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AUTOMATION IN ORGANIZATIONS: ETERNAL CONFLICT

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Abstract

The purpose of this paper is to present some ideas on and insights into the problems associated with automation in organizations. The concept of automation, its relationship to the individual, and its impact on system performance are three areas that will be emphasized. An analogy is drawn, based on an American folk hero, to emphasize the extent of the problems encountered when dealing with automation within an organization. A model is proposed to focus attention on a set of appropriate dimensions. The function allocation process becomes a prominent aspect of the model. The current state of automation research is mentioned in relation to the ideas introduced. Proposed directions for an improved understanding of automation's effect on the individual's efficiency are discussed. The importance of understanding the individual's perception of the system in terms of the degree of automation is highlighted. The number of automated systems will increase drastically in the future, and everyone — individuals, management, and organizations — must be able to adapt to the wave of the future or flounder in a sea of turmoil.

Index categories: Automation; Automation of Organizations; Perceived Automation; Impact of Automation; Organizational Automation.

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Background

The concept of automation has been a source of philosophical discussion for centuries. Descartes relegated brute animals to the status of mere machines or automata since they have no consciousness, while Paley attempted to establish the existence of God by arguing that the existence of a complex machine (watch or eye) indicated a creator.[1] Philosophical issues focus on a concern for the supposed dehumanizing application of automation or the possible detrimental effects of automation to society and the spirit of the individual. Pragmatic managers generally ignore these issues and become embroiled in the problems of implementing automated systems. However, underlying many scathing denunciations of automation is a basic concern for individual worth and the dignity of man.

Systematic study of automation was not apparent until the 1940s, when a surge of reports and studies is evident in the literature. However, the application of new technologies for automation which began immediately after World War II has never been adequately studied in terms of human behavior. Automation is a concept that has seldom been studied independently. The introduction of automated systems into organizations provides a context for studying the impact of automation on individuals.

The term automation encompasses many different systems and a wide range of applications. In any organization some degree of automation exists. The future will only increase the degree of automation in organizations. Generally automation is discussed in terms of a specific highly sophisticated system which is a component of the organization.

Military weapon systems represent the type of complex systems that are evolving toward increased automation through continuous additions of automated subsystems. One example of the introduction of extensive automated subsystems to a basic system is the "Black Knight" helicopter, which is a modification of the standard HH-53H. It includes in its sophisticated avionics a centralized computer, a terrain following/ terrain avoidance radar, a combined Doppler and inertial navigation system, and a forward-looking infrared and projected map display. The addition of these systems allows for an all-weather night operational capability for search and rescue missions that could not be obtained with the standard helicopter.

Such an advance in system performance, however, is gained at the cost of increased maintenance skill requirements and the changed maintenance tasks. Both the advantages and disadvantages of this type of helicopter can best be summed up by the following quote; "...It's mind-boggling — the systems and what they will do and how they work. The maintenance person has to know how each part works — individually and together — and be able to trouble-shoot and fix them."[2] What is the cost to the individual? Seldom is this question asked before the additional "gear" is installed. The classic assumption is that people will adjust to the technological change and that any automated system reduces workload and skill requirements. As systems increase in complexity and sophistication these assumptions become more tenuous.

Automation in industrial organizations has usually been studied from the standpoint of alienation, turnover, and unemployment. Few attempts have been made to understand the advantages and disadvantages of automation within the context of a total systems analysis. The impact upon system performance and organizational performance in terms of the organization's human resource has not received the proper emphasis. Industrial and union management concern has centered around automation's impact on unemployment and retraining. Although engineers address the hardware problems associated with automation, only recently has attention been paid to the possible implications to systems performance by attempting to understand the individual's contribution.

System performance in this context means the resulting performance of the interaction between the operator(s) and the system. The research efforts stimulated by such concerns are oriented to distributive management of responsibilities between the man and the machine and the generation of human response models which introduce Kalman Filter techniques to predict the basic human response to simulated machine characteristics. Considerable focus is placed on computer models of human behavior which can be run interactively with computer models of a system to study the engineering aspects of different approaches to system design. Neither behavioral scientists nor engineers have adequately defined and measured the changes in system performance that occur when functions are reallocated between equipment and people. Much of the consternation that occurs within an organization because of automation is due to a misunderstanding of the impending change.

The implications of automation to the organization are not well known. "A careful examination of the present state of knowledge about automation shows a large collection of unknowns. Although information is available on certain technical aspects of automation, answers to important questions concerned with public interest are virtually unobtainable."[3] This allegation is still valid today. The necessary understanding of automation's impact on the individual, management, and the organization are key issues. Two major points of this paper are to seek a better grasp of the individual's perceptions of automation and the resulting behavior with automated systems, and to begin to develop a systems analysis clarification of automation within the total organization.

Importance

The ability to understand and predict the impact of automation in terms of people may conserve an organization's resources. Introducing automated systems into advanced weapon systems, commercial aircraft, word processing centers and areas of industry could determine the success or failure of the organization. As automated systems increase in capability and cost, the critical trade-off between cost and additional effectiveness cannot be avoided. Because adaptations of a massive word processing system, command and control systems, or automated plants would probably require a multi-million dollar investment, a precise understanding of what level of system performance may be attained is critical. As computer manufacturers point out, cost per unit of performance is constantly dropping; however, the initial cost is still a considerable investment. As shown in Fig. 1, the cost of data handling is declining; however, in Fig. 2, other costs (supplies and quarters and personnel) drive computer system operation costs higher than the initial acquisition cost.

Although these examples suggest a large totally automated system which makes up 90% of the organization, another automation situation of equal interest exists: the replacement of current equipment with more automated models. In this context we are dealing with a modification brought about by replacing an existing subsystem. When an automated subsystem is introduced, the problems revolve about the operator, the operating procedures, and maintenance.

The introduction of an automatic subsystem into an existing system visibly impacts the system when it becomes operational and the automatic subsystem must be implemented by the operator. Because ideally all systems have undergone rigorous testing and evaluation by skilled test specialists and engineers, no problems are anticipated. However, the normal operational environment is more variable and demanding than the test environment and the operators perform at an experience level different from the specialists. Therefore, when the system becomes operational any difficulties associated with the new automatic subsystem will first appear as a result of unexpected aspects of the operator-machine interface.

The next level of impact will be experienced through the procedure-operator interface. A new system, which may be employed without established procedures or practices being considered or designed, may produce a series of system failures. Frequently systems are designed in terms of machine functions but they consider neither the operator functions nor the resulting mix. This is crucial for emergency operations.[5] For example, the procedure for operating a digital clock radio is described in its operators manual. If a manual is unavailable the operator functions on the basis of experience. If the experience is inappropriate, the operator may incorrectly set the alarm and wake up late. It is a minor error, but it happens easily without the proper procedural documents. In the more complex environment of aviation an error can result in never waking up.

The automation subsystem will also impact maintenance functions which, in turn, generally increase maintenance training requirements. The basic engineering concerns of reliability and maintainability are only the first level of possible machine difficulty. Changing procedures or the introduction of new procedures may cause considerable upheaval in the operator population and/or maintenance population. Although efforts are made to reduce these types of problems, there are currently no adequate data sources or guides that may be applied. In addition the methods used are generally not introduced until the system is operational and cannot be modified. The immediate concern of developing a system to perform to established standards takes priority over problems involving people.

Total automation, a system devoid of all human involvement, is one extreme of a continuum of possible applications of automation. The opposite extreme would be no equipment utilization. In general, we are dealing with problems generated by systems which fall somewhere between these two extremes. In addition to alluding to the ripple effect of automated systems, since the systems will eventually impact all members of the organization, we must examine the impact on the organization. Increased automation is accompanied by change to organizational operation and structure. The ramifications to the operator may be inconsequential compared to the organizational changes that are precipitated.

Automation: What Is It?

A major difficulty in studying automation is finding an established workable definition. Rather than examine the subtle ways each discipline approaches the definition of automation, I would suggest that there is no absolute way to define automation. It is the individual's perceptions of systems and the operator functions that determine the perceived level of automation. If this assumption is accepted, then a given system, as understood or perceived by different individuals (i.e., operator, supervisor, management, etc.), will have different levels of automation, dependent on the individual's perception.

Level of automation or degree of automaticity are concepts that frequently appear in the literature. Topmiller[6] conducted an interesting experiment in comparing the evaluation of level of automation between engineering psychologists and design engineers. He found that, ". . . different disciplinary groups use different subjective frames of reference in defining 'level of automation' of checkout equipment." This would support the concept that "level of automation" may vary depending on the evaluator. An aircraft equipped with an automatic pilot may be perceived as automated by the manufacturer, not by the operator who does not use the system except under extreme emergencies. In any system, therefore, an assessment of perceived automaticity or level of automation must be obtained to study automation. Although this idea complicates the issues, it must be considered to understand the resulting system performance.

The introduction of automated equipment heralds the beginning of automation for any organization. As more complex equipment is added the automaticity increases. Organizational automaticity frightens people within the organization because it brings change, and change requires adapting to new structures and concepts. The perceptions of the employees may create considerable conflict and dissention in the application and performance of new automated equipment. To reduce this problem a general pattern must be recognized and controlled. The syndrome that will be outlined is based on an American myth.

The Myth and Man

John Henry was a steel driving man. John Henry died with a hammer in his hand.[7,8] This paraphrase of the closing lines of the song and tale that immortalizes the death of John Henry, a folk legend, dramatically symbolizes the struggle of man against technology. John Henry has, perhaps, become a figure of status comparable to Paul Bunyan. In any event, his tale, which may be based on the life of a real individual, emerged in the 19th century as a tribute to his prowess, strength, and integrity.

To recapitulate the legend, John Henry was a man of unusual physical and personal prowess. He worked his way around the United States: in the cotton fields as a picker, on the docks as a stevedore, on the railroad as a spike driver. He was always moving, always displaying phenomenal physical superiority. He culminated his career as a steel driver on the construction of the Chesapeake and Ohio Railroad in the rustic West Virginia hills in 1873. The occupation of steel driver involved drilling the holes for the dynamite charges used in blasting the railroad tunnels. This was accomplished with the use of a sledge hammer and steel rod drill.

John Henry, as always, excelled above all other men in his capacity to drive steel. He drove steel with a sixteen-pound sledge hammer in each hand. It was during this time that the demon of technology in the form of a steam drill caught up with John Henry. A contest was arranged between John Henry and the steam drill. At the height of this herculean battle John Henry fell victim to the unrelenting, indefatigable machine. Although John Henry maintained a pace slightly ahead of the steam drill for over 10 hours, his body and spirit could not sustain the inevitable physical deterioration. John Henry died with a hammer in his hand.

Paradox of Automation

Although this myth has many interpretations, it accents man's concern with forces designed to constrain or restrain him. It is paradoxical that mankind's own creativity embodied within technological advancement is viewed as an enemy to mankind. Perhaps it is a struggle perceived as a symbolic contest between individual independence and societal dependence. The physical strength of the individual becomes the initial statement of independence. The acceptance of technology then becomes an admission of weakness or reliance upon society. Dependence on society's technology is viewed as surrendering independence. Although technology was developed to enhance man's capability, it appears that not all men are willing to subjugate their independence to take advantage of it.

Automation is a word frequently used to symbolize the introduction of more complex equipment to enhance man's capability to accomplish a required function. The steam drill mentioned in the story equalized men by providing the physical stamina most did not have. The introduction of the steam drill was perceived as a threat to individuals who were skilled steel drivers. Although the classical drama of automation was usually played against the backdrop of machines replacing mankind's physical skills, we are now confronted with advanced technology which may replace mankind's intellectual skills. The use of automation to make decisions in a complex situation is an example of the reallocation of intellectual functions from the operator to the machine.

The Federal Aviation Administration is currently studying the use of computers to conduct decisionmaking functions now performed by human controllers in an attempt to deal with projected traffic growth. The program is known as AERA: Automated En-Route ATC. The technology would allow the computer to make decisions about conflict resolution and the generation of clearances and their automatic transmissions, with the operator standing by to take over in an emergency. This system has advantages as well as problems. The two major problems are 1) how the controllers retain proficiency and 2) how the system is introduced so that both controllers and airspace users retain confidence in the system.[9] This example demonstrates the fact that automated systems can perform intellectual functions. This new prospect, which is rapidly becoming a reality, accentuates the struggle between man and machines.

The struggle that occurs because of an automated system is generally one between two different groups and their perceptions about the automated system. The crux of the problem is that the employee or operator is not for the introduction of the automated equipment and therefore has only partial knowledge of its advantages. The lack of knowledge grows into a feeling of loss of control because the individual is only thinking about himself in terms of a present fixed job. The job in this context is defined as a set of functions. The set of functions that is necessary to perform the job is usually well known and can be identified. The set of functions becomes static over time as the individual perceives the job as a fixed and finite set of functions. If the individual could perceive the job as a dynamic changing set of functions, part of the difficulty would be dissipated. The individual must also attain a level of ego flexibility so that transitions to other jobs and functions are not associated with reduction in individual value. Since the introduction of automation forces change, the change must be described in terms of benefits to the individual rather than the organization (e.g., the automation will take over the worker's rote functions while increasing the time available for creative functions). It is difficult for individuals not intimately associated with the new automated system to have a comprehensive view of their organizational environment as an individual tends to be concerned about his well being first and the organization second.

John Henry Syndrome

The spectre of automation in the organization generates a rash of symptoms which constitute the "John Henry Symdrome."[10] The major symptoms of the John Henry Syndrome may be characterized within three areas: 1) quality enhancement, 2) time reversal, and 3) displacement jitters. Each symptom is displayed to some degree when management begins to discuss the introduction or increase of automation within the organization.

The quality enhancement symptom is manifested by excessive discussions of the quality of the present product or service in terms of the individual's skills or capabilities. Emphasis on the demand for craftsmanship and personal attention to insure a better product or service will be discussed. Examples that dramatize the effect of unusual excellence or of substandard quality will be given great emphasis. The basic argument will be that only skilled employees can provide the necessary product quality that is required. The obvious conclusion to be drawn is that automation will replace the skilled employee without maintaining the appropriate level of quality.

The time reversal symptom is evidenced by an increased concern with how things have changed for the worse. The wish to return to simpler, basic, safer times becomes apparent. Much of the talk centers on how previous managements respected and placated their employees. The basic concern is with the apparent lack of management interest in the present employees' well being. The employees imply that automation is a weapon used by management to diminish their reliance on the employee. Parallel to this feeling is the fear that the major portion of cost savings attributed to an automated system is derived from reducing the required number of employees.

Finally, the displacement jitters are characterized by allocating more time to discussing retirement, other job opportunities, and general dreams of some level of independent status. This symptom may also cause increased friction between employees, and flaring tempers and job tensions may be noted. A surge of individual motivation may be briefly experienced, as the employees try one more time to prove their value before falling prey to complete fear of their job future. As an anticipatory response, the employee assumes that he will be fired and is seeking controllable alternatives. The employees anticipate the worst possible outcome and attempt to establish alternatives which they claim to have selected prior to the dreaded pink slip notification of job termination.

In an international study on automation, Jacob and Jacob[11] provide some interesting data on the answers to survey questions about three aspects of automation. Workers in non-Communist countries do not perceive automation as improving their environment and are more fearful of displacement than in Communist countries. This is the attitude faced by management before new automated equipment arrives. Subtle changes occur in the work climate. The increase in these types of behavior will indicate the development of the John Henry Syndrome and should alert management to take the appropriate action, assuming management is attuned to these symptoms.

General Model

To understand the impact of automation, a general systems model was developed (Fig. 3). The model attempts to switch the focus from the machine system to the human resource and machine interface. The model draws upon the classic man-machine interface concept but emphasizes the functions necessary for system performance. The allocation of functions then becomes the most critical aspect of the system design. The functions may be allocated to the operator, the machine, or to either with a choice option exercised by one or both. In addition, the maintainer functions must be considered. Although the maintenance function will change with the introduction of new subsystems, these functions are not generally considered in terms of the typical function allocation analysis.

As a rule, the introduction of automated equipment results in the restructuring of the required interaction between the operator, the equipment, and the maintainer. A function reallocation takes place either formally, as documented in an operating instruction, or informally, as operators become familiar with the idiosyncracies of the new system.

The immediate environment is the location of the system operation. The procedural aspects are the stated methods of operation either passed along by word of mouth or documented in a "handbook for operations." The more complex the system, the higher the probability of procedural directions including considerations beyond the basic system operation (e.g., special procedures to improve safety or to insure adequate periodic maintenance). A system functions within the total organizational environment, and any system performance may result in interior or exterior output relative to the organization. For example, in the aircraft industry the system performance of the aircraft is an external output that is critical to the airline. The system performance of the ticket-issuing computer is an internal output of major importance to the functioning of the airlines. The organizational environment is composed of the policies which affect the system operation. A policy to assign confirmed seats on all connections at one time requires a different process to be programmed into the ticketing computer than does a policy to confirm seats prior to immediate boarding. Therefore, the policy affects the operation of the hardware systems.

As shown in Fig. 3, changes in the function allocation and the resulting system performance that occur from introducing automated systems may impact the operator performance, maintainer performance, machine performance immediate environment, or the total system effectiveness. The key issue is that the introduction of automated systems may displace the previous procedural and policy system and redistribute functions.

A function is any unit of activity and can range from a simple monitoring unit to a decision unit. The total set of functions constitutes the requirements necessary to attain system performance. Although the model includes the three dimensions of function allocation, the function set could be described without reference to any job role. Theoretically the function set could represent a series of jobs or machines or combinations of jobs and machines. The functions required for system performance are independent and basic to objectives of the organization. Historically and generally system designers think in terms of current systems and how functions are presently allocated. This is perhaps too parochial an approach.

An intriguing report completed by McDonnell Douglas[12] on the function allocation for the F-18 fighter aircraft established a suitable methodology to allocate functions. Starting with a mission analysis, a function is identified as more appropriate for the operator (pilot), machine, or a combination of the two: "Routine functions, memorization tasks, precision and sequentially timed operations, etc., which do not require pilot judgment or which do not vary as a result of changing tactical events are obvious candidates for automation." As an example of this approach, in the escort mission prelaunch sequence, under the functional requirement to "activate and check aircraft systems," the first subfunction of aligning the inertial navigation system is allocated to the machine. The rationale for this allocation is to relieve pilot workload during a scramble operation. This approach certainly addresses the issue, but a caution against perpetuation of past decisions and reliance on known technology must be considered. It may be easier to repeat the previous allocation of functions than to analyze the situation from a new perspective.

Changes introduced through an automated system have the potential to impact the entire organization, depending on the organization's degree of reliance on the system. If an organization is visualized as having a total set of interacting functions necessary to attain its goals, then the degree to which functions are allocated to machines becomes an index of organizational dependence on automation.

Normally an organization is viewed in terms of personnel, titles, and structure, but if this is translated into the total set of functions necessary for the organization to operate, a far more important insight into the dynamics of the organization emerges. As this organizational set of functions (which may be considered a series of job subsets) is increasingly allocated to the machine(s), the higher the dependence of organizational effectiveness on automation. Any function change that occurs in a system will affect the operator, maintainer, and the other levels of management. The higher the total level of automation the greater the impact of any function reallocation. A change that specifically modifies the operator's functions may have a cascading impact on the total resource of the organization.

The model represents one unit of one system and focuses attention on the function distribution to obtain system performance. This establishes a micro model of automation within an organization. An organization could have several independent areas of operation, each of which has a specific level of automation for different systems. It is at the micro level that systems are initially designed and developed. This is the beginning of the implications of automation within the operation; therefore, to understand the impact of automation, the focus of attention must start at this level. The John Henry Syndrome will first be detected at the operator level and then permeate the other layers of the organization. To counteract the syndrome, we must review the appropriate dimensions of the model.

Dimensions of Interest

Although the concept of automation has not been directly studied as a variable of interest, it is a dimension of systems design that is critical to the operator functions, maintenance functions, and procedural functions. The maintenance functions are assumed to be located in the immediate environment of the system. Although the maintenance structure of a specific organization may be far more complex, for our purposes it will be considered located in the immediate environment. Maintenance functions are those required to maintain and service the equipment, but a similar concept could be applied in terms of maintaining the operator (e.g., providing eating facilities, parking space, on-site medical staff, etc.). Generally organizations do not have total operator or human resources support within the facility, although this varies across organizations.

"A preliminary system design proceeds by determining 1) prime system goals, subgoals, and their feasibility; 2) alternate mechanization schemes for achieving subgoals; and 3) a selection between alternate mechanization schemes so that a given prime system goal will be approached in some optimal sense."[13] The authors are attempting to indicate the function of man's role in space. In more general terms they are considering man's role within a total system: "In more functional terms, man has been viewed as an ideal component of sorts, capable of serving as an organizing, computing, decisionmaking, controlling, actuating, and information-recording system." In a space system these advantages are secured at a cost in providing for man's physiological requirements. The authors further elaborate on the value of man in space being dependent on the desired mission performance.

The role of man in a self-contained system introduces a greater level of concern for life support systems. This is not the case when we are considering the typical factory situation. However, the inclusion of humans within a system demands a concern for their basic well being. This only emphasizes the point that an automatic system without human interaction may be more appropriate given the desired system performance. It is assumed that humans will be required in some capacity and therefore it is critical to understand the relationship of functions allocated to each component of the system.

In an article concerned with the operator tasks in a process control system, Edwards and Lees[14] discuss four aspects of process operators:

1) manual control, 2) specific operator function, 3) process characteristics, and 4) control system sophistication. They maintain that little research has been accomplished on aspects 2-4 and that much completed in the first aspect was not very complex. Their review of the chemical industry leads them to state, "Whatever view is taken of the ultimate role of man in process control systems, it can be agreed that there is need for greater general understanding of the operator and his task." This article supports the contention that, given any system of some degree of automation, the operator functions must be understood and studied.

The degree to which maintenance tasks depend on automated test equipment introduces another set of interactive functions and another layer of automation. In order to understand the immediate impact of automation, the five dimensions of primary concern are: 1) operator function(s), 2) equipment function(s), 3) maintenance function(s), 4) procedural guide(s), and 5) system performance(s).

The constant improvements in technology are producing increasingly complex systems. The current expansion within the computer industry, spearheaded by IBM which believes it may have a prototype three-pound computer capable of 70 million instructions per second (MIPs) (a fourteen-fold increase over today's systems), is an indication of the rapid growth in technology to be considered in designing new systems. One factor forcing the complexity is the increased use of automated systems to perform subfunctions within the total operational sphere. The availability of automated systems and the subsequent perceived improvement in reliability is indisputable. The effect of adding to or enhancing a system with automated subsystems is always anticipated as an improvement in total system performance, but this may not always be true.[3] The battlefields are strewn with systems that were unsuccessful due to some aspect of equipment failure, operator failure, or organizational failure. The last two elements demand a full scale effort to determine the causes. The effect of automation on human performance, organizational performance, and system performance needs to be studied systematically.

Richards[15] proposed applying the technique of natural computation and control (NCC) to problems of information processing in biological systems. The critical aspect of his effort was to establish the objective of the biological systems computed representation. As he points out, "A complex system cannot be understood as a simple extrapolation from the properties of its elementary components." Once the goals are established a theoretical representation is identified and the appropriate algorithm generated; the algorithm is then tested against the biological system for accuracy. This approach offers an interesting alternative to the accepted classical approach. The starting point should be the effect of function allocation on human performance and the resulting system performance.

Types of Allocations

Automating a part of a system or a total system usually results in three outcomes to the existing system functions: 1) New functions are introduced, 2) previous functions are deleted, and 3) existing functions are changed (Fig. 4). The introduction of new equipment such as Head-Up Display (HUD) for tactical weapon delivery, may appear to be the ideal way to increase system performance. However, if the HUD, in addition to all other instruments, does not provide the necessary information required by the operator for the function, it will increase workload because attention will be split between the HUD and other information sources. If the operators perceive the HUD as unreliable, they will not depend on it and will "work around" it. In either case, the expected system performance will not be attained.

Removal of the familiar instruments which are replaced by a HUD may cause the operator to lose confidence in the aircraft control systems, and he may employ heuristic methods for accomplishing the task. This type of situation will also result in poor system performance. This illustrates the beginning of a John Henry Syndrome which must be anticipated to preclude failure. If the HUD is introduced and procedures are changed, the operator must retrain to insure that he will not revert to the former procedure. Again, anticipated improvements in system performance will not occur. The same problem will be magnified as the impact on maintenance and other organizational elements is addressed.

In a review of the flight deck of civil transport aircraft, Edwards[16] emphasizes the point that, although automated systems are profuse and available, the crew's workload has not been diminished. As he points out, "The main effect of automation is to increase the operational effectiveness of the man-machine combination, rather than to achieve any easing in crew workload." As the functions of the pilot of an automated aircraft are changed but not reduced, the pilot becomes a manager of a complex set of complex support systems.[16] In an earlier report on Flight Deck Automation, Edwards[17] introduced a model (SHEL) which has four components: 1) software, 2) hardware, 3) environment, and 4) livewire. He indicated that more must be understood than the man-machine interface (livewire-hardware) and that all components interact and must be considered in the function allocation process.

In a brief agenda item from the International Air Transport Association's 5th General Flight Crew Training Meeting[18] a practical series of examples of problems associated with flight deck automated systems is provided. The major concern is the development of pilot complacency in aircrews, and the suggested areas to counteract this occurrence are design criteria, proper procedures, and training. The emphasis is on the hazards of automation in terms of failure and more specifically "sneaky failures."

In a study of eye scan during simulated ILS approaches Spady[19] found, "The pilots consistently ranked the instrument in terms of most used to least used. The ranking obtained from the oculometer data agrees with the pilot ranking for the flight director and airspeed, as the most important instruments. However, the pilots apparently ranked the other instruments in terms of their concern for information rather than according to their actual scanning behavior." This finding may only indicate a difference in operational definitions of importance or it may be an indication of the fact that perceived importance (stored in memory) overrides actual performance as recorded.

In another study of pilot scanning patterns, Waller[20] established a relationship between dimensions of scan, such as the time on instruments, and number of transitions that was predictive of pilot evaluated workload. In a function set which may be performed either visually, with instruments, or with a combination of visual and instruments, the operator apparently perceives workload in relation to amount of time associated with the instrument concerned. This may have some impact on the degree of complacency which may, in turn, depend on the active or passive demands of the automated system.

Unfortunately, the human factors analysis and the engineering analysis are not interrelated. Each accomplishes its objectives but only a system analysis of the man and the machine in terms of function allocation can tell the full story. As was indicated earlier, research concerned with the second condition (deletion of functions), especially to the level of deleting total jobs, predominates studies documented in industry. Much of what occurs in the Air Force falls under the first condition (adding functions). In this case, more automated equipment is introduced and the operators, procedures, and maintenance functions are increased. An understanding of the interaction of the operator, procedure and maintenance functions, and the function distribution as contributory aspects of system performance is required.

Function Allocation

Expecting increased operator and maintenance training to offset the function allocation problem is no longer viable. The complex functions and excessive workload experienced during critical system phases demand a different approach. The necessary functions to be accomplished per operational segment must be determined. The current system has an established function distribution pattern; new systems do not.

When an automatic subsystem is introduced, a clear indication of change in operator function must be understood and considered. Automation should be considered in terms of function allocation: How do the function distributions within the system change due to the introduction of automation? Emphasis should be placed on the functions allocated to the human resources in the system. The assumption must be made that the functions allocated to the machine have attained a level of reliability to preclude failure.

Some functions cannot be accomplished by even the most superior individuals. These functions are accomplished only with the assistance of automatic equipment or totally by an automated system. For example, automated systems are necessary to complete the complex and important function of film hybrid circuit inspection. Arlan et al.[21] reported on an electro-optical system which can inspect 750 hybrid substrates per hour. This is accomplished with the use of a high resolution (10,000 TVL/H) Return Beam Vidicon (RBV) to provide an image of the 2 in. × 2 in. substrate. The operator selects a suitable image magnification, then instigates a preprogrammed automatic test system to identify unacceptable hybrids. At the other extreme are functions a machine cannot perform. Complex decisions under uncertain conditions cannot be made by machines. Currently some functions can only be accomplished by machines that are prohibitively expensive.

A large segment of the engineering field is dedicated to the study of control and distribution of intelligence throughout large and complex industrial facilities. Although this is a sophisticated approach to controlling a process system totally by computers there is a lack of theoretical approaches to provide discrete answers to problems of system structure, task allocation, fault tolerance, communication protocols, and data management.[22] In a completely automated system the processes that become critical are fault isolation, fail-safe procedures, and warning and alert systems. The system will be acceptable until a failure occurs, then action must be initiated to maintain the process. Errors are costly terms of waste and destruction.

The major difficulty of large-scale control systems falls in the area of the software requirements. "In order to manage the resources of the control computer and to allocate them among the competing control tasks in real time, elaborate executive programs have to be developed."[23] These programs must embody the same characteristics as a human manager, i.e., be capable of scheduling the central processing unit, managing main memory, handling input and output operations, maintaining data base (memory), and establishing communications between two tasks of processes. These programs may exceed 25,000 words of the main memory. We have the technology, but do we have the incentive for investment? In a classic article on software, Boehm[24] pointed out that for almost all applications, software (as opposed to computer hardware, displays, architecture, etc.) was "the tall pole in the tent" — the major source of difficult future provisions and operational performance penalties (Fig. 5).

In a special effort to help engineers design electronic systems with minimal human resource requirements, one researcher developed an intriguing set of concepts.[25] The approach hinges on the reduction of the number of operator and maintainer tasks required for the associated design. The report maintains that the critical aspects of tasks are number, frequency, and difficulty. Twenty-one design approaches were analyzed to indicate their impact on the human resources to operate and maintain the system. The analysis of "automated decisionmaking" indicates a significant savings in operator and maintenance personnel as well as savings in training. Although the intent of this effort is not directly in terms of automation, the focus on the dimensions of tasks and the strong implication that the increase in automatic systems may reduce the skill requirements of operators and maintainers sheds some insight into the problems associated with automation. If we design to reduce skill requirements, perhaps operators and maintainers are correct in fearing automation.

Lloyd and Mills[26] conducted a field study of automation in both automated and nonautomated automobile plants in England. The two types of plants observed represented a machine process. The authors found that although each type of plant was different in terms of level of automation they were not extremely different, therefore they actually were studying two, relatively similar levels of automation. Their findings are interesting in that they attempted to measure automation levels and that the resulting attitudinal and task data can be viewed with this background. They concluded that "...job level analysis revealed how uneven the overall pattern of change was at the individual work situations."

Crossman and Kvålseth[27] performed a field investigation in 18 plants on the impact of technological change on manpower and skill requirements. Their findings indicated a shift of skill level requirements to some degree, but the data were insufficient to establish a firm position. The technological changes observed were the type that could also be called automation.

A separate but important area of concern is the degree to which the operator is willing to assume that the automated system is reliable in the operational environment. If the operators are not convinced that the system is reliable, they will adapt a strategy which established informal cross-checking behavior in addition to the prescribed procedural behavior. This strategy will increase workload, perhaps beyond the operator's capability.

Conclusion

Automation is only one aspect of technical advancement. It is a variable to be considered in determining total system performance. The introduction of automation changes the function allocation between the operator, the maintainer, and the equipment. The individual's perception of the equipment in terms of his individual skill is critical. With the advent of computer technology, many of mankind's most burdensome tasks can be delegated to the machine.

The functions required to accomplish an objective is the important variable that unlocks the difficulties encountered in systems which have a people-machine mix. Since an organization's human resources are its most important asset, the impact of automation must be understood and offset. The John Henry Syndrome is a way to alert the organization to potential problems. Before mankind can reap the benefits of automation, the early warning symptoms of the John Henry Syndrome must be identified and alleviated. Men can then look forward to more time to be creative, thinking individuals. Perhaps what is needed is a crash course in ego support. Whatever the medicine, it must be administered. Heroic battles may still be fought, but martyrdom to automation is no longer appropriate. Do not die with a hammer in your hand.

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Figure Captions

Fig. 1 The cost of data handling.

Fig. 2 Relative computer costs for the average computer user in the early 1970s. These averages are very rough, since users display a wide variation in their cost experience (from Ref. 4).

Fig. 3 General model of automation impact.

Fig. 4 Function allocation as automation is introduced.

Fig. 5 Hardware/software cost trends (from Ref. 24).

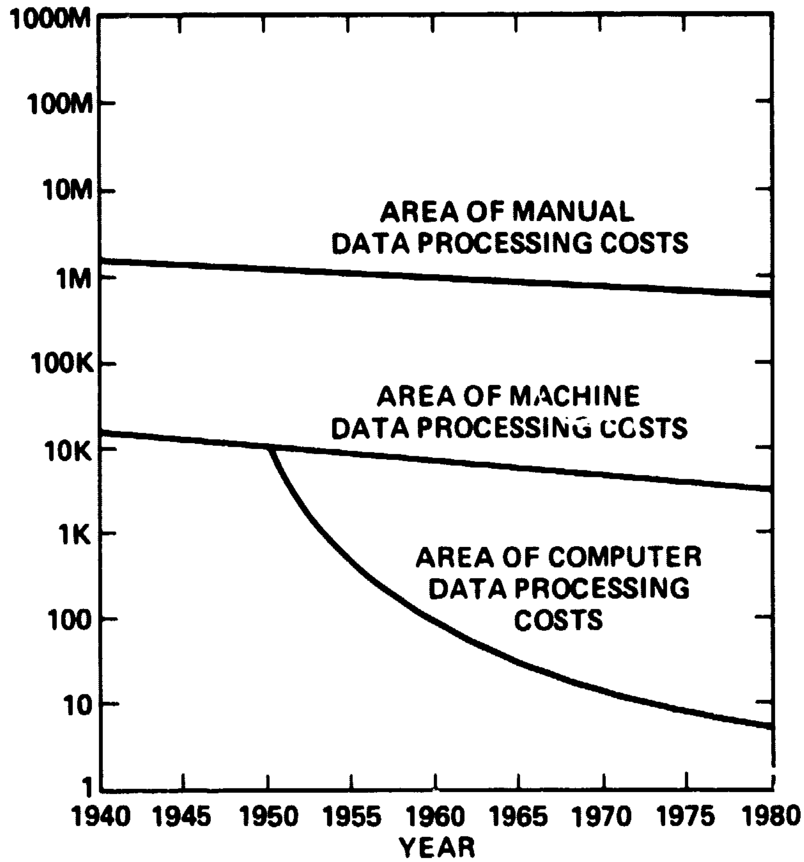
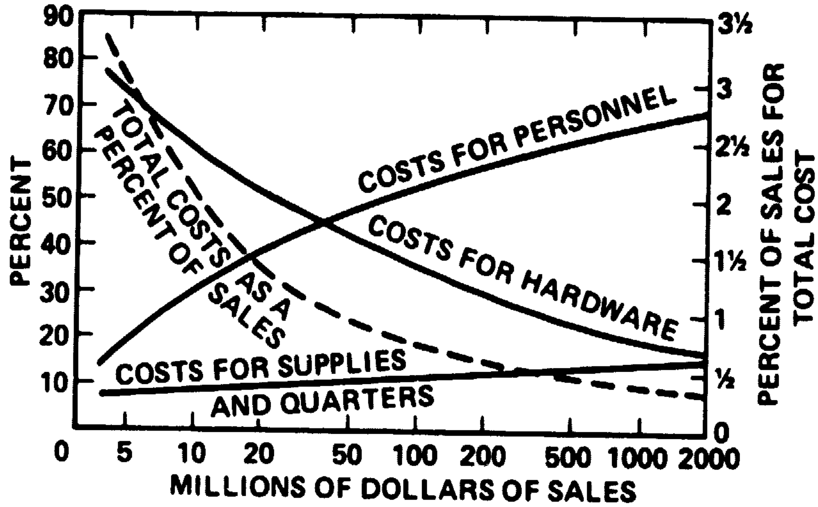

1000M
100M
10M
1M
100K
10K
1K
100
10
1
AREA OF MANUAL
DATA PROCESSING COSTS
AREA OF MACHINE
DATA PROCESSING COSTS
AREA OF COMPUTER
DATA PROCESSING
COSTS
1940 1945 1950 1955 1960 1965 1970 1975 1980
YEAR

Fig. 1



90
80
70
60
50
40
30
20
10
0
PERCENT
5
10
20
50
100
200
500
1000
2000
MILLIONS OF DOLLARS OF SALES
3½
3
2½
2
1½
1
½
0
PERCENT OF SALES FOR TOTAL COST
COSTS FOR PERSONNEL
COSTS FOR HARDWARE
COSTS FOR SUPPLIES AND QUARTERS
TOTAL COSTS AS A PERCENT OF SALES

Fig. 2

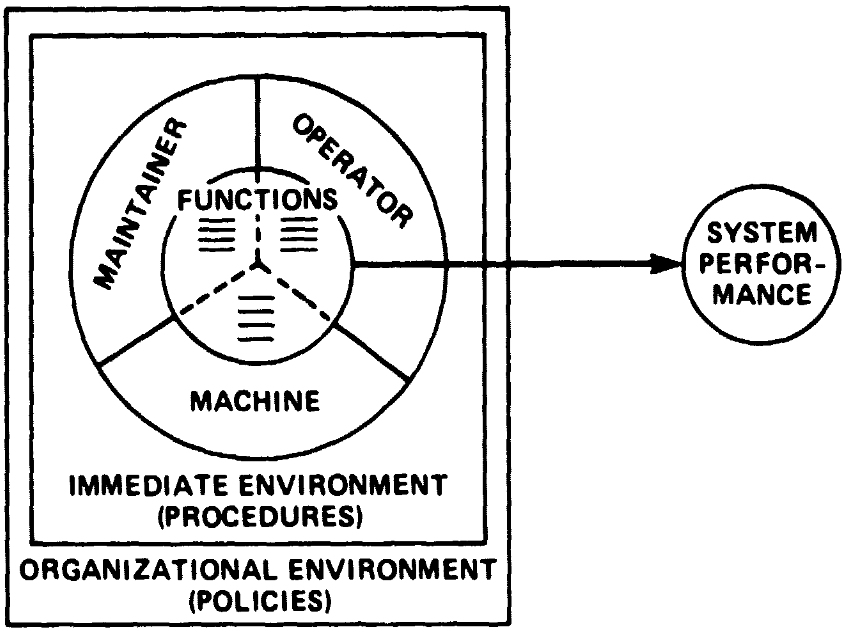

MAINTAINER
OPERATOR
FUNCTIONS
MACHINE
IMMEDIATE ENVIRONMENT
(PROCEDURES)
ORGANIZATIONAL ENVIRONMENT
(POLICIES)
SYSTEM
PERFOR-
MANCE

Fig. 3

AUTOMATION

	ADD	DELETE	CHANGE
OPERATOR			
MAINTENANCE			
POLICY			

Fig. 4

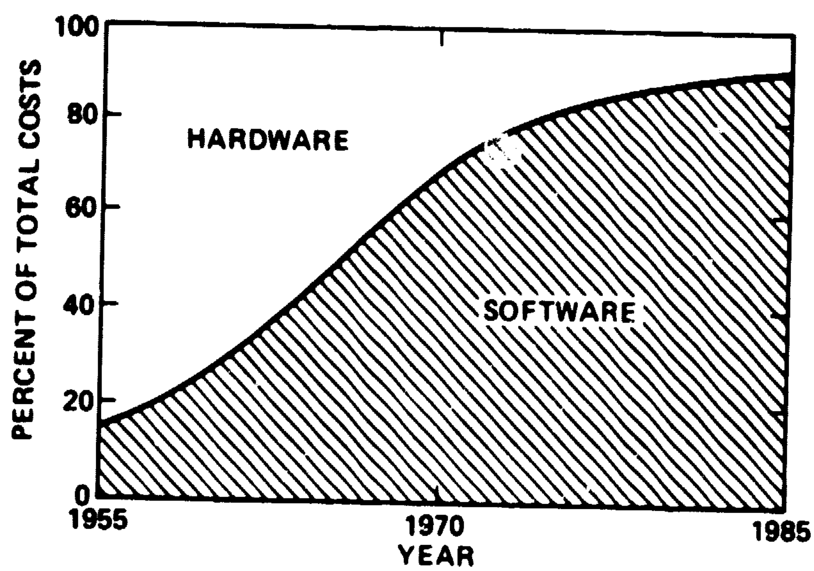

100
80
60
40
20
0
PERCENT OF TOTAL COSTS
HARDWARE
SOFTWARE
1955
1970
1985
YEAR

Fig. 5