Looking Ahead

Human Factors Challenges in a Changing World

Raymond S. Nickerson

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"Wise folk may or may not form expectations about what the future holds in store, but the foolish can be relied upon to predict with complete confidence that certain things will come about in the future or that others will not" (Peter Medawar). Alas.

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by

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The publisher has gone to great lengths to ensure the quality of this reprint but points out that some imperfections in the original may be apparent.

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To

Amara
Daniel
Timothy
Bryan
Laura
Rory
Erin
Danielle

and their generation


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Preface

For the second time in my experience, a background paper prepared for an activity of the National Research Council's Committee on Human Factors has grown into a book. The immediate precursor to this book was a paper written for the committee's use in the planning of a report on Human Factors Research Needs, which was to be a sequel to a report on this topic issued by the committee in 1983. Involvement with the Committee on Human Factors has been immensely stimulating and rewarding, and I feel very fortunate to have been a member of it and to have participated in its activities.

As its title indicates, this is intended to be a forward-looking book. I am very interested—as I assume most of us are—in the question of what kind of a world we are moving toward. More particularly, as a parent and grandparent, I am concerned about some current trends and would like to understand better what can be done to increase the probability that the world we are bequeathing to future generations is one they will want to inhabit.

I believe that if one begins as a dyed-in-the-wool pessimist one will find plenty of support for that pessimism. On the other hand, I believe also that if one wants to be an optimist, one can find much support for that view as well. But we should not, I think, be easily persuaded to accept the inevitability of any particular scenario. The future is full of possibilities, some good, some bad. It will be what we make it.

The focus here is on the question of what major challenges and opportunities a world that is changing rapidly may have for the human factors profession. Or reversing the question, what does the human factors profession have to offer by way of solutions, partial solutions, or approaches to help solve problems that seem to be looming as we look ahead?

An obvious first step in beginning to think about this question is to try to understand what the problems are likely to be. To this end, I collected predictions, projections, forecasts, conjectures, and guesses about the near future, as well as data regarding recent developments and trends that struck me as having some relevance to the task of identifying challenges and opportunities that relate to human factors, broadly conceived.

I have not tried to define what I mean by human factors, but it will be clear that what I have in mind is considerably broader than the science and technology of designing equipment that is suitable for human use. If I offend some readers by stretching the bounds of human factors too far, I beg their indulgence and ask that they give more consideration to whether the problems being discussed are important and whether human factors, ergonomics, engineering psychology, or applied psychology more generally could have anything to contribute to solutions than to whether I have the turf and terminology just right..

A major risk in any book that focuses on the future is that, given the rapidity of change, much of its content is likely to be overtaken by events before the ink is dry. I am well aware that that is true of this book. I have had to make many changes in the evolving text because of unanticipated events that occurred during the time it was being written. Apologies in advance for projections that turn out to deal, accurately or inaccurately, with history by the time they are read.

My hope is that readers will find here a stimulus to think about certain problem areas in ways that they might not otherwise have thought and that some will see opportunities to address specific problems not yet addressed—or not often addressed—from a human factors perspective. If any of the specific suggestions pertaining to these problems in the book are pursued by researchers, that will be very gratifying of course; but even more rewarding would be the emergence and pursuit of better ideas that result from more thought and dialogue on these issues. What I have to say is directed primarily to people engaged in human factors research, or in the support of such research, and in the application of its results. But I have tried to write for a broad audience and will be pleased if others with an inclination to speculate about the future and to influence it for the better find it of some use.

I owe thanks to many people. Fellow members of the Committee on Human Factors and its technical staff over the period of time during which the book was written were Paul Attewell, Mohamed Ayoub, Jerome Elkind, John Gould, Miriam Graddick, Oscar Grusky, Douglas Harris, Robert Helmreich, Julian Hochberg, Beverly Huey, Roberta Klatzky, Thomas Landauer, Herschel Leibowitz, Neville Moray, William Rouse, Thomas Sheridan, Joyce Shields, Harold Van Cott, Christopher Wickens, Robert Williges, Frank Yates, and Lawrence Young.

I learned from all of these people and thank them for their inspiration and

collegiality. In this context, I especially thank those who encouraged me to expand the background paper into this book. I have benefited greatly from discussions with committee members about problem areas addressed, but I do not attempt to represent the committee's views, or indeed anyone's but my own. The preparation of the committee's report has been proceeding on schedule, and the report should be issued in 1993.

Very helpful comments on parts of the manuscript were obtained from Erich Bender, Sanford Fidell, Tom Fortmann, Robert Glaser, Alex McKenzie, Robert Oliphant, and Sidney Smith. Carol Stillman read it from beginning to end and made numerous valued suggestions for improvement. My thanks to each of these people.

When I started working on the book, I was at Bolt Beranek and Newman Inc. I have retired from BBN after 25 years there but I want to express my gratitude to the company for its policy of encouraging members of its staff to participate in activities such as those sponsored by committees of the National Research Council and for making time available for them to do so.

I want to thank my friends and colleagues at BBN for an abundance of intellectual stimulation over the years. During the time this book was being written, I benefited especially from discussions with Sheldon Baron, Frank Heart, Richard Pew, and John Swets.

My thanks also to Lysa Stark, my secretary at Bolt Beranek and Newman, who patiently worked with more early drafts of the manuscript than either she or I care to remember, and to Marian Bremer, Maria Kneas, and Bridget Mooney, who helped me acquire numerous hard-to-obtain reports.

As always, my greatest debt of gratitude, by far, is to my wife, Doris, for her constant love and support, and to our family for being what it is.

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Looking Ahead

No one knows what the world will be like 50 or 100 years from now. Trying to project even 10, 20, or 30 years ahead is a fool's game, because there are so few ways to be right and so many ways to be wrong. The only truly safe prediction that one can make is that the future will be different from what we expect it to be, that it will be as full of surprises as it has been in the past. So, why should we play this game at all? I believe there are good reasons for doing so, the most compelling of which follows from the assumption that there are many possible futures, some much more desirable than others, and that the kind of future we will get depends to no small degree on the kind we work to achieve. The only alternatives to this view that I see are an insipid fatalism, which is singularly uninspiring, or a live-for-today let-the-future-take-care-of-itself form of egoism, which seems objectionable to me on moral grounds.

Most of us, I suspect, are futurists in the sense that we are interested in the kind of world that our children, their children, and their children's children will inhabit, and would like to play some part in making it better than it might otherwise be. To do so intelligently we need to have some idea of what the possibilities are so we can work toward those we prefer and against those we do not. As I think about what the world of tomorrow might be like, the thing that impresses me most is the enormous range of possibilities there appears to be, some very attractive and others quite frightening. I see justification for neither unbridled optimism nor petulant doomsaying, but many goals worth working toward as well as potential disasters to be avoided, and reasons to believe that thoughtful effort can make a difference.

My purpose in this book is to review some of the recent developments and trends that seem to me to be especially relevant to any attempt to understand,

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even fuzzily, near-term future possibilities, to consider what a variety of knowledgeable people are saying about changes and developments that could occur, and to relate the possibilities to needs and opportunities for human factors research. Human factors, for this purpose, is taken to include not only the implications of human capabilities and limitations for the design of equipment and machines that are intended for human use, but applied psychology much more generally. In particular, it is taken to involve social systems as well as physical ones, the interaction of people with the environment as well as with machines, the facilitation of communication between people as well as between people and computers, and the design of policies and procedures as well as of equipment.

Although a consideration of recent developments and current trends is an obvious starting point for any attempt to understand what the possibilities for the future are, one must bear in mind that many of the twists and turns that the future will take will not be revealed by any analysis of the past. As Kay (1984) has pointed out, in warning against attempts to predict the future by looking at trends, "There is no trend that led from the railroad to the airplane. There is no trend that led from the horse and buggy to the car; no trend that led from the desk calculator to the pocket calculator; no trend that led from the ditto machine to the Xerox machine; no trend that led from the mainframe computer to the personal computer" (p. 111).

On the other hand, the automobile has evolved over this entire century; and there is every reason to believe that it will be a preferred means of transportation for the foreseeable future and that it will continue to evolve for some time to come. Electric power is generated in a variety of ways; each of these ways, as a technology in its own right, is undergoing development. How the various possibilities will compare in cost effectiveness in years ahead remains to be seen, but it seems reasonable to expect all of the ongoing efforts at improvement to continue in the future. Trends are apparent in the automation of industrial processes, the study of which should help improve our understanding of future labor needs. Long-term environmental changes are among the more worrisome trends that are attracting attention today, and we can ill afford to ignore them. I believe that Kay was right in suggesting that the study of trends will not reveal coming technological breakthroughs and innovations that can change qualitatively the way things are done, but it does not follow, nor did he suggest, that the study of trends is of no help in attempts to understand what some of the possibilities of the future are.

One reason why simple extrapolation of trends is risky is the fact that the growth history of many processes—biological, social, or technological—can be described by an s-shaped or logistic function. If one is observing such a process at a relatively early stage of its maturity, one can easily be misled into believing that the growth process is an exponential one. In the early part of the 20th century, the demand for wood for making railroad cross ties was

growing sufficiently rapidly to cause concern among some leaders, including Theodore Roosevelt, that the forests could not continue indefinitely to meet the need and that a timber famine would result. In this case, the worst fears were not realized, and for several unforeseen reasons: Creosote and other wood-preserving techniques were used to extend the life of ties (apparently by a factor of about three), concrete was increasingly used for tie materials in place of wood, especially in Europe, and the rate at which new track was laid was eventually slowed (Ausubel, 1989).

There are these and many other reasons to be wary of projections, forecasts, and predictions, whether based on the extrapolation of trends or anything else. Perhaps one should be especially wary of one's own projections, given our penchant for convincing ourselves of the worthiness of our own ideas. None of these reasons, however, is a legitimate excuse, in my view, for not trying to understand, as best one can, what the possibilities for the future appear to be and how one might help shape things for the better.

My intention is to focus on anticipated problems (read *problems* here to include opportunities as well as troublesome difficulties) and then to ask how human factors research might contribute to their solutions, rather than to use the human factors research that is being done as the point of departure and then to look for future problems to which it might be applied. One risk of this approach is that of identifying problems for which such research has little if anything to offer. In fact, I do not limit attention only to problems for which experience indicates clearly that human factors research can be relevant. I assume, rather, that there are ways in which such research could be useful in addressing societal problems that the profession has not yet realized, and that they are more likely to be realized in the future if the community is actively seeking to identify them than if it is not.

Inasmuch as the impetus for this exercise came from an activity of the U.S. National Research Council, the focus is more on the United States than on any other country, although attention is also given to international and global issues. I have noted some research studies from the human factors and applied psychology literature that relate to various aspects of the problem areas discussed, but I have made no attempt at a comprehensive review of the relevant work. I do believe, however, that the studies cited are broadly representative of the relevant research that has been undertaken in the past few years and/or that is currently under way.

Projections, forecasts, and predictions were gathered from a variety of sources, which I identify when possible. In addition, I have not hesitated to include my own quite unauthoritative guesses. Whatever their origins, they are, for the most part, fairly conservative; that is, they are quite plausible, at least in my view. In their entirety, they are offered more as a stimulus to thought than as a serious attempt at forecasting. The time scale is the next few decades, 30 years at the outside in the vast majority of cases. The emphasis is

on possibilities; the intent is to identify what could happen rather than to say what will happen. For convenience I have organized these thoughts under a few specific headings. There is a certain arbitrariness about these groupings: Many observations could as easily been put under some other heading.

When trying to anticipate what the future could hold, it is probably useful to remind ourselves how often people who have attempted to look ahead have been quite wrong. Each of us, undoubtedly, has a set of favorite prognostications that looked a little silly after the fact. The following are some of mine:

- In 1876, William Orton, president of the Western Union Telegraph Company, decided not to buy the rights to the telephone patent, with the comment: "What use could this company make of an electronic toy?" (S. Aronson, 1977).
- About 10 years later, in 1885, Arnold Morley, then Postmaster-General of Great Britain, told Parliament "the telephone could not, and never would be an advantage which could be enjoyed by the large mass of the people" (quoted by Marvin, 1988, p. 101).
- Late in the 19th century, Sir John Erichsen, a British surgeon, described the abdomen as "forever shut from the intrusions of the wise and humane surgeon." In 1930, George Moynihan, another British surgeon, judged it to be impossible to perfect surgery beyond its then-current state (Medawar, 1984).
- The 19th century Scottish mathematician and physicist, William Thompson (Lord) Kelvin ruled out the possibility of flight in heavier-than-air craft (Hardin, 1985). Early in the 20th century, the American astronomer Simon Newcomb did so, too: "The demonstration that no possible combination of known substances, known forms of machinery and known forms of force, can be united in a practical machine by which man shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be" (quoted in Clarke, 1962).
- In 1926, American radio pioneer Lee DeForest made the following assessment of the prospects for the commercial exploitation of television: "While theoretically and technically television may be feasible, commercially and financially I consider it an impossibility, a development of which we need waste little time dreaming." This pronouncement (p. 207) is one of many compiled by Cerf and Navasky (1984) in a compendium that makes for delightful, but somewhat sobering, browsing.
- As late as 1936, Ernest Rutherford ruled out the possibility of the use of nuclear energy, at least in this century (Eiseley, 1970).

Inventors of technologies that have changed the world typically have not foreseen the eventual uses of their inventions. Marconi, for example, saw radio not as a means of broadcasting speech and music to a wide audience, but

as a wireless analogue to the telegraph and, in particular, as a means of providing point-to-point communication between one ship and another and between ship and shore. The American corporations that initially invested in radio also failed to see its potential as a qualitatively new form of communication and, treating it like a wireless telegraph, nearly went out of business as a consequence. The idea of using radio for broadcasting, in the modern sense, grew out of the activities of amateur ham operators whose numbers increased rapidly during the first decade or so of the 20th century. The amateurs used the radio for one-to-one communication, and many of the turn-of-the-century predictions about the future of radio assumed this to be the natural and continuing mode of operation. By the second decade of the century, however, amateur stations had begun to broadcast music and speech, and some of these stations became commercial in the 1920s (Douglas, 1986). As late as 1922, however, Thomas Edison predicted that the radio craze would die out in time (Cerf & Navasky, 1984).

Similarly, the pioneers of computer technology saw their creation, for the most part, as a device for mechanizing the arithmetic operations that were then being performed by cadres of human "computers." The then-current ideas regarding what these machines could do came primarily "from looking at the new invention strictly in the context of what it was replacing: calculating machines and their human operators" (Ceruzzi, 1986, p. 194).

These examples of views of the future were all too conservative in some way. One can easily find examples of views that erred on the side of extravagance as well. Often in the past, inventions and other scientific developments have prompted visions of idealistic and utopian change. The July 1899 issue of *Scientific American* carried the following prediction of how motor cars would affect urban life once mass production had brought their price low enough for people to acquire them: "The improvement in city conditions by the general adoption of the motor car can hardly be overestimated. Streets clean, dustless and odorless, with light rubber-tired vehicles moving swiftly and noiselessly over their smooth expanse, would eliminate a greater part of the nervousness, distraction and strain of modern metropolitan life" (Dubos, 1970, p. 95).

Most of us today, being sensitive to the automobile's contribution to air and noise pollution and aware of the nervousness, distraction, and strain that can be caused by the all-too-common urban traffic snarl, are likely to see only irony in this turn-of-the-century vision, but we should give the motor car its due. Citing some calculations made by Montroll and Badger (1974), and some plausible assumptions about a horse's per diem travel range and its solid and liquid waste generation, Ausubel (1989) has pointed out that a horse emits roughly 940 g of waste per mile, to the ground, whereas an automobile puts out only about 5 g (composed of .25 g of hydrocarbons, 4.7 of carbon monoxide and .4 of nitrous oxides) to the air.

There were many utopian visions, stimulated by the discovery in the middle of 20th century of the possibility of harnessing nuclear energy, of "power too cheap to meter," and of atomically powered airplanes and personal vehicles (Del Sesto, 1986). Work on the development of a nuclear-powered aircraft was carried on seriously for some years between 1946 and 1961, and was terminated by President Kennedy only after expenditures of more than $1 billion. Nuclear enthusiasts saw the potential benefits of nuclear energy but failed to foresee the problems—such as safety hazards and the disposal of radioactive waste—that would be encountered in attempting to realize that potential (Corn, 1986).

More generally, there was a good deal of utopian visionary writing late in the 19th century and early in the 20th based on what appears to have been an implacable faith in science and technology, coupled with a model of human nature not yet tarnished by two world wars and the major economic depression in between. Segal (1986) pointed out, for example, that "between 1883 and 1933, twenty-five individuals published works envisioning the United States as a technological utopia" (p. 119). Although most of the writers of these utopian visions were obscure, their values were representative of mainstream American thinking and in particular of the "belief in the inevitability of progress and the belief that progress was precisely technological progress" (p. 121).

Attempting to forecast the country's energy needs, or the way the needs would be met, has proved so far to be a particularly risky enterprise. According to a prediction by the Atomic Energy Commission in a 1962 report to the President on civilian nuclear power, by the year 2000, 30% of the demand for energy in the United States would be supplied by fission reactors. A report from the Interdepartmental Energy Study Group, issued in 1964, asserted "no ground for serious concern that the nation is using up any of its stock of fossil fuel too rapidly; rather there is the suspicion that we are using them up too slowly (A. M. Weinberg, 1988–1989). We are concerned for the day when the value of untapped fossil fuel resources might have tumbled and the nation will regret that it did not make greater use of these stocks when they were still precious" (quoted by A. M. Weinberg, 1988–1989, p. 81).

Thus one easily finds examples of past views of the future that were much too conservative in specific respects and examples of others that were, in retrospect, too radical. My sense however, is that, especially during recent years, we have been more often surprised by the ways in which technological advances have out-distanced our imaginations than by the ways they have lagged behind them. In any case, if the past gives us any clues at all as to what the future holds, the one thing that we can be quite sure of is that there will be surprises. No matter how carefully we try to anticipate all the possibilities, some of the most significant developments are very likely to be those that no

one foresees. As C. Evans (1979) has pointed out, Alvin Toffler in his book *Future Shock,* which was published in 1970, painted a sufficiently radical picture of the near-term future that the book was criticized for being sensationalist, but he missed completely what has turned out to be among the most sensational of all developments—the microprocessor—and it came along within a very few years of the publication of the book.

In short, projections are just that; they can, and often do, prove to be wrong. We should, in keeping with Kay's admonition, be especially wary of projections that are based on simple extrapolations of past trends. None of the numbers in this book that refer to the future should be taken as more than somebody's opinion as to what is likely to happen. Before using any of them as the basis for decision making, one should have thought deeply enough about them to have an opinion of one's own as to their plausibility. Even numbers that are intended to represent historical data should not be accepted completely uncritically. The techniques by which such numbers are developed or derived are not error-proof; they often involve assumptions that are not made explicit, and different sources sometimes report different numbers for the same variables.

If the point needs illustration with a concrete example, a recent study by the National Research Council's Committee on National Statistics revealed that the number of scientists and engineers in the United States in 1984 was 1.9 million, 3.7 million, or 6.1 million, depending on whether one used the figures of the Bureau of Labor Statistics, the National Science Foundation, or the Bureau of the Census (Citro & Kalton, 1989). The discrepancies stemmed from various differences in counting policies—whether to count people with degrees in science or engineering who were working as managers or people with degrees from foreign institutions—and in sampling and measurement techniques. The Committee's study provides an unusual opportunity to compare estimates from three sources and it points up the importance of looking critically at the counting or estimating processes that produce any number on whose accuracy one wishes to depend.

Sometimes what appear to be discrepancies may be the result of sampling over nonidentical time periods or from different populations. What population is being described is not always clear in the way numbers are reported; counts that underlie unemployment statistics, for example, may or may not include unemployed people who, for one reason or another, are not actively looking for jobs. Despite these caveats, my general sense is that, although there are some discrepancies in the historical data in what follows, they do not, for the most part, negate the major points that are made.

There are, of course, many possibilities for the future that could have truly profound effects, should they occur: a world-wide economic depression, the discovery of intelligent extraterrestrial life, a natural disaster of global magnitude (such as collision with a sizable meteor), or an AIDS-like

world-wide epidemic caused by a new virus transmittable by casual contact. Although such possibilities cannot be ruled out, no attention is paid to them here. Discussion of every imaginable event that could affect the future in a major way is clearly impossible and would not be very useful in any case; attention is limited here to what seem to me to be both reasonably likely possibilities and possibilities about which something can be done. My selection of topics on which to focus undoubtedly reflects my personal interests and biases, to a certain degree; I believe the topics included are especially significant for the future, but I do not wish to suggest that they are the only important ones. I have made no attempt to deal with ideological variables—philosophical, religious, or political—despite their obvious importance as causal factors in shaping local, national, and international events. Such variables lie farther outside the domain of human factors, as traditionally delimited, than any of those I have included, and some readers may consider a few of the latter already over the edge.

I had difficulty deciding how to organize this book. The problem is the interrelatedness of the topics discussed. Issues relating to energy and those relating to the environment are inextricably interwoven, because energy production and use are major causes of environmental problems and problems of the environment have profound implications for the cost—both present and deferred—of energy production and use; one cannot say much about economics without mentioning energy; further, any extended discussion of economics, energy, or the environment must, sooner or later, bring in transportation; one can hardly get started on a discussion of work, especially office work, without saying something about computer and communication technology. Growth in productivity is dependent in part on the availability of capital for investment in plant and equipment resources, the availability of capital is dependent in part on budget deficits which are affected by international trade balances, and so on. The organization that was finally adopted has a considerable degree of arbitrariness in it. It proved to be impossible to discuss any one of the selected topics without involving several others. Thus, some material in a given chapter could just as well have appeared in one or more of the other chapters, but I know of no way to avoid that, given the degree to which the topics overlap.

2

Economics, Industry, and Productivity

The U.S. economy has been the strongest and stablest economy in the world for many decades. Its continuing strength, stability and long-term growth are now threatened by a large federal deficit, an adverse balance of trade, and the country's recently acquired status as the world's leading debtor nation. The large deficit, coupled with a relatively low rate of private savings, means the country is dependent on foreign capital for investment in the new plants and equipment needed for economic growth. A continuing deficit probably means a weakening of the U.S. economy in a variety of ways. As D. Lewis, Hara, and Revis (1988) put it: "If continued over the long run, large budget deficits will either reduce domestic investment or be financed by increasingly uncertain, and potentially reversible, capital inflow from abroad. In either case, living standards of U.S. citizens would fall: a reduced level of investment would retard the growth of the economy, and continued heavy foreign investment would send a larger share of U.S. output abroad in payment of debt service or other returns to foreign investors" (p. 46).

The United States' position in the world economy is determined, to a large degree, by its ability to produce goods and services that can compete effectively in world markets, and this ability has been challenged severely in recent years. Our debt and trade balance depend on how what we consume relates to what we produce, and at the present time we appear to be better at consumption than at production. A simple extrapolation of current trends gives a picture of the future that is not very comforting. Changing the current course is certainly possible; whether we will do so is anything but certain.

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WORRISOME ECONOMIC INDICATORS

As of 1986, the total public and private debt in the United States was over 200% of the gross domestic product (Landau, 1988). Due in large measure to the explosion of corporate debt—symptomized by junk bonds and leveraged buyouts—in the 1980s, the value of all debt issued by nonfinancial U.S. corporations now exceeds $2 trillion. This compares with a total market value for all U.S. corporations of $2.4 trillion (Dentzer, 1989). The total governmental debt (federal, state, and local) as of 1987 was $3.1 trillion, or about $12,600 per person; the federal debt accounted for about 77% of the total. The situation has worsened by more than a factor of two since 1980, when the total governmental debt was $1.25 trillion, or about $5,500 per person (Bureau of the Census, 1990). The federal debt tripled and the interest on it quadrupled during the decade of the 1980s (Nathan, 1991).

The U.S. balance of trade dropped steadily through most of the 1980s. The drop was precipitous for manufactured goods other than high-technology products; for high-technology products, the balance went negative in 1986, for the first time ever. (Although the total trade balance was still negative at the end of the decade—by about $100 billion—the balance at that time was again positive for high-technology products.) The interpretation of trade balance figures is complicated by the fact that they are influenced by changes in currency exchange rates, but a persisting trade deficit means that the United States is consuming more than it is producing (i.e., spending more than it is earning), a trend that cannot continue indefinitely. Landau (1988) summed it up this way: "The U.S. has been consuming too much, producing too little, and borrowing from abroad to maintain its standard of living" (p. 52). Hatsopoulos, Krugman, and Summers (1988) argue that the answer to the trade deficit must include some slowdown in the growth of national consumption, and that to ensure the future strength of the economy the United States must begin to produce more than it consumes.

Since 1960, the average annual rate of growth of the U.S. economy (3.1%) has been less than the average annual rate of growth of the world economy (3.9%; W. B. Johnston & Packer, 1987). Landau (1988) estimated 2.2% as the annual growth rate of the United States' real gross domestic product (GDP) since 1979, as compared with Japan's annual GDP growth rate of 3.8% during the same time period. Thurow (1987) gave 3.8% per year as the rate of growth of the gross national product of the United States in the late 1960s and 2% per year in the early 1980s, noting that it decreased by nearly 50% over a decade and a half. (*Gross national product* [GNP] is the total national output of goods and services valued at market prices; *gross domestic product* [GDP] is the output of all labor and property located within a country [Bureau of the Census, 1990]. For present purposes, the distinction is not important.)

D. Lewis et al., (1988) project a growth rate of about 2.6% per year, on

average, over the quarter century from 1988 to 2013, which they consider insufficient to sustain the current U.S. standard of living. P. O. Roberts and Fauth (1988) see the GNP growing at about 2.3% per year until the turn of the century, and trending down to 2.0% approaching 2020. In the aggregate, these figures support the conclusion that the rate of growth of the American economy is currently lagging somewhat behind that of the world economy and the expectation that it will continue to do so for the near-term future at least. This means that our share of the world economy is on the decline and is likely to continue to be so.

Among the economic statistics that I find the most disturbing are those that appear to indicate a growing concentration of wealth in fewer and fewer hands. The proportion of total income in the United States that is going to the least affluent segment of the population (the bottom 60%) has been decreasing over the past couple of decades, while the proportion going to the most affluent segment (the top 20%) has been increasing. Excepting homes and real estate, 54% of all net financial assets in the nation are owned by the top 2% of all families; 86% of these assets are owned by the top 10% of all families; the bottom 55% of families have zero or negative financial assets (Thurow, 1987).

An increasingly visible and troublesome indication of the plight of people at the bottom of the distribution is the homeless population. Homelessness is a problem of growing proportions in the United States, although estimates of the number of people who are homeless vary over a very large range (from a quarter of a million to 3 million; Rossi, 1989). Whatever the correct number is, it is unacceptably large. The problem, undoubtedly, is more complex than is generally believed. Researchers do not entirely agree on what would constitute effective approaches toward solving it, but until more effective approaches are developed, the problem will remain a shame to the nation.

The robustness of an economy is a complex function of many variables. Especially important among those variables, however, is the efficiency with which goods and services are produced. When it costs more to produce goods and services domestically than to import them, the balance of trade suffers and the growth of the local economy is slowed. Human factors research aimed at increasing productivity is obviously relevant to this problem. Moreover, productivity can influence standard of living in two ways: When the productivity of one country increases relative to that of others, that country's products become more competitive on world markets; and increases in worldwide productivity mean more goods and services available generally for the same cost. We shall return to the topic of productivity shortly, because of its importance to economic well-being and its appropriateness as a target of human factors research.

Perhaps the other single most important determinant of the economic

well-being of a country, according to many economists, is consumption. Consistent consumption by a population of more than it produces requires an outflow of cash, which cannot be sustained indefinitely by the selling of assets or by borrowing. The modification of consumer behavior, at either the individual or national level, has not been viewed traditionally as within the human factors domain. Perhaps the field has nothing to offer with respect to this aspect of the problem; on the other hand, the problem is related to other issues (e.g., manufacturing for durability and maintenance versus planned obsolescence) that are of interest to the field.

COMPETITIVENESS

Seventy percent of the goods produced in the United States compete directly with goods produced abroad (President's Commission on Industrial Competitiveness, 1985). Competitiveness in world markets is determined by the relative prices of the goods to be sold. Because labor represents a large fraction of the costs that must be recovered, an economy with relatively high wages will be competitive only if the productivity of the wage earners is commensurately high. Competitiveness is clearly related to balance of trade, but it should not be equated with it, inasmuch as it is possible to have a trade surplus and still be in poor shape financially, especially if the surplus is needed to service debt. The proper test of competitiveness is a country's ability to balance its trade while achieving an acceptable rate of improvement in its standard of living. It is possible to have either a positive balance of trade at the expense of a decreasing standard of living or an increasing standard of living at the expense of a negative trade balance, for a short time (Hatsopoulos et al., 1988).

The President's Commission identified four causes for the recent decline in U.S. competitiveness: failure to develop human resources as well as other nations, inadequate incentives for saving and investment, trade policies not adequate to today's international commerce, and shortcomings in commercialization of new technology. Other factors that can contribute to competitiveness are restraint in consumption (a willingness to live somewhat more frugally) and a strong work ethic (L. R. Klein, 1988).

The failure of the United States to develop its human resources as well as other countries is a particularly bothersome conclusion from the Commission's study. At the present time, the number of engineering doctorates awarded in the United States to non-U.S. citizens exceeds the number awarded to U.S. citizens, a fact that prompted W. E. Massey (1989) to observe that the country's "trade deficit" extends not only to goods and services, but to human capital as well. Although the problem of human resource development does not seem to fit comfortably within the domain of

human factors, as usually conceived, the question again arises as to whether the human factors community can address it. I return to this question in discussing education and training.

The problem of inadequate saving and investment in the United States is closely related to that of overconsumption. Currently, the United States saves about 2% of its national income, compared with an average of 11% among other industrialized countries. The overall net savings rate in the United States has decreased from 7.9% in 1970–1979 to 2.1% in 1985–1987; the personal savings rate was 3.2% in 1987, compared to 8.0% in the 1970s (Dentzer, 1989). Hatsopoulos et al. (1988) argue that there is no reason to believe the United States can remain a first-rate economy unless it has an average savings rate close to that of its competitor nations. The situation is compounded by the fact that a significant percentage of savings are used, via the purchase of U.S. Treasury securities, to service the national debt and are therefore not available for investment in new business development. Investment in U.S. industry, therefore, is being financed to an increasing extent by foreign capital.

Complicating the problem of the low rate of personal saving in the United States is the scandalous mismanagement of a large segment of the banking industry. In 1987, the General Accounting Office's annual audit of the Federal Savings and Loan Insurance Corporation, which insures thrift institution deposits up to $100,000, found it to be insolvent. The federal financial exposure from the thrift industry was estimated to be $30 billion, a figure which now appears to have been low by an order of magnitude or more. According to the General Accounting Office (1987a), the problems with the nation's lending institutions developed over time as a consequence of institutions being allowed to hide, or delay recognition of, certain losses and to continue to operate with insufficient capital. The long-range implications of these problems for the economy, and of deeper troubles they may hint at, are not yet clear.

That the problems that have surfaced in the finance industry may be symptomatic of deeper troubles in the U.S. economy is a serious worry. Indicative of this possibility is what some observers see as the squandering of an unquantified, but probably large, percentage of the country's intellectual energy and other resources on a variety of financial games—what R. B. Reich (1983) called "paper entrepreneurism"—in which one wins by increasing one's personal wealth or improving a corporation's near-term earnings statements, but contributes nothing to the nation's productivity or the general standard of living.

One of the most striking aspects of the troubles that surfaced in the banking industry during is the extent to which they caught the American public, as well as many business people and financial professionals, by surprise. Was this because of a general lack of understanding of how the

industry works? Was it because of the unavailability or inaccessibility of data that would have pointed to the fact that a serious problem was building?

What could be developed by way of information systems that would provide the average person with the kind of information needed to make enlightened decisions about savings and investments? One can imagine systems that would provide information, at various levels of detail, regarding investment options available to individuals with specific interests and assets. They would indicate not only what was available, but what the risks and contingencies would be in each case. Design, implementation, and evaluation of such systems would involve a variety of human factors issues relating not only to information representation and presentation but to such methodological issues as how to determine whether the information made available is understood well enough to be the basis for decision making.

MANUFACTURING

Manufacturing in the United States is also in trouble (Office of Technology Assessment [OTA], 1990a, 1990b). U.S. manufacturers have been losing market share to foreign competitors in many areas: steel, automobiles, textiles, appliances. Even in the case of semiconductor production equipment, the market share held by the United States dropped from over 75% in the early 1980s to less than 50% ten years later. "The history of consumer electronics is a history of successive retreats by American firms, with the result that foreign manufacturers have won an entire market without ever having to fight a pitched battle" (Dertouzos, Lester, Solow, et al., 1989, p. 12). Global economic pressures are likely to force significant changes in the long-standing U.S. approach to industrial production:

> The industries in which the United States can retain a competitive edge will be based not on huge volume and standardization, but on producing relatively smaller batches of more specialized, higher valued products—goods that are precision engineered, that are custom tailored to serve individual markets, or that embody rapidly evolving technologies. Such products will be found in high-value segments of more traditional industries (specialty steel and chemicals, computer-controlled machine tools, advanced automobile components) as well as in new high-technology industries (semiconductors, fiber optics, lasers, oil technology, and robotics). (Reich, 1983, p. 13)

The U.S. steel industry is one of the most obvious cases of a highly capitalized mass-production operation that is struggling, having decreased its employment roster by 60% (from 500,000 to 200,000) between 1975 and 1987 and having lost $6 billion from 1982 to 1987 (Szekely, 1987). Szekely

suggested that hope for the long-term viability of this industry lies in its switching to the manufacture of novel high-value-added products that requires implementing innovative steel-making technologies for producing customized steels based on less energy- and capital-intensive processes. The products from such operations would acquire their value from the unusual processing involved.

R. B. Reich has warned that the organization of high-volume production is so different from that of flexible-system production that changing from the former to the latter will be difficult, but necessary. Others also have stressed the need for flexibility to enable a quick response to changing consumer tastes and facilitate the rapid application of new industrial technologies if this industry is to maintain competitiveness in the international arena (Cyert & Mowery, 1989; Landau, 1988; Lawrence & Dyer, 1983; OTA, 1988c). The importance of flexibility becomes apparent when one realizes that probably over half of the industrial production in the United States comes from production lots of 50 units or less (N. H. Cook, 1975). Carried to an extreme, flexible-system production can become customized manufacture where one-of-a-kind items can be produced for individual consumers. This is part of the vision of some futurists (Toffler, 1980).

An often-cited study by Dertouzos et al. (1989) took a "bottom-up" look at eight sectors of American industry: automobiles; chemicals; commercial aircraft; computers, semiconductors, and copiers; consumer electronics; machine tools; steel; and textiles. The study focused explicitly on production systems and productivity in manufacturing. No attention was paid to services, agriculture, mining, or construction. The primary conclusion drawn by these investigators was that American industry shows "worrisome signs of weakness". Although they explicitly noted that there is no cause for despair, inasmuch as many American firms are doing very well indeed, they saw in their results, in the aggregate, symptoms of systematic and pervasive ills. In their view, problems with American industry cannot be remedied simply by putting more energy into past practices. "The international business environment has changed irrevocably, and the United States must adapt its practices to this new world" (p. 8).

The need for such adaptation appears to be gaining increasing recognition. A recent report from the OTA (1990a) characterizes how organizational patterns in American industry are changing in terms of a set of contrasts relating to production, personnel practices, job ladders, training, and overall corporate strategies; these are shown in Table 2.1. The two central themes of these changing patterns, according to the OTA report, are "(1) reorganizing production so that lot sizes can be smaller and production runs shorter with little sacrifice in efficiency, and (2) transferring decisionmaking authority downward and outward to semiautonomous divisions and/or the shopfloor" (p. 6).

TABLE 2.1 Changing Organizational Patterns in U.S. Industry

Old model	*New model*
Mass production, 1950s and 1960s	*Flexible decentralization, 1980s and beyond*
Overall strategy	
• Low cost through vertical integration, mass production, scale economies, long production runs. • Centralized corporate planning; rigid managerial hierarchies.	• Low cost with no sacrifice of quality, coupled with substantial flexibility, through partial vertical disintegration, greater reliance on purchased components and services. • Decentralization of decisionmaking; flatter hierarchies.
Production	
• Fixed or hard automation. • Cost control focuses on direct labor. • Outside purchases based on arm's-length, price-based competition; many suppliers. • Off-line or end-of-line quality control. • Fragmentation of individual tasks, each specified in detail; many job classifications. • Shopfloor authority vested in first-line supervisors; sharp separation between labor and management.	• Flexible automation. • With direct costs low, reductions of indirect cost become critical. • Outside purchasing based on price, quality, delivery, technology; fewer suppliers. • Real-time, on-line quality control. • Selective use of work groups; multi-skilling, job rotation; few job classifications. • Delegation, within limits, of shopfloor responsibility and authority to individuals and groups; blurring of boundaries between labor and management encouraged.
Hiring and human relations practices	
• Workforce mostly full-time, semi-skilled. • Minimal qualifications acceptable. • Layoffs and turnover a primary source of flexibility; workers, in the extreme, viewed as a variable cost.	• Smaller core of full-time employees, supplemented with contingent (part-time, temporary, and contract) workers, who can be easily brought in or let go, as a major source of flexibility. • Careful screening of prospective employees for basic and social skills, and trainability. • Core workforce viewed as an investment; management attention to quality-of-working life as a means of reducing turnover.
Job ladders	
• Internal labor market; advancement through the ranks via seniority and informal on-the-job training.	• Limited internal labor market; entry or advancement may depend on credentials earned outside the workplace.
Training	
• Minimal for production workers except for informal on-the-job training. • Specialized training (including apprenticeships) for grey-collar craft and technical workers.	• Short training sessions as needed for core workforce, sometimes motivational, sometimes intended to improve quality control practices or smooth the way for new technology. • Broader skills sought for both blue-and grey-collar workers.

From Office of Technology Assessment, 1990a.

What role automation will play in manufacturing in the future is a question that evokes much speculation. One thing that seems clear is that the nature of industrial automation is likely to change qualitatively. Robots with very limited versatility are used widely in high-volume operations (e.g., Unimate machines in auto assembly); it is expected that over the next few decades "smart" robots will become sufficiently versatile and inexpensive to be used in low-volume operations, as well. The goal of much current research on robotics and automation is to increase the flexibility of robotic devices so as to enhance the ability of manufacturers to respond rapidly to the changing demands of their markets (Wilfong, 1989). Abilities that robots are expected to have within the next few decades include: vision (sufficient to discriminate among various objects on an assembly-line conveyer belt or in a parts bin), mobility (permitting relatively free movement from place to place), much greater dexterity (grasping extremities modeled closely, in some cases, after the human hand with fingers, wrists, and many degrees of freedom of movement), and hand-off capability (selection of parts from a parts bin by a transporter robot, and delivery and hand-off to an assembler robot; Kinnucan, 1981).

In recent years, some attention from researchers has been given to human factors issues relating to manufacturing. Much of this work has focused on the control and operation of flexible and computer-aided manufacturing systems (Ammons, Govindaraj, & C. M. Mitchell, 1988; Hwang & Salvendy, 1984, 1988; G. I. Johnson & Wilson, 1988; Sanderson, 1989; Sharit, 1985; Sharit, Chang, & Salvendy, 1987; Wall, Clegg, & Kemp, 1987). Some of it has also focused on scheduling, which is especially important to manufacturing operations because inefficient use of either labor or equipment, and maintenance of unnecessarily large inventories of either parts or finished products, make for higher-than-necessary costs. According to Malone and Rockart (1991), the textile-apparel industry spends about $25 billion in inventory costs annually, about half of which might be saved through better coordination of the various activities involved in bringing clothing to the point of sale.

Sanderson (1989) has reviewed the literature on human scheduling and related it to the needs of modern manufacturing systems that use various degrees of automation for planning and scheduling purposes. Although attempts have been made to automate scheduling completely in some instances, and have human beings do it all in others, the evidence seems to suggest that most cases involving any significant degree of complexity are best handled by some combination of human and computer capabilities applied through an interactive system. Sanderson cautioned that generalizations based on the limitations of current scheduling algorithms could be invalidated as more adequate algorithms are developed, but she also noted that investigators tend to assume that interactive systems are unlikely to be replaced soon by fully automated ones and may be around indefinitely.

Manufacturing is, in my view, an aspect of U.S. industry on which human factors research could have a substantial impact, especially in view of the need for new and more flexible approaches to production and the increasing involvement of information technology in all aspects of production processes. Total automation is unlikely to be realized in many industries in the foreseeable future. What is likely is the increasing use of semiautomated and interactive processes in which people interact with semi-intelligent machines and systems in new and ever-changing ways. The types of problems that will have to be resolved to make flexible manufacturing systems truly cost-effective in today's world economy are precisely the kinds of problems on which human factors researchers have traditionally focused, although some of them are likely to appear in new forms.

MATERIALS

An area of very active research that could have far reaching implications for manufacturing in particular, and for the economy more generally, is that of materials science. A great deal of effort is going into the development of new materials and of methods for processing materials (OTA, 1988c), and this effort has resulted in considerable progress in understanding materials and their composition. The ability to control more accurately the chemical composition of materials, coupled with recently developed techniques for rapid solidification (bringing a material from a liquid to a solid state by lowering its temperature at rates of up to a million or even a billion degrees per second) provides an enormous range of possibilities for the development of materials with made-to-order characteristics (Chou, McCullough, & Pipes, 1986; Liedl, 1986; Steinberg, 1986). By controlling a material's microstructure, one can design that material to match the distribution of stresses that it is expected to endure. An increasing variety of new materials (ceramics, polymers, fiber composites, metal matrix composites) with made-to-order characteristics (high strength-to-density ratios, wear resistance, high or low electrical or thermal conductivity, flexibility) will become part of the array of "raw" materials for production and manufacturing.

The image of polymers (plastics), at one time associated with cheapness and goods of low quality, has changed for the better as these materials, sometimes reinforced with carbon fibers, are finding more and more uses in the production of ultradurable goods with many desirable properties. In 1976, plastics replaced steel as the nation's most widely used material. Now we use more plastics—over 10,000 varieties of them—than steel, aluminum, and copper combined (Childes, 1985). The production of plastics requires less energy than does the production of some of the metals they can replace;

unfortunately, plastics can cause serious waste management problems, about which more further on.

Interest in materials and how to make them more useful for specific purposes undoubtedly predates recorded history, but until recently, much of what was known about materials was based on empirical investigations, not on well-developed theories of atomic forces and energies (Slichter, 1988). The availability of supercomputers has helped the advance of materials science by making possible the kinds of calculations necessary to represent the atomic forces and energies within molecules and their implications for molecular structure and activity, and to represent the dynamics of collections of atoms or molecules. Computer simulation is proving to be an indispensable tool for synthetic chemists and materials scientists studying the interactions of materials at the atomic or molecular level. Such simulations allow researchers to observe on a computer display the motion of individual atoms as they interact in the growth of a crystal or the docking of a drug molecule at the receptor site of an enzyme. They permit chemists and materials scientists to see, literally, how the interactions of molecules depend on the details of their shapes. They also permit researchers to explore the consequences of adding, subtracting, shifting, or substituting atoms in synthetic materials without having to deal with the materials themselves (Goddard, 1988).

Composites currently being investigated include matrices of organic resins or metals with embedded high-strength fibers such as graphite, glass, or silicon carbide. (The use of carbon-epoxy composites to build Voyager, the first plane ever to fly around the world without refueling, gave it the ability to carry five times its weight in fuel and cargo [Childes, 1985]). Fibers of graphite, tungsten, or niobium may be embedded in copper to improve heat conduction; silicon carbide, silicon nitride, and aluminum fibers are being used to add strength to ceramics (Corcoran & Beardsley, 1990). In addition to providing high strength-to-weight and stiffness-to-weight ratios, such composites are typically resistant to fatigue and corrosion, can have a near-zero coefficient of expansion, and are relatively easy to mold into complex shapes (Economy, 1988). The integration of ceramic thin films with semiconductor technology is an active area of research that holds the potential for a new class of electronic devices with numerous applications in communication technology (Sayer & Sreenivas, 1990). The use of ceramics for a variety of purposes in industry has the attractive aspect that the elements from which ceramics are made are among the most abundant on earth.

Some scientists see the spectacular advances that are currently being made in materials science, especially with ceramics, composites, and semiconductors, as having profound implications for productivity and competitiveness in the world marketplace. One gets some feel for the potential of this impact from the fact that "on the average, every person in the U.S. requires the securing and processing of some 20,000 pounds of nonrenewable, non-fuel

mineral resources each year" (J. P. Clark & Flemings, 1986, p. 51). The OTA (1989a) has estimated that the value of components produced in the United States from advanced materials will grow from about $2 billion in 1988 to nearly $20 billion by 2000. It cautions, however, that whether the United States will lead the world in commercializing these materials, as it has in developing them, is uncertain.

The U.S. government spends about $170 million per year for research and development on advanced materials, more than is spent by any other nation. In the past, the United States has spent more on advanced materials research and development than Japan, West Germany, France, and the United Kingdom combined. The magnitude of its lead, however, has diminished. Between 1965 and 1986, the United States' share of the total research and development of the five countries just mentioned dropped from 69% to 55%. As of 1987, Sweden, Japan, and West Germany spent a greater proportion of their GNP on research and development than did the United States. About 70% of the U.S. expenditures (and 50% and 34% of the expenditures of the United Kingdom and France, respectively) went to defense-related projects; in Japan and West Germany, almost all of it (95% and 87%, respectively) went to nondefense objectives (National Science Foundation, 1988). In addition, the United States has not been as aggressive as some other countries in initiating programs to commercialize the products resulting from this research (OTA, 1989a).

DEVELOPMENT VERSUS COMMERCIAL EXPLOITATION

The United States has led the world in developing new technologies, but it has been more effective at generating new knowledge than in applying that knowledge to the production of goods and services (Cyert & Mowery, 1989). It is in a very strong position in the science of high-temperature superconductivity, for example, but is not pursuing commercial applications very aggressively (Institute of Electrical and Electronics Engineers, 1988; OTA, 1989a). There is a great deal of concern, both in the government and in industry, that the United States will lose the race in the development and commercialization of high-definition television (HDTV), primarily because it is not running very hard (C. Norman, 1989). A variety of efforts to promote industry–government collaboration on the development of HDTV in this country have not met with much success so far (Corcoran, 1989).

The OTA (1989a) noted that similar observations can be made about many American industries. According to a recent report from the Technology Administration of the U.S. Department of Commerce (1990), by 2000 the United States will be behind Japan in most emerging technologies and behind Europe in several of them. Emerging technologies cited in the report include

advanced materials, semiconductor devices, artificial intelligence, biotechnology, digital imaging technology, flexible computer integrated manufacturing, high-density data storage, high-performance computing, medical devices and diagnostics, optoelectronics, sensor technology, and superconductors.

Starting new companies around new technologies is risky business in the United States. If one needs evidence of how difficult it is to predict how new technologies will fare in the marketplace, the carcasses of countless technology-based start-ups that did not make it to the second round of capital funding should provide it (although it is quite amazing how rapidly the visible remains of defunct companies can disappear from view). Established corporations that have decided to put large amounts of money into new technology-based ventures have also guessed wrong on occasion. Wright (1990b) points out, for example, that "Knight-Ridder sank $50 million into its Viewtron project before folding it in 1986, while the IBM-Sears joint venture, Prodigy, has gathered only 200,000 subscribers. Scholastic, Inc., lost millions in its first bout with educational software in the early 1980s. No one has cashed in on electronic banking either; years after its introduction, fewer than 100,000 people nationwide bank by computer" (p. 85). What the government's role should be in nurturing the development of new high-technology industries has been, and continues to be, a matter of considerable debate (Corcoran, 1990b).

Some economists have been pointing to the importance of chance and of positive feedback processes in the economy as important factors in determining the success or failure of new ventures. Such processes can magnify small effects, and help to lock in and amplify an initial advantage that some product or nation has gained over competitors, perhaps strictly by chance. According to this view, two competing products that are equally good may start life with small and equal claims on the market. Eventually one product will begin to get ahead of the other, possibly as a consequence of some chance event. Once it is in the lead, the lead itself becomes an advantage that tends to increase the distance between that product and its nearest competitor. Arthur (1990) argues that knowledge-based parts of the economy are more likely than resource-based parts (agriculture, goods production, mining) to be subject to such positive feedbacks. "Standards that are established early (such as the 1950's vintage computer language Fortran) can be hard for later ones to dislodge no matter how superior would-be successors may be" (p. 99).

Such effects undoubtedly occur and complicate greatly the task of predicting how specific companies or countries will do in the marketplace with respect to specific products or technologies. One expects these effects to distribute themselves more or less randomly, however, and they do not account for consistent and systematic trends such as the regular loss of market share by the United States to foreign competitors in a large number of emerging technology areas.

Human factors is closely identified with the problem of designing machines and equipment in such a way that they are safe to use and that the requirements of their use match well the capabilities of their intended users. Referring to a piece of equipment as "well human-engineered" usually means that the device is well-designed from the user's point of view. This is appropriate, inasmuch as a primary objective of human factors work has been to help ensure the safeness and usability of devices intended for human use. Less attention, however, has been given to the problem of designing production procedures and processes that will yield usable products and that will do so in ways that are both cost-effective and desirable from the worker's point of view.

Of the various ways in which human factors as a discipline could have a direct and significant impact on the U.S. economy, easing the way from technological innovation to market-worthy products would appear to be a high-leverage possibility. If the United States cannot produce products that compete effectively in world markets, the U.S. human factors community must ask itself to what extent it shares the responsibility for that failure. More importantly, it should see the current situation as an opportunity for impact.

MICROFABRICATION

The ability to make components ever smaller has been, perhaps, the most obvious trend in computer technology since its inception. A natural extension of the continuing progress in miniaturization is interest in the development of ultra-small machines: for example, machines that are sufficiently tiny that they can function inside human organs, blood vessels, or, conceivably, even single cells. According to a recent news article in *Science,* "in the 1990s one of the major themes of physics, chemistry, and materials science is likely to be the study of how matter behaves at a scale of nanometers—billionths of a meter. The ability to design and manufacture devices that are only tens or hundreds of atoms across promises rich rewards in electronics, catalysis, and materials" (Pool, 1990a, p. 26). Goddard (1988) notes that about one sixth of the U.S. GNP requires catalytic manufacturing processes and that, in the search for new catalysts for processing petroleum, which he refers to as the hottest field of catalyst research, molecular engineering has practically replaced traditional research methods.

With the development of the scanning tunneling microscope, it is now possible to see the individual atoms that comprise a material's surface. In April, 1990, two IBM scientists reported in *Nature* their success in positioning individual xenon atoms on a crystal of super-cooled nickel so as to spell out the IBM logo with a total of 35 atoms. Each letter was 50 angstroms in height and the distance between adjacent atoms in the display was about

12 angstroms (Eigler & Schweizer, 1990). A team of scientists from Belcore and AT & T succeeded recently in etching almost 2 million lasers in an area less than one square centimeter; others have succeeded in building devices that can transmit electrons one at a time (Corcoran, 1990d).

This domain of interest is sometimes referred to as *nanotechnology*. If Drexler (1986), who has written extensively on this subject, is right, the technology of ultra-small machines will be a serious enterprise, and people who are less than about 65 in 2020 will have a good chance, thanks to this technology and "cell repair machines" that can slow the aging process, of living in good health for a very long time. As it happens, silicon at the scale of microns is stronger than steel and consequently is a preferred material for the building of ultra-small machines. Inasmuch as silicon has been so widely used in the construction of integrated computer circuits, much has been learned about how to shape it into structures with micron and even submicron feature sizes. With certain extensions and modifications, the technology that has been used in the fabrication of integrated circuits is beginning to be applied to the production of microminiature sensors, motors, pumps, valves, resonators, and various other mechanical devices. At MIT, for example, a motor with a 100-micrometer-diameter rotor has been built using such techniques (Howe, Muller, Gabriel, & Trimmer, 1990; Stewart, 1990).

Materials research and microfabrication make extensive use of computer-based tools for simulation and visualization. The design of such tools involves all the usual human factors interface issues. It has the added dimension that many of the structures that have to be represented visually are too small to be seen "in the flesh." Some of them are too small to be resolved by visible light, so the question of what they would "really look like" if we could only see them does not have a straightforward answer. How to represent such structures and the processes involving them is often a matter of intuition. There is room here for some research.

For the most part, when human factors researchers have attempted to design interfaces that are well-matched to the capabilities and limitations of their users, these machines have been approximately—say, within an order of magnitude—the same size as their users. When this has not be true, they have tended to be much larger than their users: jet aircraft, ocean-going vessels, power generation plants. In these cases the interaction occurs through display and control panels that are close to their users in size. This fact has obvious implications for the design of displays through which information is provided to the users and controls through which users affect the machines. The emergence of nanotechnology and the appearance of ultra-small machines adds a new dimension to the problem of machine design from a human factors point of view. What issues of usability, safety, and comfort are likely to arise vis-à-vis machines that are too small to see? How will one be able to

tell whether a machine is functioning as it should? How will such devices be handled? Will there be problems of monitoring, repair, or replacement?

Perhaps the most significant effects the appearance of micromachines will have will be through their use as components in other machines and systems. Their proliferation will undoubtedly cause changes in the way familiar devices are constructed and operated. Just as microcomputers are beginning to appear everywhere—in automobiles, in cameras, in household appliances, in children's toys—so will micromachines, in time, surprise us with their many uses. What this will mean from a human factors point of view remains to be seen; what seems clear is that the development of this technology will broaden considerably the connotation of person–machine interaction and present some human factors problems that we can, at this point, only vaguely anticipate.

SERVICES

Future growth in the U.S. economy is expected to come more from the services sector than from manufacturing. Aggregate consumer expenditures on services have been increasing gradually but steadily since the mid-20th century. Some of the basic services that were traditionally provided at home by family members (e.g., care of children and the elderly) are now being purchased (OTA, 1989a). Service industries now account for over 70% of the GNP in the United States and about 75% of all jobs. From 1976 to 1986, services accounted for 85% of new private-sector jobs (Quinn, Baruch, & Paquette, 1987). Botkin, Dimancescu, and Stata (1984) characterized the economic changes that are currently taking place as a move from a capital-intensive, physical-resource-based economy to a knowledge-intensive, human-resource-based economy. The general shift from goods-producing to service-producing activities is a worldwide phenomenon (Klein, L. R. 1988).

Quinn et al. (1987) described the services sector as including "all economic activities whose output is not a physical product or construction, is generally consumed at the time it is produced, and provides added value in forms (such as convenience, amusement, timeliness, comfort or health) that are essentially intangible concerns of its first purchaser" (p. 50). They pointed out that it can sometimes be difficult to draw the line between products and services, because in many cases they are interchangeable (e.g., a home washing machine—a product, and use of a laundromat—a service), and the value of products often stems from the services they provide (e.g., transportation from an automobile, entertainment from a television set).

Manufacturing and product development are perhaps what come to mind first when one thinks of how human factors relates to the economy, because they suggest machines and devices; and the interaction of people with

machines and devices has been a central concern of human factors research. In fact, a great deal of the work done by human factors researchers in the past has had at least as much relevance to service industries as to manufacturing and production. Problems pertaining to the layout and lighting of workspaces, the design of visual display terminals, the readability and intelligibility of instructions and printed forms, the effects of stress of various types on human performance, the development of decision-making aids, the study of human error in supervisory control situations, and numerous other subjects are encountered in the service sector as well as elsewhere, and research addressed to these problems has many applications in service industries.

The growing importance of services, as distinct from products, to the U.S. economy, and indeed to the world economy, should motivate even more thought on the question of how human factors know-how can be used to help improve the performance of the service sector. There must be many human factors issues pertaining to services that deserve attention and that represent opportunities for improvement. The challenge is to identify them and to develop the approaches necessary to work on them effectively. As the fraction of the population that is employed by service industries continues to grow, issues of job satisfaction in these industries will become increasingly important as well.

PRODUCTIVITY

A general answer to the question of what the human factors community might do to help improve the U.S. economy—or some sector thereof—is anything that would increase productivity. There appears to be a broad consensus (a) that the United States must improve its productivity if it is to stay competitive in world markets and (b) that only if productivity is increased globally will there be any hope of improving the standard of living everywhere.

Productivity is one of those words that most of us probably believe we understand until we have occasion to try to say precisely what it means. As applied to the production of material goods, productivity is usually expressed as a ratio, for which the numerator is some measure of output (what is produced or the value of same), and the denominator is some measure of input (what is used up in the production process or the cost of same). In theory, the same ratio may pertain when what is produced is a service or other intangible good, but in practice, quantification can be very difficult because of uncertainty about what exactly gets consumed in the production process or about what the "product" is really worth.

Closely related concepts are those of *effectiveness* and *efficiency*. A productive individual, system, industry, or nation is one that gets the intended job done

with a minimum of wasted resources. If whatever one produces has value, increasing the efficiency of one's production is tantamount to increasing productivity. Whenever it is possible to accomplish the same task with fewer resources or to get more done for a given cost, we would probably say that productivity has increased. It suffices for our purposes to settle for this connotation of *productivity,* vague though it may be. In what follows, the word appears in a variety of contexts and undoubtedly does not always have precisely the same connotation. I pass it on as I found it, and assume that the intended meaning is usually adequately clear.

Input variables relevant to estimates of industrial productivity include labor, capital, energy, and materials. When focusing on competitiveness, profit margins constitute another factor in the equation, because they contribute to product prices. One definition of *labor productivity* is "the total market value of all goods and services produced, divided by the number of labor hours that went into the production process" (Baumol, 1989, p. 611), or dollars of output (adjusted for inflation) per hour worked. *Multi-factor productivity,* which takes into account inputs other than labor, is then defined as "the market value of total output divided by the market value of all pertinent inputs" (p. 611).

There seems to be broad agreement that a nation's productivity is a primary determinant of the general standard of living of its populace (Baumol, 1989; Hatsopoulos et al., 1988; L. R. Klein, 1988; Young, 1988). Some economists argue that the only way for the United States to deal effectively with the budget and trade deficits—which requires increasing savings and investment while reducing spending on consumption—without suffering a decrease in standard of living is to realize a greater rate of growth in productivity than it has in the recent past (Cyert & Mowery, 1989). Productivity per worker in the United States is expected by some observers to grow by about 1.4% per year, on the average, over the next quarter century, with a higher rate (3.4%) in manufacturing and a much lower one in the service industries (D. Lewis et al., 1988). D. Lewis et al. (1988) cite lower worker productivity as the greatest threat to the United States' long-term economic competitiveness and standard of living. (*Productivity* here is defined as GNP divided by the total number of people in the workforce.) A reversal of the recent trend and an increase in productivity in the service sector has been seen by some as the key to domestic economic growth in the future (Johnston & Packer, 1987).

SLOWING PRODUCTIVITY GAINS

The United States leads the world in overall economic output, as measured by GDP per employed person or by output per worker hour; however,

several countries have been increasing productivity faster than the United States has since the 1950s, and, as of 1987, some of them had closed the gap considerably (Bureau of Labor Statistics, 1988a, 1988b). It has been claimed, for example, that between 1950 and 1983 the output per hour of U.S. workers increased by 129%, whereas that of Japanese workers increased by 1,624%; the increase in the productivity of Canadian, French, and West German workers fell between these extremes (Johnston & Packer, 1987). According to Thurow (1987), the rate of increase in productivity declined from 2.7% per year for the period from 1960 to 1970, to 0.9% per year from 1979 to 1985. Hatsopoulos et al. (1988) give 2.2% as the annual rate of growth in productivity between 1973 and 1985, compared with 3.8% for the period 1960 to 1973. They cite the annual rate of increase in output per worker as 0.3% and 1.9% for the same respective periods. Dertouzos et al. (1989) claim that increases in U.S. labor productivity averaged slightly under 3% from 1948 to 1973, a little over 0.5% from 1973 to 1979, and about 1.5% from 1979 to 1986. Small differences, they point out, can have very large cumulative effects: Had labor productivity continued to increase at 3% per year during the 1970s and 1980s the United States economy would now be almost 50% more productive than it is. The recent history of multifactor productivity, according to their estimates, is similar to that of labor productivity, averaging about 2% from 1948 to 1973, and going almost to 0% between 1973 and 1979. From 1979 to 1986 it bounced back up to roughly 0.5%.

Although most of the writing about recent trends in productivity in U.S. industry has been gloomy and much of it startlingly pessimistic, a more optimistic picture has been painted by Baumol (1989), who argues that despite legitimate grounds for concern, the situation is not ominous. Slowdown in productivity growth, particularly after 1965, has been universal in the industrial world and "probably attributable in good part to the exhaustion of the opportunities for spectacular productivity gains that had accumulated during the Great Depression and World War II" (p. 612). It is true that the productivity of most major industrial countries has been growing faster than that of the United States in recent years, Baumol argues, but this is mostly a matter of their playing catch-up. Given the ease with which technology can now be transferred between countries, it is to be expected that the productivity of leading industrial economies will converge, so that those that started behind will increase at a greater rate until they catch up. No other country has yet surpassed the United States in overall productivity level, he contends, and none is likely to do so in the near future.

As welcome and refreshing as this relatively optimistic view is, it is not a great source of comfort, because it fails to reflect what many economists who are writing about productivity are saying, and because among the factors that Baumol considers the determinants of productivity are some with which the

United States appears to be having considerable difficulty. One in particular, which is discussed further in chapters 5 and 11, is the skill and training of the country's labor force. Dale (1991), who, like Baumol, is generally optimistic about the U.S. economy and its prospects, also sees the problem of public education as a "potentially menacing" threat if not dealt with adequately, because of its implications for the quality of the future workforce.

In comparing productivity estimates from various sources, one is struck by the considerable differences among them, or at least by the appearance of such differences. Such a comparison is complicated both by the use of different time periods by different writers and by the uncertainty, in some cases, as to what type of productivity (e.g., labor, multifactor) is involved. What is significant is the general agreement among the estimates as to the slowing of the rate of productivity increase in the United States over the past few decades, especially relative to what has been happening on the world scene. Dertouzos et al., (1989) point out that a decline in productivity was experienced by every advanced industrial country beginning around 1970. What is most disquieting to U.S. economists is the fact that the United States has been trailing all other industrial countries in productivity growth since about that time. There are also indications that the country is not doing as well as it should with respect to the quality of its products and services or the speed with which its products are developed.

There is considerable variation in productivity growth from industry to industry and in many cases this growth has been negative in recent years. Manufacturing productivity growth increased sharply over the very recent past going from about 1.5% and 0.5% for labor productivity and multifactor productivity, respectively, during the 1973 to 1979 period to about 3.5% and 2.5%, respectively, during the 1979 to 1986 period. This is an encouraging development, but as Dertouzos et al. (1989) point out, the improvement was obtained, in part, by shutting down inefficient plants and laying off workers. By their calculations, the loss of jobs accounted for about 36% of the improvement in labor productivity. Also, because the improvement followed a recession, which is the normal course of events as factory output is increased to take up slack in the economy, they question whether the improving trend can be sustained. Mishel (1988) has argued that the appearance of a substantial increase in the output of U.S. manufacturing since 1973 is largely an artifact of an erroneous downward adjustment made to government statistical data on output and productivity in 1973.

Although many economists seem to take as a given the low productivity of the service sector relative to that of manufacturing, Quinn et al. (1987) concluded from a 3-year study that they should not do so. They noted that many service industries are as large-scale, as capital-intensive, and as grounded in technology as is manufacturing, and argued that technology, properly applied, can enhance the productivity of the service sector as it has that of

manufacturing. They also pointed out the need, however, to be cautious in interpreting aggregate productivity data about services.

The more productivity figures one sees, the more likely one is to despair of getting a clear picture of productivity trends in which to put great confidence. In the aggregate, however, such figures provide a fairly strong signal that all is not well in this area. Increasing productivity in all economic sectors is among the major challenges facing the U.S. economy, and, indeed, the world economy, in the foreseeable future. An attractive aspect of the goal of improving productivity is the fact that success is not necessarily realizable only at someone else's expense. To be sure, more efficient production can result in greater competitiveness in specific marketplaces because it permits the selling of goods and services at lower prices, but in a larger frame of reference, it makes goods and services more widely available to consumers at relatively lower prices. Increased productivity, in the sense of more efficient, less wasteful, use of energy and other resources, is, in the long run, good for everybody; it is the best hope of being the rising tide that can lift all ships.

Finding ways to increase the productivity of individuals, systems, corporations, or other entities is an appropriate concern for human factors researchers and an objective that the human factors community is in a position to help attain. Germane to this issue are research studies on human capabilities and limitations; the cognitive, perceptual, and motor demands of tasks that people perform; motivation; physiological state; training; the way functions are allocated to people and machines; the design of machines (and especially person-machine interfaces); organizational and scheduling factors; and social and interpersonal variables that help define the character of the workplace.

Closely related to the issue of productivity is that of the quality of jobs. It is possible to increase the productivity of an industrial system or of an industry at the expense of degrading the quality of the individual worker's situation. From the human factors point of view, this is a poor trade. The objective should be to increase productivity and simultaneously enhance job situations, or at least not downgrade them.

DETERMINANTS OF PRODUCTIVITY

Determinants of productivity, according to Baumol (1989), include the "country's flow of inventions and innovations, the rate at which it learns to benefit from the flow of technology contributed by other economies, the rapidity with which it increases the capital stock per worker (including the plant and equipment at the worker's disposal), the skill and training of the country's labor force, and the incentives provided for the productive activities of entrepreneurs" (p. 614). Among the generally recognized causes of low

productivity are failure of the government and industry to invest adequately in research and development, with a consequent shortage of innovations in the production process; failure to provide workers with adequate tools; inadequate training or motivation of the workforce; and inadequate quality control (resulting in wasted labor). Total private- and public-capital investment in plants and equipment and in infrastructure (highways, bridges, airports) in the United States in the late 1980s, came to about 14% of the GNP; the comparable figures for West Germany and Japan were 18% and 25%, respectively (Dentzer, 1989). Dentzer argued that this relatively low rate of capital investment, coupled with the fact that the U.S. labor force is expected to grow more slowly in the 1990s than at any time since the 1930s, bodes ill for American productivity in the future.

In its study of productivity in the United States, M.I.T.'s Commission on Industrial Productivity expanded the conventional notion of productivity to what it called *productive performance,* which encompassed "efficiency, product quality, innovativeness and adaptability, as well as the speed with which they [industries] put new products on the market" (Berger, Dertouzos, Lester, Solow, & Thurow, 1989, p. 40). This commission identified six "systematic weaknesses" that it considered to be hampering the ability of many U.S. firms to adapt to the changing international business environment:

- The use of outdated strategies: overemphasis on mass production of standard commodity goods and a parochialism that fails to recognize the worth of innovations originating elsewhere.
- Neglect of human resources: economically feasible in a system based on the mass production of standard goods where cost matters more than quality, but a serious problem when production requires flexibility in the workplace.
- Failures of cooperation, (within and among U.S. companies).
- Technological weaknesses in development and production: good at basic research, but poor at turning the results of that research into high-quality products that can compete in the market place.
- Government and industry working at cross-purposes, more so than in the countries that are our major competition.
- A short time horizon: preoccupation with short-term profits and steady growth in annual, or possibly even quarterly, earnings.

Technological innovation is seen by some economists as a primary vehicle for increasing productivity (Cyert & Mowery, 1989; L. R. Klein, 1988; Young, 1988). In the past, the application of technology in the workplace has typically had the effect of increasing the productivity of the individual worker. Perhaps the most striking illustration of this is seen in agriculture: In 1850, the average farm worker produced enough food for 4 people; now, with of the

application of technology, one farmer can provide enough for 78 people; the number of person hours needed to produce 100 pounds of cotton in the United States went from about 42 in 1945 to about .07 in 1975 (W. D. Rasmussen, 1982). The application of technology includes mechanization and the use of fertilizers and pesticides, as well as application of scientifically gained knowledge about crop rotation, irrigation, breeding, and hybridization. (Unfortunately, some farming innovations have had costs, in terms of damage to the environment, that were not anticipated; see chapter 4.) A similar effect has been obtained in mining where, as a consequence of mechanization, less than 1% of the U.S. labor force now suffices to produce more than 80% of the country's mineral needs (Marovelli & Karhnak, 1982).

Although mechanization has had unquestioned positive effects on productivity, it has not always been the case that the greater the degree of mechanization the better. In coal mining, for example, it has been found that mines mechanized to an intermediate degree operate more efficiently than either the least or the most mechanized ones (Marovelli & Karhnak, 1982). Determining the appropriate degree of mechanization or automation for any given process is likely to be a continuing challenge to industry. This is one form of the problem of function allocation, and there appears to be no general solution to it. This is a problem, however, to which human factors researchers have paid a great deal of attention in various specific contexts, and it is one that will become increasingly important as the possibility of automation, to varying degrees, becomes a reality for more and more activities, including many in predominantly white-collar businesses.

The United States economy has been making a very large investment in information technology, in the belief that it will increase productivity. Information technology should, for example, contribute to increased productivity through information systems that facilitate the timely manufacture and movement of supplies and products, thus mitigating the need to maintain large, costly inventories. Inventories, including material and supplies, work-in-progress, and finished products, represent an enormous cost to manufacturing operations. Any steps that reduce the need for inventories without introducing delays into the manufacturing process or resulting in the unavailability of goods for a ready market should have an immediate beneficial impact on productivity by lowering capital costs. Electronic communication systems are beginning to be used in some industries to shorten the feedback loop between retailers and manufacturers so as to minimize the production of goods that do not sell and otherwise tune the production processes more finely to the desires and preferences of consumers (Corcoran, 1990d).

Gunn (1982) has argued that the major opportunity for improved productivity in manufacturing lies not in the direct work of making or assembling a product, which accounts for a relatively small fraction of the total cost of manufacturing, but rather in "organization, scheduling and

managing the total manufacturing enterprise, from product design to fabrication, distribution and field service" (p. 115). The most important possible contribution to productivity of the factory from new information technology, he suggests, is the feasibility it represents for linking design, management, and manufacturing within a network of commonly-available information. "Information and the ability to transmit it quickly will come to be recognized as a resource as valuable as money in the bank or parts on the shelf" (p. 130).

Malone and Rockart (1991) made a similar point in observing that, unlike the industrial revolution, which was driven by changes in production and transportation, the revolution under way today will be driven by changes in coordination; furthermore, computers and computer networks, which make the coordination possible, "may well be remembered not as technology used primarily to compute but as coordination technology" (p. 128). In the office the use of information technology should increase productivity by reducing information "float," by making information more readily accessible to users when and where they need it (Giuliano, 1982).

In spite of these expectations, which seem very reasonable, numerous attempts to quantify the productivity gains that have been realized as a consequence of investment in information technology have yielded generally disappointing results. Although in some cases gains have been realized, in most they have not; in some instances productivity seems actually to have decreased. Attewell (1990), who reviewed the efforts to determine the effects of information technology on productivity, was careful to note that if it turns out that information has had no effect on productivity, in the sense of increasing the efficiency with which firms produce goods and services, it does not follow that it has left no mark on the world or on firms. Because it unquestionably has helped create new products and services that are bought in open and competitive markets, by definition, it has helped create value. There remains the interesting question, however, of whether the enormous investment that individual companies have made in information technology is paying off for those companies through resulting increases in either their productivity or their profitability. (Attewell pointed out that it is possible to increase profitability without increasing productivity; an increase in sales volume at a fixed level of productivity can generate an increase in profits. Similarly, an individual company can increase its profitability at the expense of competitors by getting a larger portion of market share, also without necessarily increasing the productivity of the industry or the nation as a whole. In this regard, Attewell warned that "if IT [information technology] investment is focused on the strategic goal of market share, and is shunted away from productivity-enhancing areas, the productivity stagnation currently experienced by American industry will continue" [p. 18].)

Attewell identified several mechanisms that could, in his view, negate or attenuate productivity gains that might be realized from the use of information technology. These include substituting slower channels of communication for faster ones (e.g., e-mail, which requires typing, for speech), the formalization of communication, the amount of time people must devote to learning to use new systems, increases in personal output that do not translate into greater cost-effectiveness for the firm (extra paper work or administration that does not contribute to improved corporate efficiency), and the expansive appetite of some managers for quantitative data that may or may not make for better managerial decision-making.

Clearly how the uses of information technology are affecting, or could affect, productivity requires more study. Among the questions that deserve attention are many of a human factors nature: What are the advantages and disadvantages of various methods of intracompany communication, and how does the answer to this question depend on the specifics of the communication situation? How should businesses go about determining what information their managers and other employees really need? (The assumption that managers need all the information they can get leads to very expensive management information systems that are wasteful of staff and other resources.) How can one distinguish between administrative procedures that contribute significantly to valid corporate goals and those that are simply consuming employees' time, or that are being done because of the illusion that technology makes them possible at no incremental cost?

White-collar productivity is of special interest and especially problematic. What is it? How should it be measured? How can it be improved? All of these questions lack definitive answers, but there is no lack of discussion of the subject. There seems to be general agreement among economists that, however defined and measured, white-collar productivity is not what it should be and the rate at which it has been increasing in recent years, in spite of office automation and its attendant wonders, is vanishingly small.

An inescapable conclusion of much of the discussion of white-collar productivity is that the ways in which specific business establishments are organized, the policies that guide their operations, the specific tasks that members of the organizations perform, and the ways in which they do them often lack any very clear rationale. Certain things are done, and they are done in certain ways, because of tradition, convention, or habit. Organizations, jobs, and tasks become self-perpetuating and the reasons for them, assuming there once were some, become lost. Too infrequently is it asked about any specific task, "What is its purpose? What important corporate objective does it serve? Who would suffer if it were not done?" Being busy is not necessarily the same as being productive, at least in any economically meaningful sense. Doing more efficiently something that should not be done at all is not

necessarily progress, especially if all the greater efficiency accomplishes is to permit one to do more of the same.

Underlying many of the questions that can be raised about productivity, within white-collar industries and elsewhere, is the need to be explicit about goals and about the extent to which specific policies, practices, and procedures do or do not serve them. Systems analysis techniques that human factors practitioners have applied in many contexts should, perhaps with some adaptation, be useful in making clear how information technology serves, or fails to serve, corporate goals in specific companies and how it contributes to or impedes their productivity.

ORGANIZATIONAL AND CULTURAL EFFECTS ON PRODUCTIVITY

Although organizational and cultural determinants of productivity are not well understood, there is little doubt that there are some. It is known, for example, that many organizations become more productive with experience, and that different organizations "learn" at different rates. Studies have focused on such variables as organizational forgetting (e.g., following a strike or other disruption), turnover, and the degree to which knowledge transfers across products or across organizations. So far, a completely clear picture of the relationship between such variables and productivity has not emerged (Argote & Epple, 1990). Whatever the organizational effects on productivity have been in the past, they may well change in the future if, as a consequence of greater ease of communication, predominantly hierarchical organizations evolve into structures that are more in the nature of networks.

Culture, as the term is applied to organizations, has been defined by Schein (1990) as "(a) a pattern of basic assumptions, (b) invented, discovered, or developed by a given group, (c) as it learns to cope with its problems of external adaptation and internal integration, (d) that has worked well enough to be considered valid and, therefore (e) is to be taught to new members as the (f) correct way to perceive, think, and feel in relation to those problems" (p. 111). Bair (1987) defined *culture* simply as "the common awareness among people that forms a collective understanding for perception of events" (p. 178). Cultures vary in strength and degree of internal consistency with such factors as the stability of the group, the length of time it has existed, and the strength and clarity of the assumptions held by the group's founders and leaders. Schein argued that culture will become an increasingly important concept for organizational psychology because without it, it is not possible to understand change or resistance to change.

Competitive pressures are forcing organizational and cultural change in many companies. Such change is intended to increase productivity by