (Process Control) Electr. Rev. (GB) vol. 208, no. 11 20 March 1981, 35 - 37.

Efficient process control depends on rapid and effective communication between the controlling hardware and the human operator. Poorly designed information display systems can lead to unnecessary delays in operator response which can result in expensive disruptions of the process being controlled.

Duncanson, L.A. Interfaces with the Process Control Computer <u>IFAC/</u>
71 (1).

In the Heavy Organic Chemicals Division of ICI Ltd., the installation and use of on-line computer control is seen in the context of the development of a hierarchy of mathematical models of the production situation and their use to maximize profits at all levels. The present situation in the development of these models is described and a detailed account is given of a typical large on-line computer system. The problems of the interfaces between the computer and the operator, the engineer and management, are considered in the light of this experience, and possible future developments are briefly discussed.

Dupuis, L.J. Computer Operator Interface for Steel Plant Application.
<u>IEE</u>/75.

The ingrained procedures and egos of operators are challenged in making the adaptation to a computer controlled system. In order to wean the operator from conventional manual operation to the concept of an interactive role with a process control computer the system engineer must recognize and accept the challenge of engineering both computer compatible and operator acceptable man/computer interfaces. Unless this aspect of the overall system is given thorough consideration, neither the timely nor the successful implementation of a process computer control system is likely to be realized.

Edwards, E., F.P. Lees. Information display in process control. IEE/1971.

Over the past twenty years or so, an enormous literature has appeared concerning the human factors aspects of displays. Experience of large and complex information systems has given rise to the concept of a 'computer-supported system' in which the hardware, software and liveware components are appropriately integrated in a manner which best exploits the virtues of each. The introduction of computers into control systems enlarges considerably the ways in which displays may be designed. But in any system with or without sophisticated devices, display recommendations can only follow upon an analysis of the exact requirements of the interface, that is to say of the nature of the role of the user of the display. (20 refs.).

Edwards, E. The Influence of the Process Characteristics on the Role of the Human Operator in Process Control. Inst. Measurement and control, March 1972.

The functions normally performed by a process control computer are described and those consequently left to the operator are defined. The wide variety of operator's function and the implications of this for studies of the operator's performance and for the design of man-machine interface are emphasised.

Edwards, E. and Lees, F.P. The influence of the process characteristics on the role of the human operator in process control. Applied Ergonomics, 1974, 5 (1), 21-25.

Rational design of a process, control system using an on-line computer requires a definition of the total control task and an allocation of function between the human operator and the machine. Both the nature of the total task and its subdivision depend very much on the process characteristics, which vary widely between different processes. The functions normally performed by a process control computer are described and those consequently left to the operator are defined. The wide variety of the operator's functions and the implications of this for studies of the operator's performance and for the design of the man-machine interface are emphasized.

Edwards, E., Lees, F.P. The Development of the Role of the Human Operator in Process Control ISA/76.

Rational design of a process control system using an on-line computer requires a definition of the total control task and an allocation of function between the human operator and machine. A knowledge of the historical development of the role assigned to the human operator provides useful guidance in making the allocation decision. This development is described, with emphasis on the function performed by the operator in modern computer control systems, on the importance of different process characteristics, on the increased understanding of the operator's role obtained from attempts to automate it completely and on the need to choose appropriate systems when carrying out experimental studies of the operator.

Engel, S.E. and Granda, R. E. Guidelines for man/display interfaces. International Business Machines, Report No. TR 00.2720, December, 1975 .

This report documents a set of human factors guidelines relating to this interface between a user of an interactive computing system and a display terminal connected to the system. Though intended primarily for the use of developers of software for an interactive system, many of the guidelines should be of interest to hardware developers. Areas covered include display frame layout., frame content, command languages, error prevention and recovery, response times, and behavioral principles.

Ficarro, P. Distributed Systems for Process Control. AIChE/ 1979.

Distributed and hierarchical control systems have evolved over the last few years as a natural outcome ofthe need to segregate process control functions by Process Area and Level of Control while maintaining overall system security and ease of use. Working definitions are advanced for control levels and the paper illustrates their implementation with presently available process control modules. Various trade-offs related to the issues of system through-put, flexibility, data-access and bakcup are addressed within the context of total system usability and man-machine communications.

Foley, J.D. The human factors - computer graphics interface, Washington, D.C.: The George Washington University, Department of Electrical Engineering and Computer Science, June, 1978.

Most Interactive Computer Graphics Applications (ICGA) in use today have been developed with absolutely no help from human factors specialists. This situation is frustrating to all of us who recognize that good human engineering can be central to the success of an application. The cause of this dilemma is examined, and several remedies are prescribed. The role of human factors engineering at each step of the design process, and to suggest a conceptual framework within which current human knowledge might be structured and future research might be performed.

Foley, J.D. and Wallace, V.L. The art of natural graphic man-machine conversation. Proceedings of the IEEE, 62 (4), April 1974, 462-471.

The design of interactive graphic systems whose aim is good symbiosis between man and machine involves numerous factors. Many of those factors can be judged from the perspective of natural spoken conversation between two people. Guiding rules and principles for design of such systems are presented as a framework for a survy of design techniques for man-machine conversation. Attention is espceially focused on ideas of action syntax structuring, logical equivalences among action devices, and avoidance of psychological blocks to communication.

Freer, B.C. Considerations when using colorgraphic terminals with programmable controllers. IEEE/1982.

Color graphic terminals have been on the market for several years now and were mainly used in the process control industries. The process industries used them to monitor and control PID loops. Alarms were also annunciated by the colorgraphic terminal and used to correct these faults. Today the colorgraphic terminal has spread into many different industries other than process. The main reason for this expansion is the need for operator communication. No longer is it sufficient to rely on indicator lights and expensive mimic diagrams. The colorgraphic terminal has added a new dimension to operator control by providing a 'window' to the operation. This window allows the operator to be kept informed of any changes. The colorgraphic terminal has allowed an entire plant to be monitored from one central control station. But the colorgraphic terminal doesn't do the job by itself. It has to be supported by a communication network and control equipment.

Friedwald, W., Charwat, H.J. Design of Graphic Displays for CRTs in Control Rooms. Process Autom (Germany) No. 1 1980, 7-12.

Proper design of graphic displays should account for the tasks of the operator in process control. The authors show that his main tasks (monitoring, control, diagnostics) determine the organization, his elementary tasks (perception, searching, identification, counting, comparison and verification) determine the coding of the information. From this, concrete hints and rules for the design of graphic displays are derived.

Galitz, W.O. and Laska, T. J. Computer system peripherals and the operator. Computer Design, August, 1969, 12, 52-56.

Little effort has been directed toward increasing the understanding of the role of the (computer) operator in the system. Observing, measuring and understanding his behavior is essential if systems engineered and designed for humans are to be developed. Highlights of a study of the computer operator's relationship to peripheral devices is presented here.

Geiser, G. Ergonomic Design of Man-Machine Interfaces. IFAC/80

The ergonomic adaptation of the human operator's working conditions to his abilities is fundamental for the acceptance of computer control systems. The corresponding ergonomic design areas are: Anthropometry, working environment, social context, training, personnel selection, and man-machine communication. Man-machine communication is determined by information presentation on displays by control devices, and by human operators processing of information. For the presentation of the information, displays have to be elaborated according to the following steps: perceptibility, coding, and organization of information. Mathematical models are needed to predict human performance in man-computer information processing tasks.

Gillenson, M.L., B. Chandrasekaran. A heuristic strategy for developing human facial images on a CRT. Pattern Recognition (GB), vol. 7, no. 4, (Dec. 1975) 187-96.

Sketching a recongizable human face involves artistic talents and an intuitive knowledge of which aspects of the face are important in recognition. A man-machine system calles WHATSISFACE, has been developed with which a nonartist can create, on a graphic display, any male Caucasian facial image resembling the face of a photograph in front of him. The computer system contains pre-stored facial features, an average face used as a starting point and a heuristic strategy which guides the user through a carefully constructed sequence of questions, choices and feature manipulation. The user makes all the visual decisions and can change the individual features of hierarchically organized sets of features using analog input devices (11 refs.).

Good, L.p. Operator communications in modern process plants. IEE/1971.

Earlier work has categorised the process operator's need for information on the basis of overall process plant control being a co-operative effort between the instrumentation system and the human operator where the assignment of tasks to each depends to a great extent on the plant designer's ability to define concisely the operation of the plant under all normal and abnormal conditions. Briefly, this means that, under *normal operation*, the lower levels of the control system are automated and control of the primary specifications for production is left to the operator. He requires accurate information about the relatively few main process variables, preferably in digital form.

Gopalakrishnan, R. Electronic Instrumentation for Control. J. Inst. Electron. and Telecommun. Eng. (India) vol. 27, no. 2, Feb. 1981. 53-60.

Advancement in the area of electronic devices, particularly microprocessors, have pushed electronic systems in process control, far ahead of other known and established systems. With increased reliability of the present day devices and provision of redundant systems of marginal extra cost, the confidence of the plant operator in electronic instrumentation is restored to the same level as with the conventional pneumatic systems. Intrinsic safety features limiting the energy at the field equipment at the minimum permissible level, have rendered electronic systems acceptable for the most hazardous plant environments. The early electronic analog system on the low level current signal concept (4-20 MA) is being fast replaced by digital systems with visual display units. The underlying emphasis being ergonomics or human engineering. In this system the process control components have been made functional by split architecture, wherein controllers are de-linked from display systems and operator control.

Gould, J.D. Visual factors in the design of computer-controlled CRT displays. Human Factors, 1968, 10, 359-376.

This paper is concerned with the important visual variables that determine image quality on computer-controlled CRT displays. A strategy is developed that leads to general conclusions about each variable even though most of these variables interact. For each variable considered, the recommended range of values is determined on the basis of experimental evidence and is compared with the values presently used on idsplays. Where discrepancies between these two exist, alternative solutions are mentioned. Conclusions are (i) presently used values of display luminance, chromaticity (color), and resolution are adequate; (ii) several displays flicker; (iii) characters are large enough but may be marginal in terms of number of elements (iv) liminance contrast is not adequate.

Gray, D.J. Central Control System for a Modern Cement Plant at Cape Girardeau, MO. IEEE/1982.

A control approach of using solid state motor control and microprocessors for process control with necessary peripherals for supervisory and management reporting is described. The interactive color graphic system for operator interface is explained. In conclusion, a good, operable system was developed for the operator

Hampel, J., Wilkie, D. A microprocessor controller for interactive control applications. IFAC,IFIP/ 1980

With current electronics technology, a microprocessor based controller optimized for sophisticated control is feasible. Such a controller must provide multiple PID algorithms and numerous computing and logic functions. The paper presents a concept for such an interactive controller. The interactive controller offers many of the capabilities commonly found in minicomputer based process control systems. It offers the control engineer prewritten software which includes a standard library of numerous sophisticated control functions. The interactive controller can be applied in a distributed control system using VDUS for operator interface or as a standalone uint with panel mounted stations. In either application the interactive controller offers minicomputer-like capability in a smaller package at a fraction of the cost of a typical minicomputer based process control system.

Hanson, H.R. , D.G., Shively, R.J., and Kantowiz, B.H., Process Control Simulation Research in monitoring analog and digital displays. HF/81

An experiment was conducted to determine analog versus digital CRT displays in error detection monitoring. The first part of the experiment examines the degree to which check reading and rate of change of information are more appropriately displayed in an analog format. The results of this experiment showed that there was a significant effect of display type favoring the analog format. They concluded that the digital display led to poorer overall performance than the analog format.

Hitt, H.D., Schutz, H.G., Christner, C.A., Ray, H.W., and Coffey, J.L. Development of design criteria for intelligence display formats. Human Factors, 1961, 3, 86-92.

A broad research program to develop design criteria for intelligence display formats is outlined and the general findings of the program are discussed. Five specific areas of investigation are selected for study: a comparison of vertical and horizontal arrangements of alpha-numeric material, an evaluation of formats for trend displays, an evaluation of methods for presentation of graphic multiple trends, an evaluation of five abstract coding methods, and an evaluation of the effect of selected combinations of target and background coding on map reading performance. The five succeeding articles treat the five areas of investigation in detail.

Hurd, E. Process plant data transmission and display - the future possibilities. Inst. Measurement & Control 1972, 42-9.

The paper is in two sections. The first attempts to describe what an ideal man-machine interface might be in the control room; the second deals with a hardware implementation that could lead to an improved interface.

Intech (USA) Selected CRT-based Process Interfaces. Vol. 26, no.2, February 1979, 28-33.

Process operator interfaces have improved during the past few years. Taking advantage of the capabilities afforded by digital signal processing. Cathode ray tubes are the most visible feature of the new workstations. But a number of other hardware and software factors should be considered before making a selection.

Janes, C.C., Brodzik, D.A. Eliminate the keyboard with touch-sensitive CRT screens. IEEE/1983.

Kitt Peak National Observatory (KPNO) is experimenting with the use of touch technology as a method for human interaction with the computer in process control. The authors describe an application in which a touch sensitive terminal is used for a large telescope control, discuss the design considerations, and review the strengths and weaknesses of the technology.

Jervis, M.W. CRT displays of graphics in CEGB power stations. IEEE/1971.

In power stations with centralised control the large amount of information required by the operator can be presented on moving coil indicators, lamp alarm annunciators and chart recorders, mounted in control room desks and panels. This arrangement has limitations and these have led to the adoption in some modern power stations of computer-based cathode ray tube displays. These replace most of the indicators by alpha-numeric displays, the alarm annunciators by messages on the crt's and chart recorders by graphical displays. Permanent records are produced by electric typewriters on demand or automatically at regular intervals. This paper reviews crt displays of graphs and gives notes on the layout of graphs on crt's. Permanent records are not discussed.

Jervis M.M. The Use of Alphanumeric-CRT Data Displays in CEGB power stations. IEE/70.

This paper is a discussion of the alphanumeric tabular displays and can be regarded as a progress statement of the current situation. However a further object of the paper is to raise the question of the importance of the design of object of alphanumeric displays in process control applications and the criteria which can be applied to assess these merits.

Johnson, Roger R. Centralized Control Concepts: an Evolution of Operator Interfacing in Process Control. ISA/1976.

Nowhere in present society has the dynamic innovation of the electronics industry had more impact than process control. Electronic controllers have enabled the application of centralized control concepts to improve quality and productivity. In the last ten years, evolution of process operator interfacing has taken place. The intent of this paper is to show progress in this area and indicate what the 1980's has in store.

Jong, J.J. de ing., ir. T.W Oerlemans and K. Spaargaren. Technical, Economic, and Human Factors in Computer Control. IFAC/71.

In this survey paper an attempt is made to describe present thinking on the technical, economic and human aspects of computer control. At the same time it is tried to assess the interaction between those three topics.

Jossi, H., Schweizer, P. Process Control with DP System Family for Cement Works. Brown Boveri Rev. (Switzerland) Vol. 68, no. 10-11. Oct-Nov. 1981 365-72.

For cement works BBC employ a process control system with a hierarchical structure, characterized on the one hand by extensive delegation of tasks to a large number of systems distributed throughout the process on a lower hierarchical level and, on the other hand, by autonomous control of five subprocesses. The higher-order system responsible for the overall processes, besides performing some special control functions, satifies the highly divergent operational and information requirements. Current development indicates a trend towards the use of alphanumeric and semi-graphic CRT displays. The control structure specific to the cement manufacturing process can be realized by the DP family of data systems. Not least due to their modularity and compatibility. DP systems have proved their worth in numerous industrial plants, including cement works, and at the same time provide a sound basis for the future development of control functions.

Julian, Peter R. Control Center Where Man and Computer Work Together ISA/1976.

The concept of a control center has been rapidly changing over the past several years due to the development of computer control.

This paper will attempt to integrate man and computer by means of the control center and to present a prediction of the future of control centers.

Kawabe, K., Homma, M., Terauchi, Y. Instrumentation and Automation Systems for Waterworks. Toshiba Rev. (Int. Ed.) (Japan). No. 133, May-June 1981, 5-13.

TOSDIC is a distributed total process control system, comprising process console with CRT displays access station, DDC station, loop station (DDLS) analog output category, contact output category, digital input/output category, process I/O station, micro-sequence controller (TOSMIS), and data highway (TOSWIRE: Toshiba Wire Sharing System). The process sequence control ability, quantitative and qualitative control, was significantly improved and a system for resources conservation and energy saving was established. Several systems for practical application to waterworks are described.

Kishi, S., Y. Nagaoka, M. Serizawa. A conversational data access procedure for CRT operator consoles (nuclear power plants control). IEEE Trans. Nucl. Sci. (USA), vol.ns 22, no.5, (Oct 1975) 2113-17.

A conversational data access method is proposed in order to avoid the complexity of procedures for data access of CRT operated consoles. The procedure proposed is composed of three hierarchical steps (three structural steps), related to the systems of plant components and operational modes. It is concluded from the simulation experiment that the procedure proposed is superior in many respects to that of the long code entry method. (5 refs.).

Kompass, E.J. Integrated Hierarchical Process Control System is Distributed to Dedicated Loop Controllers. Control Eng. (USA) vol. 30, March 1983, 93-4.

A new system is described, which includes a number of firsts. It covers the entire range of control from simple process loops to plant-wide management systems. All in an integrated package from a single supplier. It uses a separate interactive keypad touchscreen that dynamically changes with the main color CRT display and permits system access and control with no cursor, no codes, and no reference manuals. It uses distributed dedicated microcomputer controllers for single-loop control, with available hot backup. It has a 38-KBAUD serial local network connecting local controllers and supervisory processors and consoles, and a 1-MBAUD serial highway connecting supervisory processors and consoles upward to process management computers and terminals. Total system capability is more than 100000 inputs or 12000 control loops.

Konaka, K., Kamata, Y., Takata, M., Takei, K. Color Monitors for Computer Graphics. Hitachi Rev. (Japan) vol. 29, no. 4 Aug. 1980, 201-4.

Color CRT monitors offer an extremely high man-machine capability as computer terminal display units. Yet they have not been popularized as much as originally expected because their application has been limited to process control and the like. With the recent announcement of color display terminals by IBM and DEC, manufacturers of color monitors have been stimulated into stepping up production of color monitors, which consequently are expected to undergo rapid diffusion in the months ahead. In the field of technological seeds, the last few years have been spectacular advances: First, high-precision monitor screens made their appearance, then in-line electron guns were introduced in high-precision monitors. Hitachi was one of the first manufacturers to introduce the in-line electron gun. It has thus completed a monitor repertory aimed at low price and ease of use.

Kornstein, H. The 8048 Microcontroller in Process Control. Electron Ind. (GB) vol. 4, no.4, April 1978, 39.

Shows how the intel 8048 single-chip microcomputer ('microcontroller') could be used to advantage in a process control system. This system could be a closed loop three-term controller, a sophisticated transducer processing station or a local controller in a hiearchical microcomputer system. The system has an operator interface formed by thumbwheel switches and a numerical output display.

Kuschnerus, Hans J. "Transparent Interfaces", IFAC/71 (1).

Man-machine interface devices and computer peripheral equipment have experienced a hardware proliferation with sufficient choices to meet virtually any control system interface requirement. By comparison, systems and application software packages needed to support these devices and to make the system interfaces effective have been sparse. Efforts by users to develop such software result in substantial cost burdens. Industrial computer control systems at Ford Motor Company are used to illustrate the dynamic nature of discrete manufacturing processes and the functions performed by engineers, operators and managers which can be facilitated by desirable software features. Interface devices can be made more "transparent" through software that adapts control systems to user needs and changing management expectations.

Kuwahara, H., Hayashi, Y., Murayama, N., Hamada, M., Hara, T. Process Display Units. Hitachi Rev. (Japan) vol. 26, n.3, March 1977, 95-101.

Cathode ray tube (CRT) display units in the field of process control were analyzed by utilization into terminal display units and central monitor display units; then for terminal display units, ease of operation, wide coverage and environmental resistance were pursued, and for central monitor display units, new functions were developed such as continuous rolling in all directions and enlargement of screen information. Aiming at appropriate effective, and economical application of these CRT display units in the process control field, the authors have developedthe H-7840 series process display unit which come in three repertories and with various optional features.

Lagana, T., Jr. Digital Control System User Interfaces: The Same but Different. INTECH (USA) vol. 28, no. 11 Nov. 1981, 55-7

Almost all digital process control systems are now being provided with cathode ray tube terminals as primary operator interfaces. Although there are no standards of presentation and interaction, some interface characteristics have become widely accepted. This can create the illusion that systems are all essentially the same, when the reality of the situation is that many options and choices are available, these are discussed in the paper.

Lange, R.A. Apache Container Corporation Process Control System General System Description. IEEE/IAS Annual Meeting 1977.

The Apache process control system is a direct digital control system consisting of the following basic elements: process controller, line interface unit, programmable display, paper tape punch and reader, CRT terminal and machine interface module(s). The system is designed for use as a total plant process controller, the process may be can manufacturing, product assembly, chemical processing, or other complex processes.

Lauher, V.A. How to put a control room on a CRT . Can. Cont. & Instrum. vol. 11, n.3, March 1972, 33-38.

The paper shows how in an analog display concept in status of set points process variables and value positions can be presented to one CRT for as many as 200 control loops. It looks at plant tests of the concept,the results and a glimpse of future process control room designs.

Laugher, V.A. CRT control center for a multi-loop process . Instrum. Technol. vol. 17, n.9, Sept. 70, 33.

In an analog display concept, the status of set points, measured variables and value is presented on one CRT for as many as 100 loops. Designed as either an information display or a control center, this CRT system can be connected to analog controllers only as used with any combination of analog control, DDC and supervisory computer control. The author describes variations on the analog display and explain how the system works.

LeCocq, A.D. The design of a CRT computer terminal - a human factors dream or nightmare?. HF/77

Designing a CRT-type computer terminal within a short period is a significant challenge to engineers, marketing staff, and human factors specialists. During the entire design phase of a new CRT terminal, requirements were generated using empirical studies, evaluations, and application of basic human factors data and techniques. This paper describes in detail how the human factors requirements were determined, and illustrates how human factors can have total involvement in a product, from initial conceputalization to hardware testing.

Lees, F.P., E. Edwards. The influence of the process characteristics on the role of the human operator in process control. Inst. Measurement and Control 1972.

The functions normally performed by a process control computer are described and those consequently left to the operator are defined. The wide variety of the operator's functions and the implications of this for studies of the operator's performance and for the design of man-machien interface are emphasized.

Liss, R. Toward a more colorful supervisory control system . Telecommunications (USA) vol. 7, n. 6 (June 73), 44-47.

Discusses the application of color CRTs in computer based supervisory control systems.

Martino, F.J., Manne, R.E., "Interactive color CRT terminals take on more supervisory duties." Can. Controls and Instrum. (Canada) vol. 14, n.4. April 1975 22-25.

Multi-color CRT displays increase the amount of data which can be presented in a process control room. These displays are a result of a marriage of colour television and computer technologies.

Martin, J. Design of man-computer dialogues. Englewood Cliffs, New Jersey: Prentice-Hall, 1973.

This book is based on a course given at the IBS Systems Research Institute. It deals with many aspects of human-computer transactions. Section headings include the following: alphanumeric dialogues, dialogues with sound and graphics, psychological considerations operators without training, and implementation considerations.

Masucci, P. Computer peripherals give you operator control. Instrum. and Control Syst. (USA) vol. 50, no.7 July 1977, 35-8.

After describing the advantages of computers for process control the author gives some guidelines to implement the peripheral equipment in order to ease the communication between the operator and the computer.

McMorris, A.H. Are control rooms obsolete? Can. Contr. & Instrum. (Canada), vol. 10, no.9, (Sept. 1971). 23-7.

There are a number of incentives for the application of interactive graphic CRT's for industrial process control, especially on complex, changing facilities. This paper looks at a trend that may render the traditional control room obsolete.

McMorris, A.H., J.L. Kekenay, B. Tapadia, E.L. Dohamann. Are process control rooms obsolete? Control Eng. (USA) vol. 18, n.7, July 1971, 35.

CRT consoles can replace graphic panels, indicators, recorders, and annunciator panels - in other words, most of the operator interface gear-in process and utility control rooms. Graphic CRT consoles with light pens for direct operator interaction give plant operators more of the important process data faster - and cost half as much as the conventional control rooms they replace.

Merrit, R. CRT Terminals - an update. Instrum. and Control Syst. (USA) vol. 52, no.5, May 1979, 20-8.

Discusses terminals available today which are finding their way into more and more process control applications. Virtually all full-line instrument manufacturers offer CRTs with their process control systems. The author looks at the wide span of products available and points out a few things one should be aware of when choosing among them.

Mohan Rao, K.C. The use of computer driven displays in the supervision and control of large power systems. IEE/1971

In the supervision and control of a modern interconnected power system, operational personnel need tools to constantly monitor the network, detect alarm and abnormal conditions and perform control actions. Computer driven video display units have been found to well satisfy these requirements to display the network, present the right level of information, indicate alarms, provide operator guidelines on methods of dealing with normal and emergency conditions and to implement control actions.

Muckler, F.A. and Obermayer, R. W. Information Display. International Science and Technology, August, 1965, 44, 34-40.

Displays are intended to provide a human operator with the kind of information that he can transform into useful decisions or control actions. While the technology exists to present qualitative, quantitative, symbolic, and pictorial data, it is not always certain how these forms are best used to assure that the human receiver is getting clear, unambiguous information that can lead to the desired output of the total man-machine system. Man is a unique information processor because he gives meaning to information. But his processing ability is limited by data load and speed stresses to which he adapts remarkably in ways that are not fully understood. The context in which information has value is in a man's head. This context is in a machine only to the degree that some human has put it there as prior contextual rules of how a system should operate. Combining several types of data on one display indicator does not assure the integration of information, which really occurs in the context of man's interpretation of the display. Most display design has suffered from a pre-occupation with hardware, rather than developing better communication with man.

Myers, W. Interactive computer graphics: flying high. I . Computer vol. 12, n. 7 (July 1979) 16-17.

This article views some of the latest hardware available from leading graphics manufacture.

Myers, W. Interactive computer graphics: flying high, II. Computer vol. 12, n. 8 (Aug. 79) 64-67.

Look better to the eye, higher performance in vector displays, a box that gets full speed out of electrostatic plotters and more.

O'Hare, R.A. Interactive CRT terminals. II. Alphanumeric CRT Terminals and Systems . Mod. Data. vol. 14, n. 7 July 1971 62-69.

For part I. see Ibid., June 1971. This profile describes the characteristics of CRT terminals and their role in computer communication systems. It divides the CRT market in to a number of application areas, exploring the question of economic justification, the benefits of real-time operation, and the associated terminal requirement.

Ostmeier, B.F. Process Control by Distributed Intelligence. IEEE/1980.

Process control by distributed intelligence, commonly known as distributed and hierarchical control systems, has developed over the last few years as a natural outcome of the need to separate control functions by process area and level of control, while maintaining overall system security and simplicity of operation. The author describes its evolution and illustrates its implementation in the cement industry with the latest available control modules. Various aspects related to the issues of system flexibility, improved alarm handling, increased trending capability, features of the CRT-based display as an operator interface, system redundancy, and ease of operation are addressed.

Pluhar, K. Distributed Systems. Control Eng. (USA) vol. 27, n.9 Sept. 1980, 137-40.

The development of integrated distributed process control systems in West Germany and Japan is shown.

Purdue Laboratory for Applied Industrial Control. Significant accomplishments and documentation of the International Purdue workshop on Industrial Computer Systems. Part VI. Guidelines for the design of man/machine interfaces for process control. Lafayette, Indiana: Purdue University, Laboratory for Applied Industrial Control, January 1977.

This volume represents Part 6 of a six volume set reproducing the major work accomplished by the International Purdue Workshop on Industrial Computer Systems during the past eight years. This material is reprinted from the Minutes of the Workshop and represents some of the work carried out by the Man/Machine Communications Committee of the Workshop.

Ramaker, B.L. and J.S. Halajko. 'Computer Interface Hardware - Its Effect on the User. ISA/1976.

This paper considers the input and output hardware requirements and philosophy of computer users oriented to both pneumatic and electronic instumentation. The aspects of operator interface and distributed control are also addressed.

Rasmussen, J. Man as information reciever in diagnostic tasks. IEE/1971.

During abnormal operating conditions in modern industrial process plants the operating and repair staff is left with a very complex data handling task, and it is becoming increasingly important to give the staff proper support as the complexity of the plants and thus the amount of data involved in the task are growing.

Reynolds, B.A. Alphanumeric display terminals. <u>Mod. Data</u> (USA) vol. 9, n. 2, (Feb 76) 44-51.

This is a first part of a 2-part product profile on alphanumeric cathode ray terminals, discusses how and why they came about, what they do, and how they do it.

Rijnsdorp, J.E. and Rouse, W.B. Design of man-machine interfaces in process control. IFAC/77

Computerized CRT-displays are rapidly being introduced into man-machine interfaces for process control and supervision. The flexibility of these devices can promote the incorporation of human factors in interface design. This paper gives a survey of design criteria and guidelines for: Allocating system functions between "man" and "machine"' coping with operator skills; evaluating CRT-displays and choosing controls and dialogue structures for these CRT-displays type of displays. Also, attention is paid to experimental comparison of design alternatives, and to the influences of the human organization, high mental stress and job satisfaction on interface design.

Rooney, T.B., Jacobs, H.H. Evaluation of Consoles for Process Operation. IFAC/71(1).

New process communication equipment requires testing and evaluation throughout the development cycle to ensure product excellence. This paper describes a series of techniques developed jointly by process control and human factors engineers to evaluate the man machine interface. These techniques include functional and operational analysis, operational testing on a pilot plant and overall evaluation by comparative ranking of alternate consoles.

Rouse, W.B. Design of man-computer interfaces for on-line interactive systems. IEEE/75

An attempt is made to integrate a wide range of material into a conceptual structure for the design of man-computer interfaces for on-line interactive systems. Typical roles for the human in man-computer systems are considered. Suggestions for the design of systems are developed in discussions of displays and input devices, visual information processing, and mathematical models of human behavior. Possible developments and avenues of research in man-computer systems are suggested.

Ryan. J.W. Three significant areas of change in modern industrial process control. Electric Energy Conference 1981 88-91.

State of the art micro-electronic devices have revolutionised all types of control systems. The change has manifested itself in three significant aspects: operator interface, plant interface, and system configuration: this paper discusses the merits of the advancements recently achieved in these facts of process control.

Schlatter, H.G., Schnegg, P.A. Electrical equipment with microcomputer-aided process control system for a merchant bar and wire rod mill. Brown Boveri Rev. (Switzerland) vol. 69, n. 9-10, Sept-Oct 1982 332-40.

The Merchant Bar and Wine Rod Mill of Von Moos Stagh ag in Emmenbrucke/Switzerland, comprises a 19-stand continuous rolling mill with cooling bed, a wire line and two coiling lines. The article describes the power and process control equipment supplied by Brown Boveri which includes procontic DP 800 programmable logic controllers and microcomputer systems of type DP 800. The high-rpecision, super-imposed speed control system for the rolling strands and the communication system with semi-graphic, color crt terminals, are also described.

Shutz, H.G., An Evaluation of Formats for Graphic Trend Displays -Experiment II. Human Factors, july 1961.

This study was designed to determine which of three types of trend formats results in superior performance of a task req-uiring the subject to make complex decisions. Three commonly used formats were included in the study: line type, vertical bar type and horizontal bar type. Two secondary independent variables were: number of time points and amount of missing data. Results of the study indicate that preference should be given to line-type, following closely by the vertical - bar type. A secondary finding was that irrelevent points and missing data on graphic trend type displays represent impor-tant factors in the degradation of operator performance.

Smith, H.T., Perceptual organization and the design of the Man-Computer interface in process control. Monitoring and Behavior and Supervisory control, T.B. Sheridan and Gunnar Johansen (EDs), Plenum Press, 1976, 417-428.

This study demonstrates how the representation of a control Problem may influence the interactive program users performance. Two groups of subjects were each given a set of problems to solve with the aid of an interactive computer program and a visual display. The problem sets were identical but differed in the form in which they were represented to the two groups. The first representation was that of resource allocation task in the context of PERT (Project Evaluation and Review Technique) type process net work. The second was an apparently unrelated reasoning task involving pattern substitution and matching. The results indicated that pattern (substitution and matching) group was clearly superior to network group. Stastical analysis showed a significant difference between the two groups.

Stradler, N.R. CRT consoles new look in control rooms . Chem. Eng. April 30, 1973 83-86.

CRT systems currently available can be categorized as digital TV or stroke-write. These categories can be identified as full graphic, limited graphic or alphanumeric.

Stoddard, J.L. CRT system definition . J. Systm. Manage (USA) v. 26, n. 2, Feb. 75, 20-24

The cathode ray tube system is unique tool to some people and therefore, techniques used to define and describe such systems also have to be unique. The author focuses on ways to define and describe CRT processing in systems using a CRT as the principal input-output device.

Sublett, J.G. The human component in man-machine systems. ISA/1976.

Human Factors Engineering is the term often used to describe the application of specific human data (factors) in the design of man-machine systems. Although well intended, this term causes considerable misunderstanding of the total scope of effort required to achieve efficient/productive man-machine systems.

Humans are not engineered. Work environments and machine systems, however, can be designed to be compatible with humans. This requires deliberate and specific considerations of physical, social, and psychological data (factors) about humans.

Selig, F. What is Computer Graphics . ISA/68.

Concentrates on the difinition of graphics, the current state of art and the potential areas for the use of computer graphics.

Sharpe, C. Electronic Displays: Interface between man & machine. Des. Eng. Mater. and Comp. Dec. 71, 59-64.

Display units of various types have traditionally incorporated CRTs and indicator tubes. Now, semiconductor light emitting devices are growing in popularity and solid state displays are on the horizon.

Sheffield, H.E. CRT terminals for supervisory control . Computer Des. (USA) vol. 11 n. 3, March 1972, 91-96.

The author describes a system used in supervisory control, the supervision being carried out with a color CRT screen.

Shephard, A.G. Penetration cathode ray tubes. New Electron (GB) vol. 10, n. 21, 1 Nov. 1977, 51-2.

Describes penetration CRTs which are tubes intended for high performance displays for process control where different types of information can be advantageously displayed in different colours of persistences.

Sperandio, J.C. and Gisseret, A. Human factors in the study of information input devices. Farnborough, England: Royal Aircraft Establishment, Report No. RAE-LIB-TRANS-1728, ER41239, March, 1974.

One problem area in man-machine system is that of communication between man and machine. A good knowledge of the various communication devices and of their compatibility with the operator is therefore very useful when preparing the optimization of a working system. Keyboard and comparisons based on speed, accuracy, ease of training, users convenience are considered following, as a guideline, the development of input devices to permit higher speeds. The implications of parallel inputs (chord playing keyboards) and the consequent loss of flexibility are considered. Other non-keyboard systems are dealt with and some speculation as to usefulness of devices permitting perception and decoding of natural language is presented.

Suret, P. Simplifying the man machine interface with the touch terminal. Conference on displays, IEEE/1971.

A touch terminal is a simple input/output peripheral. As a stand alone piece of equipment it cannot provide the simplest of input or control functions. When a touch terminal is enhanced by the use of a software support package any function can be made readily available to the user in a simple straightforward manner. The touch terminal with a correctly designed set of control tables can significantly reduce operator work load and more important in well defined sequences eradicates invalid inputs to the applicaton programs. The touch terminal demands computer power and storage and in some cases would need to be supported by other peripheral input devices. However since the operator is the most important, and is very rapidly becomeing the most expensive, component in the loop, the use of a touch terminal to reduce his workload will provide operational and economic savings which more than counter balance initial outlay.

Uetani, A. Ikenoue, S., Ichida, K., Tohyama, T. Refinery supervisory control by using process control oreinted software system. Advances in Instrumentation vol. 31, 1976, 844/1-17.

Problem oriented language (POL) using fill in the form specifications and procedural language with data base, was developed and applied to the refinery supervisory control in the sodegaura refinery, FUJI Oil Co. Ltd. the implementation of POL and standardized graphic CRT operator's console are described.

Umbers, I.G., CRT Displays in Process Control. CE/80.

The paper notes that CRT- based information systems are the essential component of the centralized work-station used in modern distributed control systems. A recent survey of current distributed control systems is described, in which various man-machine interfaces are evaluated from the point of view of display legibility and design and ease of data input. Limitations in the criteria available for such an evaluation are discussed, and the need for further experimental studies of process control displays are identified.

Umbers, I.G. Facing up to CRT Communication. Process Eng. (GB) April 1978, 75-9

Design guidelines are presented for legibility of CRT displays used in process control systems.

Umbers, I.G. Models of the Process Operator. Int. J. Man-Machine Stud. (GB) vol. 11, no. 2, March 1979, 263-84.

The process control literature is reviewed for evidence on the following aspects of the process operator: characteristics of human control behaviour, development of process control skills, individual differences between process operators. Task factors that affect performance, the organization of operator control behaviour. The various theoretical constructs which have been proposed to model these aspects of operator behaviour are described and discussed. Since the majority of the methodological problems in using verbal protocols is presented. The review concludes that an information processing approach based on protocol data seems to be the most fruitful technique for modelling the human process controller.

Umbers, I.G., King, P.J. A design methodology for operator interfaces. ISA; Inst. Meas. Control Promecon Volume 1. Proceedings of Promecon/81: Process Measuremnt and Control Conference 1981, 187-93.

The design approach described is directed towards operator interfaces which use VDUS as the main interface device. The design process considers the allocation of tasks between operator and automatic equipment, and the interface requirements for the tasks which the operator may be expected to perform. An effective man-machine interface needs to be compatible with the information processing characteristics of the operator. The following features of VDUs are examined from this point of view: (I) visibility and legibility of information, (II) display organization and format design, (III) methods of man computer communication, (IV) data entry devices. It is concluded that the prerequisite for interface design is a detailed analysis of the tasks which are to be performed by the operator.

Uyetani, A. Distributed total process control system-TOSCID-200 series. Toshiba Rev. (Int. Ed.) (Japan) no. 115, May-June 1978, 17-22.

Distributed control system, TOSDIC features high reliability and cost performance and is widely and rapidly applied into process control. Its hierarchical architecture suits any scale of instrumentation. The control functions of this system are performed by one microprocessor per eight loops, and the control room is centralized by means of the process console with CRT displays. System integration is possible for all types of processes through the adoption of the data highway and other devices.

Vartabedian, A.G. Legibility of symbols on CRT displays. Appl. Ergonomics (GB) vol. 2, no.3, (Sept. 1971), 130-2.

The effects of several parameters - such as letter orientation, slanting versus upright, dot matrix size, etc - of symbol formation on the legibility of CRT displays were studied. Symbols were tested by subjects attempting to identify them when presented briefly on the display screen. Speed and accuracy of identification were used as the measures of legibility. The 7x9 dot matrix symbols drawn with circular dots were superior to all others for both reaction time and errors. Slanging had a detrimental effect on dot and stroke symbols and circular dot symbols were superior to elongated dot symbols.

Vartabedian: The design of visual displays , Bell Lab. Rec. (USA), vol. 48, no. 8, Sept. 1970, 86.

Business operations are increasingly turning to computer-driven terminals having displays of information on CRT-displays that are made more efficient and easier to use by the careful design of letters, numbers, and other symbols that appear on the CRT. In the experiments described the legibility and readability of both dot-matrix and stroke generated symbols were tested.

Vartabedian, A.G. Human factors evaluation of several cursor forms for use on alphanumeric CRT displays. IEEE Trans. Man-Mach. Syst. (USA), vol. MMS-11, no.2, (June 1970) 132-7.

The result of an experiment to evaluate several cursor forms for use on alphanumeric CRT displays are presented. Cursor form and cursor blink rate were investigated in terms of their effect on operator search time in finding the cursor in a random location and their effects on tracking the cursor as it is moved between fixed random locations. Six cursor forms at five alternation rates were examined. The cursor forms were box, underline, cross, diamond, blinking, and wiggling cursors. Alteration rates were 0, 2, 3, 5, and 6 $H_z$. Based on results and additional criteria about the use of cathode-ray-tube displays, it was determined that, of the cursors examined, a box cursor around each graphic character blinking at 3 $H_z$ is most effectively searched and tracked. Subjective evaluations support this finding.

Vartabedian, A.G. The effect of letter size, case, and generation method on CRT display search time. Hum. Factors vol. 13, no. 4, 1971, 363.

The effect of letter size, case and generation method were studied in a task of searching for a common five letter wording in a CRT display. Symbol sizes g 0.12, 0.14 and .16 in were evaluated, words were composed of all upper case or all lower case letters. Two symbol generation methods letters drawn by means of continuous strokes and by means of a seven side-by-nine high pattern of dots in a fixed matrix were investigated.

Watts, J.L. Information at work-operator interfaces and displays for process control.

The process control operator is required to perform tasks that can be categorized as searching, counting, comparing, varifying and taking corrective action. To fulfil these tasks the operator must be presented with information. The evolution of instrument displays is examined, with consideration of the manner in which information is presented as a process interface to the operator to assist in carrying out these tasks in the most efficient manner. 10 refs.

Watts, J.L. Information at work-operator interfaces and displays for process control. Inst. of Engineers (Australia) n 79/4, 32-38.

The process control operator is required to perform tasks that can be categorised as searching, counting, comparing, varifying and taking corrective action. To fulfil these tasks the operator must be presented with information. The evolution of instrument displays is examined. Consideration of the manner in which information is presented as a process interface to the operator to assist in carrying out these tasks in the most efficient manner.

Watts, J.L. Operator interfaces and displays for process control. Autom. and Control (New Zealand) vol. 9, no.5 1979 27-31.

The evolution of instrument design-indicators, recorders, controllers and centralised control-in considered. Then the author discusses minature instrumentation and operator operating aids, panel design, electronic insturmentation-digital techniques and cathode ray tubes and display systems.

Weber, R., St. Aubin, R.J., Halberg, M.R. Graphics-based process interface. Exxon Chem. Americas, Baytown, TX, USA CEP (Chem. Eng. Prog.) (USA) vol. 78, no. 1 Jan. 1982, 50-3.

Describes the control systems at the baytown olefins plant where a TDC-2000 is the base level of instrumentation. A Honeywell 4500 process control computer system is used for control applications and for driving the CRT based man-machine interface. The Key feature of the interface is the live, updating process flow schematic.

Which Comput. (GB) vol. 5, no.1, 43 Jan 1981, 39-40. Flexible Route with micro developments (for process control).

What sets active systems apart from passive systems is that they perform the more routine corrective functions of the supervisor and bring only malfunctions or more severe differences from the preprogrammed norms to the attention of the supervisor. Typically, all controls are routed through the computer to an operator console, the supervisor activating them via the computer with no direct switching needed. A table of available products is discussed.

Weisberg, D.E. Graphic Displays: Matching man to machine for on line control . Control Engg. vol. 15, no. 11 Nov. 68, 79.

Three types of displays are evaluated for on-line system use and examples are given of their use to satisfy the requirements of different control systems. No one technique has universal applicability, but storage tubes appear to have great promise for both on-line and alphanumeric data.

Wiercinski, G.M. Project coordination for mineral process software requirements. Instrumentation in the mining and metallurgy industries. Vol. 8. Proceedings of the 9th annual Mining and Metallurgy Division Symposium and Exhibit. 129-34 1982 29 April - 1 May 1981, Salt Lake City, UT, USA.

The mining and metallurgical industry has in recent years become involved with microprocessor-based and computer-enhanced process control systems for more efficient and economical recovery of minerals. When this evolution came about, conventional analog control rooms were replaced with CRTs, keyboards, hardware, and software. This development has added unique requirements to the task of coordinating a project involving process, plant design, client requirements and vendor control system. The replacement of hard-wired panels has brought in the concepts of data base, graphic displays, control algorithms, logging requirements, program languages and operator interface. This paper presents some of the project coordination requirements which must be fulfilled to issue a complete software package.

Wilder, C.H. Color display for easier process monitoring. Systems (GB), vol. 2, no.3,(March-April 1974). 30-1.

The increasing use of computers for control and supervisory operations means that large quantities of data are processed and presented for rapid visual interpretation by operating and control staff. Mimic and mosiac diagram process control displays are being replaced by video information presentation systems. However, the need for a more effective display than that provided by monochrome c.r.t.s has existed for some time.

Williams, D.L. Microprocessors enhance computer control of plants. Chem. Eng. (USA) vol. 84, no. 15 18 July 1977, 95-9.

Rapid advances in microprocessor technology have had a significant impact on the design of control systems. As a result, the question often arises concerning the proper approach to take in designing such systems. Overall design of any control system must have: 1. the necessary control-system functions. 2. an adequately designed operator interface. 3. strong emphasis on system reliability and maintainability. 4. cost effectiveness. The author reviews how these requirements are met for process control in conventional direct-digital-control systems and in distributed systems incorporating microprocessor technology.

Williams, D.C. Graphic display facilities for on-line process control. IEE/71

In the field of process control using on-line digital computers, communication of information between plant, computer and human operator isa vital factor contributing towards efficient plant control. In the past emphasis has been on the development of the process measurement and controller actuation interface between plant and computer so that direct digital control (d.d.c) could be successfully implemented. In d.d.c. the purpose of the computer/operator interface is essentially to present a regular log of relevant process information and advise the operator of any alarm conditions. Manufacturers of process control computers have developed d.d.c. support software together with specialised operator/computer consoles. These consoles facilitate the manual adjustment of control system structure and control algorithm parameters, however they are not sufficiently flexible to implement more sophisticated control.

Williams, D.C., D.G. Delaney. On-line design and implementation of digital compensators. 5th European Symposium of the EFCE Working Party on Routine Calculations and the Use of Computers in Chemical engineering, London, England, 19-21 Sep. 1972 (London, England: Inst. Chem. Engrs. 1972), 6/14-19.

A visually interface control scheme is developed in which a human operator interacts with both computer and controlled plant via a graphic display console. Plant model identification is carried out on-line by statistical means where by the model is matched to the process dynamics using correlation fucntions calculated from input/outpud data. Should this data be contaminated with spurious components, the records may be displayed and the undesirable components removed - interactively by the operator - in order to minimise their effect on the accuracy of identification. The plant model, estimated in descrete form, is then used to design a digital compensator for control purposes. This design may be carried out automatically or by the operator, aided by the computer display, and the resulting compensator implemented directly by the on-line computer.

Yamaguchi, T., Ishida, M., Zenda, T. New Instrumentation system permitting easy change of control mode-application of Hitachi Unitrol Sigma series to batch process control. <u>Hitachi Rev</u>. (Japan) vol. 27, no.6, Oct. 1978, 339-42.

Describes a control system for polymer manufacturing which uses the Hitachi Unitrol Sigma series microcomputer and an operator's console with cathode ray tube (CRT) which makes it possible to change the control mode by dialogue. Its configuration and special features are discussed.

Yates, J.E. Panel instrumentation and control modules of the future. <u>Meas. & Contr</u>. (GB) vol. 4, no. 4, (April 1971), 59-63.

The interface problems between process, Plant Engineers and Operators are briefly examined and alternative means of achieving high density displays for digital and analogue systems are described. Reductions in displayed information are forecast with a high degree of automatic data logging. High level plain language programs are predicted in much simpler forms with translation into "Machine Language" effected by built-in compilers. Essential programs will be hard wired into systems.

Zey, R.B. Using interactive color CRTs as operator interfaces. Instrum. Technol. vol. 25, n. 12 (Dec. 1978) 49-51.

Interactive cathode ray tube terminals offer new and powerful tools for providing operators with better means of supervising processes. The terminals not only consolidate display and adjustment functions, but also make it possible to guide operators through process control procedures and check for certain classes of human errors

SECTION A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