PART I

SCOPE AND METHOD OF PROCESS ANALYSIS

CHAPTER 1

INTRODUCTION

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PROCESS ANALYSIS

The studies in this monograph analyze the production capabilities of industries and of industrial complexes. Models of technology are employed to answer questions concerning the product mixes achievable with various combinations of resources. The models are generaly based upon relationships well known to the industrial engineer or to his agricultural counterpart. The aim has been to cast these relationships into a form usable for the analysis of economy-wide capabilities.

In most cases, the models are of the activity analysis type, with the simplex technique of linear programming being used to compute numerical answers. Simulation techniques and integer programming also play a role (albeit a small one) in the present studies, and they will probably receive increasing emphasis in future work of this sort.

The phrase "process analysis" was chosen to identify studies, such as those presented in this monograph, which approach the analysis of industrial capability through models reflecting the structure of productive processes. Process analysis treats industrial capabilities in terms such as blast furnace capacity, petroleum product specifications, and metal machining operations—in contrast to approaches which treat capabilities in terms such as gross national product or interindustry sales and purchases. Process analysis is closely related to the conventional requirements calculation for critical resources. Unlike such requirements calculations, however, process analysis allows for alternate inputs per unit of output (reflecting alternate processes for making the same product), and uses mathematical programming techniques to determine the extent and circumstances under which one or another process should be employed.

Unfortunately, the phrase "process analysis" has at least two other meanings (one in economics and the other in industrial engineering) distinctly different from the meaning attached to it here. Over the years, we have attempted to find a better label for our studies, but none presented itself which was preferred by a majority of us.[1] An occasional resolution to do without a

[1] The following are some alternate labels which were considered and the reasons they were rejected. *Capabilities analysis* or *feasibility analysis:* process analysis is but one

label broke down as soon as someone reported "Mr. A. is doing a process analysis of industry X."

As a practical matter the existence of two other, distantly related meanings of the phrase "process analysis" should rarely, if ever, cause confusion. Throughout this monograph in particular, "process analysis" always refers to the construction and use of industry-wide, multi-industry and economy-wide models which attempt to predict production relationships on the basis of technological structure.

A Division of Labor

We shall distinguish three areas of activity which are involved in process analysis. First is the model building activity itself. This starts with a study of technology and ends with a numerical mathematical model of an industry or industrial complex. Second is the development of algorithms. The object of this activity is to provide computing procedures to trace through the implications of models quickly and economically. The third area of activity is that of using models to throw light on practical problems of public policy. The prime interest here is not the model per se but the insight it can provide into the problem at hand.

We shall refer to these three areas of activity as model development, algorithm development, and policy application. Each is closely tied to the other two. In model development the size and form of the model is highly dependent on current computing capabilities, and the decisions as to aggregation and emphasis are based upon the needs of the potential policy maker. In the development of particular types of algorithms, the impetus and direction have frequently come from actual models and applications. Finally, to the policy maker, the usefulness of the process analysis approach depends on both cost and timeliness, which in turn depend on the state of the arts with respect both to models and to algorithms.

The construction of a process analysis model for a sector which has never been thus analyzed is time-consuming, and subject to substantial uncertainties. The same holds true for the development of a new type of computing algorithm. By contrast, the application of an existing model and/or algorithm—perhaps with minor modifications—requires relatively little time. The initial development activities represent an investment adding to our stock of multi-

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type of capabilities analysis; GNP analysis, for example, is another. *Activity analysis:* this phrase already has a well defined meaning; activity analysis is to process analysis as calculus is to physics; in both cases the latter uses the former as a technique of analysis to help deduce implications from initial postulates. *Economy-wide industrial engineering:* if industrial engineers cared to describe process analysis in this manner, they could make a strong case for it, particularly as they themselves increasingly make use of techniques such as activity analysis. But since most of the early process analysts were economists rather than industrial engineers, it would have been presumptuous for them to claim this label.

purpose models and computing procedures. When policy problems arise that demand decisions in weeks or months, only the models and algorithms in this available stock may be relied upon safely. Questions of industrial capability not covered by these models must be analyzed by cruder means or left to guesswork. As the stock of available models and algorithms increases, the more likely it becomes that a new problem will be related to an existing model, the cheaper it generally becomes to trace through implications, and the easier it becomes to put together broad-scope models involving industrial complexes or large portions of the economy.

This monograph is centered around the construction and application of models. The case studies deal at length with technological relationships—their measurement, aggregation, and representation—problems central to the building of process analysis models. Little emphasis is placed either upon algorithms or upon the broader issues of public policy. The policy maker may find one or more of the models presented here to be of practical value, but should take care to note the associated discussions as to the range of reasonable applications and the ways in which judgment may be needed to supplement formal analysis. The algorithm developer will find here several large linear and nonlinear programming problems with special (perhaps exploitable) structures.

Building a Process Analysis Model

Building models of industries and industrial complexes is closely related to the building of models of shops or plants for intra-enterprise analysis. Both require an understanding of technological relationships, both face problems of selection and aggregation, and both have a common body of analytical techniques upon which to draw. The differences are mostly a matter of degree. In models of broader scope, one faces a much more acute problem of selection and aggregation, does not have as immediate an access to primary data, and has a much more difficult time constructing meaningful tests of the model's validity. As a result, one should not expect the same degree of accuracy as is achievable with intrafirm studies. The task of constructing industry-wide models is simplified to the extent that detailed intrafirm models are available from which to borrow. With time, such intrafirm models should become increasingly available.

We will distinguish the following stages in the construction of a process analysis model: the study of technology, selection and aggregation, the choice of formal analysis, the collection of data, and the testing of the model. These stages are not isolated in time. While the analyst is studying the technology of the industry, he is mulling over alternatives with respect to selection; when he decides on aggregation he must worry about data as well as computation; at every stage he must return to find new information about technology. Thus the sequence in which these stages are listed reflects only the general order in which certain problem areas tend to command the principal attention of the analyst.

In brief outline, the nature of the stages may be characterized as follows:

THE STUDY OF TECHNOLOGY. An understanding of the principal products, processes, and resources of the industry is sought from its industrial engineering literature and trade journals. Contact with men who have production planning responsibilities provides valuable orientation. If the analyst is himself an engineer with experience in the industry, much of this is already part of his background.

SELECTION AND AGGREGATION. Some aspects of technology, although essential to the design of processes or the scheduling of equipment, can be ignored in making predictions of overall capabilities. Certain distinctions among products, processes, and equipment (although important for fine calculations of profit and loss) need not be made for the degree of accuracy required in a capabilities analysis. By selecting the important, aggregating the less essential, and ignoring certain distinctions altogether, the process analyst attempts to shape a manageable picture of technology.

THE CHOICE OF FORMAL ANALYSIS. The form in which the technological relationships should be cast depends on the nature of the questions to be asked and the availability of computing procedures with which to answer them. One or another type of analysis—such as linear programming, integer programming or simulation—will serve best depending on, among other things, the size of model, and the importance of features such as randomness and economies of scale. Algorithm availability frequently affects the size and nature of the model, not so much by laying down absolute limits as through differences in costs. The model builder should understand the costs involved with currently available algorithms, even if he does not completely master the details of their construction.

THE COLLECTION OF DATA. Frequently, much or all of the required data is to be found in engineering or trade sources, and in census sources. Care should be taken to understand the operational definitions—e.g., methods of measurement and aggregation—before using such numbers. In some cases, sample surveys may be undertaken to supplement the existing data.

TESTING THE MODEL. A common method of testing is to see if the model performs approximately as did the economy for some past period. The problem of validating a model is a difficult one, to which we will return in Chapter 3.

Potential Applications

One area of application which particularly deserves attention is that of investment planning within the newly developing countries. Such planning, aimed at rapid economic growth, is subject to a variety of constraints in the form of bottleneck resources: foreign exchange, low-cost iron ore, skilled urban machinist labor, etc. Problems of substitution and of interindustry ramifications are of central importance in these investment programs. It is toward such problems that process analysis addresses itself.

Process analysis has other areas of potential use. For example, the early support of this work was motivated by the possibility of applications to military economics. At least before the advent of thermonuclear weapons, important aspects of military planning included the industrial ramifications of strategic bombing. Economic mobilization for nonnuclear warfare would still raise problems of industrial capability and program timing, as does any action which rapidly alters the composition of national output.

In general, a "potential application" of process analysis may be said to exist whenever part of a practical problem (albeit not the whole of the problem) concerns either the feasibility or the cost of achieving desired outputs in the presence of limitations on resources. Whether or not any particular potential application should be pursued as an actual application depends in part on the state of the art with respect to models and algorithms.

A Preview

Parts II through IV of this monograph deal with individual sectors. Part II is concerned with petroleum and chemicals; Part III with agriculture; and Part IV with metals and metalworking.

Part V considers applications of process analysis to investment planning for newly developing countries. The Appendix (at the end of the book) discusses activity analysis and linear programming at an introductory level.

Although the studies in this monograph are interdependent with respect to objectives, approach, and areas covered, almost any part or chapter can be read before or after any other. There are a few exceptions: The four metalworking chapters form a whole, and the two petroleum chapters are best read in the sequence presented. If the reader is not already familiar with activity analysis and linear programming, he should first look at some introductory source such as the ones cited in the Appendix. Otherwise he can pursue the case studies and methodological discussions in whatever sequence his interests dictate.