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AUTOMATION LITERATURE: A BRIEF REVIEW AND ANALYSIS

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SUMMARY

The concept of automation is a burning flame of intriguing potential which has lured engineers, industrialists and businessmen into creative applications of the abundant technological advances which are constantly exploding into existence. Unfortunately, all too often the introduction of automation into a system turns out not only to fail to achieve the promised advantages, but also results in major system failures. The paradox occurs, therefore, that automation which should improve performance, in fact, debilitates system performance. Increased automation does not always lead to increased system performance. Part of the problem for the tales of failure is that the concept of automation encompasses many varied applications and in itself is not a single variable.

The purpose of this paper was to establish the current thought and research positions which may allow for an improved capability to understand the impact of introducing automation to an existing system. The orientation was toward the type of studies which may provide some general insight into automation; specifically, the impact of automation in human performance and the resulting system performance. While an extensive number of articles were reviewed, only those that addressed the issue of automation and human performance were selected to be discussed. The literature is organized along two dimensions: time, Pre-1970, Post-1970; and type of approach, Engineering or Behavioral Science. The conclusions reached are not definitive, but do provide the initial stepping stones in an attempt to begin to bridge the concept of automation in a systematic progression.

INTRODUCTION

With new technology accelerating dramatically, mankind has available alternative automated equipment to deal with complex situations. This availability does not assure acceptability or increased performance. Automation usually implies that a system includes, or will include, equipment assumed to enhance man's capability to accomplish a required function, but experience does not clearly support this assumption. Adding automated equipment is usually assumed to be an improvement in total system performance. "However, the battlefields are strewn with systems that were not successful due to some aspect of equipment failure" (Dieterly, 1980, p. 7). The cost of adding automated equipment is usually astronomical. Therefore, the successful integration of automated technology into systems is of utmost importance.

One of the first steps toward successful integration should be to examine what is known about this elusive concept. The objective of this review of automation literature was to focus on three aspects of automation in terms of their impact on human performance. Emphasis was placed on how automation was defined, from what viewpoint the subject was approached, and limitations associated with each approach identified. For ease of discussion, the literature was grouped prior to 1970 and after 1970. This division is appropriate since a shift in research objectives may be detected in the early 1970s.

Automation Literature Before 1970

Automation was an emotional topic during the fifties and sixties. People across disciplines discussed and wrote about the impact new technology would have on such things as profit, human resources, job satisfaction, and motivation. The focus was whether or not to automate. Generally, these articles were narratives speculating changes people should expect and overall impact if systems were automated. During this period predictions were about evenly split between catastrophe and triumph.

The pro-automation experts viewed a Utopia of improved quality of life for all persons touched by it. Turner (1956) discussed human adjustment to automation in unusually positive terms for the times. He drew an analogy between automation and a three-legged stool -- one leg being highly engineered mechanization, another involving feedback or closed-loop control, and the third representing the electronic computer. Turner contended that too many things said about automation as a whole were applicable to only one of the legs, and that too many arguments based on facts about one leg ignore the other two. He argued that persons should not assume that any economic and/or social effects will be the same as those associated with mechanization in the past. He believed automation might actually reverse the trends of past experience.

Davis (1962) speculated on the possible effects of automation on job design. He examined the literature and determined that very little knowledge on automation was available. What he found indicated that the fears about technological lockout of workers seeking to enter automated industries seemed unwarranted. The belief was that automation would tend to increase the responsibility of workers. New jobs would combine the functions of monitoring, regulating, adjusting, and maintaining. Jobs generally would be upgraded and enlarged by automation. Davis defined automation as a process or continuous type of production system characterized by integrated, automatic movement of materials through a production system and built-in self-control or regulation of production units.

A survey study concerning job satisfaction before and after automation was done by Hardin (1960). Automation was equated with computerization. The conclusion was that changes in the work environment and job satisfaction were very similar to changes that occur normally without automation.

Lipstreu and Reed (1964) used a checklist questionnaire, observation, and interviews to contrast low vs high automated systems on morale, selection,

training, and performance. They defined automation as something significantly more automatic than that previously existing. Their example of a lower level was where machines are actuated by introduction of a work piece. Higher level meant that machines inspected while operating and modifying their own performance, so potential rejects would be avoided. They concluded that morale and performance were substantially higher for the more automated system.

The con-automation experts perceived dehumanization and/or unemployment as inevitable results of automation. Bogardus (1958) discussed attitude changes expected after automation. It was argued that the number of workers required to turn out a product would decrease after automation, and many older workers and those less able to make the required changes in work habits would have to be downgraded, receive less pay, or become unemployed. Bogardus defined automation as having three aspects: (a) linking several machines so materials pass automatically from one unit to the next; (b) system maintenance of instructions through opening and closing electrical circuits; and (c) given instructions, system performance of thousands of operations per second.

Mann and Hoffman (1956) compared an automated with a nonautomated plant on employee perceptions and feelings about working conditions, selection, training, shift work, and supervisors. Workers in the nonautomated plant perceived certain changes resulting from automation: (a) a reduction in the work force, (b) a redefinition of jobs, (c) more tension and interdependence between workers, and (d) a need for retraining when employees were expected to perform on higher levels of automation.

As the 1970's approached, introduction of various degrees of automation supported the idea that automation was more beneficial than detrimental. Grudgingly, as automation was accepted as a necessary fact of the industrial environment, discussion and writing about the broader impact decreased rapidly. The focus appeared to shift toward considering what automation was doing or could do to human performance. Although general studies of automation and job satisfaction still persisted, a more problem-specific research began to predominate the literature.

In summary, before 1970 a plethora of literature was published concerning automation. However, definitions of automation were seldom agreed on or clearly specified. Authors defined the concept according to their needs and viewpoint. The central issue was whether or not to automate and, depending on the side chosen, an argument was offered. The focus was on the impact automation would have on humans in an industry and how they would be likely to respond. Of the literature reviewed, the majority presented opinions, not empirical research. The few documents that were not statements of opinion were field studies. No laboratory studies were found.

Current Focus of Automation Literature (1970 to Present)

Around the early seventies, a major change in the automation literature can be noted. Interest shifted from automation generally and its impact on

people toward specific systems and their design. Unfortunately, interest and research shifted before researchers could agree on a standard definition of automation.

Definition of Automation

As a result, many different definitions of automation have been proposed. Thomas, Pritsker, Christner, and Byers (1961) defined level of automation as the extent to which decisionmaking functions associated with control of a man/machine system are performed by machines. It has also been defined as a mechanical or chemical process directed, controlled, and corrected within set limits such that no human intervention is needed once a system is established (Dunlop, 1962). After a literature review, Dieterly¹ integrated the varied definitions. This definition as modified seems to encompass most others: "The operation of a system or production process by mechanical or electronic devices that takes the worker's place in terms of effort, observation, and decisionmaking."

Some researchers would object to this definition because they differentiate between mechanization and automation. They maintain the distinction that mechanization entails the machine performing tasks that do not require decisionmaking, whereas automation entails the machine performing tasks that require decisionmaking.

In research studies, automation is typically not directly defined. Hoppe and Berv (1967) developed in the field an instrument to assess attitudes toward automation. They developed and validated a 22-item scale without defining automation. Some studies assume a system to be automated and research begins. Fried, Weitman, and Davis (1972) developed a questionnaire to study absenteeism for jobs that required different levels of man/machine involvement. They did not use the term automation, but the facets chosen for study were based on whether man or machine was responsible for control, that is, flow of materials and/or corrective action. They found that absenteeism was lower when employees rather than machines were more in control.

Research has also been done comparing two or more levels of automation, although the concept is not directly defined. This is particularly the case when the system in question is computerized. Jacobson, Trumbo, Cheek, and Nangel (1959) designed an extensive questionnaire to compare attitudes before and after computerization of an insurance company. No justification was offered for the equating of computerization with automation. Puig, Johnson, and Charles (1974) compared computers (assumed to be automatic) with instructors (assumed to be manual) on training and performance scores. Again, automation was not directly defined and assumptions were not defended.

¹Dieterly, D. L.: Preliminary Program Plan: Automation's Impact on Human Resource/Management. Unpublished report, 1979, p. 9. (Available from the author, NASA-Ames Research Center, Mail Stop 239-2, Mountain View, Calif. 94035.)

When a definition is offered, it is usually specific to a system and not quantified. Couluris, Tashker, and Penick (1978) compared six levels of automation to 17 human factor variables. The six levels of automation were represented by six different air traffic control (ATC) operations systems (current system plus five plausible future automated systems). The systems differed in the amount of control and decisionmaking responsibility assigned to the controller. The research findings were highly specific to the systems examined. The purpose was to determine which system led to highest satisfaction and motivation and lowest failure rate. The strong and weak points of each system were discussed. The conclusion was that automation tends to reduce both job satisfaction and stress. The reduction in satisfaction occurs primarily because the controller's expert skills are not utilized in the automated systems. The system in which the controller is almost completely "out of the loop" (highest level of automation) would be acceptable only if the type of person performing the job and the training the controller receives were changed radically. The ideal controller for the highest level appears to be someone who does not need to maintain active control of the system. It also appears that humans want to use whatever level training they receive. Therefore, job satisfaction could only be increased if the amount of training were reduced. However, severe problems would arise if the system failed and the controller had not been adequately trained.

Mueller (1969) did a cross-sectional survey on changes brought about by automation, including attitudes, and offered one of the better methods for defining and measuring different levels of automation, although the levels were not quantified. The definition began with the concept of control. The manual level became the control of equipment which is not powered. Levels not classified as manual required powered equipment. Middle levels required power and were controlled either by the operator or mechanization, and could be single or multisystems. The highest levels required power and computer control. These levels vary from low to high degrees of feedback, and either a low or high degree of flexibility. Any piece of equipment may be classified according to this scheme, and the classification represents the level of automation for that piece of equipment. The major conclusion was that automation changed relatively few jobs significantly. Any impact was largely indirect.

Noll, Zvara, and Simpson (1973) compared the impact on controllers of two ATC systems that functioned on two different levels of automation by two different types of ATC systems - a typical ATC system and an advanced system of the future. The more automated system eased pressure and reduced workload. The results are specific to the systems examined. Although the differences were not easily determined, it appears they primarily involved allocation of responsibility and control functions to man or computer.

Ratner and Williams (1973) compared four levels of automation for the air traffic controller's contribution to ATC system capacity. Again, this research was highly specific to ATC systems and could not be easily generalized to other systems. Level of automation was determined for terminal area sectors according to whether the functions involved (i.e., decisionmaking or communication) were performed by man or computer. The findings indicate that

automation of decisionmaking functions has a good potential for improving sector capacity in terminal operations. In addition, Ratner and Williams contented that workload should be reduced.

The one article found that does include a quantification method is specific to the equipment the authors designed. The method, therefore, could not easily be adapted to other systems or equipment (Thomas, Pritsker, Christner, and Byers 1961). They were only concerned with decisionmaking. Therefore, automation was narrowly defined as a function of the extent to which the decisionmaking functions of a system are performed by machines. The authors quantified levels of automation by developing a stochastic model. Equipment was built in accordance with the developed model. The results seem to indicate that the equipment and the model describe different levels of automation. The literature reviewed further substantiates the contention of Potter and Dieterly (1971) and Potter, Korkan, and Dieterly (1975) that no easily adaptable method of quantification of level of automation has been developed.

In summary, the shift toward equipment specific implementation and modification research studies offers increased understanding of the impact for a given system, but does not provide the general information necessary to predict the implications of other systems. If definitions of automation were varied or avoided before 1970, they appear to be even more so after 1970. Definitions offered are still based on interest and viewpoint. Many are so specific to a particular system that they make no sense if one attempts to apply them to another system. Quantification is one method of standardizing definitions. One study attempted to quantify levels of automation, but the method was highly system-specific. Therefore, no apparent advances have been made toward a standard definition of automation. Another aspect of the literature during this period is that it stems from two different approaches, the behavioral science approach and the engineering approach.

Behavioral Science Approach to Automation

Current automation research seems to be divided between behavioral scientists and engineers. Behavioral scientists are concerned with human responses to and attitudes toward automation.

It is a well documented psychological fact that attitudes affect behavior. If, for example, an individual has a negative attitude concerning automated systems, and a system is perceived to be automated, behavior will most likely be negatively affected in working with this system. This outcome would prevail whether or not the system is defined as automated by the designer. If an operator perceives the automated system to be unreliable, whether it is or not, the operator will use alternate procedures to accomplish the objective. Resulting performance will be poorer than expected because the operator's attention will be split between the automation information source and the alternative information source. Therefore, when we seek to define automation and/or level of automation, human perceptions and responses must be considered.

The object of a study by Nealey, Thornton, Maynard, and Lindell (1975) was to forecast motivational problems likely from increasing automation and to suggest behavioral science research to ameliorate these problems. Automation was not directly defined, but it was implied that an increase in automation meant the addition of more sophisticated equipment. They found that in most cases the initial discontent was short-lived and resistance was overcome as system reliability increased. In other cases, discontent persisted. Most controllers interviewed said they would find their job boring if conflict prediction and resolution and instructions for metering and spacing functions were taken away. The authors contend:

Resistance to change is very much affected by employee expectations regarding future changes. At worst, highly negative expectations can seriously block the willingness of employees to give a system change a fair trial (p. 28).

Dieterly (1980) suggests that there may be no absolute way to define automation because an individual's perceptions of a system and its operator functions determine a "perceived level of automation." If this is true, the level of automation might vary for a given system as a function of the varied perceptions of different individuals, for example, operators, supervisors, designers, and management.

Topmiller (1963) developed a paired-comparison, equal-interval scale in an attempt to determine if different groups of people use "different subjective frames of reference" to define level of automation. The results support Dieterly's idea that level of automation may vary dependent on perceptions of the task or set of tasks.

Some current literature is apparently attempting to improve attitudes concerning automation. An article by Morgenbrod and Schwartzel (1979) attempted to convince readers that automation could improve the work environment. They concluded that automation could improve communication, decrease unskilled office positions, and increase medium and highly skilled specialists. Unfortunately, they did not define automation nor make statements derived from research.

Research concerning the man/machine interface should certainly include the limitations and quirks humans bring to the system. Humans are capable of sabotaging what designers consider a perfectly designed system. System performance is affected by psychological variables of operators. Therefore, it is important to understand the behavioral science approach and adjust for it when dealing with automation.

Limitations of the Behavioral Science Approach

The variables behavioral scientists are interested in, that is, attitudes and motivation, are difficult to study. This can be attributed to several problems: (a) the variables are not easy to measure; (b) no accepted standard

has been established; (c) behavior and the reasons for behavior are extremely complex; and (d) causal relationships are difficult to establish.

Objective methods of studying human resource variables have not been perfected. Smith and Westland (1971) concluded that the correlational approach to predicting behavior appears to be the best empirical approach for use early in system design. They stressed the importance of a relevant list of equipment characteristics and the necessity for a valid data base. Topmiller (1964) contends that it is necessary to sample across different classes of equipment so results can be generalized sufficiently to be practical. Potempa, Lintz, and Lucken (1975) developed regression models in the hope of being able to predict the interactive influence of system design and maintenance skills on job performance. The main problems with behavioral science research seem to be lack of agreement about how to study human factor variables and studies rarely build on previous knowledge. The result is many different methods and many different hypotheses, but no solid theory.

Engineering Approach to Automation Research

Recently, engineers have been interested in the function allocation between man and machine. As used here, a function is any unit of activity from a simple monitoring unit to a decision unit. The total set of functions constitutes the requirements necessary to attain system performance (Dieterly, 1980). Models are created that are designed to predict human performance for many different functional allocations. Much effort has been devoted to developing computer models of human responses and computer models of how systems function. These models of men and machines are integrated to study performance characteristics of system design.

Curry, Kleinman, and Hoffman (1975) developed a mathematical model as an attention allocation scheme for predicting performance for automated (with flight director) vs nonautomated systems (without flight director). The hypothesis was that humans give priority to controlling the systems, and monitoring is performed with any remaining attention. The results indicate that automated systems improve performance. Work is continuing to further validate the model.

Palmer (1977) studied pilot-computer interactions for monitoring and data entry tasks to develop time-sharing attention models for interrupted monitoring of a stochastic process. Palmer contends that models are important to system design because:

As computers are added to the cockpit, the pilot's job is changing from one of manually flying the aircraft to one of supervising computers which are doing navigation, guidance, and energy management calculations as well as automatically flying the aircraft (p. 1).

Rouse (1975) examined workload problems that resulted from an increase in automation and the allocation of responsibility between man and computer. He found that workload increased with number of tasks, performance rate, lack of

similarity among tasks, and level of direct involvement the human has with the tasks to be performed. He also studied the importance of feedback from man to machine and vice versa. By dynamically allocating more decisionmaking functions to the machine (increasing automation), human workload was decreased and system performance was increased. Feedback between man and machine improved performance by eliminating competitive decisionmaking.

Rouse, Govindaraj, Greenstein, and Neubauer (1979) experimented with an optimal control theory in an effort to study attention allocation. Pilots were assigned control tasks, with discrete tasks interjected. They were also interested in multiple process monitoring and how decisions were made when no control is involved. In their study, automation meant that an increasing number of control tasks were performed by automatic systems (primarily computers). As a result, humans spent more time monitoring and only intervened when failure occurred. If more than one failure occurred, the person had to decide which to correct. This decision was influenced by the cost a delay would create to the system, they concluded.

Walden and Rouse (1977) used queuing theory to develop a simulation model for allocating decisionmaking responsibility between man and computer. They were able to predict performance for a multitask, control and monitoring situation. Again, the assumption was that automation of a system means that increasing amounts of decisionmaking responsibility were allocated to the machines.

Koroleu (1970) defined a fully automated system as one devoid of man in the control loop. A man/machine system was some mix of man and machine in the control loop. An analytical expression was developed in an attempt to determine the proper mix or allocation of functions to optimize system efficiency.

Display and design analysis research usually refers to a specific system and how the display should be designed or improved. Baron and Levison (1975, 1977) analyzed the effect of display parameters on performance and workload for manual flight control using the optimal control model, a model of the operator machine system. It assumes that the human controller will adopt an optimal response strategy that considers task requirements and the person's inherent information-processing limitations. They concluded that a more sophisticated (assumed to be more automated) flight director system would improve performance and reduce pilot workload. Their analytical model primarily determines the information needed, and how it should be displayed so humans can perform at maximum levels with minimum attentional workload.

Curry, Kleinman, and Hoffman (1977) examined design procedures for control and display systems under varied levels of automation. They place automation on a continuum from fully manual control with no monitoring through fully automated control with monitoring only. The result was an analytic design procedure that considers human performance and different levels of automation.

Stewart (1978) compared an automated and a manual system in terms of performance. The manual system was represented by the present manual access

file system. The automated system meant file access through a computer terminal. The conclusion was that automation significantly increased both accuracy and completeness in accomplishing performance requirements, but not the speed of completing those requirements.

Ephrath and Curry (1977) used level of automation, as defined by level of pilot participation, to examine workload and failure detection. They found that within the scope of their simulator-based study, a fully automatic approach is the preferred level from the failure detection point of view.

Kessel and Wickens (1978) did a laboratory study using tracking tasks to compare manual and automatic systems on failure detection performance. Manual was defined as the participation mode where the subject was actively controlling a system; automation meant the subject was monitoring an autopilot controlling a system. The results indicated that failure detection performance was faster and more accurate in the manual mode. This contradiction appears to be only an example of the different failure detection tasks and variable operational definitions developed.

In summary, as with the behavioral science approach, in the engineering approach automation is usually either not mentioned or not directly defined. Assumably, the more automated a system is, the more functions, for example, decision making and control, will be allocated to the machine. It seems that when humans are interacting with an automated system, they spend more time monitoring machines than physically manipulating or controlling them. When automation is defined, the level of automation is the degree that different functions have been transferred from man to machine. When only this factor is considered, we have a very limited definition of automation similar to the control loop feedback "leg" mentioned earlier (Turner, 1956).

Limitations of the Engineering Approach

DeGreene (1975) points out one of the problems in automation research. Currently, the majority of automation researchers describe human behavior in engineering terms or in terms geared to our understanding of present machines. Human behavior is much too complex to be molded to fit simple models or machines.

Another limitation of the engineering approach is that the experimental design is usually applicable to a specific type of equipment so the results cannot be generalized to other types. Not only is some research specific to a system, other research is specific to a particular function within a specific system.

Although the engineering approach is important, without considering human perceptions and responses, it does not contribute to advancing the theory of human behavior necessary to predict the impact of automation. DeGreene's (1975) comment may be generalized to automation when he strongly contends:

Experts at artificial intelligence appear to have become so engrossed with the manipulation of numbers and symbols as to lose contact with

the real world functions their eventual designs must perform
(p. 68).

CONCLUSION

It is apparent that automation has become an important factor in our changing world. More job descriptions include some form of computer experience. More families own home computers. As was suggested, the concept of automation also includes other aspects of technology. One major difficulty in understanding how automation impacts human performance is determining what it is. It is not difficult to find problems that seem to result from automation, that is, unreliable systems, people refusing to use the automated system, and confusing instructions. Increased understanding seems to reduce problems. Research is needed to increase the probability of successfully integrating automated systems or subsystems into existing work environments.

Currently, improved equipment design and reduction of equipment failure is the focus of the research effort. At least for now, neither equipment nor organizations can operate without humans. Therefore, human response to, attitudes about, and perceptions of automation should be considered. However, at the present, automation research appears to be generated by two different approaches: the behavioral science approach and the engineering approach. Engineers concentrate on system design and performance models while human resource requirements receive minimal consideration. As a result, personnel must merely react to hardware requirements. On the other hand, behavioral science research focuses on attitudes, behavior, and the human resource requirements, while generally ignoring equipment characteristics and constraints.

Eckstrand, Askren, and Snyder (1967) pointed to one possible solution. They concluded that research is needed in quantifying, formating, and modeling human resource data in a form usable for engineering analysis and design of automated equipment. For example, skill requirements could be translated into equipment-oriented task statements. Some transfer function could then be used to relate these data to available personnel. They emphasize the importance of establishing better dialog between design engineers and human resource specialists so that automated systems consider the capability of humans.

The increasing application of equipment with automated characteristics is certain. Development of cost-effective systems requires data, methods, and models before human factor specifications can be presented to engineers during system development. Knowledge of how equipment, training, experience, aptitude, and attitudes influence system performance should be integrated into the total evaluation. A concerted effort is required to gain insight into the human resource implications of increased automation in organizations. Only in this way can system failure be avoided.

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16. Abstract <p>The concept of automation is a burning flame of intriguing potential which has lured engineers, industrialists and businessmen into creative applications of the abundant technological advances which are constantly exploding into existence. Unfortunately, all too often the introduction of automation into a system turns out not only to fail to achieve the promised advantages, but also results in major system failures. The paradox occurs, therefore, that automation which should improve performance, in fact, debilitates system performance. Increased automation does not always lead to increased system performance. Part of the problem for the tales of failure is that the concept of automation encompasses many varied applications and in itself is not a single variable.</p> <p>The purpose of this paper was to establish the current thought and research positions which may allow for an improved capability to understand the impact of introducing automation to an existing system. The orientation was toward the type of studies which may provide some general insight into automation; specifically, the impact of automation in human performance and the resulting system performance. While an extensive number of articles were reviewed, only those that addressed the issue of automation and human performance were selected to be discussed. The literature is organized along two dimensions: time, Pre-1970, Post-1970; and type of approach, Engineering or Behavioral Science. The conclusions reached are not definitive, but do provide the initial stepping stones in an attempt to begin to bridge the concept of automation in a systematic progression.</p>			
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