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A Study on the Historical Development and Basis of Human Factors Guidelines for Automated Sytems in Aeronautical Operations

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FOREWORD

This report was prepared by Nelson and Johnson Engineering, Inc. (NJE) under NASA Contract NAS 2-11523, A Study of the Historical Development and Basis of Human Factors Guidelines for Automated Systems in Aeronautical Operations. Technical direction for this study was received from NASA, Ames Research Center (ARC), Moffett Field, California 94035 with Mr. R. Leon Harrison acting as Technical Monitor. The contract was administered under the direction of Mr. Drayton L. Swartz, Contracting Officer. This report is a summary of the work completed under this contract during the period of December 15, 1982 until December 15, 1983. This report has been submitted for review on November 17, 1983 and is being issued in its final form on February 15, 1984.

The authors wish to acknowledge the many helpful suggestions made by Mr. R. Leon Harrison, Dr. David C. Nagel, and Dr. Ren E. Curry of Ames Research Center. Further acknowledgements are conveyed to the numerous representatives of government, aviation, and industry who willingly gave of their time and contributed their experience to this study.

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SECTION 1
INTRODUCTION

For over twenty-five years "automation", or more specifically the computer augmented control of systems, has been playing an ever-expanding role in our technological society. Initially the application of computer automation was severely limited by the sheer size and unavailability of computers themselves. For example, the IBM 702, typical of the 1950's generation of computers, weighed 28 tons yet did not have the processing capacity of contemporary computers which are a fraction of that size. Today, however, the rapid development of microprocessor technology is spreading the influence of automation to every aspect of daily life. To put this growth into perspective, the president of Commodore International, a major manufacturer of personal computers, estimates that from the beginning of time through 1980 one million computers were built; his company alone projected sales greater than one million units in the single year of 1982 (Naisbitt, 1982). This proliferation of computers made possible by microprocessor devices has resulted in a corresponding increase in the application of computers to automate a variety of systems and processes which would have been impractical just ten years ago.

1.1 THE IMPACT OF AUTOMATION ON AVIATION

One of the areas which has been experiencing increasing automation is the area of commercial air transport. From the introduction of instrument landing techniques until the advent of auto-coupled approaches, little basic change had taken place in the skills needed to pilot a commercial aircraft. The DC-10 and L1011 represented a significant departure from preceding generations of aircraft. A sophisticated flight guidance system which can literally fly the airplane was introduced on these aircraft. When programmed with certain data such as weather, air temperature, runway length, etc., the computer will calculate and display the necessary takeoff data. If desired, the computer can actually adjust certain controls, such as engine thrust, to their proper settings. During flight, heading, altitude, and airspeed can be maintained at preselected settings automatically by using the flight director and autothrottle computers. Airspeed can be stabilized at a level calculated to achieve maximum fuel efficiency by the Performance Data Computer (PDC). When nearing the desired destination, descent can be computer controlled, localizer and glideslope can be captured, and flare and touchdown executed automatically. An almost totally "hands-off" flight is within the capability of existing technology. These advanced avionics systems have begun what has been characterized as a progressive role change for airline pilots, from a hands-on operator to a systems manager. This progression was advanced yet further with introduction of the Boeing 757 and 767 in the fall of 1982. For the first time, airline pilots were presented with digital cockpit control panels which depart radically from the traditional analog panels that have been in use for decades. Six cathode ray tube (CRT) display screens and several dozen other major indicators have taken the place of the familiar rows of dials, lights, switches, buttons, and indicators. The flight management system on the 757 and 767 is composed of four subsystems. One system governs flight controls and displays on the cockpit panel. A second system controls automatic flight. A third system monitors the engines and alerts the crew to malfunctions. The fourth system consists of the sensors themselves. Figure 1 presents a diagram of the 757/767 flight management system.

The availability of this advanced technology raises important new issues regarding what, when, and how automation should be introduced into the commercial air transport environment. The purpose of this study has been to survey various fields in which automation has reached a level of maturity and to extract guidelines which will help designers of future automated aviation systems to deal with these issues.

Particular attention has been paid to such issues as:

- In what situations should automation be introduced?
- What benefits can be derived?
- What problems must be anticipated?
- Impact on crew working environment.
- Special training requirements.
- Long-term psychosocial effects.

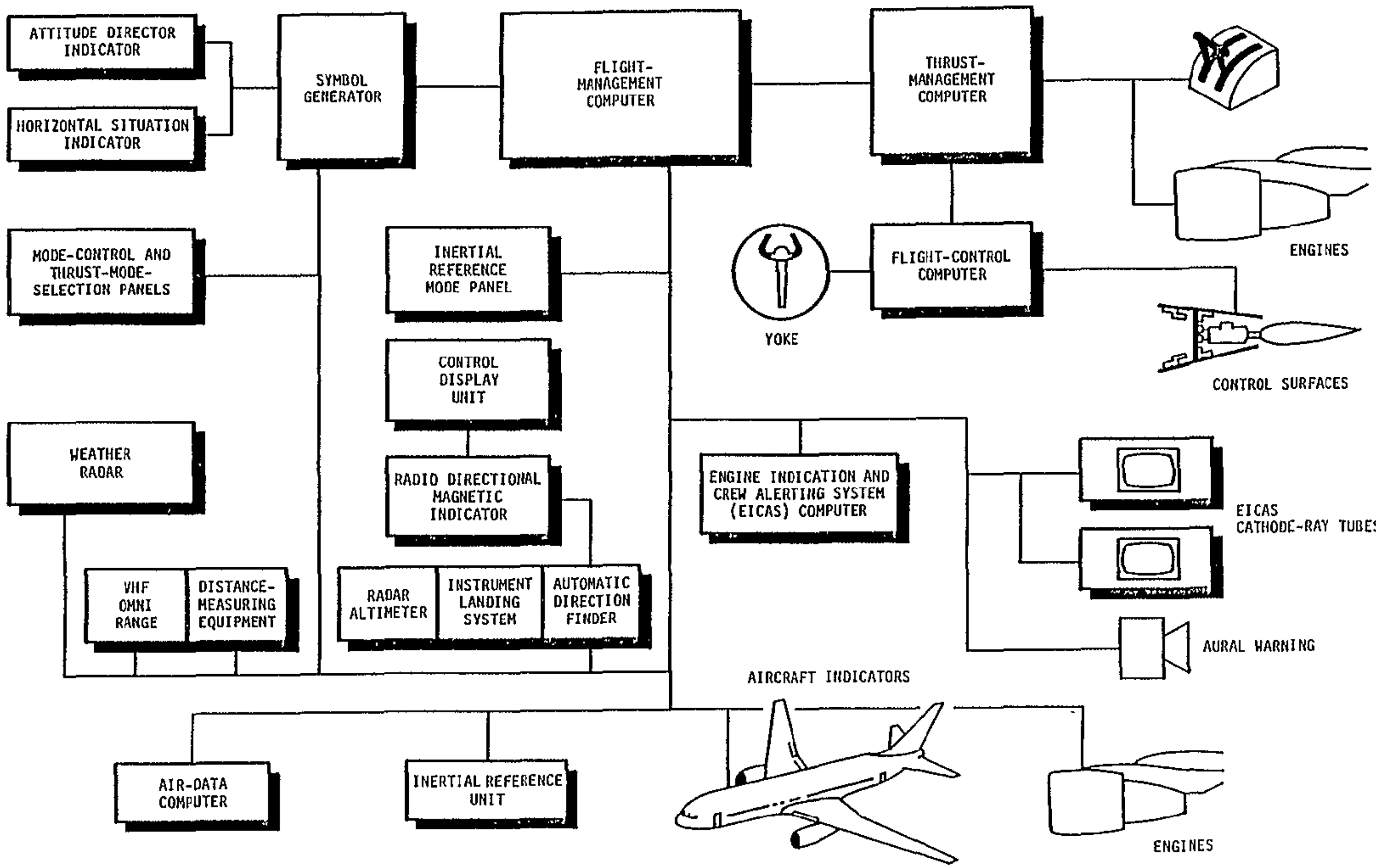


FIGURE 1. 757/767 FLIGHT MANAGEMENT SYSTEM

SECTION 2
TECHNICAL DISCUSSION

2.1 BACKGROUND

2.1.1 Human Factors

The discipline currently called Human Factors in the United States and Ergonomics in Europe has its origin in the need for greater ease and efficiency of operation of machines controlled by man. The original and strongest impetus to the development of human factors principles has been the requirement that military subsystems be operable by humans. In what might be called traditional human factors, the efforts have been directed toward development and application of principles for signal presentation, display and control arrangements, control characteristics of apparatus, and selection and training of operating personnel. Principles for operating procedures are also included within this general definition.

A result of extensive research in these areas has been the development of many general and explicit principles. These principles have been codified in various ways (e.g., MIL-STD-1472, Woodson (1981)). The more general principles of the human factors discipline are derived from basic research in the broad areas of learning, perception, and motivation, while specific applied research has produced much empirical data resulting in specific principles.

The development of complex man-machine systems and the participation of human factors professionals in such development has broadened the scope of the discipline. In particular, concern has been shown with problems of decision theory, stress management, and the position of man as a system component.

In simple systems the human operator responds to the presence of a signal with an action, however simple or complex, which results in the application of power to some operational element. When the result of this action does not require a further action by the operator, the system is said to be open loop. An example of such a system might be the pushing of the lever which dumps a premeasured load into a railway car. A diagrammatic representation is shown in Figure 2. The operator in this system merely decides whether or not the arrangement of the system elements is in the start position and then operates the device which controls the operation. In this example the device performing the physical operation could simply run for a predetermined time and would not itself require any feedback.

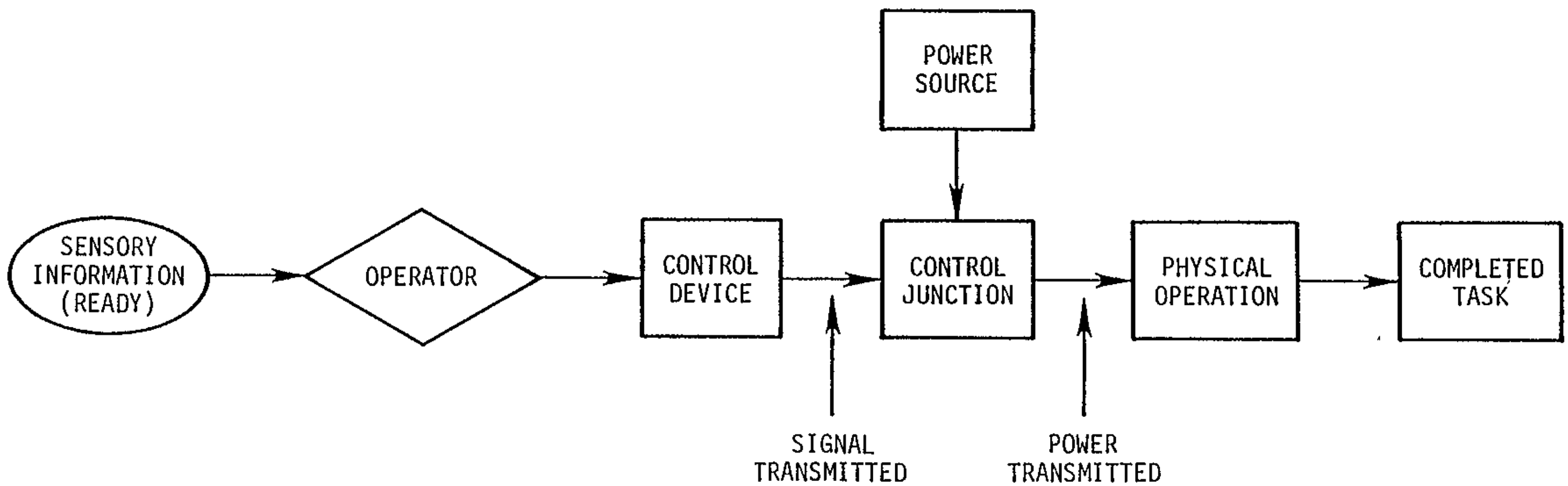


FIGURE 2. DIAGRAM OF SIMPLE OPEN LOOP CONTROL SYSTEM

When the action produces an event which results in feedback that must be evaluated and may require additional actions on the part of the operator, the system is a closed loop system. Figure 3 represents a simple closed loop system. An example of a simple closed loop system is the loading of a dump truck by a front-end loader. Since the operator of the loader must observe the amount already loaded and determine whether or not additional material is to be added, a feedback process is involved.

Simple systems often require fairly high levels of skill and coordination on the part of the operator. As systems become more complex, the physical skills required of the operator may be diminished by displacement to mechanized devices. Further, as the systems concept is expanded, we may conceptualize a set of hierarchical loops (in which several human operators may be used) that operate to produce an ultimate state through the achievement of several intermediate states. For example, the operator of a front-end loader actually operates within two loops. The outer loop is concerned with the ultimate criterion (for the operator) of whether or not the dump truck is properly loaded. The inner loop is concerned with the question of how much of the total load the operator has in the bucket. Note that the sensor(s) in a system may be physical devices, such as a scale, or may be simply the use of a human sensory system, such as the visual impression of the height of the load in a dump truck.

A general representation of a hierarchical closed loop system, taken from Kelley (1968a), is displayed in Figure 4. In this system a desired variable X_d is affected by producing a desired value Y_d of a second variable which is in turn a function of achieving a desired value of another variable Z_d. The values of X and Y change with changes in Z (represented by ΔZ). The value of ΔZ will be affected by the difference between Z and Z_d. In turn Z_d may change as a function of the difference between Y and Y_d, etc.

The demands on the human operator will vary with the operator's level in the hierarchy. At lower levels the operator will serve more as a monitor of signals which call for specific responses. The use of informative feedback is limited to determination of whether or not specific events have occurred. In the outer loops at the higher levels of the hierarchy, the human operator serves as a setter of goals and manager of resources.

Kelley (1968b, Chapter 6) has pointed out that inner loop processes are generally weaker, but occur with higher frequency than outer loop processes. Some conceptions of automation may consider a completely automated process as one which removes the human from the feedback loop, but Kelley suggests that increasing the number of processes which are self-controlled merely moves the human to a higher level loop in the hierarchy. He points out that the concept of optimal control must be associated with a

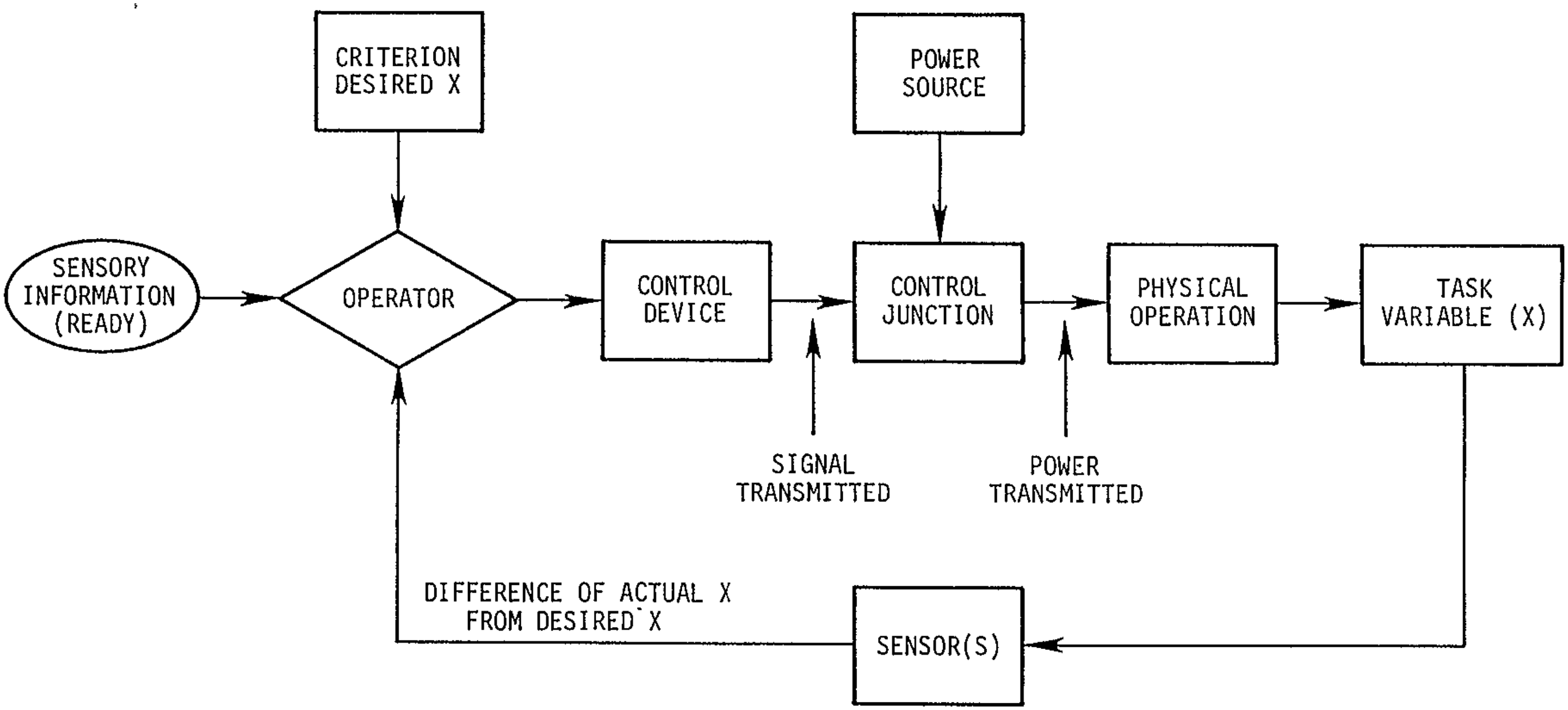
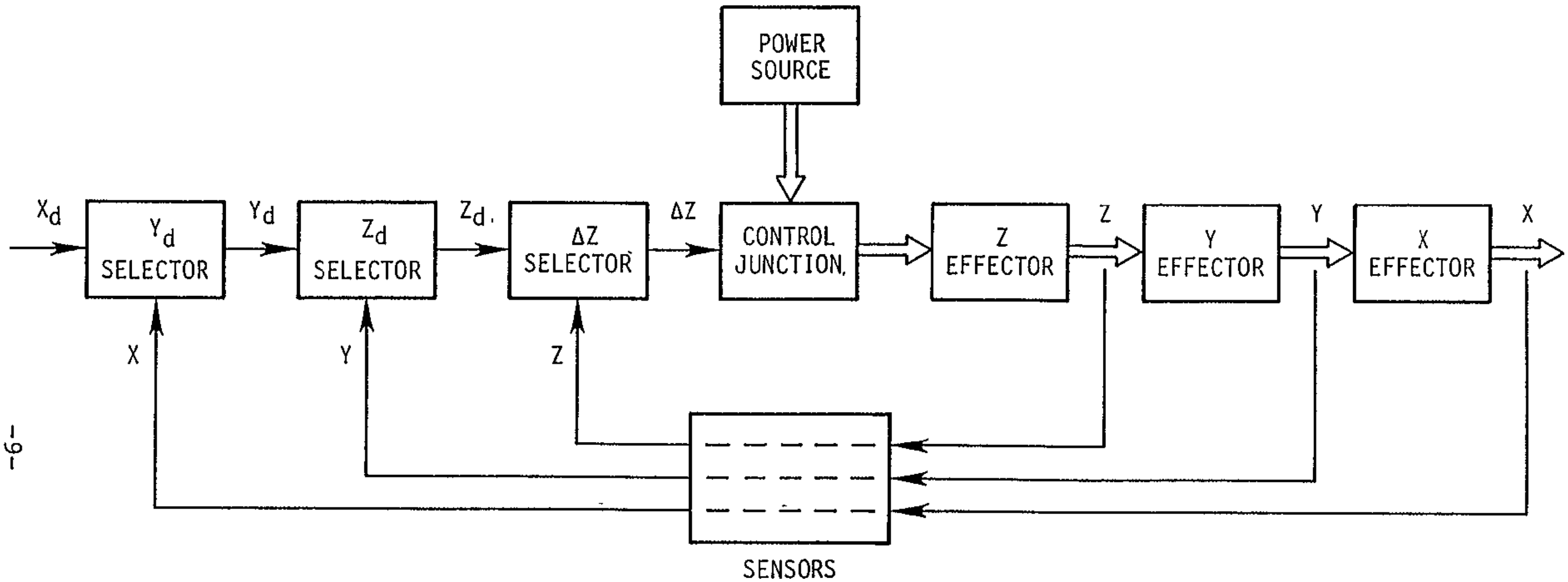


FIGURE 3. DIAGRAM OF SIMPLE CLOSED LOOP SYSTEM
Operator decisions are required concerning when to start and whether or not the criterion has been achieved.



General hierarchical system to control X when X is controlled by changes in Y and Y is controlled by changes in Z. The power of control is applied to institute a change ΔZ in the inner-loop variable Z. ΔZ is a function of the error in Z [$\Delta Z = f(Z_d - Z)$]. Z_d is a function of the error in Y, and Y_d is a function of the error in X

FIGURE 4. GENERAL HIERARCHICAL CONTROL SYSTEM

criterion of what is to be optimized. For example, the same system might be operated to optimize energy usage, amount produced per unit of time, or maintenance. The selection of which criterion is a function performed ultimately by the human.

2.1.2 Automation

The definition of automation has been discussed extensively in a collection of articles edited by Weeks (1961). For present purposes we shall simply distinguish between what we consider to be automation and mechanization. For example, one early "automatic" factory was the flour mill of Oliver Evans (circa 1785) which completed the process of turning grain into flour "...without the aid of manual labor, except to set the different machines in motion, ..." (Evans, 1795). In this instance the replacement of human tasks by machines would be classed as mechanization, since the operations were those of performing tasks which required no changes to be made as a function of their results. The basic characteristic which distinguishes automation from mechanization is whether or not the machine has the capability to replace the human in a decision-making capacity.

When considering automation relative to the hierarchy of a system, we may find that automation can be complete at any but the outermost level of a system. In most instances the lower the level of the loop, the more likely it will be automated. In accordance with the conceptual approach of Kelley (1966c, Chapter 6) we shall consider the outermost loop to include the human as the definer of the criteria for system performance.

Briefly, let us consider two aspects of the complexity of systems. One sort of complexity involves the number and types of informative inputs, tests of status, and decisions made during the process to achieve a particular optimal output. The other aspect of complexity is the presence of different sorts of requirements which must be satisfied by the same system. For example, an airline has requirements for maintaining schedules and the comfort of passengers.

There are times when these separate requirements involve activities that are incompatible with one another. It is conceivable that proper programming of the control system could optimize either requirement, but the decision of which criterion to use will ultimately be made by a human.

At this stage of technological development, it is fairly safe to say that, with sufficient lead time and willingness to commit resources, almost any system could be automated to optimize a specific requirement. In general the reasons for automating systems and processes may be categorized as:

- To avoid loss of life, such as remote handling of highly toxic substances.

- To obtain a quicker response time, faster than a human can react, such as aircraft mid-air collision avoidance systems where two aircraft traveling toward each other have such a short closing time that a human does not have sufficient time to react.

- To obtain high quantity production, more products per unit time to meet the demand and capture a larger segment of the market.

- To perform more precise operations than a human can achieve, for instance in the production of microelectronics.

- To maintain cleanliness levels in industries where cleanliness is critical, such as the food processing industry.

- To move heavy loads requiring more force or quicker acceleration/deceleration than a human can provide.

Several points must be considered in conjunction with the decision to automate a system. One consideration which is obviously important is the relative cost of automation compared with use of a human operator. The cost comparison should include the various subsets of the total system which might be automated. In addition, comparisons of cost should be made in terms of the relative reliabilities of the human and automatic systems.

In most cases some requirement for human monitoring of an automated system will exist. This leads to the additional considerations of user acceptance and reliability of monitoring. These factors may interact to some extent in that low user acceptance might contribute to reduced reliability of monitoring. An extensive survey of attitudes toward automation broadly defined (including what we have classed as mechanization) revealed generally positive attitudes among a broad range of workers affected by automation (Mueller, 1969). As indicated in the report, however, these attitudes may be constrained by the conditions of a generally expanding economy and the fact that in most cases the transition to the new situation resulted in decreased physical effort and improved income.

A matter of possibly greater concern is that some evidence suggests passive monitoring is less productive of failure detection than monitoring while controlling the system (Kessel, C. J. and Wickens, C.D., 1982).

SECTION 3
DATA GATHERING

This study effort, entitled "A Study on the Historical Development and Basis of Human Factors Guidelines for Automated Systems in Aeronautical Operations", was intended to survey several diverse fields in which automation has reached a level of maturity, and to extract human factors guidelines which can be used in the implementation of automation in commercial air transport.

The study consisted of ten major tasks which in turn incorporated several subtasks. Figure 5 shows the flow of these tasks. These tasks and subtasks will be discussed in greater detail in the following paragraphs.

3.1 PROGRAM PLAN

Working with the Technical Monitor, a plan for accomplishing the objectives of the research effort was formulated. This plan involved the establishment of goals for data gathering and analysis, as well as for human factors guideline development.

3.2 LITERATURE SEARCH

The contract effort began with a search for any applicable literature related to the subject of human factors and automation. A computerized "key word" search of all unclassified technology published by all U.S. Government agencies, industries, and technical societies throughout the world was conducted by The Technology Application Center (TAC) in Albuquerque, New Mexico. A total of 739 citations were generated by this search; from this list approximately seventy-five documents were selected for possible inclusion in our bibliography. About 75 other references were identified from our review of pertinent journals. These journals include:

International Journal of Man-Machine Studies
Ergonomics
Applied Ergonomics
Human Factors
Journal of Applied Psychology
Mechanical Engineering
IBM Systems Journal
IEEE Transactions on Systems, Man, and Cybernetics
Control and Instrumentation
Instrumentation Technology
American Psychologist
Journal of Experimental Psychology
Technology Review

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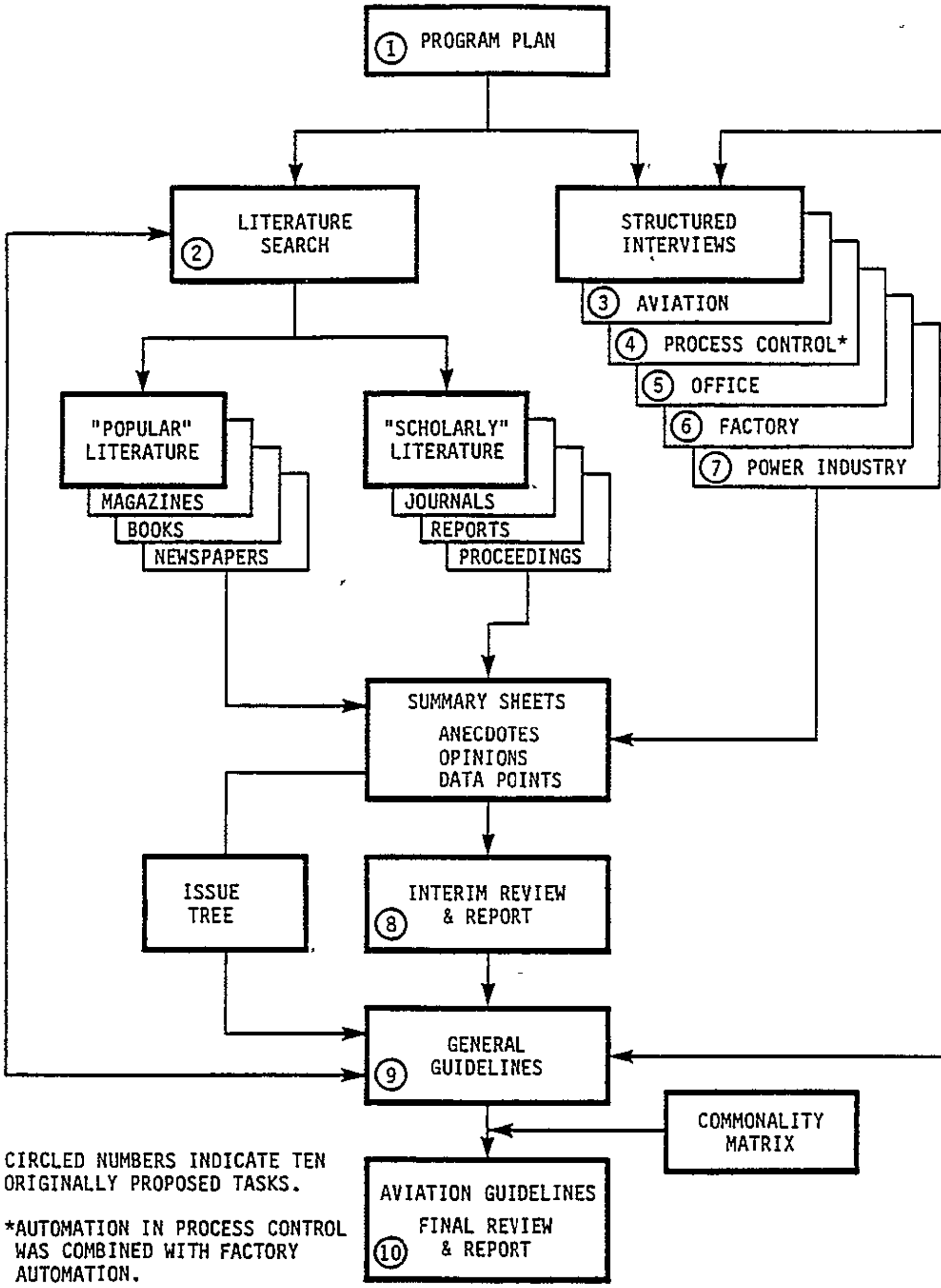

CIRCLED NUMBERS INDICATE TEN ORIGINALLY PROPOSED TASKS.

*AUTOMATION IN PROCESS CONTROL WAS COMBINED WITH FACTORY AUTOMATION.

FIGURE 5. GUIDELINE DEVELOPMENT PROCESS

IEEE Transactions on Automatic Control
Automatica
Psychological Review
IEEE Spectrum
Organizational Dynamics
IEEE Transactions on Professional Communication
American Journal of Psychology

The list of these references is included as Appendix A to this report. About 50 of these references were judged to be pertinent enough to justify preparing abstracts. These abstracts were presented in the interim contract report, dated August 19, 1983. The abstracts were referred to in the process of guideline development and were used to reinforce anecdotal data gathered in structured interviews. The techniques used in identifying and extracting potential issues and guidelines from these abstracts will be discussed in Section 4, Human Factors Issues in Automated Systems.

3.2.1 Existing Guidelines

One of the main objectives of the literature search was to discover any existing automation guidelines, aside from the standard human factors handbooks such as MIL-STD-1472, which may have resulted from previous efforts. Despite the general concern about the human factors implications of automation, no comprehensive set of guidelines exists which can be utilized by a system designer when designing a new automated system. The literature search did identify several documents which shed some light on the problems encountered when implementing automation.

Perhaps the most pertinent study was done by Macek et al. at Honeywell, Incorporated in 1981. The study, sponsored by the Air Force, sought to analyze the human factors problems which arose in the implementation of a computer-aided-manufacturing (CAM) system used to produce the F-16 aircraft. The study identified a comprehensive set of issues which when taken together define the overall problem. Guidelines were offered for dealing with a number of these issues. The study limited its focus to the computer-aided-manufacturing environment and did not attempt to generalize to other fields such as aviation.

A document entitled Guidelines for Man-Machine Interface Design (Ranta, J., Wahlstrom, B., and Westesson, R.) describes a set of guidelines for man-machine interfaces (MMIF) in process plants. These guidelines have been developed as a part of the KRU Project, a Nordic project on the human factors involved in the design of nuclear power plant control rooms. The KRU Project worked with the Purdue Workshop in Industrial Computer Systems and the European Workshop of Industrial Computer Systems. The format of the guidelines is based on the work done at these two workshops.

The guidelines are presented in the form of a handbook to be used as a checklist in the various phases of MMIF design. A checklist design was used because the authors believe that most of the deficiencies of existing process control rooms result from "neglected" or "overlooked" items at different design stages. By improving the design process itself, the authors hope that most potential system deficiencies can be avoided.

The KRU Project guidelines are intended to:

1) bring existing guidelines to a more concrete level, nearer to today's design policies and practices;

2) weigh and combine design criteria arising from different viewpoints and conditions, in order to ensure that all relevant items are included at different project phases;

3) translate and convey the theoretical concepts and models to practical design criteria.

The guidelines follow a "top-down" design process logic and are divided into three major levels. The first level is intended for use by top management to aid in decision making on automation project startup, and specification of the the aims to be achieved by automation. The second, a more detailed set of guidelines, is intended for the project management and automation system design level. The third set of guidelines is provided for detailed MMIF design, in which practical implementation is carried out and details of various parts of the system are designed. Once again, while this document is of general interest to the study, it does not specifically address the aviation environment.

Another document entitled <u>The Human Side of Automation</u> (Saltman, R.G., 1974) states that automation should be viewed by management as a problem in conflict resolution and the achievement of cooperation among diverse interests. Several general guidelines are suggested for resolving these conflicts.

The question of which tasks can best be performed by computers and which tasks are most appropriate to the human operator has been addressed by a number of authors. In several instances these efforts have taken the form of guidelines. A document entitled <u>The Allocation of Functions in Man-Machine Systems: a Perspective and Literature Review</u> (Price, H.E., Maisano, R.E., and Van Cott, H.P., 1981), prepared for the Nuclear Regulatory Commission (NRC), provides an excellent summary treatment of these previous works.

A report entitled *Man/Machine Interaction in Adaptive Computer-Aided Control: Human Factors Guidelines* (Steeb, R., Weltman, G., and Freedy, A., 1976) offers guidelines for establishing interactive allocation of functions between human and computer.

3.3 STRUCTURED INTERVIEWS

The second aspect of our two-pronged approach to gathering data relevant to human factors and automation involved conducting structured interviews with people who have experienced first-hand the problems and possibilities associated with the transition to automation. A format was developed to act as a guide in conducting interviews with people who are in some way involved with automated systems. Since the nature of this involvement has varied from individual to individual, not all questions have been appropriate in all instances. It has been our intent to keep the interviews informal and maintain the impression that the questions are as spontaneous as possible. This approach seemed most conducive to eliciting candid comments and anecdotes. Therefore whenever it appeared desirable to deviate from the prepared format in order to pursue a particularly interesting line of discussion, we have done so.

Interviews were conducted with two general classes of individuals: pilots and industrial personnel. The term industrial is used to encompass a wide variety of different groups. The pilots were drawn from those available to us from one major airline and from contacts developed with individual non-airline pilots. The sample was selected to include persons who had recently made transitions from more automated to less automated aircraft as well as persons who had gone from less automated to more automated aircraft. This approach allowed us to gather informed opinions about the possible loss of skill which might occur while flying automated aircraft. In addition, the opinions of those who had flown the automated aircraft for some time could be compared with the opinions of those who were just beginning to fly them.

The investigators selected several types of applications of automation and attempted to draw a small sample of cases from each application. An attempt was made to include individuals from more than one company or plant in each category, and attempts were made to include individuals from both management and labor categories within each industry. The industrial applications were divided into the categories of office, factory, process control, and power generation. As the study progressed it became apparent that the factory and process control applications were rather similar. Consequently, they were coalesced into a single group in order to have a larger number of cases in one set.

A total of 88 interviews were conducted in the various fields. An additional 15 survey questionnaires were completed by personnel in the field of office automation.

The goal of the interviews has been to seek statements based on personal experience which:

1) contribute new insights into the field of human factors in automation;

2) contribute to a wider understanding of known issues or add statistical weight to previously stated issues;

3) express known issues in a clearer, more logical or more elegant manner.

A copy of the structured interview format is included as Appendix B to this report. Narrative summaries of the interviews are presented in Appendix D.

3.3.1 Automation in Aviation

Automation in aviation represented a key area of investigation since ultimately all of the study findings must be interpreted in the context of the cockpit environment. Consequently this subtask has received special attention. A great deal of effort has been devoted to gathering information available in the airline industry and interpreting information gathered from outside that industry.

The structured interview format was adapted for use in obtaining information from pilots experienced in automated systems. (See Appendix B). Flight crew personnel from major scheduled airlines in the following categories were selected for interviews:

CATEGORY	NUMBER OF SUBJECTS
DC-10 Captains, First Officers and Second Officers	12
747 Captains, First Officers and Second Officers	15
767 Captains and First Officers	8
727, 737 Newly Transitioned Captains	8

This group has provided an interesting and informative cross-section of flight crew personnel with varying exposures to automated systems. The Captains and First Officers of the heavily automated jets have had considerable first-hand experience with automated avionics. The Second Officers of these aircraft have a different view toward automation. On the one hand, being younger they might be more open to change; on the other hand, the flight engineer's position is probably the most seriously threatened by advanced automation. Most new Captains of 737's and 727's have recently transitioned from First Officer of the heavily automated jets to the relatively non-automated aircraft. Their perspective is that of a person who has made the change to automation and now has to revert to the previous manual mode of operation. In addition, two pilots who are also members of airline management were interviewed.

While the primary source of information about the effects of automation in aviation was based on personnel employed by the scheduled airlines, it also seemed relevant to examine the experiences of other professional pilots. To this end interviews were conducted with non-airline pilots who have flown aircraft with varying amounts of automation. These interviews revealed several relevant differences between airline pilots and non-airline pilots. For example, while both groups of pilots are responsible for equipment and crew, non-airline pilots have additional responsibility for such activities as scheduling, flight planning, maintenance, passenger accommodations, baggage and cargo handling, and commissary supply. In addition, non-airline pilots often fly a variety of aircraft with radically different characteristics and must be available on an on-call basis. The unscheduled nature of their flying and the lack of a set duty-time creates greater possibility for fatigue. They are especially interesting since they often have a greater input with regard to selecting automated equipment than the pilots who fly for the scheduled airlines. Their relative autonomy gives them greater control over the selection and use of automated equipment. These factors, as indicated by the relatively small sample of non-airline pilots interviewed, suggest that it would be valuable to conduct a larger, statistically meaningful comparison between the two pilot populations.

Since the airline pilots represent a relatively homogeneous population, the interviews were conducted in a fairly standardized manner with the same questions being asked in the same sequence. Consequently, the interviews resulted in responses which could readily be compared with one another. A technique has been developed for tabulating interview data by using Interview Response Summary Matrices. Examples of these matrices are presented in Tables 1 through 4. These particular matrices give an

TABLE 1.

TRANSITIONS FROM LESS AUTOMATED TO MORE AUTOMATED AIRCRAFT

SECTION I & II — Aviation Interview No.	3	4	10	11	15	22	23	39	43	16	2	24	5	9	1	21	34	35	17	18	6	14
A/C from	DC8	DC8	DC8	DC8	DC8	DC8	DC8	DC8	DC8	727	727	727	DC8	DC8	727	727	727	727	727	DC8	DC10	747
A/C to	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	747	747	757	767	767	767	767	767	767	767
Position	C	C	C	C	C	C	C	FO	FO	C	FO	SO	FO	SO	C	C	C	C	FO	FO	FO	Mgr
AGE	58	55	55	55	51	59	58	45	40	55	43	40	44	41	50	57	51	53	39	39	39	51
Job requirements																						
1. Psychomotor skills	=	=	=	=	+	–	+	=	=	–	–	A	=	=	=	+	A	A	+	+^j	=	+
2. Physical strength	=	=	=	=	+	+	+	=	=	=	=	=	+	=	A	+	=	=	+	=	=	+
3. Finesse	=	=	=	+	+	+	+	–^a	+	+	+	–	+	=	=	=	+	+^b	+	+	=	+
4. Understanding of systems	–	=	–	=	+	B	B	–	B	–	–	=	+^c	=	–	B	=	ND	+	B	–	N
5. Vigilance and attention required	=	=	=	=	=	–^d	+^e	–^d	=	–^f	=	–	A	=	=	=	=	–	=	–	–	+
6. Physical workload (phase of flight)	=	=	=	=	=	–	=	+	+	=	+	=	A	=	=	+	+	=	+	=	=	+
7. Mental workload (phase of flight)	+	–	=	+	–	=	+	–	+	–	A	–	–^g	=	+	–^g	=	+	+	–	–	+
8. Training requirements, duration and methods	=	–	–^h	A	+	–^i	+	S-P	+A	S-P	+	=	A	+	+	=	+	+	+	+	=	+
9. Communication among the crew	=	=	+	–	=	=	ND	Im	Im	A	=	+	–^k	=	=	–^j	–	=	–	–^j	=	–
10. Ease of learning a new airplane	=	=	–	=	+	–^i	=	+	+	=	A	=	–	+	=	+	+	+	+	A	=	=
11. Reliability of systems	=	=	=	–	+	+	+	+	=	Mn	=	=	=	+	=	+	=	=	=	=	=	=
12. Skill retention problems	=	–	–	=	=	–	–	–	–	=	A	=	=	=	=	–	=	=	=	=	=	–
13. Command/Leadership/Resource management skills	=	=	=	ND	=	–	=	–	=	=	=	=	–	=	=	=	–	=	=	=	A	+

C = CAPTAIN   FO = FIRST OFFICER   SO = SECOND OFFICER   I = INITIAL POSITION AT THIS RANK

(+) - More automated aircraft easier
(-) - More automated aircraft harder
= - No difference as function of automation
? - unknown
A - Different but no difference in difficulty level
B - Want to know more than they are taught
C - More loss of confidence than of skill
Mn - Maintenance is the key
ND - Needed
N - Doesn't want to know all of inner workings
S-P - Self-paced is best
Im - Increasingly important with automation

a - have mechanical consistency
b - through programming computer
c - feels it isn't possible to "know" systems
d - Vigilance taken up by systems
e - Frees up pilot
f - Need to check accuracy of automatics
g - qualified with newness
h - flight guidance system requires more time
i - Not enough "hands on"
j - Specifically refers to two man crew
k - associated with humanistic societal influences
l - Because of expectations
m - more anticipation
n - refers specifically to 747

o - less taught, more needed
p - because more IFR involved
q - less to do
r - more experience, high transfer
s - fewer takeoffs and landings because of longer hauls
t - hearsay

TABLE 2.

TRANSITIONS FROM HIGHLY AUTOMATED TO HIGHLY AUTOMATED AIRCRAFT

Aviation Interview No. / A/C from / A/C to / Position / AGE	7 DC10 747 C 58	8 DC10 747 CP 58	19 DC10 747 C 59	26 DC10 747 C 56	27 DC10 747 C 57	28 DC10 747 C 58	29 DC10 747 C 59	30 DC10 747 C 56	33 DC10 747 C 57	42 DC10 747 C 57	37 DC10 747 FO 47	38 DC10 747 FO 48	31 DC10 747 FO 47
SECTION I & II													
Job requirements													
1. Psychomotor skills	+	$-^{m}$	+	+	-	-	=	-	=	=	=	-	-
2. Physical strength	=	$-^{n}$	+	=	=	=	+	+	+	=	=	=	=
3. Finesse	+	+	+	=	=	=	=	+	=	+	+	+	+
4 Understanding of systems	=	=	B	+	=	=	$=^{o}$	=	=	ND	=	ND	-
5. Vigilance and attention required	=	=	=	$-^{p}$	=	$-^{d}$	-	=	-	=	-	-	-
6. Physical workload (phase of flight)	+	=	+	=	+	$+^{q}$	+	=	+	+	=	=	+
7. Mental workload (phase of flight)	-	$-^{l}$	=	=	=	-	-	-	=	-	='	-	-
8. Training requirements, duration and methods	=	=	+	+	+	=	=	-	+	-	+	=	=
9. Communication among the crew	+	=	-	-	=	-	=	-	-	-	-	-	-
10. Ease of learning a new airplane	+	-	-	$+^{r}$	=	$+^{r}$	=	=	A	-g	$=^{r}$	=	$+^{r}$
11. Reliability of systems	=	=	=	+	+	+	=	+	+	=	+	=	+
12. Skill retention problems	=	-	=	$-^{s}$	=	-	$-^{t}$	=	-	=	-	-	-
13. Command/Leadership/Resource management skills	+	=	=	-	=	ND	+	-	-	-	ND	-	-

TRANSITIONS FROM MORE AUTOMATED TO LESS AUTOMATED AIRCRAFT

Aviation Interview No. / A/C from / A/C to / Position / AGE	12 DC10 727 IC 42	13 DC10 727 IC 41	20 DC10 737 IC 45	32 DC10 737 IC 43	25 DC10 727 IC 45	36 DC10 737 IC 44	41 DC10 737 IC 43	40 767 DC10 IC 51
1. Psychomotor skills	=	=	A	=	-	+	=A	-
2. Physical strength	=	+	=	=	=	=	=	=
3. Finesse	+	+	+	A	-	-	-	-
4 Understanding of systems	ND	-	-	=	=	-	-	A-b
5. Vigilance and attention required	=	-	=	=	=	-'	Im	+
6. Physical workload (phase of flight)	=	+	=	=	=	A	+	=
7. Mental workload (phase of flight)	=	-	=	+	=	A	-	-
8. Training requirements, duration and methods	+	+	=	=	+	=	=	A
9. Communication among the crew	=	-	=	=	=	=	=	Im
10. Ease of learning a new airplane	=	+	=	=	+	=	=	r^{o}
11. Reliability of systems	+	+/-	=	+	+	+	=	f
12. Skill retention problems	=	-	-C	=	+/-	-	=	=
13. Command/Leadership/Resource management skills	=	=	=	=	=	=	=	Im

C = CAPTAIN FO = FIRST OFFICER SO = SECOND OFFICER I = INITIAL POSITION AT THIS RANK CP = CHIEF PILOT

(+) - More automated aircraft easier
(-) - Less automated aircraft harder
= - No difference as function of automation
? - unknown
A - Different but no difference in difficulty level
B - Want to know more than they are taught
C - More loss of confidence than of skill
Mn - Maintenance is the key
ND - Needed
N - Doesn't want to know all of inner workings
S-P - Self-paced is best
Im - Increasingly important with automation

a - have mechanical consistency
b - through programming computer
c - feels it isn't possible to "know" systems
d - Vigilance taken up by systems
e - Frees up pilot
f - Need to check accuracy of automatics
g - qualified with newness
h - flight guidance system requires more time
i - Not enough "hands on"
j - Specifically refers to two man crew
k - associated with humanistic societal influences
l - Because of expectations
m - more anticipation
n - refers specifically to 747

o - less taught, more needed
p - because more IFR involved
q - less to do
r - more experience, high transfer
s - fewer takeoffs and landings because of longer hauls
t - hearsay

TABLE 3.

TRANSITIONS FROM LESS AUTOMATED TO MORE AUTOMATED AIRCRAFT

SECTION III — Aviation Interview No. / A/C from / A/C to / Position / AGE	3 DC8 DC10 C 58	4 DC8 DC10 C 55	10 DC8 DC10 C 55	11 DC8 DC10 C 55	15 DC8 DC10 C 51	22 DC8 DC10 C 59	23 DC8 DC10 C 58	39 DC8 DC10 FO 45	43 DC8 DC10 FO 40	16 727 DC10 C 55	2 727 DC10 FO 43	24 727 DC10 SO 40	5 DC8 747 FO 44	9 DC8 747 SO 41	1 727 767 C 50	21 727 767 C 57	34 727 767 C 51	35 727 767 C 53	17 727 767 FO 39	18 DC8 767 FO 39	6 DC10 767 FO 39	14 747 767 Mgr 51
A. Have you ever been "surprised" by the actions of the automatics?	N	po	Y	N	N	AP	N	po	N	po	N	N	N	N	N	AP	AT	N	Df	SB	Y	Alt
B. Have you ever experienced a sudden failure of the automatics?	N	N	N	AP	N	N	INS	N	N	PC	Y	N	N	INS	N	N	N	N	N	N	Y	N
C. Do you think that younger pilots catch on to automation faster than older ones?	N	Y	Y	YQ	Y	N	Y	YQ	Y	YQ	YQ	YQ	Y	YQ	N	YQ	N	N	YQ	YQ	NQ	YQ
D. What did you expect and what has been reality with respect to automation in the cockpit? (E)	W	U	U	–	+	C	U	Btr	+	U	W	P	U	U	P	K	P	P	+	+	U	+
(R)	D	E	E	P	E	+	ENG	E	MO	B	MD	J	P	E	E	E	E	E	B	B	P	I–
E. What has been gained by automation?	0	–	+	+	+	+/–	+/–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
F. What has been lost?	0	S	S/Dd	0	S	R	0	S	S	SM	R	J	S	S	S	Dd	0	0	Wk,R	Wk	R	R

TRANSITIONS FROM HIGHLY AUTOMATED TO HIGHLY AUTOMATED AIRCRAFT

SECTION III — Aviation Interview No. / A/C from / A/C to / Position / AGE	7 DC10 747 C 58	8 DC10 747 CCP 58	19 DC10 747 C 59	26 DC10 747 C 56	27 DC10 747 C 57	28 DC10 747 C 58	29 DC10 747 C 59	30 DC10 747 C 56	33 DC10 747 C 57	42 DC10 747 C 57	37 DC10 747 FO 47	38 DC10 747 FO 48	31 DC10 747 FO 47
A. Have you ever been "surprised" by the actions of the automatics?	U	N	N	pe	pe	pe	No	pe	No	No	pe	pe	No
B Have you ever experienced a sudden failure of the automatics?	N	AP	N	FD	No	Y	Y	FD	AP	No	No	AP	AP/FD
C. Do you think that younger pilots catch on to automation faster than older ones?	Y	YQ	Pr.	YQ	Y	Y	YQ	Y	YQ	YQ	YQ	YQ	N
D. What did you expect and what has been reality with respect to automation in the cockpit? (E)	Sp	U	–	Slow	U	Slow	Slow	+	Smooth	Sp	Help	Sp	+
(R)	U	E	+	E	Pl	E	E	–	=	MD	Change	=	=
E. What has been gained by automation?	+	+	+	+	+	+/–	+	+	–	+	+	Un-sure	+
F. What has been lost?	0	S	R	Cont	0	S	0	0	S	R	S	S	S

TRANSITIONS FROM MORE AUTOMATED TO LESS AUTOMATED AIRCRAFT

Aviation Interview No. / A/C from / A/C to / Position / AGE	12 DC10 727 IC 42	13 DC10 727 IC 41	20 DC10 737 IC 45	32 DC10 737 IC 43	25 DC10 727 IC 45	36 DC10 737 IC 44	41 DC10 737 IC 43	40 767 DC10 IC 51
A.	N	Y	pe	No	pe	pe	N	Y
B	N	N	N	No	AP	FD	Y	N
C.	Y	YQ	YQ	N	Y	YQ	Y	Y
D. (E)	–	P	–	Hard	Y	Slow	+	Sp
(R)	P	E	+	Easy	=	Help	E	MD
E.	+	+	+	+	+	+	0	–
F.	0	R	S	WK	0	S	0	J

Y - Yes
N - No
Q - Qualified
Pr - Probably
pe - Pilot Error
AP - Autopilot
INS - Inertial Navigation System
Alt - Altitude capture
Df - Operated differently than pilot
SB - Speed break
Pc - Pitch

P - Pleasant
W - WILD
U - UNKNOWN
K - KNEW What TO EXPECT
Sp - SPECIFIC Things
C - COMPLICATED
(+) - POSITIVE
(-) - NEGATIVE
B - BETTER Than EXPECTED
D - DISAPPOINTED (M - MILDLY)
AT - Autothrottle

E - AS EXPECTED
I - IMPLEMENTED PIECEMEAL
ENG - GET WHAT ENGINEERS WANT TO GIVE
J - Job may disappear
S - SKILLS
Dd - ATTN TO DETAIL
R - ROMANCE
0 - NIL
SM - SIMPLICITY
Wk - WORK
CONT = CONTROL

TABLE 4.

TRANSITIONS FROM LESS AUTOMATED TO MORE AUTOMATED AIRCRAFT

SECTION IV	Aviation Interview No.	3	4	10	11	15	22	23	39	43	16	2	24	5	9	1	21	34	35	17	18	6	14
	A/C from	DC8	DC8	DC8	DC8	DC8	DC8	DC8	DC8	DC8	727	727	727	DC8	DC8	727	727	727	727	727	DC8	DC10	747
	A/C to	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	747	747	767	767	767	767	767	767	767	767
	Position	C	C	C	C	C	C	C	FO	FO	C	FO	SO	FO	SO	C	C	C	C	FO	FO	FO	Mgr
	AGE	58	55	55	55	51	59	58	45	40	55	43	40	44	41	50	57	51	53	39	39	39	51
E.	How do you view future automation in the cockpit?	0	-	U	-	IN	+	+,TD	IN	+,D	IN	IN	IN	+	-	+	TD	+	IN	+	+	+	+
F.	Has the major thrust of automation been to unburden the pilot or to displace him?	UB	0	UD	UBo	UB	UBo	D	D	Do	UB	UBo	UD	UD	D	UB	UB	UB	UB	UB	UD	UD	UB

TRANSITIONS FROM HIGHLY AUTOMATED TO HIGHLY AUTOMATED AIRCRAFT

SECTION IV	Aviation Interview No.	7	8	19	26	27	28	29	30	33	42	37	38	31
	A/C from	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10	DC10
	A/C to	747	747	747	747	747	747	747	747	747	747	747	747	747
	Position	C	CP	C	C	C	C	C	C	C	C	FO	FO	FO
	AGE	58	58	59	56	57	58	59	56	57	57	47	48	47
E	How do you view future automation in the cockpit?	+	+	TD	IN	IN	IN	IN	IN	+	IN	IN	In	+
F.	Has the major thrust of automation been to unburden the pilot or to displace him?	UB	UB	UB	UB	UB	UB	UD	UD	UD	UB	D	D	UB

TRANSITIONS FROM MORE AUTOMATED TO LESS AUTOMATED AIRCRAFT

	12	13	20	32	25	36	41	40
	DC10	DC10	DC10	DC10	DC10	DC10	DC10	767
	727	727	737	737	727	737	737	DC10
	IC	IC	IC	IC	IC	IC	IC	IC
	42	41	45	43	45	44	43	51
E	+	+	0	+	+	Mxd	Oe	+
F	UB	UD	UD	UB	UD	UB	UD	UBo

(+) - POSITIVE
(-) - NEGATIVE
0 - NEUTRAL
U - UNKNOWN

IN - INCREASING
TD - TOTAL (NO PILOT) IS DANGEROUS
o - UNDESIRABLE SIDE EFFECTS

UB - UNBURDEN
D - DISPLACE
UD - BOTH UNBURDEN AND DISPLACE

overview of responses of 43 pilots to the survey questions. By scanning across the rows, trends regarding responses to particular questions can be observed. By scanning down columns, respondents who are consistently positive or negative can be identified.

3.3.2 Automation in Process Control/Factory

The field of process control, particularly as it is applied in the petrochemical industry, offers rich potential for gaining insight into the human factors problems associated with the implementation of automation. Although not immediately apparent, many aspects of automation in the process control industry have parallels in the area of cockpit automation.

The process of flying a commercial air transport has evolved from an unpredictable, highly interactive task to one which under normal circumstances is quite routine. However, no matter how routine flight may become, the potential for serious mishap is always present. This requires constant vigilance and a thorough awareness of the status of all aircraft systems. In the early days of commercial aviation, practically every flight involved some event which today would be categorized as an emergency. As a result of frequently reacting to such off-nominal situations, pilots became intimately familiar with the capabilities and limitations of their aircraft. As aircraft have become more reliable, simulators must be used to provide pilots with experience in dealing with emergency situations.

Similarly, process control, including the refining of petroleum and other similar endeavors, has evolved into a continuous process encompassing operations which are essentially steady-state but which can at any time be punctuated by off-nominal conditions requiring immediate corrective action. Like aviation, process control began as a poorly integrated operation, coordinated by operators who depended on a highly sophisticated internalized model of the process to allow them to predict the results of their actions. Early process instrumentation consisted of such simple devices as gauges, sight glasses, and handwheels located inline with the process being controlled and monitored. Over the years, ever-improving control technology has isolated the operator in a control room and transformed him into a systems monitor who depends on training and well-defined operating procedures to predict the consequences of his actions. Many of the classic questions facing the designers of automated aviation systems have been addressed by the designers of automated process control systems.

Process control is perhaps the most mature of the automated technologies. An article which appeared in _Scientific American_ more than thirty years ago describes a refinery which had been recently built near Tyler, Texas and the role of its operators.

It is a role which may sound strangely familiar to the pilots of state-of-the-art automated aircraft:

> "It is a bewildering kind of factory, with metallic towers rising 20 stories high, hundreds of miles of pipe, and only an occasional modest building. A few lonely men wander about the spectral monster doing supervisory or maintenance tasks here and there. The plant is almost noiseless, all but devoid of visible moving parts. Despite its apparent inertness, however, the plant is throbbing with internal heat and motion. Every day a quarter of a million barrels of oil flow unobtrusively into its maw, and about as many flow out in the form of dozens of finished petroleum products--all profoundly and specifically altered by processing. Forty tons of catalyst are being circulated every minute of the day and night. Great volumes of chemicals are being consumed in processing, and greater volumes of chemical intermediates are being manufactured. Scores of unit processes are interlocked, with a meticulous balance of energy distribution.
>
> The nerve center of this mechanical organism is the control room with its control panel. Here are ensconced the human operators--attendants upon the little mechanical operators of the plant. The human operators watch, they sometimes help or correct the instruments, but only occasionally do they take over the major part of operating responsibility. Barring emergencies, they take over completely only when the plant is starting up or shutting down--normally only about once a year."

As the study progressed, it became apparent that considerable overlap exists between the fields of process control and the factory. The problems which have been encountered and the user attitudes which exist proved to be largely the same in these two areas. The processes themselves are very similar, with an arbitrary distinction being made between those companies which are engaged in a continuous process (process control companies) and those firms which manufacture discrete products (factories). In order to better utilize available resources and increase sample sizes, it was decided to treat process control and factory automation as a single field.

3.3.3 Office Automation

The particular type of automation which has been made possible, initially by the development of the computer but more directly by the advent of the microprocessor, differs from previous types of automation in that it is heavily information based. Large quantities of data can be gathered, processed and used to control a system, whether it be an assembly line, a refinery, a nuclear reactor, or an airplane. It is only natural that this revolution should have some of its greatest impact on the hub of information processing - the office. In the office, information processing is often an end unto itself. Here people communicate through words, numbers, and graphic images. The computer has had a profound effect on this communication process and in fact on the very structure and organization of the traditional office. Before automation found its way into the office, the flow of information, especially in a transaction-intensive organization, was segmented into discrete steps. Letters were written in draft form by one person, typed by a secretary, copied by a clerk, and sent out through the mail room. In an engineering organization, a circuit may have been designed by an engineer, drawn in schematic form by a drafter, turned into a printed circuit (PC)layout by a PC designer, and eventually fabricated by a manufacturer. Not only is this multi-step process error-prone, but it also segments work into simple, repetitive, and often unrewarding tasks. Work moves through the organization from desk to desk, in assembly-line fashion. In its worst case, a worker may be responsible for only one element of the entire process, such as folding, stapling or copying a document. A phenomenon called "information float" has resulted from this type of organization. Once in the "pipeline", it is difficult if not impossible to extract a particular piece of information until it appears at the other end.

The advent of the computer workstation, whether for accounting, word processing, or drafting and design, holds the promise for restoring work to comprehensive, coherent tasks. The delay and frustration caused by "work in process" such as letters in typing, checks that are in the mail, or correspondence which has been misfiled, can be eliminated.

A number of people were interviewed who are employed by a firm involved in the preparation of a large number of drawings. These drawings fall into two major categories: some are three-dimensional illustrations used to pictorially convey information; others are engineering drawings used in the design of structural and mechanical hardware. Previously the drawings had been produced by traditional manual methods. However the workload increased to the point that management decided the only practical way to keep pace was to install a computerized system. Since the system has been in place for a little over a year, a number of the people have been involved in the transition and are familiar with both the manual and automated approaches. Both types of drawings involve the addition of significant amounts of text; the engineering drawings also involve a good deal of computation. Consequently, the organization is using the computer to facilitate all three types of information processing: verbal, numeric, and graphic. Interviews with people who work with the system have indicated good acceptance and general satisfaction with both systems. In order better to understand this situation and expand our sample size, we conducted a questionnaire survey of all the workers who use the two computer-aided systems.

A copy of the questionnaire is presented in Appendix C. The raw responses to the questions are presented in Table 5. The questions were divided into two sections. One of the sections, labeled the information section, dealt with the individuals' background, experience, and subjective impressions of how well the system and individual worked. The other section was called the attitude section and required the individuals to express agreement with a number of statements which reflected feelings toward automation and their systems in particular. Out of a total of 22 individuals in the two groups, 16 returned their questionnaires. One questionnaire was discarded because a number of items were left blank. From the remaining 15 questionnaires, statistical means were obtained for those items which involved ratings that could be considered to be on a continuum of some sort. Four of the usable data sets came from the design group and eleven came from the illustrators. One of the design group was a female and five of the illustrators were females.

The scale values for the items from the questionnaire are presented in Table 6. A number of questions were dropped from the analysis for one of the following reasons:

- The question elicited discrete responses which could not be arranged on a continuum and therefore would not yield meaningful correlation coefficients.

- There was no discrimination among responses; i.e., all the respondents gave essentially the same response and therefore, by definition, no correlation coefficient could be calculated for that item.

- There were too few responses to the question to yield meaningful correlation coefficients.

To assist in interpreting the data, all scales in which a high value indicated a negative attitude toward automation were transformed so that a high value indicated a positive response. The transformation consisted of subtracting the obtained value from the highest value and adding 1.

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TABLE 5.

CAD QUESTIONNAIRE RESPONSE TABULATION

	ILLUSTRATORS											DRAFTERS			
	FEMALE					MALE						FEM.	MALE		
INDIVIDUAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BACKGROUND															
POSITION	2	2	2	2	2	2	2	2	4	1	3	1	3	5	3
AGE	1	4	1	1	1	2	1	1	3	1	2	3	1	6	2
SEX	2	2	2	2	2	1	1	1	1	1	1	2	1	1	1
EDUCATION	2	2	4	4	2	3	1	3	2	3	2	2	3	4	2
EXPERIENCE															
PRESENT FIELD	3	3	3	3	4	5	4	3	6	3	5	3	3	6	4
WITH CAD	3	2	3	2	3	3	3	1	2	-	3	1	2	3	1
PRESENT CO.	3	3	3	3	4	3	-	3	4	-	3	3	2	3	3
PRESENT CO./SYS.	3	2	3	2	3	3	1	1	2	-	3	1	2	3	1
WHICH SYSTEM	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
CROSS TRAINING	2	2	2	2	2	2	1	2	2	2	1	2	2	1	2
INFORMATION															
ITEM 1	3	2	2	2	2	3	3	1	4	1	2	2	2	1	3
ITEM 2	4	3	3	3	3	4	3	2	4	3	3	3	4	3	2
ITEM 3	3	2	2	3	3	1	1	3	1	2	3	1	2	2	3
ITEM 4	1	1	2	1	1	2	2	1	2	2	1	1	2	1	1
ITEM 5	2	4	2	2	2	1	3	3	3	2	2	-	5	4	5
ITEM 6	1	3	2	1	1	1	2	5	1	1	2	-	3	1	2
ITEM 7	1	3	1	1	1	1	2	5	1	1	2	2	2	1	3
ITEM 8	4	3	V	4	4	-	4	1	5	4	3	-	3	4	1
ITEM 9	3	3	1	4	2	-	3	1	4	4	3	3	3	4	3
ITEM 10	*	5	4	2	*	3	5	3	4	1	3	1	1	1	4
ITEM 11	4	4	4	3	3	2	4	4	4	3	3	4	3	3	3
ITEM 12	3	3	-	3	3	-	-	1	-	3	-	2	-	3	3
ITEM 13	4	4	-	4	4	-	-	3	-	4	-	4	-	4	4
ITEM 14	4	4	-	3	3	-	-	2	-	5	-	3	-	3	3
ITEM 15	3	3	-	3	5	-	-	1	-	4	-	1	-	5	4
ITEM 16	3	3	-	3	3	-	-	1	-	3	-	3	-	-	3
ITEM 17	2	2	-	2	2	-	-	2	-	2	-	2	-	2	2
ITEM 18	4	2	4	4	3	5	3	2	2	5	3	2	3	3	1
ITEM 19	5	4	2	4	4	3	2	4	1	2	2	3	4	3	3
ITEM 20	4	4	4	4	1	4	2	3	1	4	3	4	4	4	2
ITEM 21	3	3	1	2	1	3	5	2	2	5	2	1	3	3	3
ITEM 22	3	2	2	3	2	4	1	5	2	4	3	-	3	1	5
ITEM 23	2	2	2	3	2	2	2	2	2	2	2	3	3	3	3
ITEM 24	2	3	-	2	2	3	3	2	2	2	4	5	4	5	3
ITEM 25	2	2	3	2	2	2	2	3	2	2	2	2	2	2	2
ITEM 26	3	3	2	3	3	-	4	2	3	2	2	4	3	3	2

* = AFTER NEW SOFTWARE UPDATES

V = VARIABLE

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TABLE 5. (CONT.)

CAD QUESTIONNAIRE RESPONSE TABULATION (CONT.)

	ILLUSTRATORS											DRAFTERS			
	FEMALE					MALE						FEM.	MALE		
INDIVIDUAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PHYSICAL ENVIRONMENT															
LIGHTING	2	2	1	2	2	-	3	1	3	2	3	-	2	2	2
NOISE	4	4	4	3	4	-	2	4	2	4	4	2	3	2	3
EYE STRAIN	1	2	1	1	1	-	1	1	1	2	2	2	2	3	2
SEATING	4	4	3	3	3	-	3	3	2	3	3	4	5	4	3
INTERPERSONAL - INTERACTION	3	4	4	3	3	-	3	4	2	3	3	4	3	3	3
PRIVACY	4	4	4	3	4	-	5	4	3	4	4	4	3	3	3
SPACIOUSNESS	3	5	3	3	3	-	4	5	3	4	3	3	4	3	3
TEMPERATURE	3	2	1	1	1	-	4	3	1	3	4	3	3	3	3
ATTITUDE															
ITEM A	5	4	3	5	4	4	4	5	3	3	4	4	5	2	3
ITEM B	1	3	1	1	1	1	1	3	1	1	1	2	2	1	1
ITEM C	2	2	2	2	1	3	1	4	1	1	1	4	2	1	1
ITEM D	3	4	4	2	3	3	2	5	4	2	3	2	1	1	2
ITEM E	4	5	1	5	4	5	5	3	5	5	4	3	4	5	3
ITEM F •	3	2	3	3	2	3	1	5	1	1	2	2	1	1	3
ITEM G	3	4	3	4	4	3	1	5	3	3	4	3	3	-	2
ITEM H	3	4	1	2	3	5	1	5	1	5	3	2	3	1	2
ITEM I	2	4	1	2	1	4	3	1	3	3	5	4	4	3	4
ITEM J	2	3	1	1	1	1	2	4	1	1	1	2	1	1	1
ITEM K	4	4	3	5	2	5	5	4	5	5	1	3	3	5	5
ITEM L	5	4	1	3	5	4	3	3	5	5	3	3	-	-	-
ITEM M	2	2	2	2	2	2	2	4	1	4	3	3	1	1	1
ITEM N	2	1	1	1	1	1	1	5	1	1	1	2	3	1	1
ITEM O	3	4	2	3	3	4	4	3	5	5	4	4	4	5	3
ITEM P	4	5	5	4	4	5	5	2	5	5	4	3	4	5	4
ITEM Q	4	5	5	4	3	4	4	1	5	5	3	4	3	1	4
ITEM R	4	2	3	3	2	4	4	1	3	5	3	2	4	5	3
ITEM S	1	5	4	4	1	2	1	5	3	1	2	2	4	4	3
ITEM T	2	4	5	1	3	3	1	5	1	1	3	3	4	-	3
ITEM U	2	3	1	2	4	1	1	4	1	1	2	3	2	1	1
ITEM V	4	4	5	5	5	5	5	5	5	5	4	4	5	5	2

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TABLE 6.

CAD QUESTIONNAIRE ITEM GROUPINGS

ATTITUDES TOWARD AUTOMATION

	ILLUSTRATORS											DRAFTERS			
	FEMALE					MALE						FEM.	MALE		
INDIVIDUAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
General															
Item B –	5	3	5	5	5	5	5	3	5	5	5	4	4	5	5
Item E	4	5	1	5	4	5	5	3	5	5	4	3	4	5	3
Item I	2	4	1	2	1	4	3	1	3	3	5	4	4	3	4
Item K	4	4	3	5	2	5	5	4	5	5	1	3	3	5	5
Item N –	4	5	5	5	5	5	5	1	5	5	5	4	3	5	5
Item P	4	5	5	4	4	5	5	2	5	5	4	3	4	5	4
Item T –	4	2	1	5	3	3	5	1	5	5	3	3	2	3*	3
Item V	4	4	5	5	5	5	5	5	5	5	4	4	5	5	2
Total	31	32	26	36	29	37	38	20	38	38	31	28	29	36*	31
Reliability															
Item D –	3	2	2	4	3	3	4	1	2	4	3	4	5	5	4
Item M –	4	4	4	4	4	4	4	2	5	2	3	3	5	5	5
Item O	3	4	2	3	3	4	4	3	5	5	4	4	4	5	3
Total	10	10	8	11	10	11	12	6	12	11	10	11	14	15	12
Skill															
Item F –	3	4	3	3	4	3	5	1	5	5	4	4	5	5	3
Item G –	3	2	3	2	2	3	5	1	3	3	2	3	3	3*	4
Item S –	5	1	2	2	5	4	5	1	3	5	4	4	2	2	3
Total	11	7	8	7	11	10	15	3	11	13	10	11	10	10	10
Workload															
Item C –	4	4	4	4	5	3	5	2	5	5	5	2	4	5	5
Item H –	3	2	5	4	3	1	5	1	5	1	3	4	3	5	4
Item Q	4	5	5	4	3	4	4	1	5	5	3	4	3	1	4
Total	11	11	14	12	11	8	14	4	15	11	11	10	10	11	13
Employer Relations															
Item R	4	2	3	3	2	4	4	1	3	5	2	2	4	5	3
Item U –	4	3	5	4	2	5	5	2	5	5	4	3	4	5	5
Total	8	5	8	7	4	9	9	3	8	10	6	5	8	10	8
Miscellaneous															
Item A	5	4	3	5	4	4	4	5	3	3	4	4	5	2	3
Item J –	4	3	5	5	5	5	4	2	5	5	5	4	5	5	5
Reduced combination totals															
Information/ System Perf. Total	6	7	6	6	7	5*	9	3	7	4	5	7*	6	9	3*
Attitude General Total	25	24	20	29	23	28	30	14	30	30	22	20	20	28	25

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TABLE 6. (CONT.)

CAD QUESTIONNAIRE ITEM GROUPINGS
INFORMATIONAL ITEMS

	ILLUSTRATORS											DRAFTERS			
	FEMALE					MALE						FEM.	MALE		
INDIVIDUAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Background															
Edcuation	2	2	4	4	2	3	1	3	2	3	2	2	3	4	2
Gen. Exper.	3	3	3	3	4	5	4	3	6	3	5	3	3	6	4
CAD Exper.	3	2	3	2	3	3	3	1	2	3	3	1	2	3	1
Item 1	3	2	2	2	2	3	3	1	4	1	2	2	2	1	3
Item 2	4	3	3	3	3	4	3	2	4	3	3	3	4	3	2
Personal Performance															
Item 5 –[a]	4	2	4	4	4	5	3	3	3	4	4	3*	1	2	1
Item 6 –	5	3	4	5	5	5	4	1	5	5	4	3*	3	5	4*
Item 7 –	5	3	5	5	5	5	4	1	5	5	4	4	4	5	3*
Item 8	4	3	3*	4	4	3*	4	1	5	4	3	3*	3	4	1*
Item 9	3	3	1	4	2	3*	3	1	4	4	3	3	3	4	3*
Total	21	14	17*	22	20	21*	18	7	22	22	18	16*	14	20	12*
System Performance															
Item 22 –	3	4	4	3	4	2	5	1	4	2	3	3*	3	5	1
Item 24	2	3	3*	2	2	3	3	2	2	2	4	5	4	5	4
Item 26	3	3	2	3	3	3*	4	2	3	2	2	4	3	3	2*
Total	8	10	9*	8	9	8*	12	5	9	6	9	12*	10	13	7*
Management Factors															
Item 18	4	4	4	4	3	5	3	2	2	5	3	2	3	3	1
Item 19	5	4	2	4	4	3	2	4	1	2	2	3	4	3	3
Total	9	8	6	8	7	8	5	6	3	7	5	5	7	6	4
Evaluation															
Item 25 +/–[b]	3	3	2	3	3	3	3	2	3	3	3	3	3	3	3

a Items followed by a minus sign have had the rating scores reversed to make high values indicate high amount of automation or high regard for automation.

b Scale values were changed to make positive evaluations higher in scale value.

* Estimated score.

Based on the judgment of the investigators the items were grouped into categories which appeared to address the same issues within the information section and within the attitude section. The categories used in the information section were:

- Background of the respondents,
- Personal performance by the respondents,
- System performance as judged by the respondents, and
- The perceived attention paid by management to the workers in development of the systems.

A general evaluation of automation was also considered as a possible category, but only two subjects yielded differential responses, and it was dropped from further analysis.

Within the attitude section the categories were:

- General attitude toward the systems,
- Attitudes concerning the reliability of the systems,
- Attitudes concerning ability to retain physical skills,
- Attitudes about how automation affected workloads,
- Attitudes about how the employer was affected by automation, and a miscellaneous category.

Correlations were obtained among items individually and among the sums of the categories. All correlations were Pearson Product Moment Correlation Coefficients, commonly referred to as the Pearson r. It was assumed that the latter correlations would be more dependable, since some error of measurement would be reduced by having more observations. However, items within the rough categories did not always correlate highly. In some cases this probably resulted from lack of variability for an item. For example, Item V received a rating of "5" from 10 of the 15 respondents and a rating of "4" from the remainder. Based on the lack of correlations of items with their category sums, some items were dropped from the categories and the sums and correlations were recomputed. However, no substantial differences resulted from these changes.

Results

The small size of the sample limits the extent to which we may generalize from these data. Since inferential statistics would be very limited in power, we felt it was better simply to present the descriptive data for individual items. In the main, it appeared that the attitudes did not differ as a function of the sex of the respondent. Further, both the illustrators and designers were favorable and did not differ substantially from one another. It did appear that the designers were less concerned that the system would "crash" at an inopportune time, as they responded (in transformed score) favorably with an average of 3.20 to the illustrators' 1.81 on that question. The illustrators also expressed greater concern over the reliability of the system (Item M of the attitude scales). Another difference was that the designers indicated greater possibility that they could be creative while using the automatic system. It is quite possible that these differences could be traced to the sorts of tasks which the different users must perform and to the fact that the system which the designers use was an off-the-shelf system which presumably would have had fewer bugs at the beginning than the illustrators' system which was developed for the specific task.

Responses of males and females and illustrators and designers were also similar on the informational items, but, as might be expected from the natures of the systems, the designers reported taking longer to learn to produce usable drawings (Item 5). However, they were also more pleased with the quality of the drawings (Item 24). This seems reasonable from the nature of the drawings the different systems do.

Intercorrelations among informational items and among attitude items are presented in Tables 7 and 8, and the correlations of attitudinal items with informational items are presented in Table 9. Again, it must be noted that the power of statistical tests of the sizes of the correlations is low. A correlation of 0.52 is required for significance at the 0.05 probability level. Correlations among the sums of categories are presented in Table 10.

Conclusions

Several possible relationships are of interest in conjunction with the general problem of effects of automation on those who are using it. Because negative attitudes may ultimately result in lowered performance, a primary concern was to evaluate factors which contribute to attitudes. Secondarily, there was interest in how attitudes related to one another. That is to say, will negative attitudes developed in conjunction with one factor affect other attitudes?

TABLE 7.

CORRELATIONS AMONG ITEMS FROM CAD QUESTIONAIRE

ATTITUDE ITEMS

	General									Reliability				Skill Retention				Workload				Employer			Misc.	
	B	E	I	K	N	P	T	V	SUM	D	M	O	SUM	F	G	S	SUM	C	H	Q	SUM	R	U	SUM	A	J
General																										
B –		.12	–.03	.12	.67	.50	.58	.02	.58	.38	.31	.04	.37	.32	.49	.61	.62	.62	.43	.22	.60	.55	.65	.64	–.40	.83
E			.34	.44	.30	.40	.66	.26	.78	.30	.13	.71	.51	.49	.08	.20	.34	.34	–.18	.02	.04	.41	.16	31	.01	.10
I				–.05	.27	.21	.13	–.43	.36	.40	.16	.55	.51	.43	.28	.08	.32	.11	–.06	–.16	.08	.15	.31	.24	–.13	.21
K					.12	.33	.46	.04	.56	.16	.22	.30	.31	.04	.40	.11	.10	.60	.05	.16	.13	.52	.51	.55	–.25	–.03
N –						.80	.49	–.13	.72	.28	.38	.21	.41	.52	.43	.37	.56	.66	.39	.56	.75	.38	.55	.49	–.56	.67
P							.36	.18	.76	.20	.45	.37	.47	.62	.50	.18	.52	.65	.27	.52	.66	.64	.72	.75	–.57	.54
T –								.08	.82	.37	.07	.46	.42	.48	.42	.58	.65	.47	.22	.36	.49	.46	.42	.47	–.09	.37
V									.15	–.08	–.17	.21	–.04	19	–.22	–.03	–.01	–.09	–.06	–.15	–.15	21	–.04	.10	.10	.02
Reliability																										
D –									.44		.34	.35	.84	.58	.51	.26	.55	.32	.29	–.13	.22	.64	.38	.55	–.17	.55
M –									.32			.04	.66	.35	.43	–.18	.20	.43	.61	07	.55	.32	.40	.38	–.26	.47
O									.63				.61	.72	.19	.15	.44	.27	–.05	–.02	.07	.44	.31	41	– 40	.16
Skill Retention																										
F –									.64				.76		.49	.32	.75	.61	.37	.24	.57	.55	41	.51	–.44	.50
G									.51				.55			.44	.78	.39	.50	.35	.60	.60	.70	.69	–.36	.36
S –									.38				.12				.81	.30	– 03	.26	.23	31	.17	.26	–.03	.35
Workload																										
C –									.57				48				.54		38	19	.71	.44	.48	.49	–.50	.59
H –									.19				.41				.31			09	.75	14	.38	.27	–.39	37
Q									.39				–.04				.36				.61	.12	39	.26	–.10	.26
Employment																										
R									.68				.67				.59				.31		.76	.94	–.38	.53
U –									.67				.51				.50				.58			.93	–.56	.61
Miscellaneous																										
A									–.37				–.37				–.32				–.47			–.50		–.43
J –									.52				.57				.52				.57			.60		
Background																										
ED	.07	– 18	–.33	.16	– 08	.05	–.27	.40	–.09	.11	.02	–.14	01	–.22	.35	– 52	– 39	–.16	–.02	–.24	–.20	.25	17	23	– 15	.24
GEN	45	39	29	.14	.39	.40	25	.08	.49	.08	.43	.54	.46	37	–.18	.10	.29	.43	.32	23	.24	23	.41	34	–.57	.41
CAD	.59	.28	–.11	–.11	.52	66	25	45	.45	.13	.06	13	.15	38	– 19	.47	.54	.52	04	.11	.28	.54	37	.49	– 22	.45

Items with a minus sign have had the rating scores reversed to make high values indicate high amount of automation or high regard for automation

TABLE 8.

CORRELATIONS AMONG ITEMS FROM CAD QUESTIONNAIRE

INFORMATIONAL ITEMS

	GE	CE	1	2	5	6	7	8	9	22	24	26	18	19
Background														
Educ	-.06	-.19	-.53	-.02	.12	.09	.21	-.03	-.03	.07	.03	-.37	.36	.10
Gen. Exp.		.29	.32	.22	.01	.44	.30	.32	.39	.32	.24	.06	-.20	-.51
CAD Exp.			.00	.46	.54	.65	.69	.61	.12	.51	-.18	.00	.69	-.19
1				.47	.04	.34	.25	.24	.19	.11	-.17	.32	-.19	-.24
2					.26	.47	.64	.66	.36	.33	-.12	.40	.45	-.01
Personal Performance														
5						.41	.45	.35	-.11	-.01	-.50	-.05	.61	-.12
6							.90	.71	.57	.34	-.17	.11	.42	-.23
7								.80	.47	.48	-.06	.23	.51	-.23
8									.56	.70	-.25	.46	.40	-.25
9										.19	.14	.31	.14	.20
System Performance														
22											.15	.54	.13	-.22
24												.21	-.35	-.12
26													-.04	.12
Management Factors														
18														.10
19														

TOTALS	GE	CE	I-1	I-2	I-5	I-6	I-7	I-8	I-9	I22	I24	I26	I18	I19
Pers.	.37	.68	.27	.61	.56	.92	.93	.87	.61	.42	-.23	.26	.54	-.15
Sys.	.32	.20	.08	.25	-.27	.14	.31	.41	.27	.81	.65	.72	-.11	-.15
Mgt.	-.47	.35	-.29	.30	.34	.14	.19	.11	-.03	-.05	-.32	.05	.75	.73

Items with a minus sign have had the rating scores reversed to make high values indicate high amount of automation or high regard for automation.

TABLE 9.

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CORRELATIONS OF ATTITUDE WITH INFORMATION ITEMS

	Prior Skills 1	2	Personal Performance 5	6	7	8	9	Sum	System Performance 22	24	26	Sum	Management Factors 18	19	Sum
General															
B	.36	.27	.39	.87	.78	.49	.87	.75	.22	−.05	−.03	.09	.19	−.41	−.14
E	.13	.37	.04	.42	.26	.54	.77	.50	.24	−.17	.38	.17	.31	.00	.21
I	.21	.19	−.32	.00	−.04	−.08	.52	−.05	−.08	.61	.15	.30	−.08	−.25	−.22
K	.21	.01	−.13	.24	.06	.11	.46	.17	−.08	−.20	.15	−.10	.11	−.09	.01
N	.34	.20	.22	.79	.70	.53	.49	.70	.46	.09	.13	.35	.31	−.43	−.07
P	.30	.44	.10	.68	.65	.58	.44	.62	.55	−.02	.10	.33	.51	−.46	.04
T	39	.29	.25	.66	.52	.67	.56	.72	.19	−.29	.35	.07	.15	−.29	−.09
V	−.26	.39	.43	.11	.33	.53	.04	.36	.41	−.35	.20	.12	.48	−.12	.25
Workload															
C	.20	.08	−.13	.63	.45	.46	.43	.46	.42	−.07	−.16	.15	.03	−.47	−.22
H	.35	.03	−.26	.28	.34	.35	.16	.22	.64	.34	.34	.63	−.41	−.51	−.52
Q	.51	.40	.22	.35	.39	.32	.21	.38	.07	−.29	.08	−.08	.34	−.28	.01
Reliability															
D	−.12	.24	.34	.36	.39	.22	.59	.29	.17	.54	.35	.47	.01	.01	.03
M	.54	.37	−.47	.38	.34	.23	.29	.19	.42	.27	.28	.45	−.22	.02	−.15
O	−.02	.32	−.17	.23	.20	.45	.73	.34	.23	.24	.26	.33	.05	−.35	−.24
Skills															
F	.12	.72	−.24	.44	.52	.67	.64	.50	.62	.29	.41	.62	.08	−.49	−.23
G	−.49	−.17	.23	−.34	−.30	−.19	−.30	−.22	−.27	−.29	−.38	−.41	.09	−.34	.33
S	.31	.27	.47	.53	.48	.41	.21	.55	.06	−.14	.26	.04	.19	−.10	.05
Employment															
R	.04	.45	−.01	.61	.61	.46	.57	.56	.23	.10	.12	.22	.45	−.17	.20
U	.36	.29	−.01	.56	.50	.28	.48	.45	.15	.17	−.08	.15	.22	−.59	−.24
Miscellaneous															
A	.04	.15	.15	−.39	−.31	−.18	−.25	−.25	−.30	−.34	.18	−.28	.10	.65	.49
J	.24	.37	.14	.77	.79	.44	.44	.66	.19	.18	−.07	.18	.18	.39	−.13
Attitude															
GEN	.36	.43	.15	.75	.62	.67	.84	.76	.27	−.06	.32	−.19	.37	−.41	−.02
REL	.17	.37	−.46	.46	.44	.41	.75	.38	.38	.51	.42	.60	−.08	−.15	−.15
SKL	.38	.38	.07	.58	.57	.56	.48	.57	−.38	.15	.43	.42	.10	−.42	−.20
WKL	.52	.20	−.09	.58	.56	.53	.37	.49	.56	.02	.17	.38	−.05	−.52	- 38
EMP	.21	.40	−.01	.62	.59	.40	.56	.54	.20	.14	.03	.20	.36	−.40	−.02

Items with a minus sign have had the rating scores reversed to make high values indicate high amount of automation or high regard for automation.

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TABLE 10.

INTERCORRELATIONS AMONG COMBINATIONS OF ITEMS

	SP	MG	ED	GE	CAD	GA	RA	SR	WK	EM	JR
PP	.416	.203	.101	.367	.683	.774	.380	.570	.490	.544	.659
SP		-.024	-.130	.315	.386	.365	.491	.425	.445	.202	.129
MG			.311	-.474	.350	-.001	-.148	-.203	-.375	-.016	-.134
ED				-.056	.096	-.079	.007	-.485	-.195	.227	.240
GE					.285	.442	.461	.265	.242	.337	.411
CAD						.448	.148	.472	.285	.489	.446
GA							.637	.619	.580	.711	.514
RA								.564	.398	.636	.574
SR									.562	.582	.516
WK										.474	.573
EM											.604

Significance levels for bidirectional tests

Alpha	r
.10	.441
.05	.525
.01	.623

Number of significant correlations with other variables

Variable	Number @ .01	.05	.10
GA	3	5	8
EM	2	5	7
SR	1	5	8
PP	3	5	6
RA	2	4	6
JR	1	4	7
WK	0	3	6
CAD	1	1	5
GE	0	0	3
SP	0	0	2
MG	0	0	1
ED	0	0	1

PP	Personal Performance	WK	Workload
SP	System Performance	EM	Employer Relations
MG	Managment Factors	JR	Job Retention A-10
GA	General Attitude	ED	Education
RA	Reliability Attitude	GE	General Experience
SR	Skill Retention	CAD	CAD Experience

Items with a minus sign have had the rating scores reversed to make high values indicate high amount of automation or high regard for automation.

In considering the question of which factors are most associated with attitudes, it is clear that the measure obtained in this study which had the greatest relationship with attitudes was the way the individuals perceived their own performance on the automated system. As may be seen in Table 10, the highest correlations are obtained between personal performance and all of the attitude categories except the attitude concerning the reliability of the system. From this we may infer that the extent to which the individual feels that he or she can succeed with the system may affect acceptance of the system. It may also be noted that Computer-Aided-Design (CAD) experience provides the second highest set of correlations with attitudes, despite the fact that as a single item its reliability is likely less than that of the combinations. It is possible that the greater the amount of experience the more competent the individual becomes, and thus, will have a greater sense of accomplishment with the system.

Another item of considerable interest is the item included within the attitude section, but which is perhaps more general; that is the question of whether or not one is likely to be displaced as a result of automation. This item correlated highly with the personal performance total and with the other attitude totals. This fits a pattern that includes feelings of self-confidence and security.

A somewhat anomalous finding is that the questions concerning managerial relations did not correlate much at all with the attitudinal items. Two possibilites could account for this. First, one of the questions, Item S, was somewhat bipolar and this could have reduced the correlations. To evaluate this, an analysis was done in which the scores were rescaled from the null point, and correlations were calculated between the item and the attitude sums and between the revised management sum and the attitude sums. Although there were minor differences in specific item correlations, the general results were basically unchanged. The second possibility is that in order to show strong differences it would be necessary to compare across different groups of management. This view is somewhat supported by the individual protocols. In only one case was there indication of strong disaffection. Thus, most employees seem to have good rapport with management. A contraindication to this second explanation occurs in the fact that the totals concerning attitude toward employers' needs tended to correlate well with the other attitude measures. This would indicate that some variability does exist in individual attitudes toward management.

Another interesting area was background experience where few correlations were found which could be considered to show even modest relationships. Even CAD experience did not show high correlations, even though it was better than any of the other informational items except personal performance. Although this could be related to the small sample size and thus low reliability of the items, it is possible that background can be obscured by other factors, perhaps training.

Taken as a whole, these results suggest that to produce favorable attitudes it is best to provide the conditions for rapid development of productive performance on the part of the individual. This would have implications for training and in some cases early job assignment.

Summary

The questionnaire data from the CAD employees must be considered tentative in light of the small number of respondents, but they do suggest that the greater extent to which individuals perceive their capabilities to operate the system as being high, the more accepting they are of the system. There is also some indication that fear of displacement affects attitudes negatively. We found that for this sample, there was little correlation between feelings of involvement and user acceptance.

Additional interview subjects in the area of office automation have included manufacturers and users of computer-aided-design systems and manufacturers and users of word processing systems. Narrative summaries of these interviews are included in Appendix D.

3.3.4 Automation in the Power Industry

While it is difficult to characterize any system as fully mature, in some systems automated technology has been available for several decades. The electric power industry provides examples of such systems. This industry has been of interest to this study because it not only includes some relatively stable instances of automation, but, in the case of nuclear power, it also provides situations where the application of existing human factors guidelines has not been entirely successful.

For example, Three Mile Island's (TMI) control panels contain over 1900 displays. Of these, about twenty-six percent were so high that about five percent of the operators could not read them at all. Some 800 improvised changes were made by the operators to clarify panel nomenclature or to rectify contradictory labels.

In an analysis of the TMI accident (Cordes, 1983) a number of violations of accepted human factors principles were pointed out.

> "Nuclear plants generally include thousands of controls to manipulate and meters and trouble indicators to monitor. Should something go wrong, the resulting maze of lights and ringing alarms tend to inundate operators with sensory overload...while often failing to tell them exactly what they need to know."

One of the fossil fuel generating plants at which interviews were conducted has been in operation since 1924 with additional generating capacity being added at intervals since then. It has been referred to by others in the industry as an "electric power museum" because of the cross-section of technology which it represents. The newest generator was installed in the mid-1960's and is representative of a typical automated system. Automation in this case is achieved by pneumatic devices and hard-wired electromechanical devices such as relays. The process is controlled by an operator positioned at a large boiler-turbine-generator (BTG) control board. His job consists of initiating changes in the process, monitoring the ongoing process, and responding to alarms. Most of the power generated by the plant is generated by the automated process. However, during periods of peak demand or equipment maintenance, the old generator will be brought on-line, giving the operators the opportunity to experience the old manual way of operation. The operators are being introduced to computer-based automation through a recently installed maintenance documentation system. This encounter with the computer has given them a foretaste of the upcoming introduction of computer-based system control. Another generating station was visited which has had a computer-based system in place since 1969. This system uses a large mainframe computer to process system information and display it to the operator. This system is currently being replaced by a state-of-the-art system.

Another phase of our study of automation in the power industry involved an investigation into nuclear power. The thrust of these efforts has been in terms of interviewing personnel concerning the problems which have arisen particularly since the Three Mile Island accident. The nuclear power industry, despite its state-of-the-art image, has avoided automation to a large extent. This is attributed by some to its close relationship to the development of the U.S. Navy's nuclear submarines under Admiral Hyman G. Rickover. Admiral Rickover believed that control by disciplined and well-trained operators was the best means of ensuring system reliability. This influence has been carried over into the design of civilian power-generating reactors. Three Mile Island has caused a careful reevaluation of this .pa philosophy; as a result the industry in general is quite conscious of human factors issues as they relate to automation. Consequently, this is a particularly good time to be investigating this subject.

We have visited a nuclear power plant and interviewed members of plant management. In addition, we have interviewed control operators at the facility. Narrative summaries of these interviews are presented in Appendix D.

SECTION 4
HUMAN FACTORS ISSUES IN AUTOMATED SYSTEMS

A large quantity of raw data was generated during the study, from both the literature search and the interview process. Several techniques were developed to aid in reducing this body of data and to ensure that it was interpreted as objectively as possible.

4.0.1 Issue Tree Evolution

The task undertaken in the study was quite broad and many alternate courses of action were possible within its scope. The danger existed of pursuing a narrow aspect of the field in great depth while ignoring other equally significant areas. As a result a need existed for a structure to act as a guide in ensuring even coverage of the field. A study by Honeywell personnel, dealing with computer-aided-manufacturing, used an "Issue Tree" to hierarchically arrange the topics with which the study dealt. This issue tree served as a useful point of departure in identifying the issues relevant to human factors in automation. However, the structure of the issue tree was static and as such belied the more dynamic aspects of human factors issues which arise at interfaces and involve interactions. The diagram presented in Figure 6 represents an approach toward redefining the structure behind the issue tree. Organizations undergoing automation can be divided into three primary elements: 1) management, 2) workers, and 3) the system or process. Human factors issues are the result of communication, information flow, and interaction between these elements. The original Honeywell issue tree was reorganized according to this structure. Throughout the course of the study, the issue tree was continuously modified to reflect the issues raised in the course of the interview process. The reorganized issue tree, in its final form, is presented in Figure 7.

4.0.2 Interview Response Summary Matrices

The Interview Response Summary Matrices have been discussed in subsection 3.3.1. They have proven to be very valuable in achieving an overview of the interview results and discovering trend information.

4.0.3 Anecdote, Opinion and Data Point Summary Sheets

The literature abstracts and the narrative summaries of the structured interviews have been carefully reviewed to extract relevant anecdotes, opinions, and data points. The entire body of data was reviewed several times to make certain that no relevant points were missed and to weed out irrelevant points. Anecdotes, opinions, and data points were entered on summary sheets

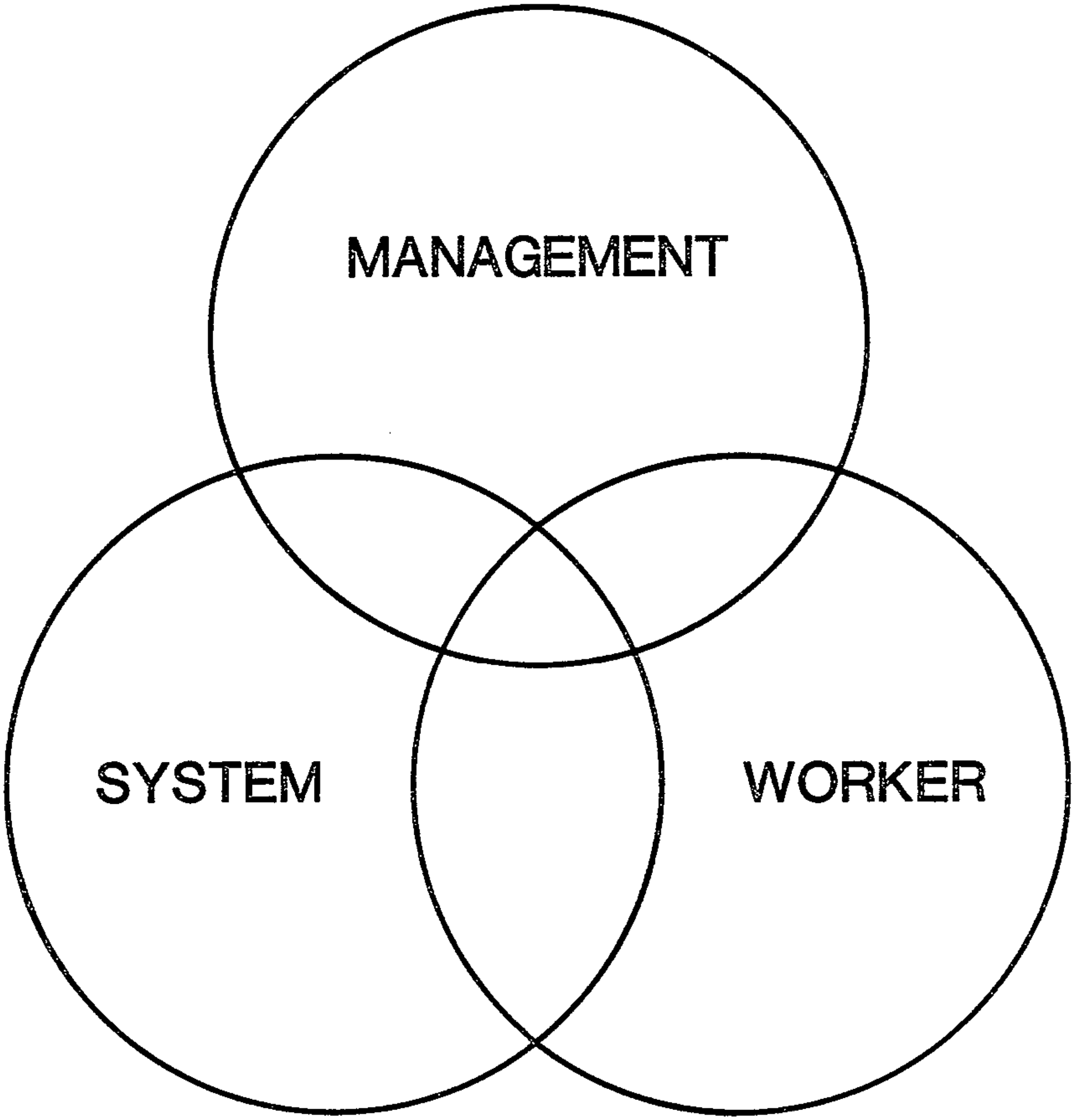

FIGURE 6. INTERACTIVE ORGANIZATIONAL ELEMENTS

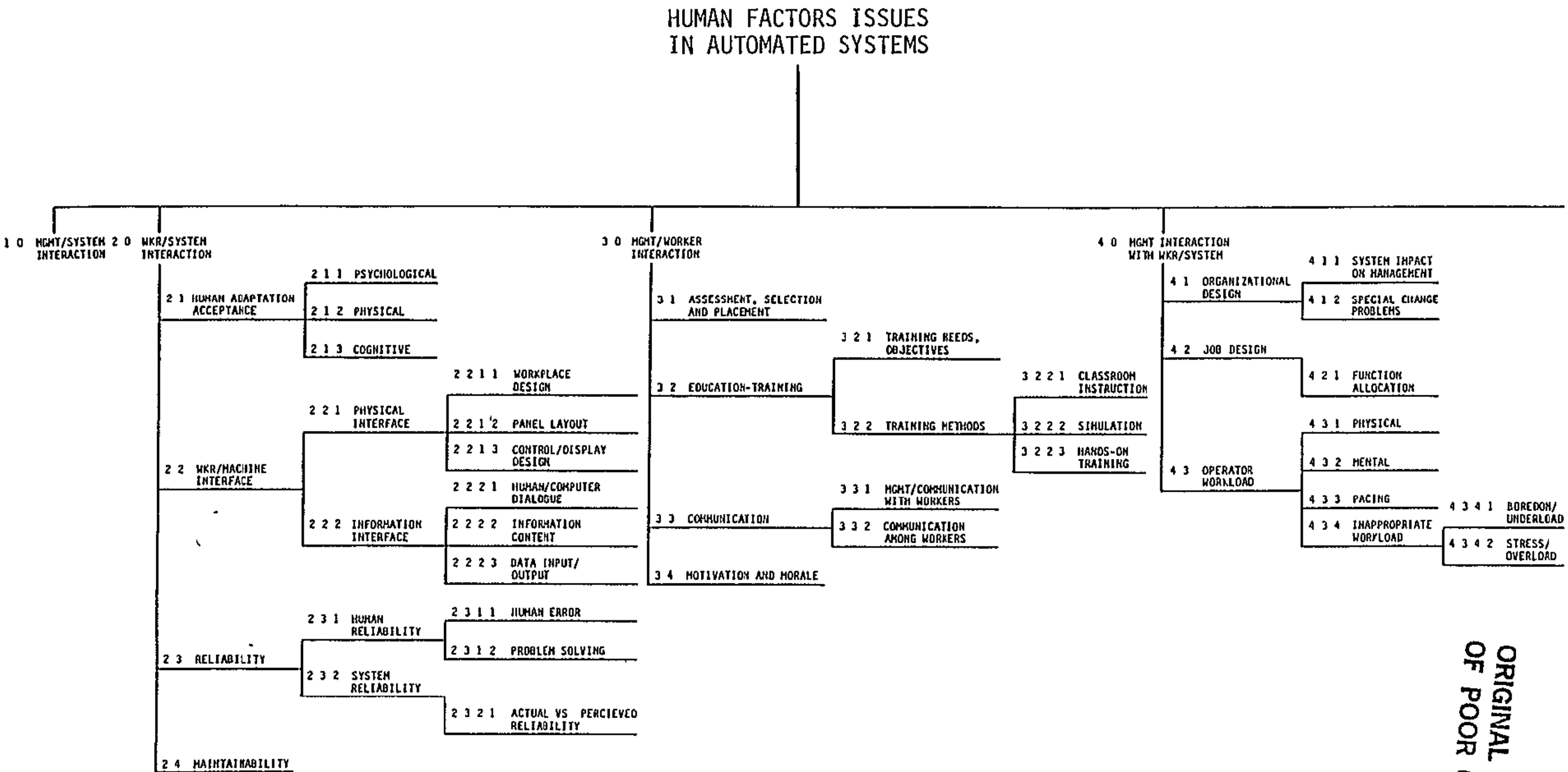

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FIGURE 7. ISSUE TREE

such as the one illustrated in Figure 8. These sheets were re-arranged and grouped according to the pertinent issues as shown on the issue tree. By studying each issue as it has been raised by a number of different sources, guidelines were developed to assist future system designers in dealing with these issues.

4.0.4 Tabulation Matrix

The number of times issues were referred to in the literature and in the interviews was tabulated on a matrix. The matrix does not concern itself with the content of comments regarding particular issues, merely the frequency with which issues are raised. This technique minimizes subjective interpretation of comments and provides an indication of the relative importance of the various issues to the populations which were surveyed. The Tabulation Matrix is presented in Figure 9.

4.0.5 Commonality Matrix

A "Commonality Matrix", shown in Figure 10, has been developed to aid in establishing a basis of comparison between the various fields which were studied and the field of aviation. This matrix lists the various characteristics which constitute a profile of the tasks we have studied as well as a profile of the operators who perform these tasks. These characteristics have been cross-referenced to the tasks studied and a notation has been made of the degree to which a particular characteristic is relevant to a given task. This matrix has served as a handy tool for analyzing the relationship between the various fields which have been investigated as part of this study and in identifying subtle relationships which otherwise might not be apparent.

SUMMARY SHEET

SOURCE: INTERVIEW Office Automation No. 5

RELEVANT ISSUE(S): 2.1.1 Psychological Adaptation

ANECDOTE, OPINION OR DATA POINT

Attitudes toward the system have changed as workload in the group has increased. Some of the most vocal opponents have come to appreciate the increased speed which the system offers. It is generally conceded that the computerized system is the only way the task can be accomplished within the time available.

COMMENTS: User acceptance will be high if the system is really needed and it in fact does the job. When workload is not excessively high to begin with, an automated system which reduces workload will usually meet with resistance.

FIGURE 8. TYPICAL SUMMARY SHEET

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	AVIATION	OFFICE AUTOMATION	PROCESS CONTROL/ FACTORY	POWER INDUSTRY	LITERATURE ABSTRACTS	TOTAL
SIZE OF SAMPLE	50	10	18	10	50	
1.0 MANAGEMENT/SYSTEM INTERACTION		1	5		2	8
2.0 WORKER/SYSTEM INTERACTION		1	2			3
2.1 HUMAN ADAPTATION/ACCEPTANCE	(4-)(25N)(21+)	(3-)(2N)(5+)	(3-)(6N)(9+)	(0-)(7N)(3+)	N/A	(10-)(40N)(38+)
2.1.1 PSYCHOLOGICAL	47	9	16	2	13	87
2.1.2 PHYSICAL	26	4	3	3		36
2.1.3 COGNITIVE	19	3	7			29
2.2 WORKER/MACHINE INTERFACE			1			1
2.2.1 PHYSICAL INTERFACE					1	1
2.2.1.1 WORKPLACE DESIGN	1	3	1			5
2.2.1.2 PANEL LAYOUT	1	1		1		3
2.2.1.3 CONTROL/DISPLAY DESIGN	6	6	8	3	9	32
2.2.2 INFORMATION INTERFACE	2	2	2		4	10
2.2.2.1 HUMAN/COMPUTER DIALOGUE		6				6
2.2.2.2 INFORMATION CONTENT	6		7	4	11	28
2.2.2.3 DATA INPUT/OUTPUT		4	5		9	18
2.3 RELIABILITY	1	1	3			5
2.3.1 HUMAN RELIABILITY				1		1
2.3 1.1 HUMAN ERROR	14	5	8	1	4	32
2.3.1.2 PROBLEM SOLVING		3		5	6	14
2.3.2 SYSTEM RELIABILITY	23	1	15	9		48
2.3.2.1 ACTUAL VS. PERCEIVED RELIABILITY	2		5	5		12
2.4 MAINTAINABILITY	1		4	2		7
3.0 MANAGEMENT/WORKER INTERACTION					1	1
3.1 ASSESSMENT, SELECTION AND PLACEMENT		3	5	4	8	20
3.2 EDUCATION-TRAINING	1		3	3		7
3.2.1 TRAINING NEEDS, OBJECTIVES	29	4	7	4	6	50
3.2.2 TRAINING METHODS	19	3	2	1	10	35
3.2.2.1 CLASSROOM INSTRUCTION	3		2			5
3.2.2.2 SIMULATION	7		3	3		13
3.2.2.3 HANDS-ON TRAINING	5	2	6	1		14
3.3 COMMUNICATION					1	1
3.3.1 MANAGEMENT COMMUNICATION WITH WORKERS		1	2			3
3.3.2 COMMUNICATION AMONG WORKERS	25	1		1		27
3.4 MOTIVATION AND MORALE	1	3	2	1	6	13
4.0 MANAGEMENT INTERACTION WITH WORKER/SYSTEM		8	6	1	1	16
4.1 ORGANIZATIONAL DESIGN			2		2	4
4.1.1 SYSTEM IMPACT ON MANAGEMENT		2	5	2		9
4.1.2 SPECIAL CHANGE PROBLEMS			1		1	2
4.2 JOB DESIGN		1		4	3	8
4.2.1 FUNCTION ALLOCATION	2	7	7	6	26	48
4.3 OPERATOR WORKLOAD	3	6	6	4	13	32
4.3.1 PHYSICAL	20	2	11	4		37
4.3.2 MENTAL	36	5	8	3	3	55
4.3.3 PACING		3	5		2	10
4.3.4 INAPPROPRIATE WORKLOAD					2	2
4.3.4.1 BOREDOM/UNDERLOAD	20	2	7	2	2	33
4.3.4.2 STRESS/OVERLOAD	1	1				2

(-) = NEGATIVE VIEW OF AUTOMATION
(N) = NEUTRAL VIEW OF AUTOMATION
(+) = POSITIVE VIEW OF AUTOMATION

FIGURE 9. TABULATION MATRIX

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		AVIATION		PROCESS CONTROL/ FACTORY		OFFICE		POWER	
		MANUAL	AUTO	MANUAL	AUTO	MANUAL	AUTO	MANUAL	AUTO
COGNITIVE SKILL REQUIREMENTS	VERBAL ABILITIES					●	●		
	IDEATION FLUENCY					●	●		
	ORIGINALITY			X	X	X	X		
	MEMORIZATION	●	○			●	○	●	○
	PROBLEM SENSITIVITY	○	○	○	○	○	○	○	○
	MATH ABILITIES	○	○	○	○	○	○	○	○
	REASONING	●	●	●	●	●	●	●	●
	INFORMATION ORDERING	●	●	●	●	●	●	●	●
	SPATIAL ORIENTATION	●	●	○					
	VISUALIZATION	○	●	○	●			○	●
	CLOSURE	●	●	●	●	○	○	●	●
	SELECTIVE ATTENTION	●	○	●	○			●	○
	TIME SHARING	●	○	●	○	●	○	●	○
	PERCEPTUAL SPEED	●	●	●	●	●	●	●	●
PHYSICAL SKILL REQUIREMENTS	PHYSICAL STRENGTH			○					
	STAMINA	○	○	○	○	○	○	○	○
	FLEXIBILITY								
	EQUILIBRIUM	●	●						
	REACTION TIME	●	●	●	●			●	●
	SPEED OF MOVEMENT	○	○	○	○				
	COORDINATION	●	○	●	○				
	MANUAL DEXTERITY	●		●					
	RATE CONTROL	●	○	●	○				
	CONTROL PRECISION	●	○	●	○				
SOCIAL SKILLS	LEADERSHIP	●	●	○	○	○	○	●	●
	SUBORDINATION	●	●	○	○	○	○	●	●
	TEAMWORK	●	●	○	○	○	○	●	●
	INDIVIDUAL INITIATIVE			X	X	X	X	X	X
JOB CHARACTERISTICS	REPETITION FREQUENCY	●	●						
	HIGH STRESS	●	●						
	RESPONSIBILITY	●	●						
	HIGH LEVEL OF PRESTIGE	●	●						
	FINANCIAL REWARD	●	●						
	PROGRESSION BY SENIORITY/MERIT	S	S	S/M	S/M	M	M	S	S
	PROFICIENCY INCREASES WITH EXPERIENCE	●	●	○	○	○	○	○	○
	SKILLS DEGRADE WITH AGE								
	HIGHLY STRUCTURED	●	●						
	SELF-ACTUALIZING					●	●		
	DEFINED BY COMPLETION OF TASKS	●	●	○	○	X	X	○	○
	DEFINED BY ACCOMPLISHMENT OF OBJECTIVES					X	X		
	LENGTHY TRAINING	●	●	○	○			○	○
	FREQUENT TURNOVER					○	○		
	PHYSICAL ACTIVITY LEVEL			○	○				
	OBSOLESCENT								
	SECURITY	○	○	○	○	X	X	○	○
	UNIONIZED	●	●	●	●			●	●
	DEADLINES/PRESSURES	●	●	○	○	●	●	○	○
	EXPERIENCE LEVEL REQUIRED	●	●	○	○	○	○	○	○
NATURE OF INDUSTRY	PROGRESSIVENESS	●	●	●	●	○	○	○	○
	EXPANDING			X	X				
	AGE OF WORKFORCE	HI	?	X	X	X	X	X	X
	PROFITABLE								
	DEGREE OF SPECIALIZATION	HI	HI	HI	HI	X	X	HI	HI
	HIGH TECH	○	●	○	●	○	○	○	●

	CHARACTERISTIC SLIGHTLY INVOLVED IN JOB OR INDUSTRY
○	CHARACTERISTIC MODERATELY INVOLVED IN JOB OR INDUSTRY
●	CHARACTERISTIC HEAVILY INVOLVED IN JOB OR INDUSTRY
X	CANNOT GENERALIZE

FIGURE 10. COMMONALITY MATRIX

4.1 MANAGEMENT/SYSTEM INTERACTION

Relatively few human factors issues were found which belong primarily in the category of Management/System Interaction. In most cases, management's interaction is with the ensemble of worker and system. There are, however, some cases in which management wishes to bypass the worker and interact with the system itself. For example, if the plant superintendent tours the facility for the purpose of inspecting its condition and observing the conduct of his employees, it is important that he do so without having to depend on the word of the workers. In a traditional plant, such as the refinery which has been referred to previously, he merely has to walk through and observe the position of valves and other control devices. In an automated facility, he must be familiar enough with the system to interrogate the computer to learn what he could previously observe directly.

A factory which manufactures glass bottles was among the industries surveyed as part of the study. The process involves taking specially selected and prepared sand, mixing it with chemicals such as iron pyrite (for amber color glass) and a percentage of reground glass (cullet), and firing these ingredients in "tanks" until they are molten and can be cast into the desired shapes. The ingredients are fed by a conveyor and hopper system to one of three tanks that produce molten glass and feed the glass into the bottle-making machines.

The three tanks were built at different times and have completely different control systems and philosophies. Tank No. 1 is primarily a manual system with conventional "knobs and dials" controls; process data are monitored through the use of chart recorders which prominently display the records for a twenty-four hour period. Tank No. 2 is automatically controlled from a panel which incorporates a cathode-ray-tube color graphic display and a uniquely formatted keyboard for entering control commands. The keys on the keyboard each have different functions, depending on the order in which they are depressed. As a result, the keytops are blank and their functions must be learned in a week-long training course. The system is very flexible and can provide a great deal of information to the operator or manager, but it requires extensive training to be capable of accessing this information. As a result, management tends to feel shut off from the process and has expressed preference for the manual process used on Tank No. 1 with its direct access to process data.

In another case, the supervisor of a group of drafters expressed frustration with the computer-aided-drafting system which they were using. Under the traditional pencil-and-paper approach, it was easy for him to walk through the drafting area and quickly see the status of all of the projects. With the CAD system, he must go through the formal procedure of interrogating the computer to find out if the work is progressing according to schedule.

On the other hand, automation can have a positive effect on the relationship between management and system. Computers, and in particular large-scale-integration (LSI) and microprocessor technology, have led to the widespread application of programmable controllers. The significant difference in this type of automation is the ability to gather and evaluate extensive data on the performance of the system. A problem can arise when operators are not taught how to use this to their advantage. Often this capability is viewed as merely another technique of management to scrutinize employee performance. The computer is considered a "tattle-tale", resulting in an adversary relationship between the operator and the system.

There are two chief reasons for automating: to optimize cost or to optimize product quality. Optimizing costs, especially in recessionary times, is often equated with worker displacement. On the other hand, when automation is used to optimize quality, parameters which previously were difficult to monitor can be watched very closely. This presents a unique opportunity for management to be very closely in tune with the operation of the system without relying on reports prepared by the workers, which might be biased in their favor.

4.2 WORKER/SYSTEM INTERACTION

4.2.1 Human Adaptation

One of the most important aspects of the transition to automation involves the adaptation of the human operator to the new process or system. This adaptation takes place on one or more of the following levels: 1) psychological, 2) physical, and/or 3) cognitive.

4.2.1.1 Psychological Adaptation

It is difficult to treat psychological adaptation as a separate issue since in almost all cases, psychological adaptation, or user acceptance, is dependent on the successful resolution of some other more tangible issue or set of issues.

The issue of psychological adaptation to automation was raised 80 times in the interviews and referred to 13 times in the literature. Problems with adapting psychologically to automation can take several forms. One of the most commonly expressed problems is the perception of automation as a threat, either to one's job in its entirety or to authority or control of an aspect of the job.

Among the pilots who were surveyed, very few saw automation as an attempt to eliminate jobs, although several pointed out the trend toward two-man cockpits in the 767, 737-300, the A-300 and the DC9-80. Second Officers, whose jobs are most likely to be eliminated first, did tend to feel that the thrust of automation is to displace pilots rather than simply unburden them. In the words of one Second Officer: The thrust of automation is to "displace (people) and unburden whoever is left...no doubt." Senior pilots and copilots generally were confident that the human pilot would always be needed in the cockpit. They did express concern that automation could, if not properly implemented, erode their ability to control the aircraft under certain circumstances.

The comment was made and borne out by repeated examples that workers who have acquired "esoteric" knowledge of system operation often are the most threatened by automation. They have achieved a status because of their special knowledge and are most fearful of having this knowledge become obsolete or having their performance equalled or exceeded by a machine.

In some instances, automation has shown the ability to protect jobs by increasing productivity. For example, an automated mine system was accepted almost immediately even though it replaced some personnel, because without it the mine would have been shut down completely. A number of pilots (11) stated that an advantage of the automated avionics is their positive effect on fuel efficiency and consequently airline profit.

In a similar positive vein, the introduction of computerized systems can lend prestige to a job. In all of the fields which were studied, an employee's understanding of and familiarity with automated systems increases his value to the employer. In summary, those employees who have the ability to cope with change and adjust to new opportunities tend to view automation as a means of job security, while those who have difficulty adjusting view automation as a threat to their jobs. The exception is represented by those employees who do not feel that automation will eliminate their jobs, but who feel that automation may diminish their control and thereby jeopardize their ability to perform their jobs adequately. Examples can be found in each of the fields which were studied. In the office, automation has brought about a basic reorganization in the way work flows through the office. Under a traditional office organization, correspondence would be carefully reviewed and proofread before being typed and sent out; with word processors, it is possible for finished work to be generated at any point in the office, thereby bypassing the existing quality control procedures. In non-automated industrial situations, such as traditional process control and power generation facilities, it was possible for management to walk through the plant and follow an "audit trail" of physical evidence left by the operator's activities (e.g., closed valves) and be immediately aware of system status. New techniques must be learned when computerized systems are introduced and the systems must be implemented in a way which gives management full visibility into system operation. Similarly, pilots have expressed concern about the adequacy of displays to keep them "in the loop" and constantly aware of what the automated systems are doing and the raw data on which those control actions are based.

Another aspect of psychological adaptation involves the trust which the operators place in the system. A number of factors have the ability to either engender or destroy this trust. For example, the initial performance of the automated system has a lasting effect on the perceived reliability of the system. In one case, an automated process control system was installed in a factory. The system had been in place for over four years during which it had experienced only two problems, one at startup and the other after it had been in operation for three years. When the serviceman arrived after the second failure, the users were complaining about the poor reliability of the system. The initial performance of the system made a stronger impression than the three years of trouble-free service. The serviceman disassembled the system, could find nothing wrong, only to have the system work normally when it was reassembled. Even though the system had a demonstrably reliable record, the users' first impressions were reinforced because the reasons for the failures were mysterious and not well understood. "Reliability" as it concerns user acceptance is not an objectively quantifiable fact, but a subjectively perceived notion on the part of the user.

Not only failures but also normal operation must be reasonably well understood if the user is to trust the system. If the decision process which the computer uses is not apparent, the operator is not likely to trust the system. In one of the situations which was studied, a new automated inspection system was to be introduced into a factory environment. Prior to implementing the new system, a rumor circulated to the effect that the workers "don't like it and they won't make it work". In order to counteract this negative attitude, the engineer in charge took each inspector aside for about two hours and gave them a brief introduction to computers. This exercise included writing a simple ten line program. Once the inspectors felt that they had a basic understanding of the computer's decision-making process, they became excited about the prospect of working with a computer-based system.

This particular case offered several other examples which illustrated that the techniques used in introducing an automated system can have a profound impact on user acceptance. The crew responsible for setting up and maintaining the system had a similar negative attitude, claiming that the human operators could outperform the automated machine. They were sold on the advantages of the new system by observing its improved accuracy and repeatability. It was important to emphasize that this improvement was not due to any fault of the human operator but simply the result of the precise repetitive nature of the machine's operation.

Another very important factor affecting the high acceptance of this level of automation is that the company has a general bonus procedure, and any increased production could cause higher bonuses. Since this particular department was somewhat understaffed, none of the workers felt that their job was threatened by the new system. On the contrary, the automatic equipment offered the prospect of enhanced productivity and the potential of increased bonuses.

Although the new process has eliminated the portion of the job which takes the most mental effort, the increased speed seems to keep the job satisfying to the present inspectors. Since their measurements are also more reliable, they tend to go with the automated process unless a malfunction forces them to do otherwise.

In talking with the group of managers responsible for the system, it was apparent that they had a very strong concern with involving the workers at the earliest possible point in the process of automating a procedure. In fact, they said that they felt that they should have probably involved them earlier than they did.

In addition, the importance of follow-up consultation with the end users was mentioned. Several potential refinements to the system had been suggested by the workers.

Just as the negative first impressions tend to be perpetuated regardless of subsequent system performance, the positive attitudes toward accepting the automated system tend to be communicated to new workers who are brought into the group. As a consequence, once a positive attitude has been established, the time-consuming introduction process does not need to be repeated with each new worker.

If operator workload does not warrant the introduction of automated systems, user acceptance cannot be expected to be high. As a case in point, recently a new system was installed to automatically monitor conditions in a mine. The system had been developed by the engineering staff without input from the ultimate operators. When the new system was in place, the operators ignored it and referred to it as "the engineer's toy". They continued to do their job in the old manual way until a reduction in force increased their workload to the point that the labor-saving features of the automated approach were needed just to keep pace. They then voluntarily began to use the automated system.

In some instances, an automated system may be accepted by the workforce for the wrong reasons. A case in point is a municipal waste water treatment plant which was visited as part of the study. Although the plant was fraught with problems from the day it opened, the operators spent a great deal of their time trying to solve the problems with the automatic control system, often at the expense of keeping the plant operating within acceptable limits. Ultimately, the automatic controls were torn out and the plant reverted to manual operation. The president of the firm which manages the plant said that the operators liked the automated system and "miss their toy". The implication was that the challenge of trying to make the automated system work, even though these efforts were unsuccessful, was more interesting than the routine operation of the facility.

In another case, the personnel recruiting functions of a corporation were automated through the application of a computerized data base management system. Whereas the primary activity in the department had been to screen resumes and interview applicants, after the automated system had been adopted, the primary emphasis became maintaining the data base rather than selecting suitable employees.

Many generalizations were made in the literature and by interview subjects about the characteristics of the user and the affect they have on acceptance of automation. These generalizations will be discussed in greater detail in Section 4.3.1, Assessment, Selection, and Placement.

4.2.1.2 Physical Adaptation

Physical adaptation involves the learning of new skills which often must accompany the transition to automation. In many cases, a variety of skills which once depended on refined eye-hand coordination have been supplanted by an entirely new set of skills such as those needed to enter data into a terminal via a typewriter keyboard. In the field of office automation, drafters and designers have been judged by their drawing skills; now spelling ability and typing skills are often more important to the successful utilization of computer-aided-drafting systems.

During one of the office automation interviews which were conducted as part of the study, the example was cited of a drafter who was generally quite productive when creating traditional pencil-and-paper drawings. His productivity declined sharply after the transition to a computer-aided-drafting system. Upon investigation it was learned that he had difficulty in making the decisions needed to choose the appropriate procedure from the menu presented by the computer. For him, hand-drawing simply meant the application of physical skill which had been mastered over a period of time; working with the computer meant continually making conscious mental choices, a process with which he was unfamiliar and apparently uncomfortable. Similarly, in the factory and power plant, processes which traditionally involved a great deal of physical skill have been reduced to inputting of data, process initiation, and subsequent system monitoring. These changes in skill requirements are making their way into the cockpit as well. The Captain of a 767 described the change as: "With most (non-automated) planes you do something manually to an instrument and then fly where the instrument says to fly. With modern (automated) planes, you do something to a computer, the computer flies and you monitor."

Along with the requirement for new skills comes the concern for the eventual loss of existing skills and the possible detrimental effect this may have. Of the 43 interviews conducted with airline pilots, 22 referred to potential problems with skill retention and 14 referred specifically to the difficulty which many First Officers of highly automated aircraft such as the DC-10 experience when transitioning to Captain of less automated aircraft such as the 727. As one DC-10 First Officer said: "They tell us DC-10 First Officers to hand fly a lot before we bid Captain. I guess that's because all we do on the '10' is to dial knobs and punch buttons. Skill retention will become a problem with automation." This concern was also expressed in other fields, such as the interview with a seasoned machinist who had seen several technologies come and go, from the punched paper tape, numerically controlled machines of the 1960's to the present state-of-the-art computerized numerically controlled (CNC) machines. As he stated in the interview, traditional machining skills are still needed to set up a part, choose appropriate speeds and feeds, select the right cutting tool, and in some cases, grind a tool specifically for a job. Much of this skill is the result of a "feel" for the process which has been developed over time. Once the machine has been set up, an apprentice machinist can produce parts of the same quality as a journeyman machinist. However, experience is still needed to analyze problems and make corrections. The interview subject expressed some concern about how these skills will be acquired with the automated machines.

Clearly the issues regarding the acquisition of new skills and retention of old skills have implications with regard to selection, training and operating procedures. These implications will be discussed in the appropriate sections of this report.

Many process control systems have become so automated that man's only duty is to intervene in rare cases of emergency. What are the consequences of accepting a design that almost entirely excludes man from action for long periods of time? Infrequently practiced skills deteriorate. Operators recognize this, and seek opportunities to maintain high levels of proficiency for handling the rare but stressful event to which they may be called upon to respond (Price, et al., 1981).

None of the fields surveyed involved strenuous physical activity on the part of the operator. All of the airline pilots who were interviewed were in agreement that physical strength has not been an issue in newer aircraft, with several commenting that the DC-8 without hydraulics was the last transport that presented significant physical strength requirements. The lack of physical exertion has implications regarding operator fitness which can in turn affect job satisfaction and operator error.

4.2.1.3 Cognitive Adaptation

The thrust of most automated systems is ostensibly to unburden the operator by reducing his workload. It has been pointed out by a number of the people interviewed (52) that although automation may reduce the physical workload, it in fact increases the mental workload of the operator. This requirement for "cognitive adaptation" results from the information-intensive nature of computer-based systems. One pilot assessed this change by stating that "even though the plane does a lot for you, you still have to program and monitor and at critical times take over." Another pilot said, "The more sophisticated planes have features which reduce physical workload, but no matter what help you have, the mental workload always seems to be there. If something is navigating for you, for example, you still are worrying about whether it's doing it right." An interesting insight for systems' designers can be found in the statement: "Mental workload has gone up with automation. <u>It's</u> <u>self-imposed.</u> If you want to know what the aircraft is doing (the black box) you have to look at the raw data and interpret just like the old days, plus you have to monitor the automatics for failure." "As planes become more sophisticated in terms of automation, the vigilance and attention should be freed up for outside-cockpit work. But what's happened instead is we're either fascinated by the equipment or afraid of it failing so all our attention stays inside."

4.2.2 Worker/Machine Interface

4.2.2.1 Physical Interface

Aside from the traditional anthropometric considerations which have been the focus of existing human factors guidelines, new issues have arisen as a result of the human/computer interface. These issues have been addressed by other authors and a detailed investigation of them lies outside the scope of this effort. However a brief overview of the subject will be presented.

4.2.2.1.1 Workplace Design Considerable controversy has arisen surrounding the increasing use of video display terminals (VDT). The term VDT Sickness has been coined to describe a syndrome exhibited by a large number of steady users of computer terminals which incorporate CRT displays. The symptoms include eyestrain, dizziness, nausea, headache, as well as sore back, neck, and shoulder muscles. Some researchers have even suggested such long-term problems as increased incidence of cataracts as a potential hazard of widespread use of VDTs. Many of these problems can be traced to physical causes such as poor seating arrangements, inadequate lighting, or screen flicker. However a study done by the National Institute for Occupational Safety and Health suggests that there may be more subtle reasons for the physical ailments reported by VDT users. The study involved five companies located in the San Francisco area who were in the process of introducing VDTs. Three groups of employees were studied to determine the impact of the new technology on them. These three groups were:

- clerical workers using the new video display terminals;
- clerical workers using traditional office machines;
- non-clerical employees (reporters, editors, and printers) using the new VDTs.

The first group registered the greatest number of complaints related to physical stress and discomfort. While the third group spent a comparable amount of time at the terminals, they had far fewer complaints about physical discomfort and stress. Closer analysis revealed that the clerical workers have relatively little control over their jobs and must follow rigid work shedules and procedures. The non-clerical workers experienced greater job satisfaction due to the greater flexibility they had in arranging their work. Clearly, issues which on the surface may seem to be entirely physical in nature can stem from less obvious problems related to such issues as job design.

The results of this study agree with the experiences of one of the interview subjects, a Ph.D. psychologist with a background in human factors. The automated system with which the interview subject worked is a classic example of a poorly implemented system. A bullpen area was established in which fourteen video display terminals were installed. Wiring and cabling were strewn around the area, creating trip hazards. Lighting was not adjusted to meet the specific needs of the work area. Proper sound attenuation was not provided. Temperature control was inadequate.

The VDT operators' responsibilty was simply to enter a series of numbers from paper forms into the computer data base. The position was regarded as one of the lowest in the company and typically was used as a stepping stone to other positions. However, the prospect of "working with the computer" was used as a lure to entice job applicants to accept the position.

Management became aware of problems with the system because of the unusually high rate of absenteeism in the group. Of the fourteen terminals, it seemed that two were always vacant because of sickness. Employees complained of headaches, eyestrain, backaches, nausea, and dizziness, the classic symptoms of VDT sickness.

Many of the symptoms could indeed be traced to physical causes such as lighting and poor seating accommodations. These physical problems must be attended to and corrected. However the interview subject felt that a deeper problem was hidden in the structure of the job and the way the system was implemented. The system was put into place by management with no regard for the feelings of the operators. The decision to buy a-particular system was based entirely on purchase cost. The unspoken attitude of management seemed to be "if you don't like the system, you can be replaced". In fact the employees were continuously being replaced as they moved on to better positions or quit the company.

The interviewee prepared a report to management stating the physical problems with the automated arrangement. Due to political considerations, she did not address the underlying motivational problems in her report.

As computer hardware becomes more sophisticated, color displays can be used to great advantage in increasing legibility and ease of understanding information content.

4.2.2.1.2 Panel Layout Much of past human factors research has focused on the subject of control/display panel layout. While many of the concepts set forth in MIL-STD-1472, the HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN, and other texts and handbooks which deal with human factors, still apply to automated systems, state-of-the-art technology presents new possibilities and problems with regard to panel layout. The advent of the "glass cockpit" in which multiple CRT displays replace traditional electromechanical instruments has brought these problems and possibilities into the field of aviation. The multifunction nature of the CRT display presents clear advantages from the standpoint of reducing weight and saving valuable control panel "real estate". Since the continuous dedicated display of all system parameters is no longer necessary, it is possible to design control panels which are less intimidating and easier to comprehend. When multi-function CRT displays are used in conjunction with continuous automatic monitoring of system status, out-of-tolerance parameters can be identified and displayed in a single fixed location. This arrangement offers obvious advantages for rapid recognition and reaction to system faults. Investigations of advanced displays for presenting aircraft operating information regarding engine and subsystem status have led to the development of the Advanced Systems Monitor (ASM) by Boeing Commercial Aircraft Company. On a four engine airplane, a system such as the ASM can lead to a reduction of control panel area of approximately 65 percent.

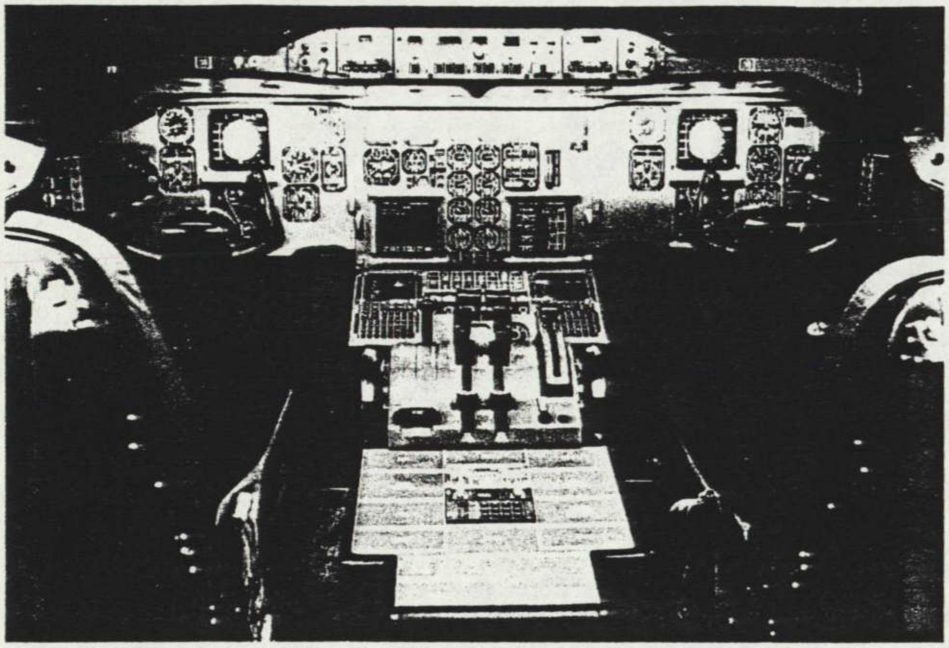
The reduction in size of the control panel is not without its negative aspects. The conventional "T" shaped layout of the critical flight instruments and its associated scan pattern is eliminated with the CRT-based display system. The fixed location of key displays coupled with the almost hypnotic glow of the CRT screens can induce staring with an accompanying loss of information transfer (Clauzel and Stone, 1982). When the information displayed on the CRT is updated, the changes involved can be so subtle as to appear as a mere flicker. Users have complained about the difficulty in detecting these changes and have said it is often necessary to read the entire message very carefully to be certain that critical information has not changed.

Although the electronically generated displays have the potential for greatly reducing visual clutter, a significant amount of clutter is the result not of the display itself but of the hardware used to mount the display. Airbus Industrie conducted a study in conjunction with the international design bureau of the German auto maker Porsche which was intended to improve the working environment for pilots of A300/A310. One recommendation of the study was the use of plastic panels on the main instrument panel to cover the bare metal as well as the screws, safety wires, and other mechanical elements which are not necessary for

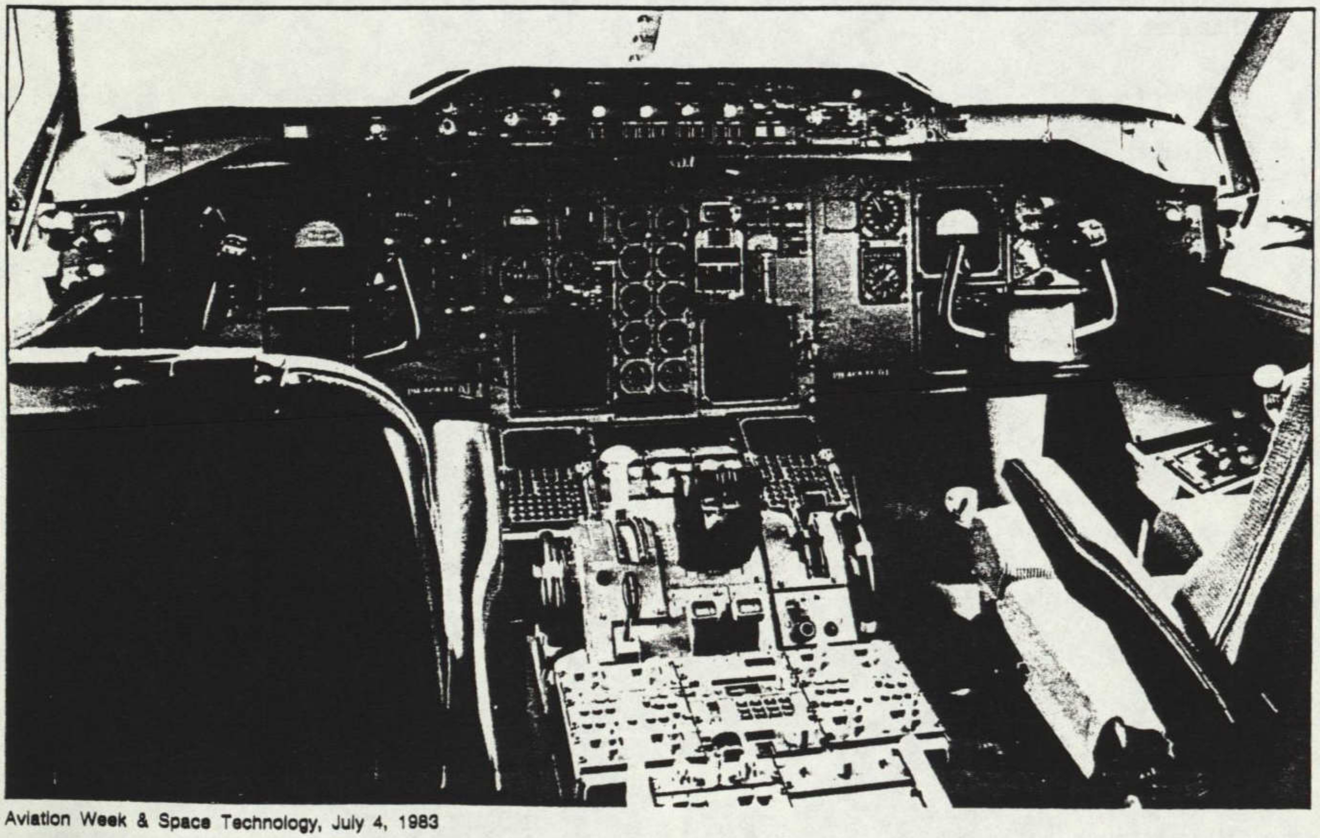
In several of the fields which were studied, including aviation, problems were reported with caution and warning systems. In many instances, caution and warning indications are given but not needed; conversely, caution and warning indications are often needed but not given. Several instances were cited when repeated false alarms led to these alarms being ignored or disabled. For example, one of the process control interviews brought out the fact that the onset of cold weather predictably brought with it a high number of out-of-tolerance alarms until eventually the circuit breaker for the alarm was pulled, rendering it useless. The assumption in this case is that the human operator will monitor the process more closely and compensate for the fact that the alarm is inoperative. When viewed objectively it is apparent that there are basic flaws in the design of such a system which would not be very difficult to correct had they been discovered while the system was still being designed. However, similar examples can be found in almost every field where a caution and warning system is used. These problems arise from oversight in the initial system design which cannot be easily remedied because of the inherent inflexibility of the design. Since computer-based systems are flexible by their very nature, the potential exists for designing systems which can be upgraded to eliminate problems which are not detected until after the system is in operation.

In most complex systems, failures are seldom isolated to a single cause with a single effect. Consequently, failure modes often generate multiple alarms simultaneously. The operator is faced with the dilemma of sorting through these alarms and determining which must be acknowledged and attended to first in order to restore the system most expeditiously to normal operation. The criticality of the alarm should be apparent to the operator as it relates to other alarms which might be presented at the same time, as well as its priority in relation to other control tasks which are currently being performed.

4.2.2.1.3 Control/Display Design The flexibility inherent in computer-based systems is being reflected in the design of control and display hardware. Multifunction displays, such as the CRT screens which have already been discussed, are being complemented by multifunction controls. Multifunction switch panels, where a specific switch can be programmed by software to control any one of a number of functions, depending on circumstances, are already commonplace. In their most common form, the switch nomenclature is changed to conform to the selected function by interchanging hard-copy overlays. New technology is making it possible to electronically generate nomenclature, resulting in a fully dynamic multifunction control and display panel which will replace the dedicated controls and displays which are currently in use. As with all new technology, multifunction control/display panels bring with them new problems which must be faced by the systems designer. The situation was



Mockup of Airbus Industrie's new A300/A310 cockpit configuration (above) is compared with the cockpit of a KLM A310 (below) in these photos. The new cockpit incorporates a number of changes designed to improve the flight-deck work environment and comfort. One of the most apparent differences is the use of lightweight covers on the main instrument panel and center-front pedestal to provide a more uniform look and a cleaner appearance.



Aviation Week & Space Technology, July 4, 1983

FIGURE 11. COMPARISON OF AIRBUS 300 FLIGHT DECK CONFIGURATIONS

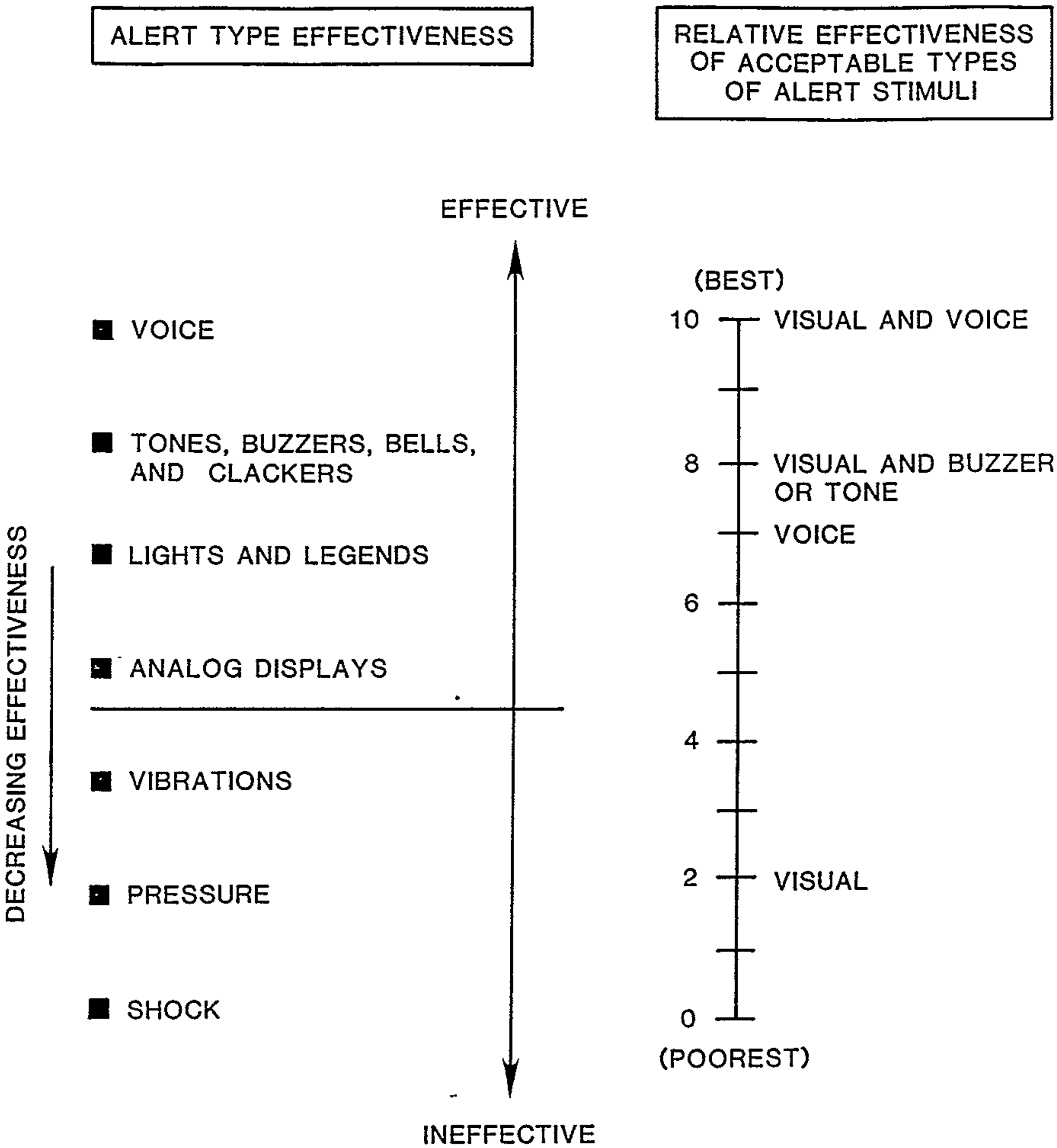


FIGURE 12. EFFECTIVENESS OF ALERTING TECHNIQUES

4.2.2.2 Information Interface

Whereas early control systems involved the transfer of a good deal of physical energy across a control interface, computer-based control systems deal primarily in the transfer of information. The specification and design of this information interface is one of the greatest challenges in designing an ergonomically suitable system. While the design of the physical interface involves the selection and arrangement of hardware elements, the design of the information interface concerns itself with the software and firmware which support the hardware. These are relatively new fields for the human factors engineer and are gaining increasingly more attention as the proliferation of microprocessors makes possible the application of computers to all facets of daily life.

4.2.2.2.1 Human Computer Dialogue The problem-solving capability of the human mind is characterized by the apparent ability to follow several alternate paths to reach a solution to a problem. Significant variations in information input are easily dealt with and judgments are constantly made concerning new information. In contrast, present day computers are locked into following a rigidly prescribed set of instructions and cannot deal with any but the slightest variations in format or syntax. The design of a software interface which permits a smoothly flowing dialogue between such divergent problem-solving styles is not an easy task.

The problem is compounded by the diverse backgrounds and expectations which various users bring with them when they attempt to master the automated system. A dichotomy seems to exist in that computer systems tend to be either easy to learn or easy to use, but never both. Whether a system is easy to learn or easy to use is determined by three characteristics which are, for all practical purposes, mutually exclusive. These characteristics are:

- Flexibility
- Power
- Simplicity

A flexible system presents a large number of options to the knowledgeable user. With an absolutely flexible system, it is possible to do almost anything that is needed or wanted, however a great deal of training is necessary to be able to use this flexibility. An example of such a flexible system is one based on machine language.

A powerful system is one which allows multiple functions to be accomplished with a single command. Many word processing programs utilize a powerful style to allow a trained user to achieve great productivity. For example, a single key stroke can set a complex editing function in motion. Typically, this type of system is based on a "command language" approach. This technique emphasizes the activity to be performed, often at the expense of making it easy for the user to understand. However, speed and efficiency can be continuously improved as the user becomes more familiar with the system. Multiple functions can be combined and executed by a single "user-defined command", resulting in a very "powerful" system.

A "simple" system utilizes simple formats and vocabularies which are easily associated with their respective functions. A "wordy" approach is typical of such a system with the user given extensive feedback concerning system function. Usually the system is menu-driven with extensive use of prompts making it very accessible to the user. A tutorial approach is used making it possible for the user to learn the system simply by interacting with it. Such systems are essentially "surface level" in that they make it very easy to do a limited number of tasks, but beyond a certain point there is no improvement in speed or flexibility. This sort of system is often referred to as "transparent" and is well suited to the casual or infrequent user who cannot justify spending very much time learning to use the system.

Four distinct styles were identified by Miller and Thomas (1977) which can be used in establishing human-computer dialogue. These styles, and the appropriate application of each, are:

STYLE	COMMENT
1. Computer Guides/Human has forced choice.	Good for routine tasks. Relatively fast; low error rate.
2. Computer Guides/Human has free response.	When information must be gathered in an unstructured manner.
3. Human Guides/Human has forced choice.	Human knows what he can request; can select desirable system alternatives.
4. Human Guides/Human has free response.	Considerable flexibility; appropriate for experienced users.

Typically, there are a myriad of options available to the computer user and each must be exercised before the computer can begin its work. To minimize the number of decisions which the operator must make, a "default" strategy is often used. The default mode defines a set of assumptions regarding the options which the operator would most likely exercise. The operator must make conscious decisions only in those instances where he wishes to select options other than those to which the system automatically defaults. This sort of "control by exception" strategy can result in greatly reduced operator workload.

4.2.2.2.2 Information Content Since the success of an automated control system depends to a great extent on the ability to quickly and accurately transfer information across the control interface, the information content of a particular display or display format is of great importance.

When digital technology was first introduced, alphanumeric displays were commonly used to replace analog meters and dials. It soon became apparent that while digital readouts allowed information to be presented in very precise terms, such accuracy was often unwarranted by the situation. In fact trend data was often more useful, faster to interpret, and more easily applied to the control task.

Current practice involves electronically generating a copy of the electromechanical analog display. This approach has several advantages. The electronic representation of an existing display can ease the transition to automated control by giving the operator a familiar frame of reference. Presenting data in much the same way as in the manual system can minimize negative transfer and give the operator the impression that not much has really changed. Furthermore, the flat nature of electronic displays eliminates the parallax problems which have traditionally plagued moving-needle instruments. The mechanisms behind the panel which were needed to drive electromechanical displays are no longer needed in the electronic translation. This allows greater flexibility in grouping displays in ways which are dictated by the information they convey rather than the limitations imposed by packaging constraints.

Merely mimicking existing displays with new technology can have its disadvantages. Several operators who were interviewed referred to subtle cues on which they rely to tell them more about system behavior than would be discernible from the absolute value of the information displayed. Subtle aspects of system dynamics are communicated by such nuances as the vibration of a needle on a gauge which is actually plumbed into the system. Operators refer to reading such information as "taking the pulse of the system". Engineers and designers must be careful that the ability to be attuned to such subtleties is not lost in the conversion to electronic instrumentation.

In addition, the danger always exists that a better, more integrated way of presenting data may be overlooked by merely striving to faithfully reproduce familiar formats. The freedom to develop innovative graphic techniques which convey a great deal of information in a simple, easily comprehensible format must be fully explored. In systems where a process is being controlled, a diagram of the process is often presented in flowchart form. Although actual values, as measured by sensors throughout the plant, can be displayed very precisely, the use of color and symbology to display changes in plant state is usually more meaningful.

The human capability for pattern recognition can be utilized in developing display formats. A large amount of information (several hundred variables) can be monitored simultaneously if, in the normal state, the overall image is a recognizable pattern. When system parameters drift out of tolerance, the image is distorted. Only when such distortion occurs is it necessary to identify the pertinent parameters. The pictorial aspects of such display formats reduce the operator's need to attend differentially to discrete display elements. In simple form, set points and alarm limits are normalized and displayed in bar graph form. Up to 100 measured values can be readily monitored with such a display. A more advanced application of this technique is called the Wolff Diagram (Burton, 1978). In this approach, parameters are normalized and plotted along the radii of the diagram such that when all are normal, their envelope forms a perfect circle. Small errors in the state of the process produce slight distortions in the circumference of the circle while large errors result in significant distortion. Other variations of this approach to multidimensional scaling techniques which allow many variables to be monitored simultaneously involve the use of musical tones. Deviations from the norm cause distortions in the pitch of the tone. Experiments have shown that such distortions are relatively easy to detect.

Although much opportunity exists for innovative ways to present interpreted data in a manner which can easily be assimilated, the raw data upon which this integrated display is based should always be accessible on demand. If the raw data is always present, it can inhibit the operator's ability to analyze and respond to a problem. This was borne out in experiments conducted at a nuclear power plant by one of the interview subjects. Computerized graphic displays of the status of a system were shown to operators, supervisors, and engineers for their use in tracking down the sources of various problems. One group of individuals was shown three levels of display, including a global level, a subsystem level, and a primitive level. The second group was shown only the two higher levels of information. The group with less detailed information did as well or better in determining the source of problems. This was attributed to two possible factors. First, the group which received the three levels tended to drop rapidly to the most primitive level and spend most of their time working at that level. This produced a good bit of step-by-step activity. Second, it appeared that the basis for going to the lowest level was that the individual had formed an hypothesis about the cause of the problem, and the activity was directed toward eliminating the perceived problem. Because the problem was assumed to be known, other possibilities were not explored. An interesting sidelight to these results was that the tendency to go to the most primitive level was greatest among those individuals who had the most operating experience. It would appear that they tend to do what they know best.

4.2.2.2.3 Data Input/Output Before selecting the hardware devices which will constitute the information interface, the kind of information to be dealt with must be determined. Essentially, the data will be some combination of verbal, numerical, and visual information. The surveys conducted during the course of the study involved a cross-section of all three data types as does the information which pilots must deal with in the cockpit. In addition, the choice of information input device should take into account the background and training of the users. Excessive skill requirements will frustrate users, while a medium which does not take full advantage of available skills will be inefficient.

A large amount of verbal information, such as is typically involved in word-processing applications, is best handled with an alphanumeric keyboard configured in the standard "QWERTY" typewriter format. To be handled efficiently, large amounts of information require a trained typist, although adequate data rates can be achieved by casual users with a "hunt-and-peck" style. Specific pieces of information can be selected from a relatively small field by using a special function keyboard or by using an interactive device such as a mouse or light pen to select from a menu of choices. This style of input is well suited to a casual or untrained user but is naturally inflexible and limiting.

Large amounts of numeric information can be rapidly input by a trained specialist using a keypad which is laid out in the format found on standard ten-key adding machines.

Graphic information is input by either drawing directly on a CRT screen with a light pen, creating a drawing by describing its contours as a set of points and entering them into the computer, or using a digitizing device such as a mouse to transfer the coordinates of an existing drawing into the computer's memory. In other systems, a "vocabulary" of shapes and relationships can be used to construct graphs, mechanical drawings, and other visual images. If the data input is sufficient to describe the image in three dimensions, the computer can generate three-point perspective drawings which can be manipulated in various ways to simulate the behavior of the real object. Such computer-driven animation techniques have tremendous potential for enhancing cockpit displays, especially for use under instrument flight rules (IFR) conditions. Figure 13 shows an example of this type of display being developed by Dr. John Reising of the U.S. Air Force Flight Dynamics Laboratory at Wright Patterson Air Force Base. This type of display, called a "Pathway in the Sky", uses full color "cartoons" to enable the pilot to understand a large amount of vital information at a glance.

4.2.3 Reliability

System reliability is an issue which was raised in 48 of the 88 interviews which were conducted, indicating the importance attached to it by users of automated systems. Reliability is the probability that an item (equipment, system, subsystem, etc.) will perform its intended function for a specified interval under stated conditions. This engineering definition of reliability does not take into account the affect of the human operator, which can serve to either enhance or degrade system reliability. Human performance can degrade system reliability by introducing an error factor. On the other hand, human problem-solving ability can correct or circumvent failures as they occur, thereby maintaining the system in operation.

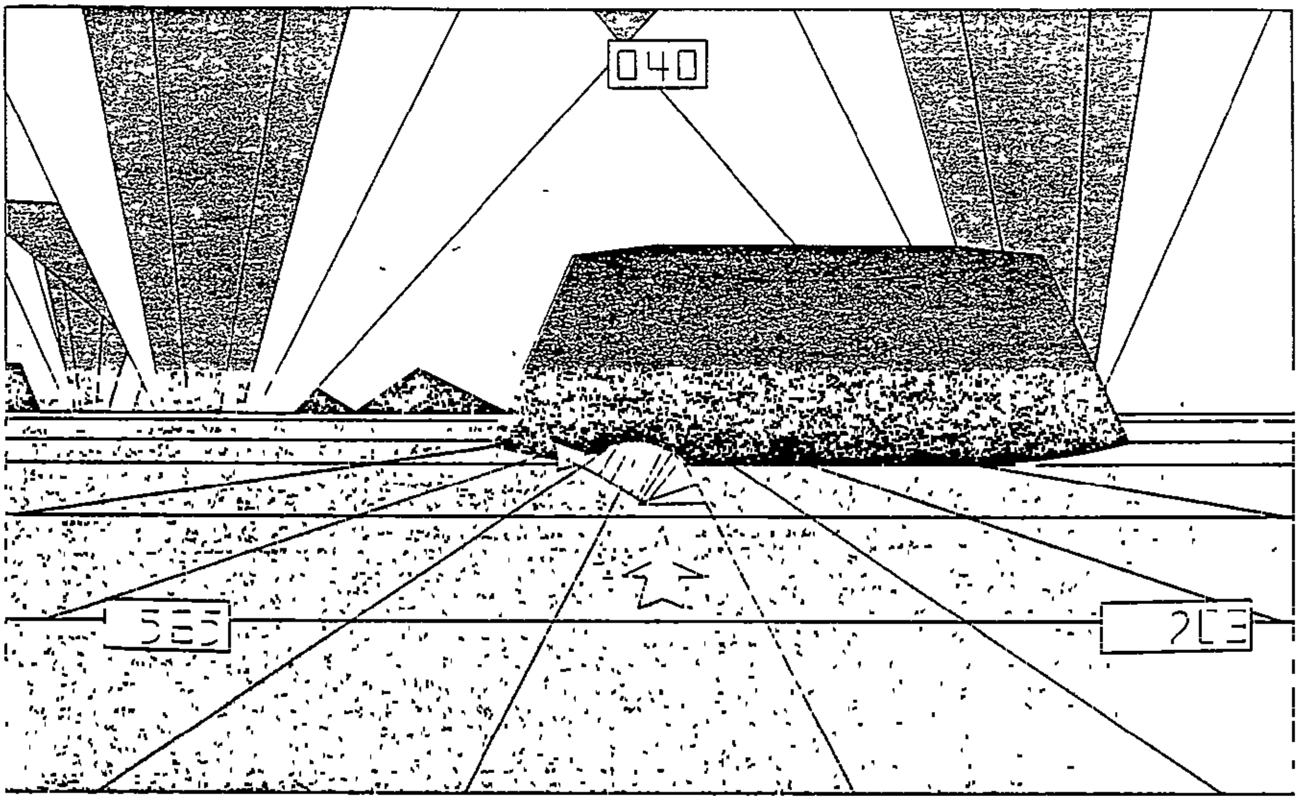
4.2.3.1 Human Reliability

4.2.3.1.1 Human Error Clauzel and Stone (1982) identified several factors which contribute to human error in the cockpit environment. The following list is based on their work:

- Channelized attention
- Discipline
- Physical condition
  - Vertigo
  - Fatigue
- Distraction
- Experience
- Training
- Panic
- Personality characteristics
- Age
- Workload

These factors are closely interrelated with other human factors issues. The potential for human error should be considered when dealing with each of these related issues.

Clauzel and Stone noted that most accidents involving human factors occur when the pilot is pushed to his information processing limits. It is then that a minor disturbance such as a distraction can cause him to lose control of the situation.



Aviation Week & Space Technology, January 17, 1983

New tactical situation display concept, being evaluated for future applications by USAF's Flight Dynamics Laboratory and Boeing Co, shows the pilot significant topographical features in a look-ahead view Green represents terrain below and brown terrain above his present flight level, while red and yellow "beams" represent, respectively, areas of most severe and somewhat less severe threats from ground-based missiles and guns The leftward-turning ribbon indicates the flight path the pilot should follow to minimize his exposure to threats Note that the aircraft symbol is placed as it might appear to an observer located slightly above and somewhat behind his own aircraft Boxed digits represent heading, airspeed and altitude Assessment of effectiveness of new instrumentation, as well as total performance of a new or improved weapons system design, requires the use of man-in-the-loop engineering simulation

FIGURE 13. PATHWAY IN THE SKY

4.2.3.1.2 Problem Solving A study by Rouse and Rouse (1981) indicated that properly designed computer-based systems can reduce certain classes of human error. The ability of the human operator to intervene in the event of system malfunctions, although difficult to quantify, can enhance system reliability. Automation can greatly aid the operator by performing the bookkeeping aspect of problem solving. The computer can keep track of what has been done and the ramifications of these actions. In this form automation can contribute to system reliability by reducing the frequency of human errors while still leaving the human crew with overall responsibility for troubleshooting and problem solving.

The introduction of automation causes significant changes in the job requirements in the fields of engineering, design, and drafting. In the past, a major part of engineering analysis has required considerable skill in mathematics. When using computer aided systems, the emphasis can be placed on the ability to arrive at creative solutions to problems with the computational details being relegated to the computer. Similarly, in drafting, the emphasis has been on the ability to create orderly layouts, print neatly, and do consistent linework. These skills are no longer needed when working with a computer-based system. Similarly, in the cockpit, automation can relieve the pilot of many of the routine computational tasks which when done manually can be quite error-prone.

While the computer can be of obvious value in enhancing human problem-solving ability, care must be taken to avoid "underload". From this standpoint, human factors principles should be applied to maintain a meaningful workload level which is sufficient to ensure a vigilant posture. The implication of this is that although pilotless flight may be technologically achievable, it is not desirable at this time from a human factors standpoint. The pilot must remain in the loop (Clauzel, 1982). All of the airline pilots interviewed echoed these sentiments by stating the importance of knowing at all times what the automatic systems are doing and the resulting status of the aircraft.

4.2.3.2 System Reliability

System reliability was touched on briefly in Section 4.2.1.1 under the discussion of psychological adaptation. This issue has a profound effect on shaping users' attitudes toward automated systems. Economic factors often compel a manufacturer to introduce a new product prematurely in order to capture an early market share and begin to recoup development costs. Unfortunately, in the case of computer-based systems this usually means that a system is introduced before the "bugs" are out. This can be extremely frustrating for users of a new system since they can never be certain if problems are the result of their mistakes or are caused by system faults. This uncertainty can result in rejection of the automated process. One of the subjects interviewed during the course of the study is the president and founder of a company which designs and manufactures control centers for use in various industries, including petrochemical, power, and municipal water treatment plants. As a result of his interest in the field, he has conducted an informal poll among his clients and contacts. Based on this poll, he is convinced that "fully one-half of the automatic control loops in the United States are being operated manually and have been since the first time something went wrong".

The pilots interviewed generally expressed the feeling that modern aircraft are very reliable in the ultimate sense due to the heavy reliance on redundancy and backup. There also seems to be a feeling that this ultimate reliability of the aircraft depends to a large extent on the presence of a highly trained pilot who can deal with subsystem failures. A large number of the airline pilots (58 percent) had experienced at least one failure or unexpected action on the part of the automatic systems. As a result, they realize that all flight systems are subject to failure; however, seldom will such failures be catastrophic due to the redundant nature of aircraft design. In the words of one pilot: "Little things are always going wrong, but most major systems are very reliable on all planes." There does not seem to be a consensus yet with regard to the reliability of the latest generation of computer-based flight systems. The following quotations taken from the aviation interviews reflect some of the conflicting attitudes:

- "Things are more reliable than they used to be but the flight directors and autopilots do fail."
- "Mechanically things are more reliable. However due to the sheer volume of electronics involved, they give the impression of less reliability because there are simply more things to go wrong."
- "More reliable since we moved to the jets in the 60's. Each new plane brings more reliability and redundancy. Solid state instruments on the new aircraft are even more reliable."

Some problems have occurred. For example, early in the introduction of computerized avionics difficulty was experienced in making a smooth transition from ground power to ship's power as the aircraft leaves the gate, but no serious failures have been attributed to computer failure. There is, however a sense of expectation expressed by some pilots, as reflected in this statement by a 747 First Officer: "Engineers would like to replace us with some infallible system. But time or an accident will show that the pilot will always be there."

4.2.3.2.1 Actual versus Perceived Reliability In Section 4.2.1.1, Psychological Adaptation, it was pointed out that it is not only the actual reliability of the system but also the reliability as perceived by the users which influences acceptance of an automated system. Normally it is important that bugs be eliminated to the greatest extent possible before introducing a new system. In some cases exceptions must be made to this rule. In the field of process control, systems are often one-of-a-kind designs which are built in place and tested during a "shake-down" period of operation. In such situations, it is important to involve operating personnel in the debugging process. By doing so, they not only feel part of system development, but also can see that the developers understand the system. Faults that disappear as if by "magic" only tend to reinforce the user's suspicion of the new technology. By involving the user in the debugging process, he can gain a deeper understanding of the system. On the other hand, the frustration and negative reinforcement of early repeated failures will often outweigh this advantage and as a general rule as many bugs as possible should be eliminated before the user is exposed to the system.

4.2.4 Maintainability

The requirement for system maintenance, and its associated costs, is often not fully addressed when introducing an automated system. These costs are ongoing and will often exceed the purchase price of the system in a short time. Naturally this point is not emphasized when selling a potential user on the advantages of automation. In one situation where interviews were conducted, the lack of planning for maintenance costs led to the total failure of a sophisticated and expensive automated control system. A case in point is a municipal waste water treatment plant which was visited as part of the study. The plant was put into service in 1976 and was intended to represent the state-of-the-art at that time. The entire plant was designed to be tended by no more than two operators per shift. The instrumentation and control system cost approximately one million dollars in 1976.

From the very beginning the system did not operate properly. The system "crashed" on the average of several times per month, losing all of the data which was stored at that point; the longest period of continuous operation was four months. The program was stored on punched cards, making the process of reloading the program very time-consuming. Although the equipment was intended to automatically keep track of periodic maintenance requirements, the frequent crashes made this feature useless. At first the system allowed the process to be monitored in real time from a central control room. However, the analog sensors which were installed in the field proved to be unreliable. Apparently they were not properly designed to withstand the environment in which they were installed without frequent maintenance. The initial purchase price of the system did not include the maintenance necessary to keep it in operation. An additional $70,000 per year was quoted for a maintenance contract. Without the prescribed maintenance, float arms would stick in position, resulting in an erroneous indication of tank levels. Since the readouts on the central panel could not be trusted, it became necessary to send an operator into the field to verify readouts. Eventually, what was to be a state-of-the-art system degenerated into an outmoded operation which required distributed manual control to maintain the system in operation. Although the system was budgeted for two operators, it required six operators to run the plant, resulting in significant cost overruns. Although a great deal of time was being spent trying to make the system work automatically, it was essentially being run manually. Ultimately it was decided to abandon the automatic system and officially acknowledge that the automatics were a total failure. The equipment related to the automatic system was torn out and placed in storage.

An interesting twist to the topic of maintainability was raised by a member of a maintenance crew in charge of servicing an automated production line. When asked if the new system or the old manual system was easier to maintain, he stated that the computerized system was easier, but that problems occurred so infrequently that he had to rely heavily on the maintenance manuals for guidance in repairing the equipment. Another attitude which was expressed in various forms was that "Engineers tend to design systems that are easy to design rather than systems that are easy to operate and maintain."

4.3 MANAGEMENT/WORKER INTERACTION

In almost all cases, implementing an automated system will have a profound effect on the entire organizational structure, including relations between management and the workers. The factors which must be considered in the transition to automation include: assessment, selection, and placement of workers; education and training; communication, both between management and workers and among the workers themselves; and the maintenance of motivation and morale.

4.3.1 Assessment, Selection, and Placement

The change in job requirements which accompanies the transition to automation, a change which typically involves a shift in emphasis from physical skills to cognitive skills, can cause the employee selection process itself to be called into question. The skills which were important to the mastery of the manual process may be irrelevant to the operation of the automated process. In many instances, negative transfer may actually cause these skills to interfere with the adaptation to the computer-based process.

Of all of the factors which might influence the ability to adjust to new technology, age was referred to most often. Of the 88 people who were surveyed during the study, 36 said that younger workers caught on to automation faster than older workers. Of those who responded in depth, many stated that age was not an insurmountable barrier but it tended to make the transition more difficult for a variety of reasons. Some of these reasons were:

- Older workers learn slower, especially when the subject matter is extremely technical.

- Younger workers have "grown up with computers" and are more comfortable with them.

- The education level of younger workers is higher.

- Younger workers "have a different attitude toward it ... they haven't seen their job eroded by automation".

- "Like anything else in life, if your attitude is right and you approach it with interest, you'll do all right. The younger guys may be quicker."

- Older, more experienced personnel often do not take readily to changed methods of action, while naive subjects tend to be more malleable (Steeb et al).

Clauzel and Stone, in a paper published in 1982, reinforce these comments about the age factor. "...Experience at Douglas has shown that older pilots with a great deal of conventional airplane cockpit experience, such as with the older DC-9's, the 727, DC-8, and 707, will most likely find it quite difficult to cope with the transition to the video displays and automated flight management systems and the attendant change in flight procedural philosophy. This will probably be especially true of those who have never flown the currently accepted 'modern' flight guidance and control systems such as those in the A300, DC-10, DC-9 Super 80, L1011, and to a lesser extent the 747. In training DC-8 pilots to fly the DC-10, for example, the younger copilots made the transition with comparative ease while the older captains often had considerable difficulty in getting used to the flight guidance system."

Although the evidence is very strong that younger workers generally adapt to automation more readily and the skills of experienced workers can often be used to greater advantage than in monitoring an automated system, organizational policy often results in exactly the opposite utilization of personnel. In the case of a machine shop which participated in the study, there was little difference in the productivity of experienced machinists when compared to relatively inexperienced machinists when operating computerized machine tools. On the other hand, certain specialized jobs could only be accomplished with the skills of the experienced machinists. A conflict arose, caused by the fact that the newest machines were the most desirable to operate and the most senior machinists felt that they had earned the right to work with the best equipment. In spite of this, efficient management of the shop dictates that their skills be used where they are needed most -- to coax good work out of the older equipment. A similar conflict existed in the case of an oil refinery. Under strict seniority rules, the most senior operators should have been assigned to the latest automated equipment. However, this would have been counterproductive, since the most current hiring practice included selecting employees based on their aptitude for working with computers. The conflict was resolved by basing the pay scale on the number of systems with which an operator was familiar. This policy allowed the most senior employees to be paid most, without requiring them to work with the the automated process unless they showed the ability and desire to do so.

In the airline industry, pay-scale policies often establish a similar collision course between the most senior pilots and the most automated equipment. In the words of one member of airline management: "It's very difficult for us to get the young pilots into the automated cockpits where they belong."

One of the interviews conducted during the study was with the manager of the drafting department of a large, multinational engineering and construction company. The company had recently begun the transition to computer-aided-drafting. At the inception of the program a consultant was hired to help with the selection of the personnel to be included in the first group. An internal posting was used to obtain people from many sources to attend a seminar at which the basic concepts were discussed. Those individuals who were interested in the program and had four years experience with the company were invited to apply, and they were put through a testing program to select the training group. The testing program consisted of two phases: aptitude testing based on several Psychology Corporation tests, e.g., mathematical reasoning, and a personal preference inventory (the Cleaver). A substantial range of individuals was included in the early group, and according to the interviewee the tests validated well. Parenthetically, it may be noted that he mentioned the people who have trouble with spelling and typing also have difficulty with the system, although it did not seem to be a matter that was originally tested. Typing training is included to some extent in the training program. Because of a desire to include only those individuals who were intrinsically motivated, no additional pay grade was instituted; but people who successfully completed the program were given, unknown to themselves or others, somewhat higher pay increases.

Since most of the workers involved in the survey were male, little reference was made to potential sex differences in adapting to automation. The one exception was in the field of office automation, where a supervisor of a group of illustrators commented on differences which he has perceived. He currently has 16 people reporting to him who use the system. Of these, seven are men. Their ages vary from 20 to 38. The educational backgrounds vary from high school graduates to those with some college to a few with BA degrees. No generalizations can be made between education and acceptance of or success with the system. Reaction to the system ranged from blind obedience to open dissent. Initially, attitudes toward the system seemed to be divided along the lines of age, with the younger employees being most enthusiastic about working with a computer. After a while, the attitudes became more individualistic, with some of the originally enthusiastic workers becoming less thrilled when they found out that the system was not magic and they would have to work at it.

The interview subject reported a difference between the way male and female operators learn to use the system. The women seem to learn faster but are less willing to take chances. They want to be shown how to do something, but understand quicker and can apply what they have learned to other functions provided that they are not too different. They are very cautious and are afraid to "glitch the screen" and wipe everything out. The men on the other hand are willing to dive right in and learn by trial and error. They are not afraid to make mistakes. It seems to take them longer to understand the system.

It must be noted that these are the observations of a single individual and it would require much more research to prove or disprove their validity.

4.3.2 Education and Training

While it is very important that the system be properly designed from a human factors standpoint, this design effort must be complemented by an equally well-thought-out and effective training program.

4.3.2.1 Training Needs and Objectives

Before training evolved into a specialized and formal discipline of its own, novice operators learned to control a system by working alongside an experienced operator and being taught on a one-to-one basis. As systems become increasingly sophisticated, so must the techniques used to train the operators in the proper use of those systems under normal, abnormal, and emergency conditions. An important prerequisite for establishing an effective training program is the identification of training needs and objectives. Knowing "what" must be learned in order to adequately perform a task is an important first step in establishing how it can best be learned. In designing a training program for pilots who are transitioning to aircraft which incorporate advanced technology automated cockpits, a careful analysis must be made of the specific skills and knowledge which will be required to deal with the advanced technology. The specific knowledge, skills, discipline, and judgment required by the system define the behavioral objectives that the pilot must attain if he is to meet the training goals. These goals can then be used to generate performance criteria which represent the minimum and maximum performance which can be tolerated without jeopardizing mission objectives. Training methods and devices which are best suited to teaching specific behavioral objectives can then be identified.

Training must be tailored to the needs of the user; different approaches might be appropriate in teaching different groups of users to operate the same system. For example, the users of an interactive graphics system who were surveyed during the study varied widely in terms of their backgrounds, interests, and abilities. Operators who use the systems for solving engineering problems tend to be well-educated, degreed people. Their interaction with the system is often characterized as relaxed and exploratory. On the other hand, those who use the systems for the high-speed production of drawings often have no more than a high-school education. They are under more pressure to achieve specific results quickly and efficiently. These users undergo a highly structured, hands-on training course which lasts two weeks. Approximately six percent to seven percent of these trainees never succeed in learning the system. In fact, the interviewee stated that he knows of at least two people since the system was introduced in 1971 who suffered nervous breakdowns and were hospitalized as a result of trying to learn the system. He characterized these people as "narrow bandwidth" individuals who probably have a difficult time accepting any sort of change.

4.3.2.2 Training Methods

Traditional training methods usually consist of a mix of three approaches. These approaches are: 1) Classroom Instruction, 2) Simulation, and 3) Hands-on Training.

4.3.2.2.1 Classroom Instruction Classroom training has long been used either as the total training program or as a preliminary to other training methods. In classroom training an attempt is made to isolate the verbal and conceptual aspects of a task and teach them prior to integrating the psychomotor aspects of the task. Since classroom training usually requires very little in the way of specialized equipment, it is relatively inexpensive to implement. A limitation of classroom instruction is the false emphasis it places on verbal and symbolic learning at the expense emphasis it places on verbal and symbolic learning at the expense of coordinated skill requirements. Classroom instruction teaches the trainees what it is that they are supposed to do, but does not teach them the skills needed to actually perform the task. Recent advances in computer-based-training (CBT) and computer-aided-instruction (CAI) permit many of the objectives of classroom instruction to be met without the typical classroom atmosphere. According to Clauzel and Stone: "One of the advantages of CAI is that it allows flight crews to progress at their own pace, with the constant assurance that they know the previous material before being allowed to acquire further knowledge. This is done in private, avoiding the embarrassment of having to admit that the individual does not fully comprehend something in a classroom full of his peers. With computer-aided-instruction the role of the instructor is also considerably changed. His role as a lecturer will be quite restricted, and he will be placed in the capacity of an advisor, assessing student performance, suggesting additional study areas, and answering questions for which no programmed answers exist."

4.3.2.2.2 Simulation In simulation, an attempt is made to recreate the entire task or portions of the task to some predetermined degree of fidelity. Most current training programs use a combination of part-task trainers, whole-task trainers, fixed-based simulators, and motion-based simulators. The use of simulation has increased in various fields due to the cost of real systems, their unavailability for training exercises, and the danger of training accidents. In addition, simulators offer system operators the ability to repeatedly experience situations which would be far too dangerous to encounter in the real world. This capability allows system operators to train for all phases of operation, including normal as well as abnormal and emergency procedures. In 1979 a DC-10 airliner experienced the separation of the right engine on takeoff from O'Hare Airport in Chicago. The resulting crash killed all of the people on board the flight. Since the accident, the situation has been recreated numerous times in motion-based simulators. In these simulations pilots have demonstrated the ability to fly out of the condition after having been trained to recognize what has happened and respond appropriately. By simulating infrequent but potentially catastrophic situations, such as equipment failures and weather anomalies, including wind sheer, pilots can be exposed to circumstances which would normally not be survivable the first time they are encountered in a real-life situation. State-of-the-art motion-based simulators have achieved an extremely high degree of fidelity. Class 3 simulators are so realistic that pilots who are type-trained on this equipment can be type-certified by the Federal Aviation Administration (FAA) without ever flying the real aircraft.

4.3.2.2.3 Hands-on Training For learning normal operations, hands-on training is perhaps the best method of learning. Hands-on training, or on-the-job training (OJT) as it is often called, does not mean the lack of a carefully designed, well-structured training program. Macek et al. (1981) point out that to be effective, on-the-job training must furnish the trainee with three important elements:

1. Adequate orientation
2. Coaching
3. Timely feedback

Orientation, as the term implies, is the phase of training in which the employee is taught the general purpose of the job, the things that are needed to perform the job, where they are, and what is done with them. Coaching involves providing detailed information about the job as well as encouragement. Perhaps the most important aspect of on-the-job training is feedback. Feedback provides an ongoing evaluation of the employee's performance and specific instruction regarding behavioral changes which can lead to improved performance.

It is interesting to note that these three elements can be provided by a computer. A well-designed program, based on a tutorial approach, can guide the trainee through an on-the-job training program.

A survey of illustrators using a CAD system was conducted as part of the study. Training on the system consisted of an initial period which lasted about three days. This orientation was necessary before an operator could do productive work. It consisted of a "walk through" of the system including such basics as logging on, generating parts lists, altering parts lists, and adding callouts. The intent was to have the operator learn to solve problems with as little help as possible. Operators were then placed in one of three categories: User 1, User 2, or User 3. The process of moving up to User 3 takes five to six months. Training at the User 1 level lasts about three days and consists of the "look and see" demonstration with no capability to alter drawings which are in the system. After about four weeks at the User 2 level, the operator essentially "knows all of the ropes" and can efficiently use the system. After about five to six months, the operator progresses to the third level at which he has the power to delete drawings and release new drawings into the system. The goal is to avoid specialists and have each person be capable of doing all phases of the operation.

The following question was included as part of the survey questionnaire:

> If you were recommending the training for a new person on the system would you suggest that they be given:
>
> 1. the same training as you received?
> 2. more structured exercises?
> 3. more chance to try things and see what happens?

Half of the responses favored retaining the same training approach, while half would have preferred more structured exercises. None of the responses would have preferred more experimental interaction with the system.

It is important that some sort of follow-up training be provided. In the example based on the CAD system which was referred to previously, follow-up training was essentially built into the multi-step nature of the program. In other cases, a separate advanced course should be available to provide answers to questions which inevitably arise as users become more proficient. In the case of on-the-job training, the same function can be performed by a "resident expert" who is readily available to answer questions and provide guidance as required. It is common for users to become familiar with a few basic commands which allow them to achieve desired results, often ignoring simpler and more efficient strategies which become available to more experienced users. Follow-up training can help users to advance beyond this initial stage of "functional literacy" and achieve true proficiency with the system.

4.3.3 Communication

The introduction of automation invariably changes the ways in which communications flow through an organization. These changes occur on two levels: communication between management and workers, and communication among the workers themselves.

4.3.3.1 Management Communication with Workers

The point was raised several times during the course of the study that when automation is introduced, invariably new layers of management are added to the organization. While many people invest in automation based on the belief that it will enable them to reduce the size of their workforce, this seldom seems to be the case. Specialists are usually needed to interface with the automated system and provide the necessary maintenance capability to keep the system functioning properly. These new layers of management can act as a barrier to communication between top management and workers. As was pointed out in Section 4.1, Management/System Interaction, the automated system itself may act as a barrier between management and worker if management is not conversant with the new technology. In the survey of CAD system users which has been referred to previously, the following question was asked:

> Should managers be trained so they know what to expect from the system?
>
> 1. no 2. a little
> 3. should know basics 4. should know system thoroughly

Forty-seven percent of the responses stated that managers should know the system thoroughly; another 47 percent stated that management should know the basics of the system. Only one response stated that managers only need to know a little about the system. None of those surveyed felt that managers should receive no training on the system.

4.3.3.2 Communication Among Workers

Just as communication between management and worker is altered by the introduction of automation, so is communication among workers. One of the interviews in the field of office automation yielded the following comment:

> "A difficulty for some operators is the rather limited communication with coworkers. Most communication seems to be in a vertical direction. There are more constraints on the operator who uses the automated system than on the operator who uses the standard system."

These constraints result from a change in the way in which information is accessed. For example, it was pointed out that in the control rooms of nuclear power plants which are not automated, information regarding system status is displayed so that all persons in the room can see it. This allows each worker to act as an informal backup for the other workers. In automated control rooms, information is accessed through conscious effort by calling up desired data on a CRT screen. Workers must communicate their actions to each other in a similar conscious manner. This issue was raised frequently (56 percent of the interviewees) by the airline pilots who took part in the study. Some of their comments regarding the need for communication on automated aircraft were:

- "Communication is critical. More automated planes are dangerous in the sense that you can get complacent. In the 727 days, problems were handled by the pilot because he was driving. On the DC-10, you don't have physical control and it can kill you."

- "Communication is more critical (on the more automated aircraft) because you can push a bunch of buttons and your partner doesn't know unless you tell him."

- "Very important. Especially if you're inputting data..."

- "Very important...more automated planes especially, because unless you let the other guy know what you're doing, he can't always see it."

- "It's generally higher on automated planes because of cross-checking what the other guy's doing."

- "In terms of automation, communication is much more important. Some planes like the 737 can be flown by one person. But the bigger, more modern ones simply can't. It's dangerous not to communicate your actions or your intent to act."

- "You could fly the DC-3 by yourself. All the copilot had to be told was 'gear up, gear down and shut up'. Now you have to talk to everyone or you just can't fly safely."

- "...should be high on every plane on every trip. Even in the future, if there's only one pilot and a bunch of computers, they ought to be talking."

4.3.4 Motivation and Morale

Like psychological adaptation, motivation and morale is not so much a separate issue but rather a symptom of the resolution of other interrelated issues.

If not dealt with successfully, motivation and morale can have disastrous consequences for the ultimate implementation of an automated system. An anecdote which sheds light on the problems which can be encountered was related by one of the interviewees who works for a manufacturer of automated systems. A type of system which had been used successfully for years to generate electrical schematics and power wiring diagrams was installed in a customer's facility. Six months after installation, the customer was ready to send the system back to the manufacturer. The system was plagued with scrambled file names, blank files, and other mysterious problems. All sorts of measures were taken in attempt to solve the problem including the installation of elaborate power monitoring equipment and a complete exchange of all the hardware in the system. Ultimately the problem was traced to a disgruntled employee who was sabotaging the system. It seems this was a case of management imposing a system on a workforce which viewed the automation as a threat to their jobs.

4.4 MANAGEMENT INTERACTION WITH WORKER/SYSTEM

4.4.1 Organizational Design

4.4.1.1 System Impact on Management

Many if not most organizations which adopt automation do so in response to the implied promise of a reduced workforce. Manufacturers and salesman make impressive claims regarding the potential increase in productivity which can be expected after automation. Managers naturally equate these increases in productivity to a corresponding decrease in personnel. In the vast majority of cases, these expectations have not been realized. One of the interview subjects in the area of process control observed that the tendency is for automation to upgrade the level of employees in a given company rather than to reduce the total number of employees. This tendency leads to fewer operator-level employees and more managers in the automated facility. Macek, et al. (1981) elaborated on this point:

> "The fact that manufacturing plants add layers of management as they automate is an observed fact that is stubbornly persistent. It is hard to evaluate whether this is good or bad or, simply, necessary--a change that must occur so that things will work. Sometimes the number of managers in the management hierarchy may decrease but, even in these cases, the number of steps between the shop foreman and the chief executive officer increases. Typical job titles in these new layers of management are: factory integration manager, computer-aided-manufacturing coordinator, robot integration manager, robotics manager. It seems inevitable that new layers of management come with the introduction of automation. It is something to expect and plan for. A company may plan for it by working out the new management functions beforehand or by deciding that whatever new functions may arise will be allocated between existing managers."

4.4.1.2 Special Change Problems

The interviews with various personnel who have experienced the transition to automation revealed several problems which often accompany this change.

A problem with automated systems today is that those responsible for specifying system performance parameters often do not know what to specify. This point was dramatically illustrated in the case of the sewage treatment plant which was originally intended to be a showplace of automation technology. The plant ultimately degraded into a totally manual operation after a long, frustrating attempt to make the automatics work. When the specifications for the new plant were developed, the municipality did not have the expertise available to adequately prescribe system performance. Consequently, they were forced to take the word of the vendor. The resulting system was not properly matched to the requirements of the facility. For example, a unique oxygenating process was included in the system design. However, the sensor outputs of the oxygenating subsystem were not compatible with the input requirements of the automated control system, resulting in incorrect control of the oxygenating process and therefore out-of-spec effluent from the plant. Due to design errors such as this and the inability of the crew to keep up with the system, the effluent from the plant was frequently in violation of acceptable standards.

As has been pointed out previously, management must be prepared for the change in operator skill brought on by the new technology. This will have an impact on policies related to employee selection and training. Two disadvantages of newer automated systems are: 1) potential operator resistance to learning the new technology, and 2) dependence on unavailable skills such as software development and the ability to troubleshoot digital electronic equipment.

Trained personnel tend to migrate through a company and an industry. As a result, since they may not be available when the system develops problems, the automated features may simply be abandoned with the process reverting back, at least in part, to manual control.

When an automated system is installed in parallel to the manual process and a direct comparison is possible, the new automated system will usually be preferred. Conversely, if the old system is not available for comparison, it tends to be remembered as being better than it actually was.

4.4.2 Job Design

Automation brings about fundamental changes in the roles which people play as system components. These changes can be so far-reaching that they destroy any continuity between the old manual job and the newly automated job. Often tasks are automated simply because the capability exists to do so. The result can be a set of incoherently automated tasks which must be integrated by the human operator; this task may in fact may be more difficult than simply operating the system manually. There is a tendency to assign to the computer those tasks which are most easily automated while relegating the leftover bits and pieces to the human operator. An example was cited during an interview with a printed circuit board designer. His job entailed laying out the components of the PC board and then routing the electrical interconnections between those components. The process has been recently automated, using a computer to search for interconnections which satisfy predetermined constraints. The computer will complete only between 75 and 90 percent of the interconnections before deferring to the human operator. The remaining connections are invariably the hardest to accomplish, resulting in understandable resentment on the part of the designer.

Walter (1974) discussed the problem of maintaining coherent jobs. "The auto industry is a prime example of a workplace with dull, repetitive jobs that stifle autonomy and initiative. Widespread education has produced 'a shortage of morons', and thus discontentment in boring jobs."

Some companies, most notably IBM as long ago as the 1960's, attempted to counter the historic trend toward greater division of labor by enlarging the content and responsibilities of their employees' jobs. Former jobs of operating either a drill press or automatic screw machine were expanded to include sharpening tools, setting up the machine, and inspecting completed parts. This action increased the importance of the product to the worker, improved the quality of the product, and reduced costs. Other attempts of job enlargement, job enrichment, job rotation, etc. have helped to alleviate the problem of alienation at the workplace, but the greatest single contributer to change in jobs has been automation. Properly implemented, automation can change the worker's job from one of simply providing skills to one of accepting responsibility for a complete and coherent task.

4.4.2.1 Function Allocation

When an automated sytem is introduced, conscious decisions must be made concerning those functions which are to be allocated to the computer as opposed to those functions which are to remain the province of the human operator. The topic of function allocation has been the subject of numerous studies which have attempted to establish guidelines for making these decisions.

In 1951, Fitts published a landmark article in which he made the first formal attempt at listing those functions most appropriate to humans versus those most appropriate to machines. His original list follows:

> "Humans appear to surpass present day machines with respect to the following:
>
> 1) Ability to detect small amount of visual or acoustic energy,
> 2) Ability to perceive patterns of light or sound,
> 3) Ability to improvise and use flexible procedures,
> 4) Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time,

5) Ability to reason inductively,
6) Ability to exercise judgment.

Present day machines appear to surpass humans with respect to the following:

1) Ability to respond quickly to control signals, and to apply great force smoothly and precisely,
2) Ability to perform repetitive, routine tasks,
3) Ability to store information briefly and then to erase it completely,
4) Ability to reason deductively, including computational ability,
5) Ability to handle highly complex operations, i.e., to do many different things at once."

These attempts to construct lists for allocation of functions reflected an interest in man's ability which was essentially limited to his engineering properties.

Factors beyond man's "engineering properties" must be considered. To maximize his performance, more functions than the absolute minimum may have to be allocated to the operator. The system should not isolate man from necessary social contacts.

An elusive quality referred to as "human skill" by Whitfield (1971) is not likely to be duplicated by machines in the near future. One of the aspects of this skill is that "Given a goal-oriented situation and the prerequisite knowledge, the human operator uses a variety of paths to attain a goal. These paths may involve using some functions in a way for which they were not originally designed."

Another human skill is the ability to imagine the consequences of a control action before the action is taken. This ability is based on an internalized model of the control process which would be very difficult to duplicate in a machine.

Functions appropriate to the human operator at one point in the evolution of technology may later be automated.

Price and Tabachnick (1968) published a list of "core performance" areas. These were intended to represent the basic functional components of any system and can be used in conjunction with the Fitts list to better analyze functional allocations. The seven core performance areas are:

1) Sensing
2) Interpreting
3) Information Processing
4) Decision Making

5) Controlling
6) Monitoring
7) Information Storage

In 1980 Swain published an expanded but not significantly different list of functional allocations:

TEN CHARACTERISTICS TENDING TO FAVOR MACHINES OVER HUMANS

1) Monitoring men or other machines,
2) Performance of routine, repetitive or precise tasks,
3) Responding quickly to control signals,
4) Exerting large amounts of force smoothly and precisely,
5) Storing and recalling large amounts of precise data for short periods of time,
6) Computing ability,
7) Sensitivity to stimuli,
8) Handling of highly complex operations (i.e., doing many different things at once),
9) Deductive reasoning ability,
10) Insensitivity to extraneous factors.

FOURTEEN CHARACTERISTICS TENDING TO FAVOR HUMANS OVER MACHINES

1) Ability to detect certain forms of energy,
2) Sensitivity to a wide variety of stimuli,
3) Ability to perceive patterns and generalize about them,
4) Ability to detect signals (including patterns) in high noise environments,
5) Ability to store large amounts of information for long periods and to remember relevant facts at the appropriate time,
6) Ability to use judgment,
7) Ability to improvise and adopt flexible procedures,
8) Ability to handle low probability alternatives (i.e., unexpected events),
9) Ability to arrive at new and completely different solutions to problems,
10) Ability to profit from experience,
11) Ability to track a wide variety of situations,
12) Ability to perform fine manipulations,
13) Ability to perform when overloaded,
14) Ability to reason inductively.

The Computer-Aided Function Allocation Evaluation System (CAFES) is a system developed under the auspices of the Naval Air Development Center (Parks and Springer, 1976) to assist in providing human factors engineering input into the development of new weapon systems. The ultimate effectiveness of CAFES requires the ongoing development of a human factors data base upon which design decisions can be made. The CAFES program is composed of the following five submodels:

FUNCTION ALLOCATION MODEL (FAM) 1. Mission Evaluator 2. Procedure Generator USES: Task Data Mission Scenario Data Table of Constants Mission Objectives Mission Events Allocation Versions	• Best Crew Size • Best Automation Level • Optimum Task Allocation
WORKLOAD ASSESSMENT MODEL (WAM)	• Verification of Allocations • Detailed Procedure Analysis • Optimum Crew Station Design
COMPUTER-AIDED CREWSTATION DESIGN (CAD)	• Feasible Station Layouts • Sensitivity to Requirements Constraints, and Criteria
CREWSTATION GEOMETRY EVALUATION (CGE)	• Verification of Detailed Configurations • Task Time Estimates
HUMAN OPERATOR SIMULATION (HOS)	• Human Performance Estimates • Sensitivity to Behavioral Factors, Operating Environments, etc.

Workload assessment traditionally involves taking each candidate allocation of functions and the task time lines associated with it and analyzing them for trouble spots. Periods of high workload and overload, tasks competing for the same resources, and threats to mission success based on these data are part of the assessment. Results from the analysis can be used to modify crew size, man-machine allocation, intra-crew task allocation, and task sequences.

The Human Operator Simulator, or HOS, (Strieb and Wherry, 1979) is a microprocessor model which contains a representation of the human operator. It is based on data describing the capabilities and limitations of man performing the various tasks which HOS was intended to simulate. The HOS treats the human operator as a goal-oriented element which can modify its behavior to suit the needs of a particular set of circumstances. The HOS uses a modification of FORTRAN to specify operator procedures and functions and hardware procedures and functions. The operator procedures describe the operator tasks, while operator functions describe the cognitive actions that the operator must take to perform those tasks. Hardware procedures describe changes which result from operator actions, while hardware functions describe what has to be done by the hardware to accomplish these changes. The HOS assumes the operator is stationary, as in an airplane cockpit. For such a fixed operator, HOS helps to determine the functional requirements of a system and assists in determining functional allocations.

In 1968, Price and Tabachnick defined a series of activities to be used in the allocation of functions. They are as follows:

ACTIVITIES FOR DETERMINING THE OPTIMAL ROLE OF MAN

1) Hypothesize the potential basic role of man.
2) Hypothesize potential complementary and support role of man.
3) Review manned system solution feasibility.
4) Develop a preliminary crew concept.
5) Analyze personnel support requirements.
6) Review potential crew role for acceptance and reliability.
7) Synthesize optimal crew role.

ACTIVITIES FOR DETERMINING THE OPTIMAL ALLOCATION OF FUNCTIONS

8) Establish feasibility of man-rated allocation.
9) Develop potential man-rated allocations.
10) Review allocation potential versus psychophysical capacities.
11) Review allocation potential versus system or function constraints.
12) Review allocation potential versus human reliability.
13) Synthesize man-rated allocations.

An entirely new form of function allocation, adaptive allocation, is projected for the future. Under this concept man and machine work in a symbiotic fashion where man may provide direction and control during one time or event while the computer may provide direction and control during another time or event. This represents a departure from past philosophies where man was "hard-wired" into a system with responsibility for a rigidly defined set of functions.

While a great deal of effort has been directed at development of criteria, models, and methods for function allocation, not many of these efforts have been applied to the design of real world systems. One study by Mertes and Jenney (1974) was directed at an analysis of the air traffic control system in an attempt to identify tasks and subtasks which were candidates for automation. One product of the study was the identification of five levels of automation as follows:

<u>Level I - Automation of Computational Aids</u>

At this level of automation, repetitive computation and routine data processing tasks and maintenance of the system data base are allocated to the machine.

Level II - Automation of Aids to Decision Making

At this level, machines are assigned to more sophisticated data processing tasks, such as alerting the human operator to the need for a decision and providing him with data to support the decision-making process.

Level III - Automation of Decision Making

At this level the computer is assigned responsibility for routine and repetitive decision making.

Level IV - Automation of Communications

At this level the routine relay of information becomes the responsibility of the computer. Man remains responsible for communication of a special or emergency nature. Virtually all strategic planning and regulation of traffic flow is also delegated to automated resources.

Level V - Full Automation

This level represents a hypothetical system in which man has no direct responsibility for regulation and control of air traffic. Man's role has become that of a system monitor and manager. He controls a complex of automated resources which, in turn, control aircraft.

Several interesting points regarding function allocation were derived from these studies. For example, if it is indicated that a functional grouping of tasks does not rate highly on man's performance measures, then the best backup system might be another automated system, as opposed to a human.

4.4.3 Operator Workload

The purpose of implementing automation is often stated as an attempt to reduce operator workload. Workload is an elusive concept which is often difficult to describe in quantitative terms. Although physical workload has long been addressed by system designers, mental or cognitive workload has been receiving increasing attention.

4.4.3.1 Physical Workload

Physical workload in the sense of strenuous physical activity did not play a role in any of the fields which were studied. All of the pilots who were interviewed stated that physical strength is not an issue in modern aircraft. The centralizing effect of computer control does tend to reduce physical workload by consolidating controls and displays in a single location. Multifunction controls and displays further reduce reach requirements by minimizing the number of discrete control elements which must be incorporated into even the most complex panel.

4.4.3.2 Mental Workload

Of greater concern is the potential for increased mental workload with the advent of automation. As Wickens and Kessel (1981) observed: "Automation does not necessarily eliminate or even reduce workload, but merely shifts the focus of processing demands. While interference with other manual responses might be attenuated by automation, interference with cognitive tasks might well be increased."

Conventional automation systems tend to present large amounts of data and require the operator to key in requests for specific information. While they lower workload in non-critical times such as cruising, they increase workload during critical times (Chien, 1977). In aviation, such critical times are characterized by takeoff, landing, and abnormal or emergency operations. The resulting flight scenario, long periods of low activity during cruise followed by a period of high activity, results in missed checklist items during descent for approach and landing (Butterbaugh, et al., 1980). The shift in emphasis from physical to mental workload was mentioned in several of the aviation interviews. For example:

- "In some respects it takes more (vigilance and attention) with automation to make sure (the automatics) are doing what they're supposed to do. Below ten thousand feet, that's bad if you're 'inside' the plane instead of out."
- "In terms of effort or number of things to do, automation helps. However, the mental work increases because you have to imagine what's going on instead of seeing it directly."
- "The mental part has gone up and the motor part down. You have to process a lot more information to program computers but then there's nothing else to do but watch."

4.4.3.3 Effects of Inappropriate Workload

Although much of the emphasis on workload has focused on overload, recent work has shown that underload can have equally serious consequences.

In practice, it has been found that at low levels of workload, operators tend to treat each function as a separate item rather than applying an overall strategy. However, when an overload condition is experienced or expected, the operator develops strategies which take into account estimates of likely future events.

Under conditions of lower than optimal workload, operators tend to "get into" computer programs to discover how they work or to improve them unless specifically prevented from doing so or provided with some task regarded as meaningful or important (Price, et al., 1981). This tendency is illustrated by the following examples taken from the airline pilot interviews:

- "Sometimes we get so involved playing video games that we forget to look outside."
- "At cruise, we'll get the Flight Attendant to ask someone (a passenger) where they live. Then we punch in the coordinates and tell them how far they are from their hometown."

Although there is a general tendency to equate low workload with boredom and high workload with stress, experience points out that in situations like the cockpit boredom may in fact induce stress. This can be brought about by the coupling of repetitive, monotonous work with the requirement for high alertness, continuous and rapid decisions, with various penalties for any errors which might occur.

4.4.3.4 Pacing

When the human operator and the computer share a task, each has a pace at which it functions. If the pace of the human operator is significantly different from the pace of the machine, conflict can result. This is particularly true if the human operator must frequently wait for the machine to complete its portion of the task. In one of the factories which took part in the study, a survey had been made of employee attitudes toward automation. The survey was taken about seven to eight months after the system had been put into effect. Most of the replies to the survey indicated that the system was too slow and did not allow employees to work at their own pace. If the worker must wait for the system, overall efficiency suffers. In a study of users of computer systems (Boies, 1974), a tendency was found for user response time to increase as system response time increases. In the experiment, when system response time was increased from one second to ten seconds, user response time increased consistently from 15 seconds to 24 seconds.

From an operator standpoint, one disadvantage of a computer-paced system is that it may no longer be possible to defer dealing with unpleasant tasks. When items are assigned on a priority basis, the operation which is specified must be done before going on to the the next one. In the case of one of the processes surveyed, the automated system eliminated a situation where undesirable jobs were shunted aside and not done for weeks, while easy or pleasant jobs received immediate attention.

4.5 HUMAN FACTORS GUIDELINES FOR AUTOMATION IN AVIATION

4.5.1 Human Adaptation

As noted earlier in this report, human adaptation to automation is dependent on successful treatment of many other issues. Based on interviews with line pilots and flight operations management personnel, selection/placement and education/training are the most important factors which determine pilot acceptance of the automated cockpit. However, man equipment and software design factors will be discussed in other sections of this report.

4.5.1.1 Psychological Adaptation

Of the airline pilots who were interviewed, 22 had recently transitioned from less automated aircraft to significantly more automated aircraft. Of these, only three felt that the more automated aircraft were harder to learn. On the other hand, eight felt that the more automated aircraft were, in fact, easier to learn while the rest stated that there was essentially no difference. A typical response is that of a DC10 First Officer who commented: "They seem to get easier as the years go by. I don't know if the planes are easier, the training better, or I'm better. Automated planes aren't harder though." It seems reasonable to conclude that the complexity or degree of automation of an aircraft is not as much an issue of psychological adaptation as is the confidence a pilot feels upon finishing training. Most of the major carriers surveyed during the NASA B767 Human Factors Study (Curry) have experienced this "comfort level" problem even though the pilots are consistently passing required FAA orals and check rides. Modern training techniques such as Criterion Referenced Instruction (CRI), when compared to traditional slide/tape presentations or lectures, often leave the pilot feeling like he hasn't "worked hard enough" to acquire the necessary knowledge.

Most pilots interviewed also expressed concern about the "loss of control" in the automated cockpit, and were threatened by the idea that they will be "left out of the loop" while maintaining responsibility for the airplane. Many believed that psychomotor skills had increased with automation. One 747 Captain commented that "psychomotor skills have gone up because you still have to think what you want to set in, set that in, then monitor the results." Thus, what the pilot expects from an automated airplane, as opposed to what is actually experienced, has an influence on acceptance.

Based on the information presented above, the following guidelines are presented:

* Educate the transitioning pilot as to what to expect from training, including some information on modern training techniques and expected results from each phase of training.

* Provide "up front" information on what to expect from the aircraft systems, e.g., system idiosyncrasies.

* Build into the New Hire pilot selection, requirements for basic computer knowledge or provide necessary training.

* Select instructors who take a realistic approach to automation and can convey that through their teaching.

4.5.1.2 Physical Adaptation

Although physical strength has never been an issue as aircraft have evolved, the acquisition of new skills and the maintenance of old skills remains a problem. Whereas traditional cockpits require the pilot to set and interpret individual "hard" instruments, the automated cockpit suddenly requires an understanding of integrated panels, CRT's, data entry via keyboards, function keys, menuing, and data retrieval. However, the pilot is required to maintain basic flying skills in the event of irregularities. One 747 Captain remarked that "automated airplanes are dangerous because you tend to become complacent".

A 767 copilot related the following anecdote. "We were at the gate in Trenton expecting the standard area departure and we had programmed the EICAS accordingly. When the clearance came, ATC had changed it drastically and we could not get the computer to accept our definitions of the intersections. As a result we ran out of time and had to depart without programming the EICAS."

The following guidelines are proposed to aid in physical adaptation to the automated cockpit. More specific design guidelines will be provided in the pilot/machine section of this report.

* New Hire pilot selection requirements should include some computer data input/retrieval skills.

* Provide hands-on data entry/retrieval practice to a standard criterion level during training.

* Provide for operational procedures which require manual flying skills on a regular basis.

4.5.1.3 Cognitive Adaption

In terms of job requirements discussed during pilot interviews, cognitive adaptation encompasses mental workload, understanding of systems, vigilance and attention, and finesse. Many of the pilots interviewed believe that mental workload has increased with automation in the cockpit. A typical comment is, "with more automated aircraft you end up thinking a lot more than doing. Psychomotor effort has gone up." Another frequently expressed view is that psychomotor skills are "different" with automated airplanes, a comment most often made with regard to the interpretation and response to information presented on a CRT.

A majority of the pilots feel they would be more comfortable coming out of training if a greater emphasis were to be placed on systems knowledge. Interestingly, these same pilots have no trouble whatsoever with their oral exams, a fact that points up the need to educate pilots about the results they can expect from modern training methods. In short, there is no question that they know more than they think they know.

The problem of vigilance continues to be a serious issue. In spite of overwhelming data indicating that humans are poor monitors, we continue to design systems that humans must monitor. It is this point which pilots are directly addressing when they express the desire for "more systems information" and the feeling that "mental workload is increasing".

Closely related to this is the often heard comment that "you have to finesse the computer", i.e., the pilot feels he has to outwit the computer to get it to do what he wants it to do. This attitude can be tied to what a pilot understands about how a computer works.

The following guidelines relate to cognitive adaptation.

* Before a pilot bids an automated airplane, provide the pilot with information on how his role will change, i.e., active direction of the aircraft systems but less interaction with the controls.

* To address "comfort level" with regard to systems knowledge, provide training from a systems approach as opposed to a phase of flight approach.

* Apply workload measurement techniques during cockpit design to assure a balanced workload.

* During training, provide the pilot with information on the computer logic and generally how he can expect it to respond to particular situations.

* Avoid training pilots on system capabilities which are planned for the future but not yet implemented.

4.5.2 Worker/System Interaction

In the modern airplane cockpit the most significant change to the worker/machine interface has been brought about by the introduction of multifunction displays or panels and by the use of CRT displays. Consideration must be given to both the physical interface and the information interface. As flight displays have evolved, the number of instruments, visual displays, and status readouts has grown when compared to those previously located in the cockpit (Kuperman and Seifert, 1975). Thus the aircraft designer has unwittingly designed the ideal breeding ground for the proliferation of instruments without also breeding a species of human operators to cope with them (Braid, 1975).

4.5.2.1 Physical Interface

Some of the problems with physical interface have been noted in earlier parts of this report. Such things as flicker, rate of display, clutter, etc. are common complaints by pilots. Many of the pilots now flying the B767 have never used a typewriter, let alone a computer or data entry keyboard. A common complaint is "the time it takes to enter the proper information in the computer; first you have to copy your clearance, then you have to program -- it's very time consuming." However, an equally common comment is that "it is not more work if you really know how the system operates." One anecdote that does present a serious human factors problem was related by a B767 First Officer after having experienced a flight in which both engines had to be shut down and then restarted. "During the time that both engines were shut down, we were operating on the standby instruments. The stuff on the CRT was totally useless to us because it was unreadable in the turbulence."

4.5.2.2 Information Interface

Until the advent of the B767 and Airbus generation of commercial airplanes the problem of information interface with automated systems was relatively minor. Now however, we have a cadre of airline pilots who span three generations and bring to the cockpit widely disparate backgrounds, attitudes, and education. Just as some pilots had difficulty with the transition to the jet age, experience is showing that some pilots, especially those who are older with a lot of conventional airplane time, are having difficulty with the transition to the automated cockpit. One pilot commenting on his colleague in training said, "he fought the training techniques so hard that he really had a lot of trouble with the aircraft." The training techniques referred to in this example were largely computer based.

Although most pilots interviewed believed that they would adapt to the automated systems, most also agreed that "improvements can be made in the quality of presentation, the organization of the information, and most importantly in the 'friendliness' of the software." The pilots were most fearful of being "left out of the loop" either by the designers or by their own inability to access the data needed. The interviews yielded a virtually unanimous agreement that in order to fly the airplane certain "need to know " items must be available at all times. These items include information on attitude, speed, position, hazard avoidance, performance, and systems status.

Pilots, like any other operators of complex systems, are most prone to feeling mental workload pressure in real-time environments when time pressures force quick evaluations and actions. Under these conditions humans are limited information processing systems primarily because they have limited short-term memory capacity. Pilots frequently express a desire for more information and designers have responded by increasing the input. However, research has shown (Bejczy and Paine, 1977) that "monitoring and integrating the larger input is not offset by the completeness of information; rather, the greater demands on the human information-processing system result in performance degradation."

Pilots of highly automated airplanes can operate with competence and confidence only when the needed information is timely and readily interpretable. CRT information can be formatted so that all the data is not displayed all of the time. Integrated displays can reduce the time needed to search for relevant information. In short, what the pilots are really asking for is design input into what is displayed and when it should be displayed. The system designer must consider the total data needs of the pilot and decide how best to display it based on the needs of the operator during various system states. A properly designed integrated display will selectively display and prioritize data needed immediately and suppress less important information. Thus, the computer becomes an "assistant" in addition to being an information system. Currently, systems such as the B767 Flight Management System require the pilot to perform page selection and system control activities. Little wonder then why pilots perceive their workload as increasing. As noted by Mitchell (1983), "the introduction of integrated, computer-based displays in real-time control environments is often expected to improve operator performance by allowing access to more information and to decrease operator mental workload by delimiting the amount of data displayed at any given time. To compensate for the load created by requiring the operator to call up display pages, the displayed data must not only be preselected, they must also be preprocessed, integrated and presented in forms more compatible with the operator's higher-level information needs."

The following guidelines are suggested with regard to pilot/ machine interface.

* Design cockpits to reduce visual clutter in general as well as on the CRT displays. Screws, safety wires and other mounting hardware all present visual information that must be processed whether or not it relates to the task of flying.

* Present critical information so that it is usable under all circumstances, even turbulence.

* Present multiple alarms in such a way that the criticality of the alarm, as well as its priority relative to other tasks, is clear.

* Standardize the advanced-technology cockpit layout, display symbology, and use of color.

* To avoid "underload", the pilot should be kept in the control loop, flying the airplane, and the automated systems should be monitoring the pilot, not vice versa.

* Because the time required for routine data entry/retrieval is often high, alternative methods need to be considered. One possibility is speech recognition for input, and synthesized speech for output.

* If the pilot must physically interact with a system for data input/retrieval, consideration should be given to to touch-sensitive CRT's and user friendly or tutorial menuing so that the requirement to "outthink the computer" is minimized.

* Design electronic displays to include the subtle cues such as trend information, available from a "hard instrument" and make them available on the CRT.

* Consider innovative methods of displaying information electronically, especially the use of color or patterns.

* Format CRT data to enhance the pilots' effectiveness. Prioritize data based on the pilots' needs while allowing suppressed information to be readily accessed.

* Carefully consider which functions should be automated and avoid automating functions simply because they are easy to automate.

* Consider inclusion of Head-up Displays (HUD) and/or angle-of-attack indicators for use during periods of high workload.

4.5.2.3 Reliability

The factors which influence human reliability have been well documented elsewhere in this report. The key point is that pilots make mistakes when they are operating at their information processing limits and a relatively minor problem causes them to lose control of the situation. Paradoxically, the very equipment which designers are putting into cockpits to "reduce workloads" often is so misunderstood that pilots feel like their "mental workload has increased". A very common statement is, "once you learn the systems (after you're out on the line), the workload goes down" This comment goes hand-in-hand with the comment by a B767 pilot that "We bring it on ourselves. We become so involved in playing video games that other things get neglected." Conversely, some pilots do not use the automated systems at all because of lack of trust in them. This points to the fact that if systems can't be designed so that they are perceived as "friendly" and the pilot is in the loop, then there is a very great likelihood that the pilots will not use those systems at all.

The majority of the pilots interviewed believed that jet age equipment is reliable. Especially noted was "the introduction of solid state electronics." It should be pointed out that the perception pilots have with regard to the reliability of their airplanes is strongly influenced by the redundancy built into the systems. The interviews highlighted the fact that the interviewees often had trouble recalling system failures because those failures were not total; they were always "backed up". However, a lot of problems with perceived reliability can be minimized or eliminated by involving the actual "live pilot" in the development process. Also, frustration with automated systems can be reduced by avoiding training pilots on a "full-up" system that has not been fully implemented on the line. Based on these comments the following guidelines are suggested.

* To reduce human error, train the pilots to a high level of proficiency with regard to data input/retrieval. Train and test in realistic, Line Oriented Flight Training (LOFT)-type situations.

* Involve line pilots in the design and debugging process to ensure a user-friendly product, and thus build faith in its reliability.

* To avoid channelized attention within the cockpit, consideration should be given to a head-up-display such as is available in the DC 9-80.

* Care should be taken to avoid training pilots on system capabilities that are available but not implemented. This has caused considerable confusion and frustration on the B767.

* Beware of fielding a system that "cries wolf" too often. Even if the parameters are adjusted, the initial attitude may never be overcome.

4.5.2.4 Maintainability

Since maintainability is a major consideration in the development of a new commercial airplane, most jet age airplanes are equipped with "quick change" avionics and fairly accessible components. Also, airliners all have a minimum equipment list (MEL), which means they can be dispatched only if all of the items on the MEL are working. In general this has led pilots to the perception that their airplanes have good maintainability and are, in fact, well maintained.

In the "glass cockpit" however, this perception may be eroding. One Captain, experienced on both the DC 10 and the B767, commented, "There are lots of things you would like to know from the EICAS that you cannot get. Lack of information doesn't help the decision making process. The information is available from EICAS when you are on the ground but when you're in the air, all you get is an idiot light. In the air you sometimes need to tell maintenance what is wrong so they can help you. It would help maintenance reliability if you could tell them." The following guidelines are suggested:

* Design systems so that the information available on the ground is also available in the air.

* Carefully consider the initial and recruitment training necessary to maintain the skills of maintenance personnel who work on equipment that has high Mean Time Between Failures (MTBF).

4.5.3 Management/Pilot Interaction

In the airline industry the implementation of automated systems is already a major issue affecting the relationship between management and the pilots. One area that has been a particularly sensitive one is assessment of pilot performance via automatic recording devices. The pilots often view objective performance assessment as a threat, whereas management views it as a means of objectively measuring performance in otherwise subjective LOFT-type situations.

As noted earlier, education and training are key factors not only in assuring safe and efficient operation of automated airplanes but just as importantly in the attitudes toward, and acceptance of, automated systems. It may well be that the current philosophy of "train to proficiency" will not adequately meet the needs of pilots of automated airplanes. This is because "train to proficiency", in virtually every airline, is interpreted as, "can the pilot pass a check ride?" Since evaluation of a check ride is totally subjective, training to proficiency does not equate with total mastery of the equipment. Trainers may have to accept the tradeoff of increased training time and cost for the assurance that their pilots have thorough knowledge of the automated equipment. To hold cost down while increasing training effectiveness, the airlines may want to move toward increased use of Criterion Referenced Instruction. This type of training builds confidence, ensures knowledge, and reduces the "us against them" or "you bet your job" attitude so commonly found in training.

Pilots overwhelmingly support the need for increased emphasis on communication and cockpit resource management. They are very aware that the majority of recent airline accidents are the result of failure to communicate and properly use resources. They commonly report that "automated equipment is so complex that two or three heads are better than one".

If pilots are kept "in the loop" and management is taking steps to provide quality line-oriented training as well as training in communication and resource management, then motivation and morale will be high. If automation is to be accepted, then management must take steps to ensure this.

The following guidelines are suggested:

* Develop standardized evaluation criteria that can be used by instructors to more objectively assess pilot performance.

* Select instructor personnel based on knowledge of instructional techniques and ability to apply objective criteria to pilot assessment.

* A method of evaluating training should be built in to each training program.

* Part-task trainers should be designed and purchased based on the specific behavorial objectives, associated with the automated cockpit, that are to be learned by pilots.

* Computer-assisted instruction should be considered as a potentially cost-effective alternative to some part-task trainers and traditional instructional methods.

* Provide formal training in cockpit communications and resource management.

* To the greatest extent possible, train flight crews in realistic, line-oriented scenarios where unpredictable events allow them to put their training to a test.

The automated cockpit has the potential to eliminate or significantly reduce human error, the last major cause of aircraft accidents to be addressed. However, caution must be used to avoid negating the advantages computers give us. As long as pilots remain in the loop, computers should be used both to assist and to monitor pilot performance as well as to store and disperse system information.

SECTION 5
SUMMARY AND CONCLUSIONS

A great deal has been learned about the way human beings react to automated systems. The common characteristics which we all share can easily be obscured by focusing too narrowly on the specifics of a given task or situation. By pulling back and scanning over a number of diverse fields, the commonalities become apparent. It is time now to return to the basic questions with which we began and apply the experience gained through the study toward answering them.

5.1 ALTERNATIVE SITUATIONS FOR INTRODUCING AUTOMATION

Too often automation is treated as a solution in search of a problem. Technical people are enamored with technique and seek to demonstrate it at every opportunity. When given a "problem" to solve, they eagerly roll up their sleeves and set out in search of a solution. Often it would be wise to question whether the problem is a valid one and, furthermore, whether it has been properly stated. As an example, workload reduction is often given as the reason for implementing automation. If workload is not a significant problem, resistance to the automated system will surely be encountered. Simply substituting an increased mental workload for a reduced physical workload will not enhance user acceptance.

Figure 14 presents a hierarchical breakdown of the situations in which automation can be implemented. Obviously, in the case of dangerous or unpleasant tasks, few problems can be expected with regard to user acceptance. In the case of a pleasant, satisfying job, two situations are possible. In one case, the effect of automation may be to replace the worker. In most instances this can be expected to have a negative impact on the morale of remaining workers. However, in the case of an expanding economy, the overall effect may be to raise the general status of the workforce so that everyone appears to benefit. In other situations, automation will be accepted if it is perceived as essential to the ultimate survival of the organization, even if this entails the displacement of a portion of the workforce.

The next scenario is one in which the purpose of automating is to unburden the worker and reduce workload. This can be accomplished in two ways. In the first approach, the machine assumes part of the task. This can be useful, but great care must be taken to allocate functions in a manner which ensures that the human operator is left with a coherent and meaningful job, rather than a collection of bits and pieces which are left over after

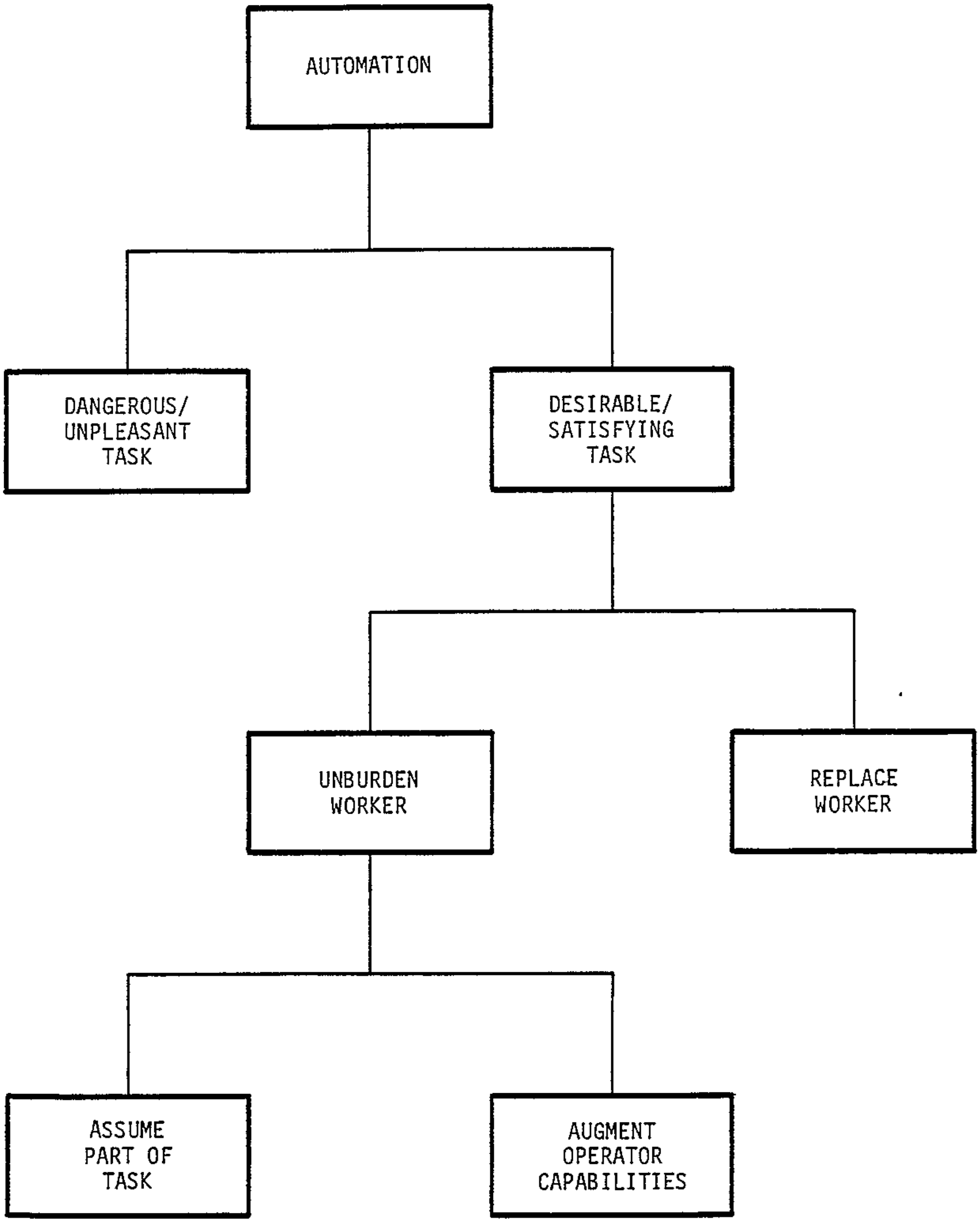


FIGURE 14. AUTOMATION ALTERNATIVES

the machine has taken care of the satisfying and rewarding aspects of the job. Technology must be introduced only after it has been adequately tested and proven to be reliable. If the human operator is to accept the machine as a partner, he must be convinced that the equipment can be expected to perform in a predictable manner. The human must always be aware of the actions of the machine and have the capability to assume control at any time.

In the final approach to automation, the machine augments the inherent capabilies of the operator. This involves extending the human physical, sensory, or mental capabilities in order to improve performance. An example of this philosophy is the use of improved displays which present information in an integrated fashion and in a manner which is most easily applied to the task at hand. It is by adopting this last approach that automation is likely to achieve its greatest potential and meet with the greatest acceptance.

5.2 WHAT BENEFITS CAN BE DERIVED?

The line between danger and opportunity is a fine one when dealing with automation. Just as automation has the potential for fragmenting work into incoherent and unrelated tasks, it also presents the opportunity to transform work from simply furnishing skills to accepting responsibilty for accomplishing a coherent set of objectives.

As Naisbitt (1982) points out: "I had thought that we might rebel against the computer for dehumanizing us. But now I think we are beginning to understand just how liberating the computer is...For example, a company with 40,000 employees has treated those employees pretty much the same for generations. It had to because that was the only way to keep track of them. With the computer to keep track, employees can be treated differently..." The computer offers potential for recognizing and accommodating individual style in terms of learning as well as actual job performance.

In a concrete sense, automation has the potential for improving efficiency, enhancing safety and increasing productivity. This can be accomplished only by a careful consideration of the respective strengths and weaknesses of the machine and its human counterpart.

5.3 WHAT PROBLEMS MUST BE ANTICIPATED?

For every potential benefit of automation, a corollary problem can be envisioned. There are, however, certain problems which seem inevitably to accompany the transition to automation. A recurrent problem is that of skill retention: infrequently practiced skills deteriorate over time. The increased use of solid state electronics, which have no moving parts to wear out, promises to make systems more and more reliable. As a consequence, emergency procedures will be rarely needed. When skills are not practiced routinely as part of the job, they must be maintained through conscious effort. The use of high fidelity simulators can be of great value in replicating scenarios which occur infrequently in the real world.

Old skills are not merely extinguished; they are often replaced by new skills. These new skills may be so different that they in fact redefine the job. These skill requirements must be accommodated by revised selection procedures, a comprehensive training program, or both.

Individual characteristics, such as age and personal experience, can greatly influence user acceptance of automation. Whenever possible, personnel policies should be avoided which tend to use economic or other incentives to force incompatible matches between operator and equipment. This is especially true when traditional skills may be more valuable if used in the remaining traditional roles.

While the reduction of workload is a worthwhile goal of automation, a level of activity which is sufficient to maintain an alert posture is necessary to avoid monotony and boredom.

When automation is contemplated, the ultimate users should be involved in the design and selection process. While this may seem to be no more than conventional wisdom, it is surprising how many otherwise well-managed organizations ignore this policy. It takes time and effort to involve the user, but in the long run, time will be saved and the effort will be well rewarded.

5.4 WHAT IS THE IMPACT OF AUTOMATION ON THE CREW WORKING ENVIRONMENT?

Traditionally, human factors has treated control as the transfer of physical energy across an interface. Down through the years, mechanization has served to reduce the level of physical energy to the point that modern aircraft require very little pilot strength. Automation is further changing the physical control interface to an information interface. To a traditional "seat-of-the-pants" pilot, his interface with the world was at the control surfaces of his aircraft. In the "glass cockpit", the danger exists that this interface will move inward, until it is an abstract concept on a CRT screen. This danger presents yet another challenge for training future pilots.

5.5 WHAT SPECIAL TRAINING REQUIREMENTS WILL EMERGE?

Historically, the inherent flexibility of the human being has been relied on to accommodate the discrepancy between the requirements of the machine and the capabilities of the operator. Given that humans are adaptable, training is the function that facilitates the process of adaptation. No matter how much attention is paid to humanizing the interface between computer and operator, there will always be a gap which must be filled through training.

5.6 WHAT ARE THE LONG-TERM PSYCHOSOCIAL EFFECTS OF AUTOMATION?

Automation is already making itself felt both in the workplace and in everyday life. One of the most striking facts to be observed by studying various automated fields is the level of sophistication of the operators. The computer is demanding higher education of workers and at the same time helping to make it possible.

While the computer holds the promise of coherent, responsible jobs for many, it will undoubtedly displace many who cannot adapt to its requirements. The concept of technological unemployment has already caused a great deal of concern in Europe and will no doubt have serious impact on the economy of the United States.

5.7 RECOMMENDATIONS FOR FUTURE RESEARCH

The pilot interview portion of this study was conducted almost exactly one year after the Boeing 767 and 757 were certified by the FAA. When these aircraft were first put into service, a significant number of problems were experienced, some but by no means all of which were related to automation. Negative attitudes were tempered by the belief that, like any new airplane, it would take a shakedown period to find and correct all of the problems. As the first anniversary of service passes, pilot attitudes are gelling and long-term opinions are being formed. As time goes on, the inherent human adaptability will accommodate design shortcomings, and the ability to learn what they are may be lost forever. Ongoing follow-up interviews, preferably including previous interview subjects, would offer valuable insight into the dynamic process of adapting to automation.

Furthermore, the automated avionic equipment which has been developed for the military and the scheduled airlines is finding its way into general aviation aircraft. Particularly, the larger turbofan and turbojet business aircraft are candidates for advanced automation. This is the result of both economic necessity on the part of the developers of the equipment and a response to the increasingly automated air traffic control environment. Accordingly, it is important to research the human factors implications of automation in general aviation.

APPENDIX A

BIBLIOGRAPHY FOR AIRCRAFT CONTROL INTERFACE

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APPENDIX B

STRUCTURED INTERVIEW FORMATS

AUTOMATION IN INDUSTRY
STRUCTURED INTERVIEW FORMAT

I. Explain purpose and goals of contract

II. Obtain personal and organizational data

A. Type of company?
   1. Goods or services produced?
   2. How long has it been in business?
   3. Number of employees?
   4. Character of company?
      a. Progressive/Conservative?
      b. Rapidly evolving/Mature with little change?
   5. Union versus Non-union?

B. Status of person?
   1. Level in company?
   2. Time in the industry?
   3. Time in this position?
      a. Age?
      b. Progression of positions?
   4. Personal factors?
      a. Level of education?
      b. Personality characteristics?
      c. Attitudes toward change, progress, and automation, both on and off the job?

III. Extent of automation

A. What is the primary thrust of the automation: worker unburdening or displacement?

B. Nature of process (continuous, batch, discrete)?

C. To what extent is process automated?
   1. General process?
   2. Specific tasks?

D. What has been automated?
   1. Organizing, scheduling, and managing?
      a. Computational functions?
      b. Record keeping and data management?
   2. Routine operation?
      a. Complex or specialized aspects of normal operation?
      b. Hazardous or undesirable tasks?
   3. Contingency operation?

IV. Characteristics of operators

A. Background?
   1. Typical socioeconomic level?
   2. Average age?
   3. Educational level?
   4. Experience level?

B. Are characteristics changing as a result of automation?

C. Is much prestige associated with the job?
   1. Related to economic or skill factors?
   2. What effects have occurred from automation?

D. The operator/supervisor progression has how many levels?
   1. Are levels associated with specific skill?
   2. Are levels associated with particular knowledge?
   3. Are factors other than seniority important?

E. Has automation produced any motivational problems?
   1. From threat to job security?
   2. From boredom or inconsistent workload?
   3. Has there been any resistance to the implementation of the automated process?
   4. Do any factors, such as age, contribute to acceptance of the new process?

V. Characteristics of the automated process

A. What are the primary functions served by the operator?

B. Is the automated process easy to learn versus easy to use?

C. What sorts of displays are used to monitor the process?
   1. Are displays different?
   2. Do they present the same information as with the manual process?

D. How are functions allocated?
   1. How much discretion does the operator have in using the automated capability?
   2. For determinate aspects of process what functions does each have?
      a. Who/what monitors versus controls?
      b. Which is primary, which is backup?
   3. Are manual and automatic modes mutually exclusive or is shared operation possible?

4. How is the transition between manual and automatic control accomplished?
    a. At discretion of operator?
    b. At discretion of computer?

5. Is the human ever "locked out" of the process?
    a. Because machine will not respond?
    b. Because operator does not have information or training to intervene in the process?
    c. As a result of skill degradation?
6. Is the process essentially steady-state or continuously changing?

E. Requirements of job?
   1. Level of refined psychomotor skills?
   2. Physical workload?
      a. Strength versus finesse?
      b. Long-term physical response?
   3. Mental workload?
      a. Understanding of the process or system?
      b. Vigilance and attention?
   4. What information is necessary to perform the job?
   5. What communication is required among workers?

F. Training requirements?
   1. Educational level?
   2. Duration?
   3. Methods?
      a. Are simulators used in training?
      b. If so, are they generic or system-specific?
      c. How successful is the use of simulators?
   4. Are computer-based training methods used?
   5. How are training results measured?
      a. Certified locally?
      b. Licensing by governmental authority?

VI. Potential system problems

A. Is any physical danger imposed by system?

B. How do errors affect automated system?
   1. Potential errors and their consequences?
   2. Potential malfunctions and their consequences?

C. Malfunction procedures?
   1. How are alarms presented?
   2. Are the causes and implications of alarms easily understood?
   3. Can a single fault affect several parts of the system, thereby triggering several alarms?

4. To what extent is the operator's response to a malfunction automated?
5. Are the operator's responses direct or indirect?

VII. Worker's acceptance of system

A. Has the automated process proven to be reliable?

B. Do the operators trust the automatic equipment?
1. Are there ways to defeat the automated process?
2. Have there been significant attempts to do so?

VIII. Evaluation of the effects of automation

A. What has been gained/lost through the automated process?
1. Degradation of operator skills?
2. Management changes?

B. Have your expectations of automation been realized?

C. Are you looking forward to further automation?

IX. Suggestions for further contacts

AUTOMATION IN AVIATION
STRUCTURED INTERVIEW FORMAT

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to automated airplanes

1. Psychomotor
2. Physical strength
3. Finesse
4. Understanding of systems
5. Vigilance and attention required
6. Physical workload (phase of flight)
7. Mental workload (phase of flight)
8. Training requirements, duration and methods
9. Communication among the crew
10. Ease of learning a new airplane
11. Reliability of systems
12. Skill retention problems
13. Command/Leadership/Resource Management skills

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
2. Physical strength
3. Finesse
4. Understanding of systems
5. Vigilance and attention required
6. Physical workload (phase of flight)

7. Mental workload (phase of flight)

8. Training requirements, duration and methods

9. Communication among the crew

10. Ease of learning a new airplane

11. Reliability of systems

12. Skill retention problems

13. Command/Leadership/Resource Management skills

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

B. Have you ever experienced a sudden failure of the automatics?

C. Do you think that younger pilots catch on to automation faster than older ones?

D. What did you expect and what has been reality with respect to automation in the cockpit?

E. What has been gained by automation?

F. What has been lost?

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

B. What specific data does a pilot "need to know" to fly the A/C?

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

E. How do you view future automation in the cockpit?

F. Has the major thrust of automation been to unburden the pilot or to displace him?

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

APPENDIX C

CAD SYSTEM QUESTIONNAIRE

CAD SYSTEM QUESTIONNAIRE

The Boulder office of Nelson and Johnson Engineering is conducting a study of human factors and automation. Your experience with the CAD system would be a very valuable addition to this study. Please fill out the enclosed questionnaire and return it to Elizabeth Hargrove. Your name is not necessary, but some information on your experience level will be helpful. To help us collate the information quickly please list the number which gives the appropriate answer in the blank. If the question calls for additional information, please enter it in the space provided.

_______ Your position: 1. Drafter 2. Illustrator 3. Mechanical Designer 4. Engineer 5. Supervisor

_______ Age: 1. 18-25 2. 25-30 3. 30-35 4. 35-40 5. 40-50 6. 50-60 7. 60+

_______ Sex: 1. Male 2. Female

_______ Education: 1. High School 2. 1-2 Years of College 3. Associate Degree 4. Bachelors Degree 5. Graduate work

Special Courses _______________________

Years Experience: 1. 0-1/2 2. 1/2-1 3. 1-2 4. 3-5 5. 6-10 6. 10+

_______ In your present field; _______ With CAD; _______ At NJE; _______ With NJE/CAD

_______ System with which you work: 1. Megatek 2. McAuto

_______ Have you worked with the other system? 1. Yes 2. No

What additional CAD systems have you worked on before?

____

_______ 1. How familiar are you with the operation of computers?
1. no prior knowledge 2. some prior interest 3. studied them some 4. own one

_______ 2. How would you categorize your typing skills before the automated system?
1. nonexistent 2. hunt and peck 3. fair 4. good 5. excellent

_______ 3. Other than your formal training how did you learn the system (If more than one applies, list in order of importance):
1. Instruction manuals 2. Trial and error 3. From other persons

_______ 4. If you were recommending the training for a new person on the system would you suggest that they be given
1. the same training as you 2. more structured exercises 3. more chance to try things and see what happens

_______ 5. How quickly did you learn to produce useable drawings with the CAD system?
1. less than one day 2. 2-3 days 3. one week 4. two weeks 5. one month

_______ 6. How long did it take before you were able to do a task with the CAD system as rapidly as you could manually?
1. under 1 mo. 2. 2-3 mo. 3. 4-6 mo. 4. 7mo.-1 yr. 5. over 1 yr.

_______ 7. How long did it take to feel comfortable with the system?
1. under 1 mo. 2. 2-3 mo. 3. 4-6 mo. 4. 7mo.-1 yr. 5. over 1 yr.

_______ 8. What do you think your present production in the CAD system is in comparison with the manual system?
1. less 2. about equal 3. slightly more (0-25%) 4. much more (25-50%) 5. very much more (50%+)

_______ 9. How do you feel that your overall usefulness as designer or illustrator is now compared with when you did only manual drawings?
1. lowered 2. no change 3. somewhat higher 4. much higher

_______ 10. Should there be a period of "booster" training after you have been on the system for a while? After how long?
1. not needed 2. 1 mo. 3. 2-3 mo. 4. 4-6 mo. 5. 6 mo.- 1yr.

_______ 11. Should managers be trained so they know what to expect from the system?
1. no 2. a little 3. should know basics 4. should know system thoroughly

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If you started to work in this group after the CAD system was introduced, please skip to Question 18.

_______ 12. What prior information did you have concerning the system when it was introduced?
1. none 2. heard rumors 3. told officially it was coming 4. were asked about your interest by management 5. were asked to make suggestions about the system

_______ 13. When the system was introduced, how helpful did you expect it to be?
1. detrimental 2. no difference 3. some help 4. very helpful

_______ 14. What were your expectations about the system?
1. negative 2. didn't know 3. realistic 4. overly optimistic 5. pie in the sky

_______ 15. What were your expectations about the system based on?
1. rumors 2. sales pitches 3. similar experiences 4. discussions with CAD operators 5. management briefing 6. demonstration of system

_______ 16. As a new system is introduced some 'bugs' will occur. How do you feel that the system you are using should have been put into operation?
1. waited until all bugs were out 2. only after most bugs were eliminated
3. the system was useful while the bugs were being eliminated 4. debugging helped me to understand the system

_______ 17. How has the number of people with whom you must communicate been changed by the CAD?
1. fewer people necessary 2. no difference 3. more people necessary

_______ 18. What input do you have into the acquisition of new enhancements to the system?
1. none 2. very little 3. asked occasionally 4. consulted often 5. a lot

_______ 19. What are the expectations of the others who rely on the products of the system but don't operate it (e.g. managers)?
1. very low 2. a little low 3. about right 4. a little high 5. overly optimistic

_______ 20. If allowed, would you like to just "play" with the system and see what it can do?
1. no 2. only for specific tasks 3. for several tasks 4. whenever possible

_______ 21. Do you think that it is possible to develop a personal style using the CAD system?
1. not at all 2. very little 3. in some aspects 4. quite a bit 5. highly

_______ 22. What proportion of drawings can be as easily drawn by hand as with the CAD system?
1. none 2. up to 25% 3. 25 - 50% 4. 50-100% 5. all

_______ 23. Do you feel that the speed of response of the system is
1. much too slow 2. too slow 3. about right 4. too fast 5. much too fast

_______ 24. Are you as pleased with the quality of the CAD drawings as with the manual drawings.
1. CAD very poor 2. CAD poor 3. about the same 4. CAD better 5. CAD much better

What sort of drawings are better done manually? _______________

_______ 25. If you had your choice of returning completely to the manual system or staying with the CAD system, which would you do?
1. return to manual 2. stay with CAD 3. don't know

_______ 26. Compared with the manual system how do you feel at the end of an ordinary work day?
1. much more tired 2. more tired 3. about the same 4. fresher 5. much fresher

Relative to the manual system rate the physical environment of the CAD system in terms of pleasantness on the following scale?

1 - much worse 2 - worse 3 - no change 4 - better 5 - much better

_______ Lighting _______ Interpersonal interaction

_______ Noise _______ Privacy

_______ Eye strain _______ Spaciousness

_______ Seating _______ Temperature

Megatek users:

Do you feel that it would help to expand the Megatek system to

________ include 3-D capability

________ include design capability

________ eliminate all manual drawing

McAuto Users:

Should the McAuto system be expanded to include

________ Unisolids

________ finite element analysis

________ PC design

What other changes have occurred as a result of automation?

If you were performing this study, what information would you want to get which has not been covered in this questionnaire?

ORIGINAL PAGE IS
OF POOR QUALITY

The following statements describe reactions to using automated technology. For each item indicate how much you agree or disagree with the statements. These items reflect your opinions, and you should answer in terms of your own feelings by placing the number in the blank.

ANSWER QUICKLY: YOUR FIRST IMPRESSION IS THE BEST. Please answer every question, even if you are unsure.

1	2	3	4	5
strongly disagree	slightly disagree	neither agree nor disagree	slightly agree	strongly agree

_______ A. Younger persons catch on to automation faster than older ones.

_______ B. I think they've gone too far with automation.

_______ C. I spend more time setting up and managing the CAD system than I would creating a drawing manually.

_______ D. I worry that the CAD system will go down when I have committed myself to using it to meet a deadline.

_______ E. I use automatic devices a lot because I find them useful.

_______ F. I can draw as efficiently as the CAD without its help.

_______ G. I draw in much detail frequently to keep my skills up.

_______ H. Automation does not reduce workload, since there is more to keep watch over.

_______ I. I like working with the CAD system the because it allows me to be more creative.

_______ J. If automation continues as rapidly as it has, I will be replaced by a machine before long.

_______ K. I am favorable toward automation in drawing - the more the better.

_______ L. Automation frees me of much of the routine, mechanical parts of drawing so I can concentrate more on "managing" the preparation of a CCCD.

_______ M. I have serious concerns about the reliability of this new equipment.

_______ N. Too much automation can be dangerous.

_______ O. The new equipment is a more reliable way of doing things.

_______ P. It is important to me that I use the most up-to-date system available in the company.

_______ Q. Automation reduces overall workload.

_______ R. Without automation my company would not be able to remain profitable.

_______ S. Illustrators or designers who overuse automation will see their drawing skills suffer.

_______ T. The manual drawing aspect is the part of the process I enjoy most.

_______ U. I use automatic devices mainly because the company wants me to.

_______ V. Automated devices make me a more valuable employee.

APPENDIX D

AUTOMATION INTERVIEWS

AVIATION INTERVIEW NO. 1

Age 50; 767 from 727 Captain

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to automated airplanes

1. Psychomotor
Need good psychomotor skills.

2. Physical strength
Not an issue. All aircraft have power boost.

3. Finesse
Not really needed.

4. Understanding of systems
Makes pilot more "comfortable".

5. Vigilance and attention required
During critical phases.

6. Physical workload (phase of flight)
Not bad.

7. Mental workload (phase of flight)
High during takeoff, approach and landing.

8. Training requirements, duration and methods
About same for all aircraft.

9. Communication among the crew
Should always be good.

10. Ease of learning a new airplane
None of them are different.

11. Reliability of systems
Good.

12. Skill retention problems
None.

13. Command/Leadership/Resource Management skills
Great program.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills

No increase/decrease.

2. Physical strength

No difference except without hydraulics.

3. Finesse

No difference.

4. Understanding of systems

Systems more sophisticated, in some instances others more automated.

5. Vigilance and attention required

No difference.

6. Physical workload (phase of flight)

No difference.

7. Mental workload (phase of flight)

Easier (now)?

8. Training requirements, duration and methods

Very modern - Computer Based Training - liked it.

9. Communication among the crew

Always needs to be good.

10. Ease of learning a new airplane

No problem.

11. Reliability of systems

Good - beats the G.B. (Gooney Bird).

12. Skill retention problems

Don't expect any - recurrent training takes care of that.

13. Command/Leadership/Resource Management skills

Same as before.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?
No. Attitude makes a difference.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Expected "smoother" operation, it's nice.

E. What has been gained by automation?
Smoother operation.

F. What has been lost?
Some "hands-on".

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Preflight flying.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude and speed, performance, position.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Attitude, speed, systems status.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Command, Leadership and Resource Management, the ability to plan ahead; what performance to expect.

E. How do you view future automation in the cockpit?
It's coming (even complete automation) so we must adjust.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Initially to unburden - not so sure.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Aircraft performance, ability to "take over", emergency performance.

AVIATION INTERVIEW NO. 2

Age 43; June 4 DC10 First Officer from 727 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Like any plane.

2. Physical strength
Only with loss of hydraulics.

3. Finesse
Some are better (easier) 737/727.

4. Understanding of systems
Flight Guidance System require more understnding than most systems.

5. Vigilance and attention required
No difference.

6. Physical workload (phase of flight)
No difference.

7. Mental workload (phase of flight)

8. Training requirements, duration and methods
Same as other program. Methods more computer based
Liked the Computer Based Training.

9. Communication among the crew
Two man increases communication.

10. Ease of learning a new airplane
Narrow bodies are all about the same.

11. Reliability of systems
Good.

12. Skill retention problems
No problem.

13. Command/Leadership/Resource Management skills
We get recurrent training on this.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills

A little more sophisticated.

2. Physical strength

Only with loss of hydraulics.

3. Finesse

Bigger is easier.

4. Understanding of systems

Flight Guidance System requires more understanding.

5. Vigilance and attention required

No difference.

6. Physical workload (phase of flight)

No difference - less on climb/cruise/descent.

7. Mental workload (phase of flight)

Not more - just different.

8. Training requirements, duration and methods

Training same, methods more Computer Based. I liked the Computer Based Training.

9. Communication among the crew

No difference.

10. Ease of learning a new airplane

Douglas Aircraft is different than Boeing.

11. Reliability of systems

No difference.

12. Skill retention problems

First Officer on DC10 has trouble going to Captian.

13. Command/Leadership/Resource Management skills

Ditto.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Easier than I thought or heard about.

E. What has been gained by automation?
Makes job "nicer".

F. What has been lost?
Some "hands-on".

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Diversion, emergency.

B. What specific data does a pilot "need to know" to fly the aircraft?
What's working, position.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Aircraft situation (status).

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Teach what to expect.

E. How do you view future automation in the cockpit?
I suppose it's coming - some concern.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Intent to unburden - doesn't always work.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Should always be able to "take over" emergency capabilities.

AVIATION INTERVIEW NO. 3

AGE 58; DC10 Captain from DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Need to be good.

2. Physical strength
Have to be able to handle hydraulics.

3. Finesse
Don't try.

4. Understanding of systems
I like to know.

5. Vigilance and attention required
High at times.

6. Physical workload (phase of flight)
Not much in jets.

7. Mental workload (phase of flight)
High at times (takeoff, landing).

8. Training requirements, duration and methods
Shorter than old days. Slide/tapes good.

9. Communication among the crew
Better than past.

10. Ease of learning a new airplane
Not hard.

11. Reliability of systems
Good.

12. Skill retention problems
No problem.

13. Command/Leadership/Resource Management skills
They teach it to us - not sure we need it.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
No difference.

2. Physical strength
No difference.

3. Finesse
No difference.

4. Understanding of systems
More complex - need to know well.

5. Vigilance and attention required
No difference.

6. Physical workload (phase of flight)
No difference.

7. Mental workload (phase of flight)
Lighter once you understand the system.

8. Training requirements, duration and methods
No difference.

9. Communication among the crew
Needs to be good.

10. Ease of learning a new airplane
No problem with good attitude.

11. Reliability of systems
Good.

12. Skill retention problems
No problem.

13. Command/Leadership/Resource Management skills
Same as before.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No, only my own.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Not really.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected much lighter workload - not really lighter.

E. What has been gained by automation?
Changes - no real gains.

F. What has been lost?
Nothing.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Aircraft operations.

B. What specific data does a pilot "need to know" to fly the aircraft?
Speed, attitude, position.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Same.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More systems training, part task training.

E. How do you view future automation in the cockpit?
They'll always need a pilot.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Unburden.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
What's it doing now?

AVIATION INTERVIEW NO. 4

Age 55; DC10 Captain from DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
About like any plane.

2. Physical strength
Only in an emergency.

3. Finesse
Not in an 8.

4. Understanding of systems
Better know them.

5. Vigilance and attention required
Fairly high.

6. Physical workload (phase of flight)
Only landing in strong wind.

7. Mental workload (phase of flight)
Critical phases.

8. Training requirements, duration and methods
Same for all.

9. Communication among the crew
Good.

10. Ease of learning a new airplane
Not hard; easier than 20 years ago.

11. Reliability of systems
Good.

12. Skill retention problems
None.

13. Command/Leadership/Resource Management skills
Good.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
No difference.

2. Physical strength
No difference.

3. Finesse
No difference.

4. Understanding of systems
Same.

5. Vigilance and attention required
Same.

6. Physical workload (phase of flight)
Same.

7. Mental workload (phase of flight)
Higher on climb/cruise.

8. Training requirements, duration and methods
Computers harder to learn than plane.

9. Communication among the crew
Good.

10. Ease of learning a new airplane
Not bad.

11. Reliability of systems
Good.

12. Skill retention problems
Hard to learn to turn a knob to fly.

13. Command/Leadership/Resource Management skills
None.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Yes. Kicked off Automatic Pilot by mistake.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes.

D. What did you expect and what has been reality with respect to automation in the cockpit?
About what I expected.

E. What has been gained by automation?
I don't really know.

F. What has been lost?
Hands-on flying.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Planning, flying.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude, air speed, capability.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Speed, attitude, position altitude.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More systems training.

E. How do you view future automation in the cockpit?
I'm glad I'll be gone.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Displace.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Same as "C" above.

AVIATION INTERVIEW NO. 5

Age 44; 747 First Officer from DC8

I. Explain purpose and goals of contract

II. Issues related to automation

NOTE: Re: IIA and IIB, it seems difficult to deal with the comparison except on a scale of some kind. I'll use 1 - 10, "one" being a relatively low requirement or demand and "ten" being relatively high. Where possible, I'll add whatever comment seems appropriate.

A. Job requirements

Of or related to motor actions directly proceeding from mental activity.

1. Psychomotor

-8

2. Physical strength

-7

3. Finesse

-8 - For example, on an instrument approach.

4. Understanding of systems

-9 - Due to tradition (primarily) and real need to know in order to compensate for failures.

5. Vigilance and attention required

-8 - Vigilance and attention focused on the equipment itself as opposed to the operating environment.

6. Physical workload (phase of flight)

-3 - "Un-power-assisted" airplanes were smaller. Slower (due in part to human strength limits).

7. Mental workload (phase of flight)

-3 - Systems, procedures, traffic and time were relatively less demanding prior to "wide body" era.

8. Training requirements, duration and methods

-8 - Due to apparent need to "understand" system and engineering information, methods more oriented to equipment than to environment.

9. Communication among the crew

-4 - Relatively un-demanding.

10. Ease of learning a new airplane
-4 - Relatively easy because type of learning was fimiliar.

11. Reliability of systems
-3

12. Skill retention problems
Relatively few problems due to ease of transfer to skills from one airplane to another.

13. Command/Leadership/Resource Management skills
-2 - These "skills" were focused primarily on a militaristic concept of command, due in part to the fact that most airplanes could be operated by one person alone.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
-8 - Probably as high as with narrow-bodies, but different type of motor actions required.

2. Physical strength
-4 - Less of a requirement than narrow-bodies, due to sophistication of powered controls throughout, i.e., flight controls, seats, etc.

3. Finesse
-4 - Due to increasingly higher sophistication and interpretation of position-revealing instruments and capability for coupled, integrated, automatic flight control.

4. Understanding of systems
-3 - Though pilots and some trainers traditionally feel they should "understand" systems, it isn't (and can't be due to inherent complexity) necessary.

5. Vigilance and attention required
-8 - Just as high but different, in that focus needs to be on the environment (Air Traffic Control, traffic, etc).

6. Physical workload (phase of flight)
-3 - "power-assist" development accompanied increases in size, speed and structural limits.

7. Mental workload (phase of flight)
-9 - Due to its relative newness.

8. Training requirements, duration and methods
-8

9. Communication among the crew
-8 - Increasingly more demanding due to complexity of systems, procedures and environment, plus time compression. Also, due to more humanistically aligned societal influences.

10. Ease of learning a new airplane
-9 - Initially, then decreasing as the pilot learned to accept automation feasibility and success.

11. Reliability of systems
-3

12. Skill retention problems
See Item 10, above.

13. Command/Leadership/Resource Management skills
-9 - See item 9, above. Plus increased emphasis on automation-derived management role.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No.

B. Have you ever experienced a sudden failure of the automatics?
Yes.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes, because they are smarter at an earlier age and because automation in all forms is a much larger part of their world.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Expected true, out of sight automatic system. Reality is semi-automatic in that a human is still involved in a cursory control and monitoring posture.

E. What has been gained by automation?
Progression toward operation in an ever more confining environment, including weather, traffic, etc.

F. What has been lost?
The "White Scarf and Goggles", hero-association aura that has surrounded piloting from its initial stages, and which has been doggedly perpetuated (with decreasing success) by the pilot community.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
To monitor automatic operation.

B. What specific data does a pilot "need to know" to fly the aircraft?
Operating knowledge of limitations of the equipment, the environment and the human influences involved. Plus knowledge of appropriate procedures.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Any data that reveals "where the airplane is" in respect to where it is supposed to be as controlled by the automation i.e., anomaly revealing data.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Increased emphasis on and recognition of the need for interpersonal behavioral skills.

E. How do you view future automation in the cockpit?
With real frustration because I see the inevitable full automation being delayed and inhibited by self-oriented, politically powerful pilot groups.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Ostensibly to unburden him, ultimately to replace him because automatic operation has the potential to become totally complete, error-free and not subject to human frailty.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Whatever information will accurately reveal potential compromises to safety.

AVIATION INTERVIEW NO. 6

Age 39; 767 First Officer from DC10 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Normal coordination - no unusual skills necessary.

2. Physical strength

No unusual strength needed.

3. Finesse

For smooth flight while the aircraft is hand flown - finesse is important.

4. Understanding of systems

Don't need to be able to build one - however, do need understanding of function, emergency procedures, and interrelationships between systems.

5. Vigilance and attention required

A relatively high level to adequately monitor the flight.

6. Physical workload (phase of flight)

Could become high in unusual situations; normally fairly low.

7. Mental workload (phase of flight)

To keep all systems and the progress of the flight adequately monitored - could become a problem.

8. Training requirements, duration and methods

Enough ground to understand systems, flight in simulator and in aircraft - regular recurrent training.

9. Communication among the crew

Depends on situation.

10. Ease of learning a new airplane

Easy if the <u>instructor</u> knows the airplane and knows how to teach - difficult if it's a guessing game.

11. Reliability of systems

Very high.

12. Skill retention problems
Same as No. 10.

13. Command/Leadership/Resource Management skills
Don't really know.

B. Job requirements following introduction of automated airplanes
1,2,3 same as "I"

1. Psychomotor skills

2. Physical strength

3. Finesse

4. Understanding of systems
Could be greater if the systems are more complex.

5. Vigilance and attention required
More to get the most benefit from the more complex automation.

6. Physical workload (phase of flight)
About the same.

7. Mental workload (phase of flight)
Same as No. 5.

8. Training requirements, duration and methods
8-12 same as "I"

9. Communication among the crew

10. Ease of learning a new airplane

11. Reliability of systems

12. Skill retention problems

13. Command/Leadership/Resource Management skills
Captain is becoming more of an office manager.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Yes.

B. Have you ever experienced a sudden failure of the automatics?
Yes.

C. Do you think that younger pilots catch on to automation faster than older ones?

Not necessarily - it is an attitude problem, not an age problem.

D. What did you expect and what has been reality with respect to automation in the cockpit?

Didn't really have expectations - reality was that automation was OK (my words - asked him later).

E. What has been gained by automation?

Accuracy, efficiency, comfort and safety.

F. What has been lost?

Romance.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Takeoff, landing, navigation, emergencies.

B. What specific data does a pilot "need to know" to fly the aircraft?

The head flight attendant's room number on layovers. Seriously - basic stuff - attitude, air speed, position, altitude.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

Location, configuration, condition of systems and fuel, flight plan.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

Increased time spent on the capabilities of the automatic system.

E. How do you view future automation in the cockpit?

Favorably for air carriers for the reasons mentioned in III E.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

In the past - unburden; in the future - displace.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

Same as B.

AVIATION INTERVIEW NO. 7

Age 58; 747 Captain from DC10 Captain

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
A semi-difficult process of mental calculations for navigation, interpretation of instruments and manual flying requirements.

2. Physical strength
Average strength required.

3. Finesse
Need to be clever and plan ahead for navigational problems and anticipate possible equipment problems.

4. Understanding of systems
Thorough knowledge necessary to understand the results of actions taken in operating the airplane.

5. Vigilance and attention required
For traffic separation a high requirement, for equipment reliability casual monitor.

6. Physical workload (phase of flight)
Physically light work and not demanding.

7. Mental workload (phase of flight)
Heavy - in responsibility, traffic separation, and manual flight.

8. Training requirements, duration and methods
Recurrent training in aircraft each six months with one check by FAA each year.

9. Communication among the crew
Poor, Captain is Captain concept.

10. Ease of learning a new airplane
Individual commitment necessary, instructor-student time heavy.

11. Reliability of systems
Excellent.

12. Skill retention problems
Not a problem.

13. Command/Leadership/Resource Management skills
Taught but not a commom practice in the cockpit.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Semi-moderate process of instrument interpretation, navigation simplified and automatic flying.

2. Physical strength
Average strength required.

3. Finesse
Established automated procedures have reduced the finesse necessary for flying.

4. Understanding of systems
Good understanding of all airplane systems necessary.

5. Vigilance and attention required
Air traffic awareness need more, equipment attention casual.

6. Physical workload (phase of flight)
Minimum.

7. Mental workload (phase of flight)
Higher because of social changes and responsibilities of numbers of people and size of equipment.

8. Training requirements, duration and methods
Recurrent each year, for three days, with hands-on phase of flight..

9. Communication among the crew
Better because of emphasis in training.

10. Ease of learning a new airplane
Better with Computer Based Training. Still requires individual commitment.

11. Reliability of systems
Excellent.

12. Skill retention problems
Not a problem.

13. Command/Leadership/Resource Management skills
Greater emphasis in training, results unknown.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

More amused than surprised.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I was expecting CRT's for landing visibility, instead CRT's have replaced instrumentation.

E. What has been gained by automation?

Safety, economy, productivity and efficiency.

F. What has been lost?

Nothing.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Navigation, equipment operation, Instrument Flight Rules flying, and ground operation.

B. What specific data does a pilot "need to know" to fly the aircraft?

Electrical, pneumatics, hydraulics and navigational information.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

How to disengage the system and fly the airplane.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

Better simulation and more hands-on training.

E. How do you view future automation in the cockpit?

Looking forward to new concepts that will make flying better and safer.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

To unburden him.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

He should know everything about the airplane's performance in the areas of electrical, avionics, weights and balances, speeds, engineer operation limits, fuel limits, safety and emergency equipment location and use.

AVIATION INTERVIEW NO. 8

Age 58; 747 Captain (Chief Pilot) from DC10 Captain

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

About same for all airplanes, but big ones require more anticipation of response.

2. Physical strength

Not much unless actual hydraulic failure.

3. Finesse

Little things come with experience but we don't teach this.

4. Understanding of systems

I think a thorough knowledge of all systems is necessary.

5. Vigilance and attention required

You can relax somewhat at cruise otherwise be on your toes.

6. Physical workload (phase of flight)

Not much.

7. Mental workload (phase of flight)

Naturally higher during "busy" times, takeoff and landing.

8. Training requirements, duration and methods

Requirements have eased up a bit from the 40's and 50's. Duration is shorter. Methods have really modernized.

9. Communication among the crew

I really emphasize this.

10. Ease of learning a new airplane

No problems.

11. Reliability of systems

Jet age brought much higher reliability.

12. Skill retention problems

None except for us management types.

13. Command/Leadership/Resource Management skills
I really emphasize this.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Big ones require more.

2. Physical strength
Same on all of them. 747 is heavy.

3. Finesse
The bigger the easier to finesse.

4. Understanding of systems
Always need to know.

5. Vigilance and attention required
Same as narrow bodies.

6. Physical workload (phase of flight)
Same as narrow bodies.

7. Mental workload (phase of flight)
747 takes a bit more planning.

8. Training requirements, duration and methods
Planes more complex, courses are shorter.

9. Communication among the crew
Needs to be good.

10. Ease of learning a new airplane
Some of us take longer - no problem really.

11. Reliability of systems
Excellent.

12. Skill retention problems
Sometimes the systems can spoil you when you have to "hand-fly" an approach.

13. Command/Leadership/Resource Management skills
Very much needed - that's why we teach it.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Only losing an Automatic Pilot.

B. Have you ever experienced a sudden failure of the automatics?
Automatic Pilot.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. Computer generation is arriving.

D. What did you expect and what has been reality with respect to automation in the cockpit?
It has come along about as I expected.

E. What has been gained by automation?
Ease of operation.

F. What has been lost?
Some hand flying.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Virtually all phases.

B. What specific data does a pilot "need to know" to fly the aircraft?
Get by with attitude, air speed, air traffic. Something for instrument approaches, if in instrument conditions.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Current status of systems.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More understanding of new instruments. More resource management.

E. How do you view future automation in the cockpit?
I like what I see so far.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Unburden for now.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
B and C above.

AVIATION INTERVIEW NO. 9

Age 41; 747 Second Officer from DC8 Second Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Always need good psychomotor skills.

2. Physical strength
Not much needed.

3. Finesse
Wouldn't know - haven't flown in 16 years except for Simulator.

4. Understanding of systems
Need thorough.

5. Vigilance and attention required
I think it's high for all of us.

6. Physical workload (phase of flight)
I'm busy (very) - especially during take out/takeoff.

7. Mental workload (phase of flight)
Same as 6.

8. Training requirements, duration and methods
Shorter for all aircraft.

9. Communication among the crew
Needs to be smoother.

10. Ease of learning a new airplane
No problem.

11. Reliability of systems
Good.

12. Skill retention problems
I would lose all if not for Simulator practice.

13. Command/Leadership/Resource Management skills
I like this idea. Important for Second Officer.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Same.

2. Physical strength
Same.

3. Finesse
Same.

4. Understanding of systems
Same.

5. Vigilance and attention required
Same - a little more critical on 8 and 47 (more engines).

6. Physical workload (phase of flight)
Same - more engines to start on 8 and 47.

7. Mental workload (phase of flight)
Same.

8. Training requirements, duration and methods
747 is a great ground school.

9. Communication among the crew
Good.

10. Ease of learning a new airplane
747 was easiest. This is our best overall program. Taught completely in Captain (hands on).

11. Reliability of systems
Excellent.

12. Skill retention problems
Piloting skills designed for Second Officer.

13. Command/Leadership/Resource Management skills
Same.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Younger is relative - but yes.

D. What did you expect and what has been reality with respect to automation in the cockpit?
The 747 isn't as automated as the DC10 but the systems do about what I expected.

E. What has been gained by automation?
Smoother flights.

F. What has been lost?
Piloting skills.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Virtually all phases of flight.

B. What specific data does a pilot "need to know" to fly the aircraft?
The basics; position, systems information.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What's going on with all systems.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More knowledge on how "Black Boxes" work, what to expect from Computer Based Training.

E. How do you view future automation in the cockpit?
I hope it doesn't replace me before I get a front seat.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
It's going to displace somebody, i.e., crew reduction.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
All information should be immediately available.

AVIATION INTERVIEW NO. 10

Age 55; DC10 Captain from DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Basic Air Transport Pilot skills. My words (straight and level turns (climb and descent) steep turns + or - 100ft. stabilized approach emergency procedures, etc.)

2. Physical strength
Average.

3. Finesse
Commensurate with basic Air Transport Pilot.

4. Understanding of systems
Good.

5. Vigilance and attention required
Good.

6. Physical workload (phase of flight)
Minimal for most; higher in early and late.

7. Mental workload (phase of flight)
Very high in early and late phases.

8. Training requirements, duration and methods
Ground Training, Simulator, aircraft.

9. Communication among the crew
Variable (depending on situation).

10. Ease of learning a new airplane
Fairly easy.

11. Reliability of systems
Good.

12. Skill retention problems
Big problem of engineers, no problem for Captain and First Officer in terms of piloting skills.

13. Command/Leadership/Resource Management skills
Variable depending on situation.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Basic Air Transport Pilot skills.

2. Physical strength
Same.

3. Finesse
Same.

4. Understanding of systems
Need greater understanding of highly automated systems which control flight pattern.

5. Vigilance and attention required
Same.

6. Physical workload (phase of flight)
Same.

7. Mental workload (phase of flight)
Greater in early and late phases.

8. Training requirements, duration and methods
Need more time on flight guidance type systems.

9. Communication among the crew
Same (more in two-crew member airplanes).

10. Ease of learning a new airplane
More difficulty with flight guidance type systems.

11. Reliability of systems
Good-resets required on many electrically operated systems.

12. Skill retention problems
Many crews have difficulty retaining basic pilot skills.

13. Command/Leadership/Resource Management skills
Same.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Yes, unusual Automatic Pilot or air traffic reactions.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Expectations same as reality.

E. What has been gained by automation?
Operating efficiency in complex machinery.

F. What has been lost?
Pilot skills, and for some less attention to detail (and this is very unforunate and potentially dangerous).

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Virtually everything.

B. What specific data does a pilot "need to know" to fly the aircraft?
How to get it safely from "A" to "B".

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
All necessary for manual flight (air speed, altitude, attitude).

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More emphasis on how, when, and when not to use automated flight control and emphasis on Attention to Detail.

E. How do you view future automation in the cockpit?
More of it (with the goal of full (not piloted) automated flight).

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Displace him or in extreme cases extend his capabilities.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Enough to "stay ahead" of the automated system.

AVIATION INTERVIEW NO. 11

Age 55; DC10 Captain from DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
High skills needed.

2. Physical strength
Before jets it could get rough. Not so bad now - practically nil.

3. Finesse
Not much.

4. Understanding of systems
"I feel more comfortable when I know how it works."

5. Vigilance and attention required
High on takeoff/landing - around airports.

6. Physical workload (phase of flight)
Takeoff/landing.

7. Mental workload (phase of flight)
Takeoff, profile descent, final approach.

8. Training requirements, duration and methods
Used to be every nut, bolt and wire - 60 days, half that now.

9. Communication among the crew
To do a good job on any airplane - good communication.

10. Ease of learning a new airplane
Not hard these days. "I'm a little slower."

11. Reliability of systems
Good.

12. Skill retention problems
None.

13. Command/Leadership/Resource Management skills
The company teaches.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Still high.

2. Physical strength
Very rarely.

3. Finesse
The big ones can be finessed - actually any plane can.

4. Understanding of systems
I still like to know.

5. Vigilance and attention required
Well, you ought to be attentive at all times but you tend to get lulled when things are going smoothly.

6. Physical workload (phase of flight)
Same as always.

7. Mental workload (phase of flight)
It's not as much of a problem.

8. Training requirements, duration and methods
Methods are more modern, computer based. Course length is about same.

9. Communication among the crew
I think the big ones require a little more crew coordination.

10. Ease of learning a new airplane
By the time you get to the wide bodies you have 25-30 years experience with transports.

11. Reliability of systems
Minimum equipment list items usually reliable. Occasional problem with radar or avionics.

12. Skill retention problems
I don't think so.

13. Command/Leadership/Resource Management skills
Well, I don't think I need this but I know a lot of guys who do. Command Leadership Resource skills are necessary.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No.

B. Have you ever experienced a sudden failure of the automatics?

Just Automatic Pilot/time.

C. Do you think that younger pilots catch on to automation faster than older ones?

Probably - just more used to it.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I heard bad things from other pilots about difficulty learning DC10. Not true in reality.

E. What has been gained by automation?

It makes my job easier.

F. What has been lost?

Nothing that I can see.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Preflight, takeoff, climb, cruise, landing, and emergency procedures.

B. What specific data does a pilot "need to know" to fly the aircraft?

Status of systems so that decisions can be made at any time. Airspeed, altitude.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

Correct airspeed, attitude, position/altitude if close to ground.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

Part task trainers, more about computers, measures of proficiency along the way.

E. How do you view future automation in the cockpit?

It may not take my job away (it won't) - but things get boring.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

Intent has been to unburden, perhaps unnecessarily, (underload) my word --

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

What is my aircraft doing?

AVIATION INTERVIEW NO. 12

Age 42; Initial Captain 727 from DC10 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

I'd forgotten how much it takes when you're responsible.

2. Physical strength

Very little.

3. Finesse

This comes with experience.

4. Understanding of systems

Not as much as 5.0.

5. Vigilance and attention required

I feel much more need for this as Captain.

6. Physical workload (phase of flight)

High during takeoff/landing.

7. Mental workload (phase of flight)

High in high density areas.

8. Training requirements, duration and methods

Same for all narrow bodies. Captain has more requirements.

9. Communication among the crew

Captain needs to promote this.

10. Ease of learning a new airplane

It's the change of seats that's hard, not the plane.

11. Reliability of systems

Good.

12. Skill retention problems

As First Officer, I flew a lot - no problem.

13. Command/Leadership/Resource Management skills

Captain needs to insure.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
Do what you're told on DC10.

2. Physical strength
Only for hydraulic loss.

3. Finesse
You can really finesse the DC10. 737 is very responsive.

4. Understanding of systems
Still needs to be good. Douglas found out the hard way. (referring to American's DC10 crash at Chicago)

5. Vigilance and attention required
Very high for Captain on any plane.

6. Physical workload (phase of flight)
High during critical phases.

7. Mental workload (phase of flight)
Ditto.

8. Training requirements, duration and methods
All altitude same length, requirements change with change of seats. Methods more modern with wide body aircraft.

9. Communication among the crew
Should be good for all aircraft.

10. Ease of learning a new airplane
The 737 is much quicker to respond but no problem to learn.

11. Reliability of systems
Improved with wide bodies.

12. Skill retention problems
Hasn't affected me.

13. Command/Leadership/Resource Management skills
The company teaches all pilots.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Not really.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes, we don't resist as much.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I heard the DC10 was a bear. Training program on Flight Guidance System (learned on old training program) was not good. Plane was easier than I thought.

E. What has been gained by automation?

Much less manual flying - Good for the passengers!

F. What has been lost?

Nothing. All you have to do is not use the automation if you want to manually fly.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Everything - Never take out of loop.

B. What specific data does a pilot "need to know" to fly the aircraft?

Systems, navigation, performance.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

What the aircraft status is at time of takeover.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

More computer assisted instructions with actual hardware.

E. How do you view future automation in the cockpit?

I think it will help. It's coming anyway. Reduces some chance of pilot error.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

Unburden. But you must remain alert.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

All of it must be available when needed.

AVIATION INTERVIEW NO. 13

Age 41; Initial Captain 727 from DC10 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Fair amount required.

2. Physical strength
Some physical strength.

3. Finesse
Some amount of finesse required.

4. Understanding of systems
Essential.

5. Vigilance and attention required
Constant vigilance and attention mandatory.

6. Physical workload (phase of flight)
Sometimes you need three hands but not overly demanding.

7. Mental workload (phase of flight)
Mental workload fairly heavy during most flight phases.

8. Training requirements, duration and methods
More training for a longer period of time using archaic method.

9. Communication among the crew
Always important.

10. Ease of learning a new airplane
Harder to transition especially to a different manufacturer's airplane.

11. Reliability of systems
Good reliability.

12. Skill retention problems
Maintenance of skills very important.

13. Command/Leadership/Resource Management skills
Very important.

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills
About the same amount as required with narrow bodies.

2. Physical strength
Some still required on occasion but less than with narrow bodies.

3. Finesse
The absolute requirement for an amount of finesse has been reduced.

4. Understanding of systems
Less system understanding required for normal operation, but as much or more required to handle unusual occurrences.

5. Vigilance and attention required
More vigilance and attention required to monitor automated systems.

6. Physical workload (phase of flight)
Reduced generally.

7. Mental workload (phase of flight)
Increased demand to monitor automatic systems.

8. Training requirements, duration and methods
Training less often, usually for shorter periods of time using sophisticated, effective techniques.

9. Communication among the crew
Possibly more important as the automated systems tend to lull a crew into complacency.

10. Ease of learning a new airplane
Easier due to automation relieving some of the burden.

11. Reliability of systems
Mechanically more reliable, however due to the sheer volume of electronics involved the impression of less reliability because simply there are just more things to go wrong.

12. Skill retention problems
Probably more important as some skills are used less often.

13. Command/Leadership/Resource Management skills
Still very important.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

Yes. Sometimes you forget that they can't think and their normal responses are not always appropriate.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes. Younger pilots are more accustomed to automation in their everyday lives.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I expected automation to provide additional tools for my use. I do not expect a panacea that will solve all problems. I am getting what I expected.

E. What has been gained by automation?

Increased safety, more precision, more information available.

F. What has been lost?

Some of the "magic" of piloting.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

To monitor the function and performance of the airplane to insure safety and correct, efficient operation.

B. What specific data does a pilot "need to know" to fly the aircraft?

Status of all systems, flight data (i.e. airspeed, attitude, navigation, information, etc.), presence of any threatening conditions.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

Status of those systems and magnitude of deviations from normal operations.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

More effective methods are needed. The information about automated systems is becoming more complex. Also more emphasis on the management of resources is needed. Also more vigilance/monitoring trainings needed to avoid complacency.

E. How do you view future automation in the cockpit?

The wave of the future. As traffic increases cost of operations climb, automation becomes more essential.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

Definitely to unburden the Pilot

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

Information that would be required to totally fly the airplane manually plus information on the status of all automated systems.

AVIATION INTERVIEW NO. 14

Age 51; 767 Fleet Manager; from 747 Captain and 737 (Fleet Manager); Everything in fleet: 737, 727, DC8, DC10, 747, helicopters and light military planes.

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

4. Understanding of systems
Systems - I don't really want to know what's going on inside (last nut and bolt). I want to know what's going to happen operationally. I like phase of flight approach (vs system).

6. Physical workload (phase of flight)
Maybe I'm different, I find automation as less workload. Maybe more mental challenge. Less physical. Use of automatic is easier for me.

8. Training requirements, duration and methods
Need only cover what's operational, not more systems.

9. Communication among the crew
Communication more critical because you can push a bunch of buttons and your partner doesn't know unless you tell him.

10. Ease of learning a new airplane
I've always liked learning. No harder on automated planes. Attitude is important.

11. Reliability of systems
No more or less reliable - very reliable.

12. Skill retention problems
It's a concern. It's obviously degraded. Every 5th leg we manually fly using Flight Director. You don't have to go to raw data to be proficient.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

Oh sure. After review I realized the system did what I asked it. Altitude Capture before I planned it. Started Capture 2,000 feet early but I was climbing at 4,000 feet per minute. Capture based on rate of climb.

B. Have you ever experienced a sudden failure of the automatics?

No I have not that I can recall.

C. Do you think that younger pilots catch on to automation faster than older ones?

Not so much age on 767. The difference is that captains haven't had computer exposure. Different era.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I guess from a logistics point of view we were expecting the whole system at once and we've had to wait and then adjust when things like the LNAV (Longitudinal Navigation) and VNAV (Vertical Navigation) became operational.

E. What has been gained by automation?

After pilot gets familiar with aircraft, a reduced workload.

F. What has been lost?

I don't think anything other than manual flying. That might be ego bending, but it does a better job than you. A different role.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Weather radar, temperature, rainy conditions, weight, aircraft performance.

B. What specific data does a pilot "need to know" to fly the aircraft?

Take over: attitude, power setting.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

You've got to get to Computer Based Training. Self-paced. Otherwise it's too cumbersome because of nature of information. Basic understanding of computers. May not have to in next 10 years.

E. How do you view future automation in the cockpit? More of it. You won't have to do anything. We're at a great point now. The future will get into winds - now poorly forecast. Data link.

AVIATION INTERVIEW NO. 15

Age 51; DC10 Captain/Lead Instructor; from DC8; 737, 727, DC8, C13s

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements
1-3. Once I got used to the plane the workload went down. Physical anyway. You have to stop and think more about what you're doing with the DC10 than the 8.

1. Psychomotor

2. Physical strength

3. Finesse

4. Understanding of systems
As an instructor I had to know all about all systems. It hasn't hurt. I like that stuff.

5. Vigilance and attention required
This doesn't change with planes.

6. Physical workload (phase of flight)
Low workload on all of our fleet both mental and physical.

7. Mental workload (phase of flight)

8. Training requirements, duration and methods
Training on the DC10 was easy compared to the DC8. Of course I'd just been promoted so my motivation was pretty high. Old Flight Guidance System training on PLATO was very poor. New stuff is more operational - much better.

9. Communication among the crew
Communication hasn't changed for me from the DC8 to the DC10.

10. Ease of learning a new airplane
See 8.

11. Reliability of systems
It was easy to learn the DC10. Going from the 727 to the DC8 was harder because some of the characteristics are backwards (e.g., flare).

12. Skill retention problems

I don't have any skill retention problems on the DC10. I hear the 767 guys have some.

13. Command/Leadership/Resource Management Skills

Command, Leadership and Resource Management is useless. You can't teach that - you either have it or not.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No.

B. Have you ever experienced a sudden failure of the automatics?

No. I've had planes where everything didn't work though.

C. Do you think that younger pilots catch on to automation faster than older ones?

Sure they do. Co-pilots on the DC10 always (almost) are faster than the Captains.

D. What did you expect and what has been reality with respect to automation in the cockpit?

Automation has been expected to help the pilot and save the company money. Toward that end it has helped.

E. What has been gained by automation?

Some time saving, fuel saving definitely.

F. What has been lost?

Some hands-on flying.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Flight planning, irregular and emergency procedures, takeoff and landing, navigation.

B. What specific data does a pilot "need to know" to fly the aircraft?

Aircraft systems status, attitude, air speed.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

What's the plane doing, what are the automatics doing to it?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More information on automation in ground school and more hands-on in the Simulator.

E. How do you view future automation in the cockpit?
No doubt there will be more.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Unburden him probably.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
What's the plane's capability at this moment?

AVIATION INTERVIEW NO. 16

DC10 Captain; from 727 Captain and 737; whole fleet, F86, C119, C45

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to automated airplanes
1-3 Doesn't require physical force. Psychomotor more DC10 and 767.

1. Psychomotor

2. Physical strength

3. Finesse

4. Understanding of systems
I don't think aircraft systems are any more complicated on modern planes. Automatic Pilot and Flight Guidance System more complex and require more understanding.

5. Vigilance and attention required
In some respects it takes more with automatics to make sure they're doing what they're supposed to do. Below 10,000 feet that's bad if you're "inside" the plane instead of out.

6. Physical workload (phase of flight)
Not much physical.

7. Mental workload (phase of flight)
Mental could be harder for some. Part may be understanding, basic intelligence or motivation.

8. Training requirements, duration and methods
As long as we have something that is as divergent among people (learning styles) I think self-paced is better in ground school for more automated planes. Simulation is best.

9. Communication among the crew
Most communication on an operational flight is navigation. Two man communication most of time anyway. On DC10 and 767 it's different in respect to awareness of what's going on.

10. Ease of learning a new airplane
No difference. What's new is interesting so it's easy.

11. Reliability of systems

A lot goes into that. Maintenance program is key. All planes better maintained. Generally the simpler the more reliable.

12. Skill retention problems

No problems on more automated planes.

13. Command/Leadership/Resource Management Skills

Command, Leadership and Resource Management easier in two-man than three-man. A lot depends on individual. Automation doesn't have much to do with it.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

Some surprises. Probably both what I did and what system did.

B. Have you ever experienced a sudden failure of the automatics?

Well yeah. Pitch mode on DC10 renders both Automatic Pilots and Flight Directors inoperative.

C. Do you think that younger pilots catch on to automation faster than older ones?

They probably do. Maybe because of environment they grew up in.

D. What did you expect and what has been reality with respect to automation in the cockpit?

Nobody knew what to expect. I liked that I saw.

E. What has been gained by automation?

I've asked that question quite a few times. Distance saved in navigation and fuel on 767. Easier on crew. More reliable Instrument Landing System - Category II and Category III landings are now possible.

F. What has been lost?

Ease of training is about the only thing. Automated things require more knowledge in order to detect faults. Simplicity.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Weather radar, navigation, fuel, system data (operative vs inoperative)

B. What specific data does a pilot "need to know" to fly the aircraft?
Depends on where you're going to fly it.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What's going on - what's the aircraft doing?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Rate when ready. People who aren't as familiar with planes learn phase of flight better.

E. How do you view future automation in the cockpit?
More and more automatic. 767 and 737-300 are great. Pilot becomes Navigator and Communicator. Systems more automated and Air Traffic Control.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Unburden him.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Specifically - that you can operate within limits.

AVIATION INTERVIEW NO. 17

Age 39; 767 First Officer From 727 First Officer, DC3, 737, 727, 767

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Automation always spoils me. I used it to make my job easier and so these first 3 items I find easier on the 767.

2. Physical strength

3. Finesse

4. Understanding of systems

This is what makes 1-3 possible. If you really understand the system you don't have to work hard.

5. Vigilance and attention required

I used to be a Flight Instructor so you know I have the habit of remaining vigilant and alert.

6. Physical workload (phase of flight)

This relates to what I said before - if you learn the modern systems it is much easier to fly them than say on the 727.

7. Mental workload (phase of flight)

8. Training requirements, duration and methods

The training for this type of aircraft (767) is very different than say the 727. I like computers so the computerized training suits me fine. The Captain I went through with fought the change from slides every inch of the way and he had a tough time learning.

9. Communication among the crew

Communication is more important - Two man airplane.

10. Ease of learning a new airplane

Automated planes do it for you I think - very easy - easier than other aircraft.

11. Reliability of systems
Systems on planes I've flown have always been reliable. Don't seem any different on 767.

12. Skill retention problems
They teach us to fly manually every so often to keep the skills up.

13. Command/Leadership/Resource Management Skills
Command, Leadership and Resource Management can certainly be used by some people. Important to all.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No. Just operating the buttons. Occasionally we do something and the computer does it differently than we would have manually. Roll rate, etc. (climb)

B. Have you ever experienced a sudden failure of the automatics?
Not yet. I try not to rely totally on them.

C. Do you think that younger pilots catch on to automation faster than older ones?
Definitely. Nothing to do with smarts - just more experience with computers.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected the 767 to do a lot and it does that plus some things they don't even teach you.

E. What has been gained by automation?
Automation frees the pilot to "manage" the flight. He can be more aware of what rest of crew is doing.

F. What has been lost?
A lot of work, some of the "magic" I suppose.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Need data to plan flight, takeoff, enroute or step climb, land.

B. What specific data does a pilot "need to know" to fly the aircraft?
Aircraft performance, limits, systems status, fuel, navigation.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Some information on attitude, airspeed, navigation, fuel status if you want to get where you're going.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
I think we will gradually have pilots who are used to the computers so CRT's will be more common. This is good because planes are becoming computerized.

E. How do you view future automation in the cockpit?
More of it. Perhaps better quality, i.e., information organized and presented better.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
For me it's been to unburden. Some guys just can't see that though.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
What will it do if I punch button "x"? Systems status, etc.

AVIATION INTERVIEW NO. 18

Age 39; 767 First Officer from DC8 First Officer; Various Commuter Aircraft, 737, 727, DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

I think psychomotor skills are increased on 767 because of two-man cockpit.

2. Physical strength

Physical strength has been minor in my experience.

3. Finesse

You can really finesse a flight plan with the 767 because of all the information that's in the computer - e.g., winds, fuel managment, arrival information.

4. Understanding of systems

Current 767 program doesn't teach enough systems and I would like to know more about what's going on (i.e., how things are done).

5. Vigilance and attention required

Because of lack of system knowledge on 767 I feel the need to be very vigilant. Also one-man cockpit so more to do for me.

6. Physical workload (phase of flight)

Not much.

7. Mental workload (phase of flight)

Learning how to make the computer work for you in various situations can require a lot of thought.

8. Training requirements, duration and methods

Training on 767 was radically different - basically good. Instructors were always available - better than the 727 or DC8 programs. Still needs some improvement.

9. Communication among the crew

On two-man cockpit communication is essential. So no difference between 737 or 767.

10. Ease of learning a new airplane
767 was no harder than others - just different. I liked it better because of self-paced instruction.

11. Reliability of systems
Would you believe I've never experienced a failure of anything other than a radio and an Inertial Navigation System?

12. Skill retention problems
We switch legs all the time so skill retention not a problem. You don't have to let the automatics fly the plane you know.

13. Command/Leadership/Resource Management Skills
Command, Leadership and Resource Management has been good. Some pilots really need reminding of this. Good on 767.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
I was surprised one time when we forgot our speed brakes were out (deployed) on 767. There is no indicator.

B. Have you ever experienced a sudden failure of the automatics?
Like I said - never.

C. Do you think that younger pilots catch on to automation faster than older ones?
More used to computers - I think so. Younger is relative though - youngest pilots around right now are all over 30.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I bid the 767 because I was fascinated by the computerization and new physical design. It has been fun and more than I expected.

E. What has been gained by automation?
Lots more information available to the pilots. Decisions are easier and a lot is done for you.

F. What has been lost?
Some of the computational drudge work.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Planning for all phases of flight and information on systems during irregular or emergency operations.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude and air speed will keep you flying.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Again - attitude, air speed, system status, power setting for particular altitude.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
We need to know more about automation. What really goes on.

E. How do you view future automation in the cockpit?
Cockpits will get more automated - that's why I'm getting familiar now. New air traffic control system will probably require some data link.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
To unburden him. If you learn the plane thoroughly you won't be burdened - the automatics will do what they were designed to do - unload us.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Same as "taking over".

AVIATION INTERVIEW NO. 19

747 Captain from DC10 Captain; B24 DC3,4,6,7, CV-340, B727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Old airplanes (Air Force) could be a constant battle.

2. Physical strength

Physically and mentally.

3. Finesse

The 727, I think, is such a responsive airplane that you can do anything with it. Of course, the big ones (DC10 and 747) do a lot for you.

4. Understanding of systems

An old buzzard like me likes to know everything that's going on. When I was on the DC10 I drove the instructors crazy with questions about the black box (Flight Guidance System).

5. Vigilance and attention required

All airplanes require constant vigilance and attention. Oh you can set the Automatic Pilot and goof-off but if something goes wrong you're up the creek.

6. Physical workload (phase of flight)

DC3 in a cross wind landing could be a handful. Not much physical work anymore.

7. Mental workload (phase of flight)

During initial phases of flight on all aircraft the mental work can be heavy.

8. Training requirements, duration and methods

Training is shorter, a little easier (maybe experience helps). Methods have changed for some planes I hear but I haven't been affected. Slide-tape and lecture is all I've seen.

9. Communication among the crew
This is always important - more so I think on the wide-bodies because of longer flights (more planning, management).

10. Ease of learning a new airplane
I took a little longer on the wide-body because I have to think about things longer than I used to - or so it seems. Actually I completed training with everyone else.

11. Reliability of systems
I've lost hydraulics, avionics and electrical from time to time - never all of anything - not often. New planes, I hear, are more reliable. DC10 and 747 are not new.

12. Skill retention problems
I've never had a problem with skills. But I've never been furloughed and I never was a Second Officer.

13. Command/Leadership/Resource Management skills
I went through that last year and thought it was a bit late for the company to be teaching me that. I suppose it's important though.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Only by the abruptness sometimes. And conversely sometimes the DC10 seemed sluggish.

B. Have you ever experienced a sudden failure of the automatics?
No. I guess that speaks to their reliability - huh?

C. Do you think that younger pilots catch on to automation faster than older ones?
Probably. Some of my co-pilots in training seem to grasp things quicker than me. But my experience helps.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected the DC10 to be difficult but I had a good instructor and he taught me to fly the plane manually then showed how the Flight Guidance System could help and I was impressed. 747 isn't as modern.

E. What has been gained by automation?
More precision, more information if you want it, probably safety.

F. What has been lost?
Not as much glamour.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Need data to make sure every phase of flight is going as it should including planning.

B. What specific data does a pilot "need to know" to fly the aircraft?
Status of systems, airspeed, attitude, weather radar conditions, navigation.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What is condition of plane relative to what it's supposed to be?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Training might be made more adaptable (flexible) to different learning styles but that really doesn't affect safety. Maybe more hands-on on the automated equipment would help conceptually. More time to experiment in training.

E. How do you view future automation in the cockpit?
If the direction goes to total automation I view it as dangerous. You can't replace pilots. It could however help a pilot fly and make decisions.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
I think to help the pilot.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Everything to fly the plane without automated aid.

AVIATION INTERVIEW NO. 20

Age 45; Initial Captain from DC10 First Officer;
Beech 99, Twin Otter, C141 (concurrently in Air Force Reserves), First Officer, 737, 727, DC10; 737 Captain

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Psychomotor skills are not any higher on automated planes, just different.

2. Physical strength

Very little physical strength needed on any plane under normal circumstances.

3. Finesse

On automated planes if you use the Flight Guidance System you can be very smooth and precise for <u>everything</u>.

4. Understanding of systems

On 727 we have 3 versions so you need to understand the systems. Actually the Second Officer is affected the most but I was surprised at how much the Captain needs to know. All aircraft require good systems knowledge.

5. Vigilance and attention required

I feel as Captain that I need to be alert all the time. Didn't always feel that way as First Officer. With regards to the plane - it doesn't matter - with more automated planes like DC10 you still need to know what the "black box" is doing in case of failure.

6. Physical workload (phase of flight)

Physical and mental workload changes more with seats than with planes. The better you know the aircraft the better able you are to "stay ahead" of it - thus reducing your workload all around.

7. Mental workload (phase of flight)

8. Training requirements, duration and methods
Training for Captain was a lot more taxing than transition from one plane to another. This was especially true for me coming from the DC10 because the automatics (Flight Guidance System) tend to let your actual flying skills deteriorate.

9. Communication among the crew
I've been on flights where practically nothing was said but I don't think that's right. We're taught in Command Leadership and Resource Management to take advantage of all knowledge and skills and that's good.

10. Ease of learning a new airplane
New plane isn't hard - never has been for me.

11. Reliability of systems
Since I've been flying systems have been very reliable, most problems come with avionics but we have so much redundancy there it isn't a problem.

12. Skill retention problems
I feel a little uncomfortable at this time moving from DC10 First Officer but the skills are still there. I don't believe the skills have deteriorated - just my confidence.

13. Command/Leadership/Resource Management skills
Like I said before it's important. Not sure you can teach it but I'm glad the company is trying.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
On DC10 I engaged autopilot and got a turn I wasn't expecting, but it was my fault, not the system.

B. Have you ever experienced a sudden failure of the automatics?
No, and that's the beauty of the DC10 - it has (I think) 6 computers cross-referencing.

C. Do you think that younger pilots catch on to automation faster than older ones?
I don't have a reference point. We don't have any "young" pilots here. Maybe recall will help that. The younger guys I've talked to like the computers better, especially in training.

D. What did you expect and what has been reality with respect to automation in the cockpit?
When I moved to the DC10 I "expected" it to be hard to learn based on what I was told. It wasn't hard and the Flight Guidance System was a pleasant surprise in terms of what it can do for you.

E. What has been gained by automation?
Automation has increased precision, saved some money and reduced workload on <u>some</u> planes. I hear the 767 keeps you pretty busy.

F. What has been lost?
Manual skills unless you force yourself to fly manually.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Every aspect of a flight.

B. What specific data does a pilot "need to know" to fly the aircraft?
Procedures, what's happening <u>now</u>, limits.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What are the automatics doing - i.e., what's going on in the black box and enough attitude information to keep the flat side down.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
I think what the training center is doing is pretty good. The programs get better all the time. 727 is not computerized training but it works - a bit boring. Maybe more hands on training.

E. How do you view future automation in the cockpit?
I haven't had experience with the really new stuff but I hear it's like a video game. I guess we'll have to adjust.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
I think the <u>intent</u> has been to unburden. I <u>hear</u> it isn't always that way (767).

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Everything. Especially as Captain. If everything fails you have to know how to get it down.

AVIATION INTERVIEW NO. 21

Age 57; 767 Captain from 727 Captain; Caravelle, B17, B29, B47, B52 SAC Wing Command

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

The first 13 items are easy to answer - some of the old military "heavies" could be a handful. The 737 and 727 are easy to handle. Never flew the DC8 - heard it could be difficult strength-wise - the 767 is a pleasure. No physical strength, very automated and modern. Lots of the systems stuff that used to be taught is not now - don't like that. Vigilance is same as always - like the self-paced training. With two-man crew communication is a must.

1. Psychomotor
2. Physical strength
3. Finesse
4. Understanding of systems
5. Vigilance and attention required
6. Physical workload (phase of flight)
7. Mental workload (phase of flight)
8. Training requirements, duration and methods
9. Communication among the crew
10. Ease of learning a new airplane
11. Reliability of systems
12. Skill retention problems
13. Command/Leadership/Resource Management skills

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

Yes, armed the Autopilot when speed knob set and the throttles came up.

B. Have you ever experienced a sudden failure of the automatics?

Never had a failure yet.

C. Do you think that younger pilots catch on to automation faster than older ones?

Only because the younger guys grew up with more automation so they <u>tend</u> to be more used to it. Totally new concepts for me - thus I'm slower.

D. What did you expect and what has been reality with respect to automation in the cockpit?

Hard to answer. I've been involved with the 767 from the planning stages so I knew what to expect.

E. What has been gained by automation?

We've gained economically because the computer can calculate faster than us.

F. What has been lost?

On 767 you have to be careful not to get so involved with the CRT's that you don't look outside.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Since we're responsible for the safety of the flight - I think we need data for everything, e.g., planning, takeoff, landing, etc.

B. What specific data does a pilot "need to know" to fly the aircraft?

What's status of aircraft, what's working or not - why, where we are - can we get where we're going.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

Pretty much the same as your previous question. Current status, where we are, what's going on.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

For those of us who don't understand computers maybe some extra knowledge on systems - concepts.

E. How do you view future automation in the cockpit?
Automation is coming - I think we have to be careful - engineers may exclude the pilot - we may have it backwards - pilots should fly.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Unburden him, but you tend to get interested in these new devices and end up "working" them a lot. Thus, maybe they create more workload - or pilots do it to themselves.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
He needs to be able to take over without the slightest compromise to safety.

AVIATION INTERVIEW NO. 22

Age 59; DC10 Captain, from DC8; DC3, DC4, C82, C119, C45, C46, B29, P51, C124, C133, Viscount

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

2. Physical strength
DC10 vs. DC8 is a test of skill vs. strength. DC8 can require a lot of strength.

3. Finesse

4. Understanding of systems
Nobody understands systems as well as they should with regard to state-of-the-art airplanes. We remove models and replace with no understanding of what's being done. Example: L1011 in Florida, DC8 at Portland, DC8 Freighter at Salt Lake City. If they knew more about systems - vigilance and attention would be greater.

5. Vigilance and attention required
767 pilots tend to not look outside because their vigilance and attention are taken up by the systems..

6. Physical workload (phase of flight)
Physical demands are never very high.

7. Mental workload (phase of flight)
Mental workload is a function of how you approach it.

8. Training requirements, duration and methods
State-of-the-art planes are found harder to learn because of what the pilots have heard before they come to training. Not enough hands-on training before the plane. We need better Captains for modern aircraft.

9. Communication among the crew
Most crews have good communication - it's very important.

10. Ease of learning a new airplane
Even as electronics change the concepts stay the same. CRT's and pushbuttons definitely require more hands-on.

11. Reliability of systems

Systems (electronics) going to solid state has improved reliability.

12. Skill retention problems

There is a skill retention problem (DC10 First Officer to 727 Captain). The ability to scan instruments deteriorates. More the aircraft does the more skill retention is a problem.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

Not really 'cause things don't surprise me anymore. Autopilot did a hard-over turn intercepting the localizer. B or C phase breaker has come open (no warning light) - affects fuel pump, pressurization, Flight Guidance System.

B. Have you ever experienced a sudden failure of the automatics?

Not really. Even the Viscount was reliable and a very good early Flight Guidance System.

C. Do you think that younger pilots catch on to automation faster than older ones?

Younger/older doesn't have much to do with it. Attitude does. The older ones who look forward with interest have more to fall back on. Younger pilots - it may be the only plane they know.

D. What did you expect and what has been reality with respect to automation in the cockpit?

E.G. Automated Communication and Reporting System - "My God that looks complicated" but it is easy. What's frustrating is why the new system doesn't do what it's supposed to. I'm always an optimist - I expect things to work. You need to learn a lot about the system in order to know what to expect.

E. What has been gained by automation?

Reduced workloads (obviously) in a lot of cases. However complacency can creep in if things work too well too long.

F. What has been lost?

Well, it's not as much fun as it used to be. Automation should free you to look out the window. Instead (on 767) it keeps your head down.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Where he is and where he's going - how to get there.

B. What specific data does a pilot "need to know" to fly the aircraft?
Route, Air Traffic Control, other traffic, weather radar, system, fuel management, radio, welfare of passengers (strapped in when necessary).

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
No different than taking over from another pilot. Situation awareness. Know "where you're at", "where you're going", air speed, what's working - if not, why not. What can you do about "it" (failure) from the cockpit - you can do a lot if you understand systems (electrical systems especially - because automated systems are all affected by electrical).

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Good instructor and one crew. We need someone who can impart information and make judgment as to what's retained. Teach understanding, not just rote movements. Better quality instructors.

E. How do you view future automation in the cockpit?
I think the data link is going to be a big deal - more and faster information and more comprehensive (traffic, collision, avoidance, Microwave Landing System).

F. Has the major thrust of automation been to unburden the pilot or to displace him?
That's the intent but it actually burdens him in the learning process and creates skill retention for basic skills.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Performance information, basic skills to totally manually fly.

AVIATION INTERVIEW NO. 23

Age 58; DC10 Captain from DC8 Captain; B17, B29, C47, 727 First Officer, DC8 First Officer, DC10 First Officer, DC8 Captain, DC10 Captain, P51

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

1-3 Depends on plane of course but DC10 is a pussycat compared to the DC8 especially re: cross wind landing. 8 can be a beast.

2. Physical strength

3. Finesse

4. Understanding of systems

Like most pilots my age I like a lot of systems knowledge. Can't get enough - even now. Trend toward phase of flight training scatters the systems knowledge.

5. Vigilance and attention required

Used correctly, the DC10 Flight Guidance System, e.g., can unburden the crew for other tasks like traffic.

6. Physical workload (phase of flight)

Truth is these things aren't hard to fly.

7. Mental workload (phase of flight)

Depends on your systems knowledge. If you know what is going on within the systems you don't have as big a task.

8. Training requirements, duration and methods

Requirements haven't changed. Courses are shorter - mainly because we don't go into as much detail. Methods have taken advantage of technology - blackboard to slides to computer, e.g.

9. Communication among the crew

You better have it - most crews do.

10. Ease of learning a new airplane

At my stage (of career) it takes longer but a plane's a plane. Systems more modern but basics are same.

11. Reliability of systems
New planes/systems more reliable. In old days we expected a problem on every flight.

12. Skill retention problems
Just ask a DC10 First Officer moving to Captain. The modern systems leave them with little chance to retain manual skills.

13. Command/Leadership/Resource Management skills
You don't teach these. You can give a one-week course and the guy will treat his wife and family better for a while but he'll still run a flight deck the same way.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No. But I've always concentrated on understanding systems not just knowing how to operate them.

B. Have you ever experienced a sudden failure of the automatics?
I've had things fail, e.g., Inertial Navigation System, attitude gyro, but nothing that wasn't redundant.

C. Do you think that younger pilots catch on to automation faster than older ones?
Like anything else in life, if your attitude is right and you approach it with interest you'll do alright regardless of age. Younger guys may be quicker.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Expectations? I've just taken whatever came along. Reality has been that automatics have mostly done what engineers expected - not always reduced the pilot's load (our "expectations").

E. What has been gained by automation?
DC10 can greatly reduce your workload. You have to have discipline to not totally rely on it (them).

F. What has been lost?
Nothing lost. Things have changed.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Route planning, takeoff, enroute altitude, profile descent, traffic, landing.

B. What specific data does a pilot "need to know" to fly the aircraft?
Weight, limitations, weather radar, fuel, system status.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What is status of the plane; where are we? What is everyone else doing?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
None. Instead I think we need to teach them to fly manually - then with automatics. More systems training.

E. How do you view future automation in the cockpit?
More automation but we have to keep the pilot in charge. Engineers don't understand that.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Overtly to unburden him. In reality to replace him.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
I think he can never stop learning. More system information - all performance information he can get.

<u>Job Satisfaction</u>
Well, I liked it when it was a challenge. Too easy now.

<u>Role</u>
If you think your role is reduced you better get out.

AVIATION INTERVIEW NO. 24

Age 40; DC10 Second Officer from 727 Second Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

I find the psychomotor skills higher on the DC10. Not harder necessarily, just more things to keep track of.

2. Physical strength

As Second Officer, I don't fly so I can't really say. My experience in the simulator has been that the planes aren't much different due to power boosted controls.

3. Finesse

Nothing can beat the 727 in terms of response. You can finesse it better than any plane.

4. Understanding of systems

My experience has been that we get plenty of systems knowledge. No more required on DC10 than 727.

5. Vigilance and attention required

Vigilance and attention higher on DC10. You have to think about what the systems are doing. Also traffic.

6. Physical workload (phase of flight)

Workload is no different for me physically.

7. Mental workload (phase of flight)

Mentally it seems higher on the 10.

8. Training requirements, duration and methods

DC10 training was easy. Good school. 727 wasn't any harder but the Ground School was lousy.

9. Communication among the crew

I've always thought it was important on any plane. The DC10 pilots tend to say very little to the engineer so maybe the <u>need</u> to communicate isn't as high on the automated planes.

10. Ease of learning a new airplane

No difference except that the school was better quality.

11. Reliability of systems

Little things are always going wrong but most major systems are very reliable on all planes.

12. Skill retention problems

The only way I can retain skills is in the simulator. The DC10 pilots don't complain about skill problems and it certainly isn't a problem for the 727 pilots.

13. Command/Leadership/Resource Management skills

No different than any plane. Always important - not always practiced.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No. But I've seen the guys up front do some things (turns, etc.) that surprised them.

B. Have you ever experienced a sudden failure of the automatics?

No.

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes. But I think it's a function of learning styles and flexibility.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I expected my job to be easier. In reality it looks like the engineer's job may disappear.

E. What has been gained by automation?

On some planes elimination of the Second Officer. Maybe some workload savings.

F. What has been lost?

A seat, e.g., 767.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Takeoff, climbing, independent computations, enroute weather radar for planning.

B. What specific data does a pilot "need to know" to fly the aircraft?

Attitude, fuel, where am I?

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What's our present condition of flight?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Better <u>quality</u> training.

E. How do you view future automation in the cockpit?
It will (like in the factories) replace a lot of people. I suppose it will get more automated.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
No doubt - to displace him and unburden whoever is left.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
What is it capable of doing based on what do I need to do?

AVIATION INTERVIEW NO. 25

Age 45; Initial Captain from DC10 First Officer; DC6 DC8, 10, 727

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Psychomotor skills are increasing as planes become automated. Even though the plane does a lot for you, you still have to program and monitor and at critical times take over. That requires a lot of psychomotor skills.

2. Physical strength

Not tied to automation and never has been a problem.

3. Finesse

Probably is decreasing. Procedures and automation have left us with a bus driver approach to flying instead of a chauffeur approach.

4. Understanding of systems

With automated systems you don't need to know what's going on inside the black box but you do need to know what effect it will have. This has stayed about the same.

5. Vigilance and attention required

It hasn't changed. It's still higher at takeoff and landing no matter what the aircraft.

6. Physical workload (phase of flight)

7. Mental workload (phase of flight)

Same for physical and mental workload.

8. Training requirements, duration and methods

The duration has changed by half. I like the training, the computers and the ability to work at my own pace. I don't think automation in the cockpit had anything to do with changes in training. More cost effective probably.

9. Communication among the crew

This has been raised as the key to human error in aircraft accidents. You can't just talk, you have to make sure you're heard.

10. Ease of learning a new airplane
It's all easy. The more modern planes make it even easier. I love it.

11. Reliability of systems
Modern technology has really improved reliability in everything from engines to radios.

12. Skill retention problems
I've not experienced much loss of skill - I do need to gain some confidence in myself now that I'm in charge. The DC10 does erode your flying skills if you only use the Flight Guidance System. We turn it off on every 3rd leg.

13. Command/Leadership/Resource Management skills
Like communication this can't be overemphasized, especially when all you're doing is monitoring (such as at cruise).

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
I've thought the Instrument Landing System failed but discovered the switch was wrong. That's what I mean about communication - somebody should have checked and spoken up.

B. Have you ever experienced a sudden failure of the automatics?
I've seen the Automatic Pilot fail on a coupled approach but that's backed up.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. There's nothing worse than sitting in a classroom for hours while the instructor painstakingly reviews information you learned the first 5 minutes. That's why I like the self-paced instruction.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I've really only seen the DC10 and the Onboard Navigation System-equipped 727's and DC8's. That's not much automation but it is nice to have. Everything has met my expectations.

E. What has been gained by automation?
A reduction in the number of instruments you have to set to get something done. The Flight Guidance System panel integrates a lot of functions.

F. What has been lost?
Nothing that I can see.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
You need the Automated Flight Planning and Monitoring (AFPAM) System for flight planning and navigation, weather radar, weight, thrust, takeoff and landing data.

B. What specific data does a pilot "need to know" to fly the aircraft?
Fuel available, navigation, attitude, altitude.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Attitude and systems information.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
No changes needed. But a lot of guys refuse to accept the training they're getting, e.g., they'll read their manual instead of using the Computer Based Training system.

E. How do you view future automation in the cockpit?
In the cockpit it's a little different than the assembly line. The pilot has to stay involved in an active sense. If we do that it will be great.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Largely to unburden. Some companies though have used this to get rid of the Second Officer on certain planes.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
He has to know everything if he is going to be responsible.

AVIATION INTERVIEW NO. 26

Age 56; 747 Captain from DC10; 727, 747; DC3,4,8,10

I. Explain purpose and goals of contract

II. Issues Related to Automation

A. Job requirements

1. Psychomotor

More with less automated aircraft. You had to do everything stick and rudder man. Different than today's pilots.

2. Physical strength

Never been a problem. DC8 is most different with manual revisions. Boost helps newer planes. Even DC3 had aerodynamic boost.

3. Finesse

Some land easier than others. It's a function of the landing gear. Wide-body easier to land, has nothing to do with automatics

4. Understanding of systems

More automated the less you need to know about system. To a point. Not much we can do. Automated have backups. Some knowledge always necessary.

5. Vigilance and attention required

It's always been important to know what's going on outside. More Instrument Flight Rules flying makes knowing what's going on inside increasingly important.

6. Physical workload (phase of flight)

Physical workload not an issue.

7. Mental workload (phase of flight)

Automatic Pilot takes a lot of physical and mental stress off the pilot. We've taken the workload from the physical to the mental. More mental now. Test getting away from the gate is stressful. Not related to automation.

8. Training requirements, duration and methods
New generation with CRT's required new methods. Old guys with good manual dexterity and little education have trouble. Even in the Viscount they had trouble with Flight Director; training can change now because better education and military experience

9. Communication among the crew
Communication is critical. More automated planes are dangerous in the sense that you can get complacent. In 727 days problems handled by the pilot because he was driving. On DC10 you don't have physical control and it can kill you.

10. Ease of learning a new airplane
Easier to learn new airplanes just because of experience.

11. Reliability of systems
More reliable with jet age and with automation.

12. Skill retention problems
Some effect with automation. 737 pilot is more skilled than 747 pilot because he makes more landings/takeoffs. More buttons - the less skills. We should hand fly also.

13. Command/Leadership/Resource Management skills
Very important with automation. Got to let crew know your action and expectations. You need crew help to monitor.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Minor surprise. I wandered off altitude because the altitude select switch wasn't on - my fault.

B. Have you ever experienced a sudden failure of the automatics?
Flight Direction failed on an Instrument Landing System approach. No big deal.

C. Do you think that younger pilots catch on to automation faster than older ones?
No doubt they do. They're better educated, know more about computers.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Automation has come very slowly for me. Each generation of aircraft has brought better devices.

E. What has been gained by automation?
Less physical workload.

F. What has been lost?
I think we've lost some control--that's dangerous. Also, mental workload has increased.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Flight plan, operatiions, flight, navigate, contingency planning, landing.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude control available, how to climb, descend, turn and land. Speed and thrust.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Where you are. We rely too much on automatic systems. Both pilots should always be aware of what is going on.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
As we get more CRT's, etc., training should probably parallel the automation in aircraft.

E. How do you view future automation in the cockpit?
Planes will become more and more automated.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
The intent has been to unburden him. Displacement has't really occurred as a function of automation. 737 is two-place and old, 767 is two-place and modern.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Everything that is happening. He has to remain in the loop for everything.

AVIATION INTERVIEW NO. 27

Age 57; 747 Captain from DC10; DC3,4,6,8,10; DC3,4 military versions

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

The 747 was the first Boeing aircraft I've flown. Everything else was Douglas. The wide-bodies are great - some perceptual difference because you're so high when flaring - also on approach it's a big plane lining up with a small (it seems) runway. So psychomotor skills are more important, physical strength not applicable. Finesse is just a matter of learning the aircraft.

2. Physical strength

3. Finesse

4. Understanding of systems

Once you learn a complex system they all are about the same. You need to know what's going on.

5. Vigilance and attention required

Attention or vigilance is no different with wide-body. If it's not one thing it's another. You have to be vigilant.

6. Physical workload (phase of flight)

The more sophisticated planes have features which reduce physical workload but no matter what help you have the mental workload always seems to be there. If something is navigating for you for example, you still are worrying about whether it's doing it right.

7. Mental workload (phase of flight)

8. Training requirements, duration and methods

They got it out of the hangar, nuts, bolts, and wires and into the classroom. That helped. Now they all seem about the same - I may be slower.

9. Communication among the crew

This has always been important regardless of the aircraft.

10. Ease of learning a new airplane
Like I said - I'm slower. The planes aren't hard to learn.

11. Reliability of systems
Lots more reliability in the things that count. Engines, electrical, radios. Not necessarily a function of wide-body - just better stuff.

12. Skill retention problems
I've never experienced any skill retention problems. If you use all equipment to the fullest you could lose some skill - but nothing says you can't hand fly it once in awhile.

13. Command/Leadership/Resource Management skills
I suppose it's good for the younger guys. I wouldn't have lived this long without seeking help from my crew.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Yes, but the cause was the "programmer" - me. Entered the wrong stuff in the Inertial Navigation System and at the way point the plane took a wierd turn.

B. Have you ever experienced a sudden failure of the automatics?
No. Not even an Automatic Pilot failure.

C. Do you think that younger pilots catch on to automation faster than older ones?
Undoubtedly. But they don't necessarily know how to fly without the fancy stuff. I may be slower but I have a lot of experience to draw on.

D. What did you expect and what has been reality with respect to automation in the cockpit?
Didn't really think about it. I've been really pleased with the ease of flying the wide-bodies - they just seem solid.

E. What has been gained by automation?
A lot of little calculations. You enter most stuff ahead of time and it helps.

F. What has been lost?
Nothing. Progress is progress - I've enjoyed all of it.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
You have to know the weather radar enroute and destination. You need to know what's deferred on the aircraft. Fuel, gross weight, Air Traffic Control operations.

B. What specific data does a pilot "need to know" to fly the aircraft?
All you really need to know is what's happening at any particular time. It's not hard to fly an aircraft if you know what's going on at any particular time.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Mostly just the basics - position, attitude, air speed, fuel. Fuel isn't necessary to take over - but you have to get where you're going.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Training has gotten better as the years have gone by. As planes become more automated I suspect that training will keep pace. It always has.

E. How do you view future automation in the cockpit?
They will become more automated - two pilot. We'll just have to adjust.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
To unburden. I've encountered no problems. Automation just creates more "toys" to play with.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Always has to be informed about everything that is going on. If automatics are flying the pilot has to be in the loop.

AVIATION INTERVIEW NO. 28

Age 58; 747 Captain from DC10; 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

With automated aircraft you end up thinking a lot more than doing. Psychomotor has gone up.

2. Physical strength

Physical strength is nil because of aircraft design.

3. Finesse

Finesse is a matter of knowing your aircraft. The DC8 "crashes" each landing because the spoilers deploy and force the aircraft down on the struts.

4. Understanding of systems

All pilots should be systems oriented. If a major system fails there is a backup but you should know what's going on and what your limitations are.

5. Vigilance and attention required

We should be a darn site more vigilant than we are. Outside especially. Inside we have bells and whistles.

6. Physical workload (phase of flight)

Never has been a problem but more automation certainly leaves you less to do.

7. Mental workload (phase of flight)

Mental workload has gone up with automation. It's self-imposed - if you want to know what the aircraft is doing (the black box) you have to look at the raw data and interpret just like the old days. Plus you have to monitor the automatics for failure.

8. Training requirements, duration and methods

Requirements haven't changed much - if anything training is shorter. Not related to automation - maybe in a few cases - 767 Flight Managament System, DC10 Flight Guidance System, Performance Management System.

9. Communication among the crew
We put a lot of emphasis on this for a reason - it's absolutely critical. There is so much to keep track of - everyone has to be communicating.

10. Ease of learning a new airplane
Experience counts. As you progress step by step you gain so much experience that new aircraft are easier. Some of the old mail pilots just couldn't catch on to the jet age but no one coming out of the 50's has any trouble. Not related to automated aircraft.

11. Reliability of systems
Systems have become more reliable. Some of our early aircraft you asked yourself what was going to go wrong, not _if_. Automated aircraft are probably more reliable because of simplified instruments - solid state.

12. Skill retention problems
Skill retention is becoming a problem principally because of automated systems. Flight Directors do most of the work. We encourage DC10 First Officers to fly raw data as much as possible just before they bid Captain.

13. Command/Leadership/Resource Management skills
As you know I'm a strong supporter of Command, Leadership and Resource Management. We can save lives with this training and by practicing what we preach.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

I got a stick shaker once - that was a surprise! Problem was because I had the speed control set wrong.

B. Have you ever experienced a sudden failure of the automatics?

I think everyone has equipment fail at one time or another. Automatic Pilot failed on coupled approach - that's not unusual.

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes they do. But they also have less to fall back on when the automated equipment fails.

D. What did you expect and what has been reality with respect to automation in the cockpit?

As with most of the old timers the automation has come so slowly it hasn't made much difficulty. The changes I've seen have been useful.

E. What has been gained by automation?
We've gained ground on physical workload.

F. What has been lost?
We've created more mental work. That's what's been lost. The raw data skills are deteriorating.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Preflight planning, actually flying, emergencies or irregularities.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude and air speed, position, performance, systems status, weather radar.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Aircraft control information, position information, traffic information, performance data, systems, environmental data.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Move to more Line Oriented Flight Training - real scenario - teach people the consequences of complacency.

E. How do you view future automation in the cockpit?
Aircraft are going to be more automated. We just have to be careful not to get away from the capability of flying the aircraft by hand.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Thrust has been to unburden. This has and hasn't worked as I said before.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Total knowledge of the aircraft's current status.

AVIATION INTERVIEW NO. 29

Age 59; 747 Captain from DC10; all Douglas Aircraft, Caravelle

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

Automation isn't related to wide-body/narrow-body. General aviation aircraft have systems as sophisticated as the airlines. I think though that automation relieves a lot of the mechanical type calculations we used to have to do but not really the workload. It relieves the workload in one sense but you still have to keep track of the automated systems. So I guess I'd have to say that the psychomotor skills are as high as ever, the physical strength is definitely less. Finesse just comes with experience period, regardless of the aircraft.

1. Psychomotor

2. Physical strength

3. Finesse

4. Understanding of systems

As aircraft become more automated they seem to teach us less about the systems. I think that's wrong. If something goes wrong you're supposed to know the systems - so I think you ought to be taught the stuff. None of this is related to automation. You simply have to know the systems.

5. Vigilance and attention required

As automation increases vigilance increases because you're monitoring instead of flying. If you're not paying attention you don't pick up the subtle failures.

6. Physical workload (phase of flight)

Automation has relieved physical workload no doubt. More important has been the power boosted controls.

7. Mental workload (phase of flight)

This goes with vigilance and attention. Takeoff and landing is highest. About the only real relaxation is at cruise.

8. Training requirements, duration and methods
The training requirements are about the same for all aircraft. Courses are shorter these days. Methods more modern. I like the 747 because it's taught in the cockpit where you can get instant hands on. But the duration of training is no longer than other aircraft.

9. Communication among the crew
It's important on all aircraft so that everyone knows what's going on.

10. Ease of learning a new airplane
Moving from Douglas to Boeing aircraft makes it a little harder but the automation really makes no difference. Just a different piece of hardware to operate.

11. Reliability of systems
With all the built-in redundancy, the planes are very reliable. I don't see any difference at present with automation. However I suppose the newer generation of aircraft will be even more reliable.

12. Skill retention problems
I've not had problems. I've heard that DC10 First Officers have trouble moving to Captain because they aren't used to flying. Automation of the DC10 probably contributes to that.

13. Command/Leadership/Resource Management skills
They spent a lot of money trying to teach this so I guess it's important. I always thought that by the time you reached Captain you had these skills. I think the more automated the plane the less Command/Leadership/Resource Management is necessary.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No. Things have quit working (Automatic Pilot, air traffic) but I wasn't really surprised.

B. Have you ever experienced a sudden failure of the automatics?
I've had Automatic Pilot failure and air traffic failures in both the DC10 and 747.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. They grew up with more of it. Some of these guys have never flown a propeller job.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I really haven't seen enough of it. It's been a slow evolution for me so my expectations really weren't much. The stuff I've seen is good and helpful.

E. What has been gained by automation?

It's eased our workload some.

F. What has been lost?

I don't think anything has been lost.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

Depends on what you want to do. If you just want to stay airborne - attitude, fuel and air speed. If you want to fly to a specific place you have to know where you are and how to get where you're going and whether the plane can get you there.

B. What specific data does a pilot "need to know" to fly the aircraft?

Attitude, altitude, where you are, status of systems.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

All you need is to know what those automatic systems are doing at the time you take over. This requires some means of interpreting them at all times.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

The training center seems to be making the changes. Command/Learning/Resource Management is a part of everything. Computer Based Training is seen more and more and I guess that's what it takes - more familiarization with computers.

E. How do you view future automation in the cockpit?

I'll retire in a year but I would guess that the 1990's cockpit will be mostly automated with the Captain playing a very different role. Manager, monitor.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

Both. In the process of unburdening him there are many facets of his job that have become possible to be performed by anyone.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

Everything that he can possibly know.

AVIATION INTERVIEW NO. 30

747 Captain from DC10; 727, DC8, DC10, 747

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

As planes have become more automated the psychomotor skills have gone up.

2. Physical strength

Physical strength needed has gone down.

3. Finesse

I think finesse has gone down. Finesse just isn't an issue anymore - we just fly the glide slope and drive 'em on.

4. Understanding of systems

They don't teach as much systems any more but that doesn't make them less important. Regardless of automation I think a pilot needs to be systems oriented.

5. Vigilance and attention required

As planes become more sophisticated in terms of automation the vigilance and attention should be freed up for outside cockpit work. But what's happened instead is we're either fascinated by the equipment or afraid of it failing so all our attention goes inside.

6. Physical workload (phase of flight)

Physical workload - there is more to do during landing and takeoff but it isn't hard to do - applies to any aircraft.

7. Mental workload (phase of flight)

Same for mental - maybe a bit more with automation 'cause you have to think so much about what you're doing instead of just doing it.

8. Training requirements, duration and methods

If DC10 Flight Guidance System training is an example of the future I'm glad I'm retiring. The training was harder than the aircraft.

9. Communication among the crew
Communication has always been a factor but more so lately. More planes, more things to look after on the aircraft, complicated Air Traffic Control.

10. Ease of learning a new airplane
I thought the DC10 was the hardest to learn. 747 was easy - just more of everything. Automation probably decreases the detailed knowledge but you still have to know what's occurring with your aircraft. No change.

11. Reliability of systems
The systems have become more reliable. We also have better maintenance and preventive procedures to avoid failure. Automation will probably help.

12. Skill retention problems
No problem whatsoever on any plane. Just hand fly it when you want to.

13. Command/Leadership/Resource Management skills
These are important. You can acquire them with experience but you can't teach this to someone. They have to want to learn and they have to observe well. Automation will probably increase the need due to complacency.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
I've flown through an altitude on the DC10 because I didn't arm (or tell the co-pilot to arm) the select switch. Air Traffic Control let us know.

B. Have you ever experienced a sudden failure of the automatics?
I've had Flight Director failures but never at a critical time.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. My co-pilots have always been younger and always seem to learn a bit faster.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I <u>didn't</u> expect automated systems to be hard to learn. Reality proved me wrong.

E. What has been gained by automation?
Fewer moving mechanical parts maybe. Computers do help.

F. What has been lost?
Nothing as long as you know you can always hand fly the airplane.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
You need data for every step of the flight. Pre-flight and contingencies are probably most important.

B. What specific data does a pilot "need to know" to fly the aircraft?
You need to know which side is up - so attitude. Also where you're going and how to get there.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What have the automated systems been doing? In other words what is the aircraft status?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
A careful look at objectives. Also a clear idea of what proficiency means.

E. How do you view future automation in the cockpit?
No matter how I view it we seem to be going that direction. It can help if carefully planned with pilot in the loop at all times.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
It looks like some displacement will occur even if it's only in control. Workload relief seems also to be a goal.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
You have to know at all times what performance the aircraft is capable of.

AVIATION INTERVIEW NO. 31

Age 47; 747 First Officer from DC10 First Officer; 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Psychomotor skills have gone up with automated systems because you still have to think what you want the aircraft to do, set that in, and then monitor to results.

2. Physical strength

DC8 is a handful without hydraulics, otherwise none of these planes demand much physical strength.

3. Finesse

I've never thought of finesse with regards to a big aircraft. But you can land the big ones consistently better than the smaller ones. Automation helps if you use it.

4. Understanding of systems

This is becoming increasingly important. In some never automated aircraft (like 767) you don't really see some gauges. You just get a warning. But you still need to know what the system is doing.

5. Vigilance and attention required

This too has become more important. Air Traffic Control is more automated, so are aircraft and the tendency is to lose your sharpness.

6. Physical workload (phase of flight)

It's higher at takeoff and landing. Automation reduces some of this but it gets transferred to the mental side..

7. Mental workload (phase of flight)

8. Training requirements, duration and methods

Training hasn't changed much in duration (a little shorter). The 767 has a more computerized training program. Requirements are the same (FAA).

9. Communication among the crew

Very important. More automated planes especially because unless you let the other guy know what you're doing - he can't always see it.

10. Ease of learning a new airplane

This comes with experience. New planes get easier after you've been through a few. Automation is only a problem if you get the attitude that it's going to be hard.

11. Reliability of systems

Reliability has been improved via redundancy. Things fail every day but redundant systems take over. Even total electrical failure is backed up with wind generator.

12. Skill retention problems

No problem yet. However I took this bid as 747 First Officer to avoid going directly from DC10 First Officer to Captain. I think automation presents skill retention problems to everyone.

13. Command/Leadership/Resource Management skills

Like communications it's very important especially on automated aircraft. You've got to draw on all skills and knowledge available.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No. Always very careful to think about what I'm setting so I don't get surprises.

B. Have you ever experienced a sudden failure of the automatics?

Sure. Automatic Pilot failure, Flight Director failure. But never a failure that couldn't be immediately interpreted and handled.

C. Do you think that younger pilots catch on to automation faster than older ones?

No. I think it's totally an attitudinal thing. If you don't get a mental block on advanced systems - anyone can learn them.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I've always expected better systems as aircraft evolved. That's pretty well been the case.

E. What has been gained by automation?
Automation has relieved some of the hand flying theoretically relieving the pilots for other tasks.

F. What has been lost?
Skill could potentially be lost.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
All functions that a pilot performs plus any functions you want a computer to perform.

B. What specific data does a pilot "need to know" to fly the aircraft?
Needs to know how to fly - i.e., what is the aircraft status, what needs to change, what has to be done to change it?

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Assuming you can disconnect the auto systems then you need the attitude indicator, and status of the rest of the system, and some way to navigate.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Probably the changes that have been made on the 767 transition course, e.g., computerized training familiarizes pilots with computers.

E. How do you view future automation in the cockpit?
The future is bright. I think the engineers are gradually beginning to realize that the pilot can do some things better than a computer.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Its intent has been to unburden him, presumably to reduce error from overload. This had led to the displacement of pilots on some aircraft, thus increasing the workload again.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
There isn't any data that the pilot shouldn't have or have immediate access to.

AVIATION INTERVIEW NO. 32

Age 43; Initial Captain (737) from DC10 First Officer; 737, 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Flying in general requires a lot of psychomotor skills. The 737 is a very simple aircraft especially in the two pilot configuration. No, I don't find different with more automated aircraft.

2. Physical strength

This job does not require a lot of physical strength. It does require a lot of physical coordination. DC10 was most automated aircraft I flew. Physically no difference.

3. Finesse

737 and 727 are very responsive and can really be flown where you want them. On the other hand the DC10 is slower to respond but can be very smooth to fly. I don't think the automation makes any difference in finesse.

4. Understanding of systems

Systems need to be understood whether they are automated or not. It isn't any harder, just more quantity on some aircraft.

5. Vigilance and attention required -

I'm a whole lot more vigilant now than I was as a First Officer but that has nothing to do with automation. No, I think regardless of the sophistication of the aircraft you have to remain vigilant. The automated systems may not require the constant attention but you have to remain alert for failure.

6. Physical workload (phase of flight)

This isn't an issue at least for me, On any aircraft.

7. Mental workload (phase of flight)

Mental workload varies during phase of flight (higher on takeoff and landing) but maybe a little less with the more automated aircraft.

8. Training requirements, duration and methods
Getting the Captain's seat takes a couple of extra simulator rides but the aircraft I've been trained on have all used similar methods and taken about the same time.

9. Communication among the crew
I'm now responsible for crew communication but my experience has been that communication is good among most crews regardless of the aircraft's automation.

10. Ease of learning a new airplane
I've always looked forward to each new airplane and none have been hard to learn. No difference between automated or not with regard to takeoff difficulty of learning.

11. Reliability of systems
Any solid state electronics are going to be more reliable than regular instruments! I suppose the more automated planes have less maintenance but I can't say that for sure.

12. Skill retention problems
Coming from the DC10 with my role as First Officer I've had to sharpen some skills but no problem retaining. A more automated plane simply does more work for you so skills have to be deliberately maintained.

13. Command/Leadership/Resource Management skills
I'm one who likes the idea of Command Leadership Resource Management being taught to everyone. Even if it doesn't "take" it raises a person's level of awareness. No difference on automated planes.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

No.

B. Have you ever experienced a sudden failure of the automatics?

Not yet but everything fails sometimes. Seriously, I've never had any serious problems with automated equipment.

C. Do you think that younger pilots catch on to automation faster than older ones?

I think younger pilots may be more interested in the gadgetry than the older guys - but not necessarily any quicker.

D. What did you expect and what has been reality with respect to automation in the cockpit?
On the DC10 I expected to have difficulty with the Flight Guidance System because that's what I heard. But it wasn't true. The automation provided by the DC10 Flight Guidance System is great.

E. What has been gained by automation?
It saves a lot of work.

F. What has been lost?
A lot of work.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Standard stuff - flight planning, takeoff and departure information, approach and landing information, gross weight and center of gravity and fuel planning.

B. What specific data does a pilot "need to know" to fly the aircraft?
Current status of all systems, fuel left, basic instruments needed for an approach.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Pretty much the same as your previous question. What's our current status?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
As planes become more automated the training technology will probably keep pace. This is most likely necessary because of familiarity with computers.

E. How do you view future automation in the cockpit?
I think it will aid the pilot - it has so far.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Definitely to unburden him. Not all of us agree that automation should eliminate the Second Officer but that's a whole additional argument.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Absolutely everything should be available to him when needed.

AVIATION INTERVIEW NO. 33

Age 57; 747 Captain from DC10; 737, 727, DC8, DC10, military transports

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

The first seven items are all related. As aircraft have evolved into more sophisticated machines it first required more knowledge and skill from the pilots. Strength is an issue (especially for women) in the DC8 but no other plane I've flown. Automation has not really increased or decreased skills required. You still have to know how to fly the raw data - in fact that's a good way to learn a new plane. Finesse comes with time in type as does a deeper knowledge of systems. Vigilance and attention has increased more external to the aircraft due to traffic density. Automation has helped physical workload during certain phases of flight.

1. Psychomotor

2. Physical strength

3. Finesse

4. Understanding of systems

5. Vigilance and attention required

6. Physical workload (phase of flight)

7. Mental workload (phase of flight)

(Takeoff and landing) Mental workload has always been high.

8. Training requirements, duration and methods

The nature of training has changed a lot over the years. Automation has brought more automated or self-paced instruction. I like working at my own pace.

9. Communication among the crew

You could fly the DC3 by yourself. All the co-pilot had to be told was gear up, gear down and shut up. Now you have to talk to everyone or you just can't fly safely.

10. Ease of learning a new airplane
New planes have been easy to learn - my experience I guess. New training techniques such as computers have been a big change. Not hard - just different.

11. Reliability of systems
Things are more reliable than they used to be but the Flight Directors and autopilots do fail.

12. Skill retention problems
When I went from DC10 co-pilot to Captain I realized that this was an issue. After getting used to all the toys on the DC10 you think you're "flying" but you aren't. I think skill retention is a major challenge on automated.

13. Command/Leadership/Resource Management skills
This ties in with communication. You have to use all the crewmembers to do a safe job.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No. That's where good communication comes in. If you turn something on or make a seating change - have someone verify it. Automated systems do what you tell them unless they fail.

B. Have you ever experienced a sudden failure of the automatics?
I had an autopilot "pitch over". It failed and just pointed us at the ground. Had to disconnect.

C. Do you think that younger pilots catch on to automation faster than older ones?
For many of the younger guys the aircraft have always had automated systems so they tend to learn faster. They're learning faster because they're younger too.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected a smooth operation with the more automated planes and that's pretty well been it.

E. What has been gained by automation?
It definitely eliminates a lot of hand flying. We also gained some mental workload - Is the thing doing what I asked it to do?

F. What has been lost?
Some of the necessary hand flying - necessary to keep the basic skills current.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Everything from pre-flight or preparation to parking at the gate.

B. What specific data does a pilot "need to know" to fly the aircraft?
Critical speeds, attitude, fuel remaining and position.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What do I need to do that the failed system isn't doing, i.e., what function do I have to manually perform?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Just keep the training programs current and stay up with the technology.

E. How do you view future automation in the cockpit?
As long as automation allows me to know what's going on the future of automation is good.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
It's been to unburden the pilots and probably in a couple of cases to replace the Second Officer (737-300, DC9-80, 767).

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Need to know everything it is capable of doing or not doing.

AVIATION INTERVIEW NO. 34

Age 51; 767 Captain from 727 Captain; Military Fighters 727, 737, 767

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements
(See section "B")

1. Psychomotor
2. Physical strength
3. Finesse
4. Understanding of systems
5. Vigilance and attention required
6. Physical workload (phase of flight)
7. Mental workload (phase of flight)
8. Training requirements, duration and methods
9. Communication among the crew
10. Ease of learning a new airplane
11. Reliability of systems
12. Skill retention problems
13. Command/Leadership/Resource Management skills

B. Job requirements following introduction of automated airplanes

1. Psychomotor skills

Seems to me the psychomotor haven't increased but they are quite different from say the 727. There seems to be more "head work" before you make a move. Especially if something is wrong.

2. Physical strength

Physical strength really isn't an issue now and I can't remember any problems on the 727.

3. Finesse
The 767 is so new I don't think we've figured out how to finesse anything other than navigation. But I think the newer planes can be finessed better than the old.

4. Understanding of systems
We don't get enough understanding of systems in training in the 767. Of course the 727 is the new-hire aircraft so everything is very basic. No, I think you need as much understanding on the new ones as the old.

5. Vigilance and attention required
There really isn't any difference between automated and non-automated. You can be a busy pilot if you choose to be, i.e., alert.

6. Physical workload (phase of flight)
The 767 has definitely reduced the physical workload via the computers.

7. Mental workload (phase of flight)
I don't see any difference. The computers do a lot for you but you still find yourself mentally checking what it's (the computer) doing.

8. Training requirements, duration and methods
The 767 training is computerized, like the aircraft. I found the training better than 727, shorter and self-paced. However, we need more systems information.

9. Communication among the crew
This to me is higher (more of it) on the 767. Partly because the First Officer is the only other guy to talk to and partly because two of us are responsible for everything.

10. Ease of learning a new airplane
The more automated plane was easiest to learn for me because of the training methods, not because of the automation.

11. Reliability of systems
The systems are very reliable on both the 767 and 727. No difference really.

12. Skill retention problems
I have only been on the 767 for a year but I don't foresee any skill retention problems.

13. Command/Leadership/Resource Management skills
I think as planes become more automated this will become even more important because everyone's skills will have to be utilized in an emergency.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
The automatic throttles are sluggish and tend to "hunt". That surprised me the first few times.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
My copilots and I seem to have the same understanding about the automatic systems. I'm 51, they're usually early 40's. I think it's more attitude than anything. Younger pilots have more computer knowledge but I have more systems knowledge and experience.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected a very modern airplane and it is. Like anything new the bugs have to be worked out and we have to learn all the little things about flying it.

E. What has been gained by automation?
I find navigation a lot easier. You can do some things (like go direct) that you simply cannot do with the 727.

F. What has been lost?
Oh I don't see anything that has been lost. We are simply entering an era where the pilot's role and job are different than they used to be. Just like other jobs - ship's captains, railroad engineers, etc.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Well you have to know where you are and where you're going. You also have to know if you can get there, i.e., systems status.

B. What specific data does a pilot "need to know" to fly the aircraft?
Attitude and airspeed will keep the plane flying but you also need to know what's working and what isn't; controls, systems, etc.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

Mostly, what's happening right now?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

More knowledge about automation. We need to realize that just because you automate a system doesn't mean you don't have to teach systems anymore.

E. How do you view future automation in the cockpit?

As long as the pilot remains in the loop the new aircraft would be easier to fly, i.e., less workload.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

The intent has been to unburden. If the pilot learns to use the automation and understand it, flying is easier.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

All performance. Under emergency conditions, i.e., engine out, glide, etc., - fuel.

AVIATION INTERVIEW NO. 35

Age 53; 767 Captain from 727 Captain; Military Transports, 767, 727, DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

If you are really on top of things psychomotor skills are high flying anything. In the 767 they aren't higher, they're different due to the CRT instead of standard instruments.

2. Physical strength

Physical strength only becomes an issue with loss of all hydraulics. No difference between automated/non-automated.

3. Finesse

The more you get to know an airplane the more finesse you can accomplish. Automation, especially in the navigation area, can really help if you know how to program the computer. I think the more automated aircraft will be easier to finesse.

4. Understanding of systems

Automated or not you need systems knowledge. Even if something goes wrong and is automatically backed up you should know what's taking place and what's left available to you.

5. Vigilance and attention required

With the more automated aircraft it is definitely harder to stay busy. You tend to get spoiled.

6. Physical workload (phase of flight)

I haven't found the physical workload to be much different between the automated and non-automated aircraft.

7. Mental workload (phase of flight)

The computers on automated aircraft relieve a lot of the mental workload during any phase of flight. However there seems to be more mental workload during the flight preparation - programming, etc. Ultimately I'd say the 767 has less mental workload overall.

8. Training requirements, duration and methods
The training program for the 767 was the best I've seen. The Ground School was self-paced, no pressure and the Simulator portion was like any other aircraft.

9. Communication among the crew
The communication among the crew is the same as for any aircraft.

10. Ease of learning a new airplane
Like I said, this plane was easy to learn. There are systems like the Flight Maintenance System that are different but no harder than other aircraft systems.

11. Reliability of systems
Systems these days are very reliable on all aircraft.

12. Skill retention problems
A lot of people seem to be concerned about skill retention, but I haven't found it a problem in any aircraft.

13. Command/Leadership/Resource Management skills
Aside from the fact that I'm not sure you can teach these skills, they are no different between automated and non-automated aircraft.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Not yet. But like any aircraft I expect the 767 will surprise me one of these days.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
No I don't. I think there are a few older pilots that have trouble learning new things but most of us have a lot of experience to draw on. If the instructor relates the new aircraft to our old one it's easy to catch on.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected an aircraft that would be amazing in its capabilities and performance and this one is (the 767).

E. What has been gained by automation?
Automation has eased a lot of the inflight mental workload. Navigation, fuel management, everything is a little easier.

F. What has been lost?
I can't say anything is lost. Maybe the generation of pilots who know nothing but automated aircraft will lose something but I still have all my skills and accumulated knowledge.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Route planning, fuel load, weight and balance, deferred items (non-functioning systems at departure), takeoff and landing. Need data for emergency procedures.

B. What specific data does a pilot "need to know" to fly the aircraft?
Where you are, what is functioning on the aircraft, attitude, air speed.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
All you need to know is what the automatics "knew" before you took over.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
I wouldn't change much from the current 767. Perhaps a bit more explanation of what to expect from this modern type of training before we actually get into it.

E. How do you view future automation in the cockpit?
All I can see in the future is more automation. I think at some point soon the pilots and various unions will need to have a bigger voice in the development of new aircraft.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
The thrust has been to unburden. So far I think this has worked. Certainly the job of Second Officer is threatened in the future.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Is it going to fly? If so for how long? Can I get down safely myself or am I going to need ground help? Will the plane respond as expected?

AVIATION INTERVIEW NO. 36

Age 44; Initial Captain from DC10 First Officer; DC8,10; 727, 737

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

The mental part has gone up and the motor part down. You have to process a lot more information to program computers but then there's nothing else to do except watch.

2. Physical strength

Strength is only needed if everything fails and then in my experience only the DC8 is hard.

3. Finesse

The mechanical or automated approach to flying will do away with finesse.

4. Understanding of systems

Automation increases the need to know what's going on, not necessarily specific hardware knowledge.

5. Vigilance and attention required

Humans are not good at this. We should fly and the computers should monitor us.

6. Physical workload (phase of flight)

Physical workload is highest during preflight, takeoff and landing. It's a little different on more automated aircraft but not more or less.

7. Mental workload (phase of flight)

Same as above.

8. Training requirements, duration and methods

Requirements are set by the Federal Air Regulations. The training center is using newer methods and this seems to have shortened the time here. The difference between planes in terms of training requirements is nil.

9. Communication among the crew

Should be high on every plane on every trip. Even in the future if there's only 1 pilot and a bunch of computers they ought to be talking.

10. Ease of learning a new airplane
They are all about the same. The more automated planes require understanding of say the Flight Guidance System panel where as the 737 is all the indicator instruments. Systems information hardly ever changes.

11. Reliability of systems
Very reliable and seem to be getting more so.

12. Skill retention problems
The skills are there. They need some sharpening is all. Automated aircraft will definitely be a problem in this regard.

13. Command/Leadership/Resource Management skills
As you move up in seats this becomes more important. You're responsible. You should know and be able to use all your resources.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No. Everyone has forgotten something sometime but the automatics themselves have not surprised me.

B. Have you ever experienced a sudden failure of the automatics?
Flight Director failure if that counts.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. We've seen more of it, we see its usefulness, and we're not afraid of it.

D. What did you expect and what has been reality with respect to automation in the cockpit?
It's been so long in coming that I only expected what I've seen. It's helped.

E. What has been gained by automation?
We've gained the ability to fly using fewer inputs manually.

F. What has been lost?
Some of the hand-ons flying.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Navigation, takeoff and landing computations, weather radar forecasting-flight planning.

B. What specific data does a pilot "need to know" to fly the aircraft?

Attitude and air speed are the key; any other data will help.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

If you want a smooth take over you should know what the automated systems have programmed in them and what they are currently doing.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

More knowledge of how computers work.

E. How do you view future automation in the cockpit?

With mixed feelings. I like the gadgets but I like to fly also. It's going to be important to keep the pilot busy for safety and morale reasons.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

To unburden him. If displacement has occurred it has been as much the result of aircraft design factors as automation.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

All the information he can get.

AVIATION INTERVIEW NO. 37

747 First Officer from DC10; Caravelle, 737, 727, DC8

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Haven't changed much with automation. Most planes you do something manually to an instrument and then fly where the instrument says fly. More modern planes you do something to a computer, the computer flies and you monitor.

2. Physical strength

Well kept secret. These beasts don't require physical skill in the sense of brute strength. Automation can't change something that doesn't need changing.

3. Finesse

I think the more automated aircraft allow you to navigate with greater finesse. The feel they put in the power boosted controls has also gotten better with newer aircraft.

4. Understanding of systems

No matter what the aircraft has in the way of systems - you have to understand it thoroughly. This will never change.

5. Vigilance and attention required

It's high now and will probably get higher with more automated airplanes and higher traffic density plus Category III capabilities.

6. Physical workload (phase of flight)

Workload is high during landings and takeoff in a physical sense - not strength, just lots to do.

7. Mental workload (phase of flight)

Mental workload goes back a step - high during preflight planning even with all the Automated Flight Planning and Monitoring System information they give you.

8. Training requirements, duration and methods
Training has definitely gotten better since the days we were taught in the hangar. FAA check airmen have come to their senses. Duration is shorter and methods are better in terms of learning efficiency. I don't think automation in aircraft had brought this, I think it's better training knowledge and technology.

9. Communication among the crew
In terms of automation communication is much more important. Some planes like the 737 can be flown by one person. But the bigger more modern ones simply can't. It's dangerous not to communicate your actions or your intent to act. That's what happened to Eastern's flight in the Everglades. No communication whatsoever.

10. Ease of learning a new airplane
New aircraft are not problem. Best thing to do is just compare the new plane to your old one in terms of what's the same, what's different. Experience helps - if you don't have an old aircraft how can you compare? Automation doesn't matter.

11. Reliability of systems
More reliable since we moved to jets in the 60's. Each new plane brings more reliability and redundancy. Solid state instruments on new aircraft are even more reliable.

12. Skill retention problems
Yes, automation does affect skill in terms of seat of the pants flying. You look at an Allegheny commuter pilot who makes 20 takeoffs and landings a day and he'll have more skill than a DC10 First Officer any day. But I'll bet it won't become an issue until a fully automated plane fails all systems and the pilot screws up the landing because he hasn't made one recently.

13. Command/Leadership/Resource Management skills
These skills are important. Two heads <u>are</u> better than one and on modern aircraft you may need to draw on everyone's skills.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

About the second takeoff I ever made in the DC10 I failed to set the speed control knob - the Captain missed it and we got a stick shaker - surprise!

B. Have you ever experienced a sudden failure of the automatics?
We've had things that didn't entirely agree between pilot and copilot instruments but never a total failure.

C. Do you think that younger pilots catch on to automation faster than older ones?
Yes. Education level is generally higher, more experience with automated systems in military aircraft. Training methods are better.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I've always expected the newer systems to help me do my job. My job is to fly airplanes - at least it was. As systems become more automated I do less flying and more data input and monitoring. That's reality.

E. What has been gained by automation?
Automation has decreased the navigation job. Just tell the computer where you want to go and it tells you how to get there.

F. What has been lost?
Hand flying. I'm not sure the answer to the human error problem is to eliminate the human's flying skills.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
All the functions that allow a pilot to influence the aircraft. In other words if I can do something to the plane via my actions then I need data for that.

B. What specific data does a pilot "need to know" to fly the aircraft?
You only "need to know" how to fly. Even a private pilot could fly an airliner. To takeoff or land is another issue.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Methods seem to keep pace with the aircraft. No changes needed.

E. How do you view future automation in the cockpit?
It will come just like in any other industry. It's future depends on careful planning - selection of automated systems just as carefully as we select pilots.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

Engineers would like to replace us with some infallible system. But time or an accident will show that the pilot will always be here.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

No different than 20 years ago. To fulfill your responsibility you need to know everything.

AVIATION INTERVIEW NO. 38

Age 48; 747 First Officer from DC10 First Officer; Second Officer on 737, 727, DC8; First Officer on 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor
Naturally they're higher if you're flying the leg. Not flying it's mostly mental. On DC10 First Officer has high psychomotor requirements.

2. Physical strength
Never flown anything that requires physical strength.

3. Finesse
The automated airplanes are easier to fly across the board so finesse is higher with them.

4. Understanding of systems
I've always felt obligated to know as much about systems as possible. Years as a Second Officer teaches you that. Even more important on two-man automated aircraft.

5. Vigilance and attention required
It should be high on any airplane in any seat. It is for me. More so on automated aircraft to prevent laziness or inattention.

6. Physical workload (phase of flight)
It's higher on takeoff and landing regardless of the aircraft.

7. Mental workload (phase of flight)
Mental workload is higher on the automated aircraft like 10 and 47 because you're always keeping track of what the Flight Guidance System is doing.

8. Training requirements, duration and methods
They all seem about the same. No problems really.

9. Communication among the crew
I get talked to more as a First Officer than as Second Officer. It's generally higher on automated planes because of cross-checking what the other guy's doing.

10. Ease of learning a new airplane
New planes pose no problem automated or not.

11. Reliability of systems
Few problems. All systems seem to be reliable.

12. Skill retention problems
You've probably heard about DC10 First Officers going to Captain. It's true. But so far I've had no problems.

13. Command/Leadership/Resource Management skills
I'm a big advocate of these skills especially on complicated aircraft.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
I was surprised when I thought the Instrument Landing System switch was set on OLS and it wasn't.

B. Have you ever experienced a sudden failure of the automatics?
Automatic Pilot failed on coupled approach. We disconnected and hand flew it.

C. Do you think that younger pilots catch on to automation faster than older ones?
By the time we get through training and out on the line most of us are pretty equal. But yes, the younger guys are more used to computers and automated systems and they do catch on faster.

D. What did you expect and what has been reality with respect to automation in the cockpit?
The only real significant automation I've seen has been the DC10 Flight Guidance System. It does what I was taught to expect.

E. What has been gained by automation?
I'm not sure. The automated systems largely do only what we tell them. If we make a mistake it's no different than a mistake in a less automated aircraft.

F. What has been lost?
Some hand flying. You still have to set the knobs and twirl the dials so workload hasn't decreased.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Dispatch, flight planning and all the various steps from takeoff to landing.

B. What specific data does a pilot "need to know" to fly the aircraft?
You only "need to know" what speed will keep the aircraft in the air. If you want to go somewhere you have to have navigation information.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
You just have to be aware of what the automated systems have been doing.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Not much change in methods is needed. But we might want to consider getting instructors and pilots who are willing to accept the new systems.

E. How do you view future automation in the cockpit?
Cockpits will become more automated. All of the accidents of late have been Human Factors errors. Automation may help that but we'll always have pilots.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
The thrust I think has been to take away as many human inputs as possible. That hasn't been achieved.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
All the information that is available.

AVIATION INTERVIEW NO. 39

Age 45; DC10 First Officer from DC8 First Officer; 737, 727, DC8, Second Officer; 737 First Officer, DC8 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Think then act, right? You'd think that automation would help but it doesn't. On say 727 you think then perform. Automation does nothing.

2. Physical strength

No issue - automation not related. Physical strength has been taken care of since early days - aerodynamics boosted controls.

3. Finesse

You can gain experience with an aircraft and really learn to fly smoothly and do nearly perfect takeoff and landing every time. Auto coupled approaches will get you down every time but it's mechanical - not finesse. Automation brings mechanical consistency - not finesse.

4. Understanding of systems

I think that automation increases the need for systems information. You have to know what's going on even in the black boxes. How else can you take over if they fail?

5. Vigilance and attention required

This has increased steadily since the 50's. Automation is an issue in that the pilot has to be alert to system malfunctions. Traffic density has also increased as has the number of general aviation aircraft at major airports.

6. Physical workload (phase of flight)

Takeoff and landing is always busiest in terms of things to do physically. Automation helps in that some things can be pre-set in the computer.

7. Mental workload (phase of flight)

It's gone up. Everyone thinks that new systems will relieve the pilot and reduce the human error. But who has the ultimate responsiblity? Who owns the aircraft if an emergency occurs?

8. Training requirements, duration and methods
The time to complete training has gone down over the years. Part of this is related to the computer based, self-paced instruction. Requirements are the same and the methods are more modern. This is sort of independent of automation on aircraft.

9. Communication among the crew
Very important. Especially if you're inputting data or something like that.

10. Ease of learning a new airplane
They seem to get easier as the years go by. I don't know if the planes are easier, the training better or I'm better. Automated planes aren't harder though.

11. Reliability of systems
Reliable. Solid state circuitry and shock resistance (vibration) have helped. I guess automation has helped that.

12. Skill retention problems
They tell us (DC10 First Officers) to hand fly a lot before we bid Captain. I guess that's because all you do on the 10 is dial knobs and punch buttons. Skill retention will become a problem with automation.

13. Command/Leadership/Resource Management skills
All of the accidents lately have been related to this. Somebody knew the answer and didn't speak up. More important with automation.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
More by my actions. I've flown through an altitude when I thought the Flight Guidance System would level off automatically. Didn't set the altitude select switch.

B. Have you ever experienced a sudden failure of the automatics?
No. I have seen the Automatic Pilot fail over a period of time though. Just switched to the other Automatic Pilot.

C. Do you think that younger pilots catch on to automation faster than older ones?
Only because they have a different attitude toward it. They haven't seen their job eroded by automation.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected equipment that helped me be a better pilot. The DC10 is like that but I hear the future aircraft designers want the pilot out.

E. What has been gained by automation?
Fuel savings is about it. Everything else a pilot can do as well.

F. What has been lost?
Second Officer on a few aircraft and some hand flying skills like dead reckoning.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
For whatever he is going to do. Preflight, flight plans, takeoff, climb, cruise, descent, landing and taxi.

B. What specific data does a pilot "need to know" to fly the aircraft?
Thrust, air speed, altitude and attitude.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
What's the current situation? Where are we? Fuel. Where are we going?

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Work on pilot acceptance. Better attitude of instructors toward automation.

E. How do you view future automation in the cockpit?
It is gradually increasing but the pilot will always be around for ultimate responsibility.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Displace him. No one can say it unburdens you. It'll just move from one place to another.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
What is needed is a pilot in the loop on everything.

AVIATION INTERVIEW NO. 40

Age 51; Initial Captain (DC10) from 767 First Officer; KC135, KC97, DC6,8, 727, 767 - First Officer, DC10, 747 - Second Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to wide-body airplanes

1. Psychomotor

If anything the psychomotor requirements have increased. An airplane with basic flight instruments - what you see is what you get. Not so with automation.

2. Physical strength

3. Finesse

Computers have no finesse - no shades of grey, just yes or no. You still have to have the basic skills.

4. Understanding of systems

Systems have been simplified. Also training on systems - does it work or doesn't it?

5. Vigilance and attention required

Vigilance has changed for the better overall. But there's lots of things you'd like to know from EICAS that you can't get. Lack of information doesn't help the decision making process. Some information is available on ground but not in the air. You only get an idiot light. In air you sometimes need to tell maintenance what's wrong so they can help you. It would help maintenance reliability. 767 is great enroute. Departures and arrivals can sometimes be a nightmare - lots of time required to insert data in computer. Sometimes clearances can't be entered in time to depart (copy, then program - very time consuming), e.g., area departure expected, air traffic control changed drastically and we had no way to define the intersection. We departed without programming the EICAS. Flight director and automatic pilot go in different boxes. Automatic pilot goes on local and flight director goes crazy. You have to learn to expect so you don't get surprised.

6. Physical workload (phase of flight)

Physical strength has never been an issue. I'm a big guy. DC8 requires most. I think we've made some strides in the right direction.

7. Mental workload (phase of flight)
Mentally you have to know more.

8. Training requirements, duration and methods
I don't know how you train different than we are doing. I thought computer based training was great. There is a lot to be said for a classroom situation.

9. Communication among the crew
Command/Leadership/Resource Management has improved communication. Need has increased with automation. Left hand needs to know what right hand is doing. You have to know to pick up on mistakes.

10. Ease of learning a new airplane
Ease of learning has increased partly by experience. However, we are turned loose with less knowledge. Confidence varies with individual. Younger pilots learn better.

11. Reliability of systems
767 has a lot of reliability but cries wolf too often.

12. Skill retention problems
Skill retention is hard for the individual to judge. But the skills remain because we all fly more manually than we have to because we can do it better than the automatic system - smoother. Only altitude and heading can be done better by a computer.

13. Command/Leadership/Resource Management skills

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
Where do I start? 767 descents on Vertical Navigation the throttles come back and the nose goes down. Autothrottles have 3 second lag so "jockey". Departures - can't climb at steeper angles. Instead of pitch change got throttle change.

B. Have you ever experienced a sudden failure of the automatics?
Tape indicators on 747. 767 only digital and no trend information. No sudden failures I can think of. Auto pressure controller was all (747 and 767) - no indication until 2nd one failed.

C. Do you think that younger pilots catch on to automation faster than older ones?

D. What did you expect and what has been reality with respect to automation in the cockpit?
I'm not as impressed with 767 as I was when I went to school. DC10 and 747 are more realistic.

E. What has been gained by automation?
Depends on side of fence. Loss of third man. 767 needs a Second Officer. Need eyes outside and inside.

F. What has been lost?

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Flight planning and enroute weather radar.

B. What specific data does a pilot "need to know" to fly the aircraft?
Heading, airspeed, altitude, attitude, and a means of navigation.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Same as "B". Get by with attitude, altitude, airspeed.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
None.

E. How do you view future automation in the cockpit?
Data link will be a mistake. Gives you no sense of what's going on around you. Knowing what the guy ahead of you did lets you stay ahead.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Displace.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Even 767 is not automated to point where you don't have this information. Engine performance, systems information and basic flying information, flight control position indicators. Copilot on dual engine failure - standby information was useless because it was unreadable in turbulence. $36,000 piece of equipment and it does us no good. 767 - side-by-side switches and dials that are identical. Pushing button instead of flipping a switch forces you to look to see the indication. Need to write application charts for <u>pilots</u>, not editors.

AVIATION INTERVIEW NO. 41

Age 43; Initial Captain from DC10 First Officer; 727 Second Officer, DC8 Second Officer, DC10 Second Officer, 737 First Officer, 727 First Officer, DC8 First Officer

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to wide-body airplanes

1. Psychomotor

Psychomotor skills have not increased per se, but the requirements have changed quite a lot. The modern airplanes will do a lot of the flying for you but you still have to think about what to input and then do it. So physical input has changed in nature. Not strength, that's no problem, just less input on the controls and more on the panel.

2. Physical strength

3. Finesse

No one taught these computers how to be smooth. Ever hear the autothrottle system on the 767? Sounds like a pilot with palsey.

4. Understanding of systems

One thing that might help us operate these automated or semi-automated systems is more knowledge of how the computers "think", that is, what is the logic to the sequences? For example, on the DC10 if you want to climb at a steeper angle you use the vertical speed knob and the throttles will automatically come up to maintain the same airspeed. It's important to know that logic.

5. Vigilance and attention required

By virtue of things like that, vigilance is increasingly important.

6. Physical workload (phase of flight)

In terms of effort or number of things to do automation helps.

7. Mental workload (phase of flight)

Mental work increases because you have to imagine what's happening instead of seeing it directly.

8. Training requirements, duration and methods
On the planes I've flown the training requirements and methods have all been about the same. Some computer training is coming into being and I don't mind it as long as it's flexible. Computers tend to be so rigid.

9. Communication among the crew
Communication is being emphasized more and I believe it should be - it's too easy to do something the other pilot doesn't see or follow. A pilot can be "out of the loop" in a non-automated airplane as well as in an automated one.

10. Ease of learning a new airplane
New planes are no harder to learn, you just have to have the motivation to do it. Money usually takes care of that.

11. Reliability of systems
Systems are pretty reliable - well maintained and redundant. If I had to pick one system that I think breaks down most often, I'd say the radar. But that may just be perception.

12. Skill retention problems
I'm not sure anyone knows just how much we manually fly these airplanes. Many of the pilots don't use the automated systems unless a check pilot is on board. The guys on the 767 do that a lot. Some of them can't wait to transition to a different plane.

13. Command/Leadership/Resource Management skills
Cockpit resource management skills go with communication. You might as well share the skills required.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No because I've never flown an automated airplane. The DC10 is just rearranged - it still requires manual input to the flight guidance system panel which gives you a chance to double check.

B. Have you ever experienced a sudden failure of the automatics?
I was just on a flight to Hong Kong that had the Performance Management System fail. About half-way there it just commanded a descent and over we went.

C. Do you think that younger pilots catch on to automation faster than older ones?

Younger pilots may trust automation more and therefore be more accepting - thus less resistance to learning. I had heard the DC10 was hard to learn but it wasn't. Had a great instructor.

D. What did you expect and what has been reality with respect to automation in the cockpit?

I expected the DC10 to be about what it was - a semi-automated plane that made it easy to fly.

E. What has been gained by automation?

I don't think we've gained anything so far - we haven't really needed the automation we've been given.

F. What has been lost?

About the only thing lost on the planes I've flown is outside vigilance. Airline pilots have a nasty habit of staying on the gauges and visualizing the traffic outside.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?

You can't do anything without data - so you need data for everything.

B. What specific data does a pilot "need to know" to fly the aircraft?

All you need to know is which way is the sky - attitude, altitude, airspeed.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?

In order to take over you simply have to have been aware of all that's been going on.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?

If I was going to change something in the training methods for automated aircraft I'd tell people more about the way the computer goes about its business.

E. How do you view future automation in the cockpit?

Automation is coming whether pilots like it or not.

F. Has the major thrust of automation been to unburden the pilot or to displace him?

I think the current intent is to ease the workload but a lot of management people see it as saving money by cutting crew and downgrading the job. Look at other industries.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

The hang-up is that the Captain is totally responsible so until we get rid of him we better keep him informed of everything.

AVIATION INTERVIEW NO. 42

Age 57; 747 Captain from DC10 Captain; Military Transport, Caravelle, DC6, 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements prior to wide-body airplanes

1. Psychomotor

About as high on any aircraft. It's a high psychomotor activity.

2. Physical strength

The 747 has powered controls so the physical "feel" is actually less than the smaller aircraft. Not really related to automation.

3. Finesse

The 747 and DC10 don't require as much finesse on my part due to the automatic flight capabilities. But the new 737-300 will also have those features.

4. Understanding of systems

It's hard to completely understand the inside of a black box but you should at least know what it's doing.

5. Vigilance and attention required

Always high, regardless of the aircraft.

6. Physical workload (phase of flight)

Lower on the bigger planes. Up to the DC9-80 and 737 this has been correlated with wide-bodies but it's really correlated with automation.

7. Mental workload (phase of flight)

At my age the sophisticated systems seem to require more thought.

8. Training requirements, duration and methods

Training on the DC10 and 747 was a bit harder for me because of the changing sophistication.

9. Communication among the crew

More demanding on an automated plane because everything is more complex.

10. Ease of learning a new airplane
I've become more comfortable with time but initially all the automated systems were harder.

11. Reliability of systems
Reliability has been high on all aircraft I've flown from the 727 on.

12. Skill retention problems
No problem.

13. Command/Leadership/Resource Management skills
Management has become more of an issue with increasingly automated aircraft.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?
No.

B. Have you ever experienced a sudden failure of the automatics?
No.

C. Do you think that younger pilots catch on to automation faster than older ones?
Well you learn faster at the younger ages - at least I did. But I still learn as well.

D. What did you expect and what has been reality with respect to automation in the cockpit?
What I expected, especially with the DC10, was a much more automated plane. It's really just a rearrangement of old instruments with a couple of computers to help.

E. What has been gained by automation?
Automation will help us in the future crowded skies.

F. What has been lost?
Some "status" as a pilot.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
To monitor all systems.

B. What specific data does a pilot "need to know" to fly the aircraft?
Operating limits and procedures.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Any problems and where we are and can ...

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
Emphasis on how computers work - basics.

E. How do you view future automation in the cockpit?
It's going to become a black box environment just like the Air Force RB71.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
To unburden him.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?
Anything that reveals information that would compromise safety.

AVIATION INTERVIEW NO. 43

Age 40; DC10 First Officer from DC8 First Officer; 737, 727, DC8, DC10

I. Explain purpose and goals of contract

II. Issues related to automation

A. Job requirements

1. Psychomotor

Psychomotor skills are what flying is all about. Some airplanes require that you think - then manually perform operations, and some like the DC10 require that you think, input data and the computers perform the operation. Either way the skills are necessary.

2. Physical strength

Physical strength is not an issue; some planes don't even have manual reversion.

3. Finesse

Finesse is not the word I'd use. I think more in terms of smoothness and these aircraft can all be operated smoothly.

4. Understanding of systems

I find myself wanting to know more about systems as the aircraft I fly become more automated. I want to know what I can do when the black box doesn't do it. So personally, understanding systems is more important with automated aircraft.

5. Vigilance and attention required

Vigilance isn't so much related to the aircraft as it is to the environment you're flying in. High density areas require more outside vigilance. All aircraft require constant monitoring of instruments.

6. Physical workload (phase of flight)

The workload increases at takeoff and landing but otherwise it isn't bad.

7. Mental workload (phase of flight)

With a more automated aircraft you can ease your workload by setting things up ahead of time.

8. Training requirements, duration and methods
Training seems to be getting easier. The more automated aircraft just require a different attitude, not really different training methods.

9. Communication among the crew
Communication becomes increasingly important because it's so easy to do something the other pilot doesn't see.

10. Ease of learning a new airplane
They get easier to learn. I understand the 767, for example, does your computations for you. So instead of learning all the details you simply learn to operate a computer or a centralized control panel.

11. Reliability of systems
The aircraft as a whole are reliable. The systems, regardless of automation, always seem to have something going wrong. Lots of backup minimizes the problems.

12. Skill retention problems
They tell me in school that the DC10 First Officer has trouble transitioning to Captain but I think that can be eliminated by hand flying say every other leg that's mine. Automation does pose a threat to basic flying skills though.

13. Command/Leadership/Resource Management skills
Command/Leadership/Resource Management is good. I've flown with a lot of Captains who could use more training. It has to become even more important with automation because of the complexity of the equipment.

III. Specific Experience

A. Have you ever been "surprised" by the actions of the automatics?

I haven't been on the thing long enough to experience failures of systems or surprises for that matter. It's bound to happen sooner or later.

B. Have you ever experienced a sudden failure of the automatics?

C. Do you think that younger pilots catch on to automation faster than older ones?

Yes because of exposure to automation during virtually their entire lives.

D. What did you expect and what has been reality with respect to automation in the cockpit?
I expected more. The DC10 is really semi-automated since the only thing different is that controls for various instruments and functions are all located on one central panel. The human still controls and monitors.

E. What has been gained by automation?
We are increasingly moving toward the ability to operate in any environment be it high density traffic, diversions, weather, whatever.

F. What has been lost?
I think we are losing our status. Less pay, less control, etc.

IV. Human Factors Guidelines

A. What functions does a pilot need data for?
Pilots need data for everything, even layover information. You need data for monitoring automated functions.

B. What specific data does a pilot "need to know" to fly the aircraft?
You really only need operating limitations such as stall speeds, flap speeds, and airplane capabilities.

C. What specific data is required at all times in order for the pilot to "take over" from automated systems?
Any data that reveals an irregularity or emergency, plus where you are and where you want to be.

D. What changes to training methods are needed to train pilots to safely fly increasingly automated airplanes?
More training on communication and command/leadership/resource management because if that's not happening when something goes wrong the consequences will be disastrous.

E. How do you view future automation in the cockpit?
Like everyone else - with marvel but with the feeling that my job is going to be done by a robot.

F. Has the major thrust of automation been to unburden the pilot or to displace him?
Ultimately to replace him. Engineers think that making aircraft fully automated will eliminate all error in flying. Computers can go haywire too.

G. If a pilot is ultimately responsible for the safety of the airplane, what information does he need about the airplane's performance to fulfill those responsibilities?

Whatever will get me on the ground safely. Probably all key stuff, systems information, fuel, position, performance capabilities, attitude, and airspeed.

AVIATION INTERVIEW NO. 44

The meeting was held at the office of Neil Johnson of UAL. In addition to Johnson and the interviewee, John Ciciora and Dave Leonard were present.

The interviewee is a member of the all weather flying committee of ALPA, and he has been charged with looking into automation. Questions of concern to ALPA are:

Is automation to be used as a substitute for information to the pilot?

Is the pilot to be the back-up on a critical system?

Questions about autoland (CAT III) available on DC-10 and 767:

Enhanced vision (HUD?) vs. fully automatic -

- Fail passive	- Pilot out of loop
- Pilot for redundancy	- No information while in mode

Is display needed when performance (e.g., track) is automated?

Problems produced by automatic systems:

Transition from copilot on DC-10 to pilot on 737 has not gone as well as it should in some cases. This is said to be loss of piloting skills, e.g., scanning technique.

Flying into stall. Has occurred on wide-bodied aircraft, pilot distracted by activity with computer. Perhaps need to keep pilot in touch with cockpit by providing tasks such as reprogramming computer at waypoints.

Question of flight critical tasks, i.e., omission or commission errors which could lead to disaster.

What can we do with ALPA?

The interviewee is going to France to observe fully automated train.

Will also discuss some of the systems which have been adopted by airlines on continent.

Will visit Elwyn Edwards (University of Aston, Birmingham).

Aviation Psychology Meeting at Ohio State in April.

Meeting shortly with Del Fadden of Boeing.

AVIATION INTERVIEW NO. 45

The Chief of Human Factors of a major aircraft corporation discussed problems of workload and recommended the recent Chiles article and AGARD 246 (Alluisi, et al.). He noted that MIL-STD 1472C is somewhat weak on CRT type displays and that he may be getting something new soon. He will send some company papers and their CADET report when it is okayed for distribution.

Liaison showed a mock-up of their generic simulator. The basic function is to try different ideas. Considerable variation is possible for displays and terminals. Airline pilots who have operated it have reacted favorably. Notes that information of greatest concern is that which is in front of the aircraft. Displays should have a capability for extending the range. Also need a good database system to incorporate weather, etc., information from stations ahead.

It is likely that some future transport may have primarily electrical controls and other systems. Displays for pilot and copilot will be interchangeable in that either or both may have a particular display on their screen at any time. Center display will be constant in terms of type of information and format used.

A suggested use of computer display is to provide simulation training of a sort while aircraft is in flight. Simply disconnect one set of displays from operating aircraft and call up program to practice landing, etc.

HUDs are not prominent in their thinking at this time, because they have had mixed results. This may stem from early displays which were placed about four inches in front of the pilot's face. Federal Express is now installing HUDs because of need for all-weather capability.

Information - suggest general route information will be in a ROM package. Pilots will enter current weather, etc.

Displays will be set up to provide certain information in default mode, e.g., immediately succeeding route. Other types of information may be individually added or dropped. Sidearm control is quite feasible, since yoke is generally operated by one hand only.

AVIATION INTERVIEW NO. 46

The subject of this interview is thirty years old with over 3,000 hours of flying time, most of it in multi-engine piston aircraft. A partial list of the multi-engine aircraft he has flown includes the following: P-58, C-310, E-55, C-210, PA-31, 601-P, PA-34, PA-44, 601, C-402, C-340, C-411, C-414, 680-E. In addtion, he has flown various single engine aircraft. He has served as corporate pilot for a number of businesses in the south-central region of the country.

BACKGROUND

The interview subject feels that flying as a corporate or charter pilot differs from flying as a pilot for the major scheduled airlines in the following respects:

While both groups of pilots are responsible for equipment and crew, non-airline pilots have additional responsibility for such activities as scheduling, flight planning, maintenance, passenger accommodations, baggage and cargo handling, and commissary supply. In addition non-airline pilots often fly a variety of aircraft with radically different characteristics and must be available on an on-call basis. The unscheduled nature of their flying and the lack of a set duty-time creates greater possibility for fatigue. They are especially interesting since they often have a greater input with regard to selecting automated equipment than the pilots who fly for the scheduled airlines. Their relative autonomy gives them greater control over the selection and use of automated equipment.

For the most part, he appreciates flying planes which have extensive automatic capability. He will often use the automatics on the enroute segment of the flight to keep himself fresh and avoid fatigue. On occasion, when he finds himself to be unusually fatigued, he will use the automatics to share his workload during the approach segment of of a flight. Since he often flies alone, he tends to use the autopilot as a copilot.

With regard to reliability and the trust he has in automatics, he has experienced autopilot loss during critical phases of a flight and therefore uses them cautiously. His experience has shown him that the mechanical parts of an airplane seem to be more reliable than the electronic equipment. For example, he has had more trouble with radios than any other category of equipment. This tends to make him leery about the extensive use of electronics in aircraft control systems. Mechanical parts tend to wear out and fail gradually while often electronic components fail suddenly and without warning.

AVIATION INTERVIEW NO. 47

The subject of this interview is in his mid to late twenties and has an industrial engineering degree from Ohio State University, where he learned to fly. His primary employment is with a large manufacturing firm which specializes in computer equipment. He has worked tangentially on their automated warehouse. While he has done occasional charter flying, he has not attempted to become involved in this as an economic venture. Rather, he has used the occasional charter opportunity for increasing his flying time.

The aircraft which he has flown include several single engine planes, but his primary time most recently has been in a Mooney 201 and in a Cessna 172. While he flies primarily for the fun of it, he also flies on short business trips and for vacations. Thus, he does fly longer distances often. On the longer trips he uses the automatic features more. He considers the automatic aspect to be very helpful on these flights. Although he is continuously monitoring the instruments and checking for his way points, he feels that it is possible that his vigilance may be lower in the middle of a leg than it is as he approaches a way point.

The primary advantage which the automatics give him is an opportunity to spend time on other aspects of the flight. In particular he likes the distance measuring factor which helps to keep him up-to-date on what his fuel needs are. He does not think that the avoidance devices are very useful at this time. Other than that he would not want to dispense with any of the various aids which he has.

When asked what sort of added automation he would like to have, he said that he would prefer more weather information to be automatically presented. Essentially, his concern is with getting more current information about the area into which he is flying. He thought he might like a CRT display which would show his track and some weather information.

In terms of additional automation, he seems generally favorable, but would like to see items before passing judgment.

In conjunction with his association with automation of the warehouse, he volunteered the information that there was some resistance on the part of workers. When asked if there were any worker characteristics which might have been correlated with the resistance, he said that age per se did not seem to be a factor but time on the job was possibly a factor. In effect, the longer one had worked under the old system, the more resistance there was to the newer system. There are possible confounding factors in this relationship, however. Many of the younger workers (including some with lesser experience) worked on the night shift in order to attend college during the day. It is possible that there could be a difference as a function of education or just in the sort of people who are pursuing higher education.

AVIATION INTERVIEW NO. 48

The subject of the interview is an electrical engineer who works for a company involved in developing multiplexing devices for use with telephone service. He previously worked for other firms as an electrical engineer and has been in his present job about four years.

The interviewee has been flying for about four years. He learned privately and has logged about 400 hours. He is currently flying about 20 hours per month. He flies two aircraft primarily: a Mooney 201 and a Grumman. Both are single engine aircraft. He instructs in the Grumman and flies the Mooney for pleasure and for longer trips.

He prefers to fly the aircraft with more advanced avionics for several reasons. A primary reason is that he feels that there is more challenge in the advanced avionics, since they allow him to do more instrument flying. In the main the more automatic devices also allow more time for making decisions. The autopilot is also useful because it frees up time for reading maps while not having to attend to the controls.

Although he is generally positive toward electronic devices, he feels that they should be debugged before they are installed in aircraft. An example of a problem is that of a light airplane which has an automatic mode for extending and retracting the landing gear. On occasion it may lower the gear when the pilot does not want them down. In addition, it has lowered one wheel separately from the other.

When asked whether or not he would accept the elimination of most gauges, etc. from the cockpit if he had the capability of calling them up on a CRT on demand, he said he didn't think so. However, he would accept this mode of presenting the information if it were cycled onto the CRT on a regular basis. He felt that the trend information would be useful. In general, he is as comfortable with electronic devices as he is with mechanical ones. When queried about the fact that some people think the electronic equipment goes out more frequently than other devices, he said that in his experience the problems were usually not electronic in nature but merely electrical. That is, there is a tendency for switches and relay contacts to get pitted or dirty and cause malfunctions, but the electronic devices themselves seldom fail.

He thinks that there is a slight loss of vigilance on long legs when the aircraft is on autopilot, but this occurs only when visibility is good so that any deviation would quickly become apparent.

As to the question of whether or not pilots would take direction from a computer, the interviewee felt that this was what occurred in the use of a flight director.

In response to what added electronic instruments he would like to have in his aircraft, he said that an accelerometer would be useful. For example, the Air Florida crash in Washington, D. C. might have been avoided if such an instrument had been available. If the pilots had known how little their speed was increasing, they might have aborted the takeoff.

When asked about a CRT which would display current track and the information on a landing chart he said that this would be very helpful.

Another problem with which he is concerned is the lack of simulator time for pilots who do not work for airlines. It seems that the small, cheap, generic simulators do not help much for many types of flying and aircraft. He thinks that with the current availability of electronic devices it should be possible to develop programs which would be tailored to specific aircraft. These could be used with many instrument flying problems.

In the main he looks forward to the forthcoming automatic devices.

AVIATION INTERVIEW NO. 49

The subject of this interview is a flight instructor and manager of instruction for a fixed base operator. He has a bachelors degree in biology and has been flying for 17 years. He has flown almost all of the single engine aircraft as well as helicopters and gliders. He has logged over 7000 hours of flight time and is rated as an air transport pilot flight instructor. He seems to have a fairly positive attitude toward automation and is involved in a company which is attempting to develop an automated weather service.

Currently, the subject of the interview flies several aircraft with differing levels of automation. He views automation as a mixed blessing. While there are many advantages to automation, such as distance measuring equipment, that allow the pilot to be more precise, he feels that in some cases they tend to reduce both proficiency and vigilance. In conjunction with the problem of proficiency, he cites instances of airline pilots who come to get checked out in an airplane who have some difficulty in flying it. While negative transfer effects may be a factor in the difficulties experienced by the airline pilots, he feels that the methodical nature of the flight procedures used by the airlines may also contribute. That is, since airline pilots generally fly only one aircraft at a time, they develop responses which are routinized and which can reduce the thinking about the effects of the action. In addition, he thinks that there are degrees of interest (or dedication) in flying that account for loss of proficiency. It would seem that there is a rough dichotomy in terms of this trait. Many pilots fly whenever possible and work to increase proficiency (a sort of contest with themselves) while others are only too willing to let the automatic devices take care of everything. It is possible that there may be peer pressures to do certain sorts of things. For example, he cited the case of a copilot who was hand flying his leg of a trip when the captain said, "Why don't you put it on autopilot?" While this would suggest some pressure to minimize one's involvement, i.e., don't show the others up, there could also be peer pressures to avoid use of certain automatic features.

A problem which seems to be a factor in general aviation is the failure to become adequately trained on new systems. While minimum standards are met for certification, he thinks that both training and retraining should be more stringently enforced by the agencies involved.

Among the added automatic features which he would most prefer would be warning signals which were inescapable. He would be interested in getting some CRT type displays of flight information, such as landing patterns and weather information. In general, he thinks that more information can aid the pilot, and he would accept a situation in which some information was not displayed continuously if he was certain he could get the information when he wanted it.

AVIATION INTERVIEW NO. 50

The subject of this interview is 37 years old and has been flying for 16 years. His experience includes most typical single-engine general aviation airplanes as well as such aircraft as Cessna's pressurized 210W and 310, the Aerocommander, and the Piper Seminole. He has experience in planes with no navigation equipment as well as planes with a Flight Director coupled to RNAV.

The interviewee felt that psychomotor skill requirements increase with more sophisticated aircraft. Physical strength poses no problems regardless of the aircraft. Most small airplanes - those he is most familiar with - are easy to finesse, but this is not really related to automation. As airplanes become more sophisticated, systems knowledge becomes more important. When first flying airplanes with automated systems, vigilance outside tends to decrease until the pilot becomes totally comfortable with the airplane. At this point, outside vigilance increases. Physical workload remains about the same--"things just get compressed because of the faster speeds." Mental workload, on the other hand, increases with more sophisticated systems. "There is more mental workload involved in setting up sophisticated avionics. You have to be more knowledgeable and more careful. More calculations are required to set things up. For example, part of a leg might be VOR, part RNAV, and you have to remember to switch. Ease of learning is related to things happening quicker--you just have to adjust."

Training for more advance aircraft was actually easier than learning to fly initially and took less time. Communication has never been a problem since the interviewee has never flown anything that required a copilot. The systems seem to be fairly reliable. With pressurized aircraft, it is really necessary to understand the systems and harder to become proficient. Skill retention for instrument conditions is definitely a problem. If he has another pilot on board, he always flies some time "under the hood" (simulated instrument conditions) to keep up his "raw data" skills.

When flying with the automatics, he has been surprised, but only because of something he did wrong--pilot error. He has experienced failures with autopilots and radios. With regard to the age factor, he stated: "Oh yes, the younger pilots catch on faster. I've found it increasingly difficult." He had no expectations regarding automation and takes things as they come. He was, however, a little disappointed until he learned what to ask or expect from a system. Once a pilot becomes knowledgeable, automation reduces workload and increases time available for other functions, resulting in a safer flight. It is more likely that the pilot will "see and be seen". It is also possible to monitor system gauges more closely: "I've often been so busy I've neglected to to look at engine instruments for as long as forty-five minutes."

Increasing automation poses the threat of significant loss of skill. "I often wonder about the guys who have the auto-coupled capability. Could they fly raw data? I doubt it."

Minimum data requirements for safe flight include: weather data, route planning, and basic flying information such as air speed and compass heading, location, attitude and "where do I go next". The interviewee stated the need to train more thoroughly on the basic flying skills--"don't assume anything based on experience". With more automation must come a realization that attitudes and roles must change. He sees that thrust of automation is to unburden but "...this can only happen if requirements are such that you can't fly a particular airplane unless you are actually 'overtrained'". The pilot must be totally aware of everything the automatics are doing if he is to be truly in control, however "...general aviation airplanes don't have anything that you can't see immediately".

INDUSTRIAL INTERVIEWS

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PROCESS CONTROL/FACTORY INTERVIEW NO.1

The interview was held with the operations superintendent of an oil refinery on the afternoon of March 15, 1983. The company is a Canadian owned company that recently purchased this refinery that had been in operation for some 30 or more years.

BACKGROUND

We discussed the general outline of operations for the refinery which produces gasoline sold primarily in Colorado, Wyoming, and the western parts of Kansas and Nebraska. At the refinery, there are systems that involve manual setting of all valves, those that require only the initiation of the process, and those that require initiation only and are monitored by microprocessors. In any case, once the process has reached a certain point it is not possible to stop and either restart or begin the process anew.

While there are relatively few management functions that have been automated, in the newer systems the data collection and recordkeeping will be done by the computer. This will be collected on a central computer and will obviate certain problems with the older system in which charts were altered, or in some cases destroyed. Some units are fully automated and the process is managed by the computer; others require varying amounts of attention from the operator. Ultimately, some of the older units will be phased out and the relative work force will decrease. Since no layoff is associated with the inception of a new system, the operators do not perceive automation as a threat to job security.

OPERATOR CHARACTERISTICS

Educational levels of operators are rather varied. Most older operators are nondegreed. Because of the need for greater educational level and the relatively high pay level, many of the newer operators are college graduates. Some operators have been with the company throughout all the various types of systems. Some have not yet learned the latest systems, while others are quite capable in them. Individuals who do not learn the new systems are usually marginal type operators. They tend to be slightly older as a group, but not all of the older operators are unwilling or slow to learn the new system.

Newer systems have resulted in a marked change in the screening process for hiring new operators. Training is more complex and involves about six months of semiformal (classroom) instruction.

Since the older and newer systems are both in operation, it would be possible to stay with the older system. However, this may mean poorer assignments in terms of work shifts. Thus, there is a bit of a balance in terms of the relative importance of knowing the older system, which involves knowledge of the steps through which the process progresses, and knowing the new system, which involves some knowledge of computer procedures. Although seniority has some modest benefits, a relatively short period is required before reaching the top, or nearly so, of the pay scale. There are basically three levels of operator: trainee, operator, and supervisor. In general, one may become an operator on one unit first and then learn the procedures for the other units. Supervisors are predominantly individuals who have knowledge of several systems.

Several factors are of concern regarding the more automated systems. Motivation is degraded by the lengthy periods of monitoring without the occurrence of any signal. There is also a tendency for defeating certain alarms that may be set off by slightly unusual weather conditions.

One problem that seemed to result from the automated process was the lack of knowledge, by newer operators, about the various steps in the process. Employees, who had learned on the earlier systems, know that if Valve A is opened, then Valve B must also be opened, et cetera, since they had to physically perform those operations in running the system. Even so, they do not seem to have a concept of the process in flowchart form. This seems to be somewhat of a stumbling block with the newest technology, because the computer will present the status of the system in flowchart form. In the older units, different dials would show the progression of the process.

PROCESS CHARACTERISTICS

In the main, the allocation of function is static. Once the process has started, the function of the operator is merely that of a monitor. If a malfunction occurs, the operator may have some actions to perform. A problem for the superintendent occurs when an emergency situation arises. Under the previous system, it was possible to follow a trail of physical evidence left by the operator's activities (e.g., closed valves) and be immediately up to date on the status of the system. This is not the case with the computerized system.

Although less physical activity is involved in the automated systems, the problem of attention or vigilance becomes more acute, since some cues from the physical operations are no longer available.

While failure to contain a process at certain stages would result in possibility of serious accidents (e.g., explosions), the ordinary operation does not pose any high risk of physical harm. The more automated the system, the less likely that the operator would make an error that would either ruin a run or lead to some dangerous situation. (On the older units more valves must be opened and shut, leading to greater possibility of error.)

Alarms are fairly distinctive and are related to specific characteristics of the operation. Some alarms can be triggered artificially (e.g., by atmospheric conditions) and under conditions whereby this might occur operators can and will defeat the alarm. The operator's responses to alarms that are perceived as true will be simply to shut down the process. In the automated system this is fairly direct, in that no set of instructions must be issued.

EVALUATION OF AUTOMATION

The automated process has been reliable and is generally accepted by the operators. By the nature of the system, it is not possible for the operators to operate it manually. In terms of an overall understanding of the process, the capability for manual operation might be useful, but since little benefit might be obtained from intervention, say in a stalled process, it is not important for normal operation.

To the question of how comfortable would he be with the computer making the decisions in an emergency situation, the interviewee replied that he would feel uncomfortable unless he knew the data with which the computer was operating was good. There are numerous cases in which the data are not as reliable as they need to be because of weather conditions, et cetera.

Overall, the automated processes are being accepted because of savings in cost. In addition, better recordkeeping is possible and it will be possible for the superintendent to monitor some of the newer systems from a central location. Some disadvantages are seen in terms of the operators' failure to learn certain aspects of the system. Further, motivational problems are seen as a likely function of boredom in the automated system.

PROCESS CONTROL/FACTORY INTERVIEW NO. 2

The interview was conducted on June 21, 1983. The company personnel interviewed were a manager and two engineers. The company originally developed its porcelain capability to support its brewery operations, but did some government work during World War I. In World War II, the company became heavily involved with government contracts. The company now has plants making porcelain all over the world. The product line varies from custom fabrication of specialized parts to mass production of millions of parts, such as ceramic substrates used in making electronic components. It is in these high volume operations that automation has been introduced. The porcelain division has had some recent upheaval. A decision, made by the chairman of the board, was to relinquish some of his personal control of the division and he brought in some new people to run the operation. All of these people have been recently hired. Their background is primarily in engineering. They have been heavily involved in changing some of the operations of the division.

BASIC PROCESSES

The primary discussion centered about some parts that are used in electronics. The process is that "green" parts must be produced and inspected before being fired in the kilns. The inspection process requires several measurements that are fed back to the press operators, who then make adjustments. There is some unreliability in measurements made in the normal manner. This is primarily because the human operator does not apply uniform pressures in micrometer type measurements and it is possible to deform the material slightly. The automated system produces a more consistent pressure and measurements typically vary no more than 0.0001 inch.

The operations are individual in nature. Although not every part is examined, a high percentage must be examined in order to maintain the tolerance required. Within this context the inspectors felt that they were not testing as many parts as they should with the manual system; thus, they felt that the automation was unburdening to them.

Basically, specific tasks have been automated. There has been some attempt to automate recordkeeping and data. However, the database management system has been developed inhouse and has not been, as yet, as useful as it might be.

CHARACTERISTICS OF WORKERS

The skill of the operators is somewhat similar to that of a machinist, but not at quite as high a level. It requires about 18 months to two years to acquire it. It involves some classroom work and a good bit of on-the-job-training. Although the setup people are accredited by the State of Colorado, they have little direct transfer for their skills in other occupations, with the possible exception of punch press operation. The progression of jobs is from operator to inspector to setup person. However, it is not necessarily the case that an individual goes in that progression. When jobs open up a bid is posted and anyone from any other job may bid. However, the majority come from within the operator group. New personnel are tested for mechanical aptitude. All inspectors are women, but this is not a necessary situation. Some setup persons are male and some are female. The age range within a particular group is very wide. Some do not have a high school diploma, but most are at about the level of a high school graduate. Experience within the company is also quite varied.

EFFECTS OF AUTOMATION

The question of what differences in the work force have resulted from institution of the automated process is difficult to answer, since there has not been sufficient time to reconstruct the selection procedures. However, it has been noted that the inspectors do not need the same sorts of skills which they previously required, particularly in the calculation of the discrepancy between what is being produced and what is desired. The likelihood seems to be that a new level of management may be required: one which understands the older system and basic problem and can take over when the automated system goes down. This will enable the typical inspector to be less qualified than those currently employed.

There was apparently some prestige associated with the inspectors who got to use the system first. This may have been due to the fact that the output was markedly increased or it may have been due to the fact that the engineer in charge gave special attention to the employee.

Prior to implementing the new system, a rumor circulated to the effect that the workers "don't like it and they won't make it work." In order to counteract this negative attitude, the engineer took each inspector aside for about two hours and gave them a brief introduction to computers. This exercise included writing a simple ten line program. This approach resulted in the inspectors becoming excited about the prospect of working with a computer-based system.

The set up crew had a similar negative attitude, claiming that the human operators could outperform the automated machine. They were sold on the advantages of the new system by observing its improved accuracy and repeatability. It was important to emphasize that this improvement was not due to any fault of the human operator but simply the result of the precise repetitive nature of the machine's operation.

Another very important factor affecting the high acceptance of this level of automation is that the company has a general bonus procedure, and any increased production could cause higher bonuses. Since no particular progression of jobs exists for these individuals, the bonus could be a greater motivator than in a situation where learning a new skill could lead to the next step up the ladder. There seemed to be very little resistance among the workers, since they viewed it as helping unburden them, but there was some indication that at the supervisor level there was scepticism. The performance of the system overcame this problem. Apparently, there was little, if any, difference in acceptance of the system as a function of age.

In this case the automated process is both relatively easy to learn and easy to use, since it is used in a relatively specialized set of tasks. The displays provide a digital readout and are similar to previous displays, but the information is different, i.e., more computations have been done.

Although the new process has eliminated the portion of the job that takes the most mental effort, increased speed seems to keep the job satisfying to the present inspectors. Since their measurements are also more reliable, they tend to go with the automated process unless a malfunction forces them to do otherwise.

GENERAL COMMENTS

In talking with this group, it seemed that they had a very strong concern with involving the workers at the earliest possible point in the process of automating a procedure. In fact, they said that they felt that they should have probably involved them earlier than they did. In addition, the importance of follow-up consultation with the end users was mentioned. Several potential refinements to the system had been brought up by the workers. In conjunction with automation of a different sort in a smaller sized group, it was noted that the acceptance occurred rather readily because the supervisor had a personal computer and was involved in working with it.

In general, the sanguine view of this group regarding acceptance of the system seems more likely to be correct than would be the case with some other individuals that we have interviewed, since they seem to be more closely tied with the workforce. This probably results from a combination of factors. One factor is the personalities of the individuals involved; a second factor is the company structure. Although the company is quite large, it is basically a family company. There seems to be a good bit of interpersonal interaction among persons at different levels as a function of historical relationships among individuals.

The comment was made that workers who have acquired "esoteric" knowledge of system operation often seem the most threatened by automation. They have achieved a status because of their special knowledge and are the most fearful of this knowledge becoming obsolete, or having their performance equalled or exceeded by a machine.

It was also stated that it is important to have people around who have a good understanding of the process. Without this understanding, further development and improvement cannot take place.

PROCESS CONTROL/FACTORY INTERVIEW NO. 3

BACKGROUND

The subject of this interview is the president and founder of a company which designs and manufactures control centers for use in various industries, including petrochemical, power, and municipal sewage treatment plants. The company has been in business for over twenty years. The company is located in spartan facilities and generally gives the impression of being a low-overhead, cost-conscious operation. It employs fewer than 50 people. About six of these are engineering personnel, with the remainder being involved in manufacturing.

The subject of the interview is in his mid-forties. He is quite articulate and evidently has given considerable thought to the implications of automation and new technology. Also included in the interview was an engineer involved primarily in the sales, development, and installation of water treatment plants.

PROCESS CHARACTERISTICS

The field of process control has been evolving since the turn of the century. The first stage of this evolution was the transition from dispersed manual control to centralized manual control. Acceptance was not a problem since this change involved a significant decrease in the operator's physical workload: he no longer had to physically travel through the process installation to set valves and monitor gages. The second stage was the introduction of centralized automatic control. Surprisingly, this took place in 1910-1920. Pneumatics were used to allow the operator to select desired set-points that were then automatically maintained by the automatic equipment. In some instances, the pneumatics have been either supplemented or replaced by electromechanical devices such as relays. The computer does not represent the introduction of automation in process control, but rather the introduction of new technology. The capability to automate has existed for about 50 years, through the use of discrete devices hard-wired into the system. Electronic controls were resisted when first introduced 15 years ago. There was also some resistance to computers, but in the last few years they have been more accepted. The primary resistance occurs when there is a new interface between the human and the system.

Computers, and in particular microprocessor-based systems, have led to the introduction of programmable controllers. The significant difference in this type of automation is the ability to gather and evaluate extensive data on the performance of the system, including system operators. A problem can arise when operators are not taught how to use this to their advantage.

Often this capability is viewed as merely another technique of management to scrutinize employee performance. The computer is considered a "tattle-tale," resulting in an adversary relationship between the operator and the system.

There are two chief reasons for automating: to optimize cost or to optimize product quality. Optimizing costs, especially in recessionary times, is often equated with worker displacement. When used to optimize quality, parameters that previously were difficult to monitor can be watched very closely. This places an additional burden on the operator. An example is the effluent from a sewage treatment plant. Previously, it was possible for it to be "out-of-spec" for a large percentage of the time. Computers allow continuous monitoring and reporting of conditions.

The petrochemical industry has a history of being up-to-date and probably is one of the most progressive fields with regard to automation. This is probably due to the economic motivation to increase efficiency and process throughput. On the other hand, municipal water treatment facilities have a history of being 5-10 years behind in introducing new technology. These two industries represent opposite ends of the spectrum with regard to "acceptors" versus "rejectors" of new technology. The mining industry has traditionally been on the rejector end of this spectrum. However, this situation is changing as petrochemical companies buy into the mining industry.

The interview subject has conducted an informal poll among his customers and contacts. This poll has resulted in his belief that "fully one-half of all automated control loops in the U.S. are being operated manually and have been since the first time something went wrong."

He has also sensed a tendency not to fix anything unless it is absolutely necessary. As a result, "when the automatics break, they tend to stay broke." Recognizing that it is an oversimplification and not always practical, he stated: "If you want something to work and stay working, don't provide any backup." A possible alternative is to make the backup unacceptable for continuous use.

Many of the company's clients, such as those in the power and petrochemical fields, are unionized. However, this does not seem to have had any impact on the acceptance or rejection of automation.

OPERATOR CHARACTERISTICS

The following opinions were expressed regarding the relationships between various types of users and their tendency to accept automation.

The lesser the degree of sophistication of the operator, the greater the resistance to automation.

Young engineers have been exposed to computers in school and are comfortable with them.

Older engineers seem to fall into two categories: some hope to avoid computers and make it to retirement by working with older, familiar technology; others are eager to tackle the new technology and learn computers. No profiles differentiating the two types could be offered.

The tendency is for automation to upgrade the level of employee in a given company rather than to reduce the total number of employees. This tendency leads to fewer operators and more managers in an automated facility.

Contrary to statements by others, this interview subject stated his belief that automation can contribute to a better understanding of the process by the operator, since there is more time to spend learning the process and less time spent physically reacting to the process. The old-time operator may not have really understood the process, but simply knew what to do when.

Most operators have a good deal of unscheduled time when dealing with automated processes. This can lead either to boredom or a constructive use of the available time. For example, the operator of a municipal water treatment facility had spent a significant part of his time back-washing filters under the previous manual system. When the system was automated, the operator was relieved of this task. Instead, he utilized the time to conduct a study of the filters and determine optimum scheduling for backwashing. In this case, the computer provided the operator with the tools, the information, and the time to expand his job capabilities.

SIGNIFICANT INCIDENTS

Recently, a new system was installed to automatically monitor conditions in a mine. The system had been developed by the engineering staff without input from the ultimate operators. When the new system was in place, the operators ignored it and referred to it as "the engineer's toy." They continued to do their job in the old manual way until a reduction in force increased their workload to the point that they needed the labor-saving features of the automated approach. They then voluntarily began to use the automated system. Another mine system was accepted almost immediately, even though it replaced some personnel, because the mine would have been shut down completely without it.

In another case a system was installed in a factory. The system has been in place for over four years during which it has experienced two problems, one at startup and the other after it had been in operation for three years. In each case, the serviceman disassembled the system, could find nothing wrong, only to have the system work normally when it was reassembled. Even though the system had a demonstrably reliable record, the users considered it unreliable because the causes of failure were mysterious and not well understood. "Reliability" as it concerns user acceptance is not an objectively quantifiable fact, but a subjectively perceived notion on the part of the user. It was also noted that this system was not the one desired by one important person in the hierarchy of that organization.

In this particular situation, since the company manufactures custom installations, it is necessary to debug the system after it is installed. This results in an overlap between development and actual operation. Furthermore, this debugging operation is often done with the cooperation and involvement of the operators, thereby serving as an in-depth training exercise. Operators who are trained in this manner usually have little problem accepting the system.

ADDITIONAL COMMENTS

A problem with automated systems today is that those whose responsibility it is to specify system performance parameters do not know what to specify.

Two disadvantages of newer automated systems are: 1) operator resistance to learning the new technology, and 2) dependence on unavailable skills such as programming and the ability to troubleshoot digital electronic equipment.

Given a choice, it is far better to automate 25 percent of a plant and have it work all the time than to automate all of the plant and have it work 90 percent of the time.

Trained personnel tend to migrate through a company and an industry. As a result, since they may not be available when the system develops problems, the automated features may simply be abandoned with the process reverting back, at least in part, to manual control.

When an automated system is installed in parallel to the manual process and a direct comparison is possible, the new automated system will usually be preferred. Conversely, if the old system is not available for comparison, it tends to be remembered as being better than it actually was.

If you wish to have an automated system used, don't give the operator an off switch.

Training is given by this company, but they consider it to be a relatively minor function. In the course of the discussion they noted that it would probably be possible to sell some training courses. But by the nature of their product, i.e., one of a kind, a substantial part of the training is on-the-job-training. Perhaps their lack of enthusiasm for training courses is related to their general approach, which seems to be very development oriented.

PROCESS CONTROL/FACTORY INTERVIEW NO. 4

The interviewee was interviewed on July 6, 1983, at Denver, Colorado. The interviewee is a representative of a manufacturer of instruments which are used primarily in process control industries, most commonly the oil and gas industry. The company has specialized in instrumentation for its entire 76 years. The interviewee has an M.E. degree and has been with the company several years. He was previously a helicopter pilot and has continued to keep up his proficiency in the Army Reserves.

At the current time he is being checked out in the Cobra S-2. This aircraft has a heads-up display (HUD) and also has several automatic control procedures. A brief part of our discussion pertained to his experiences with this system. A part of the automatic control included in this system is a compensatory position control that senses changes in the aircraft position, which are not the result of control action and institutes action to counteract the changes. This process is occasionally disconcerting because the pilot has been trained to respond to the same forces and, therefore, often an over-response may result. Another aspect of the system that is affected by negative transfer is the HUD, which has the important instruments displayed on it. Despite the presence of the information on the HUD, there is still a tendency to scan the instrument panel. This has some implication for training on some of these devices.

The company supplies instrumentation and controls of many types to the process control industry. They service companies which still use field instruments and sight glasses as the sole technique for operating refineries, as well as companies which use the latest in consoles with CRT monitors and microprocessor controls. While the cost of introducing new technology is an obvious factor in holding to the old, the rate of amortization of some of the control stations is relatively short, perhaps averaging three years. Thus, the fact that some companies hold to the older systems can be traced, in part, to the philosophies of the managers. While some may simply lack interest in new items, others distrust or fear the new systems, or both. One rather interesting phenomenon is the response of some operators to alarm signals. Rather than respond to the condition as displayed by the apparatus, the operators will go to the reporting station and check the sight glass. Unfortunately, some conditions require prompt action, and the delay can be quite damaging.

The company maintains schools for a number of its systems. In the opinion of the interviewee most of the operators who learn the system are happy with it, because it does make their jobs easier. There is, however, a tendency for some to feel that there is the threat of displacement. This is not wholly without foundation. For example, in a control room format one operator can handle only about 100 loops, while with the console workstation a single operator can handle up to 400 loops. Interestingly, the concern with displacement seems to be greater with those maintaining the older systems.

In most of the systems with which the interviewee is familiar, the operators are largely high school graduates who serve a sort of apprenticeship as maintenance men before being trained as operators. The operator's position may lead to a supervisor's position, but beyond that there is no clear sort of progression in jobs. Some individuals, of course, may progress up the ladder of management.

The systems discussed have provision for prioritizing of alarms and also capabilities for locking the operator out. The specific provisions are ordinarily selected by the particular company in which the machine is placed.

PROCESS CONTROL/FACTORY INTERVIEW NO. 5

The interviewee has a degree in engineering and was previously involved with water pollution for a large national company. He came to Colorado for western slope processes with another company and shifted to a Denver engineering firm for three months before going back to sales as manufacturer's representative with present company.

Different types of controls used by companies were discussed. Noted that trend was to fewer items on keyboards, because the early keyboards presented worries for workers. They were afraid that they might do wrong thing. Another problem is possibility that unauthorized individuals might "play" with them and create problems. Management's philosophy is to reduce implied risk.

Sabotage does occur - often from worker not directly responsible for apparatus. May not even concern automation.

When process involves larger numbers of loops -- must call directly. Potential problems with apparatus: Need to have "enter" key for most commands. This avoids errors, accidental depression, et cetera.

Question of interest in how apparatus operates -- engineers are interested in what would happen (from more theoretical view). Operators are often frustrated by lack of training and lack of information about what would happen if certain responses were made to the apparatus. Often the training is to the computer, not to the process.

Operators relate well to graphic screens. Trend is toward having redundancy of graphics. Same basic information may be included in different contexts.

Possible approach to responding to alarms -- when a subsystem needs attention, have a blinking symbol on touch panel. Then response calls up relevant information. Problem of jargon.

Touch panels are mainly optical systems (i.e., light transmission is interrupted at particular coordinates).

PROCESS CONTROL/FACTORY INTERVIEW NO. 6

BACKGROUND

The subject of this interview is employed at a municipal waste water treatment facility as a Class C Waste Water Treatment Operator. Since his background is in computer programming, he was hired to solve problems with the automated system. He is in his mid-thirties and has been in his present job for over four years. He appears to be very knowledgeable and interested in computer systems.

PROCESS CHARACTERISTICS

The process involved is a municipal waste water treatment plant, which has a capacity of twenty million gallons per day (MGD) with a peak of thirty MGD. The facility consists of approximately twelve buildings spread over ten to fifteen acres. The plant was put into service in 1976 and was intended to represent the state-of-the-art. The process was to be controlled by a Fisher-Porter Series 3000 control system interfaced to a Varian V72 Computer. A Data Point one megabyte hard disc was installed for data storage and retrieval. Six sequential control loops were used to monitor and control the various processes at the plant. Analog sensors were installed throughout the plant to feed back information on the status of the process. The entire plant was designed to be tended by no more than two operators per shift. The instrumentation and control system cost approximately one million dollars, in 1976.

From the very beginning, the system did not operate properly. The system "crashed" on the average of several times per month, losing all of the data that was stored at that point; the longest period of continuous operation was four months. The program was stored on punched cards, making the process of reloading the program very time-consuming. Although the equipment was intended to automatically keep track of periodic maintenance requirements, the frequent crashes made this feature useless. At first, the system allowed the process to be monitored in real time, from a central control room. However, the analog sensors that were installed in the field proved to be unreliable. Apparently, they were not properly designed to withstand the environment in which they were installed. Float arms would stick in position, resulting in an erroneous indication of tank levels. Since the readouts on the central panel could not be trusted, it became necessary to send an operator into the field to verify readouts. Eventually, what was to be a state-of-the-art system degenerated into an outmoded operation that required distributed manual control to maintain the system in operation. Although the system was budgeted for two operators, it required six operators to run the plant, resulting in significant cost overruns.

When the specifications for the new plant were developed, the municipality did not have the expertise available to adequately prescribe system performance. Consequently, they were forced to take the word of the vendor. The resulting system was not properly matched to the requirements of the facility. For example, a unique oxygenating process was included in the system design. However the sensor outputs of the oxygenating subsystem were not compatible with the input requirements of the automated control system resulting in incorrect control of the oxygenating process and therefore out-of-spec effluent from the plant. Due to design errors, such as this, and the inability of the crew to keep up with the system, the effluent from the plant was frequently in violation of acceptable standards.

The initial purchase price of the system did not include the maintenance required to keep the system in operation. An additional $70,000 per year was quoted for a maintenance contract. Rewriting the software to match the plant requirements would cost $60,000.

The subject of the interview was hired after the plant had been in operation for about two years. It was hoped that his computer background would enable him to solve the problems associated with the automatic system. However, the documentation furnished with the system was minimal and certainly not intended to enable modification of the system. The operating program was furnished on punched cards but a keypunch machine to modify the program was not available. The interfaces between the Varian computer and the Fisher-Porter equipment were non-standard and undocumented. Furthermore, Varian had been acquired by Honeywell and the Model V72 computer was no longer being made. Similar systems in Albuquerque, New Mexico and San Jose, California were working better, but only with a great deal of expensive, "live-in" support from the vendor. These other systems were provided with a great deal of redundancy which reduced the impact of the unreliable components.

Finally, the municipality hired an engineering management firm to operate the facility and attempt to straighten out its problems. The management firm soon concluded that not only was the automatic system not contributing to the efficiency of the plant but it was in fact a significant drain on the available resources. Although a great deal of time was being spent trying to make the system work automatically, it was essentially being run manually.

Ultimately it was decided to abandon the automatic system and officially acknowledge that the automatics were a total failure. The equipment related to the automatic system was torn out and placed in storage.

OPERATOR CHARACTERISTICS

Operators are certified by the State as Class A, B, or C, through the use of a written examination. Training is a combination of on-the-job-training and classroom training. Courses, which prepare operators for State certification examinations, are available at local junior colleges. In a separate phone interview, the president of the firm that manages the plant said that the operators liked the automated system and "miss their toy." The implication was that trying to make the automated system work, even though these efforts were unsuccessful, was more interesting than the routine operation of the facility. The subject of the interview, in particular, felt that an automated system was needed at the plant, since it was not designed to be operated manually. Since his previous background and training had been in computer programming, he is especially unhappy in the role of a manual tender of a sewage treatment plant. He expressed frustration at the current austerity program, which provides only enough budget to maintain legally acceptable operation of the plant. No resources are available to upgrade instrumentation, which he feels is necessary.

PROCESS CONTROL/FACTORY INTERVIEW NO. 7

The subject of this interview is employed by a company that manufactures glass bottles for use by the parent company, which is a brewery. He is a technician in the plant engineering section, with responsibility for troubleshooting and making improvements to plant equipment, particularly in the area of instrumentation and control. He is about thirty years old and has been with the company for approximately eight years. Because of his position, he is called upon to remedy problems associated with the various control systems used in the plant and consequently is aware of most operator complaints. He is non-degreed with technical training in electronics.

Since the interviewee occupies a staff position, he looks at the situation somewhat differently than does either management or labor. As a consequence, he was able to present a picture of the interaction of management with the system and with labor, which some other individuals might not have. A significant aspect of this situation is that the management is often bound by one or a few events just as a laborer might be. In this instance, a prior catastrophic event had conditioned management to completely abjure the use of any computerized control procedures.

In addition to the view which he has of management and labor, the interviewee also occupies a position which is likely to become increasingly important as the number of automated systems grow. He is a person who understands the capabilities of computers and how to utilize those capabilities. As such, he would like to see the system working to its maximum. However, both labor and management have reasons for not proceeding as rapidly as possible toward that goal. In effect, any individual who will be affected on a daily basis by the institution of automation may be less willing to accept it than an individual who is able to use it or ignore it at will.

PROCESS CHARACTERISTICS

The process involves taking specially selected and processed sand, mixing it with chemicals such as iron pyrite (for amber color glass) and a percentage of reground glass (cullet), and firing these ingredients in "tanks" until they are molten and can be cast into the desired shapes. The ingredients are fed by a conveyor and hopper system to one of three "tanks" that produce molten glass and feed the glass into the bottle-making machines.

The three tanks were built at different times and have completely different controls. Tank No. 1 is a primarily manual system with conventional knobs and dials controls; process data are monitored through the use of chart recorders, which prominently display the records for a twenty-four hour period. Tank No. 2 is automatically controlled from a panel, which incorporates a CRT color graphics display and a uniquely formatted keyboard for entering control commands. Backup is provided by panel meters and annunciators for immediate data display, as well as multi-channel strip chart recorders for long-term trend information. The keys on the keyboard each have different functions, depending on the order in which they are depressed. As a result, the keytops are blank and their functions must be learned in a week-long training course. A great deal of information is available to the operator or manager, but it requires this extensive training to be capable of accessing the information. As a result, management tends to feel shut off from the process and has expressed preference for the manual process used on Tank #1 with its direct access to process data.

Tank No. 2 involves innovations in the actual making of the glass, which make it unlike any other glass process in the world. These innovations caused serious problems and equipment damage (a meltdown of sorts) during the initial operations of the process. Although computer control of the process had nothing to do with these problems, management tends to link the fact that the process which caused them so much trouble is also an automated process. Thus, a computer that could improve efficiency and output remains unused because of a management directive that no computer is to be used for control.

Tank No. 3 was also designed to be automated. However, it represents a step backward in technology from the previous computerized version to the electronic control version. In this case, the engineering department of the parent company was brought in to design the process equipment. They came in with the attitude (as perceived by the glass plant employees) that "we're going to show these guys how to make glass." The resulting equipment did not lend itself to the process to be controlled. A standard typewriter keyboard was used to input commands; this technique has proven to be cumbersome for the operators who are not accomplished typists. Information is displayed on a black and white CRT. The equipment has not been accepted by the operators and the process is currently being controlled manually. A computer is being used as a very expensive data logger to display process information.

One comment, in conjunction with this situation, is that engineers tend to design systems that are easy to design rather than systems which are easy to operate or maintain.

The basic thrust of the automation is probably unburdening of the operator coupled with greater efficiency of the process. The same number of operators are required for each system. However, according to the interviewee, it would be possible to control two tanks, with relatively little added equipment, by using the capabilities of the computerized system, and a single operator could run them both.

OPERATOR CHARACTERISTICS

Process operators are typically high school graduates and usually come from the ranks of relatively unskilled laborers in other parts of the factory. Company employees are invited to bid on openings as they occur, with the ones showing the greatest aptitude being selected for the position. Thus, there is no specific progression through which the operator would come to the job. Operators undergo classroom and on-the-job training and must achieve State certification. One problem of the bid system used in this company is that an individual who is a key person for the operation or training on a particular machine can bid for another job in the company and leave a gap in the system. In the situation involving the computerized system, a key person left before the system was completely debugged and operational, and the potential of the system was not achieved for a lengthy period.

The operators are rotated among the three processes, therefore, they must be familiar with each. During this interview, which involved a tour of the facility, an operator was asked about his preference among the different systems. He commented that in general the operators seem to find the computerized tank easiest to run, but not all of them prefer to work on it. There seem to be two categories of operator. On the one hand, some operators prefer the Tank No. 1 style of control system because it gives them a very limited but simple to read display of process data. A few of the operators prefer the Tank No. 2 system because they enjoy playing "games" with the controls. These operators, no doubt, understand the system very well. If this operator and the interviewee are correct, few, if any, of the operators prefer the newest (though not most up-to-date) system.

Since all operators must run each of the tanks, there is no special economic benefit or prestige associated with operating the automatic system. However, there seemed to be a tinge of envy in the statement of the operator who said that the bright guys like to play "games" with the system.

The amount of physical effort or psychomotor skill required is quite minimal, but there is some mental workload. The individual must know what responses are to be made in specific situations and a modest amount of vigilance is required so that the process doesn't "get away from the operator."

A member of the maintenance crew was asked which of the systems was easiest to maintain. He said that the computerized system was easiest, but that problems occurred so infrequently that he had to go back to the instructions to help him to remember how to fix it.

CHARACTERISTICS OF THE AUTOMATED PROCESS

Since the process is a continuous one (around the clock, 365 days a year), the operator must monitor it and maintain a stable state. In general, this means that the various subsystems must be kept within their set points and any deviation should be acted upon to bring it back within tolerance. In the case of the automated procedure the system requires some time to learn (some classroom type training plus on-the-job-training), but once learned it is easy to operate and is also flexible.

The displays used to monitor the process are colorgraphic CRTs and are quite different from those used in the less automated systems. However, a trained operator can get a good bit more information from this system. Unfortunately, the usefulness of this additional information is not readily apparent to either the management or to most operators. Therefore, they do not feel a need to act upon it and consider the system more like a toy. While the system has the capability for running completely automatically, it may also be run almost completely by manual control. The operator may override at almost any time. This points up a bit of a dilemma. In order to gain acceptance into the situation, it is often necessary to show that a manual backup is available, but when manual backup is there, it may preclude the proper use of the automated system.

While the errors that might occur may be overcome, if detected relatively soon, it is possible for serious damage to occur to the equipment. The responses to malfunctions are not direct in the automated system, but they are direct in the manual backup system, which is in parallel to the automated system.

EVALUATION OF THE SYSTEM

The view of this system appears to be different for each of the types of individuals (and perhaps each individual) associated with it. Management is afraid of it, maintenance personnel like it, operators accept it as reliable, but not totally straightforward, and those involved in making the system work wish they could convince management of its usefulness. Our interviewee would like to see additional aspects of automation incorporated into the process, but it seems unlikely that either management or labor will push automation.

PROCESS CONTROL/FACTORY INTERVIEW NO. 8

BACKGROUND

The subject of this interview is a machinist in his fifties. He has over twenty years of experience, during which he has seen several technologies come and go. The first wave of automated machine tools came in the 1960's, with numerically controlled machines. These machines primarily used punched paper tape to drive a mill or a lathe along a set of preprogrammed coordinates. According to the interview subject, the transition to NC did not go smoothly. This was due primarily to the difficulty of programming. Mistakes could "crash" the machine, damaging the workpiece or even the machine itself. Many trigonometric calculations were needed to program the machine, making it a laborious and tedious process. Although the physical skills required to machine a complex part were reduced, the mental labor was increased. Numerically controlled techniques proved not to be cost-effective except for high volume production, due to the amount of time needed to debug programs. Only the big shops could afford to hire a dedicated programmer with the two to four years of experience it took to efficiently prepare the tapes for the numerically controlled machines.

In the late 1970's, a new generation of automated machine tools became available. These machines were called computerized numerical control, or CNC. Computerized numerical control machines can be programmed directly using an alphanumeric keyboard. Programs are stored in machine memory or on various magnetic media, such as tape or diskette. Programming is more intuitive and does not require the specialized skills necessary for numerically controlled programming. Even small jobs, requiring the machining of one or two parts, can be produced cost effectively on a computerized numerically controlled machine.

Traditional machining skills are still needed to set up a part, choose appropriate speeds and feeds, select the right cutting tool, and in some cases, grind a tool specifically for a job. Much of this skill is the result of a "feel" for the process, which has been developed over time. Once the machine has been set up, an apprentice machinist can produce parts of the same quality as a journeyman machinist. However, experience is still needed to analyze problems and make corrections. The interview subject expressed some concern about how these skills will be acquired with the automated machines.

PROCESS CONTROL/FACTORY INTERVIEW NO. 9

The interview was conducted on July 26, 1983, at a small city wastewater treatment facility. The interviewee was about 35 years old and had been in his present position about two years. Previously, he was employed elsewhere as a start-up, training, and trouble-shooting person. He came to that position from a Colorado treatment plant. His interest in this area developed out of his work in the Denver City Parks, where he worked with the swimming pools. He has an associate degree in waste water treatment and is certified as a Class A operator for both water treatment and waste water treatment. Currently, he is in charge of the waste water treatment plant and is intimately involved in both the current operation of that small facility and in the development of the larger facility, which will ultimately serve an area containing 32,000 homes.

The interviewee, a fairly dynamic individual, is strongly in favor of automated processes. He feels that he has the capability to make them work, based on his experience with a number of systems.

EXTENT OF AUTOMATION

The process is basically a continuous one, but operates at a relatively slow rate. Depending upon the facility, the process may be almost completely automated or almost totally manual. Older systems involved nothing more than a lagoon, in which the larger items were allowed to settle out before the remainder of the sludge and water were sent downstream. The process used at the plant operated by the interviewee is not fully automated because of its small size. The new plant will have a capacity of more than 16 times that of the present one, and will be almost fully automated. Included in the automatic process will be calculational functions and recordkeeping functions. The basic operation of the plant will be automated, including normal operation as well as various undesirable tasks. While one function of the automated system is to minimize the staffing required, in the present situation it may be viewed as an unburdening, since the plant is being operated with minimal staff. One reason for this approach is that it enables the operators to remain busy most of the time, thus avoiding some motivational problems.

In the automated system, as well as in more operator oriented systems, a primary function served by the operator is that of monitor. Displays are similar in nature to those used in the manual process. In most cases the information which is presented will be the same as in the earlier systems, but in the automated system more information will be available. For operators of the less automated systems, there is little difficulty in progressing to the higher level of automation, since the operations and the sequences in which they are to be done vary little, if at all. A significant problem may arise in the attitudes of some operators, however. Since the operator has the option at most times of overriding the system, some operators will go to the physical location of a device and operate it at that point so that they can be sure it is functioning.

CHARACTERISTICS OF THE OPERATORS

While the operators of these systems vary in age and background, changes are occurring fairly rapidly as a function of the certification requirements and the differences in the way the plants are operated. In the very old systems, the operators were usually at the bottom of the socioeconomic ladder. The newer operators are at a higher socioeconomic level and have more formal education. Those operating the newer systems also tend to be younger. Although the interviewee did not feel that age made much difference in the ability to learn the newer systems, he thought that "time in grade" bore a negative correlation with the speed of learning the new systems. This might be related to attitude or possibly some negative transfer.

The levels of skill in the progression up the ranks are related to the four classes of certification used by the state. The correlation between skill and certification level is less than perfect for a number of reasons. Some of the older operators were "grandfathered" in to their classifications, while some of the younger operators have passed the tests but have little experience.

There is some prestige among the operators in terms of both economic factors and having the skill of operating the more complex plant.

The physical workload is not great in the automated system, but there is a somewhat greater mental workload. The mental workload is associated with a need for vigilance and understanding the system. In some of the older systems, it is likely that the operator would have little opportunity to plan for contingencies or to think through a course of action in an emergency, because he would be busy operating valves and carrying out inspections of the processes. With the time freed up by the automated system, there is the possibility of evaluating trends.

SYSTEM PROBLEMS

While little immediate physical danger is imposed by the system, if the effluent is out of tolerance to any great extent, it may pose significant problems for the downstream segments of the watercourse.

Most potential problems have alarms attached to them, which typically ring a buzzer. Unfortunately, for the sort of biological system which is used in this plant the most damaging sort of problem is the occurrence of a large amount of a toxic substance in a short time. This kills the organisms which consume many of the waste products, and in extreme cases the system must be reseeded. Because the warning time is short, little can be done to avoid the immediate problem. In most cases, the responses to alarms are direct. Some malfunctions will automatically initiate corrective measures.

EVALUATION OF EFFECTS OF AUTOMATION

In a number of situations, the automatic process has been reliable. However, in some cases that the interviewee recounted the automated systems did not work. He attributed the causes of most of these situations to failures of management. One problem discussed was the failure to hold the installing company to the task of providing a fully operational system before they left. In one instance, this was compounded by the concatenation of two different work forces, who more or less blamed one another for the problems.

Another problem seems to arise when political factors intervene in the operation of the system. If the management is more concerned with keeping operators satisfied, or does not consider the automated process to be a good thing, then the workers will tend to operate in their accustomed fashion. A case in point was a system which was operated by a municipality, but whose costs were borne almost totally by industry in and surrounding the community. Since there was no real concern with efficiency on the part of the municipal officials, the automatic systems were allowed to fall into disrepair and were not restored to working condition. A team from a consultant was called in and got the plant operating as it should while providing some training for the permanent personnel. After the team left, since there was no demand from management for maintaining the system in the automatic mode, things soon returned to the previous state.

Yet another factor, in which management must be involved, is the maintenance of a reasonable workload for the operators. An example was given of a municipal water system that essentially shut down some of its older plants in the winter and moved all the operators to the one that remained operational. The morale of all operators was low until a new manager decided that instead of pulling the operators away from the plant they should be utilized in refurbishing and upgrading their portion of the system. This resulted in improvement of both the morale and the equipment.

A general sort of conclusion from this source is that at least one, labor or management, must be involved in making the system work. Most of the time both must be involved. If the managers do not know how the system works, they are at the mercy of the operators who say the system or some part of it won't work. Since there is often a reluctance to change, the managers must show the workers what the benefits of the change are.

Although he is eagerly awaiting additional automation for the processes, the interviewee does think that the components involved must be reliable or not be used, e.g., some sensors.

PROCESS CONTROL/FACTORY INTERVIEW NO. 10

The interview occurred July 26, 1983, at a water treatment plant of a large city. The interviewee is the chief operator for the plant. He has worked in this system for three years, beginning as a trainee in the system. However, the interviewee was previously employed in a similar capacity by a large city in Wyoming. Prior to that, he was the operator of the water system of a small town in Wyoming.

The interviewee is about 40 years old and is basically a self-taught individual. He is somewhat retiring, but is articulate and seems to be progressive in his outlook.

In addition, the engineer for the site was also in attendance for part of the interview. He has been employed by the Water Board for about 18 years. He is about 45 years old, appears to be self-confident, with a positive attitude toward automation. He is a member of the committee on automation of an instrumentation engineering society.

EXTENT OF AUTOMATION

The facility is one of the most modern and most automated systems in the state of Colorado, although the length of time between drawing the plans and starting construction was so long that some of the latest equipment is not included. Both unburdening and displacement of the worker is involved in this sort of automation. While the reduction in number of operators needed per shift in comparison with a manually operated plant is significant, many of the automated processes have little effect on the number of employees needed. For example, the logging of the data with respect to alarms and other incidents is now done by copying from the printout of the computer. It is likely that except for circumstances when the computer is down the operator will be relieved entirely of performing this task.

As is the case with other automated water treatment plants, the primary task of the operator is to monitor the operation of the plant and to take such actions as may occasionally be necessary to keep the processes in the required bounds. The automated process is relatively easy to learn and to use, since most of the operations are quite repetitive. In general, functions may be performed by either the operator or the computer, but the operator has the capacity to override the computer at most times. As a backup, the human can perform the actions of the computer in two ways, thus, the system is highly redundant.

In the main, the job requires relatively little in the way of physical strength or of refined motor skills. Training requirements are those of the state certification board. The automated process is basically learned by on-the-job-training. It is both easy to learn and easy to use.

Problems in the system are usually the result of minor operator errors and are generally correctable, readily. When any serious imbalance in the system occurs, an alarm rings to notify the operator. The responses of the operators are basically direct.

OPERATOR CHARACTERISTICS

The operators of this plant are mainly in their twenties and thirties, although in other plants of this system the average age is higher. They come from a middle socioeconomic level. Again, the level of workers on other systems is rather low. It is common for them to have an associate of arts degree in the area of water treatment. Most have enough experience to have the class A operator's license.

Some prestige accrues to working in the automated plant, but at the present time there is no pay differential. There is some feeling at the supervisory level that an increment is needed or the more highly qualified personnel will leave for other water systems or other process control sorts of jobs.

When asked about the factors, which differentiated the operators in terms of their acceptance and learning of the automated systems, the interviewees indicated that age and time of service were the primary factors affecting learning the new system. There was a feeling that the younger operators were less set in their ways and that they were more familiar with computers.

There is also more resistance to implementing the automated process among the older individuals. They may be more prone to be threatened in the area of job security, since many of them are at an age where they would find it impossible to move to a new position.

A concern, expressed by the interviewee, was that while the current operators were participating in the shakedown of the plant and learning how the automatic system responded when it was not working properly, the later operators would not have the direct experience with the problems of the automated system. Consequently, at a later time the automatic system might malfunction and no one would be around who could recognize the problem.

ACCEPTANCE AND EVALUATION

The present system seems to be well accepted and is considered reliable for such a new system. In the main, they feel that it is doing about as well as could be expected at this stage.

PROCESS CONTROL/FACTORY INTERVIEW NO. 11

The interview was conducted at a large city water treatment plant on July 28, 1983. The interviewee is in charge of the software for all of the process control operations of the water board. He was interviewed because his relationship to the automated system was different from that of others who had been interviewed and because he has personal knowledge of a number of the operators of a number of the systems. The interviewee is about 40 years old and has been with the Water Board for nearly 20 years. He began in the hydraulics area and has been involved with process control for the last ten years. His work seems largely to be development, maintenance, and upgrading of software for the various activities of the water department. An example of his activity is the development of a program for modelling the water pressure pattern for a particular period. He is an exponent of automation.

EXTENT OF AUTOMATION

The water treatment plants in this system vary, from 1930's technology to the plant at which the interview was held, which employs most of the recent technology. While a major consideration of the automation in this system is increased efficiency and would involve somewhat fewer workers, much effort has been expended in attempting to incorporate the suggestions of the operators. In some cases a feature would be requested by operators and later found to be impractical, but an estimated 90 percent of the material was kept in the operating system.

Depending upon the particular plant, different aspects have been automated. At the latest plant, most routine operation has been automated, as well as computational functions and almost all recordkeeping and data management. In the system, as a whole, some 600 different points are now monitored automatically, and one can operate on about 300 of them from a central station.

One of the problems, which has been reduced by the introduction of automated processes, is that of load distribution. At one time, three different plants were serving three separate but interconnected areas. Consequently, when the flow was adjusted at one location, it was somewhat disrupted in the other areas. Through integration of the systems, it is now possible for feedback control to tune the systems rapidly.

In addition to the displays that are more or less mimicking the older displays, in the operation of the water treatment plants there are graphics displays that enable the operator to follow the processes that are in operation. While these displays are visible, changes can be entered from the terminal used to call up the displays. All of the operations of the computer may be overridden by the operator by switching to the manual mode. Thus, while the computer may be locked out by the human operator, the human operator is not locked out by the computer.

OPERATOR CHARACTERISTICS

A fairly rapid change seems to be taking place in the level of the operators. Both amount of formal education and socioeconomic levels of the newer operators are higher than those of the older ones. His observation is that the greater the amount of experience, the greater the resistance to change. However, after the older operators become acclimated to the automated system, they complain vigorously if it goes down.

Although the operators nominally must make a walk-through of the plant at regular intervals, it is possible that if one reached a certain level of trust of the equipment, one might not bother to perform that task. This seems particularly possible on the night shift when the load is light. On that shift it is common for the operators to read or do other tasks which are not directly related to the operation of the plant. Since the operators need to monitor the instruments only occasionally, it is possible that a trend could develop without being noticed. However, if a serious condition is reached, an alarm sounds. Some operators have displayed significant interest in the operation of the computer and will likely become involved in using it to the maximum. It is possible that others may become bored when the plant is operating as scheduled.

The operators need a thorough understanding of the process. Even though under ideal conditions the system could run for some time by itself, the possibility of power failure or other system failure requires that the operator be able to handle the process manually. In effect, there are several levels of redundancy, with each level requiring less sophisticated equipment.

While the mental workload is not heavy during most of the operations, it is possible that the automation may lighten it by allowing the operator to spot trends more rapidly and thereby even out the total workload better.

ACCEPTANCE AND EVALUATION

At this stage, the operators seem to accept the automated system and to accept the malfunctions as a part of the normal shakedown process. Several factors probably contribute, in varying degrees, to this acceptance. One factor is that the individuals were selected on the basis of their performance on other automated systems. They are generally young and have more formal education than the other operators. Another plant in this system was designed as a pilot project for the automation involved in this plant. Although there was much deviation from the original plant, the operation of that plant may have convinced the operators that it is possible to have a reliable system. The company which developed the software for the system has been highly responsive, and problems have been taken care of rapidly for the most part.

While the operator can override the automatic equipment and in some cases may choose to do so, the operators who override frequently are typically the older operators with much experience on the manual systems.

Another feature which may influence the acceptance of automation is the effort made by the software and instrumentation people to involve the operators in the process. For example, in addition to writing software tailored to the needs of the operators, the interviewee takes the operator with him when a problem arises in the field (e.g., a sensor malfunction) so that the operator can see the object being repaired. This serves two functions. In some cases the problem is such that the operator can learn how to do the repair, and even when the operator does not know exactly what is going on, there is a certain amount of demystifying that occurs as the operator sees that another human can take care of the problem. In addition, there seems to be a responsive company that is responsible for the software. Thus, problems are solved with some dispatch.

The primary gain from the automated process is the capability of the operators to evaluate the situation on a more global basis and to detect trends faster than they could while operating manually. Some manual skills may have been reduced, but they are not crucial in the sense that speed or high dexterity of movement could be.

While little specific discussion of the effects of automation on management occurred, it is apparent that changes are occurring in the relationship of management and worker. It is now possible for a manager to get a computer printout of the operation of the plant for any specific period. Previously, the operator's log was the source of this information. The log was subject to omissions, whether willful or not, which might conceal what had been going on. The capability for getting information without interacting with the operator may have different effects on managers who use different styles.

The interviewee sees automation as the path of the future, but he does temper this with the notion that there is no need to replace any system just for the sake of using more exotic technology.

PROCESS CONTROL/FACTORY INTERVIEW NO. 12

The interview was conducted on July 19, 1983, at a major city water treatment plant. The male interviewee, about 50 years old, has been in charge of the instrumentation for the water system of the city for five years. His training was largely in the electrical and electronic field. He previously worked 20 years installing and repairing water treatment and wastewater systems. He is thoroughly familiar with the various sorts of systems which are in use over a large section of the country.

His view of automation is that it is good, whenever the processes are adaptable to automation. He singled out the concept of proportional control as an instance in which the capability for automation is not yet available. The basic problem is that of maintaining an appropriate level of chlorine in the water for the momentary conditions. This requires a feedback loop in which the level of chlorine is constantly monitored. Apparently it is necessary to isolate a sample for a chemical test in order to determine the level. To do so requires drawing the water off on a separate line. When this is done, the length of time between getting the sample and the test involves too great a lag and the level of chlorine is increased late and decreased late, also. Thus, in developing the design for the new plant a manual system was selected. Operators sample the level of the chlorine hourly and increase or decrease the flow of it into the system as needed.

EXTENT OF AUTOMATION

In large measure, the results of the automation in the water treatment area have been to unburden the operators. Although several plants have been designed to run almost completely automatically, unreliability of the systems or lack of support for the systems has negated the possibility of doing so. Thus, the number of operators has not been diminished greatly.

While much of the operation has been brought under computerized control, this has been done in a sort of piecemeal fashion. For instance, the alarms for level of reservoir, low level of chemical tanks, etc., are picked up by a computer and transmitted to the control panel. The use of a computer directly by the operators is restricted to printing out the data as to what alarms and other events have occurred in the system over a particular period of time.

Automated processes have been developed to handle some of the most time-consuming tasks of the operators, such as washing the tanks. However, there has been resistance to the idea of trying to make the new plant completely automatic, since there was much difficulty with an earlier attempt.

CHARACTERISTICS OF OPERATORS

The operators known by the interviewee include many older operators as well as what might be termed the new breed. In discussing the ability of operators to change to newer systems he pointed out that there was considerable diversity among them. Some operators simply would not trust any gauges other than the ones which they had used for years. Although he was unwilling to generalize directly, it seemed that level of education might be a factor in this situation. Age could also have some effect. However, no one factor could be singled out as strongly related to the problem.

While no specific instances were recounted, it seemed that he regarded boredom as a distinct possibility in the case of highly automated systems. He commented that he would find it difficult to spend that much time doing nothing. In particular, the night shift would be lacking in interesting activity.

CHARACTERISTICS OF AUTOMATED PROCESS

As the system is designed to operate, the operator is largely a monitor of the system, but with a few specific actions which he is required to perform, e.g., certain chemical analyses which are performed on schedule. The operator may also initiate certain processes which would otherwise be automatically done. For example, the washing of filters is done automatically when a certain level of turbidity is reached. This level is represented on a Light Emitting Diode (LED) scale that is patterned after the scale used with manual equipment. The different cycles of the wash are timed by timers which are set at a console by the filters. The operator can also initiate a wash of a particular filter, either at the main console or at the console directly adjacent to the filters. In the main, the operator is in control of the automated system, because he can override it at almost any time. The exception is that once a timed process has begun it will be completed.

The primary mental workload experienced by the operator under the automated system is determining the amount of chemical which must be added. This involves calculations based on the characteristics of the water as determined by the tests made by the operator. Another aspect of the mental workload is the necessity for a certain amount of vigilance, since malfunctions can compound if the original problem is not corrected early.

ACCEPTANCE OF SYSTEM

Because of the interviewee's background, he is accepting the automated processes. He feels that it is very difficult to keep up with the field, since he is now working with a very limited set of equipment. Most of his information comes from that distributed by manufacturers, and often they do not include all the relevant materials.

It seems that the interviewee's view of further automation is one of guarded acceptance. While there still are many possibilities for automating processes, he wants to see the actual performance before adopting a particular technology.

PROCESS CONTROL/FACTORY INTERVIEW NO. 13

The interview was conducted over a two-day period on the 19th and 20th of July, 1983. He is the chief operator at a water treatment plant for a city in Colorado. He has worked for the water department for seven years, four as a class A operator, and as chief operator of the new facility for the past eight months. In addition, he runs another small water district. He has obtained an associate degree in water treatment and a bachelors degree in a biological science. In addition, he has explored the possibility of graduate work in either hydrology or limnology. He is about 35 years old and was previously in the Air Force and worked in a family business.

Water treatment plants are often at the low end of the scale in terms of the amount of automation because they are often run by political appointees and on low budgets. However, this system seems to have adequate funding and the facility is almost completely automated.

Although he has a generally favorable attitude towards computers, e.g., he discussed a possible purchase, he is rather strongly negative in his attitude toward the automated systems involved in the water treatment plant. There are two possible sources for this attitude. First, his previous boss had a very negative attitude toward automation and had removed many of the automated features from the plant where he previously worked. Second, the current plant has had numerous start-up problems with its automated systems. This latter factor appears to play a significant part in the strong expression of negative feelings toward automation. In particular, the comment was made that if the automatics worked as they should, it would be a very easy plant to run. During the course of the interview we were interrupted several times to enable him to look at a problem. While as chief operator he does not take a regular shift, he does step in for the operator when necessity arises.

EXTENT OF AUTOMATION

Water treatment systems essentially involve a filtration area and an area in which chemicals are added to the water. In a totally manual system the operator will add chemicals and wash the filters by turning handles which open and close valves. In a sizeable plant two operators would be required on each shift because the physical operations would be too much (time-consuming) for one person to handle. Thus, while there is a good bit of unburdening involved in the automated processes, there is also some reduction in the number of persons required.

Although the process is a continuous one, not all of the tasks have been automated at this plant. In particular, the addition of chemicals remains under the control of the operator. That is, the operator adjusts the rate of introduction of chemicals into the process. One reason for this is that in the other plant of this system they have been unable to get automated devices to operate properly. A primary problem is the lag time between occurrence of and sensing of deficit conditions, as well as the lag between correction and sensing the correction. This results in constant overshooting and undershooting. Some other subtasks are also initiated by the operator, although once initiated they may be carried to completion automatically.

A computer with the capacity to operate the plant is physically located in the plant, but its sole task will be to log the data regarding various alarms and the frequencies with which events occurred and to collate it over periods of a day, a week, and a month. In the main, the tasks which have been automated are routine and to some extent undesirable tasks, such as manually turning the valves for washing the filters. Since these must be done in a particular order, there is some reduction in the items which must be learned during manual operation.

CHARACTERISTICS OF AUTOMATED PROCESS

In this automated process, the human is supposed to serve primarily as a monitor. In most cases the system is easy to learn for the individual who has previously been involved in the manual process. Since many, if not all, of the tasks merely involve initiation of the process when it is appropriate to do so, it is also easy to use. Although many of the displays in the automated process are different from those in the manual process, they are generally modelled after the manual displays. Often more information is given than would be available under the manual system, but it is sometimes necessary to interpret it.

Most functions are set up to be automatic in terms of initiation, but the operator also has the capacity to initiate any of these actions. Many actions of the automatics may also be overridden by the operator, although some timed operations would be difficult or impossible to override. There is no situation of any consequence in which the human is locked out of the process.

Errors are not critical if caught in a short time. An operator error or an equipment malfunction could lead to allowing water which is turbid or high in bacterial level to enter the city system. Because of the relative slowness of the ongoing process it would usually be possible to correct the error before any problem of consequence developed. Alarms are associated with almost all the possible error conditions and are clearly marked. A buzzer signals the occurrence of the alarm and is turned off by the acknowledgment of the alarm. The operator's responses are generally direct.

OPERATOR CHARACTERISTICS

In what might be considered the industry as a whole, the operators are quite varied in background and socioeconomic level. In the larger systems in Colorado, there seems to be a change to younger, better educated operators. In part this is due to the licensing law which requires a Class A operator to be on duty at all times. Some Class A operators have completed an associate of arts degree specifically in water treatment. While there is no guarantee of passing the test and the training is not specifically required, this program seems to be useful preparation for the test. There are four levels of operator, but it seems that once one gets beyond the trainee level, the big jump is to the Class A level. A certain amount of experience is necessary at each level before one is allowed to take the test for the next level. Certainly, some of the older operators come from a lower socioeconomic background. Entrance into the trade is not in any way limited, and some preference was expressed for individuals with no background in water treatment.

While there was a considerable amount of physical involvement in the older systems, neither great strength nor high level of psychomotor skill was required. The current system is both more challenging from the standpoint of knowing what the system will do, and more helpful because of allowing more time to evaluate what should be done.

In this particular citywide system it seems that some prestige accrues to working in the automated plant. Perhaps this is because it is new, or it may be because the persons were handpicked to go to the new plant.

Although there is a possibility that some individuals may become complacent in the automated situation, it is possible to participate in the operations of the system and maintain an even workload. While there is some verbal derogation of the system, it is not because of the concept, but because the execution is imperfect.

ACCEPTANCE OF THE SYSTEM

At this stage of operation, the system has proven to be unreliable in several aspects, which no doubt colors the attitudes toward the system. In some cases processes are performed at the location of the equipment because no feedback is given at the control panel as to whether or not the process is in operation. Even though the task could be initiated at the control panel, the operators tend to go to the equipment to start it, because they are then able to see directly what is happening.

Although there is great disappointment with the system as it now stands, there is still hope that it will perform according to specifications. When operating properly, the system will allow the operator to monitor trends. The interviewee was concerned with the possibility that some operators might view their job as merely babysitting the equipment, but did not think that many valuable skills would deteriorate under the automated conditions.

In spite of the current disappointment, it appears that the interviewee is looking for automation to increase because of the increasing information in the area and because of the subsequent desire to control more variables.

PROCESS CONTROL/FACTORY INTERVIEW NO. 14

The interview was held on July 20, 1983, at a city water treatment plant. The interviewee has been employed by the system for about three years and previously worked for a large city in Colorado for about seven years in a facility that had three different sorts of systems. He is about 35 years old and has been a Class A operator for approximately six years. Prior to working in the water treatment field he was in the Air Force and served there as a jet engine mechanic. The training which he received in electronics and hydraulics has been beneficial in his current position. He has a high school education and has studied on his own to pass the required exams for the four classes of licenses issued by the state.

In comparing the various systems he felt that the system on which he is currently working would be the best, if it were performing up to specifications. The basic reason for this was that it allows time for the operator to think about how each of the subsystems is performing. He described working on a manual system which required two operators, because in busy times one operator would be kept busy simply washing the filters. Since the operators are licensed by the state, most of them are concerned that the water which they "produce" be of good quality and pass any inspections which might occur. It seems that while the automated system reduces the number of individuals required to operate the system it also gives them greater personal control over their product. Thus, he tended to view the effect more as an unburdening. This was also true with respect to the physical aspect of the job, in that although no single task was demanding of great physical strength, the cumulation of turning a number of large valves during a shift was tiring.

The mental requirements of the present job are a little greater, since he feels that it is easier to read a hydraulic schematic than an electronic one. This is not so much a matter of greater experience with the hydraulic (pneumatic) systems as it is a greater complexity of the schematics. Ultimately, for the production of water, however, the problems are the same.

While there was concern with the failure of their current equipment to be reliable, he was optimistic that the problems would be taken care of reasonably well.

An interesting footnote to this discussion is the fact that while serving as an F-104 mechanic he found that almost all of the older pilots, i.e., majors and colonels, would tape a piece of string to the radome of their aircraft in order to have an independent indicator of the attitude while in flight.

PROCESS CONTROL/FACTORY INTERVIEW NO. 15

The interview was held on August 5, 1983, at the office of the interviewee. The interviewee is the manager of the materials engineering support function for a large manufacturing concern. As such he is in charge of the warehousing facility and has been instrumental in the introduction of a highly automated system. The interviewee is in his late forties and has been employed by the company for about 8 years. He is forward looking and has a positive attitude toward automation. He has been at the managerial level for a number of years.

EXTENT OF AUTOMATION

The company is a large corporation which manufactures equipment used in computer systems. The items kept in the warehouse range widely in size, character, and cost. The warehousing operation involves several steps including checking and inspection of items for quality. The system is designed to operate with relatively little handling by the workforce from the loading dock through storage to ultimate retrieval from storage for use in manufacturing. At the loading dock the items are placed on carts which are towed by an automatically operated device to the stations at which they are to be sorted and, if necessary, have other operations performed on them. Once in the system a set of items may be counted and then stored, or based on equipment type and priority, the items pulled out to be inspected. Eight sizes of bins are used and are stowed within larger bins about two feet wide by four feet long. The same sort of item may be located in several different bins. Provision is made for rotation of items which have a shelf life or a warranty expiration date.

The basic purpose of the automated process is two-fold. One aspect of the system is that it includes an inventory control feature which has enabled the company to cut its inventory requirements by over a million dollars. In addition, it has allowed the same size work force to handle a considerably increased load. While some of the workers are a little concerned about the possibility of layoffs, this may be due to the fact that the company, as a whole, had recently gone through a set of layoffs. In the main, the process seems to be as much an unburdening of the worker as a displacement of the worker. Another advantage of the new system over the older one is that expediters are rendered less necessary, since if an item has a priority established for its issuance, it will be sent directly to the operational unit.

In this automated system, organizing of several functions is performed by the computer. Items are selected for handling or inspection based on priorities managed by the computer. Records are kept of the specific items and their locations. In addition, records are kept of the number of items of various types which come through in a given time period, how many operations of each type are done by particular individuals, and totals of various operations for specific time periods.

The primary functions served by an operator are checking that items are as described, counting number of items in a set, prestocking items by organizing them into kits, storing and issuing items from storage. At each work station is a small terminal which instructs the operator as to which function he or she is to perform on a set of items. Thus, the computer essentially directs the activities of the human operators.

The operator remains at a work station while a conveyor-like system brings the items to be dealt with to him or her. This process is quite different from the nonautomated process in which the operator went to the pickup point to get the materials and the instructions about what to do with them.

Malfunctions pose no immediate danger, since they result primarily from misclassifications, but there will at some time be a deficit which will show up as a result of each error.

OPERATOR CHARACTERISTICS

Most operators are individuals with high school educations and are largely under 30 years old. Although there is a modest progression possible within the warehousing system, lower level supervision is about the maximum most persons can aspire to within the warehouse. Thus, a substantial number of persons will leave as they bid out to other jobs within the company which have greater advancement potential. Most of the operators come from low to middle socioeconomic backgrounds. The average experience on the job might be about three years. There has been little change in the sort of individual sought for this job, and no change is anticipated at this time. Since the entire warehouse was automated at once, there seems to be little added prestige within the company from working on the automated system.

The job requires relatively little in the way of physical strength and the physical workload is not extremely demanding, but there is some mental workload. In particular, problems arise in the counting process. This seems to be related to the boredom of that task.

There seems to be little resistance to the implementation of the automated system, but there have been some complaints of boredom and inconsistent workload. In particular, the workers get upset when the system responds too slowly, because not only must they merely wait for something to do, but they know the computer is counting the number of operations which they perform per day or week.

One disadvantage of the system for the operator is that it is no longer possible to defer dealing with an unpleasant task. Since the items are assigned on a priority basis, the operation which is up must be done before going on to the next one. Previously, bad jobs were shunted aside and not done for weeks.

EVALUATION AND ACCEPTANCE

Although there are some complaints, it seems that most of the workers accept the system and consider it reliable. This acceptance may be due in part to the care which was taken in teaching the operators to run the system. After the system was in place and running, the operators were given about two months of training, using the system with dummy loads before the system was used operationally.

Management is very happy with the system because it has had relatively little down time. They ascribe the success they have had in getting the bugs out of the system in part to the fact that they joined a users group prior to actually operating the system and received the benefit of a number of suggestions from the members of the group. They have also had good responsivity from the vendor. They are now planning to introduce an automated system into their large item warehouse. They feel that it will be as successful as the present system.

PROCESS CONTROL/FACTORY INTERVIEW NO. 16

The interview was conducted on August 5, 1983, at a large manufacturing plant in Colorado. The interviewee is a packaging engineer who has been with the company about three years. He is in his mid to late twenties and is currently working on an MBA degree. He is very interested in automation and regards it positively.

EXTENT OF AUTOMATION

A discussion of the features of the automated process is presented in process control/factory interview No. 15.

OPERATOR CHARACTERISTICS

The basic characteristics of the operators are discussed in process control/factory interview No. 15. The interviewee has been working closely with the operators for some time and thinks that he has good rapport with them. In pursuit of his academic degree he has conducted a survey of their attitudes toward the automated system. The survey was conducted about seven to eight months after the system was in place. The survey was conducted anonymously and included all the individuals present on the particular day for both the day and evening shifts. A total of 26 individuals responded, although not everyone responded to each item. A multiple choice format was used primarily, but the respondents were also asked to write in any comments they had, and many of them did so.

On most items the responses were favorable to the automated system. On a series of items regarding how easy each of the functions was to perform, all functions were considered easier by about two to one or better. And 18 of 25 responded that they preferred to work in the automated warehouse. It can be noted that when asked what they didn't like about the new warehouse, some people responded that the parking was not as easy at the new facility. While this may not have caused an overall negative response on the part of any respondent, it is obvious that the factors which were considered negative were not all related to the concept of automation.

Obviously, the employees felt that their jobs were made easier by the automated system. However, there was also some trepidation concerning the possibility that jobs would be lost because of the system. Eight of the 26 respondents expressed this fear. In conjunction with this, it should be noted that several respondents expressed concern with the cost of the system in view of the fact that the company was generally laying off personnel. This was suspected to be the reason that only 50 percent felt it was a good idea to automate the large parts warehouse at this time.

An interesting question deals with whether or not people enjoy working with a computer. In this survey there seemed to be little aversion to working with the computer as 68 percent said that they were either curious or excited about the new system and only 3 of the 26 said they didn't like a computer telling them what to do. In addition, 13 of 24 responding to an item about what they liked about the new system checked the fact that it was computer-based.

Despite the fact that a lengthy training period was used, over half of the respondents felt that the training was only "as good as could be expected". A matter of considerable interest here was that although they were given practice using paper "parts", several people indicated that they thought it would have been better if they could have had real parts, if only junk.

Another result, which has general interest, is that most of the replies said that the system was too slow; they couldn't work at their own pace. This seems to be a common complaint, whether the computer is delivering information or materials.

EVALUATION

It seems clear that the operators were favorably disposed to automation, but they had reservations about the economic factors involved.

PROCESS CONTROL/FACTORY INTERVIEW NO. 17

The subject of this interview is the director of the wellness center for a large multifaceted corporation. He was suggested as an appropriate person by another member of the corporation because of his interest in ergonomics and previous status as head of the safety program. It was expected that we might get some information about possible physical or psychological problems associated with transition to automated systems.

The subject of the interview is in his early 40's, and has degrees in psychology and physiology. He was employed in the insurance industry when he got involved in safety programs. From this activity, he became a safety officer in his present company and later became director of the wellness center.

The wellness center has a number of programs, all aimed at improving the quality of life. In addition to physicians, psychologists, and other persons directly associated with correcting ailments, the center has persons involved in physical fitness programs, financial planning programs, and other personal interest programs, such as weight loss and smoking-ending programs.

Although there might possibly be some data which would bear on the question of effects of transition to automation on feelings of well-being, these were considered out of bounds for two reasons: 1) the data were part of confidential health records; and 2) it was felt that any attempt to do research on the records, even on a blind basis, might appear to be using the records to spy on personnel.

Some discussion of the types of problems generated by the use of CRT devices did occur. The gist of this was that often the problems of the operators are a function of the positioning of the devices and of the seating arrangement. Another item of some importance was the point that the typical CRT presents only two colors to the operator and that it would be helpful for the operator to have more opportunity for color contrast, if any long-term operation is to occur.

OFFICE INTERVIEW NO. 1

BACKGROUND

The subject of this interview is employed by a manufacturer of interactive graphics systems which are essentially computer-based systems to aid in the production of engineering drawings. The company began by producing hardware but has expanded into the production of the software to support these hardware systems. Attention to human factors and the ability to achieve a "user friendly" system is regarded as a competitive necessity within the industry. The firm has been in this business for approximately ten years, during which it has experienced very rapid growth. Today it has approximately 500 employees and is considered a leader in its field. Consequently, it would be characterized as a progressive company which is rapidly evolving. Although the company itself is non-union, the products it manufactures are often placed in union shops, making this issue a relevant point of discussion.

The person interviewed is a middle level manager with responsibility for developing software systems and programs which satisfy the needs of specific customer applications. He was trained as an architect but has worked for this company in various capacities for about eight years. He began in the training area and consequently is familiar with the various problems which can be encountered by users of the systems. He is about 35 years of age, articulate, with a fairly aggressive personality. He seems to be quite open to change and progress.

PROCESS CHARACTERISTICS

The thrust over the past decade has been to introduce computers across the entire spectrum of engineering, design, drafting, tooling, and manufacturing. In some cases, generally those at the creative end of the spectrum such as in computer-aided-engineering (CAE), the emphasis has been on worker unburdening. In this example, tasks which involve a great deal of computation have been simplified by the introduction of the computer. On the other hand, production-oriented areas such as drafting and manufacturing seek to improve productivity while at the same time reducing the number of workers involved.

This dichotomy has many ramifications. Essentially different systems are designed for the two types of applications. One system is menu-driven and very accessible to the user. A tutorial approach is used making it possible for the user to learn the system simply by interacting with it. Such systems are essentially "surface level" in that they make it very easy to do a limited number of tasks, but beyond a certain point there is no improvement in speed or flexibility. This sort of system is often referred to as "transparent" and is well-suited to the casual or infrequent user who cannot justify spending a great deal of time learning to use the system. The other type of system is based on a "command language" approach. This technique emphasizes the activity to be performed, often at the expense of making it easy for the user to understand. However, speed and efficiency can be continuously improved as the user becomes more familiar with the system. Multiple functions can be combined and executed by a single "user-defined command", resulting in a very "powerful" system.

OPERATOR CHARACTERISTICS

Needless to say, the users of interactive graphics systems vary widely in terms of their backgrounds, interests, and abilities. Operators who use the systems for solving engineering problems tend to be well-educated, degreed people. Their interaction with the system is often characterized as relaxed and exploratory. On the other hand, those who use the systems for the high-speed production of drawings often have no more than a high school education. They are under more pressure to achieve specific results quickly and efficiently. These users undergo a highly structured, hands-on training course which lasts two weeks. Approximately six to seven percent of these trainees never succeed in learning the system. In fact, the interviewee stated that he knows of at least two people since the system was introduced in 1971 who suffered nervous breakdowns and were hospitalized as a result of trying to learn the system. He characterized these people as "narrow bandwidth" individuals who probably have a difficult time accepting any sort of change.

Another story was related which shed light on the problems which can be encountered when introducing automation. A type of system which had been used successfully for years to generate electrical schematics and power wiring diagrams, was installed in a customer's facility. Six months after installation, the customer was ready to send the system back to the manufacturer. The system was plagued with scrambled file names, blank files, and other mysterious problems. All sorts of measures were taken in attempt to solve the problem, including the installation of elaborate power monitoring equipment and a complete exchange of all the hardware in the system. Ultimately, the problem was traced to a disgruntled employee who was sabotaging the system. It seems this was a case of management imposing a system on a workforce which viewed the automation as a threat to their jobs.

The introduction of automation causes significant changes in the job requirements in the fields of engineering, design, and drafting. In the past, a major part of engineering analysis has required considerable skill in mathematics. When using computer aided systems, the emphasis can be placed on the ability to arrive at creative solutions to problems with the computational details being relegated to the computer. Similarly in drafting, the emphasis has been on the ability to create orderly layouts, print neatly, and do consistent linework. These skills are no longer needed when working with a computer-based system. On the other hand, concern for torn or spoiled drawings is minimized since a new "original" can be quickly generated from stored data.

The interactive nature of CAD systems precludes many of the motivational problems which can result from boredom or inconsistent workload. Essentially the systems are user-paced rather than being paced by some external process. This ensures that the operator will always be kept "in the loop" and maintains his continuous involvement in the ongoing process.

The interviewee stated his belief that one of the most important things to consider when designing an automated system that would involve emergency operations is the elimination of "indirection". Stated positively, this means that there should be as direct a relationship as possible between the operator's action and the desired result. The ability to select an item from a menu by physically touching an area on a CRT is an example of a direct command as opposed to typing in a word or phrase. Similarly, the use of a "mouse" to position items on a screen is superior to using such devices as joysticks.

It was recommended that we become familiar with the Apple LISA computer as an example of an extremely user friendly albeit surface level system.

Key Points

- Thrust of Automation--unburdening in the case of creative tasks; displacement in the case of production-oriented tasks.

- Two types of systems--easily learned, "user friendly" but limited systems versus command language systems which are difficult to learn but very powerful and efficient.

- "Narrow bandwith" people experience great difficulty in adapting to automated systems.

- Systems imposed from the top down by management often meet with the greatest resistance.

- Automated systems require new skills while making many old skills obsolete.

- Workload is somewhat "self-adjusting" in the case of interactive automated systems.

- There should be as direct a relationship as possible between the operator's action and the desired result.

OFFICE INTERVIEW NO. 2

The interview with the head of a Computer-Aided-Design (CAD) users group was conducted in his office at a large engineering firm in Denver, Colorado. This company is a multinational engineering and construction company which has a continuing need for engineering drawings of many types. The interviewee is in charge of the drafting operation. He has previously served the same company in other management positions.

EXTENT OF AUTOMATION

Although automation is used to some extent in other segments of the corporation, the discussion exclusively concerned the CAD system. Although the system has been in operation for 2-3 years, at this stage of the program there are still many design and drafting personnel who are using the manual systems. Ultimately, except for some minor cases which might be simpler to do by hand, the entire section will be using the CAD system. The size of the operation dictates a gradual shift to the new system. This gradual shift has also allowed the development of the system to proceed reasonably smoothly. Some problems have occurred in the development of the process. In particular, the difficulty of eliminating earlier copies has resulted in bringing up presumably later copies which have errors that had been corrected previously. At this stage they are in the process of automating the recordkeeping and assignment of priorities.

At the inception of the program a consultant was hired to help with the selection of the personnel to be included in the first group. An internal posting was used to obtain people from many sources to attend a seminar at which the basic concepts were discussed. Those individuals who were interested in the program and had four years experience with the company were invited to apply, and they were put through a testing program to select the training group. The testing program consisted of two phases: aptitude testing based on several Psychology Corporation tests, e.g., mathematical reasoning and a personal preference inventory (the Cleaver). A substantial range of individuals were included in the early group, and according to the interviewee the tests validated well. Parenthetically, it may be noted that he mentioned the people who have trouble with spelling and typing also have difficulty with the system, although it did not seem to be a matter that was originally tested. Typing training is included to some extent in the training program. Because of a desire to include only those individuals who were intrinsically motivated, no additional pay grade was instituted, but people who successfully completed the program were given, unknown to themselves or others, somewhat higher pay increases.

OPERATOR CHARACTERISTICS

The operators were selected from a number of sources and are fairly varied as a group. Some have no training beyond high school, some were trained in technical schools, some have liberal arts sort of degrees, and others are engineers. They average about 30 years of age, and a minimum of four years with the company. They are obviously a more select group than the non-CAD personnel. It is likely that in the future the selection procedures will work to eliminate some who would have earlier been included. Operators must also change some of their style of operating. One example cited was of an operator who did generally good work, but was not turning out the quantity needed because he had difficulty in making decisions about which process to use. Presumably this had not been a problem when he simply hand drew the material.

The individuals who operate the automated system could be considered to be somewhat prestigious within the section. This results from the fact that they were chosen in a form of competition, and from the marketability of the skill they have learned. A negative side effect of this is a certain amount of rivalry between those who can and those who can't operate the system. Some who haven't been selected feel left out. Others may feel threatened by the knowledge that they must ultimately learn the system, and for one reason or another they fear it.

The levels of skill in the drafting section are difficult to categorize because they include designers and engineers who may or may not be as involved as the drafters in the process. Although seniority and training may have an effect on advancement into the supervisory ranks, some problems exist in the selection of supervisors. A particular problem is that the personalities of individuals who are interested in working extensively with a machine are often not the best for assuming a managerial position.

CHARACTERISTICS OF AUTOMATED PROCESS

The function served by the operator may be simply to take a set of descriptive statements and turn them into a schematic drawing, or it may be to use the system to bypass a good bit of the intermediate work and produce a drawing directly.

The process requires a substantial amount of training and in some respects is easy to use. That is, because of the large data base, one can select from a catalog via a menu a very large number of symbols, perhaps even subsets of a drawing. Obviously, the skill involved in using this catalog is based on extensive experience. Some discretion is involved, in that the operator may also create new symbols, if necessary. The operator is largely in charge of the machine, but would presumably feel compelled to use the canned operations whenever possible because of the savings in time.

While the use of refined psychomotor skills is somewhat diminished in the automated system, the interviewee said that he felt there was a high positive correlation between performance on the two systems. This might mean that psychomotor skills aren't very important in either system or that they are related to the other factors important for good performance. Although no great physical workload is imposed on the operators, the mental workload is substantial. This involves primarily an understanding of the system. However, there is a considerable attentional factor involved also. It is important that all of the necessary items be presented and that any unnecessary items be eliminated.

A difficulty for some operators is the rather limited communication with co-workers. Most communication seems to be in a vertical direction. There are more constraints on the operator who uses the automated system than on the operator who uses the standard system.

ACCEPTANCE OF SYSTEM

Apparently, acceptance of the system by the operators is high. This is not too surprising in light of the technique for selecting the operators. Interestingly, it is those people to whom the output is directed who are less accepting. This seems to be because they feel a loss of control over the process. They cannot physically look at the partial product at all times, since until a drawing is actually produced nothing palpable exists. Another factor in their lack of acceptance is the occurrence of problems with getting the latest revisions included on the drawing as it comes to them.

There is perhaps a little gap between the overall perception of the system and its capabilities. In spite of this, it seems that additional automation will be pursued, and the presumption is that people at higher levels will be included within the system.

OFFICE INTERVIEW NO. 3

BACKGROUND

A number of people were interviewed who are employed by a firm involved in the preparation of a large number of drawings which fall into two major categories: some are three-dimensional illustrations used to pictorially convey information; others are engineering drawings used in the design of structural and mechanical hardware. Previously, the drawings had been produced by traditional manual methods. However, the workload increased to the point that management decided the only practical way to keep pace was to install a computerized system. Since the system has been in place for a little over a year, a number of the people have been involved in the transition and are familiar with both the manual and automated approaches.

Different systems were required to meet the needs of the two types of drawings. No existing software could be found which was specifically designed to prepare the pictorial illustrations. As a result, a custom software package was developed by an outside vendor to do these drawings. The end users were able to influence the design of this software and are continuing to make inputs into the development of enhancements to the system. The system is designed to perform a specific function quickly and efficiently. Additional functions and flexibility beyond that required to do the job at hand were not built into the system.

On the other hand, a number of turnkey systems were available to support the preparation of engineering drawings. The problem was to select the most cost effective and efficient system. A system was selected which had been in use for some time and was proven to be reliable. The developer of the software has a stated policy of not rushing new developments to market but rather taking a conservative approach of trying to eliminate the "bugs" in-house before introducing new products. Data is input to the system using an alphanumeric typewriter keyboard and a special function keypad. The software uses a tutorial approach to lead the user through the program in a step-by-step manner, making the system easy to learn. A basic five-day course is taught by the vendor; a follow-up advanced course is also available. Typically, companies who purchase the system will send one or two of their better employees to the formal course and then use these people to train their other users.

The subject of this interview is the supervisor of the design group which uses the off-the-shelf CAD system for generating engineering drawings. His attitudes toward the system can only be summarized as extremely positive. He stated that he deliberately adopted this attitude prior to "attacking" the system. He felt that if it was possible to learn the system he was determined to do so and be good at it. Any problems which have arisen, he feels, have been due to operator errors and not the fault of the system.

OFFICE INTERVIEW NO. 4

BACKGROUND

The subject of this interview is employed by a manufacturer of office computer systems. He is responsible for the design of printed circuit boards. He is about 30 years old and has been with the company for about five years. He began with the company as a mechanical drafter but moved into the area of PC board layout and design because he felt the demand was greater and he could always be assured of having a job. Similarly, a year ago he seized the opportunity for training in computer-aided-design because he felt those skills would increase his job security. He appears intelligent and highly motivated, particularly with regard to his own career advancement. He seems to be slightly outgoing and accepting of change.

In the opinion of the interviewee, the characteristics of the operator may be somewhat different from the manual system. It is not necessary for the designer to have as much of the more highly refined motor-skills. However, it is necessary to be able to follow the system carefully.

He feels that some prestige is associated with the job, both in terms of the additional skill that one must learn and in terms of the greater earning potential. The progression of skills is not specific in the sense of job titles, but there seems to be a considerable gradation of skills based on experience and training with the system. He feels that he is just now, after a year of experience, beginning to master the system, and he looks to those who have had greater experience for assistance. He thinks that with added OJT and more seniority that he will have a chance for some advancement, although it might involve moving to another company.

The motivational problems associated with this system are largely a function of the way in which the process has been implemented. He feels that the schooling which he received from the manufacturer was adequate to get him started, but that more schooling is required after a period of operation. Further, the system may have been oversold to his management, and meeting their expectations is often difficult. Some motivational problems result from the boredom accompanying the task of producing the net list. He thinks the boredom contributes to the number of errors occurring in the net list. Errors are fairly easy to eliminate, but malfunctions can cause much time loss.

Some resistance to the system has been noted. In some cases the engineering staff wants to see what the drawing looks like before it is feasible to do so. Under the manual format the engineer is able to look over the shoulder of the designer and observe the drawing in hard-copy form.

PROCESS CHARACTERISTICS

The process with which he works is called the Sci-Card system. It consists of a typewriter keyboard for data entry and a CRT display screen. The ergonomics of the system are poor in that the keyboard and the CRT are located at right angles to each other, requiring the operator to constantly turn his head while using the system. The subject has occasionally experienced neck and back troubles, which he attributes to the system.

The designer works with a schematic which has been produced by the electronic engineer responsible for the project. From this information he generates a "net list" which details all the interconnections in the circuit. This step is unnecessary in the manual approach to PC design. For an average board, which takes about four weeks to design, approximately one week is required for generating the net list. Generating the net list is boring, tedious work which often results in many mistakes. In larger companies it is considered a separate activity to be done by "data prep" specialists who are temperamentally suited to such tasks.

The basic purpose of the system is to speed up the process of drawing the design of the PC boards. While this would tend to reduce the need for designers/drafters, he does not feel personally threatened with any loss of job. However, because the system is not thoroughly understood by the engineers, there is a tendency to feel some stress from seemingly unreasonable demands for production.

The function of the human operator is to develop a design by which all the appropriate connections on the PC board will be made and no incorrect connections will be made. While the automated process is difficult and time-consuming to learn, some of the tasks become much easier with the automated system.

In this situation many routine operations and some of the complex aspects of operation are automated. However, the automated system cannot complete all the designs which are started with it. Thus, some of the more complex operations remain for the human to figure out. At any time the human may insert a specific connection, but usually he will wait until it appears that the computer cannot or will not do so.

Because there are occasionally some items to be manually placed on a drawing, there is a certain amount of motor skill required, but this is much less than the requirement of the manual system. Very little physical workload is involved in either the manual or the automatic system, but the mental workload is increased under the automatic system. There is a high need for understanding the total system. He feels there will be some loss of drawing skills as the majority of the time is spent on the CAD system.

Errors tend to occur with high frequency because of the multitude of minutiae involved in the drawings. This results in failure of the PC to check out, and changes must then be made in the design drawing. Correcting errors is not difficult, but results in slowing down the completion of the final product.

ACCEPTANCE AND EVALUATION

The automated process is accepted by the operators, and they see the benefits which can occur in speed and in eliminating some of the tediousness of their task. This is balanced somewhat by the fact that they are required to add some rather tedious tasks, e.g., the net list. In addition, it is necessary for them to spend a good bit of time merely waiting to bring up a drawing or to save it.

In spite of the advances which are attributable to the system, there is some dissatisfaction with the extent to which the expectations have been met. In part, this may be related to the amount and type of training which is given to the operators.

Although he does not feel very kindly disposed toward the current state of the automated system, the interviewee was willing to accept added automation because of the potential economic benefits to him.

OFFICE INTERVIEW NO. 5

The subject of this interview is in charge of training users of the CAD system used to generate illustrations. He has an Associate Degree in drafting and is working toward a B.S. in mechanical engineering at night. He was hired while attending school on a full-time basis and worked nights inputting.

SYSTEM CHARACTERISTICS

The system is a manual/computer hybrid in which an illustrator begins with a hand-drawn illustration which is then input to the computer through a digitizing process. Once the drawing is input to the computer, details are added and it is manipulated as required to achieve the desired size and orientation. The operator interface for graphics work consists of a large Colorgraphics CRT, an alphanumeric keyboard, a mouse for digitizing, and a light pen for manipulating lines on the screen. The system currently includes three such workstations, with plans to add three more. In addition to the line drawings, a considerable amount of text in the form of callouts and notes must be added to each drawing. A separate terminal, consisting of a keyboard and a smaller CRT is used for inputting and altering text. Changes are first made to the text in the form of Drawing Change Notices (DCN). After a number of DCNs have been made, the graphics are updated. A flashing note on the graphics display alerts the operator to the fact that DCNs exist which are not reflected in the graphics portion of the drawing.

Drawings are part of packages which relate to specific projects. There is a great deal of overlap and commonality between the various drawing packages for different projects. When a new drawing is begun, there is no way to determine if a similar drawing already exists in the system. The collective memory of the illustrators must be called on to determine if such a drawing exists. This leads to relying on certain employees who have developed esoteric knowledge of the system, the various drawing packages, and the projects to which they relate.

The system was implemented over a period of eight months to a year. Many problems were encountered in the beginning, but management seemed to expect these as part of introducing a new, untried system. The decision to adopt a computer-based system was based on an objective break-even analysis which showed that anticipated increases in workload would result in unrealistic manpower levels if the manual system were maintained. Since the automated system appeared inevitable, a total commitment was made to its success.

USER CHARACTERISTICS

There are currently 16 people who use the system. Of these, seven are men. Their ages vary from 20 to 38. The educational backgrounds vary from high school graduates to those with some college to a few with BA degrees. No generalizations can be made between education and acceptance of or success with the system. Reaction to the system ranged from blind obedience to open dissent. Initially, attitudes toward the system seemed to be divided along the lines of age, with the younger employees being most enthusiastic and reacting: "Oh wow, a computer!" After a while, the attitudes became more individualistic, with some of the originally enthusiastic workers becoming less thrilled when they found out that the system was not magic and they would have to work at it.

The interview subject has detected a difference between the way male and female operators learn to use the system. The women seem to learn faster but are less willing to take chances. They want to be shown how to do something, but understand quicker and can apply what they have learned to other functions provided that they are not too different. They are very cautious and are afraid to "glitch the screen" and wipe everything out. The men, on the other hand, are willing to dive right in and learn by trial and error. They are not afraid to make mistakes. It seems to take them longer to understand the system.

TRAINING

An initial training period of about three days is necessary before an operator can do productive work. This training consists of a "walk through" of the system, including such basics as logging on, generating parts lists, altering parts lists, and adding callouts. The intent is to have the operator learn to solve problems with as little help as possible. Operators are placed in one of three categories: User 1, User 2, or User 3. The process of moving up to User 3 takes five to six months. Training at the User 1 level lasts about three days and consists of the "look and see" demonstration with no capability to alter drawings which are in the system. After about four weeks at the User 2 level, the operator essentially "knows all of the ropes" and can efficiently use the system. After about five to six months, the operator progresses to the third level at which he has the power to delete drawings and release new drawings into the system. The goal is to avoid specialists and have each person be capable of doing all phases of the operation. The organization is structured so that one person has the responsibility for a given project, although he will also help out with projects that are approaching the deadline. In this way, each person recognizes the value of the automated system in helping accomplish the tasks he is responsible for.

The operators have been anxious to learn the system because they feel it will enhance their careers and give them a competitive edge. As a result, the system is viewed as an opportunity rather than a threat.

Attitudes toward the system have changed as the workload in the group has increased. Some of the most vocal opponents have come to appreciate the increased speed which the system offers. It is generally conceded that the computerized system is the only way the task can be accomplished within the time available.

Operators have changed their style of drawing in order to more efficiently accommodate the computer. The manual drawing is now reduced to a functional view with all of the "pretty details" left out. These details are added on the computer after the manual drawing has been digitized.

The best people with the manual system have turned out to be the best people with the automated system. This appears to be due to the fact that those who were willing to take the time to do the best work before are willing to take the time to get the most out of the automated system.

Software support from the vendor has been very good. This is especially important with a custom system. The vendor feels that there is a potential market for the package and, therefore, has incentive to develop the best possible system.

OFFICE INTERVIEW NO. 6

BACKGROUND

The subject of this interview is a Ph.D. psychologist with a background in human factors. In the past, she has worked in industry attempting to analyze and resolve various human factors problems which have arisen with regard to automating office procedures.

SYSTEM CHARACTERISTICS

The automated system with which the interview subject worked is a classic example of a poorly implemented system. A bullpen area was established in which 14 video display terminals were installed. Wiring and cabling were strewn around the area creating trip hazards. Lighting was not adjusted to meet the specific needs of the work area. Proper sound attenuation was not provided. Temperature control was inadequate.

Operator's responsibility was to simply enter a series of numbers from paper forms into the computer data base. The position was regarded as one of the lowest in the company and typically used as a stepping stone to other positions. However, the prospect of "working with the computer" was used as a lure to entice job applicants to accept the position.

Management became aware of problems with the system because of the unusually high rate of absenteeism in the group. Of the 14 terminals, it seemed that two were always vacant because of sickness. Employees complained of headaches, eyestrain, backaches, nausea, and dizziness. This syndrome has become commonly referred to as "VDT sickness".

Many of the symptoms could indeed be traced to physical causes such as lighting and poor seating accommodations. These physical problems must be attended to and corrected. However the interview subject felt that a deeper problem was hidden in the structure of the job and the way the system was implemented. The system was put in place by management, with no regard for the feelings of the operators. The decision to buy a particular system was based entirely on purchase cost. The unspoken attitude of management seemed to be "if you don't like the system, you can be replaced". In fact, the employees were continuously being replaced as they moved on to better positions or quit the company.

The interviewee prepared a report to management stating the physical problems with the automated arrangement. The report is attached. Due to political considerations, she did not address the underlying motivational problems in her report.

HERF No.: IP 808
DATE· 14 November 1980

HUMAN ENGINEERING

HUMAN ENGINEERING REPORT FORM
(HERF)

SUBJECT: Video Data Terminal Study. (Human Factors Engineering (HFE) response to . of Information Processing, 0/19-22, regarding complaints of physical discomfort by VDT operators).

BACKGROUND: Aid was solicited from HFE to have operator complaints investigated. These complaints consisted of headaches, nausea, eyestrain, and dizziness, and occurred during terminal use. An analysis of the situation was performed and human engineering-oriented recommendations made. This analysis was derived through:(1) questioning the operators, supervisors and management personnel; (2) lighting and workspace measurements; (3) observations of the VDT area; (4) the experience of the human engineering group in general; and, (5) the literature.

SUMMARY: The present report does not represent a full-fledged investigation into the subject, nor was such requested of us at this time. By the time I arrived, most of the reported discomfort(s) had subsided or at least decreased in frequency and intensity. The opportunity was limited to an ex post facto study at best. My conclusion is that the complaints were probably associated with a constellation of factors and their interactions. In the absence of the opportunity to investigate the precipitating complaints (eyestrain, dizziness, nausea, headaches) as they were occurring, I have advanced some recommendation which may result in beneficial and/or palliative effects.

APPROACH

* Question operators, supervisors and management regarding operator working conditions.

* Obtain measurements of individual workspaces and lighting conditions.

* Observe VDT area under normal operation and identify current or potential problem areas.

* Review all relevant articles on the subject of VDT operator discomfort.

* Peruse HFE criteria and attributes checklists.

* Request input from Human Factors group.

* Offer recommendations.

AREAS OF CONCERN

PROBLEM	*RECOMMENDATION*
Video Data Terminal (VDT)	
Screen	
Eyestrain Dizziness Nausea Headaches	* Reduce screen clutter and improve screen format design. * Lower brightness and/or increase refresh rate of "line status" symbol. * Whenever feasible, insure that operators are also involved in other non-VDT work. * Adjust scrolling rate, if necessary. * Insure that screen intensities are adjusted for each operator and to suit prevailing conditions. * Insure that no chrome or polished surfaces are visible to the operator when glare is a problem. * Insure the viewing distances from the operator's eye position to screen location is 14-20 inches.

PROBLEM	RECOMMENDATION
Video Data Terminal (VDT) (cont.)	
Keyboard layout and function	
Time lag between key activation and response to input is highly variable.	* Increase touch control on keys. (Key activation force should be 15-25 grams of force with key displacement being 3-5mm.)
"Tab" and "line feed" keys frequently activated by mistake.	* Inform manufacturer (Zentec) of the problem.
	* If none of the above can be implemented, alert the operators of the problem.
	** General Guidelines **
	All keys and switches should provide touch feedback.
	Keyboard should not contain extraneous keys.
	All controls should be protected from activation by operator body contact and spaced to prevent multiple or erroneous activation.
	Keys should be compatible with their associated functions, locations, and labels.

AREAS OF CONCERN

PROBLEM	RECOMMENDATION
Workspace General discomfort - back, neck and shoulder pains	* Adjust work surface so that the home row of VDT keyboard keys are 29.5 inches above the floor. * All operators should have adjustable chairs. * Brief all operators on all workspace equipment adjustment. * Insure that each seat surface is reasonably firm (not too soft) and compresses to approximately 2 cm. when operator is seated. * Ask operators how paper supporters can be improved to insure greater usage. * Have operator's input forms instructions say "PRINT" and return forms to points of origin if illegible. ** General Guidelines ** The normal line operator sight should be $15 \pm 5^{\circ}$ below the horizontal when she looks straight ahead.
Printers are not easily accessible to the operators.	* Rearrange furniture to allow for easy accessibility of operators to their assigned printers. * All other accessory units should also be conveniently placed.

AREAS OF CONCERN

PROBLEM	RECOMMENDATION
Workspace (cont.)	
Little to no work surface area. No place to store pencils, pens, personal items or hang coats.	* Remove all unnecessary material(s), i.e., hardware, manuals, etc., from terminal work surface. * Provide additional work surfaces - near the printer area, for example. * Provide bookcases and/or file cabinets for operators and a lockable area in which to store pens, pencils, & personal items. Allow for coat hanging facilities in the immediate area. ** General comments ** Basic documents should be stowed in or near the VDT, easily accessed, and identifiable by spine and cover markings.
A number of operators found the room to be poorly lit.	* Have the diffusion panels on the overhead lights cleaned more frequently. * Provide additional non-glaring light, as necessary, to illuminate specific workstations.

AREAS OF CONCERN

PROBLEM	RECOMMENDATION
Training Operators are very unsure of the VDT System.	* Operators should have a general understanding of the entire system and terminal usage. * More individual training is necessary. * Consider supplemental on-line VDT training. * Improve manuals. Obtain suggestions from operators of ways to improve manual(s). * Inform operators of short-cut techniques whenever applicable. * Insure personnel have received proper training * Insure that all supervisory personnel are familiar with the VDT operation, particularly those personnel most in contact with the terminals and terminal operators.

AREAS OF CONCERN

PROBLEM	RECOMMENDATION
Safety	
VDT (serial number S0196) runs "hot".	* Have repairman determine why VDT S0196 runs "hot" and correct, if necessary.
Clutter of wires, boxes, etc., in work area.	* Eliminate clutter beneath operator's work area and aisle way.
Overhanging electrical extension wires in the walk and work area of the operators.	* Overhead electrical extension outlet wires should be draped along the wall, out of the operator's work and walk area.
Emergency exit door not prominently labeled on the cafeteria side.	* The emergency exit door empties to the cafeteria and should be prominently labeled on that side and not blocked by furniture.
	** General Guidelines **
	Cords and cables should be flexible enough to avoid entanglement and routed for least interference.
	Heat sources should not be accessible to operators' skin.

AREAS OF CONCERN

PROBLEM	RECOMMENDATION
Environmental Factors	
Noise	
CAS area extremely noisy	* Heighten partitions separating the two areas.
Cafeteria noise with accompanying floor vibration.	* Remind Data Engineering and cafeteria management of the problem. * Add more sound-deadening insulation to the wall common to the cafeteria and VDT area.
Temperature Regulation	
Room too cold in winter and too hot in summer. Afternoon heat in VDT area may be above VDT manufacturer's specifications.	* Verify that building air blower is functioning properly. * Take appropriate measures to improve VDT operator's comfort whenever possible. * Obtain manufacturer's operational specifications manual.
Maintenance	
Poor janitorial maintenance; dirty floors, dirty plastic bags in waste cans, bugs, and gnats.	* Increase the frequency of floor maintenance and plastic bag changes. Have area sprayed for bugs whenever cafeteria is sprayed.

PROBLEM	RECOMMENDATION
Environmental Factors (cont.)	
Aesthetics	
Area is blocked-in and confining.	* Cover upper half of wall common to the cafeteria with a mural - possibly of an outdoor scene containing some blues. * The lower half of the wall common to the cafeteria should be covered with thick pile carpet to reduce noise level in area. (This statement also relates to the "Noise" section.) * Whenever possible, allow operators to bring in a few green plants.

OFFICE INTERVIEW NO. 7

This "interview" consisted of a demonstration of the Apple LISA computer system. Several of the subjects of other interviews mentioned LISA as an example of a new trend in operator interfaces for mini-computers. In fact, the term "LISA-like" has been coined to describe systems which share LISA's features.

The advertising slogan used to promote the system is: "LISA works like you do." An attempt has been made to utilize changes in software design philosophy to achieve maximum "user friendliness" with currently available hardware. Pictorial representations of common office equipment, such as filing cabinets, file folders, and wastepaper baskets, are depicted on the CRT screen. The user moves a cursor about the screen to point to various objects and command functions. By doing so, strings of commands can be constructed which allow the user to manipulate information in a variety of ways. It is hoped that by mimicking familiar objects and actions, the system will make the user feel more comfortable. A split screen is utilized to allow the user to view portions of two separate files simultaneously.

An "interactive" approach to software is featured. Typical computer systems utilize separate software packages for various tasks such as word processing, generating spreadsheets, or creating drawings and graphic images. The LISA system integrates these functions by allowing work done with one software package to be incorporated into work done with a different package. As a result, a graph can be drawn with the pictorial software and incorporated into text written with the software package.

A hand-held device called a "mouse" is used to move the cursor on the screen. A ball built into the bottom of the mouse rotates as the mouse is moved along a work surface. In this manner, the electronics sense the direction in which the user wishes the cursor to move. This design is predicated on the belief that using keystrokes is quite unrelated to the task of moving a cursor in two-dimensional space and is therefore less easily learned. Moving the mouse in two-dimensional space is felt to be closely related to the desired movement of the cursor.

Extensive use is made of tutorial prompts to minimize training and dependence on instruction manuals. A user can seat himself at the terminal and by following instructions displayed on the CRT and making appropriate choices from various menus, he can "walk" through the operation of the system.

OFFICE INTERVIEW NO. 8

The subject of this interview works in the same group as the subject of Office Interview No. 4. He also lays out and designs printed circuit boards which are used in the manufacture of office computer systems. He is in his mid-twenties and has been involved in drafting and electromechanical design for about five years. After high school, he worked in construction before entering the drafting field. He worked on the same type of CAD system for two years in California before taking his present job and is one of the more experienced users of the CAD system in his group.

Overall, his attitude toward the CAD system is fairly positive. There are disadvantages to the automated system, but they are easily outweighed by the economic benefits. For example, a simple board, which should take two weeks to lay out manually, can be laid out by the automated system in about eight hours. He feels that the manual board would be superior in quality but management is willing to accept this compromise. Since the system does not look ahead, the first traces laid out by the computer often interfere with the direct routes which could be used by later traces. This results in long, indirect traces and many traces which must pass through the board. The final traces must be laid out by the human operator, leading to some resentment that the computer did the easy work and left the difficult tasks for the human. Some of the "old-timers" refuse to work on the CAD system and only do manual layout of analog boards such as power supplies. Age appears to be a factor in the acceptance or rejection of the new systems. The interview subject believes that in about five years the automated systems will have practically eliminated the need for PC designers. Computer-aided-engineering will make it possible for the electrical engineer to design a circuit directly on the computer and have the computer generate a board layout from the schematic. Should his job be eliminated, he would not like to go back to mechanical drafting since he did not feel it was challenging enough. Nor would he like to return to school and become an engineer. He would prefer a more active job and might return to construction.

At the company in California where he worked previously, it was the engineer's responsibility to input the list of interconnections. This system was more efficient and caused the engineers to better understand the limitations of the system and to have more realistic expectations of the designers. At the present company, the engineers have little understanding of the system and think it should be magic. This results in some friction between the engineers and designers. He feels that the engineers should have some training on the system so that they would understand what sort of tasks take the most time and would modify their expectations accordingly.

The interviewee feels that personal style tends to be lost with the transition to the automatic systems. Three months ago, he would have preferred the manual methods for this reason. Now he finds himself learning tricks with the system which he feels allow him to interject an element of personal style. He says he has a lot more to learn and looks forward to this challenge. The system on which he works has a reputation for being the best available. It is also considered the most difficult to learn. As an operator learns more about the system, he can do more with the system.

The automated system has not resulted in any changes in the way he interacts with his supervisor. His supervisor understands the CAD system and tends to act as a buffer between the designers and engineers as well as other members of management.

OFFICE INTERVIEW NO. 9

The subject of this interview is the Manager of Advanced Projects Planning for a manufacturer of office computer systems. He is a Ph.D. psychologist with a strong background and interest in human factors.

The interviewee stated that human factors, as it is practiced in regard to the development of computer systems, is at best a very superficial effort. After the hardware is essentially designed and built, and the software is written, the human factors engineer is brought in to try to interface the system to the ultimate user. The problem is that the system designers think in ways which are totally different from the thought processes of many non-technical users. In particular, he said, software designers constitute a sub-culture which thinks the way machines think and create software accordingly. What is needed is a new approach: one which takes human factors into account from the very conception of the system. A new mathematics must be defined which is patterned after the human thought process, and only then should a machine be designed to fit. Existing computers operate in a very linear manner, taking only one step at a time, and needing to be given explicit orders every step of the way. Furthermore, these orders must be very explicit. The human mind, on the other hand, can follow many parallel paths to reach a conclusion. These inherently different approaches often lead to frustration between the flexible human and the rigid machine..

A great deal of work is being done to develop machines with such "artificial intelligence", in both this country and Japan. The Japanese have stated a national goal of developing within ten years what they term a Fifth Generation Computer which will have "man level" intelligence. Such computers will need to have an associative memory like the human brain. Current generation systems can find a piece of data only if they are given its specific preassigned address. The human mind memorizes things and stores them by association. A computer with artificial intelligence must have such an associative memory.

In addition to parallel processing and associative memory, artificial intelligence will require extensive natural language capability. Present day computers require very precise commands given in the proper order; they cannot deal with the ambiguity of natural language. Machines with artificial intelligence must be able to infer meaning from context and extract the intended meaning from the words they are given. Psychologists and semanticists must be involved in the development of truly "human friendly" machines.

OFFICE INTERVIEW NO. 10

BACKGROUND

The subject of this interview has about ten years experience in handling payroll for a medium-sized company. Recent business growth led to the decision to automate the payroll function. The company is part of a national chain; a prepackaged system was available. The system had been implemented previously in a number of other offices; as a result many of the bugs had already been eliminated.

SYSTEM CHARACTERISTICS

Prior to automating, a manual "pegboard" system was used to write about 200 checks weekly, with each check taking a couple of minutes to write. With the computer, about 400 checks are written weekly, with each check taking about ten seconds.

Physical workload has been only slightly affected in the sense that the books of tax deductions and other tables are no longer needed. Mental workload, on the other hand, has been greatly reduced since most of the manual computations and extensions have been eliminated. The work is less boring since the desired result, a completed check, is achieved much more quickly without the drudgery of manual computation and with much less chance of error.

The question of trust in the system is divided into two parts. On the one hand, there is a great deal of trust that the system will perform quickly and accurately. However, there is always a certain amount of uneasiness regarding potential system "glitches". For the first two months of operation, these glitches occurred at least twice a week. Finally, the purchase of an anti-static mat eliminated most of the problems. The interviewee felt that it would certainly contribute to the acceptance of such systems if the vendor would make such essential accessories part of the initial system package. This is especially true in a dry climate where they will almost inevitably be needed.

Presently, such glitches happen rarely, only once or twice a year. Even so, as the interviewee said: "It's enough to put the fear in me."

Initial training on the system consisted of an intensive three-day course given by the corporate office which had sponsored initial development of the system software. The documentation furnished with the system is very thorough and enables most problems to be solved without outside help. In cases where the documentation is not adequate to solve problems, the programmers who wrote the software can be reached directly by telephone. Such direct access to the originators of software is very unusual and contributes greatly to user acceptance by creating empathy between the users and the system designers. In the beginning, it was obvious that the people who wrote the software did not know much about accounting. With each new revision it becomes increasingly apparent that the programmers have learned a great deal about user requirements. Initially, the response of the system to mistakes was totally out of proportion to the seriousness of the error. For example, entering too many digits for an identification number would shut the system down with five to ten minutes needed to recover from the mistake. The program has been revised to respond with a simple error message.

The interviewee stated that it took several months before she truly felt comfortable with the system. Interestingly, she could use the system effectively long before she felt comfortable. Many people in the office know the routine operation of the system but only a few understand how to start the system up and shut it down. This creates a minor problem with access to information.

The system provides concise error messages whenever an inappropriate entry is made. The user manuals can be consulted for a clear explanation of the message, which actions might have caused the condition, and what must be done to recover. The quality of the documentation plus the access to the programmers has eliminated any need for follow-up training.

Since the physical environment was not specifically designed for the computer, the lighting is not perfect and some minor glare problems exist. The interviewee arranges her work so that she sits at the terminal for only 15 to 20 minutes at a time and then moves around to do something else. She stated that the ability to control her work in this manner contributes a great deal to her acceptance of the system. She could not tolerate sitting at the terminal for four hours at a time.

Even though the automated system is many times faster than the manual system, "when people are waiting for their checks, it can still seem slow". She has learned to work with the system and has developed "fill-in" tasks, such as preparing for the next step, to do while waiting for the system to respond.

One difference between the manual and the automated system might possibly be construed as a disadvantage. With the manual system, it was possible to quickly "cut a check and catch up on the paperwork later". With the computer such shortcuts are not possible. All of the preparation must be done and the proper backup information entered before a check can be written.

The interviewee acknowledged that the system may be rigid, but as long as the prescribed steps are followed, it will respond predictably. Perhaps, since accounting is inherently rigid and demanding of accuracy, it is easier for her to accept these conditions.

In summary, her expectations of the system have been realized and she would welcome expansion of its capabilities.

POWER INDUSTRY INTERVIEW NO. 1

On February 11, 1983, the project manager of the engineering operations department of a research institution involved with electric utilities was interviewed.

The interviewee expressed great interest in the problems of the airline industry as they seemed to be relevant to the problems faced by the power industry.

Significant changes have occurred in the power industry since the Three Mile Island incident. Previously, all operators (operator, senior operator, and shift supervisor) were more or less interchangeable in terms of their activities. Now they are more specifically assigned to tasks in the occurrence of alerting conditions. This poses some problems, since in the view of some the individuals may not be performing the tasks they do best.

Prior to TMI they used system fault detection, now the emphasis is on symptoms. There seems to be a desire to avoid looking at derived data.

Question arises as to whether in certain conditions the human operator should be locked out. This is a problem with some basis in the philosophical approach. On the European continent some systems will lock the operator out for periods of 30 minutes or so.

POWER INDUSTRY INTERVIEW NO. 2

The plant is the most unusual of the 77 nuclear power plants in the United States. Design was begun in 1966 and the plant was completed in 1976 and first generated power in 1977. The interviewee held a number of positions and at the interview was manager of operations. He is currently plant manager.

Because of the experimental nature of the plant, procedural changes were commonplace. Early human engineering efforts were not as successful as they might have been, because the human factors personnel were not well acquainted with the specific knobs and dials which were important for operating the power plant. Consequently, much change and experimentation went on, and a number of problems remain unsolved, in particular, the question of how fault indication should be handled. At one time, only one general indicator was used, but the specific indicators were not readily available (on the other side of the panel), and operator couldn't get at them from his station.

Personnel are not, in general, degreed individuals, but they are highly trained. Many are former naval operators and have additional training at the plant. The total is about three and one-half years to become an operator. Some operators have come from other electric generating plants. The succession begins with a job as a tender; after training (and passing the test) the man becomes an equipment operator; after an additional year of class, etc., he may reach the status of reactor operator, followed by senior reactor operator, and supervisor.

At some plants training is done by simulator. Many of the simulators were designed to be generic simulators. This has not worked well, and it is likely that any new simulators will be plant specific. A problem is the cost of the simulator, if it is to be used by a rather small group.

Typically, three operators are on duty at any one time. One is a shift supervisor, one a senior reactor operator. They may be doing jobs which are interchangeable under ordinary operations.

When fault detection signal is given, rather specific procedures must be followed. These are looked up in a book, even if the operator knows the appropriate steps to take. This is required by NRC regulations. Nuclear Regulatory Commission auditors may observe the procedure, and could reprimand (fine) the company for failure to follow accepted practice.

One problem, common to aircraft and the nuclear power industry, is the nuisance alarms generated by the downstream effects of the basic problem. Some automation is built in for reactor safety, but much can or must be done by the operator.

POWER INDUSTRY INTERVIEW NO. 3

The interview was held at a small electric generating station on August 4, 1983. The interviewee is in charge of scheduling of maintenance and repair functions for the facility. He is about 35 years old and has been working for this company for about 13 years. He has an associate degree in electronics and worked in the instrumentation area at the company's nuclear plant for about 11 years before transferring to his present position about one and a half years ago. He is forward looking and has a positive attitude toward automation. He opted for this position because of the fact that the system was due to become automated shortly after he entered the position.

Turbine Operation

EXTENT OF AUTOMATION

In the power plants of the company, the automation is varied from plant to plant and within plants. In effect, most of the automation has been piecemeal. Some routine operations are automated and some recordkeeping and data management functions have also been automated. At the present time the system for maintenance is automated, but the repair parts inventory and purchasing system is not. The thrust of the automation has not been to replace personnel but to increase the output available from the same personnel.

The electrical generation process is a continuous process, but the needs for power vary within relatively short time periods. Thus, some units may be shut down and refired over relatively brief intervals.

The plant has several turbines which date from 1923, when the plant was built, to 1963, when the largest, latest, and most automated turbine was installed. Some operator controls are operated manually, even to the extent of using hand signals from one operator to another as they coordinate the positions of valves. Because of the need for balancing the load throughout the system, the most automatic system may be operated, and commonly is, from a remote location about 30 miles away. However, an operator is always on duty and may operate the turbine locally. Local station operation may be manual or automated.

The operators' primary functions are to monitor the process, to gather data on various conditions, and to respond to the needs of the centrally located controller. This latter response is basically one of changing set points within which the system operates, e.g., allowing the system to produce at a higher level. Although the operator is mainly a monitor, it is possible for the operator to place the system in a manual mode. Except in the case of an emergency, this would only be done when the system was under local control. The displays used to monitor the automated operation are basically similar to those used on older systems, but there are more of them and they are gathered on a single control panel.

Very little is required in terms of refined psychomotor skills or great physical strength for either the automated or the nonautomated systems. However, the manual system requires a fairly continuous level of physical response, as does manual operation of the automated system. Since this sort of operation also requires more decision making on the part of the operator, it also seems to have a higher mental workload than the automatic process.

Relatively little physical danger would be encountered by an operator, but a malfunction could be costly in terms of both repair expense and the problems which down time would present for the system as a whole. Alarms are presented in the control room through a signal and a panel light. The cause of an alarm may not be immediately apparent to the operator who must relay it to an appropriate repairman for further determination and for remediation.

CHARACTERISTICS OF OPERATORS

Most operators come from lower to lower-middle socioeconomic backgrounds and have a high school education. Their ages range from mid-thirties up to the sixties. In the fossil fuel plants automation seems to have produced few differences in operator characteristics. This is probably related to the fact that progression in the ranks is based largely on seniority and the training for new positions is mainly OJT. Operators usually begin as laborers and work through about three levels to the position of operator. A status of station operator is gained by an individual who can operate all aspects of the system and who is used as a relief person. From station operator, the individual becomes shift supervisor.

While the automated process is easier, the interviewee thought that many operators would prefer the manual systems. This was partly based on the fact that many of the individuals who operate that system are involved in maintenance when the system is off line. Thus, operating the system is somewhat a diversion from other duties. In addition, the system is somewhat an antique, and this was thought to add to the allure of running it.

ACCEPTANCE AND EVALUATION

Most operators accept the automated system, although when it was instituted some complaints were voiced. The process is quite reliable and the operators trust it, but it is difficult to ascertain their attitudes toward further advances. It appears that the primary gains from automation are based on the speed with which the system can be changed from one level of operation to another. While operating at a steady state, the system requires little attention other than monitoring, but in an emergency the fact is that changing one parameter requires a multitude of other changes. Thus, the capability to have these changed automatically enhances the operator's ability to make a rapid recovery.

Maintenance Scheduling

The computerized system has been used for about one year. It replaced a system in which each repair or maintenance request was made on a paper form with several carbons. The primary disadvantages of the paper system were that items were occasionally lost (thus repairs not made on a timely basis) and it was impossible to derive much information from the system.

The basic function of the scheduling system, as it operated prior to the automation, was to assure that needed maintenance and repairs were done and to set priorities with respect to the items which required immediate attention. A report, called an SSR, is filed each time some operation is to be performed on a piece of equipment. The automated system also serves these functions, but in addition, the new system allows one to immediately get a history of the repair and maintenance record for any item of equipment. This is very cost effective. For example it revealed that one $13,000 piece of equipment had needed $18,000 worth of repairs in a one year period. Obviously, a replacement with more than a one year life would be highly cost effective. In addition, the capability of scheduling maintenance is enhanced by this system, in that the item will stay outstanding until a positive indication that it has been performed is received.

While there is a person in charge of scheduling who is specifically involved with the operation of the system, all of the workers at the plant may be involved in reporting items which need repair. Thus, most have received instruction in how to file a report. It is interesting to note that immediately following the institution of the system there was a dramatic increase in the number of SSRs filed. After a time this dropped off, but is still higher than it was prior to the new system. Some of this increase may be attributed to novelty, but the amount of increase remaining is presumed to be because the system is easier to use than the paper system. Paradoxically, resistance to the system was also noted at the time it was instituted. Part of the resistance took the form of saying that the individual couldn't type or couldn't spell. As time passed many of these persons have begun to participate. Perhaps the reason for the increased participation is direct or implicit peer pressure. Some individuals may have avoided using the system by getting a co-worker to fill out reports for them. It was the interviewee's impression that the older workers were the most reluctant to use the system. A reason suggested is that they had no prior experience with computers.

ACCEPTANCE AND EVALUATION

The interviewee was enthusiastic about the current system and the planned enhancements. He also thought that the workers were happy with the system, in part because it helped them to document their activities. It seems that the system is reliable and that good support services have been available, first from the vendor and now from the in-house systems people.

POWER INDUSTRY INTERVIEW NO. 4

The interview was conducted on August 4, 1983 at a small power plant of a large public utility which generates electricity. The interviewee is a control room operator for a turbine generator. He is about 40 years old and has worked for the utility for 20 years. He began as a boiler tender and progressed through the ranks to become an operator. He has operated both the manual and the automated systems.

EXTENT OF AUTOMATION

A basic discussion of the system is presented in the power interview No. 3. The interviewee operates mainly with the automated system. He feels that this system must be automated because its capacity is such that one person could not keep up with it in the manual mode. He would rather work on the automated system than the manual because the automated system does not require as much continuous effort. Essentially, he feels that the automated system unburdens the operator.

EVALUATION

Although the interviewee was not an operator when the automated system first began operation, he worked in the area to some extent. It was his impression that there was some resistance to the system, and that the resistance was greatest among the older workers. An example which he cited is that of a fan which is commonly run in the automatic mode at the present. When the system first went into service, the operators would not leave the fan in the automatic mode. His comment was that the younger operators would use the automatic system because they were more "gutsy." His feeling is that the automated system helps the operator in many ways. In addition to relieving the operator of the continuous physical effort required by the manual system, the automated system produces a much faster settling down time when the amount of production required is changed.

There is no doubt that the interviewee feels that the automated system is better than the manual one. When asked about whether or not he could control the system better than the automatics, he stated that the number of parameters which would need to be controlled made that impossible when the system was operating in any other than a steady state. However, his feelings about further automation are less clear. When asked what he thought about a control system which would replace all the current displays with a CRT, he replied, "I hope that I'll be gone by then." When pressed for additional comment, he said that he did not think that he wanted to continue working in this area the length of time that it would take for such a system to be implemented. Upon a little reflection he also said that it might be better if one could get a graphic indication of the system on command, because this would allow the operator to determine more specifically the source of a malfunction.

The interviewee's opinion was that most operators shared his preference for the automated system.

POWER INDUSTRY INTERVIEW NO. 5

The interview was conducted on August 9, 1983, at a generating plant of a large public utility company. The interviewee is the plant manager and is heavily committed to the concept of automated processes. He formerly worked for another company as a gas turbine engineer, and has been with this company for about 15 years. Prior to becoming plant manager, he was in charge of maintenance. He is about 40 years old and has an engineering degree. He is articulate, soft-spoken, and people-oriented.

EXTENT OF AUTOMATION

The plant is the largest in total capacity in the utility's system. It contains four turbines which are operated with varying degrees of automation. The largest turbine is heavily automated and uses a computer for logging data and for troubleshooting. The present computer will be replaced within the coming year by a more advanced model which will provide operational capability directly from the computer. In this case, it appears that a substantial part of the reason for bringing in the operational capability is worker unburdening, although the major factor is likely the increased efficiency of operating the turbine.

In addition to the automation of operating systems, the organizing of maintenance has been largely computerized with a system which is almost identical to the one described for the plant described in Power Interview No. 3.

In the power generating process the operator is required to regulate the amount of pressure on one or more boilers by regulating one or more furnaces which are fed by coal mills in normal operation. In the automated system the operator serves primarily as a monitor to ensure that all aspects of the system are within prescribed levels. In this system the operator may override the automatic control whenever he chooses to do so. It is unlikely, however, that the operator would override for any length of time, since the amount of work necessary to maintain a balance among the several systems is too great. While there is no great amount of physical strength required, some physical activity is required and this would be greatly increased under manual control. Consequently, mental workload is probably also less under automatic control.

Errors and malfunctions are quite costly, especially with the automated system. It is estimated that each day off-line can cost the company $150,000. However, the automated system is superior to the other systems in terms of the ease with which malfunctions can be traced. An example is that of a malfunctioning valve which was repaired within minutes of the time it began to affect the system. Under the nonautomated system it might have taken a day or more to locate the source of the problem.

Although only a high school education is required for hiring into the progression of jobs leading to the operator's position, each step increase in level requires passing a test which is administered by the company. After passing a test, an individual is given the opportunity to bid for a slot which will go to the most senior qualified individual. Supervisory personnel must be qualified for the lower positions, but are chosen by management.

OPERATOR CHARACTERISTICS

While the formal educational requirements for the operator's slot are minimal, the backgrounds of the individuals working in the position are varied. Among those mentioned by the interviewee were an ex-priest, a Ph.D. physicist, and a psychologist with a masters degree. Others, of course, have only the requisite high school diploma. Many of these individuals apparently have computers. (One is writing a book using the word processing capabilities of his computer.) They seem to be generally accepting of the automated systems.

ACCEPTANCE AND EVALUATION

While the interviewee obviously accepts automation, there are some problems with the current system. These problems stem primarily from the age of the computer, which makes service and parts difficult to get.

ELECTRIC POWER INTERVIEW NO. 6

This interview was conducted at a nuclear power plant. The subject of the interview is a senior reactor operator in his late thirties. He has been in the nuclear power field for over eight years, with several years of prior experience in fossil fuel power generation. He feels that his fossil fuel experience was directly applicable to the nuclear field since the generation process is basically the same, the major difference being the heat source used to create steam. There is, however, a major difference in operating philosophy in that automatic "trips" or shutdowns were very infrequent occurrences in the fossil plant while they are are almost routine in the nuclear plant. This is due to the critical nature of the nuclear process. Ironically, the interviewee feels that this can actually reduce safety by subjecting the plant to frequent transients such as thermal shocks.

PROCESS CHARACTERISTICS

The process is divided into three phases: startup, normal operations, and shutdown. Normal operation is defined as operation above 30 percent of capacity. Operation below 30 percent is defined as either startup or shutdown. Below 30 percent, the process is quite dynamic and involves a great deal of manual operation. Above 30 percent, the process is fairly steady state and is essentially automatic. The automation utilizes programmable controllers and, although it is quite sophisticated, it is not computer based. The various process loops are heavily interrelated and feedforward is used to predict the effect of control inputs on other related loops. A computer is used to monitor, display, and log process data. The interviewee is familiar with both manual and automated operation of fossil power plants. Essentially, he feels that there is little choice but to accept the automation since it would not be possible to operate the plant manually at full power with any sort of transients. Due to the heavy interrelationships between loops, many control actions must be initiated simultaneously to maintain process stability. To do this manually would require an unrealistically large number of operators. In theory, the operator is in control and can override the automatics at any time. In reality, according to the interviewee, he is often locked out of the process by a series of hardware interlocks. He is often frustrated by situations where he knows that equipment malfunction has resulted in an erroneous signal which is about to result in a "trip" or process shutdown, yet he is unable to override the faulty equipment. He feels that more capability for manual override is needed to allow for human judgment. These interlocks are designed to err on the side of caution and prevent the operator from intervening and stopping an unnecessary shutdown rather than preventing him from initiating a shutdown. He feels that the human operator is needed to interpret indications and determine their validity in light of his experience and other related process characteristics. There is a danger that a computer would respond to a single data point no matter how illogical that information might be. There is also a danger that a human operator may become "wired into" a single indicator, but he is more confident that this danger can be overcome with human operators than with a machine. There are numerous alarms built into the system which are intended to give the operator early warning. The alarms are prioritized and presented in different modes, depending on the criticality of the problem. He then responds with a well-trained series of procedures to stabilize the situation. These emergency procedures must be committed to memory under NRC regulations. After the emergency procedures have been executed, a series of follow-up procedures are implemented. These follow-up procedures are contained in manuals and are more flexible than the emergency procedures. They allow for branching and a troubleshooting approach to determine the best response to the existing conditions.

Control of the process is shared by two operators. One is in charge of the reactor side of the process and the other is in charge of the conventional turbine and generator side of the process. These two operators switch roles on a weekly basis. Recently, the NRC has added a third man to the control room. This third man is a senior operator who functions as a shift supervisor. He monitors the overall process as well as the actions of the two operators. The control room operators are in communication with equipment operators and tenders located at various points in the plant. They use them as their "eyes and ears" to double check indications which are displayed in the control room. This capability to manually oversee the automatic process adds greatly to the operator's level of confidence in the system.

A CRT display of the computer data base is available to the operator. This information is available in a seemingly unending variety of formats. However, the interviewee feels that the control panel with its "hard" indicators is "where the real story is". He feels that control actions should be based on the raw data available on this panel. He believes that there is a danger that the computer only responds to predetermined stimuli, while the human response is a blend of reaction and analysis.

POWER INDUSTRY INTERVIEW NO. 7

The subject of this interview is in his thirties and is a control room operator at a nuclear power plant. He has ten years of experience at the plant, with the last six in the control room. Prior to that, he spent six years in the "nuclear Navy" as a power plant operator.

The interviewee compared his experience in the Navy with his experience as a civilian power plant operator. In his estimation, the nuclear process in the Navy was significantly more manual than the civilian power plant. He suggested that this might stem from a basic prejudice against automation and is possibly due to the manpower available in the military. The control process was broken down into small areas of responsibility with fifteen people being used to do what is done by two operators in civilian life. All functions were monitored manually with very few alarms used to alert the operators to an out-of-tolerance condition. Response to a malfunction was rigidly spelled out and left almost no room for operator judgment. The reactors onboard ship were much simpler than the civilian power plants in spite of the number of people used to operate them. The feeling was that this approach resulted in many trained operators who could carry on despite potential losses in a combat situation.

With the Navy system, operators traveled through the power plant and physically turned valves to control the process. In the civilian plant, the operator is isolated in a control room away from the sounds and other forms of immediate feedback present out in the plant. He stated that operating the automated system imposes a heavier mental workload because it is harder to see "the big picture".

When comparing the manual system to the automatic system, the interviewee stated: "The manual approach made me more comfortable; the automatic approach makes me more relaxed." Boredom is a problem for controllers during normal operations. He graphically described normal operation as "watching the plant draw circles on the chart recorders." At one time when the plant had been operating normally for about four months, morale seemed to be deteriorating. When the need arose to shut down a feed pump, the sudden return of purposeful work lifted everyone's spirits. The job can become so boring that even tending to paper work is considered a desirable task. The amount of recordkeeping had increased over the years to the point that it occupied a significant portion of the shift. The recent addition of a third operator in the control room has resulted once again in lower than desirable workload. The Professional Reactor Operators Society (PROS) has recently begun a campaign to alleviate boredom. They have taken the approach that to become bored on the job is equivalent to a loss of professionalism.

The computer is confined to a monitoring role and has no control capability. Based on the frequency of failures and "glitches" experienced with the computer, the interviewee feels that he would not welcome computer control. The automatic controllers themselves have proven to be quite reliable. In the past, several controllers have reacted to alarms by "throwing everything into manual mode". This has resulted in more problems than when the automatics were left to deal with the situation. As a result, experience has taught the operators to trust the automated features.

The long periods of normal operation have shown problems with skill retention. Simulators would be an effective way to maintain efficiency if their cost were not prohibitive. Generic simulators have been tested but found to be much less effective than site-specific simulators.

In the wake of the Three Mile Island accident, the NRC has imposed many new requirements on nuclear power plants. One of these requirements is for a thorough human factors evaluation of each plant. While taking part in this review, the operator for the first time questioned the validity of many aspects of the plant design. For example, one of the panels has a series of four toggle switches in a horizontal row. Each switch applies power to a valve actuator when the switch is flipped to the right and removes power when it is flipped to the left. For safety reasons, some of the valves are designed to fail open and others to fail closed. As a consequence, some of the valves are opened by flipping the switch to the right and others are closed by the same action. Now that the operators have devised strategies to deal with such inconsistencies, they are reluctant to have them corrected.

In summary, he stated that if more automation is forthcoming, it must be done with more reliable computers. With more automation, the problems of boredom and skill retention will become even worse. Operators will become "lazy, lax and unknowledgeable". Site-specific simulators will be necessary to deal with these problems.

ELECTRIC POWER INTERVIEW NO. 8

This interview subject is a senior control room operator at a nuclear power plant. He is in his mid-thirties with six years of experience in the "nuclear Navy" and ten years at the nuclear power plant.

His comparison between the civilian power plant and Navy shipboard reactors was very similar to that of electric power interview subject No. 7. The Navy reactors are much smaller with fewer sub-loops. In addition to being inherently simpler because they are smaller, Navy systems were designed to be "sailor proof". This entailed designing the system to operate within a wide tolerance band.

Civilian reactors are much less forgiving. They must operate more efficiently, requiring that the process be kept within tighter limits. The close interrelationship between the various loops can lead to a domino effect, with one malfunction or error cascading through the entire system.

He reiterated the sharp contrast between essentially manual operation at less than 30 percent power and automatic operation at above 30 percent power. Since the plant is ultimately designed to operate at full power for 300 days before a shutdown of 60 days for refuelling, operators may go for a full year without practicing the skills needed for shutdown and startup. Even with much shorter periods of normal operation (a maximum of four months to date), significant loss of skill has been experienced.

When asked if he trusts the automatic equipment, he replied, "When everything's coming down around your ears, you don't have much choice but to trust it."

POWER INDUSTRY INTERVIEW NO. 9

BACKGROUND

The subject of this interview works in the area of human factors for a consulting firm which has a number of contracts with the nuclear power industry. Some of the contracts are through the Electric Power Research Institute (EPRI) and others are directly with power companies. Activities of the consulting firm include research on training, design, and operation of power plants and studies of the decision processes involved in the activities of operators. The subject's background is in design and instrumentation. After a period of working with suppliers of nuclear power apparatus, he returned to school to obtain a Ph.D. in industrial engineering. He has recently been involved in a human factors review at a nuclear power plant where a number of the other interview subjects work.

HUMAN FACTORS ISSUES IN NUCLEAR POWER PLANTS

In working with operators at a number of different nuclear power plants the interviewee has observed their reactions to automated processes. As has been suggested by other individuals interviewed, he thinks that it is necessary for the apparatus to work well very early after its implementation. Early failures contribute to rejection or to lack of trust in the reliability of the apparatus.

In his view one of the prominent problems of the automation in the nuclear power industry has been the piecemeal application of automation to the operation of the power plants. This has in some cases made the operator's job more difficult, because the operator must integrate the activities of different automated systems. Another problem which has arisen in some cases is based on the fact that automatic systems have been developed on a compensatory basis. When certain events occur, an automatic compensatory action is taken by the automatic devices and the operator may not be aware that this action has been taken. Thus, when the operator becomes aware of the source of the original problem, he may also be confronted by a system which has been distorted in order to compensate for the problem. This can result in the operator not having the margin needed to keep things under control while solving the problem.

An interesting experiment performed by the interviewee's organization was mentioned in conjunction with the problem of the Three Mile Island incident. Computerized graphic displays of the status of a system were shown to operators, supervisors, and engineers for their use in tracking down the sources of various problems. One group of individuals was shown three levels of display, including a global level, a subsystem level, and a primitive level. The second group was shown only the two higher levels of information. The group with less detailed information did as well or better in determining the source of problems. This was attributed to two possible factors. First, the group which received the three levels tended to drop rapidly to the most primitive level and spend most of their time working at that level. This produced a good bit of step-by-step activity. Second, it appeared that the basis for going to the lowest level was that the individual had formed an hypothesis about the cause of the problem, and the activity was directed toward eliminating the perceived problem. Because the problem was assumed to be known, other possibilities were not explored. An interesting sidelight to these results was that the tendency to go to the most primitive level was greatest among those individuals who had the most operating experience. It would appear that they tend to do what they know best.

Another problem which is a matter of concern in the nuclear power industry is the number of alarms and annunciators involved in the system. Although attempts are being made to prioritize the alarms, this seems to be a difficult task. In addition, the question can be raised as to whether the alarms should be for events or for symptoms. While a symptom type alarm lends itself to prioritizing more readily, it may also be more easily dismissed, if the operator thinks that it is based on some already known factor. Another possibility is that an alarm may be disbelieved because of the global nature of the alarm. For example, one nuclear reactor had been shut down for repairs and a valve to a cooling system closed. When the system was restarted, the valve was not reopened. As a consequence, all of a set of motors showed indication of overheating. The operator took that to be evidence that something was wrong with the alarm system and continued with his startup procedures, thereby burning up all of the motors.

The interviewee stated his opinion that a very high percentage of automated systems were not being used. "If they don't like them any excuse will be enough not to use them." The two factors involved seem to be lack of trust and lack of training in using the systems adequately.

POWER INDUSTRY INTERVIEW NO. 10

BACKGROUND

The subject of this interview was a former operator and shift supervisor who is currently on loan to an umbrella organization which specializes in developing nuclear power operations procedures and systems. After service in the Navy he attended a university, but dropped out to work for a power plant. He became a licensed operator and shifted to another company. He later became a shift supervisor and shifted to another company. Therefore, he has seen differing levels of automation.

OPERATOR CHARACTERISTICS

The sort of personnel who serve as operators currently come from two general groups. One group are individuals who come into the training programs without prior experience or with experience as naval personnel. The other group comes from the fossil fuel plants. There does not seem to be much difference in the length of the training periods required for these different groups. The interviewee did not have any particular attitude about changes in the level of education required for personnel. In essence, the ones who passed the aptitude tests were adequate. However, he has a preference for those individuals who come from the fossil fuel plants. His reason for this is that they are more aware of the physical factors involved in plant operation ("They aren't afraid to get dirty") and can relate events to each other better because of this. Many of the newer personnel have spent time in a classroom and a simulator, but haven't actually been involved in the plant itself until after their licensing. He cites the experience of having an operator call back to him in the control room and say that a piece of equipment was making a funny noise. Because the man in the field had no prior experience, he could not tell that it was a valve chattering. He also thinks that the individuals who have field experience can understand the overall system better.

SYSTEM CHARACTERISTICS

A significant problem noted by the interviewee was the occurrence of multiple alarms. During the ordinary course of affairs, some alarms or annunciators may be tripped and essentially ignored, because the reason for the condition is known to the operator. He feels that in most circumstances the operator is able to filter out the noise from the system and home in on the important signals. Yet there may be some benefit to a system which prioritizes the alarms, if it is properly set up. It is his opinion that most of the systems which have been advanced to date are not very good in this respect.

Although most of the people who work at these plants are union personnel, this does not seem to be a factor in the operations of the plants. He made reference to unions as involving a lot of grief, but the problems were "petty" questions of who got called for overtime, etc.

An important concern of the interviewee was the knowledge of the system. He said that he felt that he had to know how each element of the system worked. When computerized equipment became a feature of the control room, he learned how computers work. He purchased a home computer in order to aid in his understanding of the processes. In one of his jobs he said there was a sort of seminar among the personnel on duty which studied the computer and how it worked.

As has been noted by other individuals in other settings, the interviewee said that early experience with unreliability of a system will cause operators to discard it, if possible. Despite the fact that he had no impression of difference in reliability between pneumatic and electronic equipment, he thought operators would prefer to stay with a system which they knew until the new system had been proven reliable.

A particular question which the subject brought up was that of why should a system be automated? In his thinking, some automation is introduced not because it is needed but because it is available. When asked what problems could be encountered with automated systems, he said that the problems could come at many places. One difficulty is that there are not enough sensors to take the place of a man. He noted that the computer can't smell a problem. Additionally, he thinks that many of the automated systems are devised in terms of what the engineer wants, not what the operator needs. It would be better if the operator had more options as to the information which he can get from a computer screen. It was also noted that in some systems the operator must type in a request for information which is basically available to him from other instruments. While the typing operation is occurring, the information could be integrated by the operator and the usefulness of the integrating capability is lost. When asked if a dedicated control for certain information would help, he said that he thought that would be the only way to handle some of the situations.

Although he had many negative comments about the automated systems, he thought that they were useful and would improve in the future. His primary reservations were that in many cases these systems did not do what was needed, and that they might eliminate the human from service as a sensor, thus losing valuable information.

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16 Abstract In order to derive general design guidelines for automated systems a study was conducted on the utilization and acceptance of existing automated systems as currently employed in several commercial fields. Four principal study areas were investigated by means of structured interviews, and in some cases questionnaires. The study areas were: Aviation - both scheduled airline and general commercial aviation; Process control and factory applications; Office automation; and automation in the power industry. The results of over eighty structured interviews were analyzed and responses categorized as various human factors issues for use by both designers and users of automated equipment. These guidelines address such items as general physical features of automated equipment; personnel orientation, acceptance, and training; and both personnel and system reliability.

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