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Appropriate Automation—Integrating Technical, Human, Organizational, Economic and Cultural Factors*

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Automation that is appropriate for application in realistically complex sociotechnical domains should be based on an integrated understanding of the technical, human, organizational, economic and cultural attributes of the application, and can be enhanced by development and use of particular types of concepts, principles and methods.

Key Words—Social effects of automation; human–machine systems; human factors; organizational, economic and cultural factors; manufacturing processes; process industries; human-centered design; sociotechnical design.

Abstract—Automation technology, including digital computer and communication techniques, is being applied in an ever-increasing range of private and public spheres, and reaching third world cultures not previously exposed to such technology. It is engineers' responsibility to consider the direct and indirect effects of this technology. To be able to fulfill this responsibility and make proper design decisions, engineers must both understand "appropriateness" within a given boundary, and have decision authority, together with other parties participating in the design. Whereas sound methodologies for user-centered design are appearing, anticipating and considering the cultural effects of automation are concerns that go far beyond traditional engineering. Nevertheless, engineers should be more deeply involved in comprehensive technology assessment. Encouraging experiences show how innovative design approaches and consideration of comprehensive sets of requirements can lead to better overall system performance. However, much research on open questions remains to be done.

INTRODUCTION

Modern technology involves the application of science in societal contexts. Automation technology, including digital computers and communication techniques which have become such vital elements and tools of automation, is an ever-growing technology with an enormous range of subjects and applications. Its applications range from single-machine automation, through the control of industrial processes, up to computerized administrative processes, and use in military installations. New applications are continuously being developed, including in areas not earlier foreseen—for example, in third world cultures not previously exposed to such technology.

This enormous versatility has been achieved because the methods of automatic control and computer science involve a high degree of abstraction, particularly in terms of formalized models. Engineers developing such models tend not to be primarily concerned with the social or other consequences of their subjects. However, as technological implementation becomes more application-oriented, consideration of the effects caused by automation technology becomes more important. The question is when and how to consider such effects in the design and implementation process.

In another IFAC Congress plenary paper, Sheridan *et al.* (1983) raised the issue of adapting automation to man, culture and society. In their paper, they treated general

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issues of automation and discussed the proper extent of automation by scaling "degrees of assistance" that a computerized system might provide in supervisory control. In our paper, we will discuss criteria for appropriateness of automation, and stress issues of design and design methodology. The design considerations will be illustrated by lessons learned from case studies in both process and manufacturing industries. We will also consider cultural issues related to automation. Thinking of automation from a global perspective, we as engineers can no longer be indifferent to the effects of automation technology on those countries which have neither the political drive and education to utilize this technology appropriately for their economic and cultural benefit, nor the power or insight to prevent the negative effects of automation technology exported to them by the developed countries.

OVERALL CONSIDERATIONS OF APPROPRIATE AUTOMATION

As in any other technical field, automation technology must meet a given set of requirements to justify its application. These include as a minimum the criteria of adequacy of the means (and funds) employed, and acceptability of the elaborated technical solution. Automation faces particular difficulties in measuring up to such requirements, often because of the interdisciplinary nature of the problems to be solved. Many products of engineering, such as electronic chips or fuel cells, have a technical environment only. But automation systems, methods, and techniques also have to function in a human environment. The working population concerned must be actively integrated in the modeling of work processes if an automated system is to be accepted. This requires precise determination of the necessary interactions in the division of labor between human and machine. Consequently, the large variety of user interfaces (and their design considerations) has become one of the focal points in automation technology (as will be outlined below in discussions of human-centered design).

Human–machine incomparability

The rapid and broad successes of automation technology have given rise to the hope that it is a panacea for solving complex problems. This hope is especially entrenched in the minds of many decision-makers, partly as a consequence of public relations activities and the universal tendency for successes to be more widely publicized than failures. Nevertheless, many automation projects have failed due to insufficient automatability, inadequate user-system interfaces, and incompatibility between human needs and system requirements.

With the advent of "expert systems" as a new paradigm of programming computer-based control systems, large parts of the artificial intelligence (AI) establishment have assumed, and subsequently announced, that such systems will possess almost incredible capabilities for solving complex tasks. Although formulation of ill-defined problems by statements of facts and rules, and heuristic searching for solutions, will in many cases be more successful than conventional programming, even these systems can only provide partial solutions. The hope that such systems may render superfluous the responsible evaluation of results by people is a dangerous fallacy, as expert systems are designed to admit uncertain results without these always being recognizable as such (Dreyfus and Dreyfus, 1986). Reminding ourselves of accidents that have shaken the public globally in recent years, such as Chernobyl in 1986, the stock exchange crash of 1987 and the Iran Air airbus downing in the Gulf in 1988, should give reasons enough to rethink our belief in the proper role of automation.

Kurt Goedel (1962) showed that in any formal system there always exists nondecidable propositions which cannot be proven by means of the formal system itself (Goedel's Incompleteness Theorem). An additional problem arises from the fact that the meaning of symbols is normally context-dependent and, therefore, cannot be formally described in principle. From this it follows that a computer-aided vision and pattern recognition system cannot recognize an object for certain. Therefore in the case of the airbus downing, when the radar system on board the USS Vincennes recognized an unidentified, assumed enemy aircraft, the order to shoot should not have been given. The official version for the predominant cause of the accident was "human failure". This judgement ignores the fact that the ship's hyper-instrumentation led to a complexity that the persons in charge could no longer cope with under stressful conditions (Klein, 1989). The belief in technology, having found its universal symbol in the computer, has itself become a risk factor (Perrow, 1984). False belief in automation in this case left 290 persons dead.

Completely automated systems based on heuristic processes are extremely problematic, for heuristic processes intrinsically can include wrong solutions. In situations where surprises can lead to critical situations and matters of life and death, responsible decisions cannot be left to such systems alone. Instead, final decisions must be left to people, because people have the ability to deal with unfamiliar and unexpected situations.

The unique abilities of humans, in contrast to artefacts such as control systems and computers, have been studied by psychologists. Recent observations reveal that skills based on empirical knowledge, such as a feeling for machines and materials, continue to play an important part in the work with computer-controlled machines (Böhle and Milkau, 1988). In dealing with AI techniques for automation purposes, we should abandon the idea of human–computer comparability and pursue instead the concept of complementarity. Otherwise, there is a great danger that, for example, the potential of expert systems will continue to be overestimated. This danger could result in expert systems not primarily being adapted to cope with the complexity of reality, but reality being reduced to that which can be formalized and fitted into expert systems (Moldaschl, 1989).

Responsibility of engineers

As outlined above, it is vital to determine where full or even partial automation cannot or should not be used, and where computer-aided operations, for instance, might be appropriate instead. It needs to be emphasized that decisions and actions in important technical, social, economic, and military problem areas must be handled not by automated systems and computers, but through the responsible actions of people.

For a person to be able to carry responsibility, two prerequisites must be fulfilled. The person needs the knowledge and skills to master the situation, i.e. to interpret and act in an appropriate manner; and he/she must possess the proper authority and latitude of decision-making and action.

For control engineers, this means that they must be knowledgeable about social and other nontechnical effects of automation. The IFAC Committee on Social Effects of Automation works to disseminate available knowledge. Unfortunately, in most technical schools and universities, subjects like work science, social effects of technology, and human–machine systems are not compulsory in engineering curricula. Necessary knowledge, therefore, is not readily available. Another problem can be that engineers, although attempting to keep themselves informed, do not know about all effects of their products, e.g. the cultural effects in countries to which the products are exported.

The second precondition is also problematic. Engineers designing products are situated within certain boundaries beyond which they exert little influence. While engineers may be able to design proper human–machine interfaces which consider the human-related effects in the workplace, engineers are often unable to influence environmental effects or to prevent export of products to countries where they will cause negative cultural effects. To consider responsibility we must, therefore, first define the boundaries within which the effects of automation can be considered.

Such problems should not, however, be an excuse for engineers to avoid active involvement in questions of the effects of automation. Engineers should come to grips with human, social, economic and cultural consequences of their products. This involvement can range from actively including relevant requirements in the design process, to refusal to cooperate in projects with visible negative effects which are not usually taken into account.

CRITERIA FOR APPROPRIATENESS OF AUTOMATION

Possible criteria and problem attributes to be considered for a given automation effort are manifold. Table 1 shows a possible way of structuring various issues.

In order to integrate these considerations into system planning and design, one must understand them in terms of causes and effects, dependencies and contradictions, and short- and long-term effects. Integration is, therefore, a question of balancing different values. This will, in real life, be a bargaining process taking place at different levels; those of company, country or international community. In the following, we will treat many, but not all, of the issues in Table 1—for example, environmental issues cannot be considered in this paper.

THE SOCIAL DIMENSION OF AUTOMATION TECHNOLOGY

The social relevance of automation technology is pronounced. It primarily deals with the (re) organization of work processes. In the design of automated systems, this focus on work processes becomes important in determining the relationships between humans and machines. Machines, therefore, must always be defined in relation to the subjects of the work—humans. Even fully-automated systems are in no way autonomous: they also relate to real patterns of work and life. Consequently, people are, again, the subjects of these processes.

Due to progressive divisions of labor, technical and administrative design strategies

TABLE 1. STRUCTURE OF VARIOUS ASPECTS OF AUTOMATION

Subject	Actors and "victims"	Scientific field	Goals and values
Automation system design	Automation/control engineers	Automation/control technology	Reliability, robustness, accuracy, flexibility
Human interface design	Ergonomists, system users	Human factors; ergonomics	User-friendliness, efficiency
Job and work organization design	Personnel dept, management, workers	Organization science	Job satisfaction, labor productivity
Coordination within the enterprise	Top management, enterprise departments	Organization science, information systems	Flexibility, service, profit
Interenterprise cooperation	Enterprises, customers	Micro-economics, computer networks	Mutual benefits
Society	Politicians, general public	Macro-economics,	Economic growth, employment
Intersociety effects	Developed and developing countries	Development economics	Quality of life
World	Humankind, biosphere	Ecology, geophysics	Preservation of nature

have evolved and become accepted in which humans are considered to be potential nuisances with high error probabilities. Consequently, humans are often kept out of immediate work process as much as possible. Such a strategy leads to the danger that automated systems no longer serve supporting functions, but instead become dominating factors.

Demoting the working population from subjects of their work to machine operators kills the willingness and ability to act in responsible ways. The subsequent deskilling of the workforce has been proven and documented by empirical data. The IFAC Committee on Social Effects of Automation has helped to disseminate this knowledge, and has also played a central role in developing and discussing methods for proper design of work practices in automated systems (Bibby *et al.*, 1976; Rijnsdorp, 1978; Martin, 1984; Brödner, 1987). In this vein, Jones created the notion of the "computer-aided craftsman", suggesting that automation technology should be carefully designed around skilled human work (Jones, 1984).

Sociologists are currently talking about a change of paradigm in industrial automation (Martin, 1988). The organization and division of labor, the question of which functions to automate and which not, qualification requirements and appropriate personnel structures should not be parameters determined by developments in automation technology. They must be regarded as strategic variables to be used deliberately by decision-makers.

General guidelines for development

One suggestion as a general guideline for designing automated systems is that such systems be viewed from two points of view, namely that of social relevance and that of the tool character (Rödiger, 1988). Since we are concerned with single machines as well as networked information systems, the notion of a "tool" must be seen in a broad sense.

The importance of the tool character is neglected in systems development if people are considered simply as information-processing systems. The holistic, intuitive abilities of people need opportunities to establish and attain goals independently and to acqurie an overview of work processes. This, in turn, requires latitude of action. It further requires that opportunities for communicative action be created and maintained, in order to enable discussions and cooperation with other people to take place.

For individual designers involved in product or system development, the question arises of how to combine the guidelines outlined above with the criteria and the conditions imposed by clients. In this respect, a dialogue between developers and users is of the greatest importance in the interest of achieving these goals.

The need to optimize both technical and human factors suggests a parallel design approach wherein both aspects are considered side by side throughout the design process, to achieve overall optimization of the system. A possible scheme, shown in Fig. 1, was developed within a project funded under the auspices of the ESPRIT Programme. This project dealt with the design of a flexible assembly cell (Ravden *et al.*, 1986). It was necessary to determine which criteria were relevant at which stages in the design process. This suggested a hierarchical structuring of the

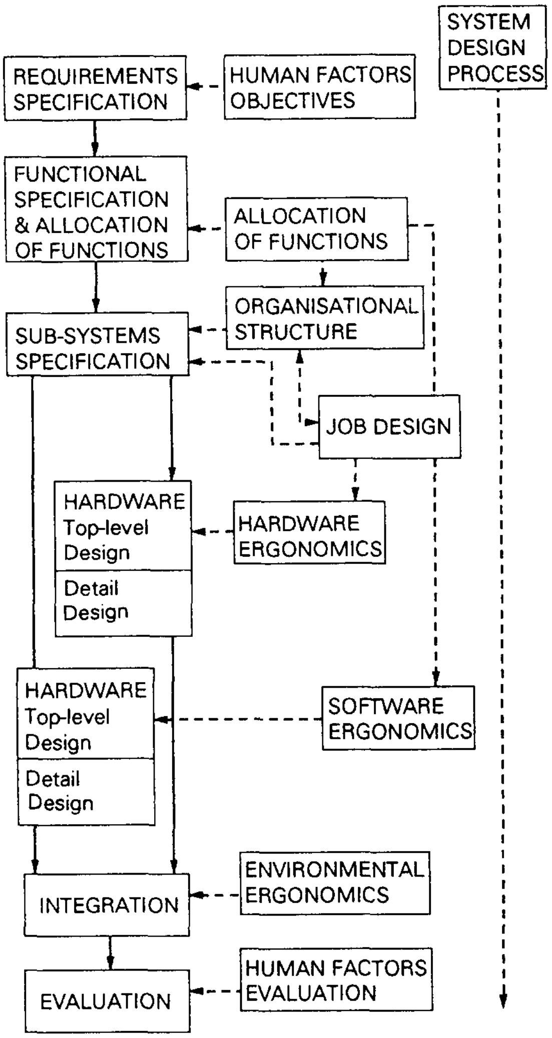

FIG. 1. Human factors mapped onto a model of the design process.

criteria, although in practice design is an iterative, cyclic process. Some of the human aspects considered were:

Allocation of functions. This addresses the methods by which functions (or tasks) within the system are allocated between humans and machines, stressing, for example, human–machine complementarity.

Job design. By advocating factors such as autonomy, responsibility, variety, etc., this area concentrates on ensuring that the human functions allocated above are designed to maximize flexibility responsiveness, and motivation of those operating, supporting and managing the system.

Organizational structure. This is possibly the most difficult area to integrate into the design process model. Organizational factors such as self-supervision, minimal functional specialization, etc., are included with the overall aim of providing a supportive organizational structure.

Whereas aims to maximize flexibility and minimize functional specialization seem to be prevailing both in the process and manufacturing industries today—as illustrated in the experiences in both industries discussed in later sections—other demands on organizations by different environments can also come into the play. In general, existing organizations tend to view new technologies within the framework of existing work designs which may be inappropriate for operating these technologies. Cummings and Blumberg (1987) describe technical, personal and environmental contingencies that determine the kinds of work design that are likely to be most successful. They found from case analyses, for example, that new manufacturing processes place increasing demands on employees to manage unforeseen and nonroutine situations. They conclude that this calls for self-regulating work groups, a conclusion also reached by our own experiences and discussed in later sections.

HUMANIZATION OF TECHNOLOGY VERSUS HUMAN ENGINEERING

An interesting discussion has been taking place within IFAC in recent years. The question of interest is, "Are 'humanization of technology' and 'human engineering' for efficiency and productivity conflicting objectives, or can they support each other?"

At the IFAC Congress in Budapest in 1984, Tom Sheridan performed a delphi study with twenty experts from the IFAC Committee on Social Effects of Automation (SOCEFF) and the Man–Machine Systems Working Group (MMS) of the Systems Engineering Committee (SECOM). The subject of the delphi study was to find out how these experts differed in their views on creating good working conditions for operations in industry. At the next Congress in Munich in 1987, Jan Forslin interpreted the results (Märtensson, 1987).

The basic issues and the differing views are shown in Fig. 2, indicating how each group views each topic in the center column. Apparently, there is an underlying psychological dimension that explains the different opinions. The ensuing discussion illustrated the changing nature of this dichotomy. As the field of human–machine systems design becomes more mature and integrated, more people seem able to combine evaluative and analytical approaches. Consequently, designs become objectives-driven instead of technology-driven.

There is a need for integration of both perspectives to achieve a common design approach. One model for this may be the layers of design shown in Fig. 3, based on the

Man-machine systems		View on		Social effects of automation
deterministic	←	TECHN DEVELOPM	→	interactive
partial	←	MAN	→	holistic
man as appendix	←	INTERFACE	→	man as tool
mechanistic	←	ORGANIZATIONS	→	organic
implementation	←	CHANGE	→	participation
control	←	SOCIAL OBJECTIVES	→	emancipation
nuisance	←	HUMAN VARIATION	→	asset
quantitative	←	DATA	→	qualitative
experimental	←	METHOD	→	interpretative
technical	←	RESEARCH IDEAL	→	socio-technical
closed	←	SYSTEMS	→	open
subject-object	←	ROLE OF RESEARCHERS	→	subject-object
manipulate	←	FUNCTION OF RESEARCHERS	→	process facilitating
need for control	←	UNDERLYING PSYCHOLOGICAL DIMENSION	→	need for less control

FIG. 2. Conclusions from the delphi study between experts on human–machine systems and social effects of automation.

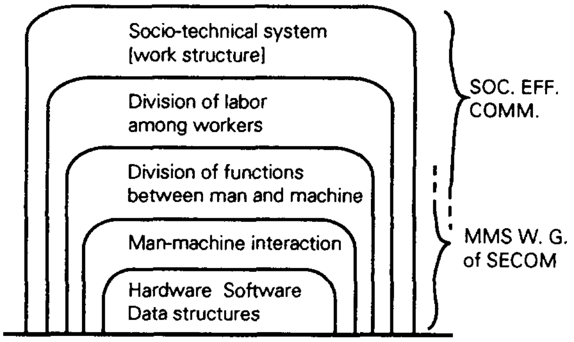

FIG. 3. Layers of design for computer-aided systems of work—trying to amalgamate two different approaches.

sociotechnical systems design approach (Martin *et al.*, 1987). The approach starts by designing the overall sociotechnical structure, trying to anticipate the social effects of the technology used. The approach then works further "from outside in", with the design of proper hardware and software at the end. A complementary approach is provided by the emerging concept of human-centered design.

HUMAN-CENTERED ISSUES OF DESIGN

As illustrated in earlier discussions, the design of human–machine systems is particularly difficult (and challenging) when the context is large-scale systems. This difficulty is due to the complexity of such contexts, although this assertion is certainly not a great insight. The human-centered design issues of concern do not involve complexity in general—they involve the consequences of complexity (Rouse, 1988a, 1991).

One of these issues involves the nature of decision-making situations faced by humans in large-scale systems. There are basically three types of decision-making situations: familiar and frequent, familiar and infrequent and unfamiliar and infrequent.

We are usually pretty good at dealing with the familiar and frequent—we know these situations are going to arise, and they happen often enough to justify investing in means of dealing with them.

Familiar and infrequent situations are the grist for the risk analyst's mill. How infrequent? What are likely consequences and their costs? Answers to these questions determine our investment strategies for dealing with these risks.

Unfamiliar and infrequent situations pose a dilemma. On the one hand, perhaps we should invest in making the unfamiliar familiar. Then, it's back to risk analysis. On the other hand, such a strategy ignores the inevitability of humans eventually having to deal with the unfamiliar—not knowing what has happened or what to do about it. The nonlinear, distributed nature of large-scale systems will result in a larger number and wider variety of unfamiliar situations. We need to be able to design for decision making in this type of situation.

A second issue concerns the nature of emerging large-scale systems which, as noted earlier, is resulting in higher-order effects being increasingly salient. Thus, for example, events in one sector of the transportation system can affect operations in another sector. Within the economy in general, industries affect each other in more far-reaching ways than in the past. Looking more broadly, economic development efforts can negatively affect the environment on a global scale. Technological development can profoundly affect educational requirements—and, as later illustrated, suffer due to educational shortfalls or misdirection.

The result of these higher-order effects is that there are a larger number and wider variety of stakeholders in particular decision-making situations. Consequently, decision-makers are pulled in all directions, decisions are made to minimize political risks, or decisions are avoided.

A third issue concerns the role of humans in large-scale systems. There are two primary reasons why humans are included as operators, maintainers and managers in complex systems. One reason is people's ability to perform—to exercise skills, judgment and creativity. Some pundits argue that intelligent computers will soon eliminate the need for humans to perform in these ways. This assessment appears to be somewhat reasonable for manipulative skills, occasionally on target for judgemental abilities, and substantially off the mark for creativity.

Even if the soothsayers are right, perhaps later rather than sooner, the second motivation for humans having roles in complex systems is seldom, if ever, addressed by new technology. Humans are included in complex systems to be responsible for system operations and performance. The ability to accept responsibility and, if required, to find innovative ways to fulfill these responsibilities is a uniquely human characteristic. This is particularly evident when things go wrong, sometimes unpredictably and uncontrollably, and some individual or group accepts responsibility and initiates efforts to set things right again.

We raise the issue of responsibility because we are concerned that the complexity and technology associated with large-scale systems will lead the people involved to lose their feelings of responsibility—to perceive that "the system's in charge". If this happens, then in fact no one will be in charge. This possibility leads to the topic of design philosophy.

Choosing a design philosophy involves selecting objectives at their highest, value-laden levels. From this perspective, it is important that design objectives involve developing the means whereby people in complex systems can achieve the operational objectives for which they are responsible (Rouse, 1991). Thus, the purpose of the people in the system is not to "staff" the system—the purpose of the system is to support the people in achieving their objectives. In other words, an "appropriate" design philosophy is simply that *people are in charge*. Based on this philosophy, the question of whether or not they should be in charge is not a technical issue. The key question is how to support them so that they can be in charge successfully. More specific questions concern where in systems people should be; how they should be trained and aided; and how we can assure that they accept and retain feeling of being responsible.

Adoption of the above design philosophy, as well as the consequent design objective, leads to three primary design goals. These goals involve developing means for:

Helping people overcome their limitations (e.g. human error)

Helping people enhance their abilities (e.g. pattern recognition) and

Fostering user acceptance (e.g. avoiding the "not invented here" attitude).

HUMAN-CENTERED DESIGN METHODOLOGY

A suitable design philosophy and design goals are necessary for appropriate automation; however, they are not sufficient. A design methodology is needed that enables designers to achieve goals in a manner consistent with the philosophy.

The determination of human-centered functional requirements for large-scale systems is difficult to do well. Balancing what users apparently want with what they may need, as well as balancing technological and economic realities, can prove to be far from straightforward. It is fairly common to discover that the "final" requirements are incomplete and inconsistent. Obviously, it is better to discover this early rather than late.

We have found that a structured methodology can ease the burden of requirements analysis, as well as provide insights that might not otherwise be gained (Rouse, 1987; Rouse and Cody, 1989; Rouse, 1991). This methodology is based on the notion that the seven measurement issues shown in Fig. 4 are central to successful system design. If these issues are not addressed by system designers, they will eventually be addressed by system users, with perhaps unfortunate implications for sales, liability claims, etc.

The list of questions in Fig. 4 is used in two ways. Measurements are executed bottom up—the system has to run, compute, etc. prior to measuring actual sales. In contrast, measurements are planned top down. Thus, the eventual measurement of viability, acceptability, and validity should be planned long before testing is considered.

From this perspective, there are two classes of problem that can arise. The first is planning too late, where, for example, failure to plan for assessing acceptance can preclude measurement prior to putting a product or system into use. The second is execution too early where, for instance, demonstrations are executed prior to resolving test and verification issues, and can potentially lead to negative initial impressions of a product or system.

The measurement issues listed in Fig. 4 encompass a fairly diverse set of questions. If each of these issues were pursued independently, as if they were ends in themselves, the costs of measurement would be prohibitive. Yet each issue is important and should not be neglected.

What is needed, therefore, is an overall approach to measurement that balances the allocation of resources among the issues, while also integrating intermediate measurement results in a way that provides maximal benefit to the evolution of the design product. We have found that this can be accomplished by viewing measurement as a process involving four phases: (1) naturalist, (2) marketing, (3) engineering, and (4) sales and service (Rouse, 1991).

The naturalist phase involves understanding the domain and tasks of users, from the perspectives of individuals, the organization, and the environment. This understanding includes not only the users' activities but also prevalent values and attitudes relative to productivity, technology, and change in general. Concerns of particular interest include identification of difficult and easy aspects of tasks, barriers to and potential avenues of improvement, and the relative leverage of various stakeholders in the organization. The results of the naturalist phase include a characterization of users' tasks and needs, as well as users' perceptions of how these needs might be met.

Viability → Are the benefits of system use sufficiently greater than its costs?
Acceptance → Do organizations / individuals use the system?
Validation → Does the system solve the problem?
Evaluation → Does the system meet requirements?
Demonstration → How do observers react to the system?
Verification → Is the system put together as planned?
Testing → Does the system run, compute, etc?

FIG. 4. Measurement issues.

This characterization of users and needs serves as input to the marketing phase. With this understanding, one is in a position to conceptualize alternative products and systems to support users. These product concepts are used for initial marketing to obtain users' reactions relative to validity, acceptability, and viability. In other words, one wants to determine whether or not users perceive a product or system concept as solving an important problem, solving it in an acceptable way, and solving it at a reasonable cost.

While one cannot resolve all of the validity, acceptability and viability questions during the marketing phase, one can test and elaborate the plans for eventual resolution of these issues. Further, one can test and refine the hypotheses that have emerged from the naturalist phase regarding the appropriate impact of user characteristics on design choices and product concepts. Thus, the marketing phase produces both an assessment of the relative merits of the multiple product concepts that have emerged up to this point, and a preview of any particular difficulties that are likely when one later tries to ensure that users perceive the resulting product as valid, acceptable and viable.

The engineering phase begins with tradeoffs between desired conceptual functionality and technological reality. Technology development will usually have been pursued prior to and in parallel with the naturalist and marketing phases. This will have at least partially ensured that the product concepts shown to potential users during the marketing phase were not technologically or economically ridiculous. However, one must now be very specific about how desired functionality is to be provided, what performance is possible, and the resources necessary to provide it. Most of the effort in this phase is associated with using various formal and informal design methodologies to transform conceptual designs to detailed design. Measurement concerns include both planning and execution of evaluation, demonstration, verification, and testing.

The sales and service phase begins once these four issues have been successfully resolved. The focus now shifts to validity, acceptability and viability. At this point, one ensures that implementation conditions are consistent with the assumptions underlying the design basis of the product.

If the naturalist and marketing phases were well done, the sales and service phase should proceed easily. Nevertheless, the final marketing, sales, installation, and ongoing service of a product are the activities that should provide the validation, acceptance and viability measurements planned earlier. Further, if the sales and service phase is well orchestrated, this will substantially lessen the investments necessary for subsequent naturalist and marketing phases for new products.

The above measurement-oriented approach provides an overall framework for human-centred design. Beyond this structure, more detailed methodological guidance is needed. During the later stages of the marketing phase, and throughout the engineering phase, methods are needed for synthesizing functionality that satisfy requirements within the scope of the design goals outlined earlier.

We have found a five-step method to be particularly useful (Rouse, 1988b). This method begins by *characterizing user-system* tasks by selecting one or more elements of a taxonomy of 13 general tasks. The next step involves *assessing relative demands on tasks*, especially to determine "bottlenecks". The third step concerns *identifying approaches to support* by mapping from high-demand tasks to one or more elements of a taxonomy of 17 support concepts. The fourth step is *determining likely applications obstacles* for the candidate support concepts selected. The last step concerns *anticipating user acceptance problems* by applying a 12-step procedure to evaluate support concepts and plan their implementation.

The methodologies outlined in this section have been applied to a variety of complex design problems, including advanced aircraft cockpits, power plant control rooms, several design support systems, and a new concept for production planning and scheduling. In all of these applications, the philosophy, goals, and methodologies enabled human-centered design issues to predominate, and technological issues to be subordinated to the goals of providing support for humans.

In the following sections, experiences in the processing and manufacturing industries, as well as crosscultural experiences, are used to illustrate various aspects of human-centered design and also show how many of the principles discussed earlier in this paper are manifested in applications.

EXPERIENCES IN PROCESS INDUSTRIES

Fashions

As with women's and men's clothing, there have been and still are dominant fashions in process control and automation. The 1960s showed a push for on-line quality measurement, and on-line computers for the optimization of process operation. The 1970s brought small-size control rooms with VDU-based instrumentation for complete production sites, handled by first-class operators in the control rooms, assisted by second-class operators in the plant areas. The 1980s showed the impact of adaptive control, expert systems, and statistical quality control.

Each new wave is advocated as the final solution, is pushed into practice, is met by difficulties, and finally subsides into a more or less stationary outcome. In some cases, e.g. for on-line quality measurement, the difficulties are mainly of a technical nature, but in others there are organizational and human problems, which were (and are) not always clearly recognized nor adequately dealt with. Consequently, one wonders if all the potential benefits have really been reaped.

Optimization

As an example, on-line optimization of process operation has run into the incompatibility between numerical computation and human methods of decision-making and action. The process operator associates critical constraints with certain controller setpoints (e.g. "Never move temperature 703 about 435 degrees, otherwise there is excessive coking in the flasher!"), and deals with them one at a time. As a result, the operator neither understands nor accepts the computer output, which shows simultaneous corrections to all setpoints without indicating relationships of these changes to the critical constraints. The operator cannot grasp, or at least has doubts, that the effect of changing temperature 703 from 435 to 439 degrees is compensated for by a simultaneous increase of flow rate 695 by 0.7%, and a decrease of pressure 706 by 0.8 bar, etc. Since the operator is still held responsible for process upsets, he or she will tend to play safe and ignore the computer.

Optimization procedures generated by computers have to be brought into a form which is familiar and acceptable to the operator. One possibility is to develop near-optimal regulatory control structures and decentralized, simplified computations, which can also cope with variations in process conditions. Then the in-plant system needs to be updated only infrequently, making this system and its supervisors (the operators!) more autonomous. In this way, appropriate technical measurements can also create opportunities for organizational decentralization.

Co-operation

A case where co-operation among operators was vital was the design of a major extension of a petroleum refinery (Pikaar *et al.*, 1985). The goal was "whitening the barrel": converting cheap heavy fractions into more-valuable lighter ones (gasoline, kerosene, light gas oil). For this purpose the number of processing plants was to be doubled, with many interactions due to common energy utility systems. These interactions would make the refinery very vulnerable to local upsets, as these spread rapidly through the utility systems and easily infect other plants. Consequently, good co-operation between control room operators was considered to be essential.

An obvious measure was to ensure eye-to-eye contact in the control room over the VDUs on the consoles, even between two short (seated) operators. This led to the choice of small VDUs (13 inch, instead of the more fashionable 19 inch models), and shallow keyboards (8 inch). But organizational aspects proved to be more problematic: the existing subdivision of the operator team into two subteams, each with its own supervisor, blocked essential communication between control room operators. Therefore much attention had to be paid to integrating the total operator team by setting up common training and having common supervisors. It is amazing how organizational divisions remain visible long after they have lost sense and purpose. Evidently, organizational and psychological problems are much harder to recognize and to solve than technical ones, and engineers can be quite irrational (in this respect they prove to be as human as other people!).

Another, unexpected problem appeared when individual plants were allocated to the different operator positions in the control room. The object was to keep process interactions within one operator position to the extent possible, and to minimize the distance between operators with many interactions. The result of this optimization was a semicircle of four operator consoles (each with one operator position during normal operation, and two operator positions during major upsets), with a fifth console in the center. The latter proved to be the console for the utilities, which caused an uproar in the design team: "What? You are going to put those stupid utilities in the middle? Unacceptable! Only our technologically advanced conversion unit deserves that location!" Fortunately, after lengthy discussions emotions were replaced by reason. Later experience has shown that major upsets can be dealt with only by coordination from behind the central utilities console.

A third problem, which became evident from observing operator actions during a major upset, is the variability of operator workload. During normal operation outside office hours, when not much is happening and there are no maintenance technicians and staff around, control-room operators can easily cope with their job. But when things go wrong, the workload can become excessive. Unfortunately, with an increasing degree of automation and centralization, this difference tends to become more pronounced. (Extreme differences are found in electric power generation, where the operator's job consists mainly of waiting for emergencies.) Improvements can be made by training central operators to take over some tasks from their neighbours in the central control room, and providing them with the corresponding displays and controls.

Small-scale plants

There is a tendency to transfer work organization concepts, as developed in the large-scale process industries (oil refineries, bulk chemical plants) to smaller plants. These concepts work well with "closed" equipment; hence operators in a central control room can clearly see what happens on the VDU screens and other displays. Therefore, they are able to direct the work of their field operators, and to coordinate the overall operation effectively among themselves.

In contrast, many small-scale plants have mostly "open" process equipment. Operators have to see directly what is going on, and to make local adjustments. Displaying information only in the central control room is, therefore, insufficient. Similar conditions exist in other industries, e.g. papermaking, where setting-up the paper machine requires monitoring both of the displays in the control room and of the conditions in the machine itself. In such cases, the concept of the central operator as the "boss" of the local operators does not fit. Instead, operators function better on equal terms, with responsibilities in the control room as well as at the process equipment. This easily leads to the concept of an autonomous work group with jobs of equal status and an informal internal organization (Rijnsdorp *et al.*, 1984).

Networks

Like any organization, industrial enterprises suffer from a lack of co-ordination and communication. Multinationals experience particular difficulties, due to their multi-dimensional structure: marketing offices distributed over various countries, active in different product groups; production in other locations, each serving several marketing offices; joint ventures and co-makerships with other firms, etc. But smaller enterprises are not free from problems either. There are always conflicts of interest between sales, production, purchasing, logistics, research and development and maintenance.

A way to improve communication and co-ordination is the computer network. Banks have already pioneered this tool with very satisfactory results. People in different parts of the world with different cultural backgrounds, who have never seen each other, interweave working together with exchanging jokes!

The application of networks in industrial enterprises is probably not so straightforward. It is unlikely that conflicts can be resolved by digital data exchanges; meetings and management guidance seem essential here. But computer networks could complement direct communication by providing objective information, e.g. "What is the cost of satisfying a very demanding customer? What is the best allocation of production runs between two factories in different countries?"

Design considerations

The usual deadlines of plant design projects make it almost impossible to pay sufficient attention to the interdisciplinary aspects of automation. It is therefore desirable to set up an anticipatory phase, well ahead of the actual project. This phase consists of:

A situation study in a comparable running production plant. Here process automatability can be analyzed, and future user needs and wishes collected and evaluated.

Developing a user participation concept. It is important to find an efficient and effective way to involve future users (or their representatives) in the design project, and encourage acceptance by lower management and project staff.

Allocation of tasks. A careful choice must be made of the degree of automation for each operational function, from plant scheduling to off-normal handling. The level of automation "intelligence" requires special attention, as this has an impact on job content and selection requirements.

Structure of the work organization. This involves setting goals for organization development, and fitting the work organization to the technical and social conditions at hand.

Job design. Within the framework of the chosen work organization, the job content of production and other personnel should be assessed. If results are negative, task allocation and/or work organization are modified accordingly.

Selection, training and career development concepts. These should be formalized.

EXPERIENCES IN MANUFACTURING

Changing conditions and structures of manufacturing

During the last two decades the markets for industrial consumer goods and, consequently, those for capital goods have shifted from steady expansion towards stagnation. This persistant global trend does not yet seem to be affected by unsatisfied needs in developing countries. Terms of trade and debts hinder these countries, preventing them from turning their needs into spending power for industrial goods. Thus, at least for the forseeable future, the world markets are and will remain constrained to the highly industrialized areas and "threshold" countries comprising North America, western Europe and south-east Asia.

The overall low growth rates of these limited markets mean that competition also changes its character from supplying expanding market shares, where suppliers are usually able to set the conditions, to displacing competitors, whereby customers gain the power to demand products adapted to their needs. Under these new market conditions, price and quality of unified products are no longer the only important assets. The ability to adapt products to customer requirements for increasing variety, and to guarantee short delivery times is becoming a more important competitive factor.

The functional requirements that follow from this market situation are manifold:

Flexibility of production facilities so that various products, even those not yet known, can be manufactured.

Simple and quick resettability of manufacturing installations in order to allow small lots to be manufactured.

Reassignment of quality assurance functions to the productive work stations (i.e. quality must not be controlled, but produced).

Rearrangement of production facilities, based on principles of group manufacturing, in order to shorten lead-times.

Ability of subsystems to work autonomously in order to permit investments to be made step by step.

In attempting to meet these requirements, there are three substantial economic difficulties the factory of today has to contend with. The following discussion is based on the German machine industry, but also seems to be applicable to other countries.

First, there is a continual increase in capital tied up in factory equipment which compels management to make better use of it. Second, long and varying lead-times caused by the functional principle of job-shop manufacturing make work in progress expensive. Third, the ratio of 144 indirect to 100 direct workers on average in the German machine industry causes excessive personnel expenses, since well-organized firms with comparable products have shown that a 90 to 100 ratio is sufficient. Two opposing concepts of manufacturing automation have emerged to surmount these difficulties.

Alternative approaches to manufacturing automation

The technocentric approach. This approach leaves the basic job-shop structure of the production process unchanged and follows the same fundamental objectives as in the past. These objectives are to reduce direct labor costs and to gain better control over the manufacturing process. Applied to the shop floor, management attempts to automate setting and operating functions almost completely for machine tools and handling systems. The activities focus on automatic part and tool changes, measuring devices and monitoring systems. They are limited by the increasing costs of this equipment. Although fully automatic operation might be temporarily possible, human operators are still needed.

This concept of the "unmanned factory" runs into several difficulties, making its success doubtful. First, the high cost and risk, caused particularly by the software needed, are too large for many small and medium-sized firms. Despite their growing economic importance, these small firms would be bypassed by such developments. Second, firms following this strategy would suffer from relative inflexibility regarding alteration of batches and process innovation. Third, as a sort of irony of automation, flexible manufacturing systems are becoming more and more complex and susceptible to breakdowns because of automation and, consequently, increasingly dependent again on highly qualified, skilled human labor (Bainbridge, 1982).

The human-centered approach: skill-based manufacturing. As discussed earlier, this approach regards automation (and technology in general) not as a constraint but an option that—when properly designed and applied—provides an oppportunity to see qualified "live work" and automated work not as irreconcilable contrasts, but as supplementary productive forces. Sociologists call this new approach a change of paradigm in industrial production.

The new organizational paradigm

This human centered or organizational paradigm views technology not as a thing but as a relationship between people and their artefacts (van Beinum, 1988). All technologies are tools and have meaning only when being used and controlled by people. Introducing a new technology means introducing a new relationship, and managing technological change means managing a relationship which is changing. Understanding work as a relationship between people and their tools takes on a special meaning when we consider this relationship on the organizational level.

Organizations are sociotechnical systems. The concept of sociotechnical systems design was developed thirty years ago by the Tavistock Institute. It arose from the consideration that any production system requires both a technical organization and a social system which creates and governs the relations among those who carry out the necessary tasks. If we design and manage the work situation so that the social system and the technical system are interrelated in a highly complementary way, we can achieve joint optimization of the two systems, and thus of the functioning of the organization as a whole.

In the quest for the proper response to this challenge, many companies have attempted over the past few years to develop and introduce new structures of organization and labor in the manufacturing sector under the general heading of flexibility. This can be achieved by a structure of functional blocks (products in assembly groups, production in working groups and manufacturing cells or islands) (Ortner, 1988). This makes more transparent what goes on in a company. Further, if the control and management system is designed in a more decentralized way and the staff have proper qualifications, this approach allows production planning and production control functions to be moved back to the operations level. This results in shorter and faster decision making pathways and fewer hierarchical steps.

Delegating to groups further activities such as setting-up, programming, repair, maintenance and quality assurance further improves flexibility. The added personnel cost arising as a consequence of needing more qualified staff is balanced by increasing utilization of systems. In order to be able to process orders quickly enough, manufacturing plants will in this way increasingly assume the character of service companies.

This new organizational concept has recently been shown to be highly successful both in small-lot production, e.g. in the machine building industry, and in the automobile industry, which—except in Sweden—used to be organized strictly along the lines of Henry Ford.

The case of Felten & Guilleaume (F&G)

In 1985, the Nordenham works of F&G had 567 employees producing low voltage switch gear and accessories and electric motors. They faced serious problems typical of so many similar operators: sales stagnated, life span of products became shorter (as did delivery times), lots became smaller, cost reduction on the labor side through further automation seemed infeasible. They realized that their problems could not be solved by technical means only and decided to restructure manufacturing and information systems. They started with one part of the mechanical workshop, assigning the following tasks to the "production island": setting of machines and tools, manufacturing the products, stock-keeping of raw materials including replenishing, routine maintenance work, quality inspection and recording, and work planning within a time-span of one week.

After one and a half years, the results were convincing, e.g. throughput times were cut by half, output per capita had gone up 25% and the workforce was proud of their work. This encouraged the firm to restructure the whole mechanical workshop and the assembly departments as well.

Since the island principle had worked so well on the shop floor, they were tempted to apply the same principle to clerical work in administration where they had similar problems with long chains between customer, sales, product design, tool design, production planning etc. They therefore installed "administration islands" in one room to speed up and improve their tending services. Again, speed, quality and self-teaching team effects were overwhelming. The next steps are to restructure materials management and production control.

Automated machinery and computers were also used, of course, but—as one manager put it—"Wherever computer application threatens to become a self-contained, self-absorbed business it should be fought like the plague!"

Design considerations

The findings experienced both in the process industries and in manufacturing correlate remarkably well. Sociotechnical design considerations which may be derived are:

Importance of overall work structure
Team approach with job rotation (so operators can replace each other)
Maximum possible degree of automation not necessarily being the optimum
Importance of (re)qualification of operators
Great difficulty with innovation within the organization (changing traditional roles and privileges)
Transformation of computer outputs (interactions) into forms that fit human criteria
New technologies favouring/encouraging more holistic work contents (tasks) and decentralized structures (local autonomy)
Autonomous work groups especially needed in smaller plants, and possibly appropriate everywhere.

ECONOMIC ASPECTS OF AUTOMATION

In industrial organizations economic aspects of automation are considered a part of the business activity. The purpose of the business unit is to satisfy the needs of individual consumers, other enterprises, or society as a whole. Sufficient profitability and balanced cash flow are essential for the existence of the business unit in the long term.

Decision-makers responsible for allocation of financial resources in different business activities are first of all interested in the efficient use of invested capital. The common practical measure is return on investment (ROI). Lower-level managers responsible for the production process have to decide how to use available financial resources. The basic reason to develop automation may be economic, technical, human or environmental, but in practice the responsibility of the manager is to make technically feasible and economically sound decisions which satisfy all the requirements for which he or she is responsible.

Such decisions can be easy if costs and performance of technology are deterministic and can be measured in monetary terms. However, traditional financial measures—like ROI—are not well suited when considering attributes which cannot be evaluated in monetary terms, such as flexibility, acceptance of the work system, or the impact of technologies on the company's long-term competitive position. Human and cultural aspects present even greater difficulties.

In recent years, methods have been developed—e.g. by Grob (1983)—that allow for consideration of nonmonetary attributes, in investment decisions. While this topic cannot be pursued in this paper, it is useful to note that, in general, decision-makers must learn to take into account qualitative long-term strategic considerations.

CULTURAL ASPECTS OF AUTOMATION

In developing countries, machines are expensive and people are cheap. In contrast, machines are often inexpensive relative to people in the developed nations. This difference is crucial when we consider appropriate technology. The key question is the meaning of the word "appropriate". As we are trading more and more with third world and nonwestern nations, the meaning of this word is becoming less and less clear.

It is inevitable that the pressure of international competition sets equal standards for the unequal? Are there no ways for viewing tasks within cultural contexts? Basic technologies are universal, but is it possible to have different implementations and applications of technology which consider specific cultural and economic needs?

In this section, we raise issues which go far beyond traditional areas of engineering. Nevertheless, control engineers who quite often accelerate the unemployment rate with their artefacts should also play their part in solving global problems.

Culture and technology

An issue which has been largely neglected by technologists for many decades is how amenable a particular culture is to the technology which is being introduced to it—or, in many cases, imposed upon it. It has been recognized by observers in African states, for example, that—as tough as it might appear politically to say it—in practice it probably takes two to three generations to change cultural values towards new technology, or to implement the subsequent absorption of this technology. The experience of many educators is that while it would be desirable to train a whole generation of engineers as rapidly as possible, this has proven to be impossible in practice.

In most African states one finds, for example, that only now are indigenously-trained engineers emerging, and that typically these have come from families whose parents have at least some technological background. Also, the grandparents were often school teachers or at least had some introduction to science or technology. Simply to impose a technology on a society and believe that it will be able to cope through extensive training has been proven not to work. It has led to rejection of technology or, in the case of colonized countries, has simply become part of the colonialist strategy.

These comments are made on the basis of engineering. However, when one considers for example that many so-called "underdeveloped" countries do not even have a language which is "numeric", then one can realize the scope of the problem of introducing new technological concepts! (A "numeric" language is one which contains inherent concepts of numbers and arithmetic functions.)

In addition to problems of language and numerics, another aspect of culture which must be considered in terms of introducing a new technology is the fundamental attitude of that culture towards labor and service. A proud culture, which has always been violently independent, will have great difficulty in absorbing technology which demands a large degree of adherence to sets of rigid rules. Again, one can look at the example of many third world countries in which stable nations were subjected to the imposition of colonialism which in many cases depended upon master–slave relationships. As part of these structures, the "masters" insisted on the "slaves" doing certain tasks which were essentially to the well-being of the colonialists, but were denigrating to a culturally proud people. For example, in many African tribes manual work was traditionally not done by men. However, in many parts of central and southern Africa the colonialists persuaded men to do manual tasks—even including housework, previously totally reserved for females. Now with decolonization it is little wonder that one of the first things which goes is any form of rigidly-structured manual work. It is no surprise that the previously proud culture reacts and wants to attempt to return to the state of freedom!

What can one conclude about eastern cultures? Again it is difficult to draw any rigid guidelines. However, if one looks at the "service culture" characteristics of Japan, one sees some interesting concepts emerging.

For many years we have been bombarded by the fact that Japan appears to maintain a low unemployment rate. While recent studies have pointed to the fact that this might not continue, it cannot be denied that Japan still has one of the highest employment rates in the world. This is true despite the fact that Japan has always been pointed to as the major consumer of automation. Of course, the concept of countries, such as Japan, exporting unemployment is well-known and there can be little doubt that the result of Japanese high efficiency in manufacturing has been the creation of unemployment in countries who simply cannot compete.

Many of us have also been intrigued for years by what the Japanese actually mean when they state that they are creating a service industry. If one looks at the UK or Europe, one sees great difficulties with the proposed involvement of more and more people in the so-called "service" industries. Indeed, if one looks at the European scene, one sees that most people have some sort of hang-up about serving their fellow human beings! Indeed, in third world circumstances, including many ex-colonies, the whole concept of service is looked on with much suspicion—largely as a result of the master–servant relationships created by the colonists.

Although things are changing, the Japanese tradition of service is extremely strong and still exists. Their culture has had a unique ability to absorb other cultures, other religions and other concepts. Despite such changes, they continue as a unified whole, maintaining the concept of service as a critical one. This is not just related to service to one company. Indeed many industrial observers have commented on the fact that the present loyalty to one single employer will probably change in the next few decades and is already changing to some extent.

However, the concept of service goes much further. The ticket inspector, for example, is respected by all whom he or she serves. The young lady who opens the lift doors perennially has a smile, and seems to find a great deal of satisfaction just doing her job properly. The person going around a hotel in Tokyo, checking that any marks on the floor have been removed and that all pieces of furniture are in order does this with much pride. As an outsider to the culture, of course, one cannot even hope to fully understand the motivations for these ideas. However, one observes that the concept is still very strong.

Cultural impact on automation

The question is, how do all the cultural issues discussed above affect automation? It has been claimed by many that automation has two prime effects. One is that it undoubtedly puts people out of work—in terms of traditional, manual labor. This appears to be attractive in that it might suit, for example, African countries to revert to a situation where the jobs in the factories are all high level and no menial tasks are required. However, the problem with this is that the new tasks which have been introduced require a high degree of training. Since, as mentioned previously, it takes several generations to produce competent engineers, the pattern which is seen throughout decolonized Africa, where high-technology industries simply do not survive, seems inevitable.

The other side of automation is the claim that its consequences are improvement in the earning power of a country which can, in turn, support many service functions. Again the Japanese example is worth looking at.

In discussion with Japanese industrialists, it appears that the intention is still to decrease the human content of their operation. Most companies state publicly that they wish to make more use of machines, and more use of computer-integrated manufacturing. They aim to lower the number of people required. This is against a background of operations such as watch-manufacturing lines, producing over 100 000 quartz crystal watches per week, and currently manned by 5 or 6 people, or complete flexible manufacturing systems, with up to 10 machine tools attached, having single operators who not only ensure that the system keeps running but also load up the pallets, adjust the workpieces, etc. Despite this the companies say that they wish to go further.

Observers are nevertheless struck by the fact that more and more people really do seem to be used in the service industry, not just in serving food, but on the railways, in farming, etc. In the busiest of Tokyo train stations, where over one million people pass through the barriers every day, the Japanese are not (as of this writing) using automatic ticket machines such as those currently being introduced on the London Underground. On entering the station, one's ticket is clipped by one inspector, and it is taken when one leaves by another. The stations themselves are supervised by many workers who ensure people get into the over-full Tokyo trains. There are always enough ticket windows open to buy tickets, and always someone around to give you directions.

Farming is still on a small scale, despite the tremendous demand. Japan imports vast amounts of its food, and yet large percentages of the land are turned over to agriculture. No attempt seems to be made towards automation here, and peasant farming still appears to be the order of the day. Throughout the countryside one sees families busy tilling the fields or their rice paddies. Occasionally tractors are used, but in many cases very simple, primitive farming methods are employed.

How does this all work? Somewhere within the Japanese structure there seems to be some careful planning to determine what can be automated—where the value can be added to a product. This planning takes place in the context of a clear recognition that it is essential to provide people with some form of employment, even though, in certain cases, particularly for internal consumption, it might appear to be more economical to automate.

However, in the African situation with a completely different approach to the service industry, one is left with tremendous problems. The concept of service held by a significant percentage of the population has been distorted by the colonialist days, and service is seen as being degrading. The concept, then, of moving employment further into the service sector is highly questionable.

These comments are made by technologists and not by sociologists. The point is that the two should get together to try to resolve the difficulties. This could mean, on one hand, developing and applying technologies appropriately within a particular culture. On the other this might mean helping a culture to utilize the possible benefits of technology without involuntarily giving up cultural values. Such endeavors will remain fruitless in the case of most under developed countries, as long as the western understanding of these cultures remains minimal and in many cases naive. One of the characteristics of our era is still the arrogance of one culture over another, particularly when the first culture is one which is technologically-based and, therefore, has strength through this technology.

Working group on cultural aspects of automation

As a result of the IFAC discussions between proponents of social effects research and human–machine systems, an increased awareness has grown that these two approaches may require a third supplementary focus on culture. It has been suggested that it would be a unique contribution if a learned technical institution like IFAC took the initiative in promoting an understanding of the larger pattern of consequences based on its own professional endeavors, and considering all its complexities. The Technical Board of IFAC has therefore just established the Working Group on Cultural Aspects of Automation within the Social Effects Committee. Its scope is to promote understanding of the interplay between technological development, social conditions and effects, and cultural change; to explore new approaches for cross-disciplinary research; and to develop and transfer views and methodologies that include cultural aspects to control engineers and interdisciplinary groups dealing with automation systems design.

CONCLUSION

If we wish engineering artefacts to be reconciled with broader aspects of life, we must consider comprehensive sets of requirements in engineering design. Ignoring any impact that an innovation might have on the environment, or the people in the environment, will be seen by history as being negligent. Of course, certain effects will have to be accepted, but we must, together with a wide cross-section of the people affected, investigate all aspects before positive decisions are made.

In view of the enormous effects of automation technology on both the private sphere and the world at large, technocentric thinking that rejects comprehensive technology assessment should be abandoned. It is also important to recognize that a large number of examples have shown how a holistic approach to automation design will result in systems with improved overall performance. Not only do the resulting systems work better, but they are better for the world in which we all live—now and in the future.

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