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Technology Assessment and Environmental Engineering*

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ABSTRACT

This paper emphasizes the significant role environmental engineering must play in the resolution of the nation's social problems. The paper: (1) delineates the nature and significance of technology assessment, providing a preliminary definition of the assessment process; (2) examines the relationship of environmental engineering to technology assessment; and (3) considers environmental engineering and technology assessment within the wider context of conversion of the nation's technical talent and resources from defense to civilian oriented programs.

Introduction

The theme of this paper is that environmental engineering has a crucial role to play in the process of technology assessment; that by effectively fulfilling this role, environmental engineering can make a significant contribution to the current conversion of the nation's technical talent and resources from defense oriented programs to projects directed at society's besetting problems in areas such as pollution control, transportation, housing, etc. To understand the role of environmental engineering and its potential for contributing to the resolution of the nation's social problems, we must:

1. delineate the nature and significance of technology assessment;
2. examine the relationship of environmental engineering to technology assessment; and
3. consider environmental engineering and technology assessment within the wider context of conversion of the nation's technical talent and resources from defense to civilian oriented programs.

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Technology Assessment

Technology assessment is the process whereby society attempts to appraise existing and emerging technologies or technological systems in terms of their impact on the environment, the economy, and the society at large. As pointed out by the distinguished historian of technology, Melvin Kranzberg, "Technology assessment as a limited art is nothing new. Simple assessment . . . goes back to pre-history."[1] But in recent years technology assessment has assumed increasing importance and will probably continue to grow in significance to society in the years ahead. Problems such as pollution of the air through automobile exhaust, of the nation's rivers and streams through industrial waste discharge, and the pervasive, insidious spread of persistent pesticides all over the globe have served to focus public attention on the need to assess existing and emerging technologies in terms of their overall impact.

The concept of technology assessment has achieved its public prominence largely through the impetus of the Subcommittee on Science, Research, and Development, Committee on Science and Astronautics, U.S. House of Representatives. Over recent years this Subcommittee has held many hearings on technology assessment and has commissioned extensive studies on the subject by the National Academy of Sciences, the National Academy of Engineering, and others. In testimony before the Subcommittee, Dr. Lee A. DuBridge, the President's former Science Advisor, stated:

> "Increasing concern has developed over the deterioration of certain aspects of our quality of life. This deterioration has arisen from a number of sources. In some instances, life has been degraded or endangered as a result of unforeseen, deleterious side effects of progressive innovation. . . . In other cases, abusive practices . . . have impaired the quality of life. In still other instances, social trends have caused environmental quality problems. A strong desire has emerged to avoid, eliminate or minimize these undesirable effects. . . . Clearly, we have established the need and the desire for technology assessments."[2]

The key problems which must be resolved through technology assessment have been stated by the National Academy of Sciences Panel on Technology Assessment as follows:

- "How can we, in the United States, best begin the awesomely difficult task of altering present evaluative and decision-making processes so that private and public choices bearing on the ways in which technologies develop and fit into society will reflect a greater sensitivity to the total systems effects of such choices on the human environment?
- How can we best increase the likelihood that such decisions (domestically and, in the end, globally) will be informed by more complete understanding of their secondary and tertiary consequences, and will be made on

the basis of criteria that take such consequences into account in a timelier and more systematic way?

- How can we do these things without denying ourselves the benefits that continuing technological progress has to offer, especially to the less-favored portions of the human population?"[3]

Those interested in reviewing technology assessments that have been performed in the past should examine the report prepared by the Science Policy Research Division of the Library of Congress.[4] The report was originally submitted April 25, 1969, and reissued in revised form on April 15, 1971. Another useful compilation of past examples of technology assessments is contained in Appendix C to the Technology Assessment Hearings before the Science Subcommittee in November and December, 1969.[5]

The National Academy of Engineering's Committee on Public Engineering Policy has carried out a pioneering project in an attempt to develop methodologies for the performance of technology assessments. In this experimental effort, the National Academy of Engineering undertook pilot technology assessments in three representative problem areas: 1) the technology of teaching aids; 2) subsonic aircraft noise, and 3) multiphasic health screening. The Committee on Public Engineering Policy submitted a report on the results of this project to the House Committee on Science and Astronautics in July, 1969.[6]

Another important paper that should be considered by anyone interested in acquiring an understanding of the technology assessment process was presented as testimony before the House Science Subcommittee by Dr. Louis H. Mayo, Vice President for Policy Studies at George Washington University.[7] In this statement Dr. Mayo documented the need for a total systems approach to technology assessment and delineated the institutional framework and the complex set of interrelationships operating among the social, economic, political, legal, and technical factors involved in the assessment process.

From these and other technology assessment activities over the past few years, a rough picture of the technology assessment process has emerged. This extremely complex process involves the identification, determination, and evaluation of the effects of various technologies on the physical, socioeconomic, and cultural environments, and on the organizations and population groups functioning within those environments. The process is further complicated because the technologies under consideration are:

1. usually intricately interrelated;
2. often must be viewed as alternatives to one another;
3. frequently must be assessed without time or resources to amass definitive data;

4. at times must be studied through the inevitable distortions of forecasting techniques, and
5. almost invariably generate secondary, tertiary, and higher-order effects which are difficult to discern or anticipate, yet are frequently of considerable significance.

Moreover, even to the extent these obstacles can be overcome, evaluating the social, political, economic, legal, and cultural effects of technologies is a primitive process still in its infancy.

Definition of Technology Assessment Process

To convey the nature of the technology assessment process in a little more detail, I should like to present a brief, preliminary model that attempts a definition of the process. (The model was developed collaboratively by my colleague, Dr. Raphael Kasper, and me, in the George Washington University Program of Policy Studies in Science and Technology.)

The National Academy of Engineering report, *A Study of Technology Assessment,*[8] identifies two types of assessment: those that proceed from a particular technology such as lasers, and those that take as their starting point a general problem area such as air pollution, or the transportation problems of a particular metropolitan region, etc.

The first version of the model presented below defines the assessment process when it starts from a focus on a particular technology. The second version of the model presented below defines the assessment process as it proceeds from a particular problem or problem area. Although these models are presented in symbolic form, this is not intended to suggest that all—or even most—of the steps in the models can be performed quantitatively. Indeed, some of the steps are inherently subjective and qualitative; however, I do not view this as a defect of the model, but rather as a reflection of the underlying reality involved in the process of technology assessment.

(Purporting only to be a preliminary definition of technology assessment, the model includes several simplifications, the most important one involving its treatment of the complex time relationships among the consequences of technology. The model assumes that all first-order effects of technology precede all second-order effects, which in turn precede all third-order effects, and so on. This is not necessarily true, of course, since some effects occur only after some delay, while others are almost instantaneous. As the model is further elaborated it is expected that this simplification will be rectified.)

The model is constructed around three major factors. The first is the technology or technological application under consideration (designated by T). This factor, for example, might be the laser, the automobile, nuclear reactors, or computers. The second factor includes those operational and physical systems that are affected by the technology. These are called "fields of impact" and are designated by the symbol F. Fields of impact range from parts of the physical environment, such as: the air or water (or particular bodies of air or water); geographical regions such as a state, city, or lake; operational systems such as a mail or freight distribution system; or other technologies that may be affected by the application of a given technology. The third key factor in the model encompasses those population groups or participants that might be affected through application of the technology. This factor is designated by P. Examples of P might include such groups as students, city dwellers, or even oysters. The choice of particular population groups and fields of impacts to be studied will, of course, depend upon the particular assessment being performed.

First Version of Model

Let us consider first, a technology assessment that starts from a particular technology or technological system. For such an assessment one can delineate the following steps:

1. Identify the particular technology (or technological system) under consideration (T_n). Carefully delineate the functions or objectives which that technology is meant to serve.
2. Identify "direct fields of impact." A direct field of impact is one that is affected directly by the technology under consideration. In terms of the factors defined above, a direct field of impact is defined as a field F_m such that when T_n (the technology under consideration) acts on F_{0m} (the initial state of field F_m) then $F_{nm} \neq F_{0m}$ where F_{nm} (the final state of field F_m) is given by $T_n (F_{0m}) = F_{nm}$. (That is, the technology acts upon the initial field of impact to yield some changed field of impact.) In those cases in which $F_{nm} = F_{0m}$, then the technology has no direct effect upon the field F_m.

   For example, if the technology under consideration is the automobile and the field of impact being examined is the air, then F_{0m} would be the state of the air before the impact of the automobile (F_{0m} = clean air); and F_{nm} is the state of the air after the impact of the automobile (F_{nm} = air with an increased concentration of lead, carbon monoxide, etc.).
3. Determine the changed field of impact or the change in the field of impact due to the first-order effect of the technology which is: $[\Delta F_m]_n = F_{nm} - F_{0m}$. In the example mentioned above $[\Delta F_m]_n$ would characterize the increase in contaminants due to the operation of automobiles.

4. Identify the "second-order fields of impacts" by noting the effect of the first-order changes upon other fields of impact. That is, a second-order field of impact is defined as a field F_p such that when it is acted upon by the changes in other fields of impact $F_{np} \neq [F_{np}]^2$ where $[F_{np}]^2$ (the final state of field F_p after the second-order impact) is given by

$$\sum_m [\Delta F_m]_n(F_{np}) = [F_{np}]^2$$

(that is, first-order effects in all fields act upon the second-order field of impact to yield some changed, second-order field.)

5. Determine the $[F_{np}]^2$'s and/or $[\Delta F_p]_n^2$ where

$$[\Delta F_p]_n^2 = [F_{np}]^2 - F_{np}.$$

6. Identify and determine higher-order effects. For example, third-order effects may be defined by

$$\sum_p [\Delta F_p]_n^2 ([F_{nq}]^2) = [F_{nq}]^3$$

The process defined in steps 2, 3, 4, and 5 may be continued to as many orders as is deemed both desirable and practical.

7. Identify those population groups that are affected by the changes in the fields of impact. A population group with certain characteristics P_w is affected if the result (or impact) P_{nw} is non-zero, where the result is defined by

$$\sum_{ij} [\Delta F_i]_n^j (P_w) = P_{nw}.$$

(This may be read as: the effects of all orders in all fields acting upon a population group with certain characteristics P_w, yields a population with certain characteristics P_{nw}.) If $P_{nw} = P_w$, the population has been unaffected.

8. Determine the changed characteristics of the various populations P_{nw}'s, which ensue through the interaction of all the fields with the populations.

9. Identify alternative technologies, or systems of technology, $(T_a, T_b, \ldots, T_k)$ which serve the same functions or meet the same objectives as the original technology under consideration, T_n.

10. For each alternative technology, perform the analysis called for in steps 2 through 8.

11. Evaluate the results of each of the technologies under consideration: i.e., evaluate the changed characteristics of the various populations (P_{nw}'s) which are caused, albeit indirectly, by the various technologies. This

evaluation procedure is, of course, the most crucial component of the entire assessment process. The significance of the changed characteristics must be evaluated in terms of various goals, values, and priorities. These would presumably differ for the various population groups; in any event they are highly subjective, qualitative factors. The preliminary definition of the overall assessment process that has been outlined here does not attempt to delve into this highly important aspect of the assessment process.

12. Compare the evaluated results for the alternative technologies under consideration.

This completes this brief preliminary outline of a definition of the technology assessment process, when proceeding from a particular technology or system of technologies.

Second Version of Model

Listed below is a brief outline of the sequence of steps that would have to be followed to carry out a problem-oriented technology assessment:

1. Identify the change in a field of impact (ΔF_m), which is of interest (e.g., pollution in the air).
2. Determine the ΔF_m (e.g., measure the pollution).
3. Identify population groups affected by ΔF_m (e.g., city dwellers) $\Sigma_m (\Delta F_m) P_w = P_w'$; $P_w' \neq P_w$; $\Delta P_w = P_w' - P_w$.
4. Determine ΔP_w, the changed characteristics of the population group due to the change in the field of impact (e.g., lung disease).
5. Evaluate ΔP_w, the changed characteristics of the population group due to the change in the field of impact (e.g., put a value on the decline in health due to this factor).
6. Indentify the T_n's that may contribute to each ΔF_m (e.g., automobiles, factory smokestacks, etc.).
7. Identify the functions served by each T_n.
8. Identify alternative T's that can serve the same function, presumably without the same detriments.
9. Identify other T's that, when used in conjunction with T_n, can eliminate or significantly reduce the detriments due to T_n.
10. For each T, identified above, perform the full technology assessment outlined in the first model presented above.
11. Compare and evaluate the various alternative technologies, and combinations of technologies, for fullfilling the desired functions.

Technology Assessment and Environmental Engineering.

Following this brief exposition of the nature of the technology assessment process and its significance to society, we can direct our attention to the relationship between technology assessment and environmental engineering. Environmental engineering impinges on the technology assessment process at a number of critical points that involve both the performance of technology assessments and the implementation of the results of such assessments. The potential contributions that environmental engineering can and must make to technology assessment fall in the following areas:

(1) *Identification and delineation of alternative technological systems that can achieve similar objectives.* This step is, of course, crucial to the assessment process, for until the technology or technological system can be viewed as one of several alternatives for accomplishing certain desired purposes, it is not possible to construct a scheme of evaluation for the technology or technological system. Thus, an electric car can be viewed as an alternative to the internal combustion engine car; similarly, mass rapid transit can be seen as an alternative to individual automobiles, and air and interurban rail transit systems can be seen as further alternatives for certain purposes. Viewing the problem in a somewhat broader perspective, improved methods of communication through computerized, cable TV systems, for example, can be viewed as alternatives to the use of extensive transportation systems altogether. Environmental engineering, through its wide perspective and approach to problems, is particularly well suited to assist in the identification and delineation of such alternative technological systems.

(2) *Monitoring and maintaining surveillance of environmental effects due to specific technological systems.* This area is equally critical to the assessment process. Measuring the content and extent of air or water pollution is essential to performing adequate technology assessments of pollution abatement devices, for example. In addition, such monitoring and surveillance are essential to maintaining effective control over the implementation of the results of technology assessments. Merely arriving at the technology assessment that a particular technology should be modified in certain ways or replaced with particular alternative technologies is not sufficient to assure the desired benefits to society. The ways in which technology-assessment results are implemented is of the utmost importance. Only through monitoring and surveillance of environmental effects can adequate control be maintained over the implementation of technology -assessment results. Since society's focus on environmental problems is a relatively recent phenomenon, there is a great unfilled need for imaginative technological innovation in the development and engineering of environmental monitoring and control devices.

(3) *Expanding the base of technical knowledge regarding the interface of technology with environmental processes.* It is of primary importance that the base of technical knowledge in this area be expanded and become a greater part of the formal educational background with which engineers are equipped. The diversity and difficulty of coping with our environmental problems pose an enormous challenge. Every contribution which expands the general base of technical knowledge of the interface of technology and environmental processes helps society meet this challenge.

(4) *Providing technical adaptations and innovations that can assist in resolving social and environmental problems.* Unfortunately much of the discussion on technology assessment has focused on the negative aspects of technology, and emphasized the adverse consequences of technological developments. Technology is merely a tool that mankind can use for good or bad depending on the way in which it is employed. Technology assessment should be viewed in a positive light as an aid to fostering technological adaptations and innovations that will serve society's needs more effectively. Technology, in and of itself, is neither the cause of society's problems, nor the means for resolving those problems. Nevertheless, technology possesses an enormous potential for helping to resolve those problems. Through technology assessment we can inhibit technological developments whose adverse consequences outweigh the benefits they bestow on society, and we can foster the development of innovations whose beneficial results far outweigh any detrimental effects they may entail. At the same time, when there are detrimental effects associated with otherwise beneficial innovations, we can anticipate the adverse consequences and take countermeasures to neutralize them while we are still developing the new technology. It is clear that environmental engineering has an essential role to play in the assessment of technological innovations: to preclude or counteract their deleterious impacts on the environment, and foster their beneficial results for the environment, the economy, and society at large.

Environmental Engineering and National Conversion of Technical Talent

As a final point, I should like to note that the recent emphasis on technology assessment has an important potential relationship to the increasing pressure toward conversion of technical manpower and resources from defense to civilian, socially-oriented programs. Most engineers are cognizant of the substantial cutback that has occurred in defense and space spending for research, development, and engineering. This cutback has by no means reached its peak as yet. It is likely to continue and increase over the foreseeable future. There are a variety of economic, social, and political reasons for this phenomenon which we do not have time to explore in this discussion. But the fact remains that conversion from defense to civilian, socially-oriented research, development, and engineering is very much of a pressing issue.

For example, the President has announced a $42 million program to be administered by the Department of Labor to provide retraining, job placement, and relocation assistance for scientists and engineers. On Capitol Hill, conversion activity has been even more intense. The Senate has seen various conversion bills introduced by Senators Brooke, Kennedy, McGovern, Muskie, and Pearson. In the House other bills have been introduced by Congressmen Davis, Harrington, Morse, and others. Some of these measures call for more than $500 million to be allocated to the conversion of scientific and technical resources over the next three years. Hearings on various conversion bills have already been held before the House Committee on Interstate and Foreign Commerce in June, 1971, and the House Committee on Science and Astronautics in June and July, 1971.

In view of the conversion programs that have already been initiated by the Administration and the much more ambitious proposals that have been promulgated by Congress, it is extremely likely that the Federal Government will take major steps over the next few years to facilitate conversion of the country's scientific and technical resources. Since many of the problems to which science and engineering can make a contribution involve environmental issues, it is clear that environmental engineering has an extremely important role to play in the conversion of national talent to peaceful purposes.

For the past twenty-five years a most significant share of the nation's scientific and technical resources has been invested in the defense, space, and atomic energy programs. Within the last few years, particularly as problems of the environment have become more pressing and obvious to the general public, a national demand has started emerging that calls for the redirection of national priorities, the reallocation of national resources, and the revitalization of national talent to be directed toward resolving the real problems which confront our society. There are innumerable challenges to be met and tasks to be fulfilled if our environment is to achieve and maintain the level of quality we desire, and if our citizens are to be able to live out the kinds of lives they deserve.

The development of national policies and programs to promote the effective application of technical talent to these problems remains the responsibility of the President and Congress, with the support of leaders of the technical community throughout the country. But it is the responsibility of each professional engineer, especially those involved in environmental engineering, to exert individual leadership in converting the nation's resources and talent to face the real problems by which we are beset. As more engineers turn their time, their thoughts, and their talents to these kinds of issues and problems, they will undoubtedly identify many projects that can be constructively pursued and develop many innovations that can render real contributions to the resolution of such problems. So environmental engineers have key roles to play in the impending conversion of national talent and resources to civilian, socially-oriented problems and projects. Each engineer engaged in environmental engineering has an individual responsibility and faces a personal challenge to direct his own thoughts and energies toward useful projects and results that can facilitate this conversion.

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