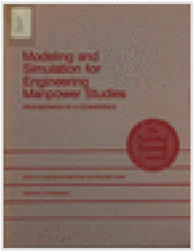

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Modeling and Simulation for Engineering Manpower Studies

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Assembly of Engineering
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NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1977

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PREFACE

This report consists of the proceedings of the Conference on Modeling and Simulation in Engineering Manpower Studies held at the National Academy of Sciences in Washington, D. C., February 9-10, 1976. The purpose of the conference was to evaluate the theory and application of modeling and simulation techniques in the field of engineering manpower. The participants, representing government, education, and industry discussed the supply of and demand for engineering manpower, which often is a critical component of their decisions.

The conference was sponsored by the Board on Engineering Manpower and Education Policy of the Assembly of Engineering of the National Research Council. The board was established in 1974 by the National Academy of Engineering, which along with the National Academy of Sciences, supports and manages the National Research Council. The charge to the Board is to define and address problems associated with improving the match between engineering manpower supply and demand, to determine the implications of this relationship for engineering schools, and to focus on improving the quality and effectiveness of engineering education.

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INTRODUCTION

M. E. Van Valkenburg

The need for a colloquy on modeling and simulation for studies of engineering manpower was recognized at an engineering manpower conference held at Henniker, New Hampshire, in July 1975. At that conference, Fred Landis stirred considerable interest among the participants by his remarks on modeling and simulation as a technique for forecasting the demand for technology. Paradoxically, the subject had not been previously explored by those concerned with engineering manpower problems. Many of the participants at the Henniker conference urged that the subject should be explored further.

As a result a second conference, sponsored by the Board on Engineering Manpower and Education Policy of the Assembly of Engineering, was organized to provide an opportunity to exchange information on modeling and simulation techniques and applications for an audience with diverse backgrounds and interests.

Two factors contributed to the timeliness of the conference: (1) increased awareness of the importance of manpower planning among engineers and other professionals, and (2) improved techniques and facilities for modeling and simulation. Viewed in retrospect, earlier modeling efforts turned out to be unrealistic. Modelers recognize the need to gather comprehensive data over long periods of time and acknowledge the need for workers in the field to compare and assess the values and limitations of models. In addition, computer simulation has become increasingly sophisticated through the application of new techniques.

Interest in the engineering profession in modeling stems largely from the manpower crisis of the early 1970's. Between World War II and the 1970's, engineers benefited from virtually unlimited employment opportunities. While the interest has waned somewhat as engineering employment has declined, many engineering societies were sufficiently stimulated to establish programs to study manpower supply and demand. The availability of engineering manpower resources relates directly to the extent of national activities in today's technology. Thus in examining just one of these national concerns the conference included discussions of large-scale energy systems and the related manpower needs.

The conference was organized into three panel discussions--modeling and simulation techniques, manpower components of large-scale energy models, and manpower modeling for future decision making. In the end a fourth panel, led by Courtland Perkins, president of the National Academy of Engineering, summarized the significance of the previous discussions, considered the future of modeling techniques, and delivered several conclusions.

As the first speaker, Charles Falk provided useful perspective on modeling. The main purpose of modeling is not necessarily to make predictions, he stated, but rather to provide a better understanding of the manpower system--a system that is complex because it deals with human beings. Falk then described the "probable" and "static" models developed by the National Science Foundation to study engineering doctorates.

Roger Bezdek discussed the rationale for manpower forecasting and summarized the various types of models and methods in use. He set out the various issues of critical importance in manpower forecasting, including the extensive influence of the federal government on both demand and supply of engineers, as well as scientists and other professionals. He also spoke of skill transferability and occupational mobility. He urged that the relationship between jobs and educational requirements be clarified. Bezdek raised the issues of increasing the educational requirements of professionals and imposing limits on school admissions, noting the effect that the American Medical Association's policies have had on medical care in the U.S.

Vern Johnson described work based on a study published in the 1975 Manpower Report of the Institute of Electrical and Electronics Engineers He noted that the study had used secondary source data and lacked some form of economic indicators. The most recent work, which makes short term projections of the demand for engineers, seeks to overcome those weaknesses while maintaining the model's basic simplicity. It assumes a stable engineering manpower system as well as consistent, factual data and the grouping of all engineering disciplines in geographic areas.

Fred Landis proposed a dynamic simulation model as a means of demonstrating the interrelationships between national spending, engineering employment, and training new engineers. Simulation studies indicate that cyclic fluctuations in the economy can have dire effects on engineering employment, said Landis, especially when companies reduce R & D funding, thereby contributing to the economic downturn that led to the R & D cuts. Thus long delays inherent in the feedback mechanism can upset accurate manpower calculations in periods of economic disturbances and lead to the training of too many new engineers. Landis said that the model, with some extensions, could be an effective tool in manpower planning for periods of three-to-seven years.

Donald Mack described a systems-dynamic model that contained various assumptions on further trends in engineering employment. This model seeks to predict the number of engineering BS graduates in the next few years based on its accurate predictions of the graduating classes of 1973, 1974, and 1975. Mack noted that the model's projections are comparable to those of the Engineers' Joint Council and the National Center for Educational Statistics.

A. Wade Blackman discussed the concerns of the U.S. Energy Research and Development Administration in modeling in general and in manpower specifically. He said that the models are used in developing scenarios for alternative energy systems and the related requirements for manpower. Kenneth Hoffman evaluated the implications for manpower in the energy models developed by the Brookhaven National Laboratory. He said that the Reference Energy Systems approach shows the technical structure of the linked operations required to apply a resource to a given end use. Both presentations were intended to suggest how manpower modeling, however imperfect today, can be integrated into large scale technological systems such as energy.

In his paper, Gary Mader discussed the Energy Supply Planning Model developed by the Bechtel Corporation for the National Science Foundation. The objective of the study, which is supported by the ERDA, is to develop the computational tools and the data base for calculating the resources that are needed to operate supply facilities for future energy programs. Mader said that the model addressed the questions relating to the capital, manpower, and materials that will be needed for various energy industries and the timing for each of these resources.

Hugh Folk described the model being developed by the Center for Advanced Computation at the University of Illinois. This model is designed to project the scientific and technical manpower for alternative economic and energy scenarios. Folk observed that even though it is extremely difficult to recognize all of the interdependencies, the model is capable of modification as new data are received or as new scenarios are perceived. The model will be available to users over the Advanced Research Project Agency's computer network (ARPANET).

At best, models can only provide an indication of future trends, Warren Veissman, Jr. pointed out, but cannot predict the future with any certainty. Richard Freeman discussed a cobweb model, which illustrates the delay between the decision to enroll in engineering school and entrance into the labor market. This model incorporates the supply of engineers and starting salaries during the period 1948-72. Freeman's paper "A Cobweb Model of the Supply and Starting Salary of New Engineers," is not included with this proceedings having been published prior to the conference in Industrial and Labor Relations Review, (Vol. 29, No. 2 January 1976, Cornell University Press).

The Economic Growth Model System developed by the Bureau of Labor Statistics of the Department of Labor was described by Ronald Kutscher. Its forecasts are the most detailed and comprehensive available, Kutscher claimed. Government officials, vocational counselors, and manpower and educational planners rely heavily on the forecasts. Kutscher cautioned, however, that manpower requirements should be considered as only one dimension of policy planning.

S. Clifton Kelley discussed the conceptual and institutional requisites for manpower planning in policy analysis and formulation. He examined the state-of-the-art in estimating future manpower requirements and the effects of conceptual and institutional factors on knowledge generation and policy analysis. In addition, Kelley suggested possible means for enhancing the policy value of manpower planning.

The final panel, concerned with whether a new approach is needed to modeling, as well as the do's and don't's of modeling, was chaired by Courtland D. Perkins. The discussions have been summarized in this report of the proceedings by John Alden, the conference co-chairman and appear at the end.

OVERALL PERSPECTIVES ON MANPOWER MODELING

Charles E. Falk

It is difficult to introduce a panel that is composed of so many experts who are likely to discuss most aspects of manpower modeling and simulation. Consequently, to prevent repetition, I will not delve into their particular subject areas. Rather, I will try to provide some overall perspectives on modeling since I suspect that the panelists will concentrate pretty much on the models themselves.

I hope that all of us realize that the main purpose of modeling is not necessarily the production of predictions or forecasts, but rather the development of a better understanding of the manpower system with which we are dealing and of the factors that drive it. Once this is achieved even to a limited extent, then models and what they forecast can help deal with current manpower problems, such as unemployment or underemployment, and we can try to analyze future situations and produce forecasts of supply and utilization both from a quantitative and qualitative point of view. We can also try to address such questions as: what will be the future utilization of scientists and engineers and what kind of training will they require? Finally, and this is of major importance, the results of these studies can be used in both a micro- and macro- fashion for policy development at the institutional, state, or national level.

Obviously, with this broad potential for utilization, we have quite a number of users who are eagerly awaiting the results of these model studies. For example, to consider an individual, we have the student who has chosen an engineering career. Having made that choice, he is probably worrying about a field of specialization, such as electrical, mechanical, or nuclear engineering. To make these career decisions, students need to know the outlook for each potential choice.

For almost the same reasons, colleges, counselors, and teachers are interested in the future employment trends so that they can develop the curricula to prepare the students and to counsel them on the various job possibilities. In fact, in some academic institutions, models have determined the size of classes. The impact of models may be even greater in the future.

Employers are also interested in what manpower studies show. The extent to which an employer can fill personnel needs will be an important factor in planning for future projects and also, and this is not unimportant, the costs of these projects. After all, the salary of engineers, like that of any other profession, is somewhat dependent upon the balance between the demand and the supply. If there is a shortage of engineers, salaries will go up; if there is an excess, salaries may not rise quite as fast. This can have an important impact on the economic planning by industrial firms. Consequently, these firms are more interested in supply-demand balances from an intermediate or short-term point of view rather than a long-term view. I am using "short term" to cover about 3-5 years and "long term" 10 years or more.

Finally, the professional societies and the government are interested in model studies. These studies can identify problems which require solutions on a regional or national scale as well as alternative solutions for corrective actions. With a little luck, the analyses can stimulate the kind of action required from organizations such as professional societies or governmental agencies.

Now, with this demand for forecasts, those of us who are in the modeling business have to be careful that we do not mislead the users of manpower studies. We must remind them that manpower models deal with the most complex mechanisms in this world, namely human beings. Furthermore, the system in which professional manpower operates is also a very complex one. There are many factors at play and there are many single and multiple interactions. Those of us who have grappled with these problems know quite well that we do not really understand the nature of these interactions. We know that they exist, but we have not been able to develop good quantitative ways to describe them. We have to be careful to emphasize that present models are still relatively crude simple analogs of very complex systems.

That said, we can take pride in the improvement in the ability of models to predict future developments in the manpower field. From my vantage point, the rate of improvement has accelerated considerably in the last four or five years. But we still have a long way to go.

I also believe that developers of models and forecasts have a responsibility to point out explicitly the assumptions. Frequently, some of these assumptions are implicitly contained in the model. Even if all the assumptions were explicit, no two people would necessarily agree on the same set. Users who do not agree with the assumptions must be able to take those assumptions into consideration when they use the results of a model. Since models are not necessarily equally sensitive to variation in all their variables, it is useful to have some kind of sensitivity analysis which indicates what happens if only one variable is changed. Then, at least for those cases where the model is simple, the user can alter assumptions and see what the results would be under different circumstances.

These are the general points which I would like to emphasize: assumptions should be explicitly stated, different scenarios should be evaluated, and sensitivity analyses should be presented.

In considering models in the manpower area, one deals primarily with two separate but strongly related entities. I briefly would like to cover them. In the process I will review the current situation since this might provide some useful background information for this meeting.

The first entity is supply, specifically, the supply of engineers. This supply is dominated by the new degree holders who are coming into the labor force. Figure 1 indicates roughly the relative magnitude of the current engineering labor force and the number of new engineers in the years 1970-85. The engineering labor force totaled about 1,200,000 in 1975. A model developed at the National Science Foundation (NSF) estimated the 1970-85 supply of new engineers at the baccalaureate, masters, or doctorate level. As the figure shows, these new engineers are likely to amount to almost 25 percent of the labor force that exists today. Actually, of course, in ten years time that labor force will have been reduced somewhat by attrition.

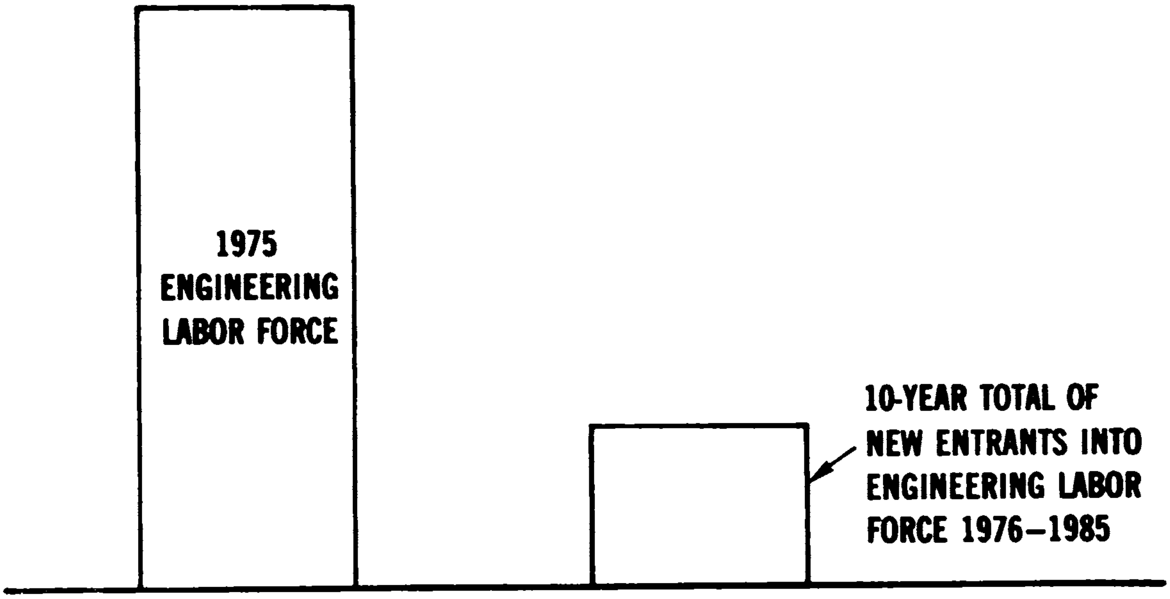
The other major component of manpower models is utilization. Seventy five percent of the engineers are employed by industry and business. A fairly large number of engineers are in government and the rest are located in academic and nonprofit institutions.

These engineers engage in a variety of activities which can be about equally split into three major subaggregates. One is research and development; the second is management; and the third covers "other activities," including anything--production, consulting, quality control, etc.--that still uses engineering skills. We need a good grasp of what engineers are doing today before we project what engineers may be doing tomorrow.

In the course of the conference, four panelists will present descriptions of the models they have developed. Although I have not seen their papers, judging from their previous work I believe that you will be exposed to quite a bit of variety. The models presented will include dynamic models based on systems analysis techniques, models which use economic input/output analysis, and other models of a more pragmatic nature.

You will not have the benefit of a specific presentation of the model which we have been developing at the NSF, so let me give you a brief summary. There are two reasons why this model is not on the agenda. In the first place, I can discuss it briefly now; and secondly, it deals with engineering doctorates, a relatively small segment of the engineering manpower group. Nevertheless, I believe many parts of the methodology could be just as well applied to the non-doctorate population.

Upon examining the trends of the last 10 years in both the supply and utilization of engineers, we noticed that some marked structural changes in both supply and utilization occured around 1970. We then identified and examined the factors responsible for these changes and evaluated the likelihood that the same factors might be at work during the next 10-year period. We concluded that they probably would be, although in a somewhat attenuated fashion. This was especially true in the supply area where, for example, there had probably been an overreaction among students and also among employed engineers to the drastic changes of the early 1970's. We assumed that, while this type of reaction would still prevail for the next 10 years, it would not be as severe. We then used simple regression techniques to project various components of the system but, because we felt that the factors of the



SOURCE: National Science Foundation

Figure 1

last five years would be the dominant ones, we gave them double weight.

Our model is not what you would call a dynamic one. However, it is important to realize that it does have some implicit feedback loops. Certainly the supply during the last five years has been very much affected by what has been happening in the utilization area. We have seen this feedback in the past and we are projecting it into the future. We are not, however, making fine adjustments every year as has been done in some of the models which you will hear about this morning.

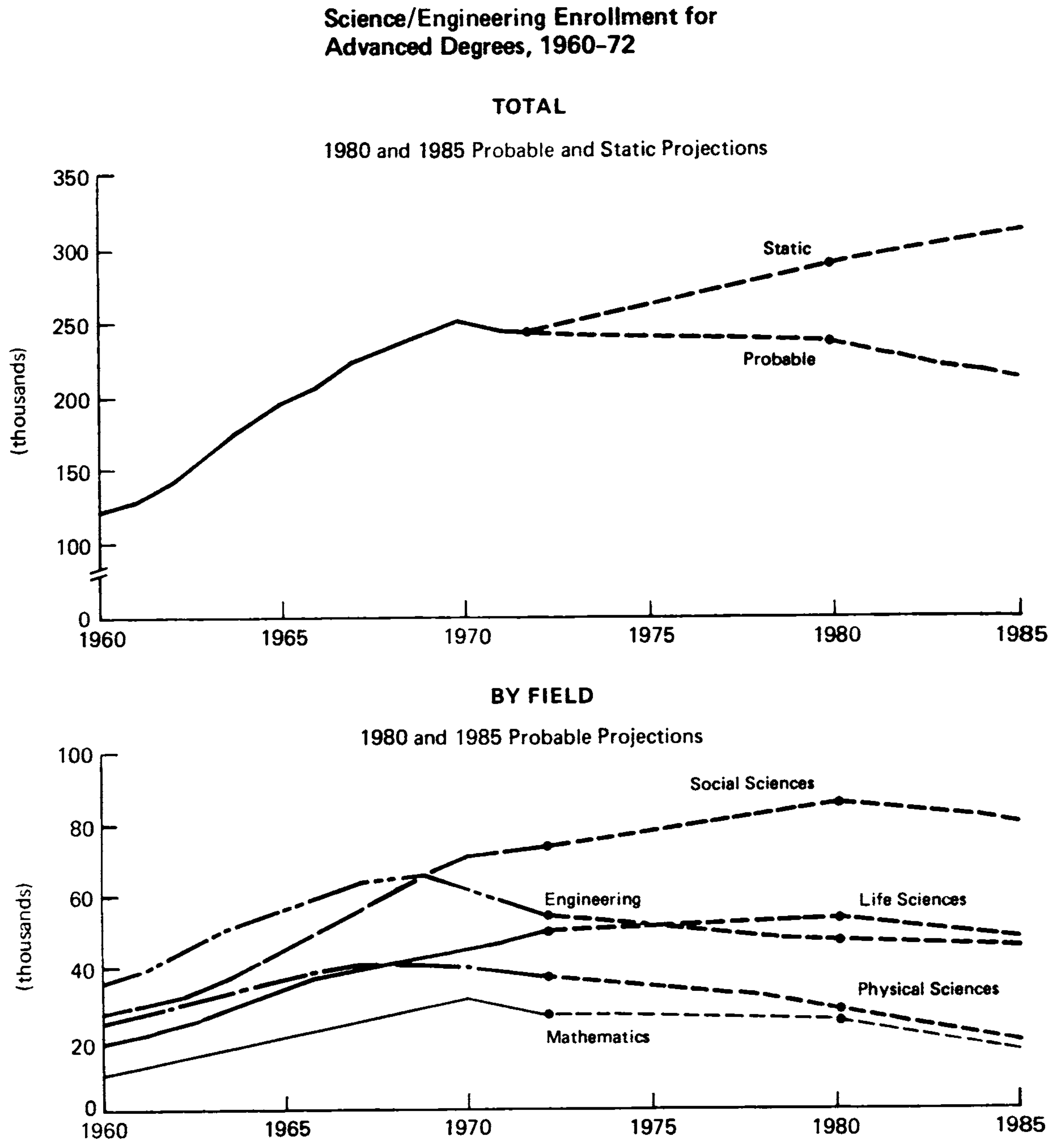
Using this methodology, we assessed the supply by looking at several factors. We started with the 1972 base, and then subtracted those engineers who would leave the system because of death or retirement, those who emigrated from the U.S., and those who moved into another profession or into non-professional occupations. This latter is an important factor about which we unfortunately know relatively little at this point.

In addition to these factors that decrease the base, there are others which add to it. Principal among these are new degrees. New degree holders are very important because they are pouring out of the pipeline. Immigration and entry from other fields also add to the numbers of engineers. To some extent, entry from other fields is another unknown. We have data now from our post-censal surveys which give us some information on this factor, but at the time we developed the model this information was not available.

We could have used an available projection to estimate the number of new degree holders. We chose, however, to develop our own model of the flow of students through the system of higher education. This we did in four steps. First we started with the number of 18 year olds entering college. We next took a look at how many of these would receive a BS degree in engineering. We then went on to examine the factors which would determine how many of them would enter graduate school. Finally we determined how many of those entering graduate school would proceed to a doctorate.

We did this quite carefully, particularly with respect to temporal spreads. Not everyone goes to college when he or she is 18 years old; not everyone gets a degree exactly 4 years later; and certainly not everybody goes to graduate school in the fall following receipt of the baccalaureate degree. In each of these phases, we used our projection technique applying double weights where they made sense. Sometimes we had to modify this methodology when the factors did not seem to apply, for example when the results gave us zero supply by 1985--a sure sign that something was wrong.

There is not time here to go into all of the details, but I thought you might like to see the projections which this degree model produces. Figure 2 shows what happens to graduate enrollments. I should mention that we had essentially two models--the one I have been describing we call the "probable" model, since we think it is more likely that the results coming out of it might coincide with what the future will hold. The other one is called the "static" model. In it we gave equal weights to each of the last five years. The static and probable results are quite different; chances are what is going to happen will lie somewhere in the area between the two.



Science/Engineering Enrollment for Advanced Degrees, 1960-72

TOTAL

1980 and 1985 Probable and Static Projections

BY FIELD

1980 and 1985 Probable Projections

NOTE: Dotted lines from 1972 to 1980 and 1985 serve only to connect the actual data with the projections and have no value in themselves.

SOURCES: National Center for Education Statistics (HEW) and National Science Foundation.

Figures 2 and 3

Figure 2 also shows what might happen to engineering graduate enrollments. Notice that the curve declines. We did not develop actual numbers on a year-by-year basis; we only calculated numerical results for 1980 and 1985. Therefore, lines between 1972, 1980, and 1985 are just connecting lines for the last three points.

Figure 3 shows the same information for the number of engineering doctorates and also illustrates what may happen to some of the other disciplines. The social sciences shoot up sharply while most of the other fields stay level or decrease. Engineering has a projected decrease from the peak in 1970, but this decrease is not nearly as severe as the one indicated for the physical sciences. That, in a nutshell, is how we handled supply.

In the case of utilization, we disaggregated engineering utilization, or for that matter utilization for all the doctorates, into three groups--academic, nonacademic R & D, and other types of activities. We related the academic utilization to enrollments and carefully separated undergraduate from graduate enrollments because of the difference in teaching loads and student to faculty ratios. Nonacademic R & D was correlated strictly to the availability of R & D dollars.

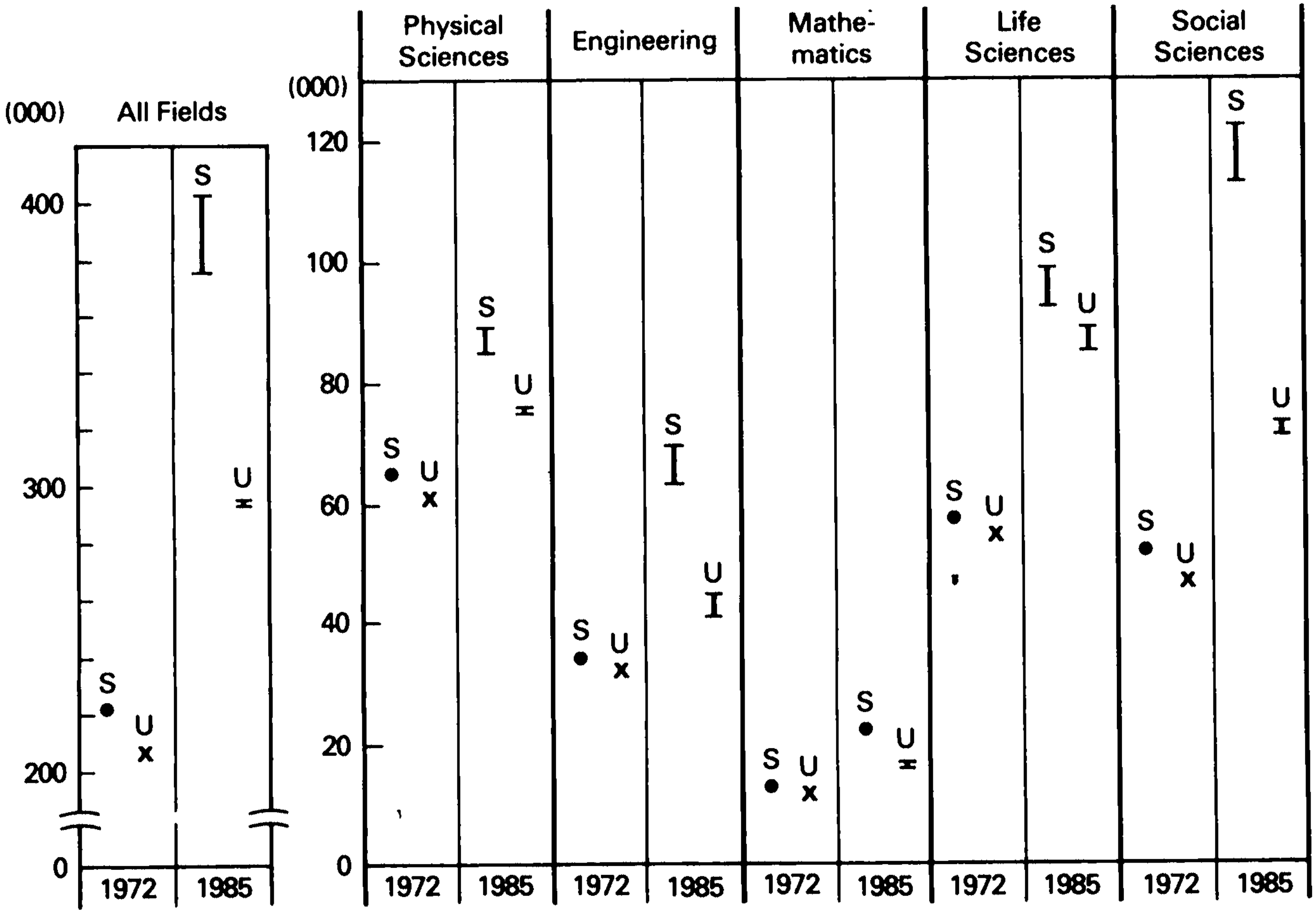
Here we used another model of ours which provides analyses of what future national R & D funding levels might be. This second model, incidentally, does not produce a very optimistic outlook. If we adjust for inflation and use "constant" dollars, the model seems to indicate that there will only be an increase in R & D dollars of the order of about 1 to 3 percent per year.

The most difficult activity to model was the one for non-academic, non-R & D, or "other" activities. Here we worked backwards, using the results of projections made by the Bureau of Labor Statistics of the total number of scientists and engineers in all types of activities. These are similar to those which Dr. Bezdek will talk about today. We then calculated the number of doctorates by projecting the doctorate to nondoctorate ratio for all types of science and engineering employment. From these two information elements we deduced the total number of PhD's from which we then subtracted the number we had projected in R & D and in academic employment. The balance represented those doctorates in "other" activities.

By adding the academic, non-academic R & D, and "other" utilization projections, we finally came up with the total estimates shown in Figure 4. As is evident, the model indicates the potential for a rather marked oversupply. However, this does not necessarily point toward extensive unemployment. Even in 1972, about 9 percent of the scientists and engineering doctorates were not working in scientific and engineering activities. But the actual unemployment level among engineers and scientists was relatively low--on the order of 1 to 1.5 percent. What the figures show is that these individuals were engaged in non-scientific or non-engineering activities. We also know from our surveys that most had chosen this career path because they were offered better promotion possibilities, better salaries, or because they became interested in an activity that was outside their area of training.

The model seems to indicate that there may be an over-supply of

Supply and utilization ranges of science/engineering doctorates, 1972 and 1985



NOTE: Vertical bars indicate range between Probable and Static Model values of supply and utilization.
SOURCE: National Science Foundation

Figure 4

engineering doctorates. I should point out that engineering is the one disciplinary area where we feel most uncomfortable with out projections. We built into the models various enrichment rates--enrichment being defined as the fraction of the science or engineering positions that are filled by doctorates. There is no question that, as supply exceeds utilization, higher levels of education attainment are required for jobs. This is especially true in academia, where in the last 4-5 years virtually all new faculty appointments in 4-year colleges and universities have been on the PhD level. That was not the case in the previous 10 years because there just were not enough PhD's.

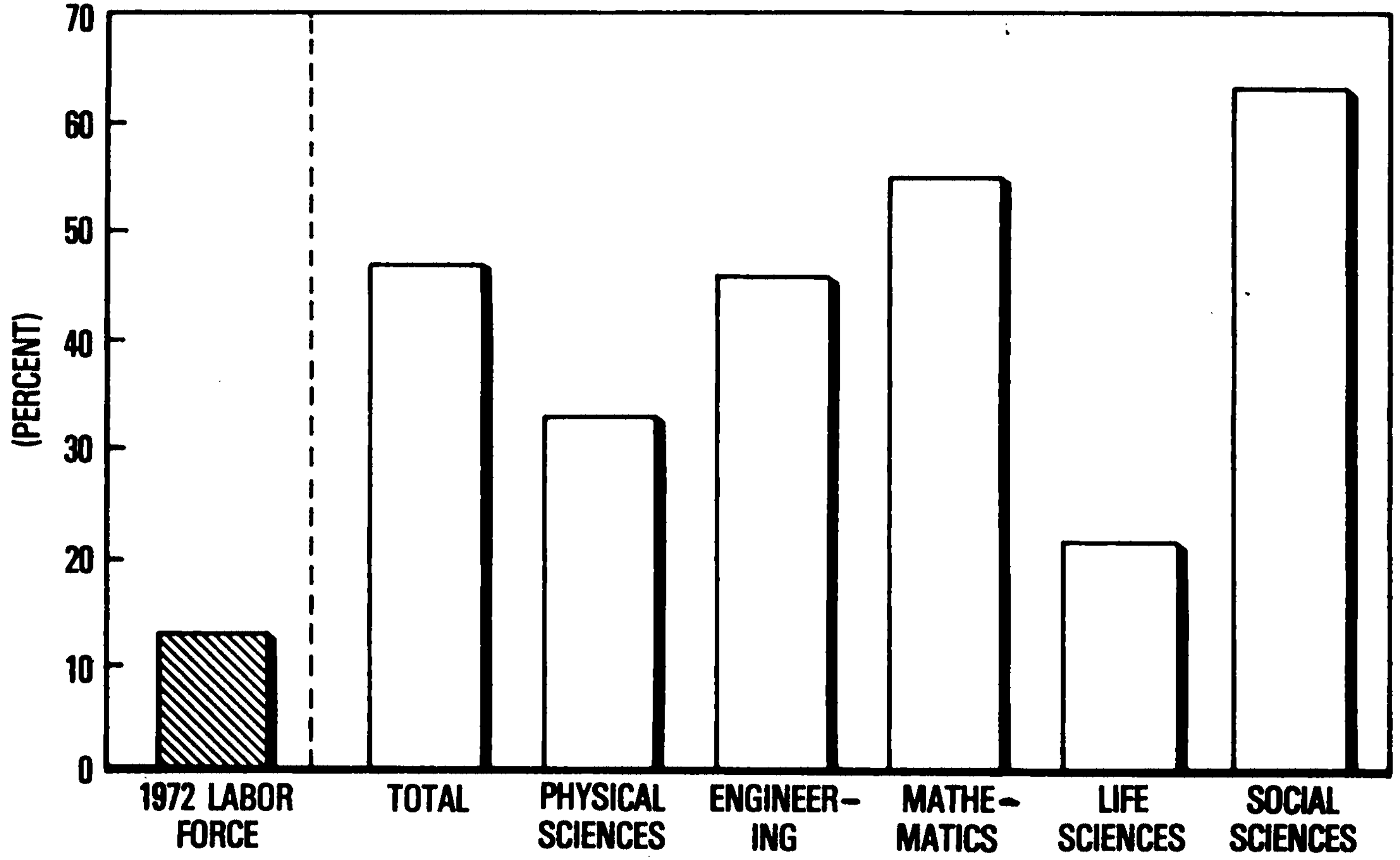
We did not develop different enrichment rates for separate disciplines. Thus, we used the same enrichment rate for engineering that we used for the other disciplines. I suspect that industrial enrichment rates for engineers should be somewhat higher than the average rates actually used in our model, especially if there will be a shortage of engineers with lower degrees. If this is the case, the supply-utilization gap would narrow.

In analyzing these projections, one should not concentrate on the numerical magnitudes of the supply-utilization differences. True, they are interesting but one should be aware of the numerical imprecisions. What is important is the distinct tendency toward an over-supply. Furthermore, as Figure 5 shows, another important broad feature emerges from the projections, which has important implications for students and academic institutions.

Remember that we had four activity categories in our model--academic, R & D, other, or being out of the field completely. The chart shows the fraction of new openings that may be in the last two categories, namely not in R & D, not in academia, but somewhere else. For comparison with the current situation, note that about 15 percent of the current labor force is engaged in these two activities. Engineers are not very different than the average.

On the other hand, if one then looks at the projected positions which are going to be filled primarily by new graduates, one observes a drastic change. In the case of engineering, almost 50 percent of the doctorates are likely to be working neither in academia nor in R & D. This has some rather important educational implications for new science and engineering PhD's, and the institutions that train them and I do not think it is necessary for me to spell them out in detail.

PROPORTION OF NEW OPENINGS FOR S/E DOCTORATES IN OTHER S/E AND NON-S/E ACTIVITIES, 1972-85



SOURCE: National Science Foundation

Figure 5

SOME CRITICAL ISSUES IN MANPOWER MODELING AND FORECASTING

Roger H. Bezdek

My remarks will have three major objectives. First, I will discuss the rationale for manpower forecasting and the "proper" use and interpretation of manpower forecasts in a democratic society. Second, I will present a brief summary of the various types of models and methods used to generate manpower forecasts and give a short evaluation and critique of each method. Finally, I will discuss a number of issues which I feel are critical in the area of manpower forecasting.

A useful place to begin is with the distinction that economists are fond of making between forecasts and projections. Loosely, we may define a forecast as that which will happen or that which is most likely to occur. A projection, on the other hand, may be defined as a conditional forecast, that is, a projection is usually based upon explicit assumptions.

While this is a distinction that economists often make, I wonder if it is really meaningful. An example of a forecast--a manpower forecast--would be the following. In 1980, I expect the requirements for engineers to be approximately 991,246. A projection, on the other hand, would be of the following nature. Given a federal government policy of high spending for defense and research and development, I would expect the demand for engineers to be 1,250,000 in 1980. Seen in this light, projections are obviously superior to forecasts because projections are based on specific assumptions.

The reason I wonder if the distinction between forecasts and projections is meaningful is that I cannot conceive of a situation in which a forecast could be useful. Any estimate of future events must be based on certain assumptions concerning the economic, technological, and social environment. A forecast is inevitably based on such assumptions but, unfortunately, these assumptions are often not stated explicitly. Empirically, the only useful estimates we have to work with are projections or, if you wish, conditional forecasts--forecasts conditioned upon specific events.[1]

Moving to my first major topic, I want to consider the question of why we make manpower forecasts. Obviously, manpower forecasting is great fun. It gives one hours of pleasure and provides a rationale for an endless series of meetings, seminars, workshops, and conventions. Less facetiously, however, I think it is important to consider the proper role of manpower forecasting in a democratic society. This is another question to which economists have devoted considerable attention in recent years. Many reasons have been devised for relying or for not relying upon manpower forecasts.

We can list a number of "valid" reasons for making and utilizing manpower forecasts--reasons which most economists and researchers would tend to agree on.[2] First of all, manpower forecasts can serve as a type of early warning system directing attention to the unforeseen consequences of current market responses and developments. This is important for several reasons. For example, the average period required to "produce" a Ph.D can range anywhere from five to eight years, depending on various factors. In talking about the optimal or desired level of Ph.D production in 1985, we must know at least eight years in advance the type of manpower requirements for Ph.Ds likely to occur in 1985. If we wish to affect this level or structure of requirements, we have to begin planning by 1977. Similarly, on the demand side, since the effects of many economic and social changes take years to work themselves out, a mechanism is needed for anticipating in advance (forecasting) the effects on the demand side of the market of these perturbations.

A second, widely accepted reason for making manpower forecasts is to estimate and evaluate the potential impacts of large scale government programs on the labor market.[3] Because the federal government has such a large influence on the demand side of the market as an employer of scientists, engineers, Ph.Ds, and other types of highly skilled labor, and because of its significance in influencing future supplies, forecasts are a necessary and valuable policy tool. Whether one approves or disapproves, realistically, we must recognize that the federal influence on the labor market is very extensive.

A third valuable use of manpower forecasts is as a device for organizing and analyzing information about market phenomena that are taken as given by individual decision makers. In a competitive market where individual actions do not alter outcomes, market-wide phenomena fall outside the responsibility of individual participants, and thus require outside analysis. For example, the effects of broad economic or demographic changes on the demand for a college education are not the concern of a single university. They are clearly vital, however, to the entire higher educational system and must be so examined.

These are three reasons for relying upon manpower forecasts on which most economists and educators can agree. When we move beyond these, however, we enter into areas of considerably more controversy.[4] One of these that I would like to discuss is the issue of whether or not manpower forecasts can be useful in aiding the career decisions of students.

There are two views on this. The negative one states that manpower forecasts are not significant in affecting career decisions because students tend to ignore the advice of guidance counselors.[5] This may or may not be true. Certainly, many students tend to ignore the advice of guidance counselors. On the other hand, I believe a number of studies have shown that the influence of many high school and college guidance counselors is quite significant.

Indeed, my own experience has been that many students and young professionals in the early 1970's entered various professional and scientific occupations in the belief that a nationwide shortage and critical need existed in these areas. When they were graduated or earned their professional degrees and found out that there was a severe excess supply of people in their fields, they were bitter. They felt that they had chosen careers requiring demanding courses of studies on the basis of a perceived national need and were frustrated when they completed their studies and found out there was apparently no national need for their skills.

There are two other uses of manpower forecasts which have been labeled as invalid. One of these is the use of manpower forecasts in a national economic and manpower planning system. This is not acceptable in a free society, goes the argument, because we do not plan on the basis of national priorities or any other criteria. The hypothesis is that in the United States there exists a democratic, free-enterprise system which is not compatible with economic or manpower planning. At the extreme this argument must be accepted. On the other hand, I had the privilege last year of participating in hearings on the Humphrey-Javits Bill which would, in effect, establish a national economic planning mechanism similar to the Leontief-Woodcock proposals. Of course, the words democratic and planning may be mutually contradictory. Nevertheless, assuming that such a planning mechanism is eventually established in this country, manpower forecasts would become as critical as those for other variables in the system.

The second "invalid" application of manpower forecasting is for use in university planning. That is, forecasts may be required to advise educators on the number of slots to be offered in college courses and, thus, determine the supply of graduates and specialists. The argument is that while forecasts may be of some value, the evidence of the past 25 years is that colleges and universities are highly responsive to market needs, as reflected particularly in student educational demands. In working with educators at the university level, I have found that they are almost unanimous in rejecting the use of manpower forecasts in developing long-range university goals and plans. I have also noted, however, that in the past several years governors' offices and legislatures in many states are forcing the consideration of manpower supply and demand forecasts upon reluctant university planners.

The second major theme concerns the various models and methods which have been developed for making manpower forecasts. There are obviously many types of both simple and complex methods for making manpower forecasts. We can distinguish several broad types of manpower forecasting models and methods and these can be grouped into the seven categories discussed below.[6]

One simple way of making manpower forecasts is to use trend methods, which are based on the assumption that the future will be a continuation of the past. Trend methods do not make assumptions about cause and effect but simply look at the surface of events. They focus on only one variable at a time, such as total manpower or electrical engineers. There are a number of variations of the trend method, one of which we may define as naive extrapolation. As its name suggests, this is a simple method where a trend line is extended either by eye, by least squares, or by moving averages. Another somewhat more sophisticated trend method is exponential smoothing, which is an extention of the idea of moving averages.[7] The logic of exponential smoothing is that more emphasis should be given to recent information. For this reason, the moving average is calculated using larger weights for more recent figures.

Finally, regression methods are an extension of least squares and permit the trend line to be curved or a number of other valuables believed to be related to the variable of interest to be taken into account.[8] Unfortunately, trend methods have the obvious disadvantage of assuming that the future will be a continuation of the present. While in a limited number of cases trend procedures may prove to be adequate, they can hardly be relied upon to produce accurate manpower forecasts.

A second type of manpower forecasting methodology comes under the heading of comparison methods, which are based on analogy.[9] If we can find another situation similar to the one we wish to consider, the few differences among the many similarities may be significant. For example, the manpower requirements of underdeveloped nations are often estimated by examining the structure of the labor market in more developed nations.

Thus, if we wish to develop long-range comprehensive manpower programs for a developing nation such as Israel, we may wish to observe the structure of the labor market in Western Europe, Canada, or the United States. The premise is that as Israel becomes more economically and technologically advanced, the same general types of manpower skills will be required as in countries which have already achieved a higher level of economic development. While this is certainly logical, I feel that comparison methods can be useful only in a qualitative sense. While we may be able to say that a developing nation will require a certain general level and mix of manpower skills, given the many dissimilarities involved, it is virtually impossible to quantify these estimates.

A third approach to manpower forecasting utilizes operation research methods, such as linear programming, dynamic programming, goal programming, network-flow analysis, game theory, and so forth.[10] Here, I will discuss only a few of these generally well-known methods. Linear programming is relevant to manpower planning and forecasting in two ways. First, manpower supply may be a constraint in the linear programming formulation of a company's corporate plans or a country's national plan. In this way manpower supply is taken account of in the plan.

Second, the organization or the state might want full utilization of the labor force subject to not making a loss, if it is a corporation, or to not earning excessive inflationary pressures, if we are talking about state planning. The linear program would then find the best mix of products and personnel for this purpose. Dynamic programming is a technique for finding the maximum of a function of variables subject to constraints on the values the variable can take and on their sum.

An Operations Research method which has thus far not been applied very widely in manpower forecasting is the use of game theory. Admittedly, the practical restriction of the method to two person, zero sum is highly restrictive, and the criteria for decision making present problems of choice. However, as a manner of exploring problems game theory may have a certain attraction. For example, if the British automobile manufacturers had thought in this way they would have hopefully seen how they were putting themselves at the mercy of small groups of workers in their quest for cost cutting and might have decided to accept a slightly higher unit costs for the sake of avoiding very costly plant shutdowns.

The fourth general method we can identify is that of using stochastic models, such as Markov models and labor wastage models. Labor wastage models represent one of the earliest developments in the area of manpower forecasting and require the estimation of the wastage characteristics of a cohort of workers in a firm.[11] Various factors affect the propensity to leave, such as the length of service, age, sex, salary, and factors related to work and the outside environment. Length of service seems to be the most important, so much so that models employing only this variable have been developed.

A Markov model, on the other hand, also considers flows into the organization and between grades. Grades may be defined as groups of workers such that the flows between them are of interest. They are often hierarchical. The flows are assumed to be governed by transition probabilities, and the grades are assumed to be homogenous and independent with respect to these probabilities. The Markov model is normally defined with constant transition probabilities over time, and with discreet time, although either assumption can be modified rather easily. Other types of stochastic models include renewal models, bottleneck models and probability simulation models.

The fifth major approach to manpower forecasting concerns the use of various types of economic models. These include the standard Leontief input-output model, productivity models (in which total manpower requirements are determined from total output and productivity), production function models (which assume a linear relationship between inputs and outputs), and different types of econometric models. Many types of economic models have been applied to manpower forecasting, and I have found combining different economic/econometric submodels into an integrated system to be a useful approach to the forecasting of manpower requirements. This approach can be illustrated by briefly discussing one such model I have developed and some empirical results obtained from using it.

This integrated econometric-interindustry- manpower model consists of five major subsystems.[12]

1. A stochastic economic growth model which estimates basic economic parameters and control data for the forecast target year.

2. A set of expenditure elements which translates social priority choices into allocations of funds to specific public and private economic activities. There are presently 220 activity categories in the model.

3. An activity-industry matrix which translates expenditures on economic activities into direct industry output requirements. This matrix represents a disaggregation of the final demand sector of an open input-output model and contains a distinct final demand vector for each economic activity.

4. An interindustry-employment matrix which generates total industry employment requirements. This component of the system is the Leontief inverse matrix transformed into labor units.

5. An industry-occupational matrix which translates industry employment demands into occupational manpower requirement. This is a modified version of the matrix of the percent distribution of occupational employment by industry, developed by the Bureau of Labor Statistics (BLS).

Three different manpower demand projections were made for 1980. Each projection was made by changing the expenditure elements in the model while holding all other components of the system constant. The expenditure reallocations were designed to represent hypothesized reorderings of national priorities and federal spending programs in the near future. The manpower requirements likely to result from each were simulated.

The first expenditure distribution analyzed was a "status quo" budget which, given recent trends, was judged to be the one most likely to exist in the near future. The major assumptions used to construct this alternative are similar to those used by the BLS in its long-range employment studies. The second set of manpower projections is based on a "social welfare" expenditure alternative representing a major commitment to domestic, social, and economic programs. This alternative implies major cutbacks in most areas of defense, aerospace, and research and development spending, and a more than proportionate increase in funding for health, education, welfare, and environmental programs. The increase in public spending by all levels of government is offset by taxes on private capital formation and personal consumption patterns.

The third priority alternative is just the opposite of the one described above. It specifies substantial increases in all defense-oriented programs at the expense of nondefense programs. In this "defense" alternative, most civilian programs are cut substantially to finance the military buildup.

One of the major purposes of this exercise was to determine how the hypothesized changes in national priorities and government spending would be likely to affect future requirements for engineering and scientific manpower. The alternate requirements for scientists and engineers generated under each of these scenarios are given in Table 1. The manpower requirements for these occupations were found to be sensitive to the spending shifts simulated. This is but one illustration of the contributions which large scale economic models can make to manpower forecasting.

The sixth type of manpower forecasting methodology we can identify is that of using structural or demographic models. This groups of models looks upon the manpower system as if it were a sort of ant hill, with groups at certain places and continual movement between these groups. One such model is the demographic model, which considers the population as a series of groups classified according to age and sex.[13]

Another type of structural model is the ecological model, which is based on the theory of what is called the ecology of the firm. The ecological principle is that the rate of growth of a population is proportional to the number available to propagate and to the environment still available to expand into.[14] Researchers have suggested that a manpower equivalent might be that promotions should be proportional to the number of promotional vacancies. The first element of this would appear to be satisfied by a principle of fairness in promotion that should actually exist.

The seventh and final method we can identify comes under the label of nonmathematical methods. These include such techniques as summing individual employer estimates, delphi techniques, and so on. The usual rationale for using nonmathematical methods is either the lack of mathematical sophistication of the user together with a fairly simple problem, or complexity combined with shortages of data so that no known techniques apply. These are the only methods that can take all the information into account, including experience and nonquantifiable factors such as fashion and taste.

One very simple nonmathematical technique which is, unfortunately, used rather widely is that of estimating the manpower requirement of an industry by asking each firm to make its own forecast and simply summing them. This method has been found to be entirely unsatisfactory, apparently, because individual employers are inherently overly optimistic or, as the case may be, overly pessimistic and subsequently often miss the mark by a wide margin.

The delphi method is a way of arriving at a consensus of opinion. Those whose opinions are sought are each asked for their estimates of the figures in question. These are averaged and then each person is approached again with a statement of the averages and his own estimates, and asked if he would like to reconsider any estimate. These new values are then averaged and the process repeated until no further changes occur. The final averages are then taken as the best estimates. The attraction of the delphi method is that weakly held briefs are given less weight than strongly held ones.

In conclusion, the type of manpower forecasting approach used will depend heavily on the problem at hand. For example, if you are employed by a relatively small firm and you want a "quick-fix" of your likely manpower requirements at some time in the future, some sort of simple, noncomplex, nonmathematical method should be used. If, on the other hand, you are with a government agency or department charged with the responsibility for developing comprehensive nationwide manpower forecasts, you would be of necessity required to use highly sophisticated mathematical methods relying on an extensive data base and computer facilities. It is my opinion that the best overall approach to the problem of manpower forecasting is that of the comprehensive integration of different types of submodels into a complete manpower forecasting system.

The third major topic I would like to discuss here this morning concerns some issues which are, in my view, of critical importance in manpower forecasting. First of all, one extremely important issue is the role of government in influencing both the demand side and the supply side of the labor market. On the demand side of the market the government plays both a direct and an indirect role. The direct role consists of the impact which government policies and spending programs have on the demand for different skills and occupations. For example, a crash government energy independence program would greatly increase the demand for many types of technical and scientific occupations related to energy research and development.

More importantly perhaps, the government has an indirect effect on the demand side of the labor market via the tone of its general economic and fiscal policies. If, for example, the government is successful in achieving rapid rates of economic growth, as was generally the case during the 1960's, one would expect the type of labor market for most skills and professions to develop which we did indeed experience from about 1962 through 1969. If, on the other hand, the government is not successful in achieving the goals of economic growth, full employment, and low inflation, as has been the case since 1969, then we would expect a rather weak labor market, which is, of course, what we have had and are presently still experiencing.

On the supply side, the government also has a significant direct impact through its education and manpower training programs, the provision of scholarships, fellowships, traineeships, and so forth. Indirectly, the government affects the supply side of the market mainly by public relations efforts to influence individual decisions to enter specific areas, such as science, technology, and medicine, for the national good.

Having recognized that the government has a significant influence on the labor market, we must also recognize that the federal government has more often than not acted as a destablizing force on both the demand side and the supply side of the labor market. Examples are not difficult to come by. The violent fluctuations in the demand for aerospace workers and individuals working in the areas of research and development, in defense related industries, and in energy programs--things which this audience is quite aware of--in the past 20 years were caused by rapid changes in government spending in these various areas.

For example, from about 1958 through about 1969-70 the labor market for most categories of engineers and scientists was tight. The reason for this was the heavy federal involvement in the space program, high levels of defense spending, and generous federal support of both basic and applied research and development. Of course, what happened in 1969 was that the bottom of the market for most types of scientists and engineers fell out due to spending cutbacks by the government in these same areas.

Similarly, on the supply side, the government, in its usual shortsighted fashion, has overreacted to current market conditions. The best example of this I can offer is that of the drastic fluctuations in support for graduate education by the federal government between 1955 and 1975. The following statistics illustrate this: In 1968 approximately 52,000 graduate students were being supported directly by the federal government. By 1975 federal support for graduate education in the form of fellowships, grants, and traineeships had declined to less than 7,000.[15] By the end of this decade, we shall be feeling the affect of the drastic decline in support for graduate education in the form of reduced output of individuals in many of these highly technical and scientific areas.

Having recognized and briefly discussed the problem, we must next consider the obvious question--can the government avoid this? While it is easy to recommend the avoidance of such drastic policy fluctuations, there are several inherent problems here. First of all, there is the very convincing argument that the proper role of government spending programs should be to solve national problems or to achieve national objectives, not to create jobs for scientists, engineers, or for any other occupations.

This has not always been clearly recognized. For example, the battle over funding of the American supersonic transport airplane (SST) in the early 1970's was conducted almost as much in terms of bailing out the ailing aerospace industry and in providing jobs for displaced scientists and engineers as it was based on the rational argument for the need, of lack thereof, for an American SST. Today, incidentally, we find much of the same thing occurring with respect to the controversy over the B-1 Bomber. Rockwell International seems to be pushing the B-1 Bomber program as much as a glorified public works program for the aerospace industry as for the increase it would provide in U.S. defense capabilities.

A second major problem here is, of course, political. Given the existence of excess supplies or demands for certain occupations, can we really expect the government to phase out or phase in programs over a lengthy period of time instead of simply reacting to political pressure to do something quickly about the unbalance?

Finally, there is the more practical question, which is of prime concern to us here today, of whether or not we have sufficient knowledge of the future or capability of predicting it to recommend the "correct" government policy. I doubt it.

Another critical issue in manpower forecasting is that of skill transferability and occupational mobility. Indeed, I would rank this as the most important issue in manpower forecasting. If skills are readily transferable and workers are relatively mobile within and between occupations and regions of the country, then the importance of accurate manpower supply and demand forecasts diminishes greatly. To the degree that there are structural rigidities in the labor market, manpower forecasting becomes more important. A closely related issue is the need for a better idea of manpower supply and demand interactions, the role of relative wage rates, and the various types of market adjustment mechanisms which operate in the real world.

Another important issue in manpower forecasting, in my opinion, is that factor the optimists call job enrichment and pessimists call credentialism. Is there any rational relationship between jobs and the supposed or imagined education requirements for these jobs? There is an excellent book with a horrible title which was written several years ago on this topic. The book, Education and Jobs: The Great Training Robbery, was written by Ivar Berg.[16] Berg's hypothesis is that education in the United States is becoming a formalized credentialization procedure which acts as a barrier to the advancement of minorities and the poor. We must determine to what degree this is prevelant in the society today. Are educational requirements for jobs being upgraded because the knowledge and skill required by these jobs are increasing so rapidly, or are they simply being upgraded because the educated manpower is now available on the supply side? For example, if a job which in 1960 was quiet adequately filled by a high school graduate now requires two years of junior or community college or perhaps even a BA, does this represent an optimal use of society's resources?

One final topic deserving mention is that of professional controls on manpower. Limits on the admissions to medical schools, frequently advanced by the American Medical Association before the 1950's, has had a pervasive effect on medical care in the U.S. Such limits have affected the cost and availability of health care as well as, not incidentally, the average salary of physicians. Thus, it is of some interest to me that in the past several years the National Society of Professional Engineers has been lobbying strongly for the authority to restrict admittance to engineering school and, indirectly control the supply of new engineers and average engineering salaries.[17]

TABLE 1
1980 Alternate Occupational Employment Estimates

(in thousands)

Occupation	SQ[a]	SW[b]	Def.[c]
Engineers, Technical	1,529	1,493	1,583
Engineers, Aeronautical	78	70	86
Engineers, Chemical	61	61	62
Engineers, Civil	235	257	232
Engineers, Electrical	332	317	345
Engineers, Industrial	189	178	198
Engineers, Mechanical	282	268	294
Engineers, Metallurgical, etc.	37	35	39
Engineers, Mining	11	11	12
Other Engineers, Technical	301	292	309
Natural Scientists	548	553	550
Chemists	185	188	187
Agricultural Scientists	64	63	65
Biological Scientists	77	82	76
Geologists, Geophysicists	38	39	38
Mathematicians	67	66	70
Physicists	55	52	60
Other Natural Scientists	60	61	53

[a] Occupational employment requirements generated by the 1980 Status Quo expenditure distribution.

[b] Occupational employment requirements generated by the 1980 Social Welfare expenditure distribution.

[c] Occupational employment requirements generated by the 1980 Defense expenditure distribution.

Source: Bezdek [3]

NOTES

1. See the discussion in Chapter 2 by Bezdek [3] and Morton [13].
2. This discussion is based on the material in Chapter 2 by Freeman and Breneman [10] and in Oi [14].
3. A model for estimating the impact of government spending on requirements for jobs and skills is developed in Bezdek [3].
4. See Freeman and Breneman [10], p. 16, Freeman [9] and Oi [14].
5. For an application of manpower forecasts to long-range university planning see Bezdek [4].
6. More complete discussions of manpower forecasting methodologies are contained in Bezdek [3] and [5], Laslett [11], Morton [13], and Ahamad and Blaug [1].
7. A good description of this technique is given in Coutie, Davies Hassell, Miller and Morrell [8].
8. See the readings in Ahamad and Blaug [1].
9. See McCarthy [12].
10. See Laslett [11], pp 7-10
11. One of the earliest developments of this technique is given in Rice, Hill and Trist [16].
12. See Bezdek [3], [6], and [7].
13. See Redwood [15] for a comprehensive application of demographic techniques to manpower forecasting.
14. Young [18].

15. Source: U.S. Office of Education and National Science Foundation

16. Berg [2]

17. See, for example, Walker [18].

REFERENCES

1. Abamad, B. and M. Blaug. The Practice of Manpower Forecasting. San Francisco, Jossey-Bass, Inc., 1973.

2. Berg, I. Education and Jobs: The Great Training Robbery, New York, Praeger, 1970.

3. Bezdek, R. H. Long-Range Forecasting of Manpower Requirements: Theory and Applications. IEEE Press, New York, 1974.

4. ________________. "Long-Range University Planning in View of an Uncertain Future for College Graduates." Journal of Higher Education, Vol. XLIII, No. 4 (April 1972), pp. 267-282.

5. ________________. "The State of the Arts in Long-Range Economic and Manpower Forecasting." Long-Range Planning, February 1975, pp. 31-42.

6. ________________. "The 1980 Economic Impact--Regional and Occupational--of Compensated Shifts in Defense Spending." Journal of Regional Science, Vol. 15, No. 2 (1975), pp. 183-198.

7. ________________. "Impact of the Federal Spending Programs on Demand for Resources." In Reconstruction of Macroeconomics, ed. Mason Gaffney. University of Wisconsin Press, Madison, 1976.

8. Coutie, G. A., et. al. Short Term Forecasting. ICI Monograph No. 2. Oliver and Boyd, London, 1964.

9. Freeman, R. R. The Market for College-Trained Manpower. Harvard University Press, Cambridge, Mass., 1971.

10. ________________ and D. W. Breneman. Forecasting the Ph.D. Labor Market: Pitfalls for Policy. National Board on Graduate Education, Washington, D. C., 1974.

11. Laslett, R. E. A Survey of Mathematical Methods of Estimating the Supply of and Demand for Manpower. Engineering Industry Training Board, London, 1972.

12. McCarthy, C. "Universities and the Future." New Scientist, Vol. 50, No. 752 (1971), pp. 440-42.

13. Morton, J. D. On Manpower Forecasting. W. E. Upjohn Institute for Employment Research, Kalamazoo, Michigan, 1968.

14. Oi, W. Y. "Scientific Manpower Forecasts From the Viewpoint of A Dismal Scientist." Working Paper, No. 7, Industrial Relations Section, Princeton University, May 1974.

15. Redwood, A. L. "Population Projections for Manpower Planning." Unpublished Doctoral Dissertation, University of Illinois (Urbana), 1972.

16. Rice, A. K. et. al. "Representation of Labor Turnover as a Social Process." Human Relations, Vol. 3 (1950), pp. 349-372.

17. Walker, G. M. "Manpower Predictions Draw Fire." Electronics, March 4, 1976.

18. Young, A. "Demographic and Ecological Models for Manpower Planning." In Aspects of Manpower Planning, ed. D. J. Bartholemew and B. R. Morris. International Labor Organization, Geneva, 1971.

A DYNAMIC SIMULATION OF THE ENGINEERING MANPOWER SYSTEM

Vern R. Johnson and L. A. Wiggins

Introduction

This paper describes a dynamic computer simulation of the national engineering manpower education and utilization system. The basic approach originates from an initial study made by the authors and described in the 1975 Manpower Report of the Institute of Electronics Engineers.[1] Two of the major weaknesses of the previous work were the use of second source data and the absence of some form of economic indicator(s). The work described here attempts to overcome these two shortcomings while maintaining the basic simplicity of the original simulation model.

This research includes the following basic assumptions:

- The engineering manpower system is stable enough to be modeled.
- The available data are consistent and factual.
- All engineering disciplines can be grouped together.
- All geographic areas of engineering employment can be grouped.

Other assumptions are discussed later in the paper.

Methodology of Developing the Simulation Model

The model presented in this paper was developed for making short term engineering demand projections. It was not designed to produce numerically correct projections, but rather to give a general indication of the peaks and valleys which are likely to occur within about five years from the time of the projections.

The final model was a small, non-linear model consisting of only seven equations. It was developed by iteratively applying a general modeling program as suggested in Figure 1. The process of developing a suitable simulation was initiated by designing a tentative schematic model of the system. This proposed model was described as a set of difference equations of the form:

$$X(k+1) = f(X(k),\ X(k-1), \ldots,\ U(k),\ U(k-1), \ldots)$$

where: X is the model variable,

U is an input variable, and

f is any function of the two variables.

This set of equations was joined with the general purpose modeling program to establish a dynamic computer simulation of the manpower system. The next step was to augment the computer model with a data base which included a time history of each variable in the system for the last 35 quarters. With this data base, and the computer simulation program, projections were made for the next 20 quarters. Error analysis techniques included in the program along with the advantage of making projections over known periods of history allowed the authors to recognize problems in the simulation model and, as suggested in Figure 1, return and modify the original schematic model of the system and the necessary data base. This iterative procedure was continued until the present model was derived.

The General Modeling Program

The general modeling program discussed above was developed as an aid in model building.[2] It combined many of Forrester's techniques[3] with regression analysis to produce a two-phase modeling approach. A least squares procedure was used in the identification phase to estimate the unknown coefficients in each of the model equations. Because of the format of this procedure, these equations were not limited to linear behavior but included the non-linear and various time delay characteristics necessary to describe this multiple-loop feedback system. In the simulation phase, these coefficients were used with the equations to simulate the system behavior for a specified future time period. During this phase, calculations were made for each of the variables in the equations at one time period before going on to the next. This allows projections to contain the required delay and feedback characteristics without any further dependence on the data base.

The Simulation Model

The model described here had two basic components: one to describe the supply of engineers into the total pool of engineers, and another to indicate the need for their services. These are described in Figures 2 and 3. The circled numbers represent difference equations which correlate the output variables with each of the input variables at their respective locations in the system. In this model it was assumed that the relative

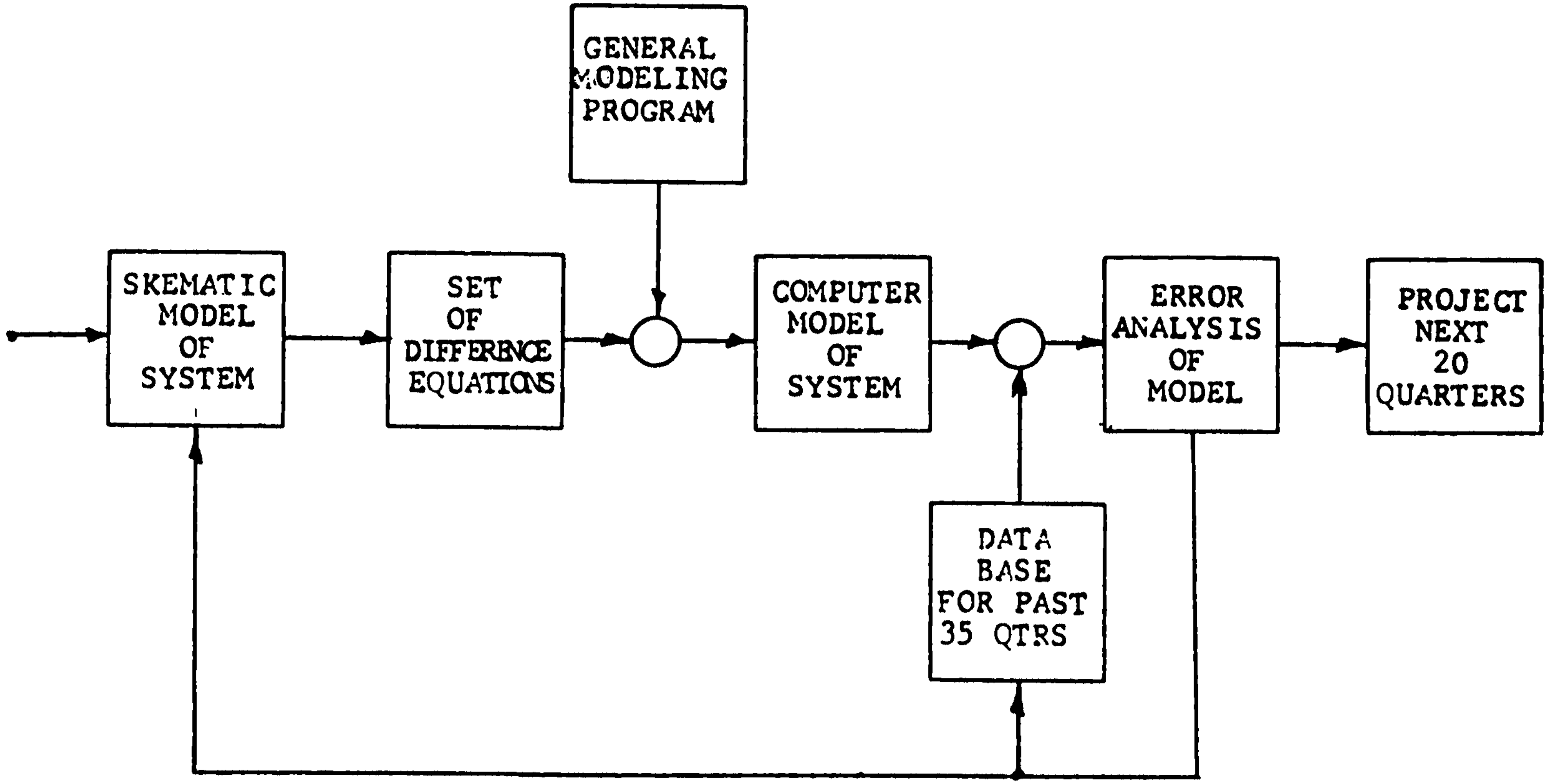


Figure 1. Flow chart describing the procedure for using the general modeling program in an iterative sequence, with error analysis, to create a simulation model of the system and use it to make future projections of system variables.

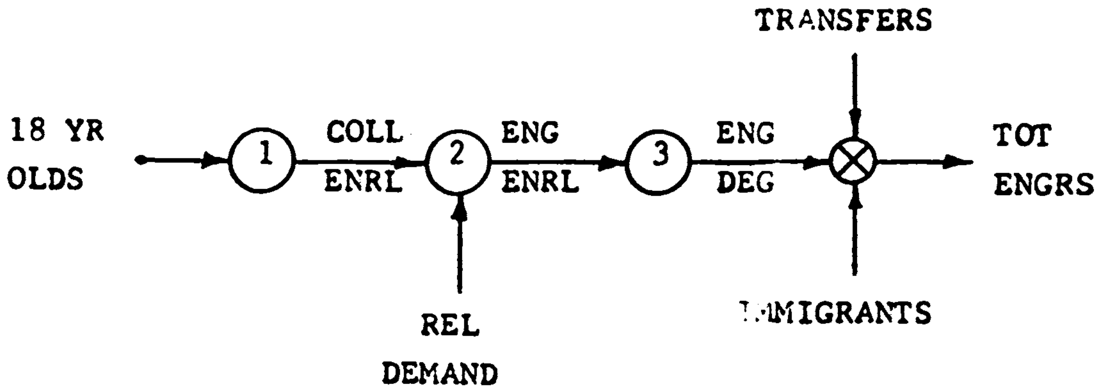


Figure 2. Schematic diagram describing the supply of engineers into the total pool of engineers.

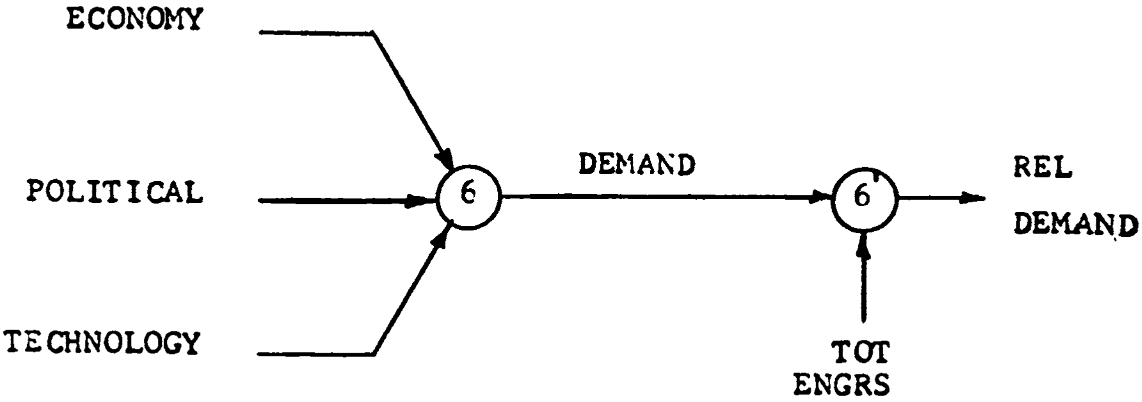


Figure 3. Schematic diagram describing the combined influences used to create the relative demand for engineers.

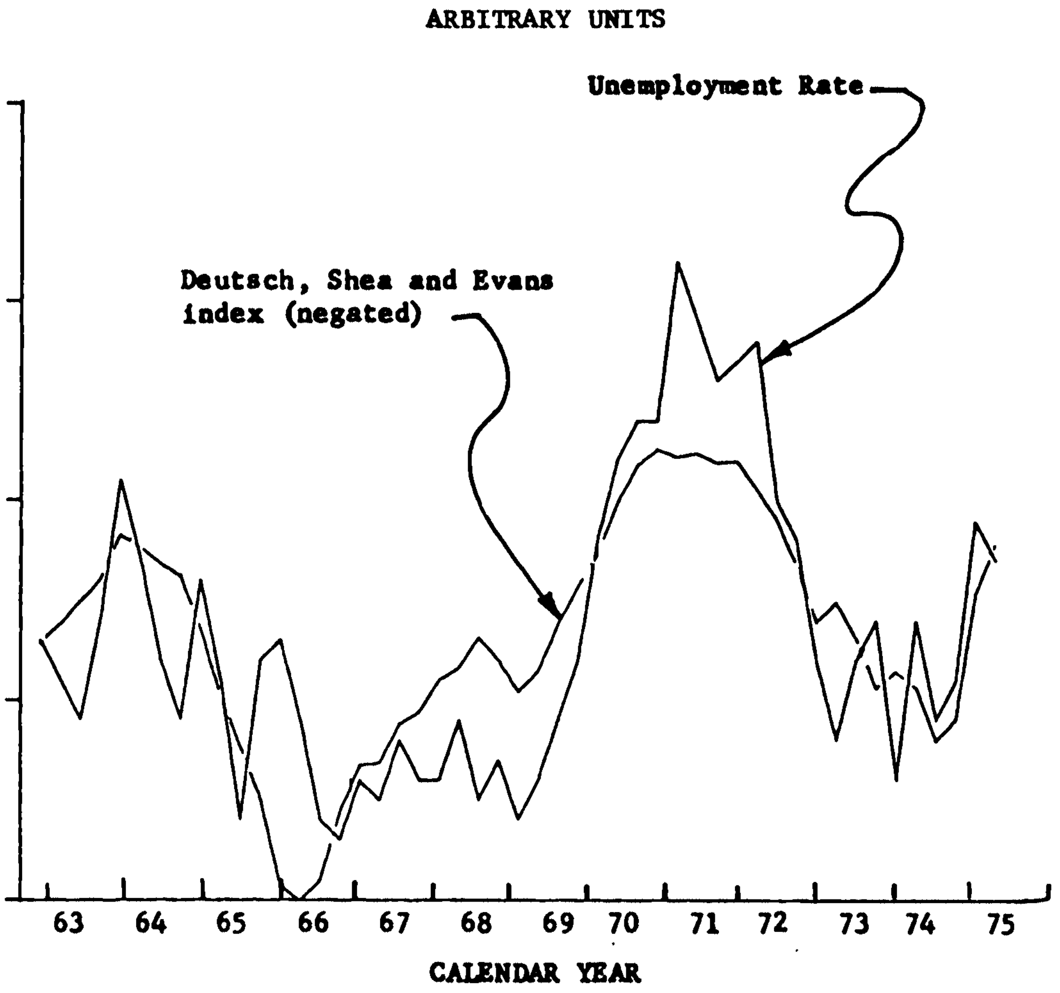


Figure 4. The correlation of unpublished engineering unemployment rates with negated Deutsch, Shea and Evans index data for corresponding time periods.

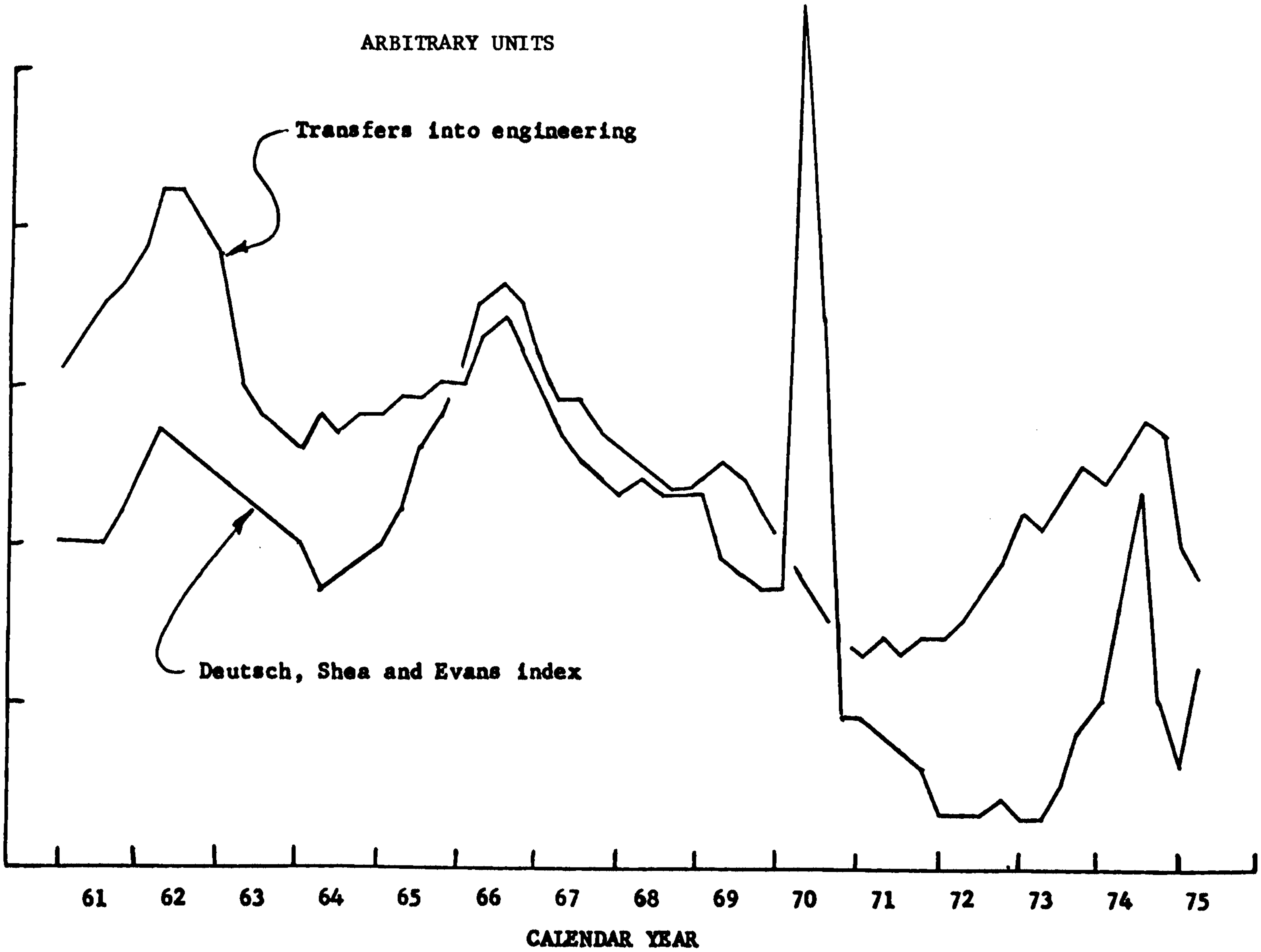


Figure 5. The correlation of transfers into engineering with Deutsch, Shea and Evans index for corresponding time periods. The number of transfers is the difference between the total number of engineers and the sum of new degrees, immigrants and the number of engineers during the previous quarter. Some mathmatical smoothing was necessary on the total number of engineers after 1971 to compensate for the two different sources of data used. (see text for an explanation of the two sources)

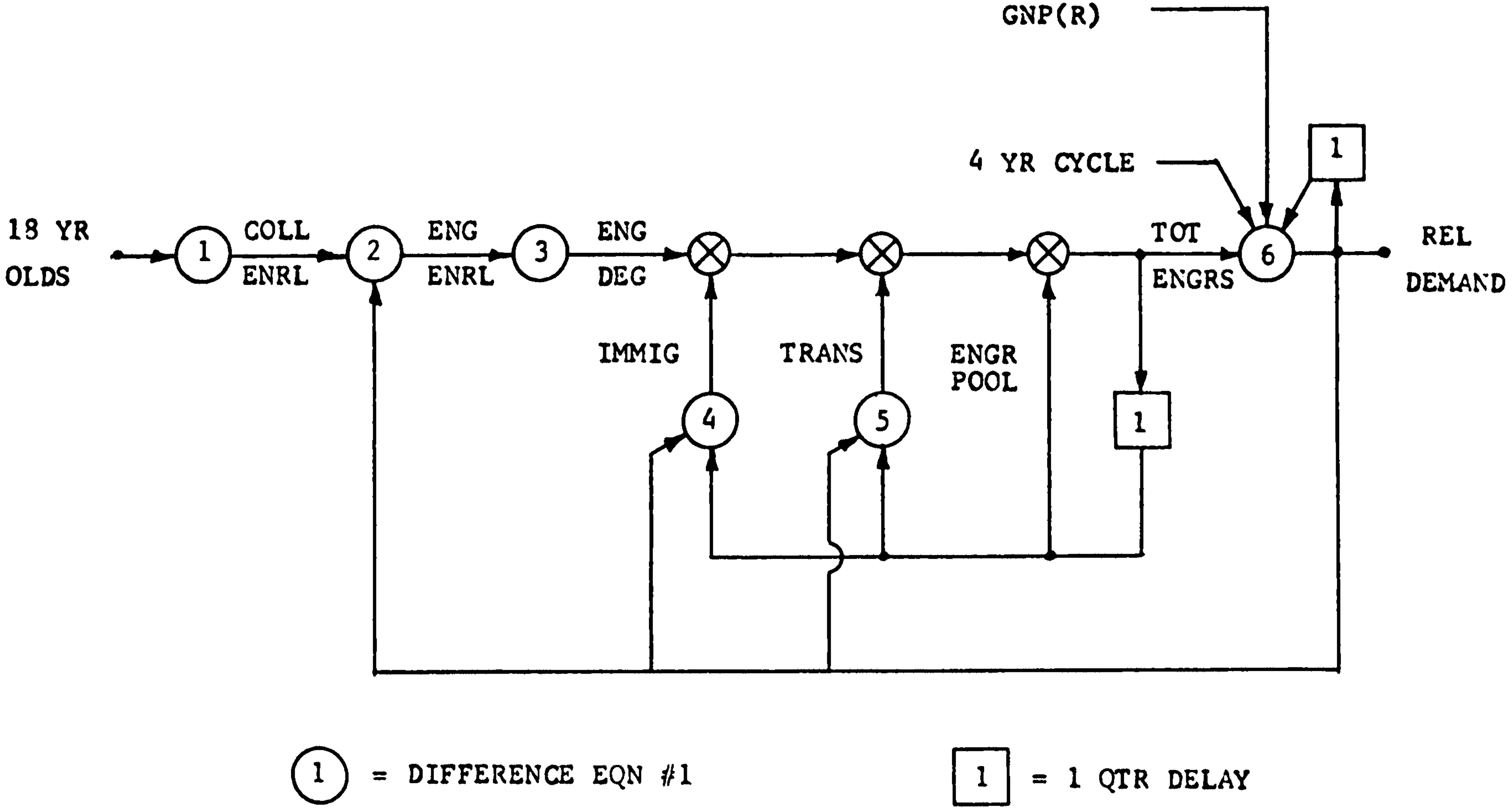


Figure 6. Schematic **diagram of the engineering manpower system.**

Table 1. Equations for the Engineering Demand model.

$$CE(k+1) = (a_{21} + a_{22}*k)*18YROLDS(k+1)$$

$$ENGE(k+1) = a_{30} + (a_{31} + \sum_{i=2}^{9} a_{3i}*ENGDEM(k-i+2))*CE(k+1).$$

$$ENGDEG(k+1) = a_{41}*ENGE(k-15).$$

$$ENGI(k+1) = a_{50} + (a_{51} + \sum_{i=2}^{9} a_{5i}*ENGDEM(k-i+2))*TOTE(k).$$

$$ENGT(k+1) = a_{60} + (a_{61} + \sum_{i=2}^{9} a_{6i}*ENGDEM(k-i+2))*TOTE(k).$$

$$TOTE(k+1) = a_{71}*(TOTE(k) + ENGDEG(k) + ENGT(k) + ENGI(k)).$$

$$\begin{aligned}\Delta ENGDEM(k+1) = a_{80} \sum_{i=1}^{4} a_{8i}*f_i(YR(k)) + a_{85}* GNP(R) + a_{86}*TOTE(k)\\ + a_{87}*\Delta TOTE(k) + a_{88}*ENGDEM(k)\end{aligned}$$

YR(k) = calendar year of time period k

$$f_i(YR(k)) = \begin{cases} 1 \text{ if } YR(k)-i+1 \text{ is evenly divisible by } 4 \\ 0 \text{ otherwise.} \end{cases}$$

Table 2. Definitions of Variables Used in the Engineering Demand Model

18YROLDS - The number of 18 year olds[6]

CE - The number of first time degree credit college enrollments at 4 year colleges[7]

ENGE - The number of first time engineering enrollments at 4 year colleges[8]

ENGDEG - The number of engineering degrees granted[9]

ENGI - The number of engineering immigrants[10]

ENGT - The net number of individuals transfering into engineering, a calculation from other data.

TOTE - The total number of engineers[11]

ENGDEM - Engineering demand as represented by the Deutsch, Shea and Evans Index[4]

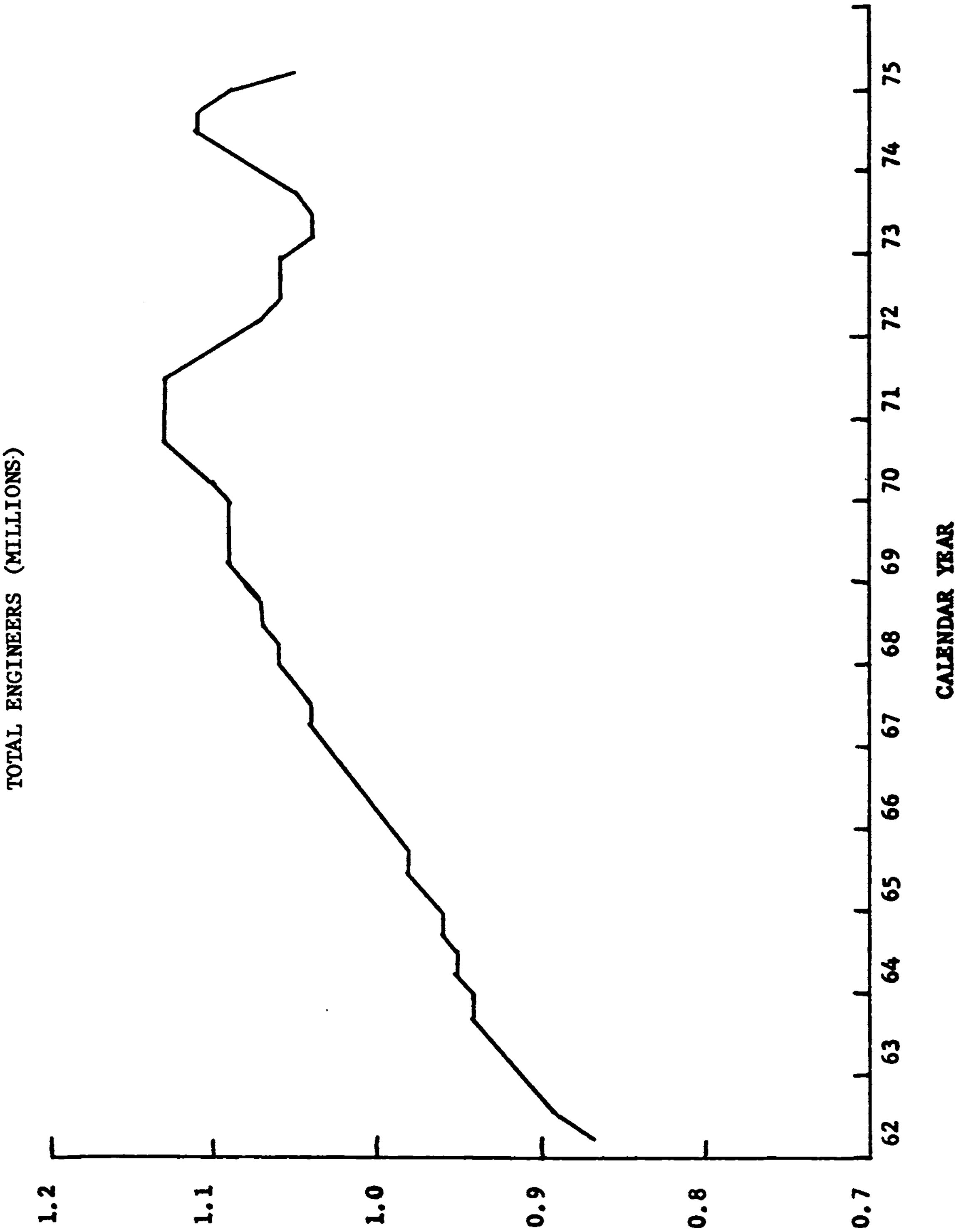


Figure 7. Total number of engineers as per text.

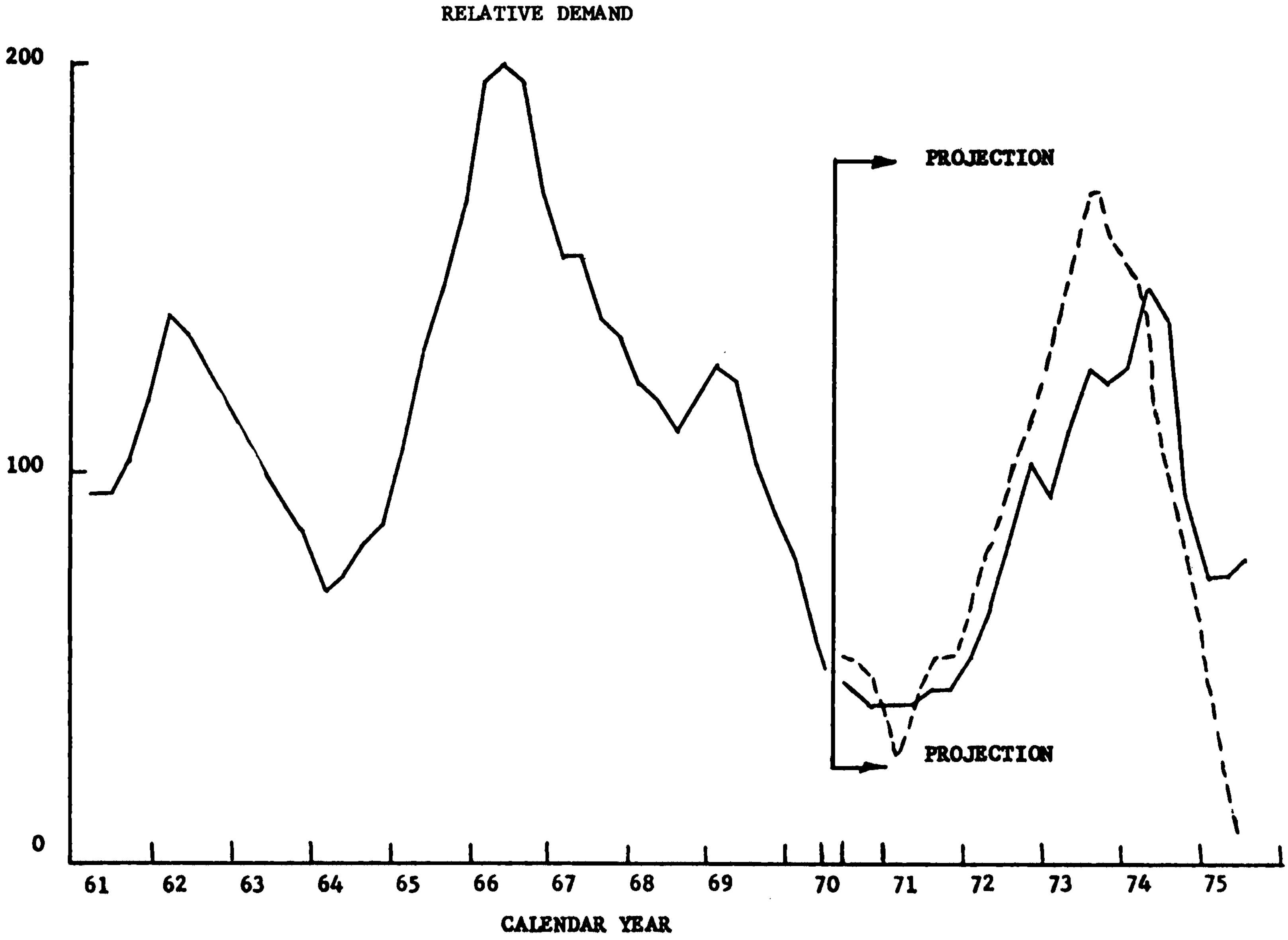


Figure 8. Relative demand as projected from mid 1970. Measured values of this variable are shown as solid lines for comparison and evaluation.

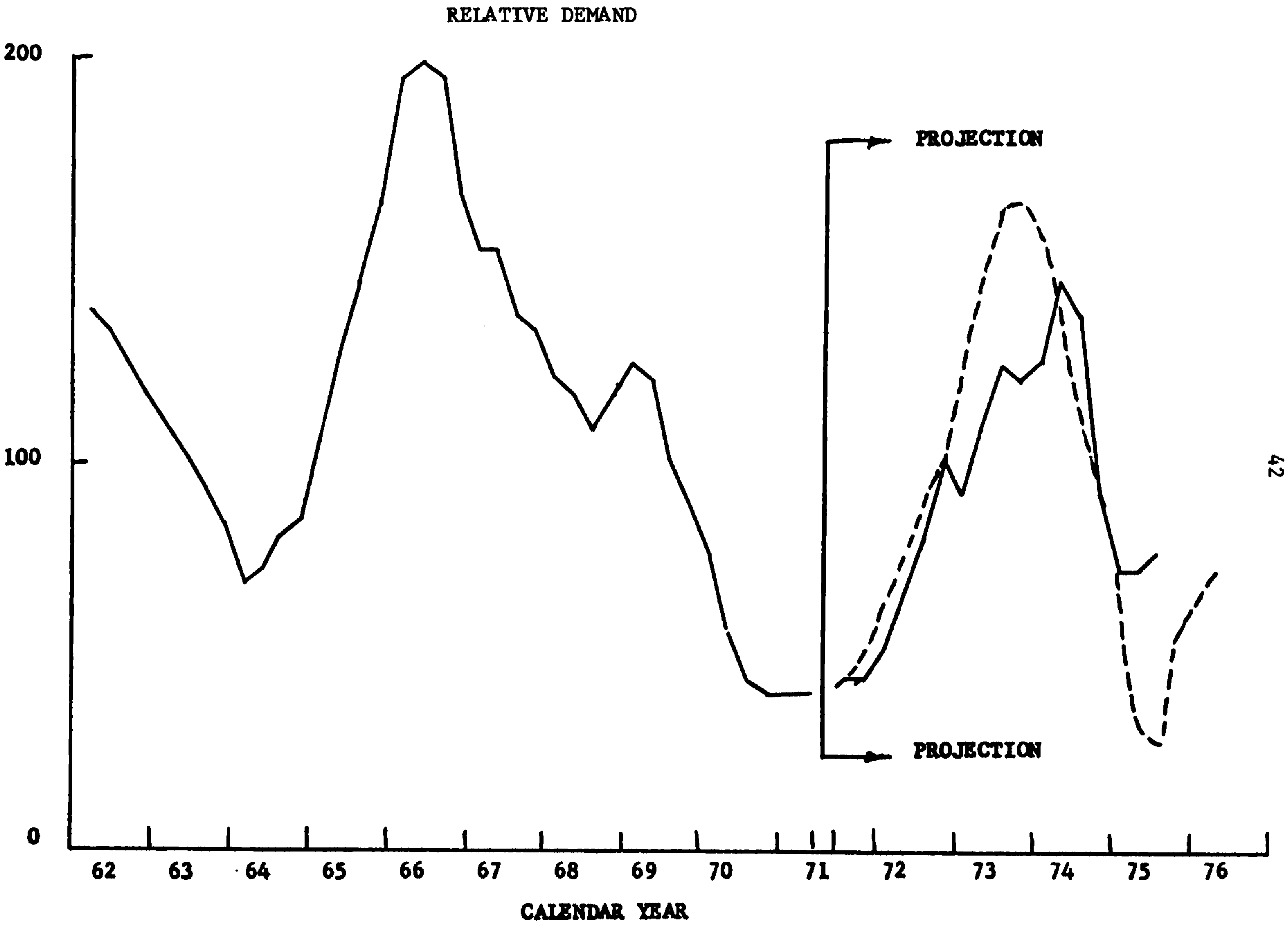


Figure 9. Relative demand as projected from mid 1971. Measured values of this variable are shown as solid lines for comparison and evaluation.

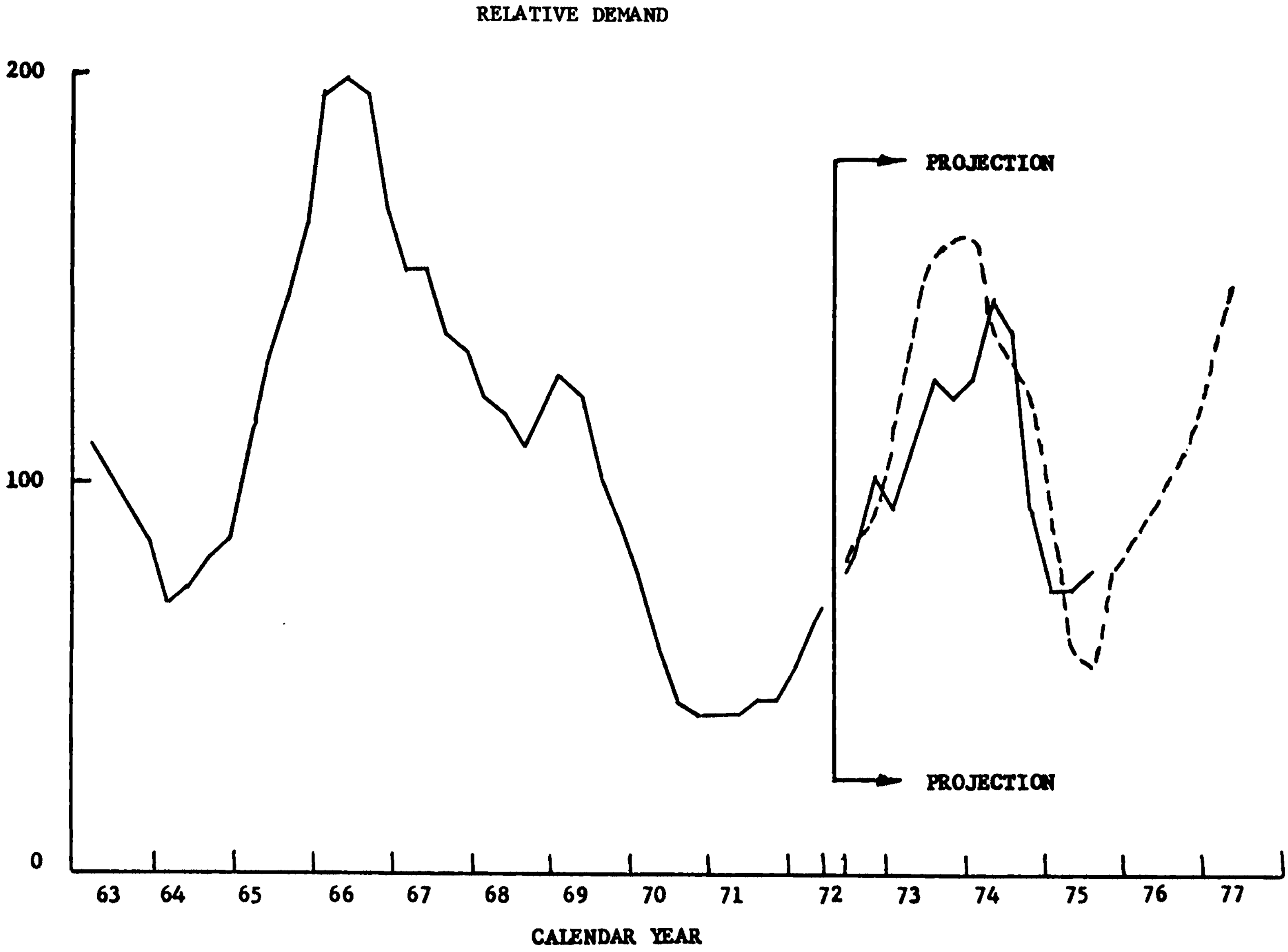


Figure 10. Relative demand as projected from mid 1972. Measured values of this variable are shown as solid lines for comparison and evaluation.

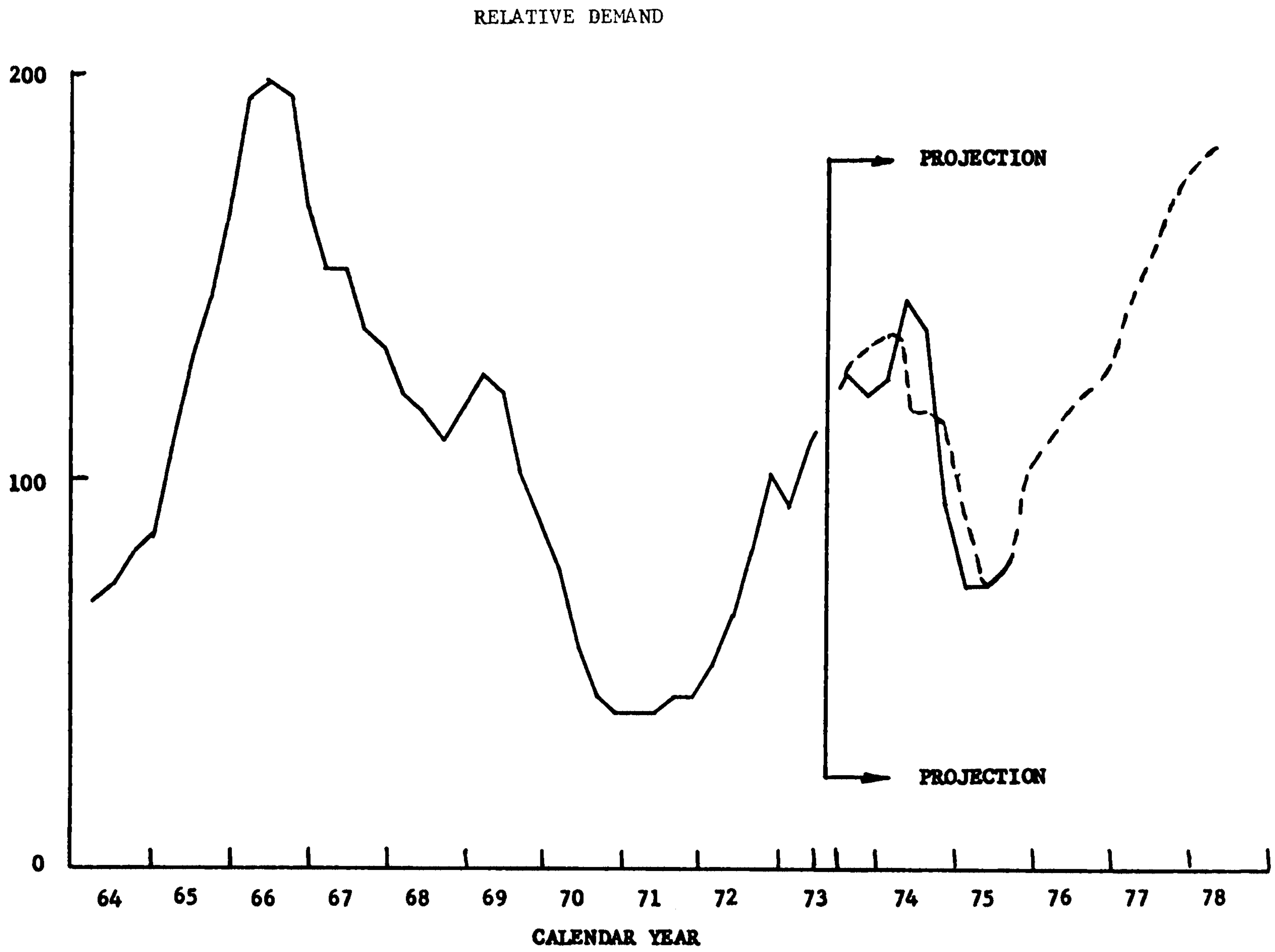


Figure 11. Relative demand as projected from mid 1973. Measured values of this variable are shown as solid lines for comparison and evaluation.

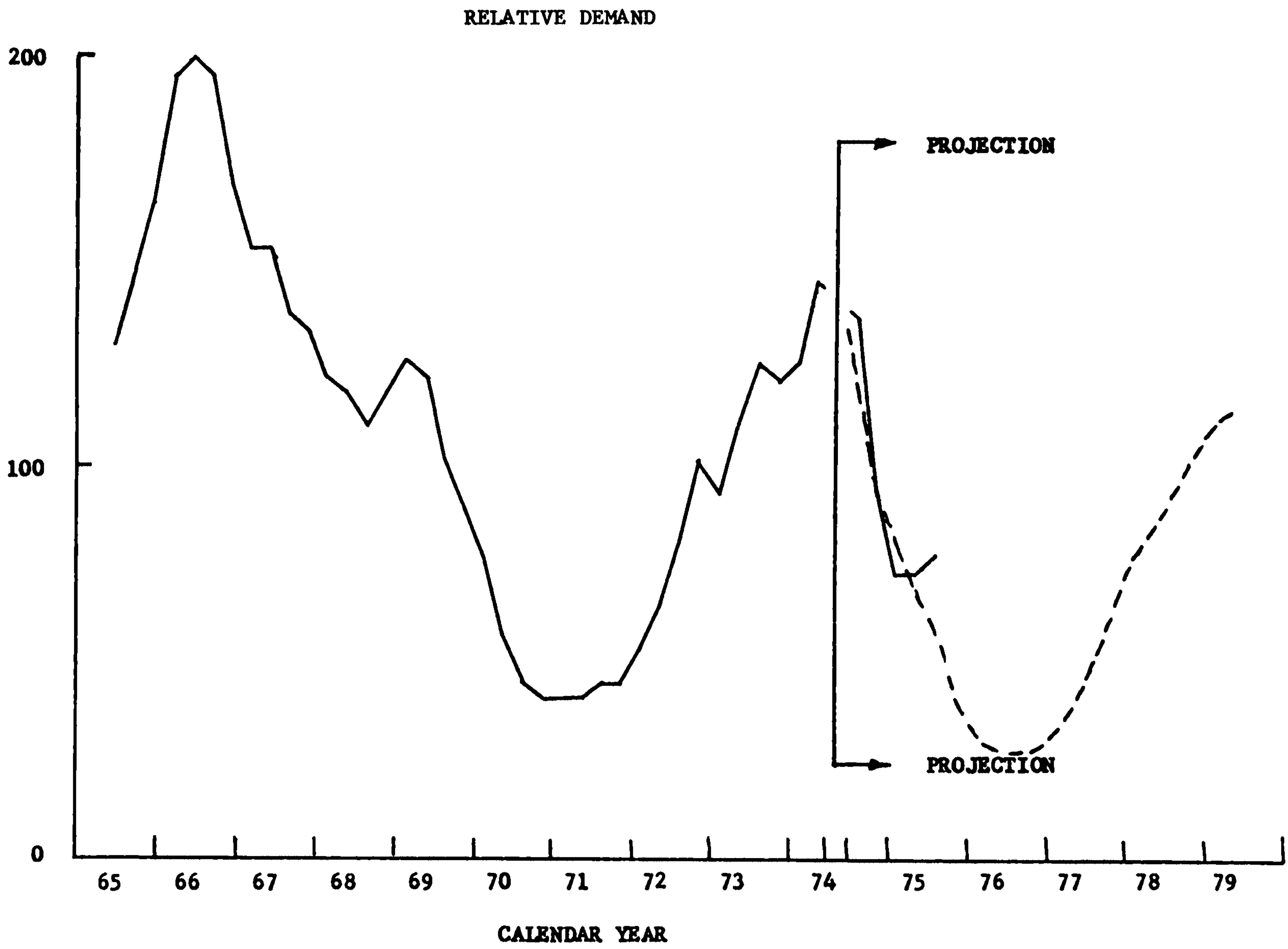


Figure 12. Relative demand as projected from mid 1974. Measured values of this variable are shown as solid lines for comparison and evaluation.

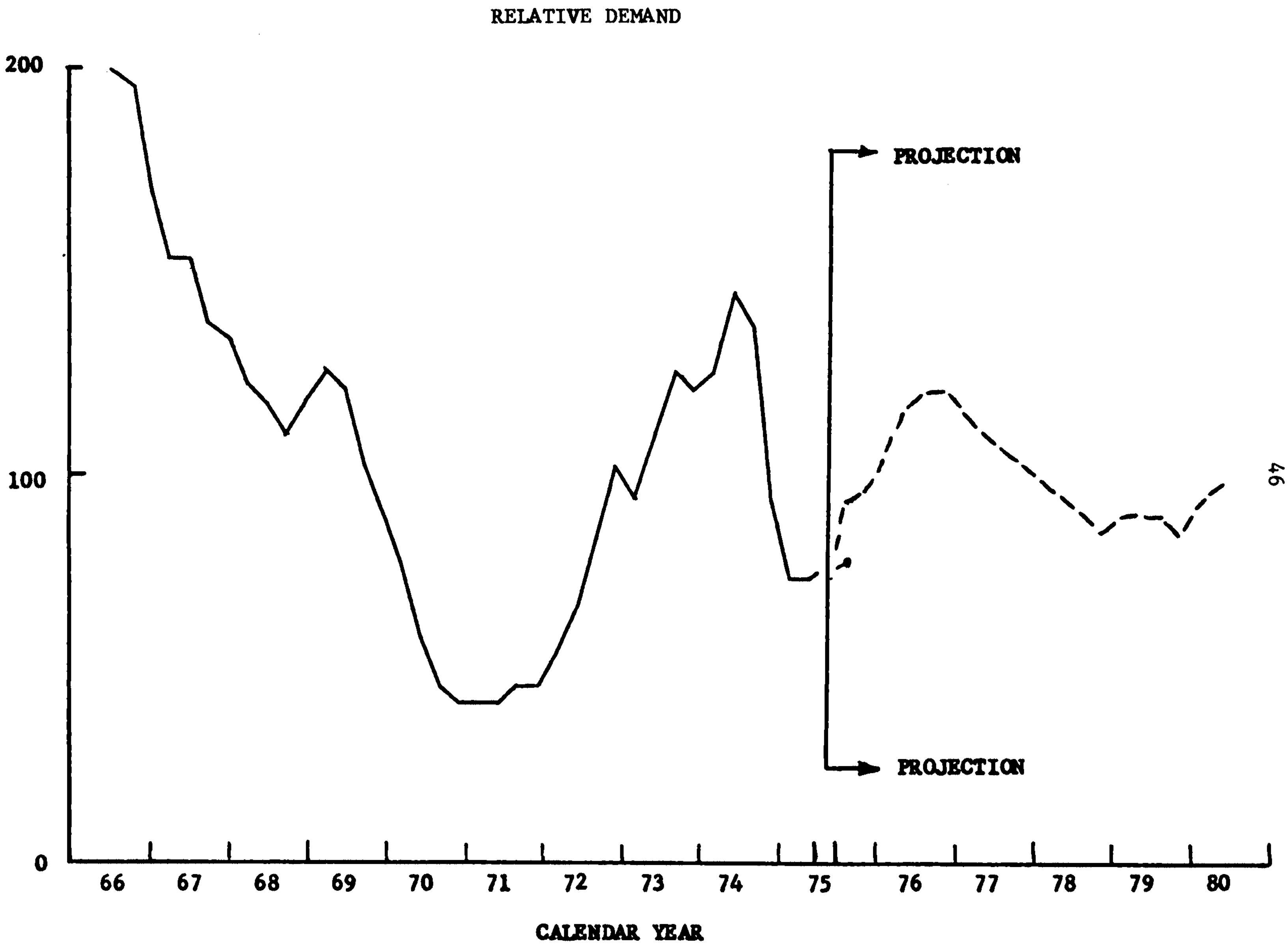


Figure 13. Relative demand as projected from mid 1975. Measured values of this variable are shown as solid lines for comparison and evaluation.

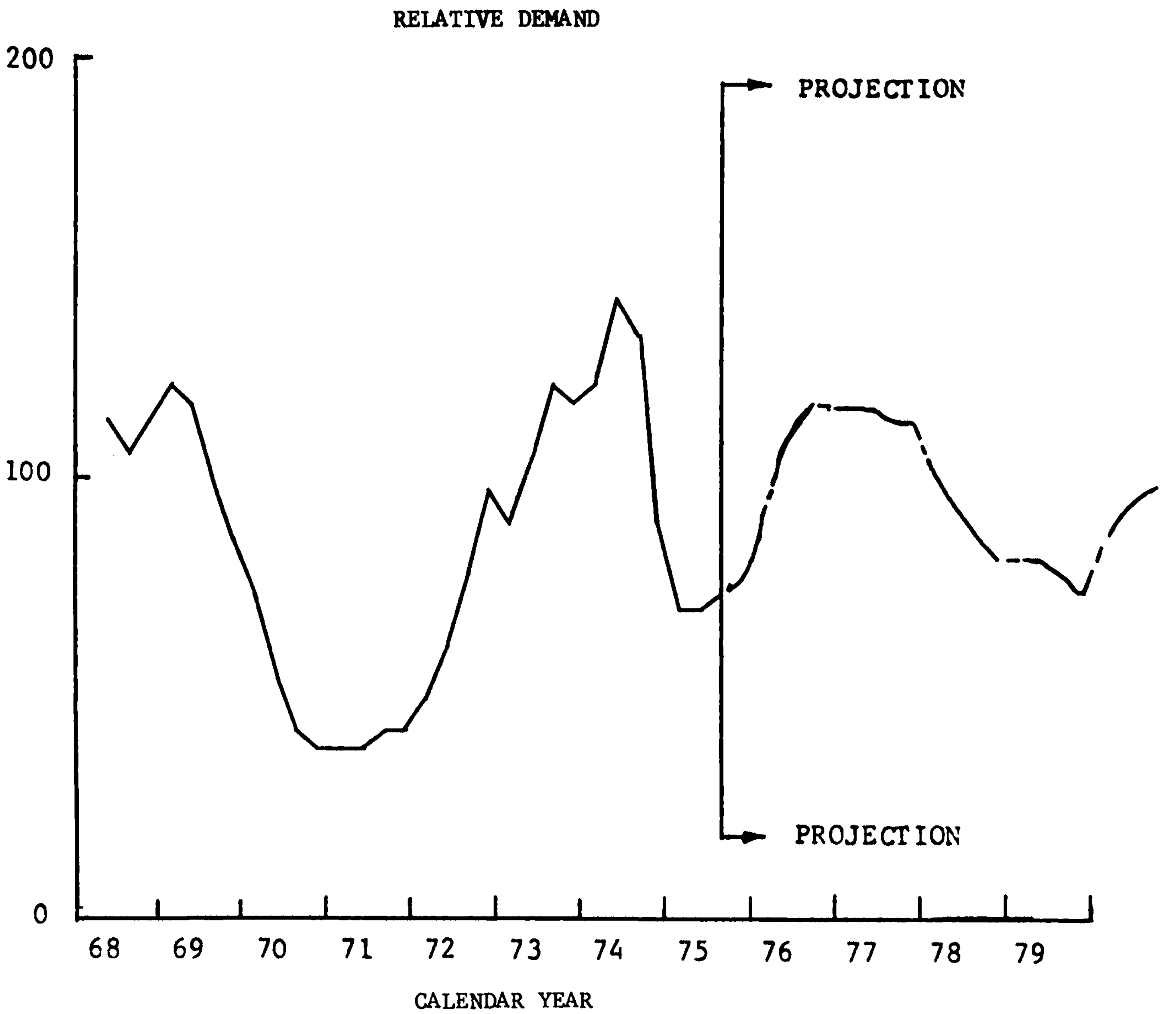


Figure 14. Relative demand for engineers, with Deutsch, Shea and Evans data from the third quarter of 1975 and then a projection through 1980.

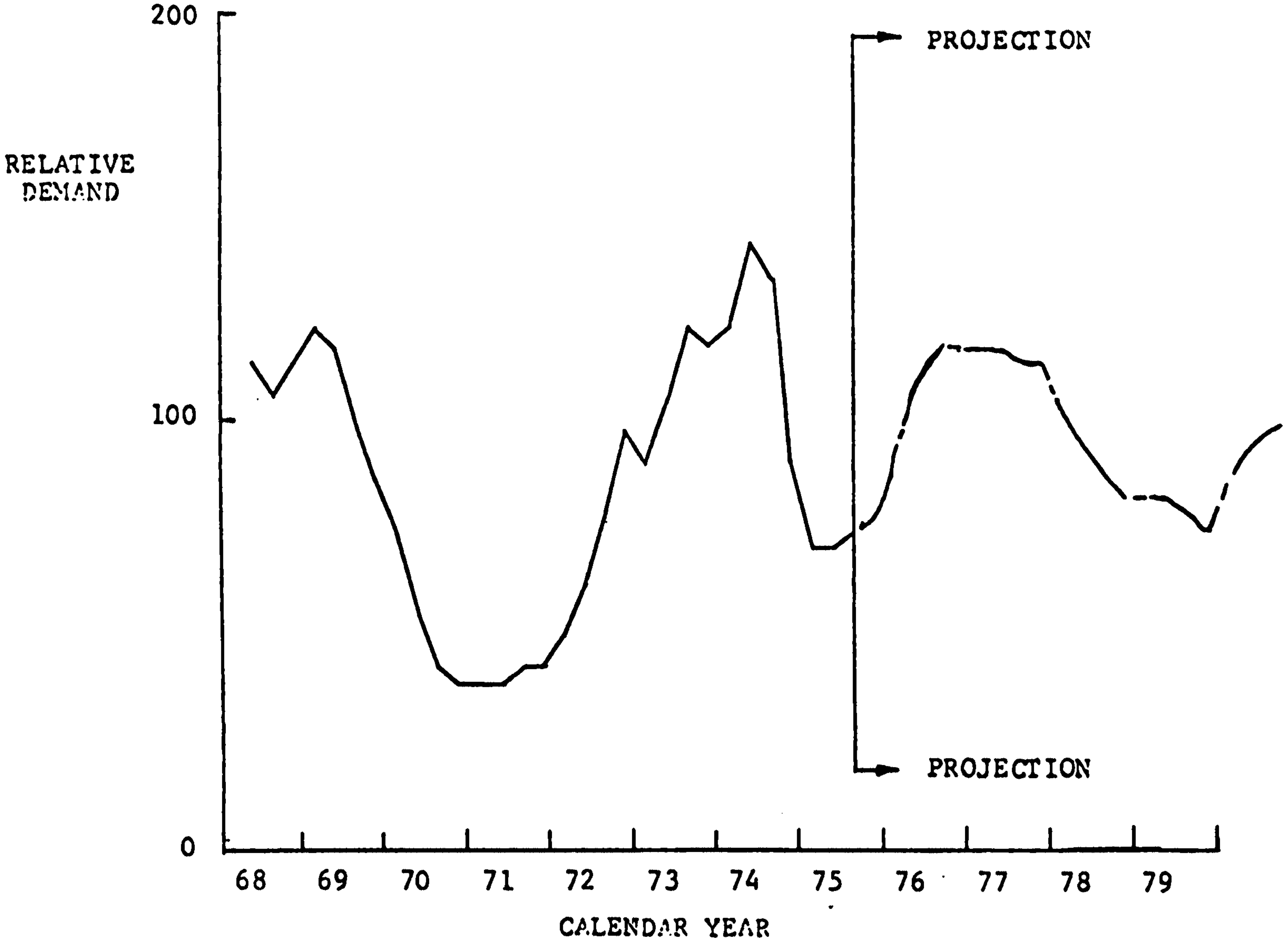


Figure 14. Relative demand for engineers, with Deutsch, Shea, and Evans data from the third quarter of 1975 and then a projection through 1980.

demand for engineers (to be discussed later) during a previous time period had some effect on the number of college enrollees who chose to enter engineering programs. It also assumed that the increase in the total numbers of engineers at any given time was the sum of the engineering graduates, the engineering immigrants into the U.S., and the number of people who transfer into engineering from other careers. Actually, in the process of using this model, the number of transfers was calculated from knowledge of the total number of engineers, the number of immigrants, and the number of degrees.

As suggested in Figure 3, the demand for engineers (thought of as the need for their services) was created by the combined effects of the state of the economy, possibly some political influence, and the state of technology. Though many other effects exist, these were assumed to dominate. This demand was then combined with the total number of engineers available to produce a measure of relative demand (thought of as a measure of the degree to which employers must seek the services of prospective engineering employees). For this study, it was assumed that the Deutsch, Shea, and Evans index adequately measured this relative demand.[4] Although the validity of this index as a measure of the relative demand for engineers could be easily questioned, it was readily available and the authors have been able to demonstrate a reasonable negative correlation between it and engineering unemployment rates as shown in Figure 4.[5] Also, reasonable positive correlation was demonstrated when this index was compared with the number of transfers into engineering as suggested in Figure 5. Both of these correlation studies offered some confidence for using the DS&E index as a measure of relative demand.

Testing was conducted to determine which economic variable(s) should be incorporated into the simulation. Those tested included: money supply, government spending, defense spending, corporate profits, real and current gross national product, and research spending. Of these, the "best" projections were produced when the change in real GNP was used. A political/economic influence was assumed in the form of a four-year periodic function with coefficients determined during the identification phase of the system modeling. The level of technology was assumed measurable by the total number of engineers at a given time.

Figure 6 is a schematic drawing indicating the general form of the resulting manpower system. A more complete description is given by the list of different equations which describe the system as shown in Table 1. Table 2 describes the meaning of each variable used in these equations. References are given to indicate where the data for these variables were obtained.

The major problem encountered with the data base used was in trying to determine the number of engineers. The Bureau of Labor Statistics has compiled a time history of the number of engineers from 1950 to 1970.[11] After 1970 there were only unpublished data from current population surveys. Then at the end of 1971 the definition of engineer was changed. This resulted in fewer people being classified as engineers. The Engineering Manpower Commission estimated that this reduction was about 6 percent. For these reasons, the number of engineers used after 1970 was taken from the unpublished data and totals between 1970 and 1972 were reduced by 6 percent. Figure 7 is a plot of the resulting data after 1962. Data before 1962 are not shown, but are very nearly a linear extrapolation backward in time.

To demonstrate the degree to which the model might sucessfully project the relative demand for engineers, a series of tests were made to see how often the projections would have been correct in the past. This was done by producing projections in successively later years. This series of projections for mid-year starting points were made from 1970 through 1975. Figures 8-13 show how they compared with actual data. During these tests, all input data during the projection periods were developed within the computer program with the exception of the values of GNP(R) which utilized actual values through mid-1975 and then assumed a 6 percent increase after that. This was done to verify that it was a reasonable economic indicator to use for the system.

The most recent projection possible from available data was made as of the end of the third quarter of 1975. For this case, GNP(R) was generated within the model as a linear extrapolation of current values. These data are shown in Figure 14 and suggest that relative demand for engineers should increase through about early 1977 and then decrease through about 1979.

The reader is warned again at this point that the model's projections are not meant to produce exact predictions of relative demand but rather to show trends and establish a framework within which decisions can be made concerning relative demand. When coupled with long range forecasting methods incorporating econometric modeling, this approach should provide a valuable tool.[12,13] Also, feedback systems are vulnerable to instabilities especially when they contain elements of delay within the feedback loop. In using this system to make projections into the future, therefore, the outside influences which can cause major changes in system performance must always be monitored.

Certainly, the model described oversimplifies many of the complex factors that exists. But it has accounted for many of the interactions of the system. This model is not intended to be a final version, but rather a flexible tool which can be changed and improved to help engineers understand the factors that influence their lives.

Future Recommendations

One of the greatest advantages of this type of modeling and methodology is that its simulation of reality allows the user to decide which are the major variables and interactions within the system. In this way, a discovery can be made of how various proposed future events might perturb the system or how the system might be made more stable by changing some aspects of the interactions involved.

Listed below are several studies that can appropriately be made or at least assisted by using the methodology reported in this paper:

- Additions to the model for the inclusion of large scale national problems or priorities which require the services of engineers.

- Testing of the model to simulate the effects that might occur because of the phasing in or out of large scale engineering oriented programs (energy, space, transportation, etc.)
- An investigation into the stability criteria of the system to specifty the primary causes of instabilities.
- Sensitivity measurements of the system to determine the most significant interactions.
- The inclusion of advanced engineering degrees.
- The sensitivity of the system to foreign student enrollments.
- The inclusion of engineering technology degrees.
- Initial attempts to determine the importance of phenomena such as the effect of national news coverage concerning the need or oversupply of engineers on the career choices of new engineering students.

The methodology and techniques described in this paper are by no means the only or even the best possible approach to the above areas of interest, but they can serve as tools to give guidance and understanding concerning each area to decision makers within the engineering manpower system.

References

1. Wiggins, L. A. and V. R. Johnson, "The Demand for Engineers - A Predictive Model," 1975 IEEE Manpower Report. The Institute of Electrical and Electronics Engineers, New York, 1975.

2. Wiggins, L. A. A General Closed Loop Model with Applications in Economics. Ph.D. Dissertation, University of Arizona, 1974.

3. Forrester, J. W. World Dynamics. Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1971.

4. These data are calculated monthly as the "Engineer/Scientist Demand Index," by Deutsch, Shea and Evans, Inc., New York.

5. Unpublished engineering unemployment data obtained from the Bureau of Labor Statistics, U. S. Dept. of Labor, Washington, D. C.

6. Lerner, W. Statistical Abstracts of the United States. Department of Commerce, U. S. Bureau of the Census, Washington, D. C. Ed. 93, 1972, Ed. 94, 1974, and Ed. 95, 1975.

7. Simon, K. and M. Frankel, Projection of Educational Statistics to 1983-84. 1974 Edition. Education Division, National Center for Education Statistics. Department of Health, Education, and Welfare, Washington, D. C., 1975.

8. First year engineering enrollments in 4 year colleges. Annual data prior to 1966 were taken from the National Center for Educational Statistics while data after 1966 were from the Engineering Manpower Commission.

9. Prospects of Engineering and Technology Graduates 1974-1975, Engineering Manpower Commission of the Engineers Joint Council, New York, January 1975.

10. "Immigrants admitted by Country or Region of Last Permanent Residence by Professional, Technical and Kindred Workers, Students,

and all other Occupations," tabulated data for fiscal years 1954 through 1974, Immigration and Naturalization Service, U.S. Department of Justice, Washington, D. C.

11. Employment of Scientists and Engineers, 1950-1970, Bureau of Labor Statistics, U.S. Department of Labor, Washington, D. C., 1973, and Employment Status of Engineers, Bureau of Labor Statistics, U.S. Dept. of Labor, unpublished.

12. Bezdek, R. H. Long Range Forecasting of Manpower Requirements-Theory and Applications. The Manpower Planning Committee, Institute of Electrical and Electronic Engineers, Inc., New York, 1974.

13. Freeman, R. B. The Market for College Trained Manpower, Harvard University Press, Cambridge, Massachusetts, 1971.

A MODEL OF THE SUPPLY AND DEMAND FOR ENGINEERS

Donald R. Mack

SUMMARY

The engineering colleges and employers of engineers in the United States constitute a feedback-control system whose behavior is less than optimal. For example, its response to the recent aerospace layoffs, which affected only a small fraction of the profession, has included a severe reduction in the number of engineering graduates through 1976. The technique of system dynamics has been used to construct a block diagram representing the system that facilitates diagnosis of the problem. Operation of the model permits testing the effect of various assumptions on the future of engineering employment and reveals at least one additional problem for the engineering work force, namely, maintenance of its educational level.

INTRODUCTION

The annual supply and total number of engineers in the United States were predictable between 1945 and 1969. After the post-war wave of returning GI's found jobs, the number of students receiving engineering bachelor's degrees each year increased nearly monotonically from 22,236 in 1954 to 44,190 in 1972.[1] The total number of engineers rose steadily and the number unemployed was negligible. In 1969 layoffs began in the aerospace industry, and by 1971 about 3 percent of the graduate engineers were out of work. These highly publicized layoffs frightened high school seniors away from engineering, and college freshman enrollments decreased. The class of 1976 will receive only an estimated 28,900 engineering bachelor's degrees, not nearly enough to fill the demand. As in the past when the demand has exceeded the supply, employers must hire people who do not have a bachelor's degree in engineering, and rearrange the job content accordingly. Since 1971 many of the unemployed aerospace engineers have been rehired or retired. Unemployment is down to about 1 percent, the crisis is over, and the profession should once again become more attractive to high school seniors.

We have learned something new about the transient response of our system for producing engineers. The news of layoffs in one segment of the profession constitutes a strong negative feedback, sharply decreasing the input of college freshmen. What will happen if another layoff occurs somewhere in the profession? Can the system be altered to produce a closer match between the supply and demand for engineers? To facilitate the study of these questions, a model of the system was constructed with 21 algebraic and first-order differential equations. As in all system-dynamics studies, the reduction of human relations to mathematics required the interpretation of available statistics, and some assumptions for which accurate statistics are not available. The information upon which the assumptions were based was obtained largely in discussions with John D. Alden, Executive Secretary of the Engineering Manpower Commission of the Engineers Joint Council. Three of his many useful publications are listed in the references.

EQUATIONS DESCRIBING THE SYSTEM

ASSUMPTIONS

The model is based on these simplifying assumptions:

1. An engineer joins the work force upon receiving a bachelor's degree.
2. Ten percent of engineering BS graduates go directly into non-engineering careers.
3. Engineering college retention, namely the fraction of entering freshmen who receive engineering BS degrees 4 years later, is 0.5.
4. The factors influencing engineering college enrollment are (a) the annual demand for engineers, (b) the ratio of graduates to available jobs, and (c) layoffs in a segment of the profession.
5. The rate of attrition of engineers by death, retirement, and transfers out of engineering is 2.6 percent per year.
6. The annual demand for engineers in 1971 was 48,000 people.
7. In 1971 there were 1,000,000 available engineering graduates, 805,000 graduate engineers employed in engineering, and 475,000 non-graduates employed in engineering. About 3 percent of the graduate engineers in engineering (24,897) were unemployed.

EMPLOYMENT OF ENGINEERS

In the computer program for the system, the outputs of the integrators will be treated as one column vector, and the inputs as another. To fit the subscript notation of the BASIC computer language, we will call the output of the ith integrator X(i) and its input D(i). According to assumption 2, if the rate of engineering college graduation is J people/year, the rate at which new BS graduates leave engineering is

$$K = 0.1\ J \quad \text{people/yr}, \tag{1}$$

and the rate at which graduates enter the profession is

$$L = 0.9\ J \quad \text{people/yr}. \tag{2}$$

If the number of graduate engineers employed in engineering is X(1), and the fractional rate at which this number is reduced by layoff is B (fraction/yr), the rate of layoff is

$$C = B \cdot X(1) \ \text{people/yr}. \tag{3}$$

Using the last two equations and assumption 5, we see that the rate of increase of the number of graduate engineers employed in engineering is

$$D(1) = L - C - 0.026\ X(1) \quad \text{people/yr}. \tag{4}$$

The number of graduate engineers in engineering who are unemployed is X(2). This number decreases by retirement, because some older engineers reach retirement age before they are rehired, and some are retired early. We will regard the latter status as unemployment until the person reaches the regular retirement age. The rate of increase of the number of graduate engineers in engineering who are unemployed is therefore

$$D(2) = C - 0.026\ X(2) \ \text{people/yr}. \tag{5}$$

The total number of graduate engineers in engineering, employed and unemployed, is

$$M = X(1) + X(2) \quad \text{people/yr}. \tag{6}$$

If A is the annual demand for engineers, the rate of hiring of non-graduate engineers is

$$S = A - L \quad \text{people/yr}. \tag{7}$$

If the number of non-graduates employed in engineering is X(3), and the frational rate of layoff of this number is E (fraction/yr), the rate of layoff is

$$F = E \cdot X(3) \quad \text{people/yr}. \tag{8}$$

The rate of increase of the number of non-graduate engineers employed in engineering is

$$D(3) = S - F - 0.026\ X(3) \text{ people/yr.} \tag{9}$$

The number of unemployed non-graduates in engineering is X(4). The rate of increase of this number is

$$D(4) = F - 0.026\ X(4) \text{ people/yr.} \tag{10}$$

The total number of non-graduates in engineering, employed and unemployed, is

$$N = X(3) + X(4) \text{ people.} \tag{11}$$

The total number of engineers in engineering, graduate and non-graduate, employed and unemployed, is

$$P = M + N \text{ people.} \tag{12}$$

The fraction of the total engineering population who are graduate engineers is

$$Q = M/P. \tag{13}$$

The fraction of graduate engineers in engineering who are unemployed is

$$R = X(2)/M. \tag{14}$$

COLLEGE ENROLLMENT

What determines the annual number of high school students who decide to major in engineering in college? According to assumption 4, we will assume that next year's engineering college freshman enrollment is

$$G = K_4\ A\ W\ Z, \tag{15}$$

Where A is the annual demand for engineers, W is a multiplier for job competition, Z is a multiplier for the frightening effect of layoffs, and K_4 is a constant to be determined from known data. Let us consider these terms individually.

Annual Demand

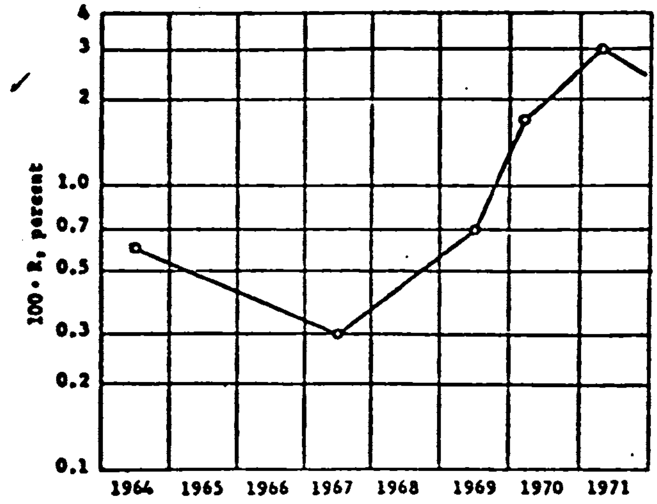
The annual demand for engineers A is a nebulous quantity for which neither a standard definition nor reliable numbers are available in the literature. Let us define A as the annual number of engineering jobs filled by people entering the profession. We will make computations with A starting at 48,000 people/yr, and then either remaining constant or increasing by 4 percent per year. If the fractional increase is C_3,

$$A = 48{,}000\ (1 + C_3)t \qquad (16)$$

where t is the time in years.

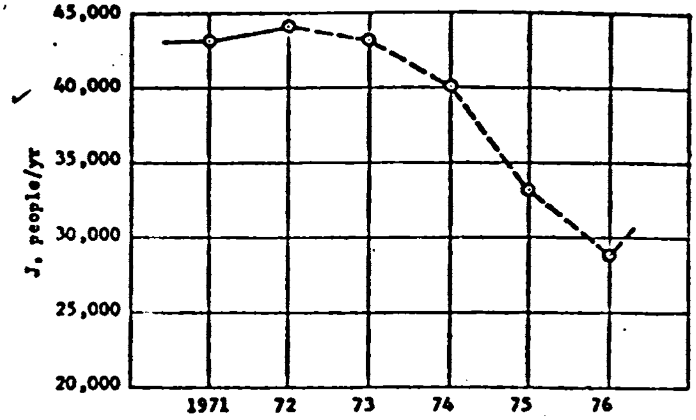
Effect of Layoffs

Fig. 1 shows the unemployment of engineers, which rose 0.3 to 3 percent between 1967 and 1971, largely because of the cutback in aerospace and military programs. Fig. 2



Year

Fig. 1 Engineering unemployment, 100 • R
Source: Ref. 2, page 2



Year

Fig. 2 Projected engineering BS graduates, J
Source: Engineering Manpower Commission
of Engineers Joint Council

shows the rate of engineering college graduation, which was 44,190 in 1972, and is expected to decrease to 28,900 in 1976 and then rise again. Evidently the delay between changes in engineering unemployment and changes in graduating class size is five years. The students need one year to receive the employment information and make their commitment, and four years for college. The delay will be represented by a pipeline delay of five years in the computer program representing the system. To determine the effect of layoffs on college enrollment, we will assume that between 1967 and 1971 the demand for engineers A and the job competition J/A were constant. According to assumption 4, the rate of graduation J is then a function only of the unemployment fraction R. If the relationship between R at time t years, namely R (t), and J five years later, namely J(t+5), is assumed to be linear between 1967 and 1971, the relationship is that shown in Fig. 3. According to assumption 3, the retention of students in engineering colleges is 50 percent.

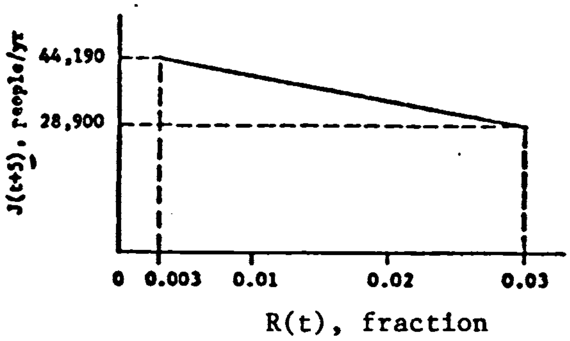


Fig. 3. Effect of unemployment fraction R(t) on graduation rate J(t+5)

If H(t) is this year's engineering college freshman enrollment,

$$H(t) = 2 \cdot J(t + 4) \cdot$$

If G(t) is next year's freshman enrollment,

$$G(t) - 2 \cdot J(t + 5) \cdot$$

Fig. 3 shows that the relationship between G(t) and R(t) is

$$\frac{G}{2} = 44{,}190 - \frac{44{,}190 - 28{,}900}{0.03 - 0.003} (R - 0.003)$$

or $G = 91{,}778 \ (1 - 12.34 \ R)$ people/yr.

This is the effect of layoffs on college enrollment when the annual demand and job competition are constant. When the latter are allowed to vary in Eq. (15), the effect of layoffs is the multiplier

$$Z = 1 - 12.34 \ R. \qquad (17)$$

Job Competition

According to assumption 7, of the 1,280,000 people employed in engineering in 1971, 805,000 or 62.9 percent were engineering graduates. The number of engineering graduates entering the profession each year is 0.9 J, and the number of job openings is A. On the average,

$$\frac{0.9\ J}{A} = 0.629,$$

and the job-competition ratio J/A is 0.70. If this ratio falls below 0.70, college recruiting becomes more intense. If the ratio rises, recruiting slows down and the graduates complain about the lack of jobs. This information gets to the high school seniors, and produces a job-competition multiplier W on college enrollment. If the multiplier is represented as in Fig. 4, its formula is

$$W=1+S_1\left(\frac{J}{A} - 0.70\right). \qquad (18)$$

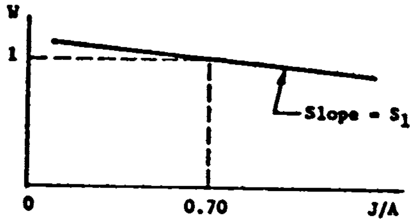


Fig. 4. Job - competition multiplier, W

The slope S_1, which is not apparent in the historical data, is assumed to be -0.2.

Choice of the Constant Multiplier

Let us use the known data for 1971 to evaluate the constant K_4 in Eq. (15). For that year R = 0.03 and A = 48,000. According to Fig. 2, J = 43,167 and G = (2)(28,900). Eq. (15) becomes

$$(2)(28,900)=K_4(48,000)\left[1-0.2\left(\frac{43,167}{48,000} =0.7\right)\right](1-(12\cdot 34)(0.03)\Big] . \qquad (19)$$

The computer program will calculate K_4 according to this formula, and use it in subsequent calculations of G.

INITIAL CONDITIONS

The relationships between the variables and parameters are shown in Fig. 5. A multiplier is indicated by an X in its block, a divider by a division sign ÷ , and the pipeline delay by a T. The model starts its operation at 1971. The initial outputs of the four integrators are provided by assumption 7. The initial number of graduate engineers employed in engineering is

$$X(1) = 805{,}000.$$

The initial number of unemployed graduate engineers in engineering is

$$X(2) = 24{,}897.$$

The initial number of non-graduate engineers employed in engineering is

$$X(3) = 475{,}000.$$

About 4 percent of the people in engineering who do not hold a bachelor's degree in engineering were unemployed in 1971.[3] Thus in 1971,

$$\frac{X(4)}{475{,}000 + X(4)} = 0.04,$$

or $X(4) = 19{,}792.$

This is the initial number of unemployed non-graduate engineers.

The five-year pipeline delay consists of a "boxcar train" of storage registers. The fourth-order Runge-Kutta method of numerical integration requires four storage registers for each computing interval. Experimentation showed that a computing interval of 0.5 yr gives accurate results. The number of registers in the boxcar train is therefore

$$\frac{(5)(4)}{0.5} = 40.$$

They were initially loaded with numbers chosen from Fig. 2 at 40 equally spaced intervals from 1971 to 1976.

No attempt has been made to show the distribution of attrition during the four college years. Each class is carried along at full strength until it appears at graduation time as I. Thus

$$I(t) = G(t - 5). \qquad (20)$$

Then the attrition of 50 percent is applied, to make the size of the graduating class

$$J = 0.5\ I. \qquad (21)$$

Since 1971 the unemployment of engineers has been decreasing at the rate of about 1 percent per year. We assume that this trend will continue until 1974, thereby reducing the unemployment ratio R to about 0.4 percent. The two layoff rates B and E are accordingly set at -0.008 for 1971, 1972, and 1973.

Equations (1) thru (21) are written in BASIC in the appendix.

RESULTS

The results of operating the model are shown in Figs. 6 through 9. The rate of engineering college graduation J, Fig. 6, was computed with the annual demand for engineers A first held constant, and then starting in 1971 to increase by 4 percent per year. This increase has no effect on the classes already in the five-year pipeline delay. The total number of people in engineering P is shown in Fig. 7. The upper curve is in good agreement with the 1,500,000 projected for 1980 by the Bureau of Labor Statistics.[4] In Fig. 8 the effect of the aerospace layoff on job competition is apparent. We can predict that college recruiting will be intense in 1975, 1976, and 1977, when the ratio of graduates to jobs J/A falls below its average value of 0.7. The transient caused by the aerospace layoff will remain until about 1979.

What would be the effect of another layoff in aerospace, or some other segment of the engineering profession? The layoff rates B and E were adjusted to simulate a new layoff that nearly duplicates the aerospace layoff. It starts in 1974 and causes the fraction of unemployed graduate engineers R to rise to 0.030 in 1977, as shown in Fig. 9. The new layoff decreases the fraction of the engineering population who are graduate engineers, Q. This fraction is a measure of the quality of the engineering work force. Fig. 9 shows that without the second layoff, the work-force quality Q starts to recover after 1978 from the aerospace layoff. The second layoff puts an additional dip of 2.8 percent in the curve of Q, from which it does not soon recover. According to our model, layoffs in a segment of the engineering profession affect neither the annual demand for engineers, nor the size of the available engineering work force. Fig. 9 shows, however, that layoffs have a long-term degrading effect on the educational quality of the engineering population.

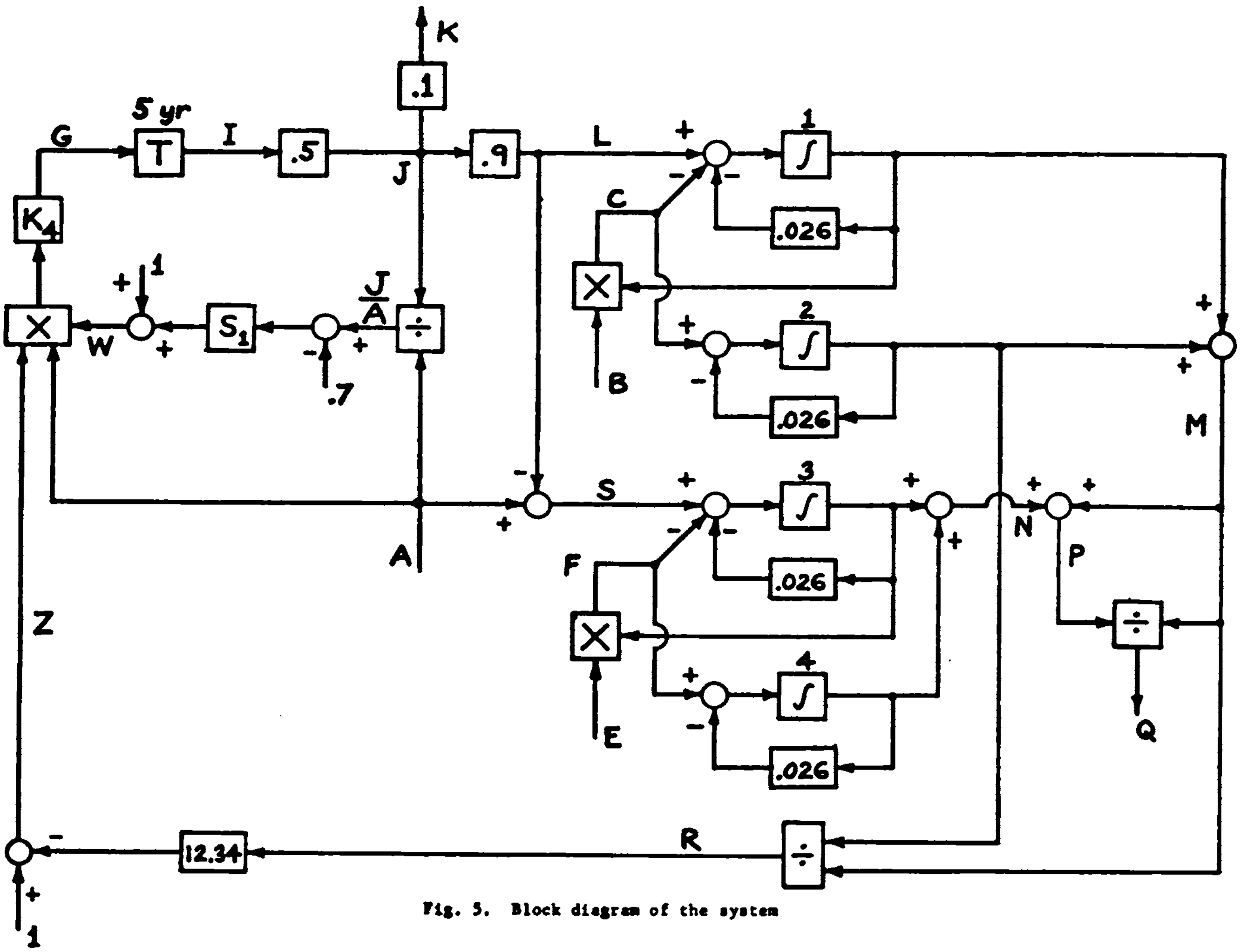


Fig. 5. Block diagram of the system

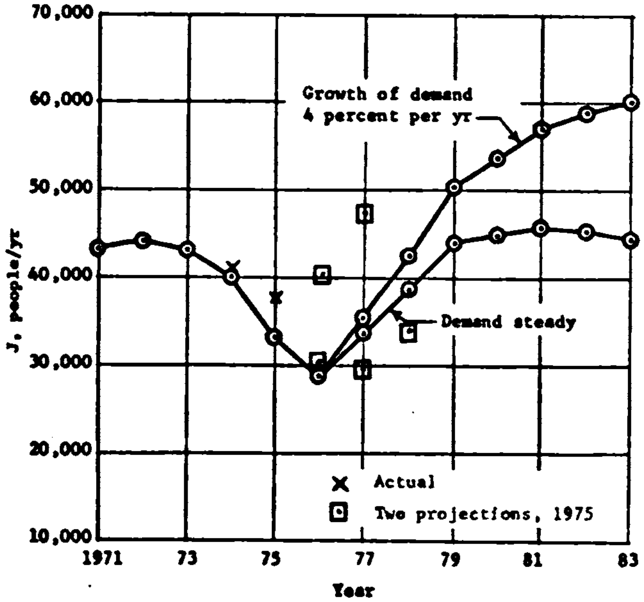


Fig. 6. Rate of engineering college graduation, J

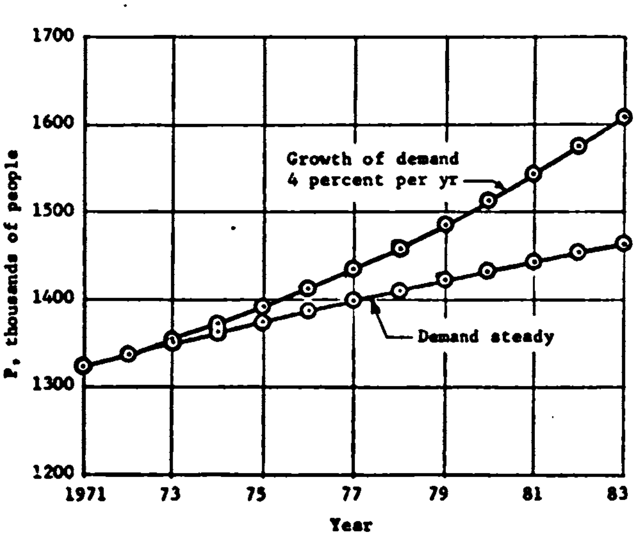


Fig. 7. Number of people in engineering, P

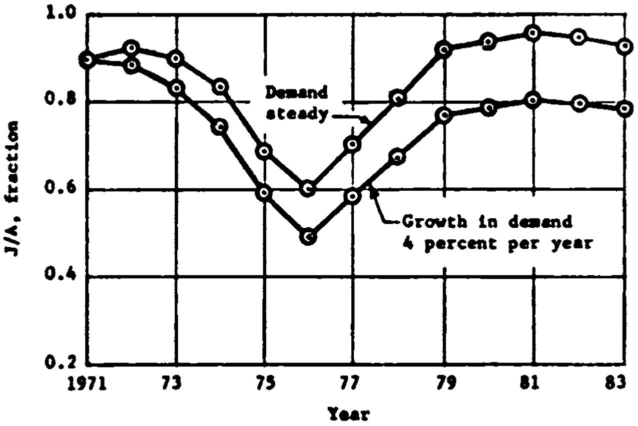


Fig. 8. Ratio of graduates to job openings, J/A

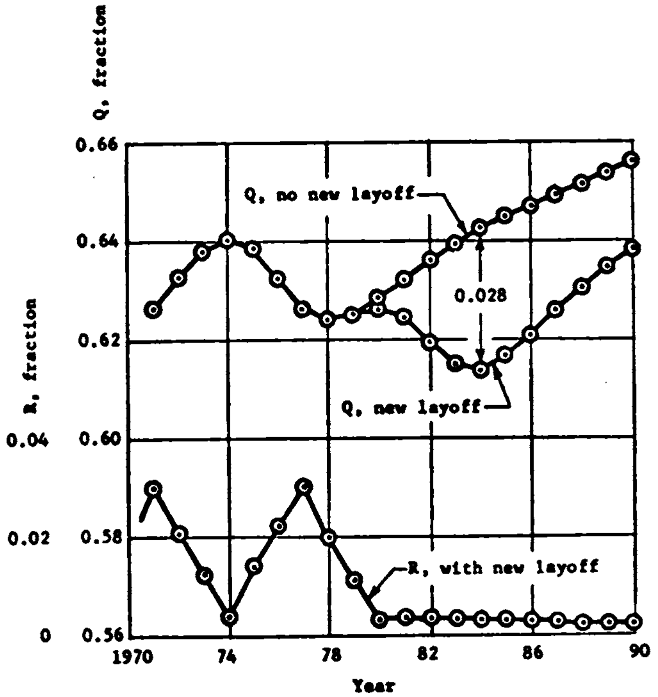


Fig. 9. Effect of new layoff on unemployment fraction R and work-force quality Q. Growth in demand is 4 percent per year.

APPENDIX

The following BASIC computer program, constructed according to Eqs.(1) thru (21), was used to operate the model of the system.

```
1 DATA .5,1,1
2 DATA .026,.1,48000,0,1971
3 DATA 805000,24897,475000,19792
4 DATA 43167,44190,43200,40100,33200,28900
5 DATA YEAR,LAYOFF RATE,GRAD. RATE,TOT. ENGRS.
6 DATA GRADS/ENGPS
100REM
110REM  ENTER AS DATA IN LINES 1 TO 99:
120REM  COMPUTING INTERVAL, PRINTING INTERVAL, TOTAL
130REM  YEARS, ATTRITION FRACTION, FRACTION OF GRADS
140REM  NOT ENTERING ENGINEERING, INITIAL DEMAND,
150REM  ANNUAL FRACTIONAL GROWTH OF DEMAND, INITIAL
160REM  YEAR, INITIAL NUMBERS OF EMPLOYED GRADS,
170REM  UNEMPLOYED GRADS, EMPLOYED NON-GRADS, UNEM-
180REM  PLOYED NON-GRADS, NUMBER OF GRADS IN THE
190REM  INITIAL YEAR AND THE NEXT 5 YEARS, COLUMN
200REM  HEADINGS.  THE PRINT STATEMENT IS LINE 960.
210REM
220 DIM B(4),D(4),E(4),W(6),X(4),Y(4),Z(40)
230 READ K1,K2,K3,C1,C2,A0,C3,C5
240 MAT READ X,W
250 READ A$,B$,C$,D$,E$
260 PRINT A$,B$,C$,D$,E$
270 PRINT
280 MAT READ B
290 DATA .5,.5,1,2
300 V1=5*4/K1
310 J1=V1/5
320 FOR I=1 TO 5
330 V2=J1*(I-1)
340 FOR J=0 TO J1-1
350 V=V2+J
360 Z(V)=2*(W(I)+(V-V2)*(W(I+1)-W(I))/J1)
370 NEXT J
380 NEXT I
390 V=-1
400 R=.03
410 G=2*W(6)
420 Z=1-12.34*R
430 S1=-.2
440 J=W(1)
450 W=1+S1*(J/A0-.7)
460 K4=6/(A0*W*Z)
470 FOR P1=1 TO 4
480 IF T>2.9 THEN 510
490 B=E=-.008
500 GO TO 520
510 B=E=0
520 A=A0*(1+C3)↑T
530 M=X(1)+X(2)
540 N=X(3)+X(4)
550 P=M+N
560 Q=M/P
570 R=X(2)/M
580 W=1+S1*(J/A-.7)
590 Z=1-12.34*R
600 G=K4*A*W*Z
610 V=V+1
620 IF V<=V1-1 THEN 640
630 V=0
640 I=Z(V)
650 Z(V)=G
660 J=.5*I
670 K=C2*J
680 L=(1-C2)*J
690 C=B*X(1)
700 S=A-L
710 F=E*X(3)
720 IF U=0 THEN 950
730 D(1)=L-C-C1*X(1)
740 D(2)=C-C1*X(2)
750 D(3)=S-F-C1*X(3)
760 D(4)=F-C1*X(4)
770 ON P1 GO TO 780,810,810,840
780 MAT E=(1)*D
790 MAT Y=(1)*X
800 GO TO 880
810 MAT X=(2)*D
820 MAT E=E+X
830 GO TO 880
840 MAT X=E+D
850 MAT X=(K1/6)*X
860 MAT X=Y+X
870 GO TO 920
880 MAT X=(K1*B(P1))*D
890 MAT X=Y+X
900 IF P1=2 THEN 920
910 T=T+K1/2
920 NEXT P1
930 N1=N1+1
940 IF N1<K2/K1-.5 THEN 470
950 Y=T+C5
960 PRINT Y,B,J,P,Q
970 U=U+1
980 IF T>K3-K1/2 THEN 1010
990 N1=0
1000 GO TO 470
1010 END
```

NOMENCLATURE

A	annual demand for engineers, people/yr
B	rate of layoff of graduate engineers, fraction/yr
C	rate of layoff of graduate engineers, people/yr
E	rate of layoff of non-graduate engineers, fraction/yr
F	rate of layoff of non-graduate engineers, people/yr
G	next year's engineering college freshman enrollment, people/yr
H	this year's engineering college freshman enrollment, people/yr
I	auxiliary variable without physical significance
J	rate of engineering college graduation, people/yr.
K	annual engineering graduates taking non-engineering jobs, people/yr
L	annual engineering graduates taking engineering jobs, people/yr
M	number of graduate engineers in engineering, employed and unemployed, people
N	number of non-graduate engineers in engineering, employed and unemployed, people
P	total number of engineers in engineering, graduate and non-graduate, employed and unemployed, people
Q	fraction of total engineering population who are graduate engineers

R	fraction of graduate engineers in engineering who are unemployed
S	annual non-graduates taking engineering jobs, people/yr.
W	contribution of job competition to the size of next year's freshman engineering class
$X(1)$	number of graduate engineers employed in engineering, people
$X(2)$	number of unemployed graduate engineers in engineering, people
$X(3)$	number of non-graduate engineers employed in engineering, people
$X(4)$	number of unemployed non-graduate engineers, people
Z	contribution of layoffs to the size of next year's freshman engineering class

REFERENCES

1. Engineering and Technology Graduates 1972, a report by the Engineering Manpower Commission of Engineers Joint Council, December 1972, page 44.

2. Engineering Manpower Bulletin Number 19, October 1971, published by the Engineering Manpower Commission of the Engineers Joint Council, page 2.

3. Reference 2, page 4.

4. Engineering Manpower Bulletin Number 22, August 1972, above publisher, page 3.

A DYNAMIC SIMULATION MODEL OF ENGINEERING MANPOWER NEEDS

Fred Landis

Introduction

In our highly technological society, we assume that engineering manpower constitutes and important national resource which has a direct bearing on the long range growth of the gross national product, on the nation's international market position and, indeed, on the very quality of life. To avoid continued misuse of this resource and to alleviate personal hardships, one must understand the patterns which have shifted from engineering shortages during the 1950's and 1960's to unemployment during the early 1970's and which may again cause a shortage in the next five years. Public policy decisions that counter the disastrous effects of cyclic movements can be formulated only if the mechanism of the interactions is understood and if the approach is sufficiently quantitative to estimate the number of individuals involved.

To address this question, I have attemped to develop a dynamic simulation model which assumes the cause-effect interactions and determines the interrelation coefficients from an analysis of historical data between 1950 and 1971. The model can be used to predict engineering employment and the enrollment of engineering students based on an assumed fluctuation in the national economy. The advantages of a dynamic simulation model are that large numbers of interrelations can be incorporated, the system can be refined to include sub-patterns such as the influence of R & D spending in various industry segments as compared to "state-of-the-art" engineering, and the highly nonlinear feedbacks inherent in such a system are accounted for. The model can also show that apparently simple countermeasures may actually be counterproductive and increase rather than stem unemployment.

In the past, dynamic simulation studies have found only limited acceptance among economists, perhaps largely due to this unfamiliarity with this approach. Economists are more attuned to classical input-output models between demand and supply. Yet, time does not enter explicitly in these models--production and absorption rates have to be entered externally and the models do not allow for feedback. Only the "cobweb" models of manpower studies proposed by Freeman allow for a time delay and are useful for cyclic fluctuations in supply and demand. However, since they are based on relatively simple interaction equations checked out by regression analysis, the models have to be relatively coarse. Transient feedbacks can only be handled in a very limited fashion.

The approach is, perforce, rather simple and makes cobweb models probably most useful for trend analyses rather than for detailed studies.

Overall Approach to the Simulation Model

The model will attempt to take economic data as input and compute engineering employment from them. Depending on the actual funding practices and their distribution into the various segments of engineering related industries, engineering employment levels can then be determined. These will vary and, in turn, effect college enrollments and the generation of new engineers. The assumptions made by the model are summarized below:

(a) Only economic factors define timewise variations of engineering employment and engineering enrollment.

While this is probably true for the actual practitioner of engineering, it may not be as true for the high school graduate considering an engineering career who may find other aspects more compelling.

(b) Fluctuations in engineering employment do not feed back on the gross national product.

This assumption is probably good for the short run where sales over a reasonable period of time are likely to be independent of the number of engineers employed.

(c) There is no distinction between the employability of engineers in different fields. The model does not allow for technological unemployment arising from the contraction of one industry segment and the expansion of another. Although this could have been incorporated into the model, the lack of data suggested that the additional complexity was not warranted.

(d) Temporary unemployment due to voluntary job changes and inherent technological unemployment in a growth economy can be neglected. This generally amounts to between 0.2 percent and 0.3 percent of the work force.

(e) A one-month time step is an appropriate forward integration step for the large number of simultaneous non-linear, time-wise difference equations resulting from the model. Here, too coarse an integration step leads to instabilities; too fine an integration step causes excessive computer time. Also, known "ramp functions" cannot be eliminated if the interval is too short. Many data are available only on an annual basis and must be interpolated. Similarly, students enter college or the labor market generally within concentrated periods which could cause large ripples unless they are smoothed.

(f) An engineer who leaves the profession will not return.

Economic Drivers - The Funding Flow

The principal components of the economic drivers are shown in Figure 1. Many of the interconnections actually used in the model are omitted for clarity.

Fractions of the gross national product (top left hand corner) can be assigned to various industry segments based on historical experience. Industry is broken down into four major components:

- Capital goods;
- Consumer goods;
- Aerospace and defense industries; and finally,
- Government and engineering services.

Each component can be further subdivided into "practice-of-the-art engineering" and "research and development," reflecting the vastly different number of GNP dollars associated with manufacturing or construction (which are classified as practice-of-the-art) and with R & D.

For any given level of these components, the total number of funded engineers can then be determined. This depends on the various unit costs and must account for the dollars of GNP/per engineer in each component, for inflation changes (where both general inflation and wage inflation may enter), for changes in productivity per man, etc.

All lead eventually to a single "employment factor" which will be the coupling link between "money" and "manpower."

An additional box labeled "pump priming" has been included to show where the infusion of separate external funds can be applied. The relative magnitude of GNP dollars associated with each engineer in the various industry components is illustrated in Table I.

TABLE I

GNP DOLLARS PER ENGINEER - YEAR IN VARIOUS INDUSTRY COMPONENTS (1970)

CAPITAL GOODS - PRACTICE OF THE ART	$ 666,228
CONSUMER GOODS - PRACTICE OF THE ART	1,488,180
AEROSPACE/DEFENSE - PRACTICE OF THE ART	348,552
GOVERNMENT AND SERVICES - PRACTICE OF THE ART	512,768
CAPITAL GOODS - R & D	48,372
CONSUMER GOODS - R & D	51,816
AEROSPACE DEFENSE - R & D	67,692
GOVERNMENT AND SERVICES - R & D (ASSUMED)	67,692

Data taken from Statistical Abstract of the United States, 1965 dollars inflated to 1970.

As noted in the table, almost $1.5 million per year is required to support one engineer in the consumer goods, "practice-of-the-art" industry. This includes food, textiles, and communications, and simply confirms the relatively low engineering employment in these industries.

GNP dollars per engineer are still near one-half million for government and services. They only come down in the research and development field where the dollars spent per engineer (about $50,000 - 70,000 per year) are from 2 to 4 times the engineer's annual salary. In contrast to practice-of-the-art engineering, R & D is highly engineering labor intensive.

One immediate conclusion may be drawn from these figures. If any anti-recession device has as its primary purpose keeping engineers employed, public works (government practice-of-the-art funding) will not do too good a job.

Rather, the improvement of engineering employment by direct "pump priming" suggests funding research and development. An R & D engineer acts--at least over the short range--like an "overhead added engineer"--only the salary and immediate support show up directly. The short term impact will probably affect neither sales nor the general economy. The model assumes that pump-priming funds will be used in this fashion and that $50,000 per year can keep an engineer on the job.

Manpower Flow

The assumptions used in the manpower flow model can be summarized as:

(a) There is a four month delay between the application of funds and their effect on employment.

(b) Unemployed, that is "laid-off" engineers, leave the profession over a three year period if they do not find other engineering employment.

(c) Unemployed engineering graduates (who never had an engineering job) drop out of the profession if they do not find engineering employment within one year.

(d) Once engineers leave the profession, they do not return to it. They fall outside of the sample and will no longer be counted as unemployed.

(e) There is a normal attrition between entering engineering freshmen and graduating seniors which has a historical base. This attrition will be augmented for freshmen and sophomore students if unemployment is high.

(f) The number of entering freshmen depends on both the level of engineering employment and the number of laid-off engineers and unemployed recent graduates (negative influence) or the number of funded but unfilled jobs (positive influence).

(g) Immigration and promotion from non-engineering ranks will vary with the total employment level and the number of employed engineers.

The model assumes a minimum of 100 persons per month and a maximum of 2,000 persons per month entering engineering via immigration or promotion. This also includes technicians and technologists moving into engineering.

The actual (but highly simplified) manpower flow is shown in Figure 2. Entering freshmen (at lower left) graduate about four years later. They then enter the ranks of employed engineers, enrolled in graduate school (only full-time graduate students are considered), or become unemployed graduates. For purposes of simplicity, the model assumes that all full-time graduate programs last 18 months.

Reduced employment opportunities will drive engineers into the "unemployed" category (upper right); increasing opportunities will draw them in from all feeders. Immigrants will enter employment rapidly if opportunities exist, otherwise they too will join the ranks of the unemployed.

There are various additional cross-linkages of which only two are shown. At times of high unemployment, ex-graduate students will join the ranks of the unemployed. Yet, at the same time, others may try to improve their eventual opportunities by first entering graduate school.

Again, the two boxes shown as "unemployed engineers" and "unemployed graduates" are much more complex than indicated in the figure. Since engineers in these categories leave the profession at different rates, depending on the length of time they have been unemployed, the model must track the inflows and outflows into these time-wise staggered manpower pools. Similarly, the rate at which unemployed graduates can flow back to graduate school must allow for time differentiations.

A specific time-wise variation used is shown in Figure 3 which illustrates the assumed rate at which unemployed (laid-off) engineers leave the profession. Almost all unemployed engineers still seek an engineering job for the first few months then they begin to seek other work. If they have not found an engineering job by the end of 36 months, they will be completely lost to the profession.

Employment Factor and Information Interlinkage

The linkage between money and men is the "employment factor" and the information flow which is coupled to it.

The "employment factor" is defined as the difference between the current number of engineers that can be funded and the number of engineers that could be funded during the past month.

If this is positive, the factor calls for the hiring of more engineers. If it is negative, it will call for lay-offs unless there are still funded but unfilled positions open due to the prior absence of available personnel.

If the employment factor is positive, engineers are hired from the various feeder groups (laid-off engineers, unemployed graduates, graduating seniors, graduate students, and immigrants) in proportion to the number of individuals waiting in these groups. The model does not give preference to any one group, although this could easily be programmed in.

If there is additional funding but no individuals are waiting in the feeder groups, the money is set aside in a category of "excess funded but unfilled jobs." The model assumes that this funding level will not deteriorate with time but will only be diminished as either new manpower enters the feeder groups or when the employment factor becomes negative and fewer engineers will be called for.

The principal information interactions arising from the employment factor can be seen in Figure 4 which is an extension of Figure 2.

The dotted lines show the information transfer generated by some of the funding and personnel levels. Each effectively actuates a "valve" which controls the feed in and out of the various personnel level. Again, only a small portion of the transfer lines actually used in the model are shown.

Determination of Coefficients and Integration Scheme

It now remains to compute all the interaction coefficients between money flow, information transfer, and personnel flows. As far as possible, these were deduced from statistical data although a number of estimates were also required. These were then checked in actual model sensitivity runs to assure that they were at least reasonable.

The coefficients may be constant, depend on the actual levels, or may even be slowly varying with time. Obviously, a simple representation over a long time period cannot predict all the local fluctuations that can occur and some scatter must be anticipated.

The actual computational scheme chosen was the DYNAMO II compiler developed by Forrester and his associates [2] for the simultaneous forward integration of large numbers of non-linear coupled first order differential equations that occurred in this type of dynamic model.

The Historical Calibration Run

To calibrate the model, which was developed during 1973 and 1974, the available data for the period from 1950 through 1971 were used. As input information, the given gross national product and the funds allocated to research and development, as shown in Figure 5, were taken.

Bringing in inflation allowances, changes in productivity, changes in funding allocations to the various industry components, etc., the number of employed engineers could then be computed and compared to historical data. This is shown in Figure 6.

As may be noted, the prediction is not perfect, but it never differed from the actual employment level by more than 6 percent.

A much more sensitive measure is the computation of the number of entering engineering freshmen per year. In the logic of the computer program, this is the final output and all assumptions built into the model will tend to amplify errors in freshmen enrollment.

The results are shown in Figure 7 where the number of predicted engineering freshmen (solid line) agrees fairly well with the number of actual freshmen (chain-dotted line) for the 1950-71 period. Both the rapid rise in the early 1950's and the decline after 1967 are reasonably well represented.

The figure also shows two additional curves which were computed by the model. The dotted line indicates the number of excess funded but unfilled jobs. These reached a peak in 1957 and again in 1966 when the maximum was about 52,000 unfilled jobs.

The heavy dot line represents unemployed (laid-off) engineers and shows that this became a problem only in 1970 when the maximum reached about 12,000 out of a labor force of 1.1 million. The increasing number of unemployed engineering graduates still has to be added to the unemployed engineers.

While this number may appear to be smaller than should be expected, it should be recalled that the model assumes that an engineer leaves the profession if he finds no engineering employment. Whether he is actually unemployed or has found a non-engineering job no longer matters.

The Basic Simulation Study

Following the historical calibration, the model should now be in a position to simulate the potential impact of changes in national spending practices.

As with the initial test case, several assumptions were made. Starting with actual 1970 data, the gross national product grows at a true rate of 3 percent per year (non-compounded). Inflation is neglected and all data are reflected to 1970 dollars. After 7 1/2 years (at month 90) an adverse cosine distrubance with a maximum ± 2 percent amplitude is superimposed on the normal growth. As shown in Figure 8 this causes a near leveling of the GNP followed by a slight over-shoot. This disturbance is assumed to be of 6 years duration and then spending returns to the normal 3 percent growth curve. R & D funding follows the GNP pattern. Here, too, a total 4 percent variation is superimposed on the normal growth curve.

To complete the specifications of the problem, productivity is assumed to increase at 2 percent per year (non-compounded) for the practice-of-the-art engineering only (research and development usually shows a negative productivity change, if any) and the annual retirement and voluntary leaving rate is kept at 4.2 percent. The 90 month starting period has been used solely to eliminate possible starting transients.

As shown in Figure 9, this small economic disturbance barely causes a ripple. Total unemployed engineers and graduates never exceed 25,000 (out of a total work force of nearly 1.4 million engineers by that time) and freshman enrollment variations are also minute.

A more realistic example would be based on the experience that even slight downturns in the economy lead many corporations to decrease their R & D funding disproportionately to save production personnel instead. If on the same 4 percent fluctuation in the gross national product, a 25 percent variation on R & D funding is superposed, much more drastic effects might be expected in view of the high engineering labor intensity of R & D work.

The basic funding variations are shown in Figure 10 where, except for the severe variation in R & D funding, all other conditions are retained as far as the previous example.

The results on employment are given in Figure 11. There is a significant drop in the number of engineers employed, but even more important is the extremely slow recovery rate. For a period of about eight years, the number of funded engineers continues to be above the number of those employed; neither the generation of new students nor immigrants and promotions can make up the shortage. The severity of the disturbance is also illustrated in Figure 12 which shows the number of laid-off engineers (solid line), the number of excess but unfilled jobs during the recovery period (chain-dotted line), and the effect of freshman emrollment (dotted line).

At the peak, about 55,000 engineers are laid off and still looking for engineering jobs. The maximum number of funded but unfilled jobs reaches about 125,000 two and one-half years after the funding disturbance is over. College freshman see a dip of over 20,000 per year with a subsequent overshoot of nearly 15,000. From a national manpower point of view, this can only be described as havoc.

If unemployed engineering graduates are added to those who have been laid off, the picture becomes even more frightening. Total unemployment of engineers reaches about 85,000 at the peak and over the period of the disturbance, more than 90,000 engineers will be lost to the profession.

The previous case has assumed that productivity in the "practice-of-the-art" category increases by 2 percent per year while the retirement rate stays at 4.2 percent annually. If for the same 6 year perturbation, subsequent to month 90 (the end of the starting up period), it is assumed that there will be no productivity increase in any aspect of engineering, a rather startling result will appear.

Figure 13 shows that there is no recovery possible within any reasonable time period--there will be more funded than employed engineers for a period of over 15 years.

This suggests that a continued growth of the gross national product coupled with a constant technological component is only possible, once any significant disturbance has been introduced, if there is an increase in productivity. Otherwise, enough new engineers cannot possibly be generated, especially with the expected over-all drop in the birthrate, to maintain a systematic growth. The only alternative would be the wholesale introduction of immigrants or an extraordinary rate of promotion of non-engineers into the profession, far exceeding the 24,000 per year allowed for in the model.

This high short-fall takes place with an annual freshman entry level of about 110,000 students. This should be compared to the maximum historical values between 1950 and 1971 of about 80,000. Since the number of high school graduates will actually decrease in the next few years, a strong perturbation in the economy imposes a difficult task if return to a growing gross national product is hoped for unless there is marked improvement in engineering productivity--i.e., if the sales dollar per engineer goes up significantly.

Many other simulation runs were carried out as part of the initial model feasibility study. These included a change in the duration of the economic depression, changes in the effective retirement rate, and various attempts to stimulate a flagging economy by pump-priming.

Direct subsidies for engineers to work on "R & D-like" projects, and retraining and scholarship programs were tried. The results are incorporated in the next section.

Overall Review of Results

(a) A dynamic simulation model has been developed which appears to represent with reasonable accuracy the interaction between the economy, engineering employment, and the generation of new engineers. Like all simulation models, it must be used with caution in forecasting; the output will depend on the time dependency of the input assumptions.

(b) Small fluctuations in the gross national product can be absorbed fairly readily and without serious long-range national impact as long as the labor intensive R & D component is maintained at a correspondingly high level. The usual reaction of industry to reduce R & D spending during a declining economy is perhaps the greatest single contributor to long-range problems.

(c) Once a major fluctuation is initiated, especially if it is reinforced by a decline in R & D spending, the disturbance tends to feed on itself. Recovery tends to be much slower than the downturn and, in the case of an anticipated overall growth economy, may lead to extended periods when open engineering positions cannot be filled. A strong recovery may also entice additional students into engineering, causing further fluctuations later on unless additional controls are imposed.

(d) Within the expected span of economic fluctuations (perhaps four to six years), the magnitude of the disburbance is more important than its duration.

(e) Of the various possibilities that have been examined for alleviating the effect of the disturbance, such as the direct injection of employment funding, scholarships, graduate student stipends, and retraining programs, only the first alternative appears to be promising. The others may be counterproductive and, depending on their timing, may actually increase the unemployment rate and slow down any recovery.

(f) Direct pump-priming should be used to hold on to engineers and put them into "R & D-like" tasks where they act like "overhead added" engineers.

(g) Public works programs introduced during a depression do not assist engineering employment significantly since the number of engineers associated with each public works dollar remains rather small.

(h) Cyclic upswings tend to result in a temporary engineering shortage which may again lead to wrong expectations and to temporary over enrollments of engineering students. Short of massive immigration or promotion programs, the temporary shortage cannot be alleviated.

(i) The model has also shown a number of interesting side effects. These include a definite limitation on economic growth if it is assumed that the engineering component of the gross national product remains essentially invariant. Thus the projected need for new engineering students would far exceed the available manpower pool if a growth rate of 3 percent is to be reached--unless there is an increase in productivity in the state-of-the-art engineering. The often touted problem that the next few years must see an increase in research funding and personnel to overcome the energy and ecological crises would only lead to further engineering shortages--unless the overall economy becomes almost stagnant.

Conclusions

Useful dynamic simulation models can be developed from the approach in this paper as shown from the abbreviated results presented. With further refinements and disaggregations it should be possible to develop an effective engineering manpower projection tool which should have applicability for a three to seven year period--assuming that the exogenous funding variables can be estimated with reasonable precision. Anticipated extensions of the model should also allow an examination of the specific impact which federal programs may have on engineering manpower, e.g. the suggested impact of major energy related engineering developments. The model also provides sufficient insight into the dynamic manpower interactions to serve as a planning tool.

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REFERENCES

1. Freeman, R. B. "Engineering Manpower Market in the 1970's," IEEE Manpower Reports, 1973, Institute of Electrical and Electronics Engineers, Inc., 1973, pp. 91-116.

2. Pugh, A. L. III. " Dynamo II F Users's Manual," 4th Ed., The M.I.T. Press, Cambridge, Massachusetts, 1973. For background see also: J. W. Forrester, Industrial Dynamics, The M.I.T. Press, Cambridge, 1961.

FUNDING FLOW

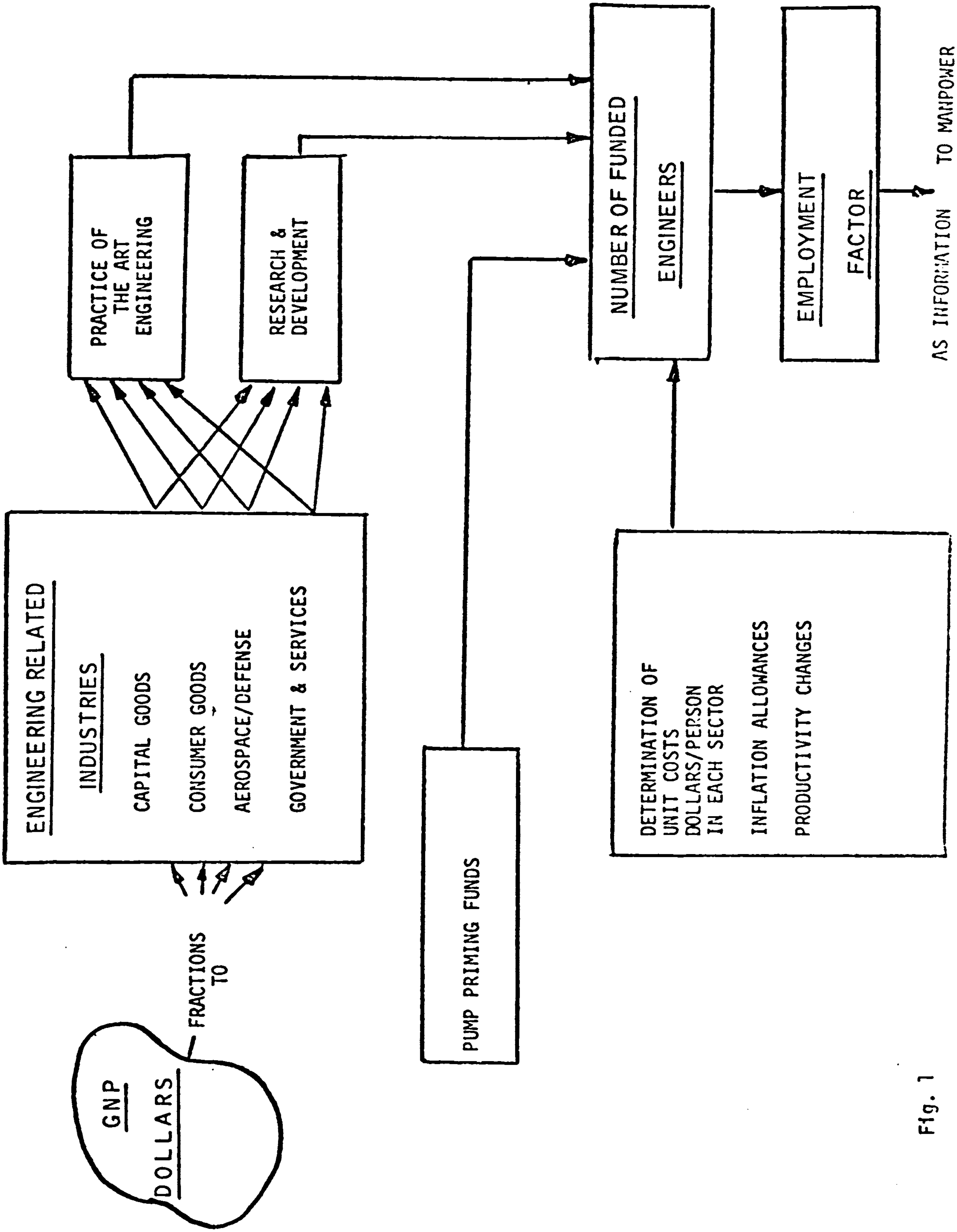


Fig. 1

MANPOWER FLOW

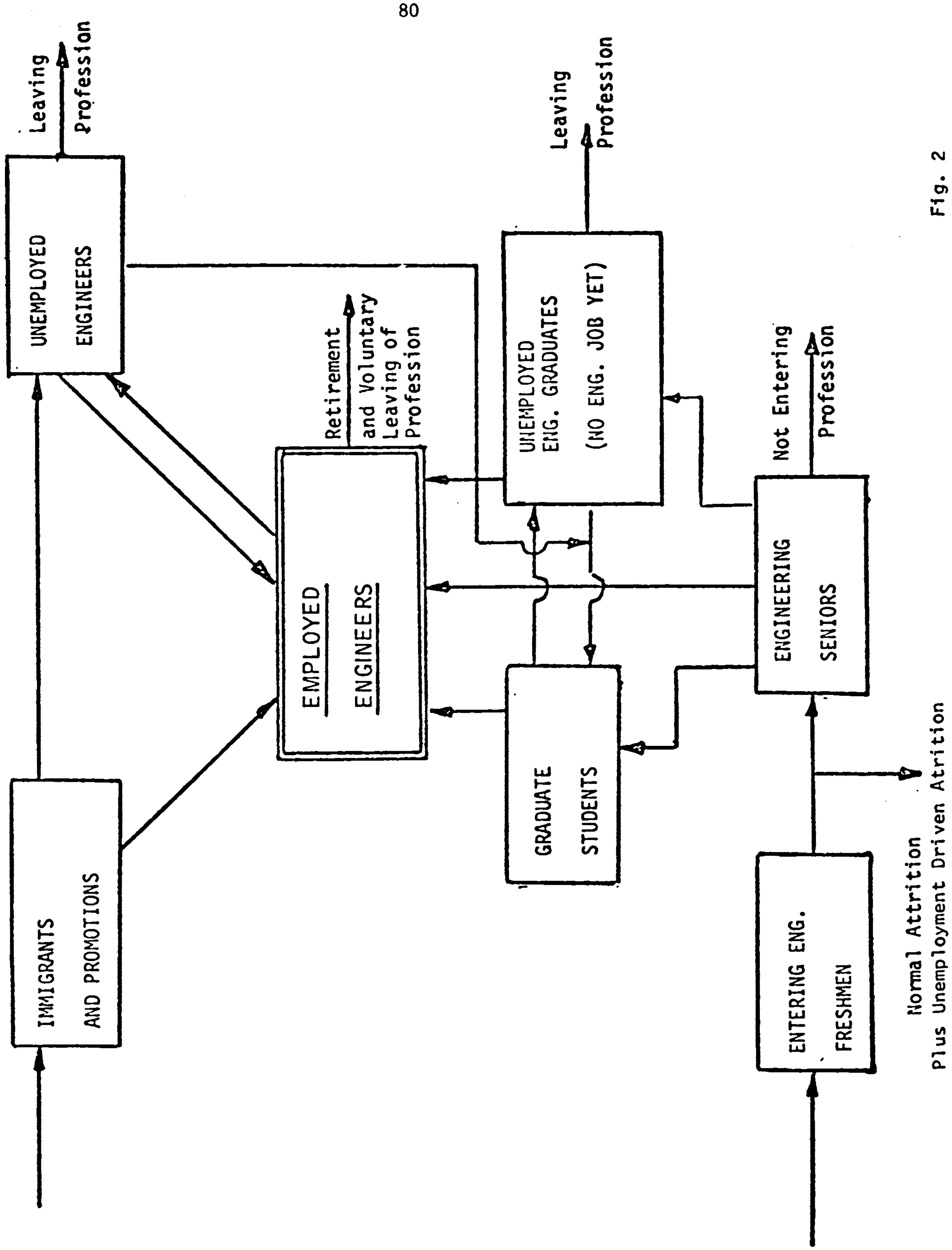
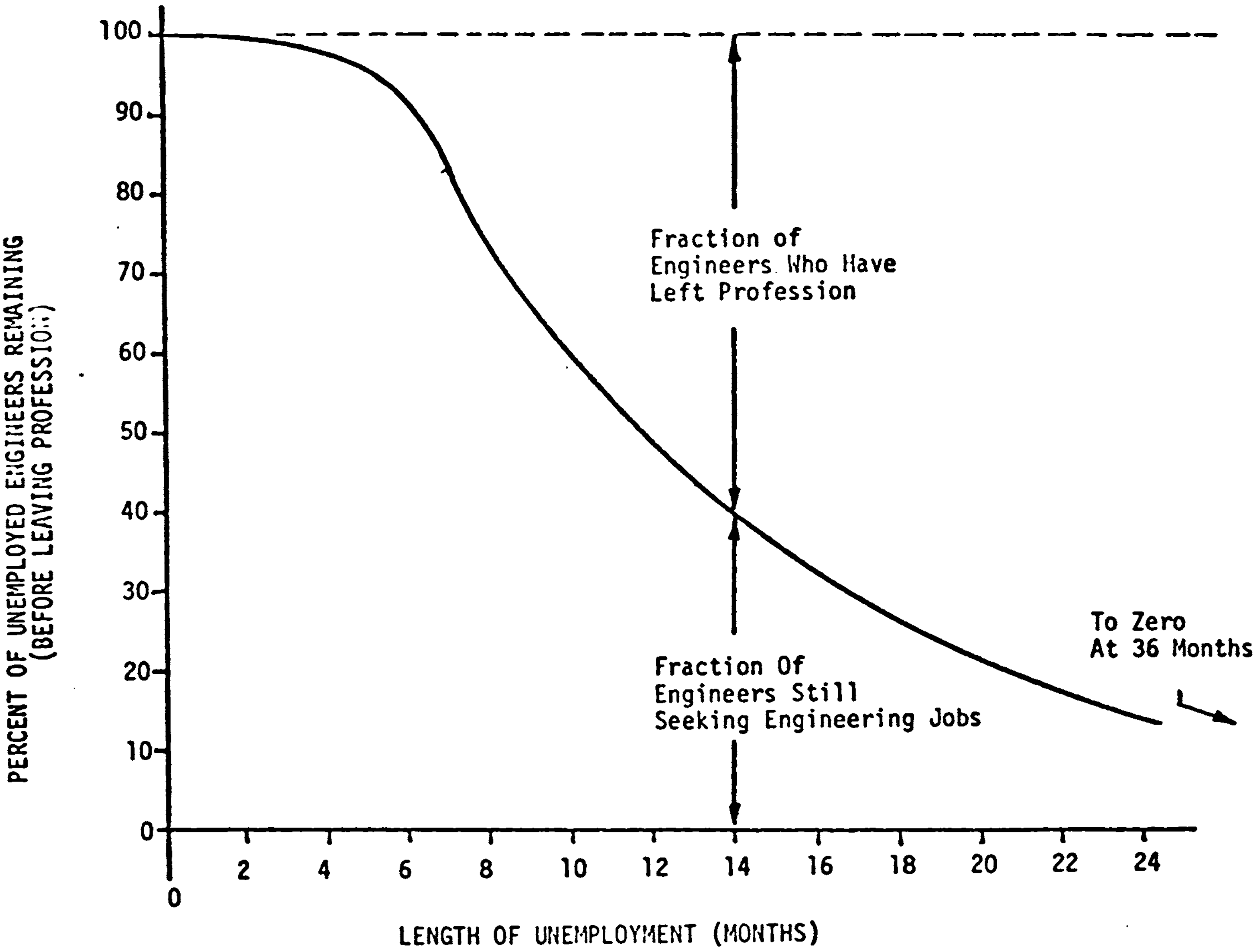


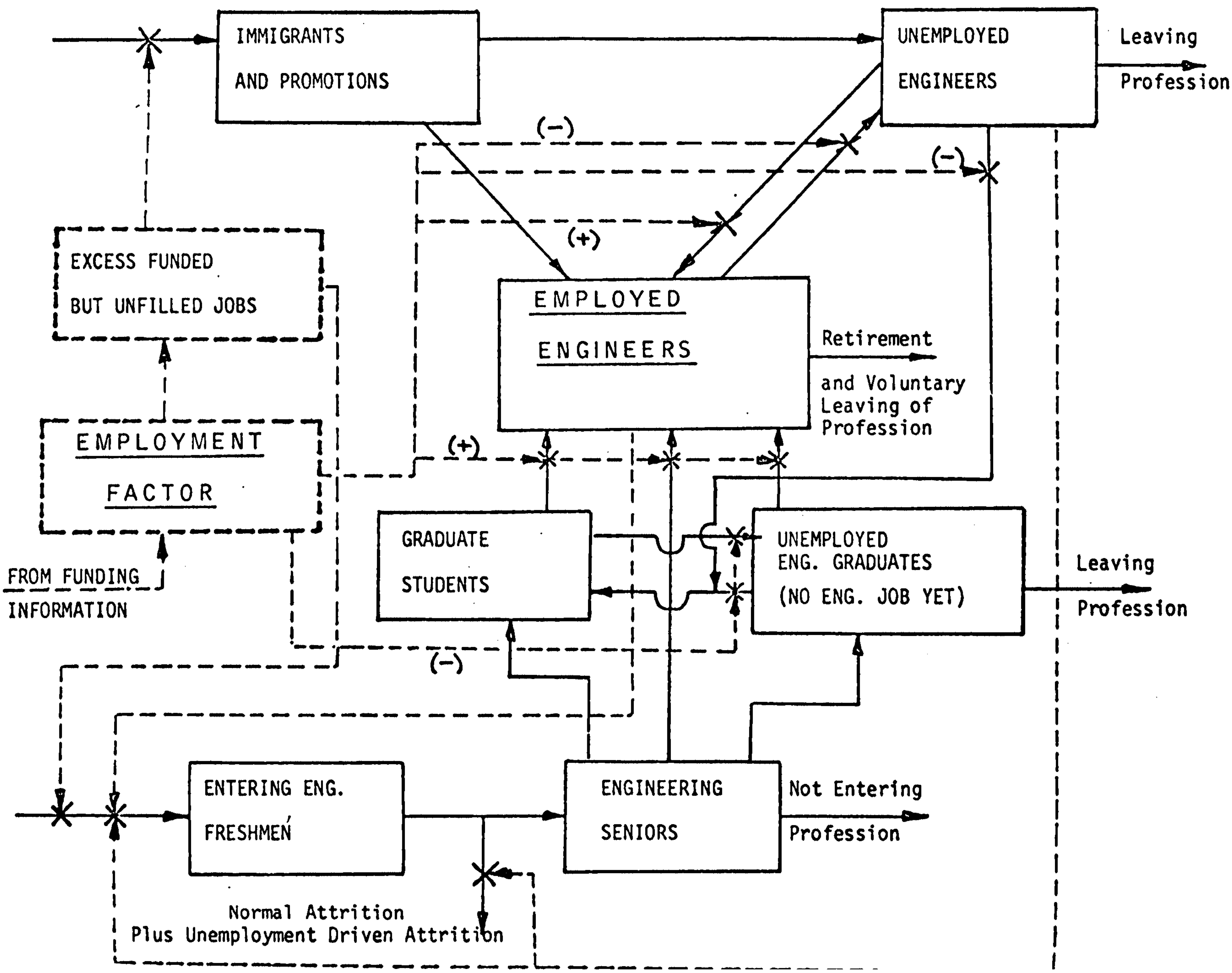
Fig. 2



PERCENT OF UNEMPLOYED ENGINEERS STILL SEEKING ENGINEERING JOBS VS TIME

Fig. 3

PRINCIPAL INFORMATION FLOWS (DOTTED LINES) SUPERIMPOSED ON MANPOWER FLOW



HISTORICAL CALIBRATION RUN

GROSS NATIONAL PRODUCT AND R & D FUNDS

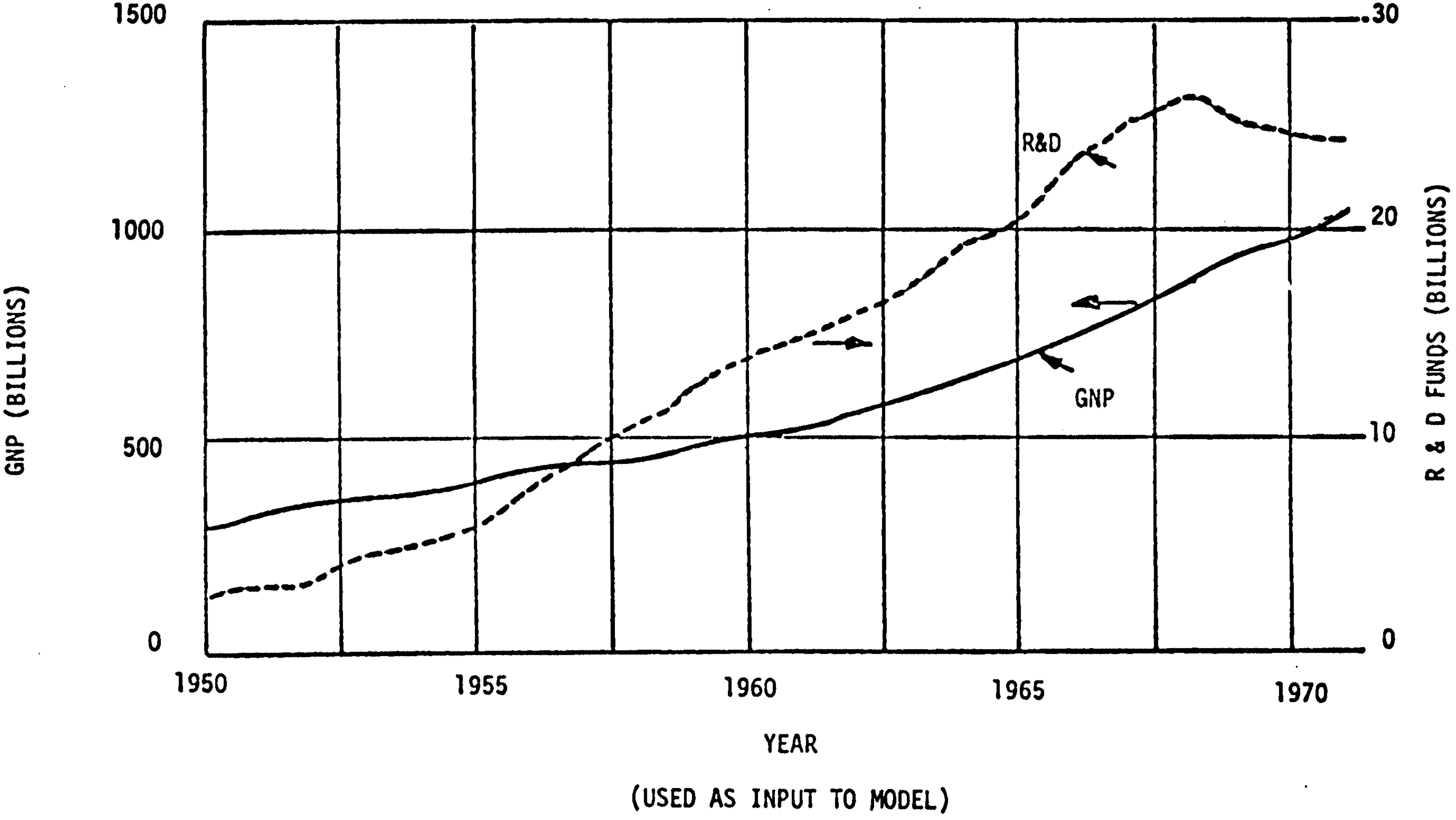


Fig. 5

(Replot of Computer Plot)

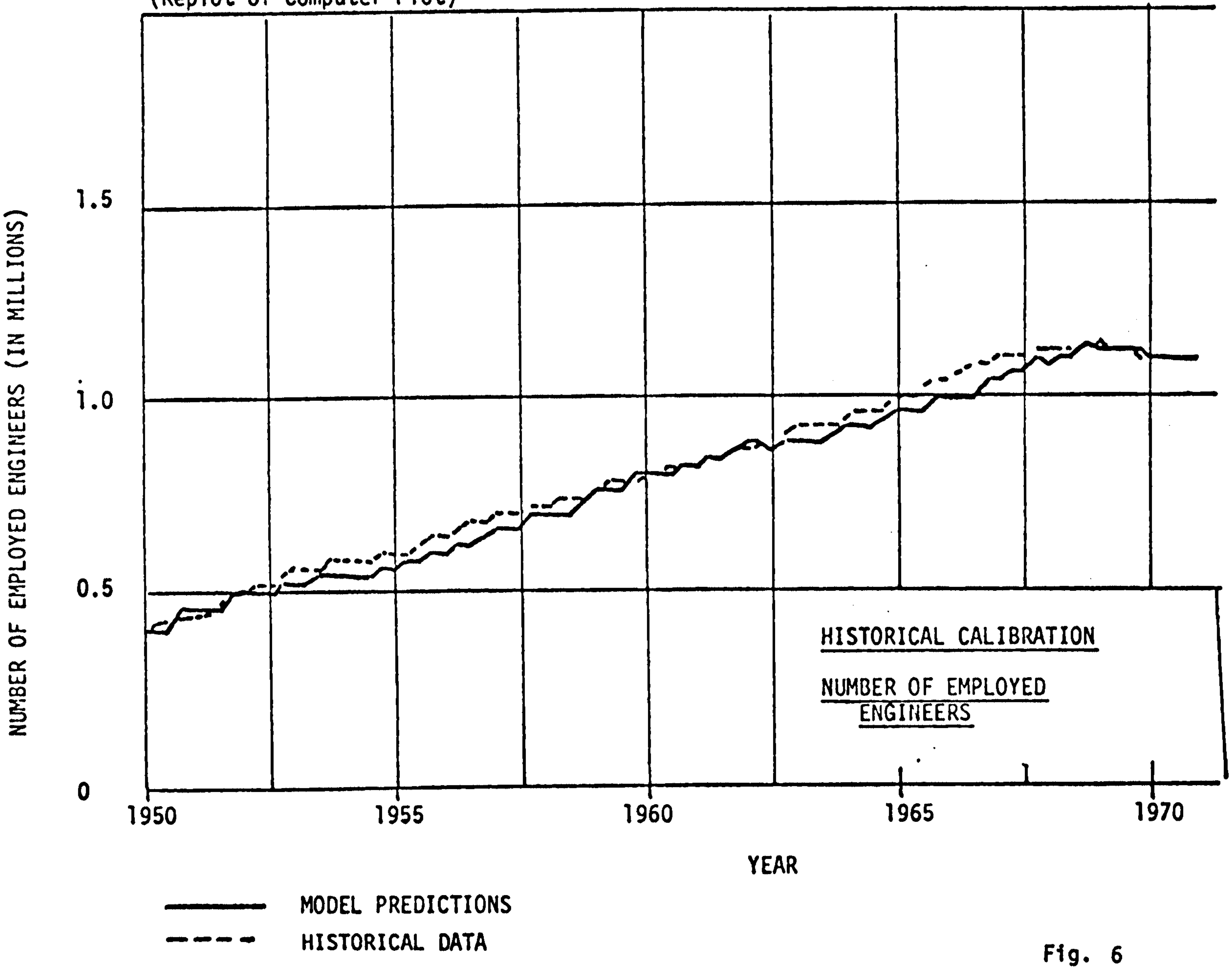


Fig. 6

HISTORICAL CALIBRATION RUN, FRESHMEN ENTRIES

(Replotted from Computer Plot)

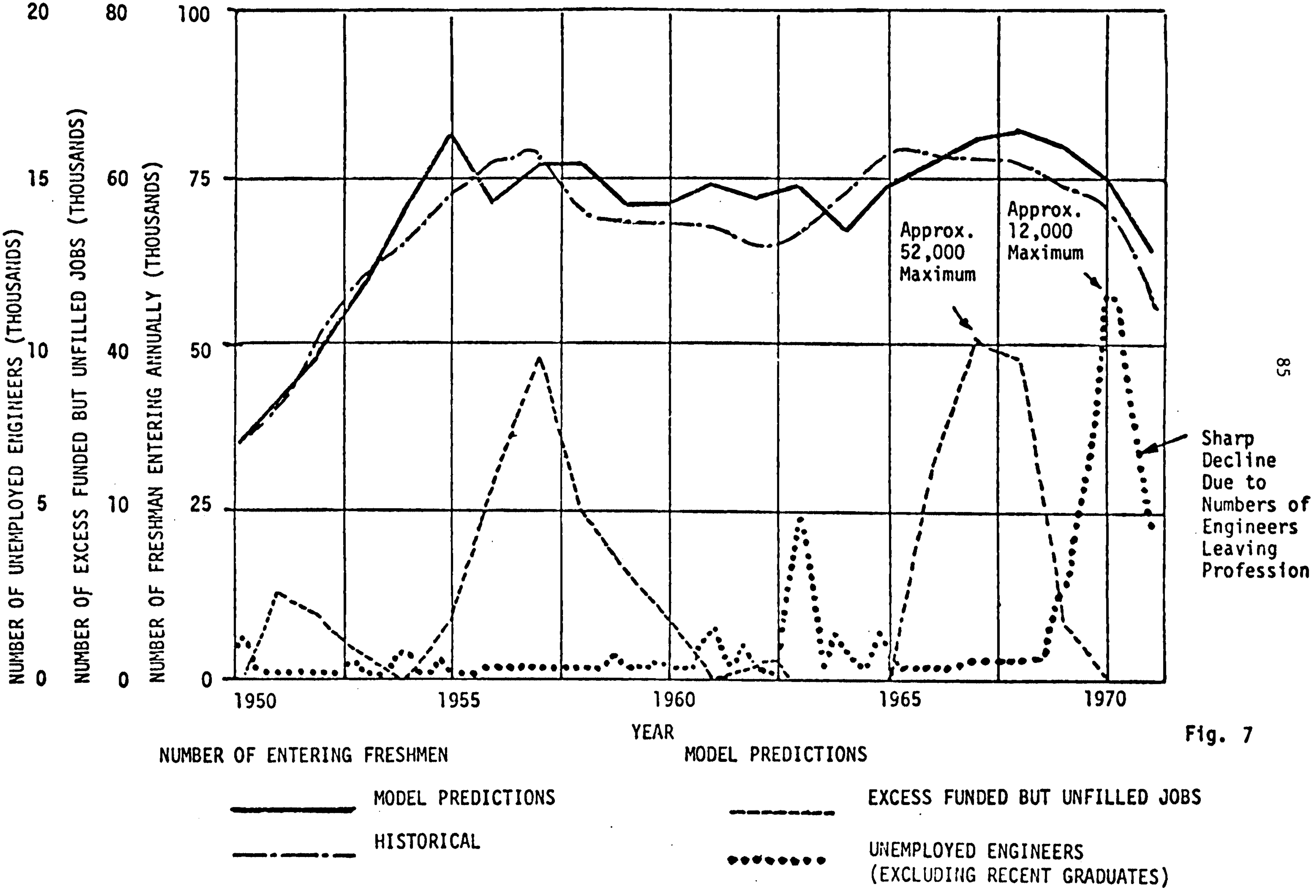
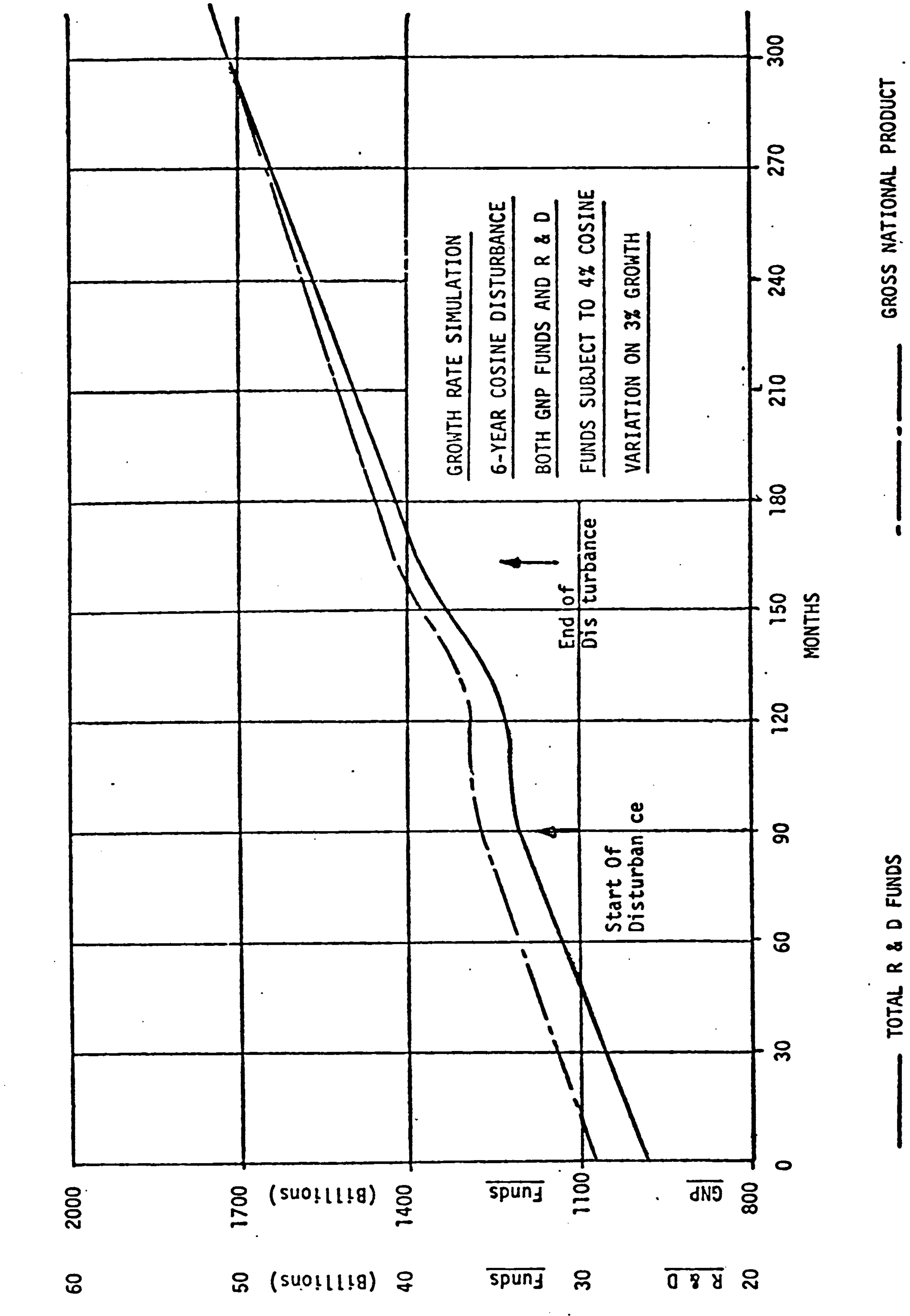


Fig. 7


GROWTH RATE SIMULATION
6-YEAR COSINE DISTURBANCE
BOTH GNP FUNDS AND R & D
FUNDS SUBJECT TO 4% COSINE
VARIATION ON 3% GROWTH
Start Of Disturbance
End of Disturbance
MONTHS
0
30
60
90
120
150
180
210
240
270
300
GNP Funds (Billions)
800
1100
1400
1700
2000
R & D Funds (Billions)
20
30
40
50
60
TOTAL R & D FUNDS
GROSS NATIONAL PRODUCT

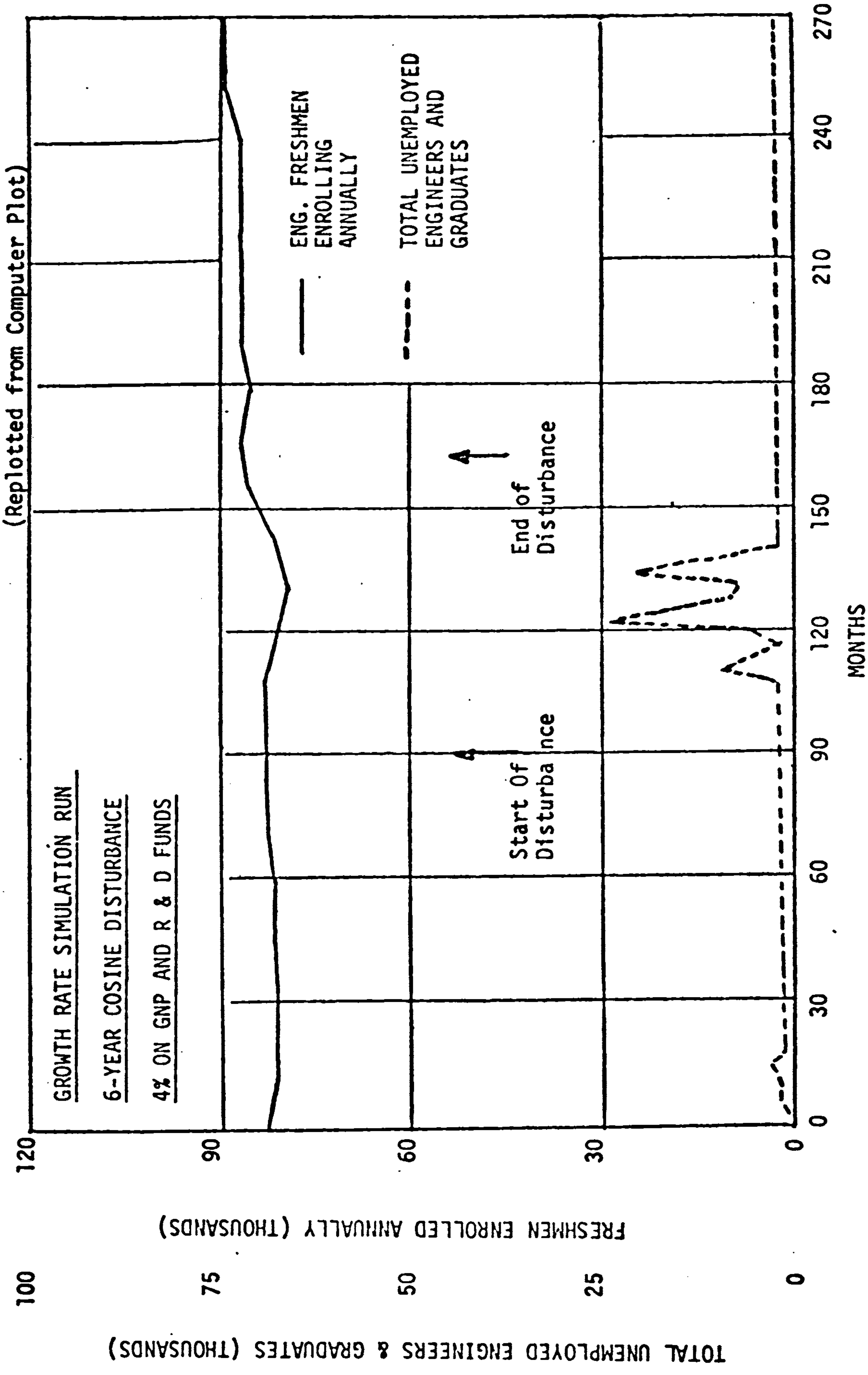
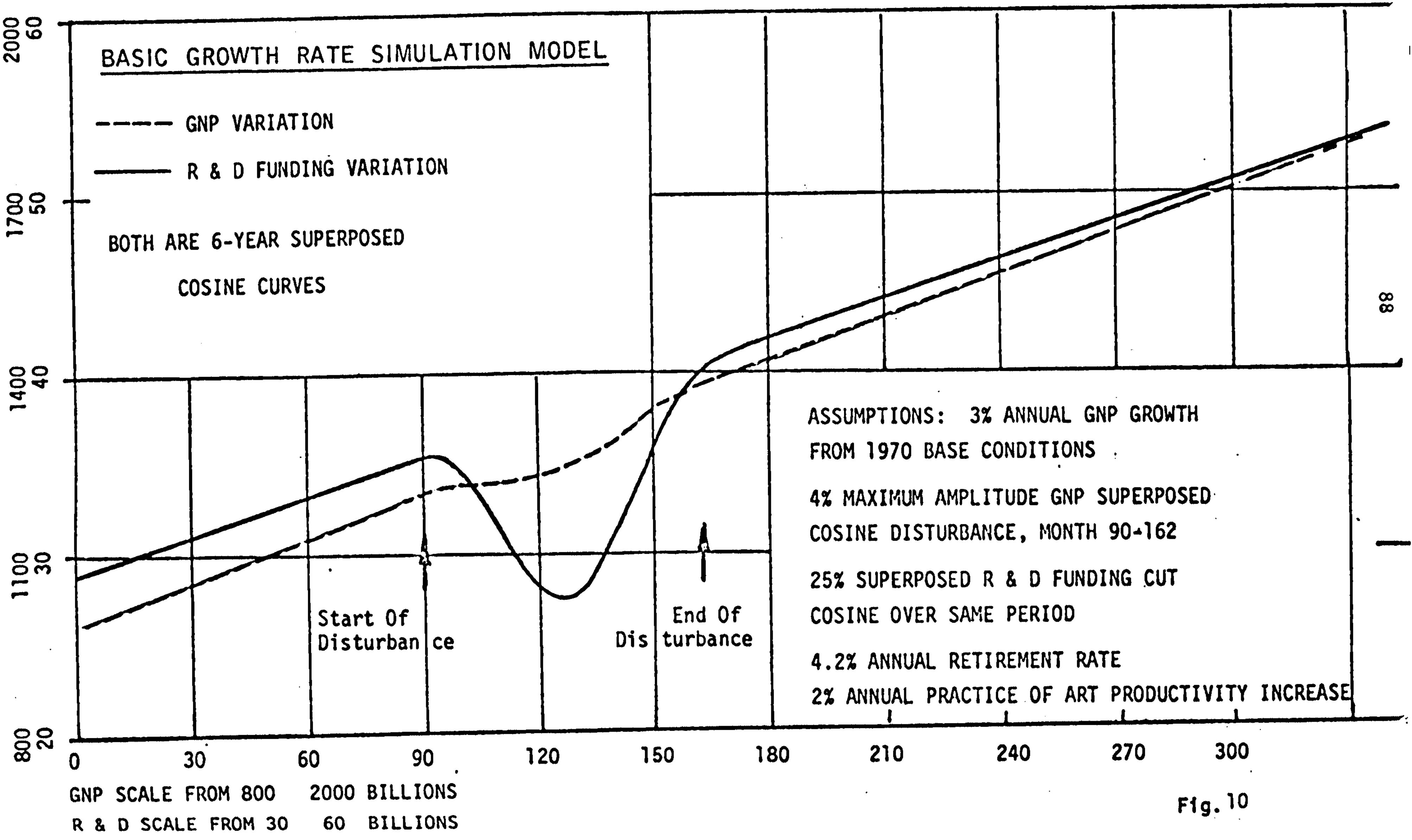

(Replotted from Computer Plot)
GROWTH RATE SIMULATION RUN
6-YEAR COSINE DISTURBANCE
4% ON GNP AND R & D FUNDS
ENG. FRESHMEN ENROLLING ANNUALLY
TOTAL UNEMPLOYED ENGINEERS AND GRADUATES
Start Of Disturbance
End of Disturbance
120
90
60
30
0
FRESHMEN ENROLLED ANNUALLY (THOUSANDS)
100
75
50
25
0
TOTAL UNEMPLOYED ENGINEERS & GRADUATES (THOUSANDS)
0
30
60
90
120
150
180
210
240
270
MONTHS

Fig. 9



ASSUMPTIONS: 3% ANNUAL GNP GROWTH FROM 1970 BASE CONDITIONS

4% MAXIMUM AMPLITUDE GNP SUPERPOSED COSINE DISTURBANCE, MONTH 90-162

25% SUPERPOSED R & D FUNDING CUT COSINE OVER SAME PERIOD

4.2% ANNUAL RETIREMENT RATE

2% ANNUAL PRACTICE OF ART PRODUCTIVITY INCREASE

Fig. 10

(Replotted from Computer Plot)

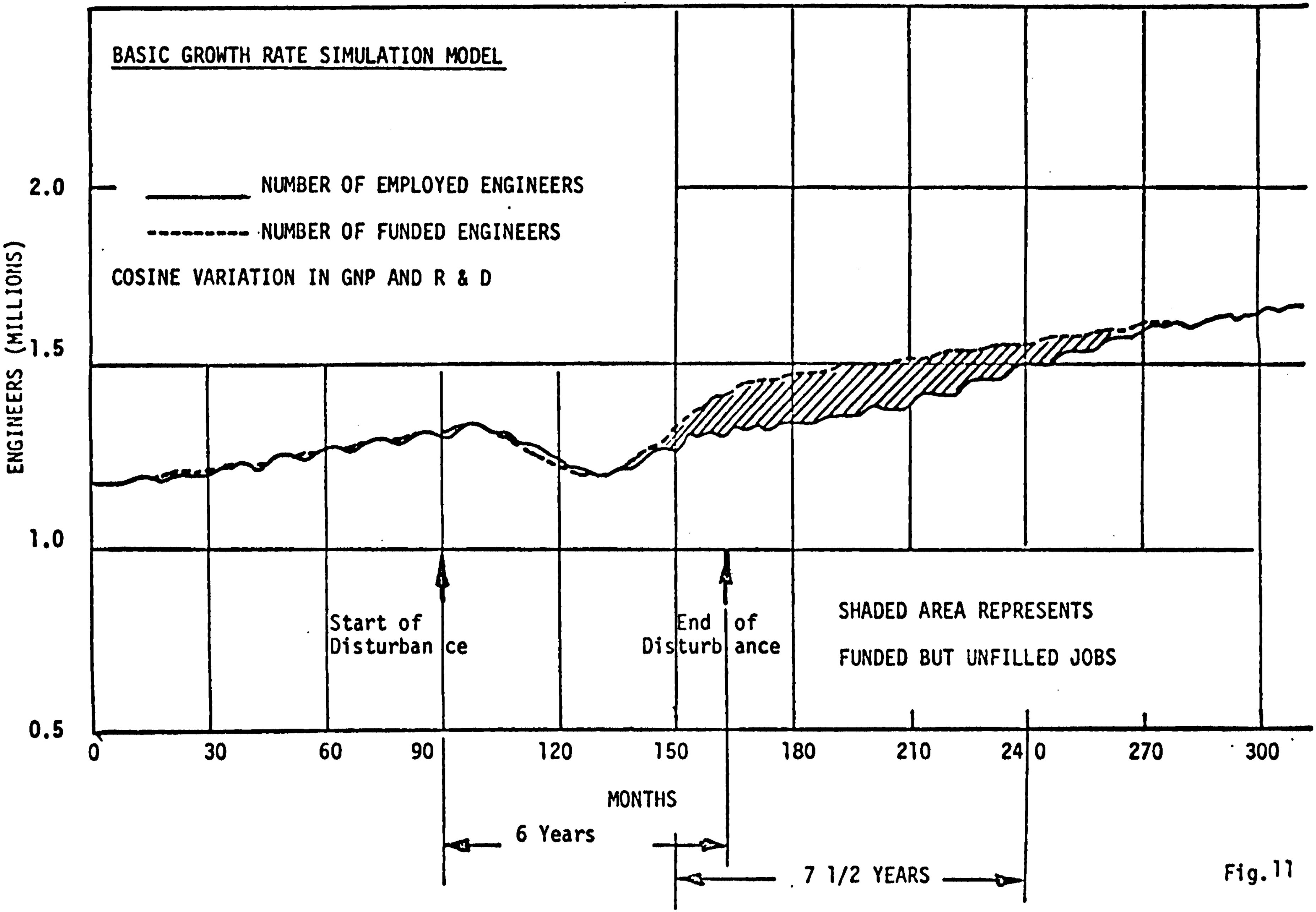


Fig. 11

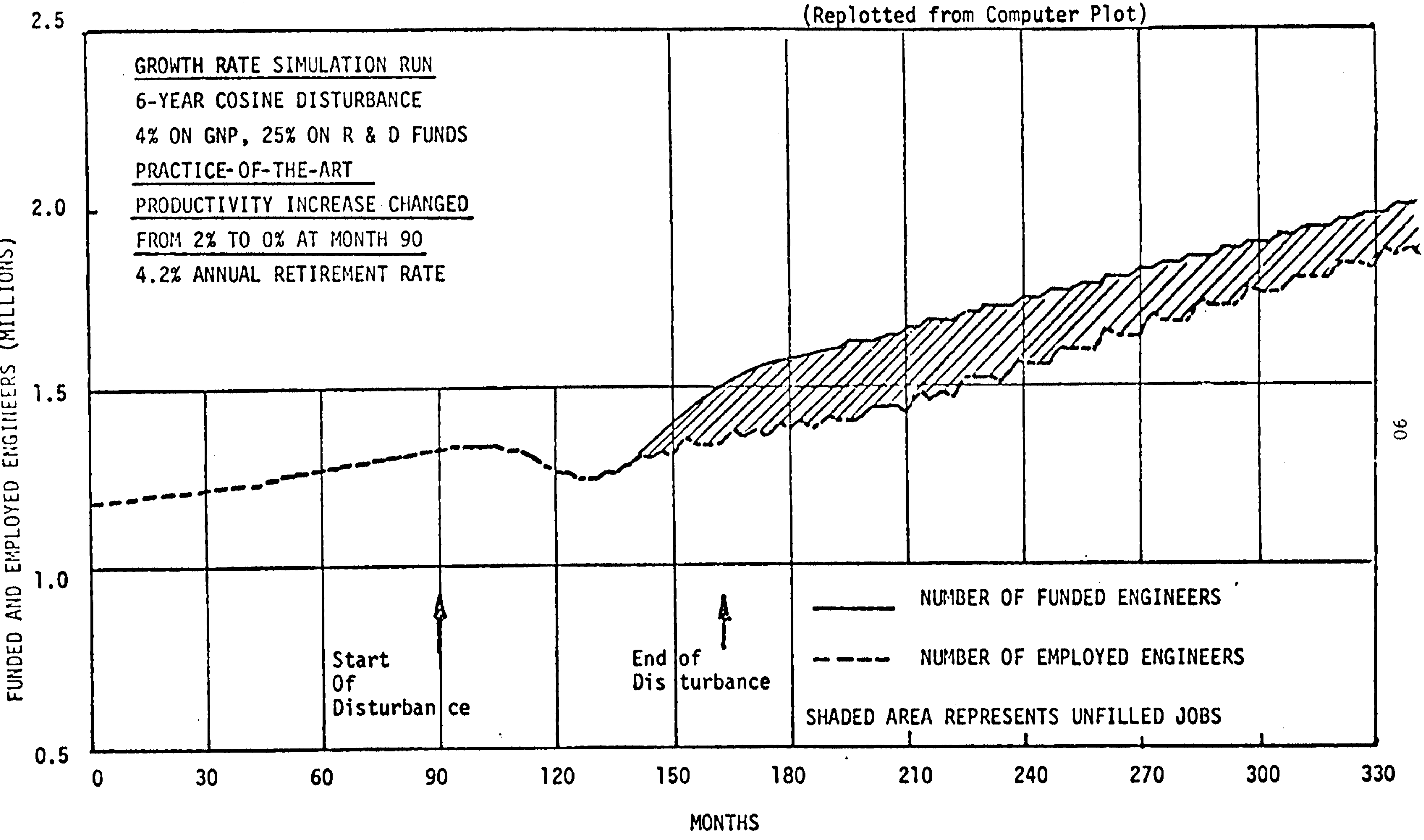

(Replotted from Computer Plot)

Fig. 12

BASIC GROWTH RATE SIMULATION MODEL

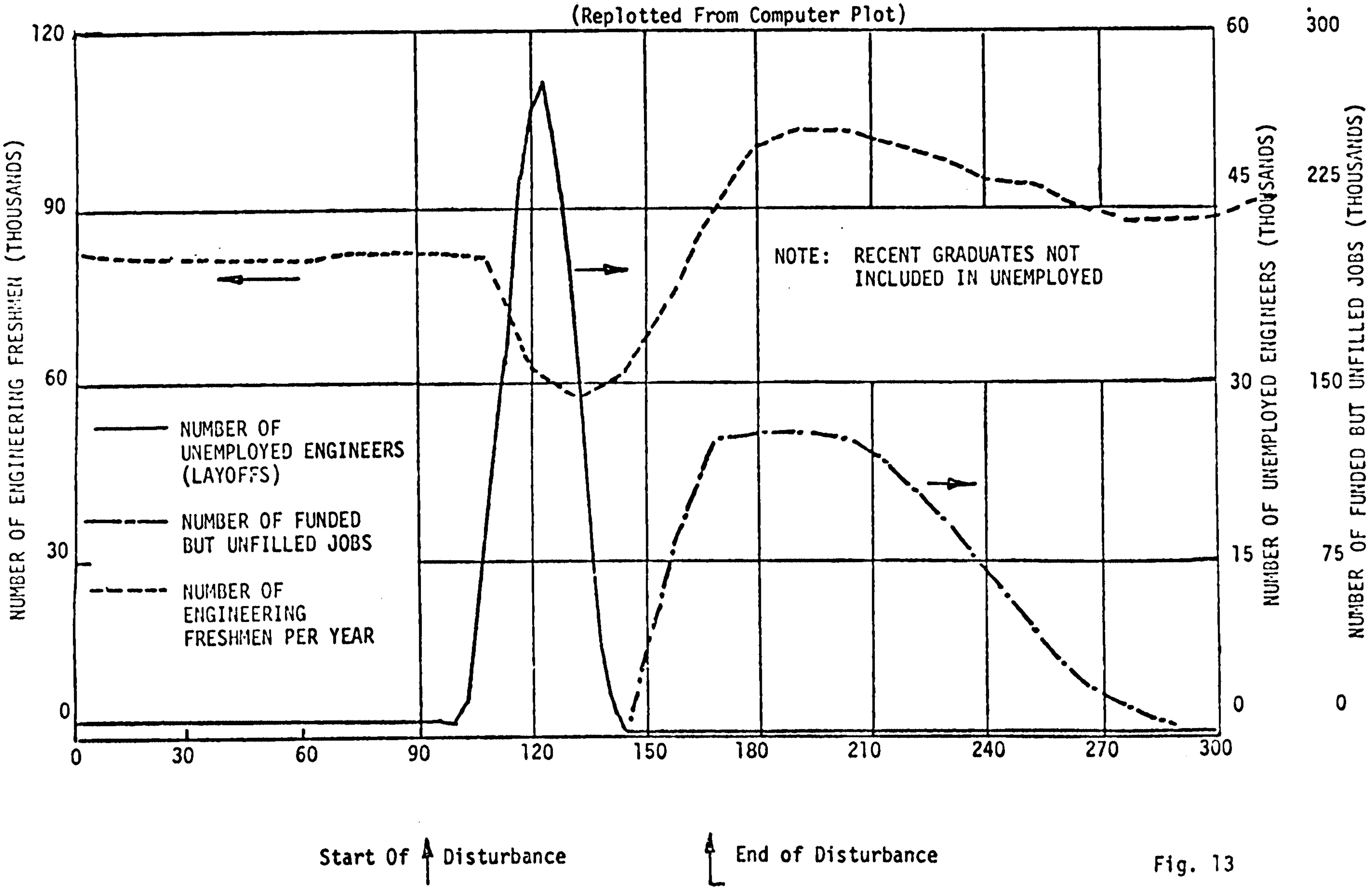


Fig. 13

MANPOWER COMPONENT FOR LARGE SCALE ENERGY MODELS

A. Wade Blackman

The Energy Research and Development Administration Planning System consists of a hierarchy of three separate plans. It includes:

- A normative plan which tells what ought to be done;
- A strategic plan which tells how it can be done; and
- An operational plan which tells what will be done.

The top level serves as an organizing system whose ends and values govern the behavior of the whole system. The objectives of the lower level are set with the aim of providing information to the next highest level.

The Normative Plan

The normative plan describes a set of desired future conditions to be achieved by the planning process. It reveals what ought to be done. It is aimed at the clarification of the consequences of proposed actions within a hypothetical time interval and within some specified environment or situation.

Normative planning is predicated upon a number of analytical building blocks. One such building block is the Reference Planning Projection. The Reference Projection serves to indicate that future state of a defined system which would be expected to exist in the absence of planned intervention in future events which are perceived to cause changes in the system. This projection defines the differences between what is desired in the future and what probably will exist without intervention. Thus, this projection serves primarily to define future problems and to indicate the need for future action.

Other building blocks for the normative analysis are based on models of the energy system that attempt to replicate its dynamic behavior. These models are used to generate scenarios which suggest alternative directions for the evolvement of the current energy system and which reveal objectives toward which planning should be directed.

The various scenarios found to be most consistent with desired ends and values are integrated into a composite scenario to depict that future which appears possible and most consistent with the envisioned ends. The composite scenario defines what the system ought to be like.

We rely heavily on the Brookhaven model, the Bechtel model, and the Illinois input-output model in developing these scenarios. More will be heard about these models later in the panel discussions.

The Strategic Plan

The next level in the planning hierarchy is the strategic plan.

Strategic planning defines those decisions that determine what can be done in a given time period and a given situation. It incorporates procedures for goal-setting that are time-specific and related to their more distant outcomes through a consonance with the higher level normative constraints.

A key ingredient of the strategic plan is a determination of the relative role of the private and government sectors in achieving planning objectives. This determination is based on models which attempt to replicate the investment decision making process in the private sector.

If the private rate-of-return and other figures-of-merit for an energy system option do not meet requirements, the venture will not be considered for private funding. If the venture meets requirements and has a high probability of private sector funding, then the government performs its legislated regulatory functions.

If it is judged that factors exist (such as high risk, high exposure, market fragmentation, etc.) which preclude private funding then it is necessary to determine if the public rate of return is sufficiently high to justify government involvement. This determination requires internalization of benefits and costs which can differ from those considered in the evaluation of private returns.

If the public rate of return is judged to be high, it must next be determined what kind of government involvement is appropriate. Many incentives exist which the federal government can use to induce the private sector to innovate and to accelerate the rate of diffusion of new products in the marketplace. These include guaranteed loans, capital grants, price supports, research and development funding, etc. The most effective incentive mechanism(s) decision are those which can cause the venture to meet the private sector's investment criteria. Those incentives which will induce private sector participation at the least cost to the government are then identified. They serve to define the government role.

The results of the strategic analysis are a rank-ordered listing of energy system options in terms of their relative importance to ERDA: A definition of the ERDA activities which will be required to achieve commercialization of the various systems, a definition of the relative roles of ERDA organization units in achieving the commercialization goals, and a pro forma allocation of expected resources among ERDA organizational units.

Manpower models provide key inputs to the strategic plan. The models used at this level are focussed more sharply on specific energy options than they are when they are used to support normative planning.

The Operational Plan

The final level in the planning hierarchy is the operational plan, which describes how decisions formulated at a higher level will be implemented. The operational plan incorporates decisions concerning what "will" be done to satisfy the "oughts" specified in the normative plan and the "hows" described in the strategic plan. The operational plan sets forth in detail what will be accomplished in the near term and serves as a key input to the program evaluation and review process.

The manpower models used at this stage of planning are near term and are concerned primarily with manpower requirements for new starts or ongoing programs.

The overall ERDA planning process is dynamic and evolving. The future development of the process will be highly dependent upon the quality of the models providing the key planning inputs. We believe research of the type reported here today will be of increasing importance in the future, because it will exert a strong influence on our ability to plan for a future in which some of our current energy problems are overcome.

MODELING AT THE BROOKHAVEN NATIONAL LABORATORY: IMPLICATIONS FOR MANPOWER MODELING

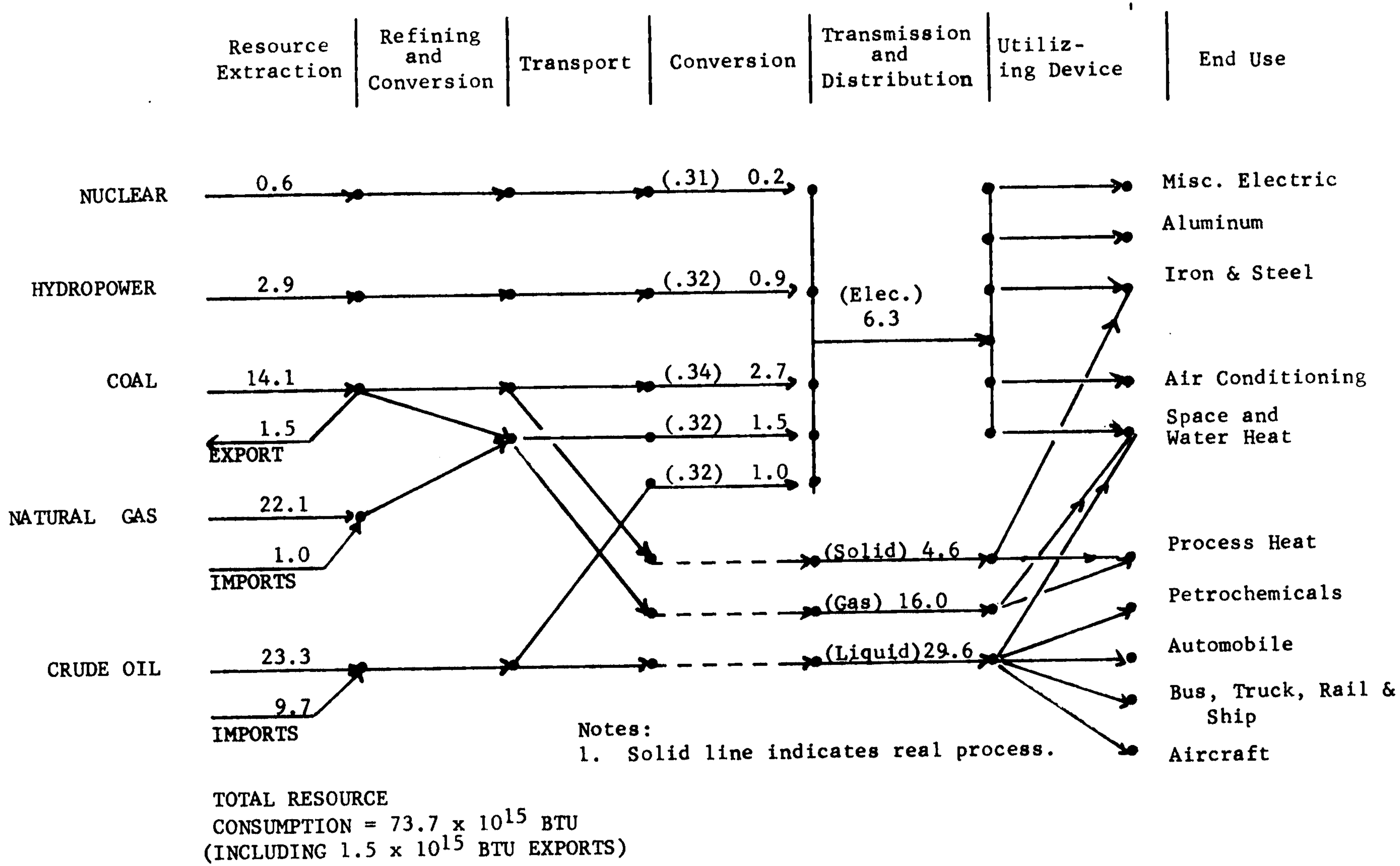
Kenneth C. Hoffman

A comprehensive series of energy models have been developed at Brookhaven National Laboratory to address the characteristics of energy technologies--both existing and new technologies that are under active research and development. In this work we relate the technical structure of the environmental effects that are produced by the energy system.

We have not done too much work with manpower, so I won't address that topic specifically. Let me first discuss our overall approach to energy modeling and analysis and then show the strength and weakness of this modeling approach to the study of manpower requirements in the energy-related industries and in research and development.

Figure 1 illustrates the reference energy system approach that we use for energy systems analysis. The Energy System is quite complex, representing a number of technologies that are required to take available resources and apply them to specific end uses. This network representation shows the technical structure of that system reflecting all of the linked operations that are required to apply a resource to a given end use. In the diagram, each of the arrows, or elements of the network, represents a real technology that is characterized in our data base. The models have important technical parameters, such as the efficiency of conversion, the environmental effects that are produced by that technology (e.g., the emissions in terms of quantities of major air pollutants, water pollutants, major land use factors), as well as economic parameters such as the cost of the technological system.

The delivered fuels are represented in terms of electricity, solid fuels, gas, and liquid. Historically, much of the energy modeling ended at that point as if those were the real energy needs of people. In fact, what is really demanded are not those specific fuels, but the services that they perform. These services are performed by technical devices that can be characterized with an efficiency and a set of environmental effects. I felt strongly that those utilizing devices had to be included as part of the technical energy system in as much detail as the supply technologies. The end use devices really limit the inter-fuel substitution that can be accomplished over a given time period. They are also the limiting factor in the conservation of energy. They are as capital intensive as the supply technologies; the environmental effects are as significant. Furthermore, some of the problems that we face, such as



Notes:
1. Solid line indicates real process.

TOTAL RESOURCE
CONSUMPTION = 73.7 x 10^{15} BTU
(INCLUDING 1.5 x 10^{15} BTU EXPORTS)

FIGURE 1. Reference Energy System 1972

Source: National Center for Analysis of Energy Systems,
Brookhaven National Laboratory.

conservation and fuel substitution, cannot be treated without having an understanding of how that stock of utilizing devices and the technological change that may occur in that stock will influence patterns of energy demand.

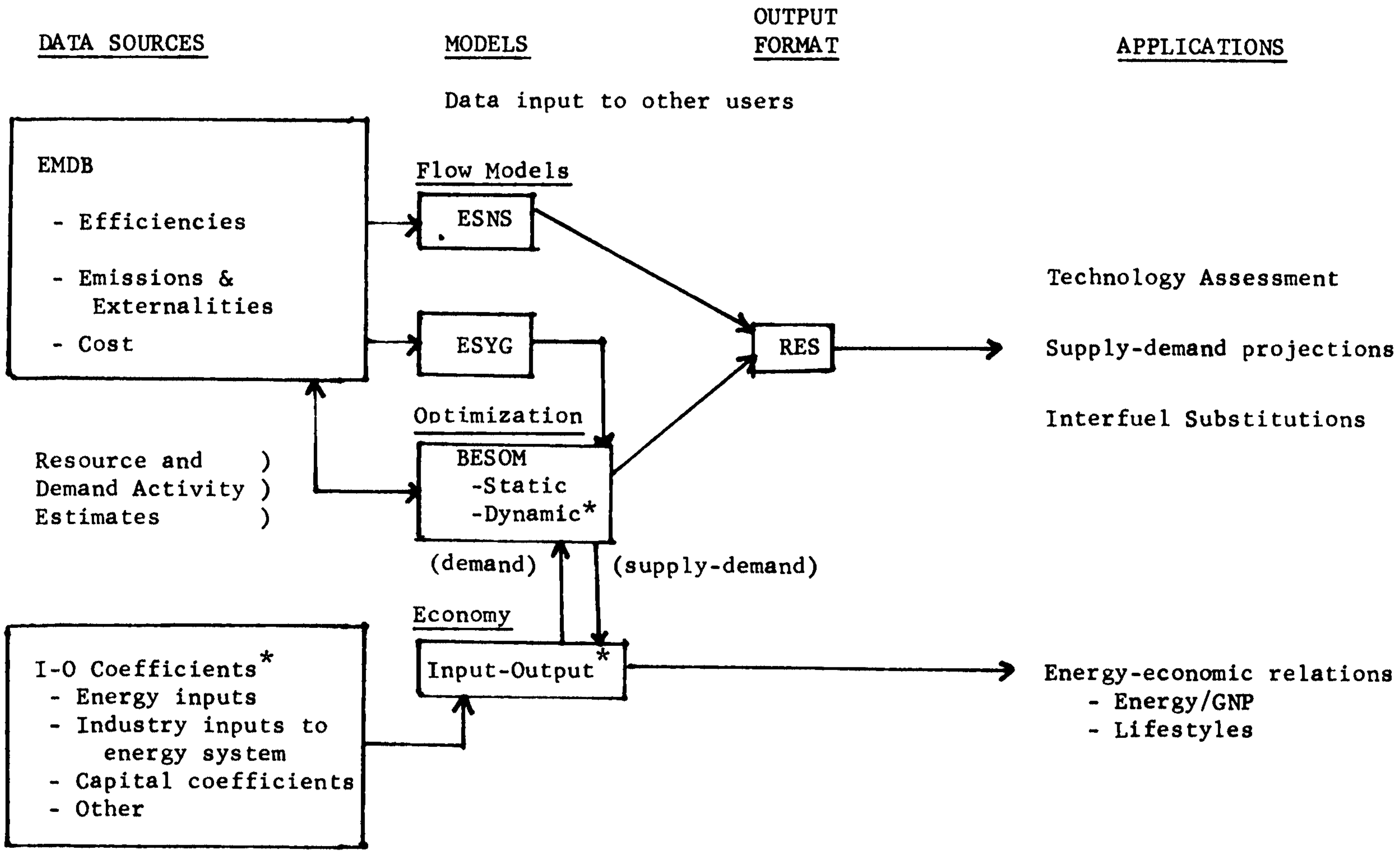
Figure 2 summarizes the models and data bases supporting the Reference Energy System. In this diagram, we distinguish between those elements of our system that are data sources, those that are models that are used for analytical purposes to produce energy scenarios, and those such as the Reference Energy System that are used as an output format. The Reference Energy System is merely a simple and convenient way to represent the technological structure of the energy system, given certain sets of demands and available resources.

Starting off with the data sources, we have the Energy Model Data Base (EMDB) which includes information on efficiencies, emissions and externalities, and the cost of specific energy technologies. Perhaps 50-60 technical processes or elements are in the Reference Energy System (Figure 1). Actually, in this data base we have those disaggregated much further. For instance, in the oil refining sector, which shows up as one process on the Reference Energy System diagram, the data base includes information on the components of that refinery such as atmospheric and vacuum distillation, catalytic cracking, delayed coking, and other steps. We have separate technical and environmental information on each one of those components represented in the Energy Model Data Base.

The data in the EMDB can be structured in a judgmental fashion to produce a Reference Energy System projection of the future evolution of the complete energy system reflecting those technologies selected. Some simple flow models are also employed that do a manual calculation and summing up of costs, resource consumption, and emissions associated with the given scenarios represented in the Reference Energy System. Optimization models are also employed in a normative fashion. These models are normative in the sense that they indicate a "best" system characterized by whatever is put into the objective function of that optimization technique. This can be a "best" system as represented by minimum cost. We have the data on environmental effects and emissions and we can represent a "best" system as measured by those parameters, or we can do the optimization on the basis of efficiency and determine the most efficient system. Thus, a very flexible optimization approach allows for an expression of multi-objective criteria in the analysis.

There are two versions of the optimization model. One version is a static model that does a snapshot optimization of the supply/demand mix, again as represented in the Reference Energy System for a given year. The other version is a time phased, or dynamic, optimization model which determines the development of that energy system over time. In addition, we have under development a regionalized optimization model, that treats the country in terms of the nine census regions, optimizing the fuel mix in each region and the flow of energy between those regions.

It is important to consider the linkages between the technical structure of the energy system and the overall economy. The Reference Energy System diagram shows, on the right hand side, the demand for fuels by specific functional end use such as space heating, air conditioning, and automotive travel. We have projected energy requirements on that



* - under development

FIGURE 2. Brookhaven Energy System-Economic Models

Source: National Center for Analysis of Energy Systems, Brookhaven National Laboratory basis, and these can be related fairly closely to life styles both in terms of housing patterns and transportation patterns. In major sectors, however, such as the industrial sector, a better understanding of how those energy demands are related to the performance of the overall economy is needed. We have chosen to explore those linkages using input/output techniques and we have collaborated with Clark Bullard at the University of Illinois in linking our energy system model to an input/output model of the economy.

The primary exogenous input to the linked models is the gross national product (GNP) level and structure. We heard a good deal this morning about how GNP is used to drive many energy models. We find that for energy studies we need to disaggregate that GNP vector quite a bit, because the energy intensiveness of various industrial sectors can be quite different. Thus, we need not only to know the level of the GNP, but we also need to come to grips with the structure of that GNP. How much of it is in primary manufacturing and hard goods? How much is in the demand for services?

The University of Illinois input/output model provides the capability for that kind of disaggregation. The problem of forecasting that GNP structure remains, but a very powerful framework exists within which different GNP forecasts can be made and the sensitivity of energy requirements to that GNP level and structure explored. In the input/output model, then, after we have expressed the lifestyles and economic development in terms of that GNP vector, we derive from it a vector of energy demands. These demands are in terms of the energy services that have to be performed, not in terms of specific fuels. We have extracted the fixed energy coefficients from the input/output model and replaced them with fixed coefficients not for fuels, but for energy services such as heating, cooling, and transportation.

Those requirements for energy services then go into the optimization model and are taken as constraints to be satisfied with various resource supply assumptions in the optimization model. The fuel mix, or supply/demand information, must be fed back to the input/output model of the economy because it makes some difference to the economy whether energy requirements are satisfied, for example, with nuclear power or with imported crude oil. In the one case, large plants must be built in the United States; while in the other case, the tanker and the refining markets expand significantly. The kind of fuel mix and resource pattern must be fed back to the input/output structure to capture fully the feedback effect of the energy system on the economy.

We have actually linked the Brookhaven optimization models with two kinds of input/output models. I have described the linkage with the University of Illinois model which has fixed coefficients now in all sectors except energy. We must recognize that these coefficients change over time, both due to technological development and as the relative prices of labor, materials, and capital change. To capture that kind of effect, we've taken a parallel approach and have linked the optimization model to an input/output model with variable coefficients that is driven by a macroeconomic mode. This is the model developed by Ed Hudson and Dale Jorgenson of Data Resources, Inc. (DRI), of Cambridge, Massachusetts.

Of course there is some sacrifice of detail in using the variable coefficient model. In the fixed coefficient input/output model, you can have anywhere from 120-370 industrial sectors. In the variable coefficients model, where the input/output coefficients change according to certain econometric relationships as a function of relative prices, we are down to some four non-energy sectors. We view that as an important step methodologically, but we are still looking for a best compromise where we can get variable input/output coefficients while retaining some of the structural detail that we think is necessary in GNP to really look at the impact of life style on the economy and energy demand.

In Figure 1 of the Reference Energy System, a number of models are shown including an optimization model and an input/output model that can be used to construct scenarios. This permits us to analyze policy issues such as the impact of a nuclear moratorium. In the optimization process, this is reflected as a constraint on the resources of nuclear energy available to the system and forces the substitution of some other resource such as coal, an increased electrification based on new technologies, or imported crude oil. We developed a number of scenarios using this technique in support of the ERDA planning process published in ERDA-48.

Here we generated a number of scenarios that stressed, in one case, the role of coal and synthetics in filling any gap that was involved between domestically available oil and gas and the full amount of fuels required by the energy system. We also looked at an all-out conservation strategy to close that gap and strategy that would use more electricity generated with either coal or nuclear power to reduce the need for imported oil.

Let me conclude by making some comments on the role of these techniques for manpower studies. If you think back to the Energy Model Data Base that includes the efficiencies and costs and environmental effects of different energy technologies, the Bechtel Corp. has developed a rather extensive data base that includes economic as well as manpower parameters. This system is compatible with our approach and definitions. It provides a natural way to interject manpower considerations into this modeling approach.

It appears to me that manpower requirements can be divided into two general categories. First, the manpower requirements needed for the design, construction, and the operation of the energy system. These requirements are very much related to the scenarios that we might construct using the approaches just described. In view of the great uncertainties that exist, however I would hate to try to predict the need for nuclear engineers in the state of California, or indeed in the United States now, because of the widespread opposition to nuclear generating plants. These and other uncertainties cannot be captured by most models. A very highly political and emotional set of circumstances are just going to have to work themselves out. I am quite anxious to see how the national priorities and the willingness to use nuclear power or coal, or offshore oil to satisfy our national energy needs is going to work out. We just can't say much about the need for manpower until we see how our national policy toward the development for these resources or toward conservation is going to proceed. It appears to us that we need to work more aggressively in all of those areas and that would be our normative forecast or projection, but it certainly can't be taken as an absolute prediction.

The other major category of manpower is for energy research and development--the people that are producing the options to steer the development of the energy system over the next few years. Here, I think that perhaps the best hard data that can be used are the projections of federal and private R & D expenditures over the next 10 years. For manpower planning, we need to know this information beyond the five year period now used in the federal plan because of the lags that are built into the system. There are other people here better qualified than I am who can comment on the projections of federal R & D expenditures over a 10 year time horizon, so I won't get into that area. I do think that we need to work out more detail in our manpower projections to try to estimate the need for chemical, mechanical, and other engineers. Cutting in the other direction rather than by discipline, we can also try to describe projections by industry. Here we need to know the need for nuclear engineers, coal, fossil fuel engineers, geologists, and the like.

THE ENERGY SUPPLY PLANNING MODEL: A TOOL FOR THE ASSESSMENT OF REQUIREMENTS, IMPLICATIONS, AND FEASIBILITY OF FUTURE U.S. ENERGY SCENARIOS.

Gary F. Mader

Events of the last few years, stimulated by the newly acquired perception of the degree of U.S. dependence on overseas sources of energy, have focused attention on the analysis of energy demand and supply patterns, with particular emphasis on and concern about future options. As a result, many exploratory energy scenarios for the late 1970's and 1980's have become available. It seems reasonable to expect that this exploratory activity will continue.

Energy scenarios typically vary in the overall level of projected energy consumption, in the assessment of the impact and form of conservation, and exhibit a particularly wide range in the levels and composition of the domestic energy supply mix.

These scenarios are becoming the indispensable ingrediants of energy policy analysis. Moreover, they are rapidly becoming the substance from which the implications for the economic well-being of the U.S. are evaluated. Yet the tools and methodology used to generate these scenarios vary from the most rudimentary to the sophisticated.

In August 1975, Bechtel's Energy Systems Group completed an 18 month, $736,000 effort designed to develop the means of evaluating the significance and implications of various future energy scenarios in the 1975-1995 time period. The study was done for the National Science Foundation and resulted in the construction of the Energy Supply Planning Model.

The Purpose of and Capability Afforded by the Energy Supply Planning Model

Future energy scenarios typically consist of different energy supply mixes, alternatively emphasizing various domestic energy conversion and supply options: offshore oil, coal, synthetic fuels, nuclear power, etc. The model provides a systematic means of calculating, based on any given scenario, the total direct resources required to build and operate the energy supply facilities needed to supply the fuel mix specified by the scenario. With this tool, the feasibilities of various proposed mixes can be assessed in terms of the time, capital, manpower and materials, and construction schedule required for the necessary energy supply system.

Description of the Operation of the Model

The model provides a systematic planning method which proceeds as follows:

1. The user chooses a candidate future energy mix of interest, typically for the years 1980, 1985, and 1990, and 1995.

2. A computer program then calculates, by year, the number of new energy facilities of various types which must be brought on-stream and operated in order to meet that specified mix. These facilities are additional to those extant on January 1, 1974. A total of 66 energy supply facilities ranging from energy extraction (e.g. mines) to energy conversion and electricity generation facilities are presently included.

3. Utilizing user specifications, and at user option, the model locates the facilities in one of 14 regions in the U.S., allocates fuels derived from the facilities to the demand of the 11 land regions, and calculates transportation facilities requirements corresponding to this distribution. A total of 24 energy transportation facilities are included.

4. The program next calculates the annual requirements of capital, manpower, and materials separately required for each energy and energy transportation facility from initial commitment to plant startup, and for the operation during their economic life. These requirements are expressed without regard to the availability of such resources.

5. The program then tabulates an annual schedule of required energy and transportation facilities to be brought on-line and attendant annual schedules of total capital, manpower, and materials requirements for the energy system as a whole.

Capability Afforded by the Model

The model is specifically designed to facilitate its use in the analysis of energy scenarios whether these are generated by other models or as they are generated from energy policy planning or legislation.

With such a statement of required resources, the feasibility of any specified energy policy and program can be tested by analysis of these requirements along the following lines:

- Will the planning environment permit the plant construction commitments to be made when required?

- Are the required capital, manpower and materials within the capacity of various energy industries and the country to provide?

The explicit, annual schedules of requirements allow the early identification of requirements for expansion in specific energy industries associated with any given scenario (e.g. what will be the dragline capacity needed for coal mining in 1983?)

In addition, the capability of the model to reflect the regional location of energy facilities provides the means for assessment of regional impacts of development scenarios

- in the survey of existing energy policy proposals and their evaluation.
- in the review and analysis of energy policy and its implications (time, capital, manpower and materials required) on various industries and regions.

SCIENTIFIC AND TECHNICAL PERSONNEL REQUIRED IN ENERGY-RELATED ACTIVIES

Hugh Folk

I. Introduction

Forecasting scientific and technical personnel requirements is at best uncertain. Both policy and technology change in unpredictable ways. An example of an unpredicted change arose with the recognition of the energy crisis. A policy of greater energy independence for the United States is far from settled, yet concern about the adequacy of supply of scientific and technical personnel (STP) has already led to several studies and much discussion. The National Science Foundation (NSF) is responsible for developing information on scientific and technical manpower. The work reported on here is the result of a contract by NSF with the Center for Advanced Computation (CAC) of the University of Illinois.

Over the past few years CAC has developed a number of manpower and energy models and this project draws heavily on this prior work.[1]

Our objective has been to develop a highly flexible and adaptable forecasting system that can be readily updated to reflect new information, data, and policies. Among the products of this research will be a set of forecasts of STP requirements under three alternative economic and energy policy scenarios.[2]

II. Outline of the Model

The first component of the model is a macro-economic model of the United States economy. The model we are using is derived from the Bureau of Economic Analysis (BEA) Thurow model. We have updated the data and modified some of the equations to improve the statistical and forecasting properties of the model. In its current state, the model produces forecasts of GNP and the major components of aggregate demand that are somewhat higher than other long-term models such as Wharton EFA or Inforum and about the same as the Bureau of Labor Statistics (BLS) which uses the BEA-Thurow model as part of its forecasting process. The exogenous variable for our model will be valued in a way consistent with the particular scenario in use, so that GNP reflects capital and labor available under the assumptions of the model. The schematic of the scenario is shown in Figure 1, in which the top two submodels depend on each other.

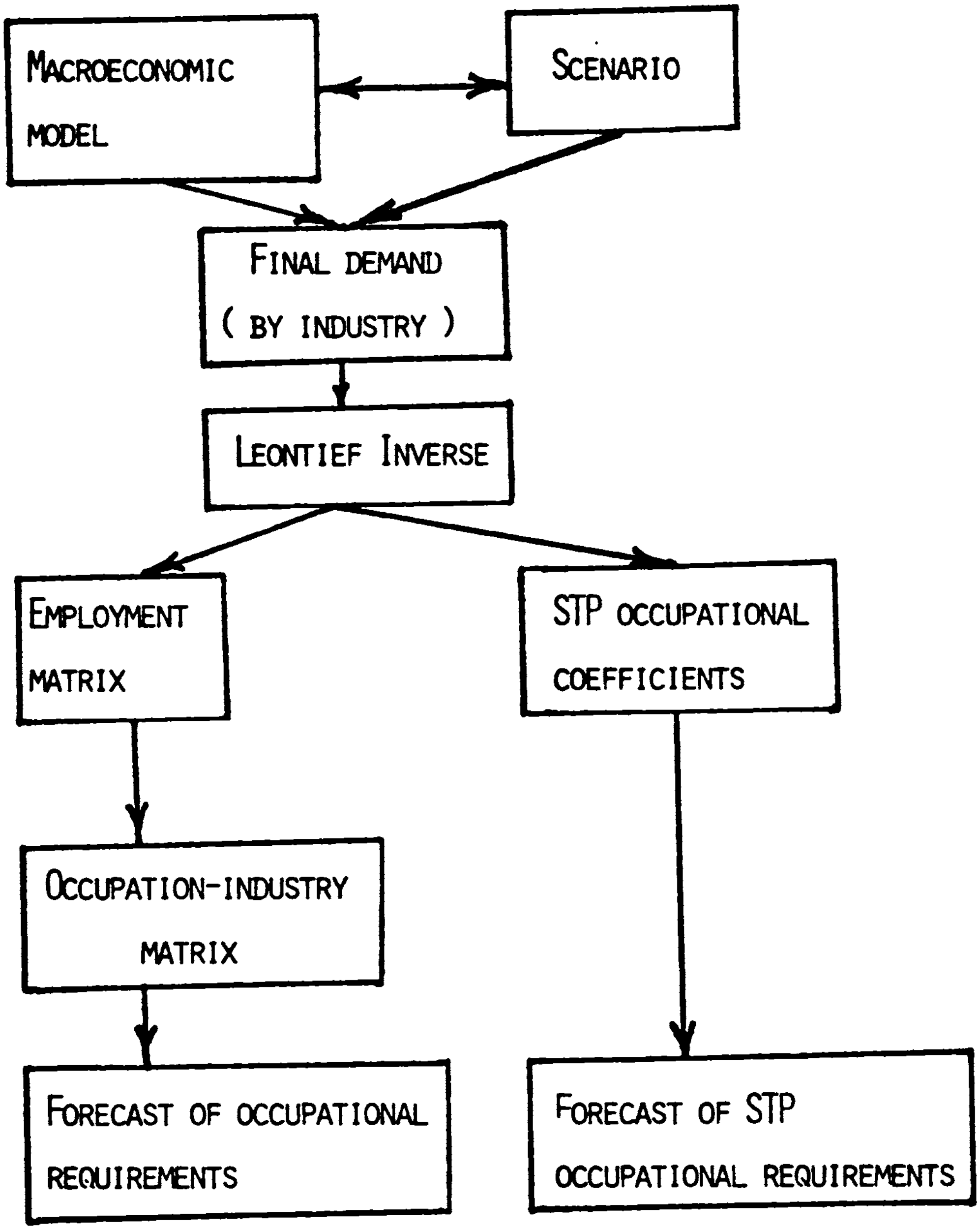


FIG. 1. SCHEMATIC DIAGRAM OF FORECASTING SYSTEM

Source: Center for Advanced Computation, University of Illinois, Urbana

INDUSTRY CLASSIFICATIONS AND SOURCES FOR CAC I-O MODEL

	OUTPUT INDUSTRIES		
INPUT INDUSTRIES	NON-ENERGY INDUSTRIES	ENERGY PRODUCT INDUSTRIES	ENERGY SUPPLY INDUSTRIES
NON-ENERGY	I. BLS	II. 0	III. CAC
ENERGY PRODUCT	IV. CAC	V. 0	VI. CAC
ENERGY SUPPLY	VII. 0	VIII. CAC	IX. 0

FIG. 2

Source: Center for Advanced Computation,
University of Illinois, Urbana

The second major component of the model is a sequence of vectors of final demand reflecting the economic conditions in each of the scenarios. A vector of final demands for industry represents spending (in constant dollars) on products of all of the industries in the system. The final demand vectors are developed from the BLS final demand patterns as a starting point, with modifications introduced to reflect final demand patterns that appear likely to result from alternative energy policies.

The third major component of the model is a Leontief inverse matrix based on several different sources. The non-energy coefficients of input-output forecasts for 1980 and 1985 are derived from the BLS model. We will use the non-energy coefficients with little or no change for all of the scenarios. In effect, we are asserting that there is little coupling (substitutibility or complementarity) between non-energy and energy coefficients. This feature of the model is not fundamental and can be readily modified.

Energy coefficients are classified into two sets: (1) energy supply industries and (2) energy product industries. We assume that energy is utilized by consumers and industry only in the form of products (such as space heat, motive power, and air-conditioning) and not directly as coal, petroleum, and electricity. The energy supply sectors sell only to energy product sectors.

This partitioning of energy into two parts is useful because it makes the model more compatible with energy scenarios and because it separates consumption from production technology. This approach requires estimation of a substantial set of coefficients, such as energy product input coefficients to the non-energy industries. The scheme is shown in Figure 2 and the model industries and their relation to the BLS model and the larger CAC energy input-output model are shown in Table 1.

The fourth major component of the model is the employment matrix that converts total output by industry to total employment by industry. The principal source for this matrix is the BLS, but it is modified to reflect the differences in labor productivity expected under the alternative scenarios.

The fifth major component of the model is the occupation-industry matrix aggregated from the BLS version and used to derive total employment for each occupation for each scenario.

The sixth major component is a set of occupation-output coefficients for energy-related industries derived from surveys of establishments that are currently in progress. The coefficients are derived from the establishments' own expectations of STP requirements under several assumptions as to level of output.

We have depended heavily on prior work in developing this model. In addition to BEA and BLS on the economic models and non-energy input-output coefficients, we have used the results of work by Brookhaven, Bechtel, and MITRE in developing the energy coefficients.

While the model is structurally quite simple and linear, it provides for a number of technological alternatives in energy supply and product industries as well as scale effects in the energy-STP coefficients. There are many possible objections to this kind of model. It is extremely

TABLE 1 Sector Correspondence Between CAC 142-Order Model, BLS Division of Economic Growth Categories, CAC 357 Order Model and BEA Sectors

CAC-142	BLS	CAC-357	BEA
1 Coal Mining	8	1	7.00
2 Crude Petroleum	9	2	6.00
3 Shale Oil		-	
4 Coal Gasification		-	
5 Solvent Refined Coal		-	
6 Refined Petroleum	[a]	3	31.01
7 Gas Utilities	102	5	68.02
8 Coal Combined Cycle		-	
9 Fossil Electric		Part of 4	Part of 68.01
10 Light Water Reactor		Part of 4	Part of 68.01
11 High Temperature Gas-Cooled Reactor		-	
12 Renewable Electric		Part of 4	Part of 68.01
13 Coke Feedstocks		-	
14 Other Feedstocks		-	
15 Motive Power		-	
16 Miscellaneous Thermal		-	
17 Water Heat		-	
18 Space Heat		-	
19 Air Conditioning		-	
20 Electric Power		-	
21	1	6-8	1.01-1.03
22	2	9-15	2.01-2.07
23	3	16	3.00
24	4	17	4.00
25	5	18	5.00
26	6	19	6.01
27	7	20	6.02
28	10	21	9.00
29	11	22	10.00
30	12	23	11.01
31	13	24	11.02
32	14	25	11.03

CAC-142	BLS	CAC-357	BEA
33	15	26	11.04
34	16	27	11.05
35	17	28,29	12.01-12.02
36	18	30	13.01
37	19	31-36	13.02-13.07
38	20	37-68	14.01-14.32
39	21	69,70	15.01-15.02
40	22	71-74	16.01-16.04
41	23	75-84	17.01-17.10
42	24	85-87	18.01-18.03
43	25	88	18.04
44	26	89-91	19.01-19.03
45	27	92-95	20.01-20.04
46	28	96-101	20.05-20.09 and 21.00
47	29	102-105	22.01-22.04
48	30	106-112	23-01-23.07
49	31	113-119	24.01-24.07
50	32	120	25.00
51	33	121-124	26.01-26.04
52	34	125-128	26.05-26.08
53	35	129,132	27.01 & 27.04
54	36	130,131	27.02-27.03
55	37	133,134	28.01-28.02
56	38	135,136	28.03-28.04
57	39	137	29.01
58	40	138,139	29.02-29.03
59	41	140	30.00
60	42[b]	141,142	31.02-31.03
61	43	143,145	32.01-32.03
62	44	146	32.04
63	45	147-150	33.00 & 34.01-34.03
64	46	151,152	35.01-35.02
65	47	153-157 &162-166	36.01-36.05 &36.10-36.14
66	48	158-161 &167-174	36.06-36.09 &36.15-36.22
67	49	175	37.01

CAC-142	BLS	CAC-357	BEA
68	50	176-178	37.02-37.04
69	51	179	38.01
70	52	182	38.04
71	53	180,181 &183,184	38.02-38.03 &38.05-38.06
72	54	185	38.07
73	55	186	38.08
74	56	187,188	38.09-38.10
75	57	189-192	38.11-38.14
76	58	193,194	39.01-39.02
77	59	195-197	40.01-40.03
78	60	198-203	40.04-40.09
79	61	204,205	41.01-41.02
80	62	206-216	42.01-42.11
81	63	217,218	43.01-43.02
82	64	219	44.00
83	65	220-222	45.01-45.03
84	66	223-226	46.01-46.04
85	67	227-230	47.01-47.04
86	68	231-236	48.01-48.06
87	69	237-243	49.01-49.07
88	70	244	50.00
89	71	245	51.01
90	72	246-248	51.02-51.04
91	73	249-253	52.01-52.05
92	74	254-256	53.01-53.03
93	75	257-261	53.04-53.08
94	76	262-268	54.01-54.07
95	77	269-271	55.01-55.03
96	78	272,273	56.01-56.02
97	79	274	56.03
98	80	275	56.04
99	81	276-278	57.01-57.03
100	82	279-283	58.01-58.05
101	83	284-286	59.01-59.03
102	84	287-290	60.01-60.04
103	85	291,292	61.01-61.02
104	86	293-295	61.03-61.05
105	87	296,297	61.06-61.07

CAC-142	BLS	CAC-357	BEA
106	88	298-300 & 304	62.01-62.03 & 62.07
107	89	301-303	62.04-62.06
108	90	305,306	63.01-63.02
109	91	307	63.03
110	92	308-319	64.01-64.12
111	93	320	65.01
112	94	321	65.02
113	95	322	65.03
114	96	323	65.04
115	97	324	65.05
116	98	325,326	65.06-66.07
117	99	327	66.00
118	100	328	67.00
119	103	329	68.03
120	104	330	69.01
121	105	331	69.02
122	106	332-334	70.01-70.03
123	107	335,336	70.04-70.05
124	108	337	71.01
125	109	338	71.02
126	110	339	72.01
127	111	340,341	72.02-72.03
128	112	342	73.01
129	113	343	73.02
130	114[c]	344	73.03
131	115	345	75.00
132	116	346	76.01
133	117	347	76.02
134	118	348,350	77.01&77.03
135	119	349	77.02
136	120	351	77.04
137	121	352	77.05
138	122	353	78.01
139	124[d]	354	78.04
140	125[e]	355	79.03
141	128	356	81.00
142	129	357	82.00

[a] Refined petroleum products (BEA 31.01) is part of BLS 42.

[b] BLS 42 also includes refined petroleum (BEA 31.01).

[c] BLS 114 also includes research and development (BEA 74.00) which is not included in CAC models.

[d] BLS 124 also includes federal electric utilities (BEA 78.02). This BEA sector has been added to its private sector counterpart in CAC models.

[e] BLS 125 also includes local government passenger transit (BEA 79.01) and state and local electric utilities (BEA 79.02). These BEA sectors have been added to their private sector counterparts in CAC models.

SOURCE: Center for Advanced Computation, University of Illinois, Urbana.

difficult to recognize all of the interdependencies between final demand patterns, technologies, and occupational coefficients. Some poor judgments will probably be made. The model includes the effect of prices only implicitly and judgmentally. Much of the data on energy technologies is provisional and must be expected to be revised.

We are developing a more elaborate model that will include prices and price elasticities explicitly. We are also conducting field research on energy consumption technologies that may change with higher energy prices. We recognize the provisional nature of this model and the need to update it in the future. Hence, we have implemented the model in an interactive mode so that modification of any of the data will be easy. This also permits us to perform extensive sensitivity analyses of our forecasts. Consequently, we will be producing forecasts with ranges of outcomes rather than single values.

III. Scenarios and Economic Forecasts

A major problem in any economic forecast is the specification of exogenous variables. The variety of outcomes observed in the available 10 year economic forecasts reflects differing judgments about the future course of investment and labor productivity. These in turn reflect different judgments about economic policy and technological possibilities.

The scenario approach is increasingly used to provide several consistent sets of values of exogenous variables as inputs to the forecasting system. Exogenous variables are not always difficult to forecast. The adult or working age population of the United States can usually be forecast with little error for a decade or more ahead.

In contrast, policy variables are for all intents and purposes impossible to forecast accurately. I do not know who will be President or control Congress during the next decade. We must forecast energy policy but it is dependent on a number of externally controlled events, such as the price of crude petroleum in the world market. This will be influenced by the persistence, strength, and attitudes of the Organization of Petroleum Exporting Countries (OPEC) cartel. These, in turn, will be influenced by American and Russian policy, pressures on the OPEC nations, the energy policies of major consuming countries, among others.

Currently, we are planning three scenarios: A) high priced oil and domestic energy development, B) stable relative price for oil and continuation of market-driven domestic energy development, and C) low priced oil and substantial contraction of domestic energy production. In choosing these three scenarios we have not been overly influenced by the question of probability. All of these alternatives seem possible, but at least the third will appear highly improbable to many observers.

We are not considering other possible scenarios that are either uninteresting or too difficult for our model to handle. An example of this is a scenario including a sizable nuclear exchange between the United States and the Soviet Union. We are seeking as much variety in our forecasts as practicable in order to determine if a wide range makes very much difference in the STP forecasts.

Some STP occupations are closely coupled to specific energy industries, so that demand for these occupations can be expected to be closely related to demand for the products of these industries alone. The closely coupled occupations include petroleum and mining engineers. For most STP occupations, however, shifting of investment and production into or out of energy production will have at least partially offsetting effects in non-energy industries. For instance, if civil engineers are extensively employed in energy construction activities, it is unlikely that this will be a net addition to demand or requirements, since less civil engineering employment will be required in other industries such as highways and general construction. Several earlier studies of substantial shifts in the composition of final demand have demonstrated that the offsetting effects of expenditure reallocation are substantial.

Scenario A assumes that the relative price of crude petroleum doubles over the next 10 years. Such a change would induce increased prices for coal, substantial substitution of coal for petroleum products, increased synthesis of liquid and gaseous fuels, substantial consumer and industrial conservation, and significant domestic energy development. Nuclear power and electrification would be stimulated as would public transport and railroad transportation. It also seems reasonable to expect that such a change would be accompanied by worsened international relations and some increase in military spending.

In such a scenario, productive capacity could be expected to grow slowly since investment would be diverted to very capital intensive energy uses (such as nuclear power, strip mining of coal, and synthetic fuel plants) that would entail high interest and slow growth of non-energy capital. Even though capacity increased slowly, total output might increase rapidly with the stimulus of investment and military demand.

Scenario B assumes no change in the relative price of crude petroleum and no substantial increase in domestic energy development. Adequate availability of foreign crude at the going price is assumed and there is no allocation or rationing and price controls on fuels are removed. In this scenario, conservation receives only a weak inducement, nuclear power grows only moderately, and coal usage increases substantially but not under forced draft. Petroleum imports grow.

Scenario C assumes that the oil cartel weakens substantially and adequate supplies of crude are available at about one-half of the present relative price. In addition, coal production levels off and begins to decline, nuclear power growth is slow, automobile usage increases, and petroleum imports increase rapidly in volume. There is little conservation.

Specific modifications to these scenarios can be easily made. One might wish to examine the consequences of a moritorium on nuclear power in the context of Scenarios A or B, or of higher military spending in Scenario B. It must be recognized, however, that such changes would require not only reallocating final demand between industries and changes in input-output coefficients, but possibly macroeconomic changes as well.

IV. Input-Output Coefficients

The input-output matrix consists of nine blocks or submatrices, as shown in Figure 2. Block I, the non-energy to non-energy industry coefficients are projected by BLS and will be used with no change.

Blocks II, V, VII, and IX are essentially zero. Block III consists of input coefficients from non-energy industries to energy supply industries. These are estimated from input-output studies by a number of agencies. New energy technologies are based on MITRE and other sources.[3] Block IV consists of energy product to non-energy coefficients and is derived from earlier 372 and 357 order matrices by aggregation that involves several corrections and modifications.[4]

So far, two sets of energy coefficients have been derived: current technology and "technical fix" (corresponding to the Ford Energy Policy Project's technical fix scenario). In the current technology version, future technologies are represented with zero coefficients. The technical fix matrix embodies changes in energy use efficiencies in the energy product sectors and shifts from energy intensive inputs to less energy intensive inputs resulting from price-induced substitution. Block VIII consists of energy supply to energy product industries. In the matrices for 1980 and 1985 that are being developed the conservation technologies and new energy supply technologies will be included where appropriate.

The development of three sets of projected 1980 and 1985 matrices is a substantial task. It involves the use of substantial judgment. We are striving to provide a high level of documentation for the values selected. The three sets of matrices represent only inadequately the infinite variety of price and technology induced regimes that might prevail. A fully specified price and technology model is preferable, but the data are not available to permit the development of such a model now. There are serious theoretical problems that go far beyond the basic data availability question that cannot be investigated adequately until the production-price model is available for testing.

V. Occupational Coefficients

The BLS occupation-industry matrix involves some problems of aggregation to the BLS inter-industry model level. The major problem in the use of the matrix is that coefficients are assumed to be fixed and not subject to error. Because the coefficients are not systematically derived from surveys, one can know little about the potential variability in the projected coefficients.

The occupation-output coefficients have both advantages and disadvantages compared to the BLS coefficients. First, they are based on a sample of establishments built from a sample frame based on a number of directories and other sources. The sample frame is doubtless incomplete and some small firms may have been omitted, although we have already run into a significant number of establishments that consist of no employees--only and answering service.

There are serious problems in response. These firms have been so heavily surveyed in the past few years that we have received a number of blanket refusals. Moreover, there are serious problems in aggregating the establishment responses. Firms differ in the manner in which they assign STP to central offices (that may be classified in another industry) and to production units. Similarly, there are problems in assigning sales or value of shipments among establishments of a single firm. Thus a multi-industry firm may have substantial STP employment in the central office with no sales that must be allocated to the constituent establishments.

Sample results nevertheless allow estimation of industry variance in coefficients. If coefficients for an industry have high variance, it may reflect heterogeneity of production function (or insufficient disaggregation of industries), or it may reflect actual variability that demonstrates a potential for reducing requirements in the event of a shortage. For example, we have been told by several refiners that the majors "like to have a lot of engineers around" while smaller refiners lack the financial resources to permit this preference.

We expect that interpretation of the variability of coefficients will be substantially assisted by the results of our companion study of current labor market conditions in which we are exploring recent experience of firms with respect to shortages and surpluses of STP. In particular, we hope to find how establishments have coped with shortages in the past. This experience will provide some guidelines for the future.

The surveys are aimed at specific detailed (four digit) industries that are either directly or indirectly involved in producing energy or inputs important for the production of energy. Lists of the direct and indirect energy industries surveyed are provided in Tables 2 and 3. The coefficients for these industries must be aggregated to the industry level used in the model.

The approach of deriving occupational requirements subsequent to the estimation of total production requirements is subject to criticism. A preferable approach would treat occupations as inputs to production in a fashion analogous to inputs from other industries. This is the approach pursued on a facility basis in the Bechtel model.

We attempted to develop survey results in our pretest on an energy facility basis. We asked the respondents to identify the number of their existing, planned, or prospective facilities and operating STP requirements. A problem of facility variability among the cooperative firms arose. Existing facilities were quite different from the model list, and many of the planned and proposed facilities differed in significant ways from the models, suggesting that a manageable set of facilities such as the Bechtel list is far from exhaustive.

This mattered little in the light of the second problem. No firm was able to provide us with facility STP requirements despite several extended attempts to do so. This experience confirms earlier findings that very few firms engage in any serious long-term manpower forecasting.[5]

This lack of long-range manpower forecasting raises some questions about the rationality of firm decisions in capital acquisition. An electric utility, for instance, presumably (and hopefully) looks at operating costs of a nuclear power facility compared to a coal facility before it decides which one to build. Since labor is a significant component of operating cost, some kind of manpower forecast must have been made in the course of the cost estmation. But these data are either ignored or forgotten. Bechtel developed some of the manpower requirements from its own cost estimating information for the large number of energy facilities where it was a major or the dominant engineer-constructor. Operating and maintenance manpower requirements were more difficult

Table 2. Direct Energy Industries

SIC	
4911	Electric Services
4931	Electric, Gas & Other, less than 95% Electric but Majoe elec
4932	Electric & Gas Services, Primarily Gas
492	Gas Production and Distribution
4961	Steam Supply, Including Geothermal
291	Petroleum Refining and Related
1111	Anthracite Mining
1112	Anthracite Mining Services
131	Crude Petroleum
132	Natural Gas Liquids
1381	Oil and Gas Field Drilling
1382	Oil and Gas Field Services
1389	Oil and Gas Field Services, nec
1094	Uranium Mining and Milling
2819	Fissionable Materials Production
4011	Coal Unit-Train
4939	Electric and Gas Services, nec
1211	Bituminous Mining and Lignite
1213	Bituminous Mining Services

Table 3. Indirect Energy Industries

SIC	
8911	Architectural and Engineering Services
9631	Regulatory Agencies
7391	Research and Development Labs
8921 8922	Non-profit Education, Scientific, and Research Organizations
3317	Oil Country Tubular Goods
3443	Fabricated Structural Metal Products (boiler shop, platework)
3494	Pipe Fittings, Flanges and Valves
3567	Industrial Process Furnaces and Ovens
3451 3452	Screw Machine Products (roofbolts)
3293	Gaskets, Packing, and Asbestos Insulation for Boilers
3433	Heating Equipment Except Electric
3531	Construction Equipment
3532	Mining Equipment
3533	Oil Field Equipment
3561	Pumps and Compressors
3511	Turbines and Steam Engines
1623	Heavy Construction Contractors Except Highway and Street
1629	Heavy Construction, nec
3536	Conveyors
3535	Cranes and Hoists
3811 3821	Mechanical Controls and Instruments
3822	Automatic Temperature Controls
3621	Motors and Generators
3623	Welding Apparatus
3612	Power, Distribution, and Specialty Transfomers
3613	Switchgear
281	Industrial Chemicals
3534	Elevators and Moving Stairways
3566	Power Transmission Equipment

to develop. The Stanford Research Institute work for Bechtel depended on a variety of sources, among which were Bechtel itself and the BLS occupation-industry estimates.

It is difficult to decide how much reliance can be placed on the Bechtel estimates, but it seems clear that the facility approach is preferable to the industry approach if it can be done accurately. The Bechtel estimates are not useful at any desirable level of occupational detail because the occupational scheme adopted is not comparable to BLS or any other occupational classification system for which national manpower projections are made.

The key problem seems to me to be that cost estimation is done inadequately or that the manpower data developed are lost or noncomparable. Manpower forecasters are usually forced to derive manpower requirements from cost estimates, even though the cost estimates, to be any good at all, must have been based on estimates of labor requirements. ERDA and the regulatory agencies should require specific and comparable (standard occupational system) manpower requirements as a part of any project for which government participation or approval is sought. This might result in more reliable manpower forecasts, and, perhaps more important, more accurate cost projections could be developed.

VI. The Computer Model

A substantial amount of data is required for the computer model. The model will provide forecasts for 1980 and 1985 for three scenarios. This means there will be six final demand vectors (each of which will have consumption, investment, government purchases, exports, and imports for each of the industries). There will be three input-output matrices and employment matrices. There will be one large occupation-industry matrix, consisting of 410 occupations, 134 industries, and several hundred non-zero STP occupation-output coefficients.

Faced with this large amount of data, we have decided to develop a fully interactive system, so that forecasters can modify the system to meet their specific requirements. Each of the matrices can be edited at a terminal by a simple substitution command, so the system can be modified to accomodate altered estimates or changes of mind.

The input-output matrix in the model is stored in decomposed form with the energy industries and other key industries arranged in a block of 60 industries so that direct input-output coefficients can be modified without reinverting (or decomposing) the I-A matrix. This approach makes modification of technologies in the model very fast and quite inexpensive.

The model is written in the C language on a PDP11/50 with the UNIX operating system. A single complete simulation with the model is completed in about 5 minutes of elapsed time (although it can take longer if there are many other users) at a cost of about $3.

When complete, the model will be available for use by others by telephone or direct access over the ARPANET on which the PDP11/50 is a host computer.

NOTES

[1] Some of the earlier work includes H. Folk, "Manpower Research Alternatives and Imperatives," in John R. Niland, editor, *The Production and Distribution of Manpower Specialists*. Ithica: New York School of Industrial and Labor Relations, 1971, pp. 181-198; H. Folk and B. Hannon, "An Energy, Pollution, and Employment Policy Model," in Michael S. Macrakis, *Energy: Demand, Conservation, and Institutional Problems*, Proceedings of a Conference on Energy at the Massachusetts Institute of Technology, MIT Press, 1973, pp. 159-173; Roger H. Bezdek, *Long-Range Forecasting of Manpower Requirements, Theory and Applications*, Institute of Electrical and Electronic Engineers, Inc., New York, 1974; R. Herendeen, *An Energy Input-Output Matrix for the United States*, 1963: User's Guide, Document No. 69, Center for Advanced Computation, University of Illinois, Urbana-Champaign, March 1973; R. Herendeen and C. Bullard, *Energy Cost of Goods and Services, 1963 and 1967*, Document No. 140, Center for Advanced Computation, University of Illinois, Urbana-Champaign, November 1974; R. Knecht and C. Bullard, *End Uses of Energy in the U.S. Economy*, 1967, Document No. 145, Center for Advanced Computation, University of Illinois, Urbana-Champaign, September 1975; C. Bullard, *An Input-Output Model for Energy Demand Analysis*, Document No. 146, Center for Advanced Computation, University of Illinois, Urbana-Champaign, January 1975; C. Bullard and D. Pilati, *Direct and Indirect Requirements for a Project Independence Scenario*, Document No. 178, Center for Advanced Computation, University of Illinois, Urbana-Champaign, September 1975.

[2] The project also includes a study of recent labor market conditions for STP in energy related industries, but this aspect of the study is not discussed here.

[3] J. Just, *Report on Energy Technology Coefficients*, MITRE Corporation, McLean, Virginia, November 1974, and C. Clark and D. Varisco, *Net Energy and Oil Shale*, presented at NSF (RANN) Workshop on Net Energy, University of California, San Diego, La Jolla, California, January 21, 1975. See Mark A. Swift, *Technical Coefficients for Inputs to New Energy Technologies*, Technical Memorandum No. 49, Center for Advanced Computation, University of Illinois, Urbana-Champaign, April 1975.

[4] See Donna L. Amado, Craig Foster, and David A. Pilati, *Two Models for Energy and Labor Impact Analysis*, Technical Memorandum No. 69, Center for Advanced Computation, University of Illinois, Urbana-Champaign, January 1976.

[5] See Roger Roderick, "An Organizational Analysis of the Hiring of Engineers," Unpublished Ph.D. thesis, Institute of Labor and Industrial Relations, University of Illinois, Urbana-Champaign, 1971.

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MANPOWER MODELING FOR FUTURE DECISION-MAKING

Warren Viessman, Jr.

In a 1971 report of the National Sciences Board entitled, "Environmental Science, Challenge for the 70's" the process of identifying the tasks and problems that confront society and universities in environmental matters was addressed. The question of manpower was a major element in all of the board's recommendations which encompassed the national program, priorities, organization for environmental science, funding for environmental science, and development of national manpower. On the strength of this and other related studies, what is needed most are new or improved policies to strengthen the development of skilled manpower for managing and solving problems of national concern.

With the increased interest in and programs to combat abuses to the environment, intelligent planning to meet the needs of manpower in this important field is essential. Until the recent increase of public awareness of pollution problems, for example, only modest attention was directed toward manpower training activities in this area. With the extensive legislation and proposed legislation designed to solve environmental problems, there has been an increase in the awareness of a need for educational programs to provide trained manpower.

Unfortunately, there is often little specific information as to what the needs for manpower are, even though many efforts to define these are in evidence. The difficulty in assessing engineering manpower and training needs has been increased by the dynamic nature of emerging issues and the rapid pace of technological change.

New legislation will certainly influence manpower and training needs. The programs of many federal agencies, such as the Environmental Protection Agency (EPA) will significantly affect these needs. Manpower shortages present significant problems in planning. Means for preventing serious shortages need to be devised. The importance of planning in manpower needs in the engineering and scientific areas was well stated by Brody in a 1971 article in Science: Brody noted that scientists and engineers are not created on short order or from random source material. Rather, they are the product of 10 to 20 years of study and application, and they must have the technical ability to begin with.

This conference has been designed to explore the role of models in manpower assessment. Models, as I see them, are planning tools. As such they are subject to the traditional hazards of the planning process, i.e., the need to make decisions based on incomplete information and relate these to conditions which have not yet occurred. In spite of these drawbacks, we must make plans and move forward, continually improving our data base and making use of the best analytic techniques available. A model, if appropriately structured and proven, can be an invaluable aid in assessing a variety of conditions.

There are some cautions, however. I have had a good deal of experience in water resources systems modeling using both optimization and simulation models. My experience indicates that one of the great concerns relates to the acceptability of models and model results. Unfortunately, those engaged in developing models often present them in a fashion which is unintelligible to those who must use or accept them. A good model may be thus obscured or never used because it is not presented in a meaningful and understandable way.

I also believe that models should be developed as simply as possible. Determine the objective of the model. If all you are after is a rough trend, then it is certainly not good judgement to develop a sophisticated model which will cost a great deal of money to formulate and operate on the computer. Another consideration relates to understanding the results obtained from a model. Too often people believe that models are devices which are designed to accurately predict the future. In reality, a model really provides only an indication of futures and trends, but this is the type of information upon which decisions can be based.

When I was with the Nebraska Water Research Institute we did a great deal of modeling on ground water systems in the Blue River basin. In particular, the objective was to assess the ground water resource. Irrigation systems were pumping large quantitites of water and underground water levels were falling. Within 10 to 20 years, at the current rate of development, significant economic hardships will result. The models we developed were not designed to determine exatly what the level of the ground water would be after 5,10, or 15 years, although such numbers are determined by the model. The important thing in terms of the planning process was to determine whether there was going to be a lot of water on hand, a limited amount, or none at all. It was important to determine if there would be a steady decline or an increase in the water level. The trend is what was important in terms of reaching necessary decisions.

The rapid pace of technological change combined with the new societal focus on environment and the quality of life has shattered the validity of directly projecting historic trends. New dimensions in modeling and understanding must accompany society's new look and goals. Dynamic manpower assessments are necessary adjuncts and there must be a strong feedback in the modeling process itself. That is to say, we ought to be looking at manpower needs in a continuing fashion and our models should be constantly improved as we aquire better data and more complete information about the systems we are studying. Manpower studies should be cast with other national planning processes. For example, it seems unrealistic to think in terms of planning for improved water quality unless we simultaneously consider the manpower needed to operate waste treatment plants.

Finally, I think it is important to be aware of the fact that legislation itself may have a profound impact on manpower needs. An excellent example of this is the Water Pollution Control Act Amendments of 1972 (PL 92-500). The massive expenditures for construction of waste treatment plants have had a significant impact on the need for trained people to operate these facilities. It would be well to monitor new legislation very carefully.

Many decisions about our future will rest on a determination of the availability and character of engineering manpower. In like fashion, programs to meet manpower needs will depend largely on fresh and innovative approaches to evaluating future trends and identifying emerging issues. Manpower modeling for future decision-making will play an increasingly important role.

THE BLS ECONOMIC GROWTH MODEL SYSTEM FOR ECONOMIC AND MANPOWER PROJECTIONS: DESCRIPTION AND APPLICATIONS*

Ronald E. Kutscher

The Division of Economic Growth develops economic and employment projections for the Bureau of Labor Statistics. This research provides a comprehensive and integrated framework for analyzing the implications of medium-to long-term economic growth for employment and the economy, both at a macroeconomic level and by individual industries. These economic projections and the projections of employment by industry constitute the framework within which occupational outlook projections are made by the Bureau of Labor Statistics. The type of projections developed by the Bureau can be characterized as having a medium to long-term horizon, i.e. 5 to 10 years; as attempting to discern secular changes in the economy and as a consequence abstracting from cyclical movement as much as possible; and by the fact that they are projections made under specified assumptions. These projections are designed to provide economic and employment information to decision makers in government and business as well as for analytical use by a wide variety of groups interested in manpower planning.

The projection process used in making the 1980 and 1985 projections, as well as the interim revision of the 1980-85 projections (necessitated by the sharply altered economic picture as well as changes in energy outlook), is outlined below.[1] The process has five major components as well as a number of substeps:

1. Projection of real potential GNP on an aggregate basis using:

    A. Labor Force
    B. Employment
    C. Average annual hours
    D. Output per all employees hours

2. Estimation and distributions of demand GNP with:

    A. Thurow econometric model
    B. Demand disaggregation models

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3. Input-output system

4. Microeconomic or industry projections of employment

    A. Output per all employee hour
    B. Average annual hours
    C. Employment

5. System balancing

    A. Imports
    B. Gross private domestic investment
    C. Employment

Factor determining real potential GNP. To develop a projected rate of growth for potential real gross national product, several factors affecting this growth rate must be projected. First, the growth rate of the labor force is projected to the target years by the Office of Manpower Structure and Trends in the Bureau of Labor Statistics. This is done by projecting labor force participation rates for men by age group, for women by age group, and separately for women with and without children under 5 years of age. To make these projections of labor force participation of women, an assumption is made as to the long-term fertility rate trend which determines the proportion of the female population in each of the last two categories.

The civilian labor force unemployment rate is set by assumption, as is the number of individuals in the Armed Forces. Civilian employment in the target years is in turn determined by subtracting military employment from the projected labor force and applying the rate of unemployment to the remainder. This yields a projection of employment on a count-of-persons basis.

The conversion of this number to a count of jobs is desirable since more detailed industry employment estimates are available on this basis.[2] Estimates of employment at the detailed industry level used in later stages of the projections are related to data series obtained from establishment payrolls, which are counts of jobs, while the labor force projection is based on a household survey, which is a count of persons. The conversion ratio, or adjustment factor, leading to a jobs concept of employment, adjusts not only for those individuals who hold more than one job, but also for other statistical differences between the two employment series. Generally, this ratio is inversely related to the unemployment rate but relatively large random disturbances appear frequently enough so as to make reasonable projections difficult. Therefore, the adjustment factor to put total employment estimates on a jobs basis for a target year is derived from an average relationship for the historical years.

Next, total projected employment is divided into three major sectors: farm, private nonfarm, and government. The private sector is divided between farm and nonfarm because of the disparity between rates of growth of output per all-employee hour for these two areas of the economy and the employment shift from farm to nonfarm industries. Separate estimates of government employment are made since the productivity change for government employees is assumed to be zero in the national income and product accounts (which form the data base for the projections model). Government employment projections are subdivided into federal civilian, federal military, and state and local.

The rates of change for annual hours paid are projected for the private sector of the economy. The projection of these items is based on historical trends in hours in the farm and private nonfarm sectors. With the estimates of changes in hours paid and the estimates of employment for each component of private employment, the next step is to calculate total private hours for the target year. This is accomplished by multiplying the estimates for each component of private employment by the estimated level of average annual hours paid in that sector in the target year.

In the aggregate, the government product is assumed to equal the compensation of government employees (in real terms). Thus, to develop projected values for the government product, the estimates of employment for each subdivision of government are multiplied by the base year average compensation for that level of government. The resulting values, summed, represent projected government product. They assume that no change in the mix of government employment will take place during the projection period. Adding this estimate to the estimate of private GNP and government product yields the projected value of total gross national product.

Estimation and distribution of demand GNP. Once supply GNP has been determined, a two-step procedure is followed to allocate this by industry. First, the macroeconometric model developed by Lester Thurow allocates GNP by major demand category. Next, each of these demand categories is in turn disaggregated to the industry level of detail.

Thurow macroeconometric model. Major demand and income components of GNP are projected using the Thurow macroeconometric model which was originally financed by the Interagency Growth Project. It is designed for long-term projections of the national income accounts on an annual basis and is formulated so as to facilitate analysis of selected fiscal policy alternatives. The emphasis is on fiscal policy; the only monetary variables included are two interest rates. The original model has been described in the Survey of Current Business.[3] It consisted of about 30 equations plus several identities, but more equations have been added in the course of its further development and use.

In its original version, the model contained 104 variables, 51 of which were exogenous. The exogenous variables--those which have to be supplied to the model--included population, prices, exports, interest rates, and various federal policy variables such as tax rates and transfer payments.

The Thurow model is divided into three distinct sections: supply, income, and demand. Although distinct, the sectors are not unrelated, since they interact with one another. The supply and demand sides are primarily in constant dollars, while the income side is primarily in current dollars. A set of deflators is used to convert from supply or demand to income and back.

The supply side consists of an aggregate production function which is designed to calculate potential private GNP. Total potential GNP is obtained by adding an exogenous estimate of gross government product to the estimate of potential private GNP. The production function used in deriving private GNP has both labor and capital inputs; consequently, the model derives an estimate of gross private investment in a simultaneous solution with the production function. However, this production function is not used in developing supply GNP since the resulting projections of GNP seem overstated but rather procedure just outlined is followed.

The income sector of the Thurow model is oriented toward the determination of personal income. Although it is an identity, the personal income equation can be considered the key equation of the income sector. The other equations in the sector are for the estimation of the various quantities that are used in deriving personal income from supply GNP estimates. The derivation requires estimates of capital consumption allowances, indirect business taxes, net subsidies, corporate profits and inventory valuation adjustments, social insurance contributions, transfer payments, interest payments of government and consumers, and net corporate dividend payments. In addition, estimates of personal taxes paid to federal, state, and local government facilitate the estimation of disposable personal income.

Since the income sector is in current dollars, however, inputs into the sector which originate in the supply side must be converted to current dollars using projected price inflators. Most of the major estimates of the supply sector, including GNP, corporate profits, and corporate internal funds net of investment, are passed to the income sector from supply.

Along with the indirect effects of policy variables on the supply estimates which are passed on to the income sector, there are many policy variables which enter directly. These include the federal tax rate on gasoline, the combined employer-employee Old Age, Survisors' Disability and Hospital Insurance (OASDHI) tax rate along with its coverage ratio and taxable wage base, the average employer contribution rate for unemployment insurance, the yield on 3-month treasury bills, the publicly held federal debt, the federal tax rate on median family income, the employment rate, and transfer payments.

The key result of the demand sector is the estimation of demand GNP. The GNP equation is an identity which sums personal consumption, gross private domestic investment, net exports, and government purchases. Some of the components of demand GNP are estimated directly in other sectors of the model. In particular, investment in producers' durable equipment, investment in nonresidential structures, and compensation of government employees are taken from the supply sector. The other components are estimated in the demand sector or are exogenous.

Disposable personal income is one of the most important determinants of the equations in the demand sector. It enters into the estimates of personal consumption expenditures, residential investment, and imports. Therefore, any policy changes which affect disposable personal income will directly affect the level and composition of demand GNP. Two exogenous policy-related variables--exports and federal government noncompensation purchases--enter directly into the demand GNP identity.

Essentially, the flow of the Thurow model is as follows: the economy's projected labor and capital resources generate an estimate of supply or potential GNP which in turn provides the basis for estimating the income generated by the production of this output, and these incomes enter into the projections of demand GNP. This simplified flow of the model ignores the many interactions and simultanieties of the model--although there is no guarantee, of course, that the demand generated by the production of potential GNP will result in an equilibrium situation. In general, demand GNP will not equal supply GNP. The resulting difference between the two measures of GNP is the supply-demand gap.

Within the model, the gap may be handled in two ways. One is to let federal purchases, other than compensation, be determined as a residual, thus assuming that any excess supply is taken up by direct federal government purchases. The alternative treatment is to estimate federal purchases exogenously and explicitly derive the supply-demand gap. The gap is then eliminated by changing the assumptions about various federal policy variables in order to stimulate or stem demand, as the case requires. BLS uses the latter approach. The result is a balanced projection, one in which outputs, income, a set of government fiscal policies and demand are consistent with one another.

Demand disaggregation models. After a balanced set of income and demand GNP projections has been completed, the projection sequence turns to a detailed distribution of the various demand GNP categories. Allocation of consumer expenditures to producing industry relies on consumption functions for each of the categories of consumer expenditures. Henrik S. Houthakker and Lester Taylor developed for the BLS a set of 82 demand-oriented consumption functions which relate expenditures on a given item to past levels and changes in expenditures for this item and to changes in consumer income. In this formulation, total Projected Consumer Expenditures (PCE) is treated as a proxy for disposable income, and is by far the most important of the explanatory variables. Annual change in PCE also has a high level of explanatory power in these equations. Relative prices are incorporated in about one-half of the equations and in addition, one or two other variables appear in selected equations.

In the demand area of state and local government expenditures, the portion of real demand GNP accounted for by state and local government expenditures is projected by the Thurow macroeconometric model. This model now also develops estimates for both educational and all other purchases, and for compensation of state and local employees in each of these two categories. Within each of these functions, projections are made for compensation, structures, and all other purchases.

Other demand areas estimated in detail include a break-out of gross private domestic investment into residential construction, nonresidential construction, investment in producers' durable equipment, and the change in business inventories. Estimates of the distribution of producer durable equipment and construction are modified later in the projection sequence once industry growth rates have been calculated. The federal government accounts are divided into two broad groups, defense and nondefense. Based on the assumed level of military employment in the projected years, estimates are first made for compensation and expenditures on major consumables directly related to the military employment level.

The remaining defense expenditures are distributed according to assumptions concerning future developments in major weapon systems. Federal nondefense expenditures, other than those for the National Aeronautics and Space Administration (NASA), are broadly broken into compensation, structures and all other purchases. The distribution for NASA is based on detailed analysis of past expenditure patterns and assumptions about future expenditures. Exports and imports are handled separately at their aggregate or total levels in the input-output system and are netted only at a final stage in order to present a conceptually correct GNP level.

The input-output system. After final demand is projected, the output in each industry necessary to satisfy the projected final demand is computed by the input-output system. The input-output transactions table, a rectangular array of numbers which represents the transactions of each sector or industry with all other sectors, provides a statistical format for the economy. By reading across a row, the relationship of the entries sales of the producing industry's output to every consuming industry, including itself, and to the components of final demand, can be seen. The sum of these entries is total output. Reading down a column, the entries represent the inputs to an industry from every industry, including itself, used to produce its output. The sum of purchased inputs plus value added equals the total output of that industry.

An input-output transactions table, when converted into ratios of entries for each cell to the total column sum, becomes a "direct coefficients" matrix. If the demand for an industry's product such as automobiles increases or decreases by a certain amount, the direct coefficients of that industry will indicate the proportionate effects on other industries such as steel, aluminum, trade, and transportation.

Each of the industries directly affected by a change in demand for automobiles has its own supplying industries. The steel and the coal and iron ore industries, in turn, need other items such as fuel to run the mining machinery and repair parts for equipment. By linking all the input-output coefficients together in a consistent and integrated set of relationships, the effects of a particular demand, such as that for automobiles, on each industry can be traced back along the production process. These effects include all the raw materials, parts, components, fuels, transportation, and distributive services which are ultimately included in making the automobile or any other final product.

The intricate relationships among industries are encompassed in the coefficients of the total (direct and indirect) requirements matrix, also called an inverse matrix, and represents the solution to the set of linear equations represented by the input-output transactions. An inverse matrix provides the basic framework for exploration of the potential effects on the industrial composition of output and employment in the years projected, which may result from assumptions with respect to the projected level of final demand. Thus, through the use of an input-output system, projections of the demand of final users such as consumers or government can be translated into total output requirements from all industries. However, since the input-output coefficients represent a static description of an economy as of a fixed point in time, for any period in the future these fixed relationships can and do change. This necessitates projecting these relationships based on changes expected because of product mix change, technological change, and relative price change. In the BLS system, this is done by two approaches, individual industry analyses and analysis of trends in the utilization of various product groups or row coefficients in the input-output system.

The projections of output by sector are the essential input to projections of employment by industry. In developing projections of employment, both changes in output per all employee hour and changes in average hours are used. The estimates of employment for each industry are derived from the projected levels of output, output per hour, and average annual hours. First, for each industry, projected output is divided by the estimated output per all employee ratio in order to arrive at total projected hours in each industry. Total hours, in turn, are divided by projected average annual hours yielding projected employment by industry. These industry employment estimates include wage and salary workers, unpaid family workers, and the self-employed.

The projections system is based on many complex relationships among economic variables which are developed through a lengthy sequence of operations. Therefore, a set of checks is necessary to insure that the various stages of the projections make up an internally consistent model. The economic growth model is designed to provide a feedback and balancing procedure with respect to three of its elements: imports, investments, and employment.

At this point, the employment developed by the system generated in each industry is disaggregated into occupations using the industry occupational employment matrix developed by the Division of Manpower and Occupational Outlook of the BLS. This matrix presents the distribution of 422 detailed occupations in each of 201 industries. By applying an industry's occupational pattern to total employment in that industry, estimates are developed by occupation. To arrive at the total national requirements for each occupation, the estimates of all the industries are summed across each row in the table or matrix.

Future directions of the BLS Economic Growth model. A number of research efforts are currently planned or underway either within the Division of Economic Growth or under its sponsorship. The objective of these research projects is the development of techniques and additional data leading to improved projections of economic growth and manpower requirements. As soon as the benchmarked GNP accounts are available from the Bureau of Economic Analysis, they will be used to reestimate the econometric models in the Economic Growth system--the Thurow Macroeconometric Model and the Houthakker-Taylor Consumption Model. The 1967 input-output table prepared by the Bureau of Economic Analysis will be incorporated as the appropriate input-output base. The underlying input-output table will be updated to 1972 or 1973 depending on data availability. The model will be expanded from 134 to approximately 165 sectors to more precisely meet the requirements of occupational projections.

Also, two demand models will be incorporated into the economic growth model. These models were developed by Terry Morlan of BLS. They project demand for state and local government expenditures in functional detail. A federal government model is being developed under contract with Frank Ripley of Data Resources, Inc. These new government demand models will enhance the capability of analyzing the impact of changes in federal, state, or local policy on demand, output, and employment, as well as improve government sector projections.

Beyond these plans, many other ideas are being explored. Among those are demand models for investment, both construction and producers' durable equipment, and foreign trade. Investment, at least in equipment, perhaps could be more meaningfully treated in the context of a factor demand model because of its relationship to output and labor productivity. A model for projecting residential structures and some or all types of nonresidential structures would also be desirable. Clearly, a foreign trade model would be useful, whether such a model took the form of improved equations in the macro model or a fully specified trade model to forecast the composition of imports and exports. It is not clear, however, whether a model to project the composition of U.S. exports and imports could be developed short of a comprehensive world trade model.

Further areas under discussion include strengthening the structural links between supply GNP and the macro model and between the macro model and the input-output model. Since these links flow in only one direction from supply GNP to the macro model and from the macro model to the input-output model, they do not provide any other links. In reestimating and refining the BLS economic growth model, there are many possibilities for structural links. The range is large, but includes derivation of supply GNP in the macro mode with some loop back from the input-output detail to the supply GNP or a linking of the demand models in the input-output phase of the model to the macro models' demand categories. A factor demand model, if developed, could play a role in the determination or validation of supply GNP projections, of productivity projections and of intermediate inputs projections.

Most of the research on the growth model has concentrated on the demand side of the national accounts. However, the income side should also be explored, particularly prices which represent the necessary link between them. Thus, an important consideration is whether or not one should develop a price/wage or a price/factor payments model which could also be expanded to include some intermediate inputs. Development of such a model would enable adjustment of input-output coefficients because of changes in relative prices, which can be done now only exogenously on an ad hoc basis.

APPLICATIONS OF THE ECONOMIC GROWTH MODEL SYSTEM

The BLS has recently completed an interim set of revised projections for 1980 and 1985 using the system just described. The projections for 1980 and 1985, first published in December 1973, needed revision because of the extraordinary events of the past two years and the resulting impact these events are expected to have on the structure of employment over the next decade. Many of the assumptions that were made for the earlier set of projections have changed appreciably, most particularly the

Table 1. Gross Product Originating in Total Private Economy: A Comparison of rates of change of previous and revised 1980 and 1985 projections

Sector	Average annual rates of change			
	Previous projections		Revised projections	
	1972-80	1980-85	1972-80	1980-85
Total private...........................	5.0	3.3	4.0	3.7
Agriculture...........................	.4	1.0	1.9	1.4
Nonagriculture........................	5.1	3.4	4.1	3.7
Mining............................	1.3	.3	.9	3.9
Construction......................	3.1	1.7	2.0	3.5
Manufacturing.....................	5.0	3.1	4.1	3.5
Durable.........................	5.9	3.2	4.5	3.5
Nondurable......................	3.7	3.0	3.6	3.5
Transportation, communication and public utilities..................	6.2	4.2	4.8	4.8
Transportation..................	5.8	3.1	4.2	3.9
Communication...................	7.4	5.1	5.8	5.8
Public utilities................	5.3	4.8	4.8	5.0
Trade.............................	4.7	2.5	4.7	2.9
Wholesale.......................	5.1	2.7	5.1	3.0
Retail..........................	4.4	2.4	4.4	2.9
Finance, insurance and real estate.	5.4	4.0	4.2	4.0
Other services....................	6.4	3.8	3.7	4.0
Government enterprises............	4.3	3.8	4.4	3.7

SOURCE: Bureau of Labor Statistics.

severe economic recession of 1974-75 as well as the radical change in the energy outlook triggered by the Arab oil embargo. The purpose of this interim revision is to provide a set of projections with more realistic underlying assumptions from today's perspective. In the future, moreover, the BLS will schedule an update of its projections regularly every two years rather than on the previous cycle of four to five years.

Projections highlights. The revised set of projections provides a projected rate of growth in real GNP between 1972-1980 of 3.9 percent a year compared to a rate of 4.7 percent a year in the earlier projections. In the span between 1972-1985, the revised growth rate is projected to be 3.8 percent a year while the earlier projections provided a 4.2 percent growth rate for real GNP. However, the 1980-85 GNP growth rate is 3.6 percent a year in the revised projections compared to the ealier projected rate of 3.3 percent annual growth.

Output (gross product originating) for the total private economy and major sectors within have changed significantly in a number of sectors with some of the changes clearly energy related as in the case of mining (Table 1). A striking change is noticeable in the area identified as "other services." In the earlier projections a shift in the composition of output was projected toward services. This is not true of the revised projections, which seem more consistent with the long-rum trend of the lack of any discernible shift in output to services. In durable manufacturing, a large part of the slower growth is related to the projection of slower growth for automobile sales. In construction, a slower growth in housing until after 1980 alters substantially the pattern of growth for this sector.

For employment, several important differences can be noted in the revised set of projections (Table 2). A preliminary revision has increased the size of the labor force by 1.5 million in 1980 and 2 million in 1985. The assumed unemployment rate in 1980 and the revised projection is 4.7 percent compared to 4 percent in the earlier projection. Productivity for the private nonagricultural sector is assumed to grow at a 2.37 percent rate in the 1972-85 period compared to a 2.85 rate in the earlier projections. The pattern is also different with slower growth in the 1972-80 period and a return to a more normal rate of 2.6 percent after 1980 whereas a constant rate of 2.7 percent a year increase throughout the entire period was incorporated in the earlier projections.

Federal government employment, military and civilian, is about 200,000 higher in the revised projections while agricultural employment is up about 400,000 compared to the earlier projections. Mining employment is significantly higher reflecting increases in the coal mining and crude petroleum extraction industries. Public utilities employment is also higher. Durable manufacturing employment is lower due in part to the slower growth of the automobile industry. Nondurable manufacturing is also lower reflecting less of a slow down in productivity in the revised projections for this sector. Employment in 1985 in transportation is moderately lower and somewhat higher in communications.

Use of the model in specific manpower studies. Over the last few years, with funding from the Employment and Training Administration in the Department of Labor, in the BLS has applied its input-output system and occupational matrix, which have been primarily for longer-term projections of industry and occupational employment, to gauge the manpower requirements

Table 2. Employment by major sector: A comparison of previous and revised 1980 and 1985 projections

	Revised			Previous		
	1972	1980	1985	1972	1980	1985
Total	86,551	101,861	109,446	85,597	101,576	107,609
Government	13,340	16,800	19,300	13,290	16,610	18,800
Federal	2,684	2,900	3,000	2,650	2,750	2,800
State and local	10,565	13,900	16,300	10,640	13,860	1,600
Private	73,211	85,056	90,166	72,307	84,966	88,809
Farm	3,450	2,750	2,300	3,450	2,300	1,900
Nonfarm	69,761	82,306	87,866	68,857	82,666	86,909
Mining	660	785	820	645	655	632
Construction	4,694	5,180	5,800	4,352	4.908	5,184
Manufacturing	19,493	21,871	22,530	19,261	22,923	23,499
Durable	11,232	13,087	13,599	11,091	13,629	14,154
Nondurable	8,261	8,784	8,931	8,190	9,294	9,345
Transportation, communication and public utilities	4,725	5,219	5,421	4,726	5,321	5,368
Transportation	2,863	3,037	3,073	2,842	3,250	3,266
Communication	1,156	1,344	1,459	1,150	1,300	1,312
Public utilities	726	838	889	734	771	790
Trade	18,751	22,504	23,228	18.432	21.695	22,381
Wholesale	4,244	5,142	5,221	4,235	4,946	5,123
Retail	14,507	17,362	18,007	14.197	16,749	17,258
Finance, insurance, and real estate	4,310	5,415	5,989	4,303	5,349	5,932
Other services	17,106	21,332	24,078	17,118	21,815	23,913

SOURCE: Bureau of Labor Statistics.

of current federal expenditures of an agency, or in some cases, of a program. These studies provide a means for policy makers and manpower planners to analyze the employment requirements in different federal programs. Among a number of BLS publications in this area is the Factbook for Estimating the Manpower Needs of Federal Programs[4] which brings together in one publication a set of 41 employment and occupational factors designed to provide a basis for roughly estimating the manpower requirements of federal outlays. The results of several special studies--the Veterans Administration (VA) health care program, the National Institutes of Health, the Manpower Institutional Training program, and both NASA and its space shuttle program--are contained in Expenditures and Manpower Requirements for Selected Federal Programs.[5] Still another BLS research study is Impact of Federal Pollution Control and Abatement Expenditures on Manpower Requirements.[6] This study, funded by the National Science Foundation, (NSF) focused particularly on the engineering and scientific manpower required by expenditures in these areas.

As an illustration of the types of information available from the BLS manpower requirements system, an examination of the differing manpower requirements, particularly by industry and occupation, of a billion dollars worth of funding for NASA is compared here to $1 billion of highway construction. The NASA expenditure is estimated to have provided approximately 62,500 job opportunities, while the same amount of money spent on highway construction is estimated to have required 57,800 jobs. Despite the fact that the total manpower requirements for these two types of expenditures are roughly on the same order of magnitude, the manpower requirements are considerably different both in terms of industries affected and occupational skills required.

The first difference is that almost 13 percent of the jobs required for NASA are directly within the agency (Table 3). In the mining sector, differences appeared with NASA's expenditures requiring a negligible amount of employment while over 2,500 jobs (more than 4 percent of the total) were in this sector in highway construction expenditures. Almost 1,800 of these mining jobs related to highway construction were concentrated in the stone and clay mining and quarrying sector.

Although the sector most affected in both instances was manufacturing, NASA provided more than twice as many job opportunities as highway construction. Out of the more than 30,000 jobs in manufacturing required by $1 billion worth of expenditures by NASA, approximately two-thirds were found in the aerospace, aircraft, and electronic components. On the other hand, of the almost 14,000 manufacturing jobs generated by spending $1 billion on highway construction, nearly half were concentrated in three industries--cement, clay, and concrete products; iron and steel foundries and forgings; and fabricated structural metals.

In occupational terms, the largest impact of the NASA expenditures was on professional, technical, and kindred workers--almost 20,000 were natural scientists and 4,400 were technicians (Table 4). The highway construction, however, generates only about one-quarter as many professional, technical, and kindred jobs. Of the 5,550 jobs of this type generated, approximately 1,200 were for engineers. Three hundred and fifty civil engineers were required, as might be expected due to

Table 3. Employment requirements per billion dollars of expenditures, by major industry sector
1972

Sector	National Aeronautics and Space Administration	Percent distribution	Highway construction	Percent distribution
Total	62,525	100.0	57,802	100.0
Agriculture	318	0.5	384	0.7
Mining	349	0.6	2,538	4.4
Construction	1,281	2.0	22,970	39.7
Manufacturing	30,281	48.4	13,584	23.5
Transportation, communication and public utilities	4,880	7.8	4,581	7.9
Trade	3,795	6.1	5,257	9.1
Finance, insurance and real estate	852	1.4	1,236	2.1
Other services	11,387	18.2	6,695	11.6
Government enterprises	1,200	1.9	557	1.0
General government	8,182	13.1	-	-

SOURCE: Bureau of Labor Statistics.

Table 4. Occupational requirements per billion dollars
of expenditures, by major occupational group
1972

Occupational Group	National Aeronautics and Space Administration	Percent distribution	Highway construction	Percent distributior
Total	62,400	100.0	57,750	100.0
Professional, technical and kindred	19,600	31.4	5,550	9.6
Managers and administrators	4,950	7.9	4,300	7.4
Clerical	12,150	19.5	7,000	12.1
Sales	1,600	2.6	1,850	3.2
Craft and kindred	8,850	14.2	16,600	28.7
Operatives	10,700	17.1	13,950	24.1
Service workers	2,700	4.3	1,000	1.7
Laborers	1,650	2.6	7,250	12.6
Farmers	200	0.3	250	0.4

NOTE: Due to difference in rounding the totals in table 3 and 4 are somewhat different

SOURCE: Bureau of Labor Statistics.

highway construction, although this number was only fifty more than generated by NASA's expenditures. In the clerical group, NASA required 12,150 jobs per $1 billion of expenditures compared to 7,000 for highway construction.

The manpower requirements for craft and kindred workers, however, were significantly different. NASA required 8,850 of these jobs, with over 2,000 slots each for mechanics and metal workers. Highway construction required nearly twice as many craft and kindred jobs, with 8,900 of these in the construction area. As might be expected, highway construction dollars required more jobs for laborers--7,250 compared to 1,650 for a billion dollars worth of NASA expenditures. Operatives too were affected more by highway construction--nearly 14,000 jobs compared to the 10,700 for NASA programs. The jobs most impacted, however, were quite different--truck and tractor drivers for highway construction and semi-skilled metal workers by NASA. Services accounted for 2,700 jobs with NASA and 1,000 jobs with highway construction; the number of farm jobs was roughly similar for both programs.

While these types of data can be very useful in the analysis of a federal program or action, a number of qualifications must be kept in mind when using employment numbers:

> BLS manpower requirements reflect the average employment and are not marginal or incremental manpower factors. Therefore, the use of these factors to estimate the manpower requirements relating to a change in a federal program should be done with great care.
>
> The BLS numbers are usually presented as the average number of full and part-time jobs. Programs where large numbers of part-time job slots are generated obviously show a larger manpower impact than a program where nearly all the employees are full-time.
>
> All other things being equal, there will be fewer jobs per billion dollars if the average salary or wage is higher rather than low.
>
> Comparison of manpower requirements for one program with those of another program for a different year can distort the results significantly because of subsequent changes in prices and in productivity.
>
> Programs with a high proportion of their outlays going directly to public employment will in general show greater employment requirements than those in which expenditures are concentrated in the private sector. This is due not only to the labor intensive nature of many governmental activities, but also to the fact that purchases from the private sector would embody taxes, depreciation, and profits for which no manpower requirements are estimated in the present BLS system.

Manpower requirements in perspective. Manpower requirements numbers, of course, should be considered as only one dimension for any program decision-making or policy planning purpose. The basic question should be one of need--does the nation's security require a new weapon system, or will health research dollars help to slow the toll from heart attacks? Yet manpower assessment can provide useful insights and help prevent severe imbalances in the supply and demand of labor once such program or priority decisions are made. The 1975 Manpower Report of the President stated: "Every Government program, either proposed or enacted, implies if a specific pattern were known when programs were first considered and if recognition of their manpower effects were insured, many of the untoward consequences of labor could be avoided or at least mitigated." If policymakers and manpower planners have the information to focus on potential labor force problems arising from federal actions, it is more likely that appropriate courses of action such as manpower training can be implemented to ease the imbalances in the job market and the resultant pressures on the economy.

NOTES

1. For more information on the earlier set of 1980 and 1985 projections and a more detailed coverage of the methodology and limitations of the Economic Growth model system see The Structure of the U.S. Economy in 1980 and 1985, BLS Bulletin 1831. The revised projections for 1980 and 1985 will be covered in greater detail in several articles scheduled to appear in a late spring issue of the Monthly Labor Review.

2. In concept, the difference between employment on a jobs basis and on a persons basis is that persons with more than one job are counted as many times as jobs they held on the job count basis but only once on a persons basis. However, since these data are developed from two entirely different statistical framework other differences between the two data sources on employment exist.

3. See Lester C. Thurow, "A Fiscal Policy Model of the United States," Survey of Current Business, June 1969, pp. 45-64.

4. Factbook for Estimating the Manpower Needs of Federal Programs, BLS Bulletin 1832, 1975.

5. Expenditures and Manpower Requirements for Selected Federal Programs, BLS Bulletin 1851, 1975.

6. Impact of Federal Pollution Control and Abatement Expenditures on Manpower Requirements, BLS Bulletin 1836, 1975.

THE POLICY VALUE OF MANPOWER PLANNING IN THE UNITED STATES

S.C. Kelley and T.N. Chirikos

I. Introduction

This paper is concerned with the use of component models in simulating change and their value or utility as policy instruments in the economic and political context of the United States. Our objective is to discuss the limitations of manpower planning as a source of policy criteria and to suggest some directions for improving the state of the art.

The discussion draws on our recent analysis of the practice of manpower forecasting in the United States[1,2] and on a long experience in manpower planning in developing countries. The U.S. study assessed the policy relevance of nearly 400 manpower plans or forecasts made between 1965 and 1973, and evaluated the theoretical and empirical base for planning. We found that manpower forecasting has only limited policy value, and that the knowledge base is not a primary constraint on the state of the art. Further, the study revealed a large gap between the current state of the planning art in the United States and its practice in the developing countries.

The research and experience leads us to the conclusion that the primary factors which limit the usefulness of manpower planning to the policy process are conceptual and institutional in nature. In particular, manpower planning in the United States is limited by the concept of planning as a decision instrument, and by institutional gaps in the policy and operating systems that planning intends to serve. One consequence is that the range of policy concerns that can be served by common types of planning models--some of which were described earlier in this conference--is extremely limited. Another is that investments in model building or in the knowledge base essential to model specification will produce only marginal returns to the policy process. Indeed, the more important limitations of the existing knowledge base are also functions of the conceptual and institutional factors that limit the practice of planning.

In view of that conclusion, the discussion must be moved beyond forecasts and models to a broader consideration of the foundations of manpower plans. Accordingly, this paper begins with a general discussion of the conceptual and institutional requisites of manpower planning in policy analysis and formulation. Section III extends the discussion by examining the current state of the art in estimating future manpower requirements and the effects of conceptual and institutional factors on knowledge generation and policy analysis. It also examines the effects of these constraints on estimations of future manpower supplies and the interaction of supply and requirements. Section IV suggests some possible means for enhancing the policy value of manpower planning.

II. Some General Observations

In the context of policy formation, manpower projections are considered as analytic criteria which serve the development of specific manpower policies or strategies. These strategies will differ with respect to policy issues and their corollary effects on the scope of inquiry. For the immediate purpose, we may suppose that strategies aim at minimizing uncertainty and hence the cost of labor market adjustment, sustaining progress toward system goals, and inducing greater rationality in public and private decision making.

Likewise, we may distinguish global strategies relating to the development and utilization of the entire human resource stock, and sectoral strategies delineated in terms of industrial and/or occupational coverage. In all cases, strategies are designed to suggest necessary and sufficient policy actions (interventions) to achieve balance between desirable and actual patterns of manpower use over time.

This task requires a conceptual and analytic framework which treats policy formation as a holistic process and provides operational criteria for rationalizing the complex set of institutions that implement policy. The preparation of manpower strategies, in other words, encompasses both a set of technical (analytic) activities and a set of institutional relationships among relevant policy makers. As will be seen, the dual nature of these requirements is critical to efforts to improve the state of the art.

In this context, we believe that manpower planning is necessarily an integral component of general economic and social planning. As such, manpower planners help specify the set of social goals and priorities to which policy variables (means) must respond, the technical and social constraints on the choice of means, the human performance roles implicit in the means, the human attributes associated with those roles, and the optimal means for attribute development. Social policy may rationalize these process elements in various ways. For instance, it may change social preference functions, influence time paths, constrain or expand the choice of means, modify qualifications standards, or adjust resource endowments. The choice of intervention possibilities as well as their relative weights and timing constitute a decision strategy. This strategic role is the primary function of planning.

In order to perfom this strategic/analytic function, the planning process should encompass the set of institutions that elaborate micro-policy and implement macro-policy. This requirement is not simply to assure the implementation of planning decisions. In our view, the conventional distinction between the preparation and implementation of plans is not very useful and its organizational implications are injurious to the policy process.

In a highly complex socio-economic system, acts of planning and implementation are not independent or sequential events. Put differently, a policy proposal must be both technically and institutionally feasible. Operating institutions are the best source of the technical information basic to analysis, and they are the primary source of institutional or organization feasibility criteria. In a pluralistic and highly decentralized decision structure, policy criteria must include or be accompanied by a set of incentives, i.e., penalties and rewards, to assure that the criteria are utilized in some appropriate fashion. As shall be seen, we are particularly concerned in this regard with the use of manpower projections to rationalize decisions arrived at on other grounds.

From the perspective of this framework, the current practice of manpower planning in the United States appears to have a very limited policy value. For example, the BLS Industry/Occupation Matrix is the dominant and technically most sophisticated planning model in use.[3] This approach links an aggregate econometric forecasting model to an input-output model to estimate sectoral output and employment. It also links employment estimates to an industry-occupation matrix to estimate the occupational structure of employment. These are interpreted as the manpower requirements of a full-capacity growth rate in output, given the assumptions of final demand, the distribution of public sector expenditures, the savings and investment parameters of the macro-model, and the technical coefficients of the input-output model.

The major limitation of the BLS Matrix does not stem from problems of estimation, but from the fact that it is not linked to supply systems in any direct way. One consequence is that the estimates of manpower requirements are independent of potential supply conditions and do not reflect the malleability of supply, i.e., substitution possibilities. A more important consequence is that the model cannot evaluate, on feasibility grounds, the structural assumptions of the projection or provide unambiguous output criteria for human resource development systems. These limitations are compounded when the matrix is applied to local or regional labor markets, where supply estimates require heroic assumptions concerning labor mobility.

The policy utility of this model is also limited by the static and somewhat mechanical form of the techniques employed in estimating sector output and employment. Although conceptually the model can be used to simulate alternative patterns of growth, it has not been used in this way. The structure of private sector final demand is extrapolated from historical data, and public sector output is estimated by trend analysis of employment.

Similarly, the effects of technical change on the occupational structure of employment is estimated by inter-censal trends and is not specified in any discrete from. Consequently, neither the structure of activity nor technology can be treated as policy variables. With the exception of macro-economic variables, the single human resource policy variable in the model is the manpower supply. That variable is specified only in the form of relative growth rates for specific occupations. Their relation to supply flows or the capacity of supply systems must be interpreted by the user.

This example illustrates our contention that the limited policy value of manpower planning in the United States is not primarily a function of limitations of the technical knowledge base essential to estimation procedures--limitations which may be overcome by additional research. Rather, it reflects a fundamental disjuncture between the concept or perception of planning as a decision instrument and the institutional environment for policy formation. It is our hypothesis, moreover, that this disjuncture is a function of the strength of the market paradigm on the generation of policy-relevant knowledge and the decision process in the public sector. By this we mean generally the impact that economic theory has had on the way in which we perceive social problems and devise solutions for them.

At root, the problem stems from the preoccupation of economics with static allocation questions and its failure to develop a unified, consistent theory of social process. In particular, the failure of economics to integrate marcro and micro analysis and consequently to move toward a dynamic process theory has separated policy into an aggregate employment policy and a disaggregate manpower policy. It is impossible to conceive of a pattern of economic growth that does not involve structural change, or a significant change in the structure of activity that does not affect the total. Yet these changes are treated independently in conventional economic constructs and, as a result, in policy formation.

The state of economic theory has also constrained the integration of economics and other social sciences, and public policy based in economic constructs reflects their simplistic psychological, sociological and cultural assumptions. For instance, human resources are defined in terms of functional skills in a narrow job context. Change is a simple function of profit maximizing behavior and the institutional and cultural context is static. Since the interdependence of human resource institutions is not specified in theory, it is not reflected in practice. Policy responses to problems of unemployment or growth reflect little sensitivity to the interdependence between educational, training, health, community, and labor market institutions.

As a consequence of the strength of the market paradigm, we have no institutional capacity for estimating a long-term social welfare function, for specifying social goals and priorities or for examining and evaluating the social implications of alternative patterns of technical change. Even if such institutions did exist, there would remain an institutional gap between policy making and implementing institutions. Those institutions that develop policy affecting manpower requirements are largely independent of and isolated from those that generate supply decisions. There is no current means by which these decisions can interact to produce an optimal long-term condition or evaluate alternative strategies and means. Furthermore, the supply system is so highly decentralized that it is incapable of responding in rational ways to external policy criteria. The use of the system term is a semantic convenience rather than a descriptor.

III. Some Specific Problems

The extent to which both conceptual and institutional factors limit the state of the planning art is manifest in each of the major components or elements of planning activity: the specification of manpower goal functions and potential supplies. This section considers in more specific fashion several of the important problems on each side of the planning equation. Space limitations require us to omit some topics and preclude more than a cursory glance at others. We have concentrated, as a result, on those facets which are fundamental to the notion of planning and points where conceptual and institutional changes might lead to substantial improvements in the state of the art.

The Goals Function

Clearly, the specification of an objective or goals function is central to the development of manpower strategies. Such functions specify in explicit form a set of desired outcomes and their manpower implications, i.e., they contain both a set of estimates of the level and structure of output and a transformation algorithm which estimates the alternative manpower configurations implied in the output statements. As we envisage the process, these are not simply forecasts. Rather, they represent an intensive search in time for a) potential or desirable changes in private and public preferences, and b) the technical alternatives for delivering a prescribed set of outputs. In the absence of such a search, the policy value of the manpower plan is reduced exclusively to recommended action on supply side variables.

Furthermore, those recommendations may not be persuasive, since they can be justified only in reference to achieving specific output targets ceteris paribus. Thus, trade-offs on the goals or "requirements" side must be considered because the rationale of the plan and the policy instruments included within its purview hinge on it. Two particularly important points imbedded in this notion are discerning shifts in preference fields and treating technology as a policy variable. Generally speaking, most current planning activities assume, as in market analysis, that preferences and technology are givens. Headway in the planning art requires a change in the way in which we perceive and treat these variables.

The structure of output.--Consider initially the question of preferences and changes in the structure of output. The impact of changes in the structure of output on the level and occupation structure of employment is not inconsequential: more than half of the historical change in the occupational structure is estimated to be a function of change in the product mix.[4] Yet, current methods of projecting structural change or in estimating a future structure of output belies this impact.

The principal difficulty in this regard is that conventional forms of analysis rely heavily (if not exclusively) on estimates of market demand as revealed (individual) preferences for goods and services.

While surely such demands cannot be ignored, they are not sufficient for the specification of outputs. They are insufficient methodologically because consumption is treated simply as a function of income or relative prices, which implies that preferences are independent of sociological, psychological, and environmental factors, or that they are constants.[5] They are insufficient conceptually because of the growing importance of collective goods and services in the mix of final outputs.

This conceptual difficulty is exacerbated by the absence, at the moment, of a relevant theoretical framework for estimating preferences for collective goods and services. This is especially critical since the concept of preferences revealed through prior decisions has little utility when there is no direct link between consumer choice and outcomes. Consequently, the need to develop a more meaningful construct and more effective estimating procedures is a first order requisite. The use of consumer survey techniques and opinion polling, and the development of Delphi procedures and goal analysis for evaluating trade-off choices reflects movement in this direction. Nonetheless, these techniques are operationally limited at the present time by the lack of a theory of public choice, particularly one that interprets the public welfare in ways different than an aggregative function of individual utilities.

A related constraint is the problem of measurement in the treatment of output statements containing intangible products and services. Of the latter, two areas of particular importance are education and health services. Although health services absorb an increasing proportion of the national income, we have no precise or even meaningful measure of its output. Conceptually, health services should produce, in conjunction with other services and the environment, states of health. Since such states cannot be specified empirically, they are usually specified in simple proxy forms and in terms of physical inputs or expenditures, neither of which has policy value.

Similarly, the outputs of educational systems are traditionally specified as body counts, degrees granted, or hours of instruction. In the absence of any explicit measure of the quality of the product, such measures have only limited policy value. Even less tangible outputs are illustrated in the current concern with environment, and reflected in the recent attempts to specify and measure the quality of life. Such measures are in effect attempts to incorporate intangibles into a social utility function. They must include currently non-measurable arguments such as psychological states. Conditions of this type are not readily inferred from expenditures or from levels of activity. They can only be derived indirectly from attitude surveys, opinion polls, or comparable instruments.

All current techniques of valuing output are short-term. They evaluate both current and future events in terms of the existing value structure. In long-term planning, values must be treated as variables, if future structures of output are intended to be optimal in terms of utility. In other words, planners must be able to specify the shift variables affecting utility functions and estimate changes in these variables over time. Much of the recent research in analysis of the future assumes that values respond to changes in technology.

They extrapolate technological change and impute a "relevant" set of values, yet the relationship between value changes and environmental changes is not well documented.

These brief comments suggest the conceptual and empirical requirements for specifying long-term changes in the structure of output and are significantly more complex than an examination of current practice would suggest. In this light, it is easy to see that improvements in the current state of the art will require more than the methodological refinement of existing models. Indeed, further refinement of conventional economic specification of consumer behavior in a market context should be accorded a very low priority in this regard. Moreover, the state of the art will not be improved in the absence of an appropriate institutional means for specifying a long-term social-welfare function. Since the institutional implications extend beyond the question of output specification, we delay a discusssion of them until we have examined other elements of the planning process.

Transformation.--The output vector, however estimated, must be translated or transformed into input statements, taken here to mean a vector of associated manpower requirements. Not unlike the earlier step, this phase of goals specification has been treated in conceptually limited form and, for lack of an appropriate institutional mechanism, has rarely entered the domain of policy analysis per se. Unlike the formulation of goal statements, however, it is an element which might be refined conceptually by applying economic constructs--in particular, the notion of the production function. In order to understand this point, it must be recognized that methodologically most manpower plans have used the prevailing or trend adjusted ratio of inputs to output (i.e., the input coefficient or its reciprocal, the productivity rate) to estimate the sectoral distribution and occupational composition of employment. This procedure has led to a number of well-known conceptual arguments relating to the desirability of preparing manpower plans.[6] Since the policy value of manpower plans hinges on these arguments, several observations are warranted here.

To begin with, the typical transform procedure has been criticized because it implies zero elasticities of substitution and/or zero or near zero elasticities of labor demand, and thereby over-emphasizes technological rigidities in determining patterns of manpower utilization. This criticism does not emerge directly but is inferred from the fact that prices appear to play no necessary role in manpower projections. That is, the critics argue that since factor prices are not explicitly considered, this must imply zero substitution elasticities or a fixed coefficient production function.

Yet, nowhere does the concept of manpower planning require that fixed input coefficients be assumed. If anything, the opposite is true in the sense that both the structural characteristics of the economy and the technological conditions of production are presumed either to change or be manipulated by policy over time. This implies that the critic's argument is erroneous in several respects.

First, from a methodological viewpoint, the transformation algorithm should be carried out in technical "space"--i.e., should explore the technical links and alternatives between inputs and outputs. The reasons are: a) that changes in manpower requirements stem from shifts in the production function as much as they do from economically-induced movements along the existing technological frontier, b) manpower utilization is determined by interactions of projected supplies and hence the criteria for evaluating such patterns must be independent of existing supply conditions, and c) the policy implications of technical change will not otherwise be visible. This means that while factor prices may be determined by planning action, their magnitudes in the base year of the plan are not considered as primary _ex ante_ determinants of factor use patterns.[7]

Second, whether there are "many" or "few" alternative technological patterns of manpower utilization at given levels of output is a question to be answered empirically. It should not be considered a postulate or assumption upon which the analysis is based without critical examination. Stated differently, it means that the parameters of the production function are unknowns to be determined through planning analysis, not given _a priori_. We believe that the magnitude of those parameters is what is at issue, not whether prices play a role in determining manpower requirements.

In this light, it can be argued that the use of productivity rates in specifying manpower goals is conceptually appropriate because it may be viewed as a poorly specified, surrogate measure of the production function. It is methodologically limited, however, because it is simply a summary measure of the myriad factors affecting manpower utilization patterns, i.e., it accounts for changes in the scale of firms and industries, changes in the amount and quality of other productive inputs, changes in managerial efficiency, and in certain cases, changes in qualitative standards. It also indicates changes in the state of technological knowledge, and shifts in the rate at which such knowledge is incorporated into the productive process. Furthermore, the productivity rate reflects changes in factor supply conditions.

As such, productivity reflects both too much and too little. On the one hand, it would be desirable to have a procedure that is independent of factor supply. On the other hand, it would be desirable to separate the differential impacts of the changes summarized above, because each is likely to assume greater or lesser importance over the course of a given planning period, and because each has rather different policy implications.

One way out of this impasse is to insist that manpower planning be based explicitly on a production function--i.e., the technical relationship between input sets and (maximal) output, and not simply on some surrogate form. As before, this suggestion has important implications for the manner in which the state of the art might be improved. Movement in this direction will not be useful, however, unless there is some agreement on the conceptual framework for planning and an institutional capacity to use such an analytic strategy for planning purposes.

Analysis of Human Resource Supply

The formulation of manpower plans requires the analyses of both goal functions and human resource supply functions. While these elements may be treated separately for analytic convenience, they are of course joined together in order to assess interactions and draw policy inferences. Our discussion of the supply side of a manpower plan, as on the goals side above, is predicated on two general positions. First, the nature and scope of supply estimates in manpower planning practice is limited, or frequently absent, for reasons relating to both technique and the decision environment. Second, our capacity to prepare useful supply estimates is limited by the perception of the supply process and the relevant knowledge base. Each point is discussed in turn.

To begin with, our earlier examination of manpower planning practice in the United States showed that relatively few plans are complete.[8] In particular, estimates of real human resource supplies to given occupational functions, sectors or areas were rarely provided, (or compared to requirements) either under ceteris paribus conditions or as a result of recommended policy changes. This fact led us to infer that policy responses or outcomes fail to achieve balance, and that manpower forecasts have a tendency to escalate requirements for changes in schooling capacity. These inferences raise important questions about the wisdom of policy acts taken in reference to manpower projections as well as something about the perception of the role of such criteria in policy formation.

It is possible, of course, to suppose that the omissions of supply analysis in forecast models reflect little more than technical lacunae, i.e., the absence of data, skilled analysis, etc. That such factors constrain the policy process is unquestionable, but it is not clear that they are always the most important constraints.[9] Indeed, there is ample reason to suppose that the weakness of manpower plans on the supply-side relates as much to the policy environment as it does to technical capacity. In fact, they may be a product of the environment--characterized as it is by both an increasing number of educational institutions and organized occupational groups. Moreover, the decision environment is not only pluralistic, but it is in most cases highly decentralized, involving in the typical case numerous different federal, state, regional, and local agencies and jurisdictions.

In these circumstances, the use of manpower criteria may take two somewhat different forms. On the one hand, individual producers may project manpower requirements in an effort to rationalize (or justify) program expansion. Supply estimates here, if they are made at all, are typically limited to the capacity of the individual producer to satisfy changing needs. On the other hand, and perhaps more common, the decision environment creates a need for policy coordination. A common premise is that the formation of policy criteria in the form of manpower forecasts serves to coordinate the activities of multiple system participants. This premise typically assumes that producers and individual entrants to the labor market can and will interpret the policy criteria, i.e., manpower requirements, in terms of individual adjustments at the margin.

For a variety of reasons, this appears to be a dubious assumption.

The principal difficulty is that the assumption requires agreement on the nature of the policy criteria and sufficient responsiveness of the supply system to goal structures. Responsiveness, in turn, requires disaggregate supply information and a sufficient set of incentives (penalties and rewards) to ensure that the information is both used and useful. Unfortunately, these conditions are rarely met. Our experience suggest that they are not met because they require an institutional mechanism for achieving agreement or consensus, and that few such mechanisms exist.

In the absence of appropriate institutional mechanisms, detailed, disaggregate supply estimates are likely to enhance the probabilities of conflict among suppliers with respect to relative allocations, jurisdictional boundaries, and the like. It appears, moreover, that this possibility explains why disaggregate supply data are rarely available for analytic purposes. The exigencies of the policy environment, in other words, appear to pressure manpower planners to limit projections to the requirements side and assume that producers will respond in appropriate ways, without necessarily evaluating the from or extent of those responses.

While this argument is surely predicated on a set of broad generalizations, we are nonetheless persuaded that it has an important message. For one thing, it implies that even technically sophisticated projections of requirements may produce less than optimal policy responses if there is no institutional mechanism for linking the decision process. For another, it implies that future research must probe both the kinds of institutional arrangements which may fill this gap in the planning art and the nature of the policy response mechanism. This latter point requires further elaboration. Even with appropriate institutional linkages, our capacity to estimate supply conditions is limited by our perception of the policy response mechanism. As before, this stems from the fact that the theoretical structure upon which most estimating techniques are based is limited. In this case, the difficulties stem from the highly individualistic choice mechanisms imbedded in the economic theory of the labor market. As is well known, individual decisions relating to work/leisure and investment in human capital, adjudicated in the context of the market, lead theoretically to a set of desired individual and social outcomes. To be sure, there are theoretical allowances made for Keynesian impacts on the labor market stemming from changes in the aggregate level of demand.

Moreover, the long line of empirical research on labor force participation, viz., on discouraged workers effects, allows for endogeous or induced labor market responses to changes in the level of economic activity. But these are generally assumed to be the exceptions to the rule. The maintained hypothesis is that individual preferences count, preferences are revealed in market valuations, and accordingly, market variables can be used to explain response patterns.

But we must recognize that a set of decision processes which affects human resource supplies differs substantially from the decision mechanism upon which neo-classical theory is based. It is difficult to imagine, for instance, that the characteristics of the university system in this country reflect policy responses to a set of aggregated individual preferences. Nor do decision processes and response patterns behave "as if" they were exclusively a function of such preferences. Rather, they reflect a set of collective decisions, particularly at the institutional level, which frequently may differ from individual judgments.

More important, these collective decisions may affect individual responses through the available choice set, i.e., produce endogenous responses as a function of relative availabilities. Briefly put, the principal implication is that labor market information, including manpower projections, may be interpreted differently by individuals and supply institutions, and/or acted upon in differential fashion. Structural imbalances may occur as a function of these differences in decision outcomes. The imbalances are a supply-side analogue to the Keynesian theory of unemployment stemming from differential decision outcomes (of savers and investors) on the (aggregate) demand-side of the market.

Such imbalances create a set of social costs, the magnitude of which remains to be calculated but doubtless is great. The minimization of these costs is a raision d'etre of the kind of manpower planning activity envisaged here. In order to facilitate that planning it is essential that we understand how both institutions and individuals respond to changes in (or projected changes in) demand conditions. Unfortunately, there is very little in the present knowledge base which permits inferences in this regard.[10] This is an area in which additional research is required.

IV. The Institutional Requisites for Policy Planning

The argument that the policy value of manpower planning cannot be enhanced in the existing institutional framework deserves some positive suggestions for institutional alternatives. The two primary requisites of a policy revelant planning process are the means for linking a diverse set of policy making and operating institutions in a more direct, systemic relationship than is afforded by a market mechanism, and the specification of institutional responsibility for rationlizing and coordinating the behavior of component institutions.

Whether these conditions can be met in the pluralistic and decentralized economic and political system of the United States is problematic. Yet there is no rational basis for the prevailing negative view. Two recent actions in the Congress suggest, on the contrary, a movement toward the requisite conditions. One is the recent establishment of the Congressional Budget Office (CBO) as a legislative counterpart to the Office of Management and Budget (OMB) in its role in policy analysis. The other is a bill sponsored by Senator Hubert Humphrey and others to establish a national economic planning board and a council on economic planning. These institutions could provide a long-term priority framework for the short-term analysis of the CBO, the OMB, the Council of Economic Advisers (CEA), and similar agencies. As the bill states that:[11]

> . . . the United States has no single governmental body engaged in the systematic and comprehensive formulation of national economic goals and policies . . . (The) formulation of long-term national economic goals, the identification of available and potential labor, capital and natural resources, and recommendation for policies to reconcile goals and resources would enable the Federal Government to rationalize its own impact on the national economy. These activities would provide assistance to State and local governments and the private sector by permitting action with greater knowledge of the nation's economic direction.

Although the flow of priority criteria and strategic information from the federal level should act to rationalize policy analysis at state and local levels, local governments can be stimulated to replicate the planning structure of the federal government and to interact with that system rather than react to it. If a stimulus is needed to encourage regional and local planning, it is available in the magnitude of current revenue sharing and other transfer payments. That stimulus is reflected in the conditions imposed by Congress on economic aid to developing countries and the federal stipulation of planning in health and manpower programs at home.[12] The failure of sectoral planning in the domestic case does not reflect a rejection of planning, but the only possible outcome of an institutional arrangement with no systemic characteristics and no source of criteria for specifying dominant, exogenous variables.

Initiatives such as the Humphrey proposal respond to both planning requisites--the stimulus to systemize information flows and decision criteria, and an institutional responsibility to explore alternative ends and means in a long-term perspective. It seems evident that the current necessity to respond to the social costs of economic growth, to the trade-offs between unemployment and price stability, and to the long-term implications of energy and environmental policy have raised the public sensitivity to the limitation of ad hoc decision making and increased the public awareness of the policy value of long-term planning.

NOTES

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2. Kelley, S. C., Chirikos, T.N. and M. Finn. Manpower Forecasting in the United States: An Evaluation of the State of the Art. Ohio State University Press (?), Columbus Ohio, 1975.

3. U.S. Department of Labor, Bureau of Labor Statistics, Tomorrow's Manpower Needs, Vols. I-IV. Government Printing Office, Washington, D. C., 1969.

4. Cf., Lecht, L.A., Frederick Praeger, Manpower Needs of National Goals in the 1970's. New York, 1969. Also, Bezdek, R. Long-Range Forecasting of Manpower Requirements. IEEE, New York, 1974.

5. Cf., Ferber, R. "Consumer Economics, A Survey," Journal of Economic Literature. Vol. II, No. 4 December 1973, pp. 1930-42.

6. See, in particular, Anderson, C. and M. Bowman, "Theoretical Considerations in Educational Planning," in Adams, D. (ed.) Educational Planning. Syracuse University Press, Syracuse, 1964, pp. 4-46; Ahamad, B. and M. Blaug, Jossey-Bass (eds.) The Practice of Manpower Forecasting. San Francisco, California, 1973, especially Chapter I; and Psacharopoulos, G. "Substitution Assumptions Versus Empirical Evidence in Manpower Planning, "The Economist Vol. 121, NR 6 (1973), pp. 609-25.

7. This view has obvious implications, of course, for goals relating to the distribution of income, but a full discussion of the point lies beyond the scope of this paper.

8. Kelley, Chirikos and Finn, op cit., pp. 120-210.

9. Data problems appear to stem from the absence of an institutional base for planning. Our earlier analysis showed, for instance,

that a large number of manpower plans were formulated on an ad hoc basis; they were one-shot affairs carried out under the auspices of special task forces, committees, etc., established expressively for those purposes. Such procedures preclude the development of technical capability and experience, they exacerbate the problem of data limitations, and they rarely establish a mechanism for improving data flows over time. Furthermore, they do little to create a flow of human capital to the decision process itself.

10. Recent research by R.A. Freeman is perhaps an exception to this point. Freeman's failure to include a broad set of institutional decision variables, however, makes his work somewhat less relevant than it might otherwise be. It perhaps also weakens his general conclusion that there is a high degree of responsiveness to changes in labor market conditions for high-level manpower, and that this responsiveness produces a relatively costless adjustment process. See, for example, his "Supply and Salary Adjustments to the Changing Science Manpower Market: Physics, 1948-1973," American Economic Review Vol LXV, N. 1 (March, 1975), pp. 27-39.

11. "Senate Bill 94: 1975" Congressional Record Vol. 121, No. 82 (May 21, 1975)

12. It seems paradoxical that no stimulus to private sector planning appears to be required, as the most extensive, on-going planning effort is in that sector--in particular, in the major national and multi-national corporations that dominate private decision making.

FUTURE DIRECTIONS FOR MANPOWER MODELING IN ENGINEERING AND SCIENCE

John D. Alden

The final panel of the conference addressed the question, "Is A New Approach Needed?" It was chaired by Courtland Perkins, President of the National Academy of Engineering, and included Charles Falk, Neal Rosenthal, Warren Viessman, and the two co-chairman. Each panel member gave a brief presentation of his views on the significance of the conference and points that should be stressed in future modeling activities, after which conferees in the audience were invited to comment. The various views and suggestions are summarized under seven major headings as follows:

Continuity. Manpower models, to be effective, must be supported on a continuing basis so that they can be updated, continuously improved, and related to changing conditions in the real world.

External Influences. There is a need to find better leading indicators of manpower demand, and to recognize that different sectors of the engineering and scientific employment will be affected differently by such influences as capital investment, consumption spending, education subsidies, etc.

The impact of major legislation should be factored into the models.

Salaries represent a link between supply and demand, and should be tied into models, if possible.

On the other hand, economic factors should be considered as only one of the driving forces in manpower modeling. Such relevant socio-economic factors as shorter work weeks, layoffs, and age and demographic distribution are probably equally important in affecting both demand and supply.

Factors Internal to the Manpower Model. Models should take into account factors that affect career mobility of engineering and scientific manpower, i.e., transfers in and out of disciplines, of employment sectors, and of employment levels such as research, management, etc. To this end, behavior patterns of manpower in various occupations should be studied in order to understand when and why people leave fields. We know very little about mobility and skill transfers and how much of an effect these have on manpower supply and demand.

Too many modelers appear to consider only the growth factor in their projections of employment. The truth is engineering job openings are the result of three factors of roughly equal importance:

- Openings caused by growth;
- Openings caused by deaths and retirements; and
- Openings caused by engineers leaving for other occupations.

Each factor calls for further study so that the extent of its influence can be properly assessed by modeling.

Coordination and Integration. Closer integration is needed between modelers and potential users of the output. It would be desirable to establish "Input Review Panels" drawn from the groups being studied to test the assumptions being built into the model before projections are run, and to review the resulting projections for consistency and applicability in the real world before they are published.

More coordination of modeling efforts within the agencies of the federal government is needed. There should also be closer coordination and interaction among engineering manpower modelers as well as models for other occupations. It is a mistake to look at only one employing system, as each is imbedded in a much broader system.

Modeling for engineering manpower should be concerned with related scientific and technical disciplines and other occupations such as health delivery and teaching. Engineers and those in related occupations do not work alone in a closed society.

Methodology. Models should be developed to determine trends rather than attempt to predict the future in absolute terms.

A "tolerance level" should be designated in all manpower models and in all projections in order to convey to users the idea of leeway and uncertainty in making decisions.

There is a tendency to develop very sophisticated models at great cost when useful output could have been arrived at much more simply and less expensively.

The temptation to do too much fine tuning or disaggregation of national models should be resisted, as tools are not now available to reach this degree of refinement. Modeling needs at local and state levels should be analyzed, and methodologies should be developed to permit aggregating these into the national picture.

High priority should be given to developing methodologies for short-range forecasting and measurement of manpower demand.

Input Data. Data are needed to establish reliable factors such as mobility, skill transfer, and the availability of job openings. The relative importance of specific kinds of information must be determined in part through operation and testing of various models.

In many cases it may not be necessary to develop or call for new data. There is a need to examine existing data for new coefficients, trends, and elements. Present and prospective modelers should have an understanding of the magnitude and availability of existing data.

Application of Results. The manpower implications of broad national programs should be analyzed before these programs are implemented. Modeling offers a means for doing this.

Models should be designed with a view toward providing outputs useful to planners at various levels. The needs of individual businesses, industrial enterprises, and education establishments should be considered as well as those of planners at the national, state, and regional levels.

In order for model outputs to be most useful, prospective users should have a greater voice in determining the characteristics and factors incorporated into the models.

Organizations such as the National Science Foundation and the National Academy of Sciences-National Academy of Engineering, to name just a few concerned with indicators of scientific and engineering talent, need to take the lead in analytical and objective assessments for all systems in which such people are employed.