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ABSTRACT

Several bodies of literature that shed light on some aspects of the relationship between information technology (IT) and research practice in science and engineering are reviewed. Subjects include: (1) the importance of calculation in research endeavors; (2) productivity in science and technology; (3) the philosophical differences between science and technology; (4) systems analysis and implementation, including effects of IT on the business aspects of research and researchers' behavior; and (5) computer support for engineering practice. A model is developed which helps identify the types of impacts that IT may have on the social system and epistemological aspects of research. Social system factors range from the behavior of individual researchers, through the organization of research laboratories, to social policy concerning funding for research. Epistemological factors include choices of methodologies, kinds of problems to be studied, and evidence to be considered. Factors which may explain why IT has particular effects in a research endeavor are proposed; these include a field's data intensity, requirements for real time analysis, availability of calculation tools, applicability of results, reliance on established principles, clerical support, control over report production, and lay interest in the research. An agenda for research in this area is suggested. (11 references). (Author/MES)

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The Impact of Information Technology on Research in Science and Engineering

Johnathan A. Morell

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A revised version of this presentation
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Comments and suggestions are welcome.

The Impact of Information Technology on Research in Science and Engineering

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ABSTRACT

There is little empirical research on the impact of information technology (IT) on how research is carried out by scientists and engineers. This paper draws on other bodies of writings which indirectly shed light on this question. Included are: the role of calculation in research, scientific productivity, the philosophical underpinnings of science and technology, systems analysis, and the use of computer aided design in engineering.

A model is developed which helps identify the types of impacts that IT may have on social system and epistemological aspects of research. Social system factors span the range from the behavior of individual researchers, through the organization of research laboratories, to social policy concerning funding for research. Epistemological factors involve matters such as choices of methodologies, judgments as to what kind of problems should be studied, and evidence should be considered.

Factors are hypothesized which may explain why IT may have particular effects in any given research endeavor. Examples of such factors include a field's data intensity, requirements for real-time analysis, and lay interest in the research.

The main objectives of the paper are to help advance a research agenda for understanding how IT affects scientific and engineering research, and to encourage further work in this area.

INTRODUCTION

At present there is a dearth of empirical research specifically concerned with how late-generation information technology (IT) affects scientific and engineering research. No such studies were discovered during a search of several data bases which were conducted in preparation for this article. Similarly, the author of a paper on the impact of microcomputers on university faculty (Snizek 1987) had an equal lack of success in finding relevant literature.

This lack of data stands in sharp contrast to almost all other workplace settings in which computers are found. There is considerable research literature on how IT affects clerical workers and managers as individuals, and manufacturing and service industries as organizations.

REASONS FOR LACK OF RESEARCH

The lack of research on scientists and engineers may stem from an implicit - and incorrect - assumption that social scientists have made about IT as an innovation. It is obvious that widespread use of distributed processing <u>is an innovation</u> in most business and government settings. Relative to research work, however, social scientists may have held a different view. Namely, that researchers have always used computers, and now they are just using more computers. In other words, there has been <u>no innovation</u>. In fact, late generation IT represents a profound change in the tools and choices available to almost everyone engaged in research.

INFORMATION TECHNOLOGY AS AN INNOVATION IN SCIENCE AND ENGINEERING

Four basic changes in computer technology are affecting scientific and engineering research. The first is the development of ever larger supercomputers, which allow researchers to push limits of calculation they could not reach before. Second, on-line databases and electronic communication are giving researchers fast access to ever growing sources of information. Third, computer technology is giving researchers new ways to collect, manage and analyze data. That same technology is also providing new capabilities to control experiments. Finally, researchers are gaining ever more personal control over continually growing information processing capacity. These changes are manifest in many ways, as illustrated by the following examples.

1- It is common for researchers to use personal computers which provide more power than did the mainframes of a few years ago. Perhaps more important, easily available inexpensive software gives those end-users new choices about data handling and analysis.

2- Computer aided design (CAD) is changing the number of design variations that engineers can consider, and the rate at which they can access information.

3- Artificial intelligence is beginning to affect some areas of engineering and research practice.

4- A growing proportion of researchers can now have their experiments and data collection controlled by computers. This allows levels of precision and control never before available. It also allows data collection in contexts where repetition and boredom would make human control ineffective.

5- Computer-mediated data analysis allows "noisy" data to be used in a meaningful way. Without such mediation, the signal to noise ratio in much data would be unacceptable.

6- Computer graphics allow people to manipulate, visualize and interpret more complex calculations and experiments. As an example, the evolution of an event can now be understood by including a time dimension in a series of graphic representations.

7- New fields (or radical changes in old ones) owe their existence to computers. Prime examples include cognitive science, robotics, and medical research which relies on computer driven imaging technology.

These changes point to three general changes in the research enterprise.

1- Individual researchers (and research groups) are becoming less reliant on other people's control of computing facilities.

2- New types of problems can be addressed.

3- Results are obtained more quickly.

IMPORTANCE OF THE QUESTION

A recent analysis by the National Association for the Advancement of Science (Shapley, Teich and Weinberg, 1984) estimates the following R&D expenditures (in millions): federal government - $9,750M, industry - $64,250M, colleges and universities - $7,400M, federally financed R&D centers - $2,600M, and nonprofit institutions - $2,500M.

Although no data exist on the percentage of these funds that are bound up with computer technology, two statements seem plausible. First, that percentage is large and growing. Second, that return on our

R&D investment is increasingly dependent upon appropriate use of computer technology.

PURPOSE OF THIS MANUSCRIPT

This document is intended to spur debate and speculation concerning the impact of late-generation IT on the course of research efforts in science and engineering. Because of the lack of empirical data, a beginning effort at understanding must:

- identify theoretical perspectives which might shed some light on the question;
- articulate variables which might explain how IT affects research work;
- develop hypotheses to explain why those variables may be important; and
- identify the possible effects that IT may have on research.

Hopefully, discussions spurred by this paper will result in furthering three goals related to our understanding of relationships between research and IT:

- an advance in the state of knowledge,
- development of a research agenda, and
- formation of an "invisible college" of people with an interest in the topic.

THE CURRENT STATE OF KNOWLEDGE

Despite the lack of empirical data, there are several bodies of work which shed light on some aspects of the relationship between IT and research practice.

THE ROLE OF CALCULATION IN RESEARCH

One such body of literature consists of efforts to articulate the importance of calculation in various research endeavors, and thus, to justify needs for advanced calculation tools (computers). The thrust of such analyses is summed up by the following quote from a report issued by the Society for Industrial and Applied Mathematics [Rheinboldt, 1985: p. 5]

> "The use of modern computers in scientific and engineering research and development over the last three decades has led to the inescapable conclusion that a third branch of scientific methodology has been created. It is now widely acknowledged that, along with the traditional experimental and theoretical methodologies, advanced work in all areas of science and technology has come to rely critically on the computational approach. Accordingly, for the advancement of the scientific and technological base of our nation, it is essential to maintain the U.S. leadership advantage in scientific computing."

This instructive quote indicates two broad areas where computers may be affecting the research enterprise. By supplying radically new methodological choices, computers may be influencing decisions about what research questions should be addressed, what scientific evidence is acceptable, and how research should be carried out. The second area of impact is in the realm of our social and economic policy as it relates to computing. Because computer technology has become so important to our scientific and technological leadership advantage, our research policy must be adapted to nurture advances in computing.

SCIENTIFIC PRODUCTIVITY

Leadership capacity is also a prominent theme in a second area of relevant literature - the study of productivity in science and technology. Although measuring scientific productivity is beset by a host of thorny problems, there has been a serious effort to address the issue [Fusfeld and Langlois 1982]. Two basic problems encompass most of the methodological difficulties in this work. First, the quality of research has proved almost impossible to quantify. Given this lack, any quantitative study of research productivity fails to capture the essence of much true advancement in science.

Second, it has been extremely difficult to establish causal links between easily quantifiable factors and the outcome of scientific endeavor. Over and above the general problems of relating inputs to outputs, there is the complication that input/output relationships may differ across disciplines or fields of study. For instance, the impact of increasing funding, or personnel, or research time in one discipline may not generalize to other fields.

Factors that do have a discernible impact on research may lie within the social-psychological realm, and thus be difficult to measure across broad, varied contexts. Examples of such factors include unit directors' leadership qualities, and researchers' satisfaction with their work.

This literature contains some important insights with respect to understanding the impact of IT on research. First, efforts to assess the impact of IT on the quality of research will prove extremely difficult, as have the more general efforts to measure the quality of scientific output. Second, because relationships between input and output variables may vary across different scientific disciplines, it becomes important to identify those factors which explain differential effects of IT in particular contexts. Finally, because social and psychological factors may have a strong impact on scientific productivity, research on the impact of IT should pay careful attention to intra-workgroup dynamics.

PHILOSOPHY OF SCIENCE AND TECHNOLOGY

An important theme in the above discussion has been one of context. As social, disciplinary or organizational factors change, so too does the relationship between IT and scientific productivity. A quite different element of context is philosophical; in particular, the differences between scientific and technological endeavor. Analysis of these differences reveals how the <u>intended</u> <u>use</u> of information may affect the impact of IT on the course of research. To illustrate this point, a review of the philosophical differences between science and technology is required [Morell 1979, chap. 5].

Technological and Scientific Action

The Nature of Technology

Many writers have tried to capture the essence of technology. The tenor of their arguments is captured in the two authors cited below. According to Wiesner (1970, p. 85):

> Technologists ... achieve their most elegant solutions when an adequate theoretical basis exists for their work, but normally are not halted by the lack of a theoretical basa. They fill in gaps by drawing on experience, intuition, judgment and experimentally obtained information.

Skolimowski (1966) states that the goals of science are to investigate reality, enlarge knowledge, acquire truth and study "what is." In contrast, the goals of technology are to increase the efficiency of given techniques, create a reality of our own design, and to be concerned with what "ought to be."

Theory

A fundamental element of scientific research is the development of theory and its testing for accuracy and truth. These criteria require careful efforts to remove (or account for) as much "noise" and bias as possible, because even small differences may have major implications for theory development. Furt er, those in pursuit of truth have no obligation to test theory in real world settings, or to demonstrate practical application.

In the technological realm, however, the situation is reversed. There, the ultimate test of a theory is whether it assists with practical action. It does not matter what combination of causal relationships are subsumed within the theory, or even whether the theory is correct. (An excellent discussion of scientific and technological theory can be found in Bunge, 1967.)

Decision Strategies

entific priority is given to research that will help clear up ual difficulties, advance theory, or otherwise further the search for truth. Technological priority goes to studying issues that will increase our instrumental control over real world events.

In scientific work, levels of accuracy for measurement are always chosen to be as great as possible because small differences between prediction and observation may have major theoretical implications. The technologist has the latitude to choose a level of accuracy that is adequate for guiding action in a particular applied context.

The scientific perspective puts a strong emphasis on the concept of "refutation," while in technological thinking, the emphasis is reversed. Much of the technologist's job is to assist people in choosing from among competing plans of action, each of which has implications for the commitment of resources, or for political and organizational relationships. The objective is to help decision makers confirm their beliefs about the relative merits of various courses of action. By so doing, technologists can help decision makers to take risks, i.e., to take action.

Implications For Information Technology

One important issue that stands out in the above analysis is that research efforts may differ considerably in the emphasis they place on achieving the greatest possible accuracy of measurement. Presumably, the greater the need for accuracy, the more IT will be applied to achieving that end. If research settings can be assessed in terms of the importance of measurement accuracy, it may be possible to predict the direction in which researchers will seek to employ their IT.

A second implication for IT derives from a combination of four related ways in which research efforts may differ from each other:

1- emphasis on making a discernible difference in practical settings,

2- emphasis on prediction and control,

3- combination of scientific and non-scientific information, and

4- willingness to combine compatible courses of action rather than tease out their differential effects.

Together these factors form a scale of the diversity of information that is important in a research effort, and the extent to which different types of information might have to be integrated into an analysis. IT might be used quite differently when the goal is integration or coordination of diverse information, rather than increasing the accuracy of a relatively few measures.

SYSTEMS ANALYSIS AND IMPLEMENTATION

A fourth body of relevant literature is the genre of writing on information systems analysis and implementation. When this work touches on research or laboratory settings, it sheds light on the interaction between research practice and IT. Horton's (1985) work on information resource management (IRM) exemplifies this approach. In his treatment of IRM in laboratory settings, it is possible to discern two general areas where new IT may affect research.

- Information technology may affect the "business" aspects of running a research enterprise. This is a traditional information systems perspective which tries to manage the data needs of any complex social organization.
- The behavior of researchers and research groups may also be affected in three areas: special information needs, relationships

to their laboratories, and their "core professional act" - knowledge production.

The Business Aspects of Research

The ability to access, manipulate and share information is being profoundly affected by office automation (OA) technology and its attendant organizational concepts - end-use computing, distributed processing, information resources management, and the like. These changes may affect research settings in three ways - sharing information among laboratories working on different aspects of a large project; production of traditional management information (e.g., money, procurement, personnel, progress on work, outputs); and relations between research settings and the outside world (government, community, etc.).

As in any such situation, the organization can be run better if an OA system contains useful data at appropriate levels of aggregation; if it allows people to access and manipulate the data they require; and if it has adequate provisions to insure the data's timeliness, accuracy and integrity. What is needed is careful systems and socio-technical analysis to make sure that unique data needs are met, that appropriate technology is available, and that organizational circumstances (training, management's expectations, communication policies, allocation of equipment, etc.) facilitate OA use.

Although no data exists to document how OA will affect these business aspects of research, it seems plausible to assume that the effects will be similar to other complex organizations which integrate OA into their operations. In general, we can expect the following:

- Appropriate use will lead to major increases in organizational performance. New types of information will be available for decision making. Opportunities will open to address issues that previously could not be analyzed. Old work will be accomplished faster, leaving time for new kinds of activities, or for accomplishing more of what was done in the past. Communication among groups will be facilitated. The quality of written reports and audiovisual presentations will improve.
- Inappropriate use will be dysfunctional. Examples of problems include the production of many drafts of marginally improved documents; "over analysis" of data simply because of its availability; dysfunctional choices about levels of centralization or control; and reliance on OA systems that do not meet their design specifications. (In point of fact, most empirical research on OA tends to show either advantages or neutral results, rather than dysfunctional impacts.)
- The distribution of impact will vary widely in the organization, with some groups exploiting the technology to its fullest, while others use OA to minimal advantage.
- Office automation will potentiate whatever movement the organization chooses in the direction of centralization or decentralization, or relative to other elements of organizational change.

Researchers' Behavior

Information technology may impact any of five aspects of researchers' behavior:

- control over information processing;
- interchange among colleagues;
- monitoring and documenting research efforts; and
- decision making about scientific issues, and the training of scientists.

Control Over Computing

Personal computers have given scientists far more control over their computing activities than they ever possessed before. Horton (1985) cites a variety of advantages and disadvantages that derive from this shift. To paraphrase from his list of consequences (pp. 136 - 137):

Advantages

- Work in process could be put on the machine rather easily, and recalled and pursued when necessary.
- R&D professionals could resort more quickly and efficiently to their own machines rather than rely on computers in a remote location.
- Graphics visualization of engineering drawings is a boon to engineers who formerly had to comply with a lot of paperwork and rules about checking out blueprints and drawings from a central records facility.

Disadvantages

- Laboratory management noticed a compartmentalization of mini-data bases, each structured in its unique way, and using disparate definitions for commonly used data element names, terms, abbreviations, codes and symbols. Management had to spend more time correlating and translating findings from one group to another.

- Data ownership became a critical issue, with access problems and procedures
- Data protection and security, formerly a relatively controllable problem, became critical.
- Data privacy - sensitive personal data (home telephone numbers, addresses, salary data) proliferated on many machines, making abuse and misuse harder to control.

Colleague Interchange

Electronic communication (electronic bulletin boards, mail and access to data bases) provides hitherto unknown potential for scientists to search out colleagues with similar interests, to exchange information, and to learn of meetings and conferences. These opportunities offer a potential for more collaborative arrangements to develop, and for the richness of those relationships - in terms of the frequency of communication and amount of information exchanged - to increase. The existence of such positive effects has been corroborated by Snizek (1987) in his study of university faculty's use of microcomputers, and by Estrin (1986) in her study of interorganizational networks. He also documented several possible negative consequences of this change, including the forced formalization of communication engendered by electronic communication, and possible shifts toward the use of data not actually collected by the researcher.

Monitoring and Documenting Research

In one form or another, most scientists keep records which document impressions, progress, problems, and plans. This record is important not only for individual researchers, but as legal and administrative documentation of work done. By recording this information in electronic form, it becomes more accessible and more malleable, thus providing considerable benefits to all those with a need for the information. Since the more accessible the information the greater the probability that it will be used, electronic technology may facilitate a new and more critical role for records of research progress.

Decision Making

Computer modeling and simulation provide opportunities to seek information that would otherwise require empirical research. Several consequences of this new ability suggest themselves. Less research may be done, thus increasing reliance on untested assumptions. More research may be done in an effort to get better data to allow the value of simulation to be pushed to its limits. Priorities for data collection may shift to areas where simulation is not feasible. A second aspect of decision making is the use of expert systems, which allow researchers to consider more factors, and be more certain that important issues have not been overlooked. The forefront of this effort seems to be in medicine, but work is also being done in engineering and a number of other contexts.

Both simulation and expert systems present researchers with potential changes in their priorities for data collection, the data they rely on for decision making, and a shift in their relationship to empirical data.

Scientific Training

Scientists' reliance on IT may affect the content of both graduate training and continuing education. This reliance may change graduate curricula, the relationship between younger and older researchers, individuals' influence in professional bodies, and the allocation of resources for continuing education.

COMPUTER SUPPORT OF ENGINEERING PRACTICE

Another body of relevant literature consists of efforts to understand the impact of computer supported efforts in engineering and manufacturing [Majchrzak et al., 1987]. Most of the empirical research on the topic relates to the impact of Computer Aided Design (CAD) on those aspects of engineering which are close to production processes, and thus not immediately relevant to changes in research practice. (Within this context, research on CAD has touched upon issues such as communication, changes in work tasks for engineers and draftsmen, and the rate at which work is done.)

This body of work does, however, contain some important insights which are relevant to the topic at hand. For our purposes, the logic of these points can be set out as follows. The design process consists of four basic phases - synthesis, analysis, evaluation and representation. Some of these phases can be analyzed through well established methods, as for example the use of finite element analysis in the analysis phase. Other phases of design rely more heavily on human judgement, intuition and experience. While an ideal CAD system would automate the entire design process, the present state of the art is far from that goal. The greatest lack of progress is in those areas which require human judgement. Thus improvement in the situation will depend on the integration of artificial intelligence (AI) with CAD technology.

One implication of the above description is a reinforcement of the notion that at present, the greatest impact of IT on research may lie within the realm of calculation tools. A second implication is that <u>if</u> significant progress is made in the AI/CAD integration, engineers will spend less time performing the entire range of their present day activities. Should these time savings be realized, there are three possibilities for how engineers may budget their new found research time. They may work on:

- the same kind of problems they did previously, but address more of them;
- problems that may not be inherently difficult but which for one reason or another, lie outside of the capacity of available IT; or
- conceptually difficult problems that push the limits of available IT.

All of these possibilities portend important new directions for engineering research.

A MODEL FOR UNDERSTANDING IMPACT

A clear implication from the literature review is that IT may have two categories of impact on research - social system effects and epistemological effects.

- The "social system" category is a continuum with three main points - individual researchers or research groups, research and development organizations, and society as a whole.
- The epistemological category refers to the influence of computer technology on theory development, research priorities, and data use.

As examples of the connection between the review and "epistemological effects," consider the following. The analysis of the role of computers in calculation placed heavy emphasis on the opening of a new branch of scientific methodology. The discussion of differences between science and technology showed that the intended use of information has a pronounced influence on methodological choices and on the goals which drive data analysis. The literature on information systems pointed up very powerful "social system" affects of IT. Changes were posited in how researchers relate to their organizational context, and how R&D organizations must organize themselves to best exploit the opportunities provided by IT.

Changes brought about by IT may affect one or both of those categories. Although no existing data speak to what those changes may be, an understanding of research and of IT suggest many possibilities. Figure #1 lists some of those possibilities, put within a structure designed to facilitate both the search for specific indicators of change and relationships among impacts.

As an example of how Figure 1 might be useful, consider the following hypothetical example concerning "beliefs about problems." On the individual level, a discipline may experience a grass roots movement as researchers begin to change their views of what research they wish to do. Those beliefs may interact with a societal change, namely priorities set by federal research funding agencies, who are also thinking in terms of new possibilities. Caught in the middle are universities and research laboratories, which must accommodate to the changes in two ways. First, they must supply the equipment needed to conduct different types of research. Second, they must organize themselves in a manner that will facilitate success in the new direction that a field is moving. Finally, there are implications for the scientific discipline itself, which is beginning to develop new traditions, new standards of evidence, and new areas where its members will have to prove themselves.

As a second example, consider the impact of IT on document production. Although there must certainly be such an impact, its nature is unclear. Word processing might lead to more drafts of only marginally improved documents, thus having a negative impact on the time of researchers and their secretaries. On the other hand, the technology might also increase the number of papers developed for submission to conferences and journals. Further, if word processing has changed reviewers' expectations about the quality of layout and eye-appeal, there might also be an impact on acceptance rates.

An important theme running throughout much of the literature review is that IT may affect different research efforts in different ways. Thus it is important to determine just which factors explain how much a specific research area will be affected by IT. Because direct evidence is lacking, we must rely on the indirect evidence brought previously, and on our basic knowledge of the research enterprise. As a beginning effort to articulate a complete list, the following possibilities are proposed:

1- Data intensity Some research endeavors involve processing much greater amounts of data than others. The importance of computers as calculation aids, and researchers' increased control over computing both suggest that the greater the "data intensity" of the field, the more profound will be the impact of IT.

2- Real time analysis Research endeavors differ in their need for immediate feedback about dynamic situations. Information about engineers' use of CAD implies that the impact of IT will increase with researchers' need to have fast access both to large amounts of data, and to the results of data analyses.

3- Calculation tools Some research endeavors have undoubtedly been held back because of a lack of calculation tools, such as routines to perform exotic statistical analyses. In these cases new technology should help these fields push their previous boundaries.

4- Research or development Although precise boundaries are nebulous, there is a continuum between research with no immediate practical application and research that is part of a specific product development process. As one moves along this continuum, there are differences in many important factors - funding mechanisms, time lines, locus of control over the research process, and definitions of satisfactory results, to name just a few. Based on the analysis of differences between science and technology, it seems reasonable to assume that IT's role may change as a function of how immediately applicable a study's results are expected to be.

5- Reliance on established principles Expert systems have enormous potential to help people do work faster, consider more data, and draw better conclusions. But these systems work well only when there is a well-established set of decision making rules. Thus the more such rules a field has, the greater will it be affected by the development and use of expert systems. As an example, much medical research depends on accurately categorizing subjects by diagnosis. As expert systems allow for better diagnosis, statistical analysis in such research will become more powerful.

6- Clerical support - research practice Clerical support is particularly important in the social sciences, where information technology is affecting two aspects of research practice. First, insuring high response rates to surveys requires careful attention to the eye-appeal of survey forms. Thus desk top publishing technology may be influencing the willingness of researchers to undertake survey design projects, or the quality of results obtained from those efforts. Second, new software for the analysis of qualitative data (interviews, field notes, etc.) is changing the amount of information that can be extracted from such data, and researchers' ability to manipulate that information.

7- Report production - Snizek (1987) discovered that personal control over document production (i.e., word processing) was the most frequently cited benefit of microcomputer use by university faculty. Many reported that such control greatly increased their productivity. On the other hand, about forty percent of his sample also voiced reservations about spending more time doing clerical work and less time doing research.

The actual value of word processing by researchers must depend on an interaction between two factors. First, research settings differ in the volume of documents that need to be produced. Second, settings differ in the extent to which responsibility for document production lies with the researcher. The balance between these factors in any specific setting will largely determine the size and direction of impact that IT may have on the production of scientific reports.

8- Lay interest in research Writings on information systems highlight the importance of control over computing. This issue can be generalized to situations where access to IT may give laymen more influence over research agendas by giving them greater access to research-derived information from computerized data bases. In cases where research results have high political salience, this distribution of knowledge may affect the demands made upon the research community through the political process.

A second aspect of lay influence on research is the combination of inexpensive computing and specially designed software which is expanding the ability of nonexperts to perform social research. Examples of this expansion include software that assists in survey development and the performance of program evaluation.

AN ACTION PLAN FOR RESEARCH - LAYING THE GROUNDWORK

The first step must be to conduct an extensive literature review in fields where people might be expected to research the impact of IT on research - sociology of science, productivity in R&D contexts, and the like. Any such research will be quite recent and as discussed earlier, not found in existing bibliographic archives. Rather, it will be necessary to conduct a "networking" effort within an "invisible college" of researchers. Data from the review would be used to sharpen and reformulate the model presented in this paper.

A second phase of the effort should be to conduct interviews with selected scientists and engineers. These interviews should have two parts:

1- Respondents' opinions should be solicited about issues articulated in the revised model of IT's impact on research.

2- Information should be collected on respondents' views about how computer technology affects their work, their relationships to institutions, and their disciplines.

A parallel effort to these interviews should be a content analysis of relevant scientific journals to determine how information technology may be driving disciplines. One target of this effort should be journals of the "Computer Applications in ______" variety. A second target should be articles within any of a discipline's journals which deal explicitly with computer applications.

Finally, information gleaned from the above efforts should be put into a questionnaire form and circulated to a wider range of scientists and engineers. Those respondents will be asked to provide three kinds of information:

1- ratings of the importance of factors which may explain the impact of IT on research;

2- suggestions about important factors that were overlooked; and

3- specific examples of how IT has influenced the respondent's work.

The information derived from the above effort would provide the ability to articulate relevant variables, identify possible impacts, and sharpen our understanding of relevant theories. This knowledge would provide a solid basis for further research and the formulation of strategies to maximize our investment in scientific computing.

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