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DEVELOPMENT OF ANALYTICAL SYSTEMS FOR EVALUATION OF US RECONSTITUTION AND RECOVERY PROGRAMS

LEVEL II

Final Report

September 1980

Technical Note
CEPR-TN-7932-1

By: Gary Fromm
Charles H. Movit

Prepared for:

Federal Emergency Management Agency
1725 Eye Street, N.W.
Washington, D.C. 20472

Contract DCPA01-78-C-0309
Work Unit 4341D

SRI Project 7932

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1611 North Kent Street
Arlington, Virginia 22209

CENTER FOR ECONOMIC POLICY RESEARCH

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DEVELOPMENT OF ANALYTICAL SYSTEMS FOR EVALUATION OF US RECONSTITUTION AND RECOVERY PROGRAMS

SUMMARY

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This study identifies economic models and techniques appropriate for use in analysing key issues in preparedness and recovery programs. The potential of each of a component of analytical systems for alternative US postattack reconstruction and recovery environments is evaluated. The research proceeds from a conceptual framework for analysis of the performance of the socio-economic system in order to define analytical objectives. Analytical issues are related to appropriate techniques. Finally, recommendations are made for a research strategy to develop analytical systems for the assessment of preparedness and recovery programs.

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SUMMARY

I. Purpose, Scope and Organization of the Report

This research was undertaken to identify models and techniques applicable to key issues in preparedness and recovery and evaluate the potential for molding sets of these tools into analytical systems for the assessment of alternative US preparedness and recovery programs.

The approach entails a parallel effort. First, a conceptual framework for the assessment of the performance of the socio-economic system as it passes from peacetime through the recovery process is developed. This framework will provide a basis for a consistent and comprehensive identification of key analytical issues and their relation to required tools and techniques. Second, program areas already identified as the concern of preparedness and recovery planning are categorized according to immediate objectives and a statement of relevant analytical concerns is derived. The issues identified in the second approach are envisioned as a subset of the concerns incorporated in the conceptual framework.

A survey of available tools and techniques is then considered. The applicability of each tool to particular analytical objectives with respect to recovery analysis is assessed as well as the conceptual limitations associated with the tools. From the conceptual framework, a set of analytical issues is derived, and based on appropriate analytical objectives, each is associated with applicable tools. Three illustrative analytical systems are outlined, each associated with a particular set of assumptions about the recovery environment.

From the foregoing results, the elements of a research strategy for development of analytical systems are identified. Upon this basis recommendations are made on the initiation of a research program.

II. The Conceptual Framework

A conceptual framework for the assessment of the performance of the socio-economic system is required because the evaluation of a program or policy must be accomplished in terms of society's preference for various outcomes. The elements in elaborating the framework are:

- the identification of goals;
- determination of the sources of welfare;
- describing the production of welfare; and
- tackling the measurement problem.

In identifying national goals, individual characteristics of an outcome can be translated into a level of satisfaction for the society as a whole. The characteristics, in turn, relate to levels of activities which are the sources of welfare. These activities may be exclusive, that is, private goods, the consumption of which by one individual reduces the availability to others, or non-exclusive, or public goods. Primary sources of welfare that stem from non-exclusive activities include:

- external security
- demographic change and public health
- operation of the political-economic system
- other governmental services.

Sets of exclusive activities would include:

- private health
- domestic security
- consumption and leisure
- accumulation of wealth

The production of welfare can be characterized as commercial and non-commercial activity. The criterion is the feasibility of charging a price, which is directly related to the principle of exclusion. Commercial activities are carried on by both the private and public sectors, while non-commercial activities include public sector services and the private use of leisure time.

The measurement problem relates both to the identification of trade-offs between activities in terms of social welfare and to the selection of indicators for levels of activities. In order to evaluate outcomes it is necessary to determine quantitative indicators for each of the activities that serve as sources of welfare. In the case of many activities, particularly in the non-exclusive category, this may be quite unorthodox--for national security, for example. Furthermore, the quantitative indicators are certain to ignore important qualitative differences between otherwise similar achievements in an activity. The task, however, is unavoidable.

III. Key Issues in Preparedness and Recovery

A second and parallel approach to the identification of key issues was pursued which served to link the more abstract categories of the conceptual framework to the concrete operational concerns of preparedness and recovery planning. Each program area can be related to the specific analytical objectives with which a relevant assessment of the postattack system would be conducted. That is, parameters in the design of preparedness and recovery programs would be determined by addressing the characteristics of one or more of the following functions in the postattack system:

- goal formulation;
- production possibilities--given resources and the set of available technologies, determination of the set of feasible output combinations;
- control mechanisms--elements in the system which can be manipulated to drive it toward a particular desired state; and,
- the setting of instruments--determination of the appropriate values for control instruments in order to achieve (or approach) the desired system state.

Potential preparedness and recovery programs can be organized according to their immediate objectives. It should be noted, however, that despite these nominal objectives, these program elements share common objectives which relate to the broader set of concerns set out in the conceptual framework, that is, with respect to the performance of the socio-economic system as a whole. A useful classification of preparedness and recovery by nominal objective is provided in the National Plan for Emergency Preparedness.[1/] The program elements in each of the three categories, mitigation of attack effects, economic survival and recovery, and institutional survival and recovery, can be examined for the relationship of key issues in the design of the program to analytical objectives in assessment of the postattack system. A summary of these relationsips appears in the table immediately following. These analytical objectives, in turn, can be used to relate key program issues to analytical tools in the design of analytical systems.

It is also obvious that both the requirements for programs and the picture of system functioning which is employed will depend to a large extent on the particular recovery environment. Three alternative environments were chosen, for which illustrative analytical systems were to be designed:

- The light damage environment--brief survival/reorganization phase, limited disruption of peacetime relationships; in absence of immediate external threat, goals would be longer term and balanced; direct controls would be restricted to the immediate post-emergency phase and primary attention devoted to programs in the economic survival and recovery category.

- The moderate damage environment--an intermediate case, in which extraordinary measures would be required to insure economic and institutional recovery for a considerable period after the onset of emergency; fixed claims on resources (national security, public health care, etc.) may severely limit achievement of other objectives in the short-to-mid-term.

- The heavy damage environment--reestablishment of production units in affected areas may well come only after an extensive reconstruction effort; recovery depends on the expansion of capacity to exceed consumption levels before inventories are depleted; direct controls will predominate for some time and new institutional structure may have little resemblence to peacetime patterns with the public sector assuming roles traditionally reserved for the private sector.

1/ Office of Emergency Planning, The National Plan for Emergency Preparedness, USGPO, Washington, December 1964, pp. 8-9.

Table 2

Policy Issues and Analytical Objectives

Program Elements \ Analytical Objective	Goal Formation	Production Possibilities	Control Mechanisms	Settings of Instruments
● **Mitigation of Vulnerability**				
- **Reduction of Vulnerability**	Relation of goals to priorities for protecting industries	Impact of increased capital surviving by sector on production possibilities	Impact of vulnerability reduction on control mechanisms available.	Implication of increased survivability on settings of instruments and responses.
- **Provision of essential community services**	Definition of other fixed claims on resources	Availability of resources to provide these services	Appropriate allocational mechanisms	Implicatio of allocational policies for system performance
● **Economic Survival and Recovery**				
- **Provision of essential resources**	Establishment of targets and priorities for essential end-use categories	Resource requirements to meet and use targets; Identification of effective resource constraints	Direct and indirect controls on resource allocation	System response to direct; indirect control
- **Management of resources**	Definition and prioritization of national requirements	Feasible production sets with alternative resource allocation	Direct and indirect controls on allocation of inputs; consumption and investment, etc.	Impact of controls on levels and composition of end-use
- **Economic Stabilization**	In addition to goals for system performance as above, establish operational definition of "stability"	Impacts of alternative policies on productivity, input mix, resource constraints, growth of capacity over time	Determination of instruments to effectively stabilize prices, wages, financial markets, etc.	Optimal settings to maintain stability given other objectives

Table 2 (Cont'd)

Program Elements / Analytical Objective	Goal Formation	Production Possibilities	Control Mechanisms	Settings Of Instruments
• **Institutional Survival and Recovery**				
- **Maintenance of Civil Order**	Establish relationship of civil order to accomplishment of objectives	Resource requirements constraints, trade-offs with other activities	Impact of "civil order" on ability to exercise control mechanisms	Settings which reinforce incentives for "civil order"
- **Continuity of Government**	Prioritization of spectrum of government services	Resource requirements, constraints trade-off with other activities; effect of government operations on production possibilities	Feasibility of control mechanisms given various levels and spectra of governmental operations	Impact of information availability, etc. on settings
- **Protection of Rights**	Priority of civil liberties relative to accomplishment of other objectives	Resources requirements, constraints, trade-offs, impact on labor productivity, accumulation of wealth, etc.	Trade-offs between control mechanisms and protection of rights	Impact of civil liberties on ability to pursue particular instrument settings

The themes of appropriateness to analytical objectives and alternative environments are pursued in the examination of individual tools and techniques.

IV. Inventory of Tools and Techniques

Given the complexity and diversity of analytical problems and the vast range of possible system responses, no single tool or technique can be used to answer satisfactorily the many issues in preparedness and recovery that are to be resolved. Included in these questions are issues of what resources are to be devoted to what purposes, in what time frame, at which locations, how the resource allocation is to be effected, how the system is to be monitored and controlled, and so forth. Some well known tools (primarily techniques from the discipline of economics) were considered as to their standard application, possible application in preparedness and recovery analysis, and their conceptual limitations in application. The techniques covered here involve extensive use of formal mathematical expressions enabling analysis to be conducted in rigorous and reproduceable fashion. Other analytical approaches, with greater emphasis on subjective assessment from disciplines such as psychology and sociology are also certain to prove useful for recovery analysis, but are not treated here.

The two tables following indicate some summary indications of the inventory of tools and techniques. The first presents a tabulation of the applicability of individual techniques in examining the four basic system functions. The second table provides very brief assessments of the character, capability and limitations of each of the individual techniques.

V. Requirements for Analytical Systems

The elements involved in the choice of an analytical technique for application to a particular issue include:

- identification of analytical objectives, i.e., the relevant system functions and the process in which they are interrelated;
- the environment in which the system operates

TABLE 3:

TOOLS, TECHNIQUES AND THEIR APPLICATION

(Partial list of use and limitation of tools and techniques being addressed under Project)

	Goals and Prototypes	Production Possibilities	Control Mechanism and Instruments	Setting of Instruments
OPTIMAL CONTROL	✓	✓	✓	✓
SIMULATION	✓	✓	✓	✓
PROGRAMMING		✓		✓
SYSTEMS DYNAMICS	✓	✓	✓	✓
DECISION THEORY		✓	✓	✓
ECONOMETRICS		✓	✓	
INFORMATION THEORY	✓		✓	✓
INPUT-OUTPUT		✓		✓
GAME THEORY	✓		✓	✓

TABLE 4:

TOOLS AND TECHNIQUES--USES AND LIMITATIONS

TECHNIQUE NAME	TYPE	USE AND METHOD	LIMITATIONS
Optimal Control	Normative	Obtain control instrument settings given objective function and constraints	Computationally laborious, expensive Generally limited to small systems and few instruments
Simulation	Normative	Obtain response surface to exogenous change	Costly when performed with large nonlinear systems due to requirement for many iterations
Programming	Normative	Maximization of returns from allocation of inputs	Corner solutions. Costly and time consuming where feasibility space is large and complex
System Dynamics	Positivistic	Ascertain system response paths given initial state	Arbitrary selection of parameters; lack of maximizing rationale for behavioral limits. Validation often lackening
Decision Theory	Normative	Ascertain optimum behavior given uncertainty of outcomes	Generally limited to small sets of conditional possibilities; probability distributions must be known or assumed
Econometrics	Positivistic	Obtain descriptions of system structure and behavior via set of estimated equations	Needs for significant sample of consistent historical information to obtain system parameters
Information Theory	Normative	Obtain optimum network organization and information flow	Generally limited to small scale systems; highly complex in many applications
Input-output	Positivistic	Given outputs or inputs, obtain other quantities	Homogeneous of degree zero in system structure; often, coefficients are fixed
Game Theory	Normative	Obtain optimum strategy given uncertain responses of opponents, allies, and neutrals	Maximization and consistency assumptions Costly when feasibility space is large and game complex

- the degree of certainty with which one can describe system functions,
- the information that will be available to decisionmakers,
- the anticipated locus of decisionmaking, and
- other environmental implications for system characteristics; and

- the spectrum of available techniques
  - information requirements,
  - computational requirements,
  - conceptual limitations, and
  - compatability with other techniques for application in hybrid analytical systems.

In light of these considerations, the conceptual framework was further elaborated to associate key analytical issues with each activity and, in turn, a set of suggested techniques compiled for each issue.

Having gained required insights from all of these foregoing considerations, three illustrative analytical systems were designed to correspond to the alternative postulated environments. In this effort, it was clear that the specific choices for the components of an analytical system depend heavily on assumptions about the recovery environment. This is an important implication for arriving at a research strategy. For the light damage environment, the analytical system includes techniques appropriate to system relationships which are readily inferred from peacetime experience in terms of production possibilities, the spectrum of control mechanisms, and system responses to the settings of instruments. As the degree of disruption increases in the description of an environment, the appropriate tools incorporate the possibility of specifying relationships which depart considerably from those of peacetime. These may draw on microeconomic behavior whether observed in peacetime or postulated from a descriptive or prescriptive analysis of decisionmaking under uncertainty. The specification of direct control mechanisms (rationing, etc.) is also appropriate to the heavier damage environments, and has implications for analytical tools appropriate to address the settings of instruments.

The analysis of the goal formulation process requires an innovative approach for each of the environments considered. If the degree of disruption in the environment considered is great, the structuring of the problem for the application of any of the possible approaches provides a considerable challenge.

IV. Research Priorities and Design Considerations

A primary concern in structuring the development of analytical systems for the evaluation of alternative preparedness and recovery programs is ensuring that analytical results and plans to cope with particular problems are consistent with overall welfare maximization and are feasible given total resource availabilities and structural and behavioral interrelations between components of the system. It is necessary, therefore, to conduct analyses within a total system framework, recognizing these interrelations and feedbacks to the extent practicable. The conceptual framework presented here provides for a comprehensive consideration of national objectives, trade-offs between those goals, identification of production possibilities and segmentation of analytical issues.

Because of the very significant cost involved in the development of highly specific analytical systems, a step-by-step approach to establishing requirements is justified. The major steps of the recommended strategy are:

- the establishment of national objectives and their relative importance in recovery environments;
- the segmentation of objectives in relation to discrete activities; ascertaining characteristics and indicators for activities;
- identification of principal analytical problems, leading to a detailed research agenda for subsequent analysis and implementation;
- establishment of priorities for analytical tasks based on
  - probabilistic assessment of potential recovery environments
  - tentative estimates of the value of possible advance preparedness and recovery programs based on likely scenarios
  - the estimated costs and benefits of developing appropriate analytical systems.

Reasonable a priori expectations can be formed that candidate analytical systems thus determined would involve sets of tools as illustrated here, including econometric system dynamics, game-theoretic and other models. Without undertaking the necessary work on detailed requirements, however, it is clearly premature to launch research and analysis of a highly specific nature with particular forms of tools.

DEVELOPMENT OF ANALYTICAL SYSTEMS FOR EVALUATION OF US RECONSTITUTION AND RECOVERY PROGRAMS

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ABSTRACT

This report identifies economic models and techniques appropriate for use in analyzing key issues in preparedness and economic recovery programs and evaluates the potential of each for use within analytical systems required for the assessment of alternative U.S. postwar reconstruction and recovery environments. Following the introduction in Section I, the conceptual framework is outlined in Section II, while key issues in preparedness and recovery are detailed in Section III. Section IV provides an inventory of available tools and techniques for the assessment of the characteristics and performance of economic systems. Section V associates these tools and techniques to analytical issues to which they are related under alternative recovery environments. The report concludes with recommendations for future research on the development of analytical systems for the assessment of recovery and preparedness programs in Section VI.

DISCLAIMER

CONTRACTUAL NOTE

Technical Note CEPR-TN-7932-1 and its summary were prepared in fulfillment of Task 1 under Contract DCPA01-78-C-0309.

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TABLES

FIGURES

I. INTRODUCTION

A. Purpose

Possibilities of nuclear exchange or holocaust have again become thinkable. Certainly the consequences of such events deserve thought. It is not that the eventuality of nuclear catastrophe is certain, a hope universally shared. But, if it should occur despite best preventive efforts and extremely low odds, resulting losses are so great and recovery tasks so monumental that it is wise to be well prepared for the contingency. An ancillary benefit of having such plans and preparations is that they can be used in anticipation and aftermath of natural disasters--earthquakes, hurricanes, and so forth.

Needs for a program to increase the state of U.S. preparedness are heightened by substantial neglect for more than a decade of such contingency plans. While emergency plans and procedures existed in good measure in the early 1960s, they were allowed to atrophy by a succession of administrations under the doctrine of nuclear war deterrence via mutually assured destruction. Yet, even if that concept were valid, which is disputable, that would not diminish the value of adequate preparations should deterrence have failed. Dismantling the emergency preparedness apparatus was extremely ill advised.

Because of population and industrial growth, the greater sophistication and accuracy of weapons, the larger destructiveness and numbers of nuclear warheads, planning tasks are more complex and difficult than those faced by planners in the post '40s era. Also, because of those same factors and that the 1980s will be years marked by slow economic growth and greater international political and economic tensions, near-term needs for a preparedness system have risen even more.

The research reported herein was undertaken in order to identify models and techniques applicable to key issues in preparedness and economic recovery, and to evaluate the potential for molding these tools into analytical systems required for assessment of alternative U.S. postwar reconstruction and recovery environments. The approach is intended to provide a consistent and comprehensive set of analytical issues related to the functioning of the socio-economic system, from which the particular concerns of a recovery environment can be identified. Through a consideration of the capabilities and limitations of individual techniques in application to the recovery environment, techniques and issues can be correlated to devise a framework for the development of appropriate analytical systems.

The approach proceeds from insights provided in past and ongoing research into recovery phenomena, but viewed in a conceptual framework which organizes economic processes according to the requirements for the functioning of the socio-economic system. This analysis then provides a continuum through the phases of economic recovery around which analytical systems can be designed when combined with special requirements postulated for specific recovery environments. Based on relations between key issues and analytical tools, the ultimate objective is the derivation of research priorities and design considerations for the development of much-needed analytical systems in the near-to-mid-term future.

A second research task undertaken for the Federal Emergency Management Agency under this contract is reported on in a separate technical note. [1/] Whereas this first task proceeds from an analytical framework for examining the performance of a socio-economic system at a level which abstracts from the set of institutional and behavioral characteristics particular to a given system at a point in time, the approach to the comparative analysis outlined in the second study, while also concerned with the accomplishment of societal objectives, is somewhat different. The approach to comparative U.S.-U.S.S.R. analysis draws on the set of concepts identified in the recent literature on comparative economic systems to derive implications for U.S. and U.S.S.R.

[1/] Herbert S. Levine and M. Mark Earle, Jr., An Approach to the Comparative Analysis of the U.S. and Soviet Economies, SRI International Technical Note CEPR-TN-7932-2, August 1980.

recovery potential based on the functional decision-making structures in the two economies. These implications would certainly be brought to bear in establishing priorities for the application of analytical systems to U.S. recovery and preparedness issues discussed here.

B. Scope

It is inherent in the purpose of the research undertaken that considerations of analytical concerns in the design of preparedenss and recovery programs be as comprehensive as possible. The consideration of program elements, however, is pursued only to the extent that key questions about their relationship to the performance of the socio-economic system can be derived. It is demonstrated below that the parameters of preparedness and recovery programs are dictated, not only by available resources and strategic and engineering questions, but also by common objectives with regard to economic performance and the anticipated state of the socio-economic system. It is therefore appropriate that primary attention was devoted to the functioning of that system under conditions of survival/reconstruction and recovery and the analytical objectives common to preparedness and recovery programs thus derived. It is clear that in meeting these analytical objectives through the implementation of research on appropriate analytical systems, important implications will be forthcoming for the design of recovery and preparedness programs consistent with anticipated requirements on the economic system, given overall national objectives and the spectrum of initial conditions. Thus, while the specific approach of existing or developing programs to accomplishing national preparedness objectives is not of immediate concern here, the embodied perception of their objectives, the aspects of the functioning of the system with which they are expressly concerned, and their analytical requirements in terms of that system were important. They served in establishing analytical objectives in parallel with the development of the conceptual framework and in the examination of the responsiveness of potential analytical systems to the needs of program planners.

While the specifics of preparedness and recovery program elements are not considered here to be key variables in the design of analytical systems, the alternative recovery environments for which they are to be designed are, of course, significant. The locus and nature of goal-setting, the continuity of peacetime economic processes, the interaction of technological, behavioral, and institutional relationships in the functioning of the system, and the set of feasible and desirable controls on the functioning of the economy can be expected to vary widely with the degree of damage sustained by the nation. The time horizon and the nature of the transition of the economy from a survival/reorganization to a recovery mode would reflect the extent of damage, possibly mitigated by effective preparedness and recovery programs. Therefore, the analysis seeks to encompass the approach to the phenomena of the survival/reorganization and recovery phases of the system under three alternative sets of initial conditions: light damage; light-to-moderate damage; and very heavy damage to population and economic assets.

C. Organization of the Report

The next section of this report sets forth the conceptual framework for the design of required analytical systems. The framework presents a systematic approach to identifying the elements of the socio-economic system. A comprehensive and consistent means is thus provided to delineate analytical issues which transcend the phases of the recovery process and the nature of the damage sustained. The development of the framework proceeds from a consideration of the nature of objectives, the spectrum of sources and production of welfare in the socio-economic system, and the problem of measuring the performance of the system in order to evaluate alternative outcomes.

Section III examines key issues in preparedness and recovery. This is an effort in parallel with the conceptual framework to identify requirements in the evaluation of alternative preparedness and recovery programs, based on an examination of the concepts and program approaches heretofore identified by research on recovery phenomena and incorporated into the development of current policy initiatives. The utility of the conceptual framework in organizing the implications of these past and ongoing efforts for the formulation of analytical objectives is demonstrated.

An inventory of available tools and techniques for the assessment of the characteristics and performance of economic systems is provided in Section IV. In each case, a description of the technique, its standard applications, suggested application in recovery analysis, and its conceptual limitations are discussed. In Section V these techniques are related to the analytical issues to which they are applicable under alternative recovery environments. Based on the foregoing analysis, recommendations for future research on the development of analytical systems for the assessment of recovery and preparedness programs are provided in Section VI. These recommendations include a suggested set of priorities for research tasks and major design considerations for the analytical systems to be developed.

II. The Conceptual Framework

A. Need for an Overall Framework

Any program undertaken to increase the state of preparedness of the U.S. to survive and recover from a nuclear attack must have as its ultimate purpose to enhance the capabilities of the nation to achieve its objectives in the postattack period. While this ultimate purpose is a task with which a Soviet economic planner may, of necessity, be acquainted, it is not one with which Western policy planners or empirical economists have coped, even relevant to the much narrower band of uncertainty associated with the peacetime economy. In regard to a postattack system, the scope of activities of concern to policy planners far exceeds that which they have addressed heretofore in a mixed economy either in peacetime or in any emergency situation without the guidelines provided by the normal operation of the political process. The analyst is confronted by a complex, rather loosely defined set of issues. These are further complicated by the broad uncertainty as to the performance of the system, both in regard to the initial conditions for recovery and the response of economic and political elements of the system to the unique characteristics of the postattack environment.

In order, then, to identify a comprehensive and consistent set of analytical issues which must be addressed by the set of tools to be developed, it is necessary to find a framework with which to organize the investigation. The framework provides the spectrum of the activities which are the sources of welfare and against which achievement of national objectives and the performance of the socio-economic system can be measured. Analytical issues can then be derived in regard to:

- The resolution of national objectives into goals for individual activities;
- Production possibilities for sources of welfare, and production trade-offs among sources of welfare over time;

- The mechanisms and instruments by means of which levels and directions of activities can be controlled; and
- Given objectives, production possibilities, and the set of control mechanisms available to policy makers, the settings of instruments which will produce appropriate responses by the system.

B. Identification of Goals

In order to evaluate alternative policies and programs, the projected impact of their implementation on the performance of the system must be compared. The standard of comparison, in turn, must relate to the measure of achievement of national objectives. Yet national objectives may be resolved along a large number of separate dimensions. To compare outcomes, achievements along these separate dimensions must be measured and combined into a composite indicator. Even if production possibilities are known (that is, along a particular dimension, given resources, the maximum achievement is known), unless some means of evaluation of the combination of achievements available from alternative allocations of resources exists, no guidance can be provided as to which point along the frontier of production possibilities is to be preferred.

Therefore, three required aspects of an analytical framework for the functioning of the socio-economic system, whether in peacetime or in a recovery environment, are apparent:

- A national objective function which translates individual characteristics of an outcome (i.e., achievements along each of the multiple dimensions) into a level of satisfaction for the society as a whole; time preferences and preferred locational patterns should also be reflected;
- A set of dimensions along which achievements are to be measured and which are the arguments of the objective function; and
- Appropriate indicators for achievements along the dimensions.

The association of a quantitative measure of achievement with certain of the dimensions, for example, national security, may be unorthodox and will certainly ignore some qualitative differences between particular achievements. A proxy measure must nevertheless be chosen to provide for comprehensiveness in the evaluation of outcomes.

The traditional approach of Western welfare economics describes the national objective as the maximization of a social utility function which is a function of the utility associated by individuals with particular outcomes, but not the summation of individual utilities. It is often assumed that, with an appropriate distribution of income, when the social welfare function indicates indifference between two sets of achievements, every individual is also indifferent between those two sets. Alternatively, it can be assumed here that the distributional pattern of goods and services provided in the economy will be a variable in the welfare function, i.e. a member of the set of characteristics to be addressed.

It remains to set forth the arguments of the social utility function. Those are the sources of welfare with which objectives are associated.

C. Sources of Welfare

The sources of the welfare of the nation are diverse activities. These activities fall into two separate classes in regard to the nature of their utilization by individuals. Thus, a distinction can be made between

- Non-exclusive activities--often termed public or social goods in the literature. Consumption of goods or services related to this class of activities by one individual does not diminish the availability or the potential utility of the good or service to another individual. Standard examples include national security, and the maintenance of law and order or a healthy environment.
- Exclusive activities--non-public or private goods. For this class of activities, consumption by one individual reduces the potential availability of the good or service to others, for example the consumption of food.[1]

Determining socially optimal levels for the production of non-exclusive activities poses a problem even in the normal market economy. If it is not possible to exclude an individual from consuming, he may not reveal his true preference for the activity. Thus, this class of activity is usually undertaken by the public sector and the mandate for provision of a given level of

[1]These definitions are actually concerned with the concepts of the pure public good and pure private good. In practice, there are goods and services which fall somewhere in the middle. The process of urban renewal, for instance, can be undertaken for esthetic improvement for the community at large, yet specific benefits pertain to those who live in the upgraded housing, etc.

these activities derived from the political process as well as acquiescence in sharing the tax burden.

Primary sources of welfare that arise from non-exclusive activities include:

- external security
- demographic change and public health
- operation of the political-economic system
- other governmental services

Sets of exclusive activities would include:

- private health
- domestic security
- consumption and leisure
- accumulation of wealth

In the elaborated conceptual framework, these sets will be further disaggregated, in order that potential indicators and key analytical issues can be identified.

D. Production of Welfare

Activities involved in the production of welfare may be carried on by both the private and public sectors. Traditionally in the U.S. economy, the public sector engages in production only in the cases for which it is not feasible to charge the consumer a price (as for national security) or where there exists a "natural monopoly," such as the postal system. In addition, if the decisions of individuals based on their assessment of private costs and benefits would result in underconsumption from a social point of view, the public sector may intervene, such as in education or social security.

Activities involved in the production of welfare, then, also fall into two classes, again differentiated on the principle of exclusivity:

- Commercial activities--goods or services which can be sold. These may be carried on either by the private or the public sector

- Non-commercial activities--those activities for which it is infeasible to charge the individual beneficiary a price.

This latter set of activities may also include private uses of leisure time, such as the participation of individuals in the political process, participation in non-political social organizations, and some forms of recreation.

Production decisions in the private sector are based upon some optimizing behavior in response to prices of inputs and demand for output. Public sector activities may operate on the same basis, at a loss subsidized by other revenues, or at some set rate of profit in the case of commercial activities. Production decisions for public sector non-commercial activities are governed by the political process. It should be noted that the distinction drawn here relates directly to the principle of exclusion used above. In order to charge a price for an activity, it must also be feasible to exclude an individual from the benefits.

E. The General Measurement Problem

An increase in the well-being of a nation is usually measured, with appropriate caveats, by an increase in the gross national product--a measure of the amount of final goods and services produced. This measure is obtained by two alternate methods: the total value of output less the deliveries to intermediate uses (value added totalled over sectors of origin) and the sum of end uses (consumption plus investment plus government expenditures plus net exports). In this accounting, goods and services which are sold are valued at their selling price, while non-saleable services which are provided by the public sector are valued at the cost of their inputs. Thus, any two sets of public sector services provided at the same cost are valued alike, under the assumption that given alternative feasible production sets, the public sector has chosen optimally, producing each service at the level at which costs are equated to benefits.

Many sorts of activities are not reflected at all in the national income accounts, although they may indeed impact on the level of social welfare. Sevices provided in the household which are not sold, even if such services are also available on a commercial basis, are not recorded in GNP. Pollution of the environment in the course of production is not negatively reflected in GNP. Illegal activities are excluded. Distributional considerations are also absent. While several more or less concrete proposals for a broadly defined indicator for the level of social welfare are available, the spectrum of activities which are contemplated here would not be adequately treated by these proposed aggregate measures, particularly the many non-economic considerations.

Thus, what is required for the evaluation of outcomes is the postulation of an explicit social welfare function. The arguments of the function would be indicators associated with each of the activities identified as sources of welfare (obviously at a more disaggregated level than given above, in light of the diverse nature of appropriate indicators), i.e., $W=\Gamma(x_1, x_2, \ldots, x_n)$. Assume now that the social welfare function is separable, i.e.,

$$W = f_1(x_1) + f_2(x_2) + \ldots + f_n(x_n)$$

where the x_1 to x_n are the indicators for activities, and further that $f_i(x_i) = a_i x_i$. Since utility is an ordinal concept only, we can define $W' = \frac{1}{a_i} W$ as the new social utility measure, where x_i will be the numeraire,[1/] so that

$$W' = \frac{a_1}{a_i} x_1 + \frac{a_2}{a_i} x_2 + \ldots + \frac{a_n}{a_i} x_n + x_i \quad .$$

[1]It is not necessary to make such assumptions about the appropriate form of the social welfare function, but these reasonable assumptions are made for clarity in the exposition.

It is now necessary to choose appropriate activities and indicators and then relate social utility of an outcome to a single value. The relative unit values are in fact social priorities. They have to be chosen on the basis of historical experience and modified to account for anticipated changes in priorities in a recovery environment.

Given a scheme for evaluation of the desirability of a set of achievements, it is also necessary to define the feasible set of achievements with a fixed amount of available resources, the production possibilities of the nation. Relevant data on relationships of resources to production are available from the peacetime economy and statistical tools can be applied to estimate the parameters of these relationships once their form has been appropriately specified. When this has been accomplished, trade-offs between achievements along alternative dimensions can be obtained. The relevance of peacetime relationships (production technology), however, in a postattack environment is not obvious. It is clear that any research strategy aimed at providing tools to evaluate policies for preparedness and recovery would include this last consideration as a critical element--the implication of classes of recovery environments for production relationships, as well as the impact of the attack on initial resources available.

F. Measurement of the State of the System

It is clear that policymakers require an information system for the assessment of the state of the system and production possibilities in order to evaluate national performance, formulate goals, and design policies. The system must collect information on the whole spectrum of activities outlined here, in terms of the indicators defined, and both commercial and non-commercial production of welfare. While this requirement is much broader than that met by existing national income accounting, much of the data are currently collected in some form.

In regard to the commercial production of welfare, in addition to national income and product accounts, output indices, financial accounts, and employment in persons and manhours are reported, although some categories of information are regarded as proprietary and access is restricted. For non-commerical activities, public sector accounts are generally published for the electorate and for budgetary procedures by legislative bodies.

In the case of exclusive activities, detailed statistics on consumption and wealth are compiled. Data on individual time budgets indicating extent and uses of leisure time are also available. For non-exclusive activities, many sorts of indicators are published ranging from the availability of cultural and health facilities to crime incidence and environmental quality. Indicators of the distribution of welfare are prepared by population groupings and region. An illustrative but by no means exhaustive listing of the variety of current reporting can be obtained from a single annual volume--the Statistical Abstract of the United States.

In the following section a more disaggregated representation of the sources of welfare is provided. There is also presented an attempt to associate with each activity an indicator or indicators of the achievement level of the activity. While the diversity of such indicators is apparent from that exercise, a manageable system of information collection designed around that framework is certainly conceivable.

G. A Framework for Assessment of System Performance

The final task in this section is to elaborate the set of sources of welfare given above. This can serve both as a basis for designing a process to assess system performance and hence evaluate alternative outcomes, and as a means in later discussion to organize a consistent and comprehensive consideration of analytical issues which the various tools and techniques must address.

Table 1 which follows presents the spectrum of activities which are sources of welfare. They are further subdivided into more specific subelements, particularly the non-exclusive activities, which may subsume quite diverse undertakings. To each of these, characteristics are associated which in turn suggest quantitative indicators of achievement. While the catalogue of activities may not be found exhaustive by some readers, it is meant to represent the major elements for further consideration.

Table 1
SOURCES OF WELFARE

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Non-exclusive	• **External Security** - **Territorial control**	Area	km^2 land; water; km. coastline
		Political Integrity	km^2 disputed; km^2 contiguous, by class-allied, neutral, adversary
		Productive	km^2 arable, cultivated, pasture, forested, etc.
		Natural resources	estimated physical reserves, by type
		Regional development concentrations	km^2; % urban, industrial
	- **National defense forces**	Personnel	number, by service type, combat, support
		Major facilities and armament	number, by type
		Budget	total dollars, by component, relative to GNP
	- **Foreign political/military relations**	Alliances and memberships	number, by type
		Defense forces and discretionary GNP of expected allies	numbers, total dollars anticipated by type of conflict status--peacetime, limited, major

SOURCES OF WELFARE (Continued)

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Non-exclusive (cont'd)	Foreign political / military relations (continued)	Defense forces and discretionary GNP of expected adversaries	numbers, total dollars anticipated by type of conflict status--peacetime, limited, major
	- **Foreign economic relations**	Imports	by type and geographic origin as a percent of domestic use and income
		Exports	by type and geographic destination as a percent of domestic production and income
		Financial flows and foreign claims	net, by region or nation
	● **Demographic Change and Public Health**		
	- Population profile	Total	total number, distribution by age, sex, ethnic origin, religion, primary and secondary language;
		Distribution -physical and cultural pattern -labor categories	labor force--number and distribution, as above, and by skill level and educational attainment
	- Nutrients available	Food production	quantities, by type
		Food consumption	quantities, by type calories, nutritional content, selected categories, e.g., protein, fat, carbohydrates

SOURCES OF WELFARE (Continued)

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Non-exclusive (cont'd)	-Public health status	Population growth	rates--total; natural; birth; death; fertility
		Life expectancy	age by population group, region
		Disease	by type of cause, rates per 1,000 population
		Mortality	by type of cause, rates per 10,000 population
	- Public health care	Outlay	total, by object-type, by source, by region
		Medical personnel available	total, by type, by region
		Hospital and related facilities	by type, by region
	• Political-Economic System - Type of system	General	republic, authoritarian, etc.
		Time profile	length of span of previous type, time since adoption, frequency of change of government
		Legal and Judicial processes	despotism, martial law, English common law, judicial review of legislation, appeal procedure, etc.
		Suffrage	population group, age, etc.

SOURCES OF WELFARE (Continued)

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Non-exclusive (cont'd)	**- Concentration of political control**	Political parties	number of major parties, memberships as share of population, voting concentrations
		Frequency of legislative elections	by level of government--local, regional, national
		Frequency of election or other form of change in executive	by level of government
		Restrictions on freedom of movement	percentage affected, temporary, permanent relocation--domestic, international
	- Concentration of economic control	Limits on private investment and ownership of assets	percentages publicly made or held by type (land, plant and equipment) and sector (agriculture, housing, etc)
		Limits on choice of employment	percentage of all positions assigned through government direction or approval
		Degree of control of wages and prices	percentages of value of transactions, by type, administratively controlled
		Other constraints	on foreign exchange, foreign trade, incomes (taxes and transfers) as percentages of base, e.g., trade turnover, international capital flows, GNP, etc.

SOURCES OF WELFARE (Continued)

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Non-exclusive (cont'd)	• Government Services - General (including juridical, international relations, etc	Outlays	by category: total; by type and source
	- Social (health, education, labor, housing, etc.)	Employment	man-hours
	- Commerce and production (transport, communications, finance, etc.)	Outputs	physical units--items processed, capacity created, etc.
	- Natural resources and environment		
Exclusive	• Domestic Security - Basic survivial *amenities*	Food	quantity: calories, nutrients;
		Clothing	quantity, by type
		Shelter	m^2, by type of facility
		Available health care	medical personnel, facilities per 1,000 population
	- Enhanced *survival* amenities	Training	quantity, by type
		Weapons	quantity, by type
	- Contingency of personal threat	From individuals	crime rates, by type
		From Government	"political" crime rate
		External	number of terrorist incidents

SOURCES OF WELFARE (Continued)

CLASS	ACTIVITY	CHARACTERISTICS	INDICATORS
Exclusive (cont'd)	**- Personal mobility**	Freedom of locational movement	transportation facilities (capacity in passenger-miles/day) administrative restrictions --area circumscribed
	- Private health	General state	qualitative assessment (excellent, good, etc.) disease rates, debilitating conditions
		Life expectancy	under alternative sets of conditions
		Performance capability - physical effort - mental effort	hours per week, by type
	● Consumption and Leisure **- Education and training**	Formal training	years or months
		Vocational training	months, by type
	- Employment	Type	weekly and annual hours by category--physical, white collar, skilled, etc.
		Compensation	structure of wage classes
	- Levels of Consumption	Nondurables, Durables, etc.	expenditure (or usage) by type
	● Accumulation of Capital	Physical assets	number, capacities, value
		Net financial assets	value
		Human capital	skill levels attained

III. Key Issues in Preparedness and Recovery

A. A Parallel Approach to Issue Identification

Apart from the effort to provide a consistent and comprehensive approach to the identification of key analytical issues via the development of a conceptual framework, a second and parallel effort was undertaken. Building on the experience of program planners and researchers garnered in designing the spectrum of preparedness and recovery programs as they have evolved over the past two decades, a separate identification of key issues was pursued. This served to link the more abstract categories of the conceptual framework to the concrete operational concerns of preparedness and recovery planning. It will been seen that in pursuing two parallel approaches, the commonality of analytical objectives across program design efforts that vary in terms of time horizons and in area of concern was demonstrated. This was a critical result in assessing the responsiveness of analytical systems to the needs of preparedness and recovery program planners.

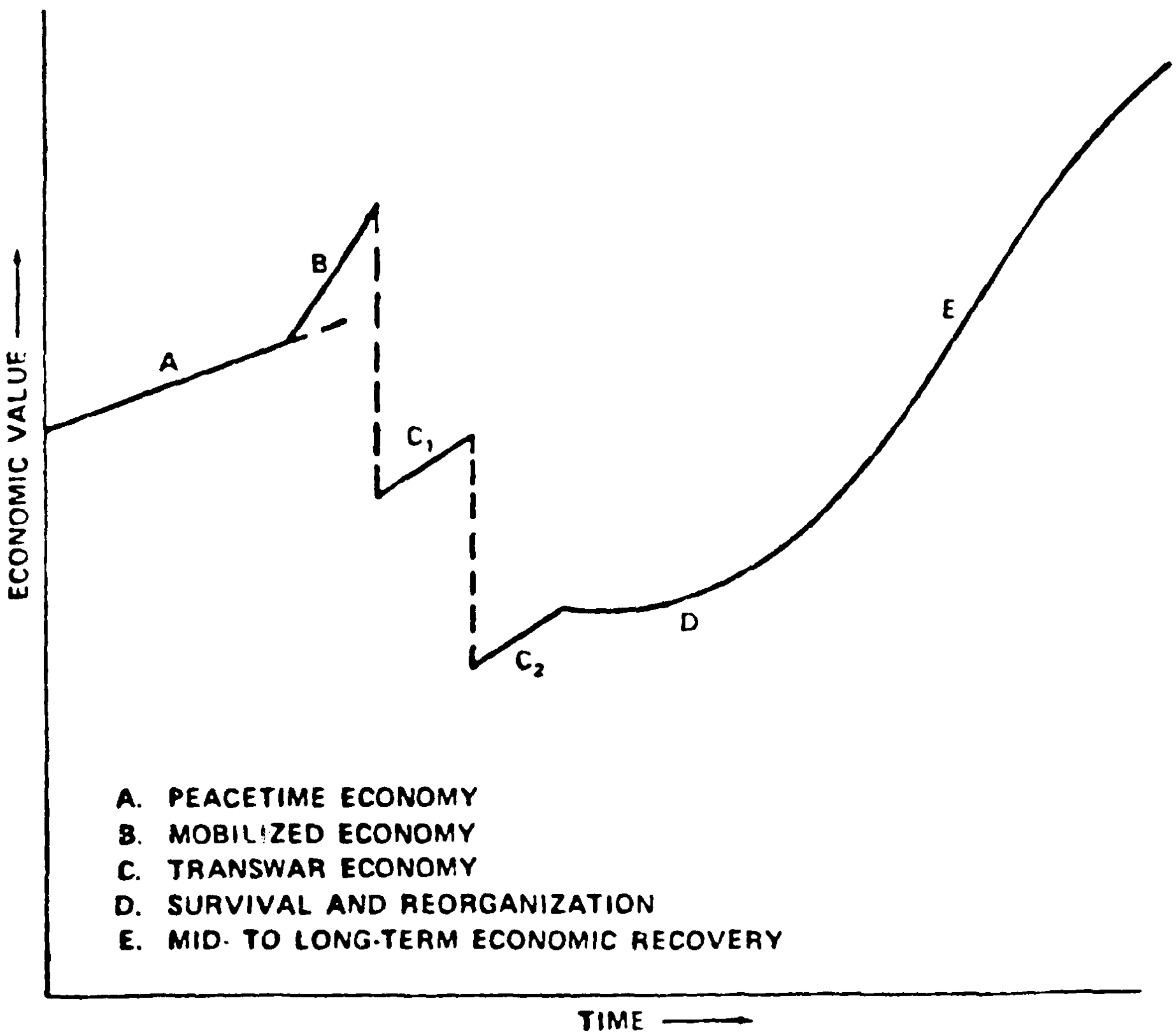
B. Recovery and the Continuity of Economic Processes

Program elements clearly must relate to the functioning of the socio-economic system as it passes through the recovery process from peacetime to the recovered economy. Operationally, the program proceeds from a perceived state of the system and undertakes appropriate activity to bring about a desired state of the system. Program goals then are likely to pertain to the system state at each point in time and to a desired state at the end of one or more time horizons.

As a first step in organizing an examination of preparedness and recovery issues, then, a consideration of a time-phased view of the system state in the recovery process is appropriate. A graphic representation of the stages of recovery and preparedness over time is shown in Figure 1. The vertical axis is labeled "Economic Value,"which will be left as an unde-

Figure 1

STAGES OF ECONOMIC PREPAREDNESS AND RECOVERY



fined index of production activity. The path indicated is consistent with much of current thinking on the evolution of the system given a pre-attack crisis period and a staged attack with moderate damage.[1/] Section A of the path reflects a growing peacetime ecnomy; Section B a mobilized economy reflecting full capacity utilization to meet increased defense needs. Sections C_1, and C_2 indicate the transwar economy as undamaged or lightly damaged capacity is mobilized to meet immediate survival and defense requirements. Section D represents what has already been referred to as survival/reorganization, as remaining capacity is reconstructed to provide the elements of a fully elaborated economic system. The transition to the next phase of mid- to long-term economic recovery is not clearly demarcated but probably can be thought of as analogous to the "take-off" of a developing country. The emphasis here, as stated at the outset, will be on the survival/reorganization and recovery phases.

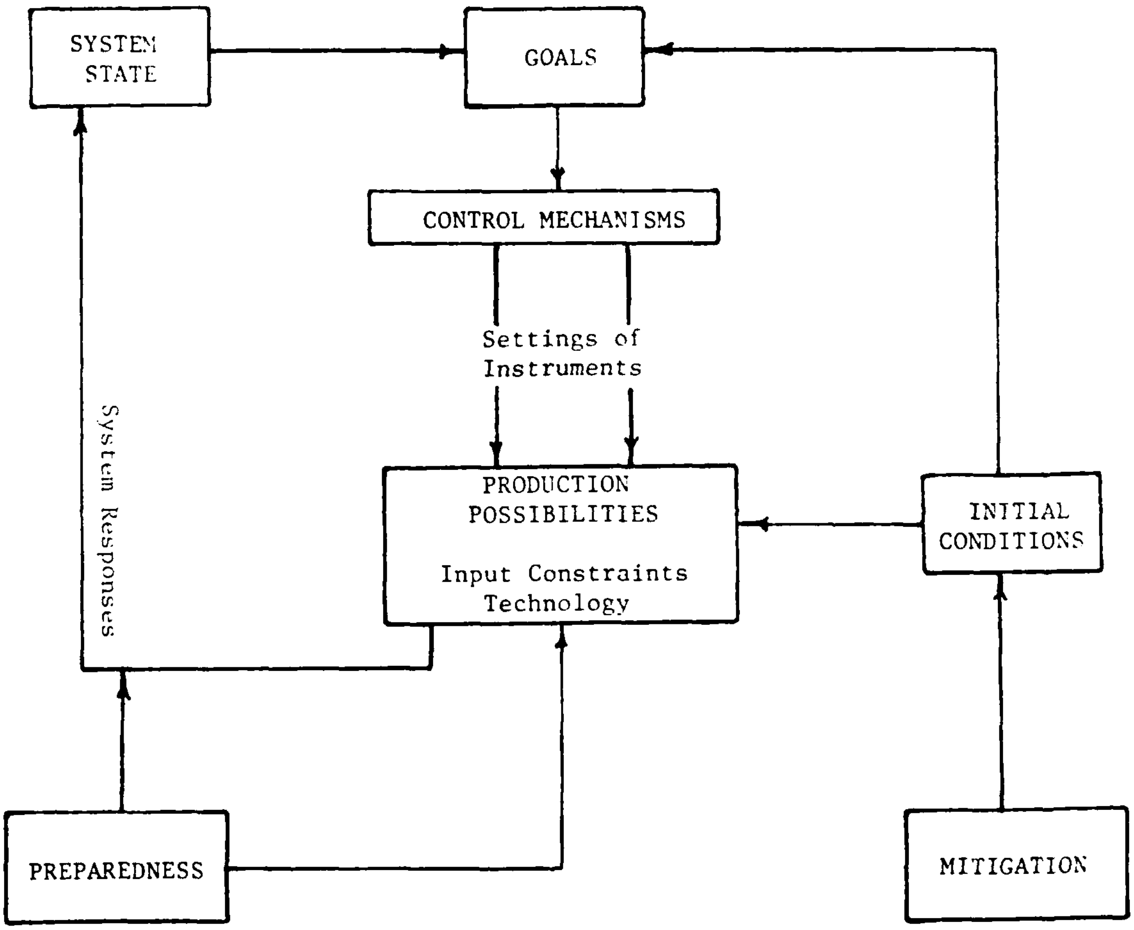
What, then, are the functional elements of the system in reorganization and recovery to which program actions must relate? In the relationship between system functioning and program actions, analytical objectives in deriving implications for program design will become apparent. The flow diagram shown as Figure 2 incorporates the functional elements of the system. Goals are formulated as a desired system state at the end of the time horizon. Given the current system state and the production possibilities, settings are arrived at for control instruments to which the system responds. The new system state is assessed, goals reevaluated, and the process is repeated.

Figure 2 also indicates where preparedness and recovery programs potentially impact on system functioning. Programs which seek to mitigate damage to human and physical assets impact primarily on the initial conditions for reorganization and recovery and hence the production possibilities of the system. Preparedness programs other than damage mitigation may impact on the ability of control mechanisms to effectively elicit desired system responses (economic stabilization planning, etc.) and also on production possibilities (stockpiling and other resource management programs). The relative effectiveness of particular program actions then is clearly measured in relative impact on the system state in the direction of achievement of goals.

1/ It should be noted that this path is only one possible path within an envelope of conceivable time paths for the system state. Both damage and value of a set of activity levels should be measured in terms of the conceptual framework.

Figure 2

FUNCTIONAL ELEMENTS IN REORGANIZATION AND RECOVERY



Therefore, the overall analytical objective in designing tools to assess these impacts is to provide an accurate-as-possible picture of the functioning of the appropriate aspect of the system which incorporates a depiction of program/policy levers. Thus the primary analytical objectives, as will be demonstrated in examining individual program areas, are to describe:

- the formulation of goals, based on initial and desired system states, including time and spatial disaggregations;
- production possibilities ;
- control mechanisms; and,
- the setting of instruments, based on anticipated system responses and articulated goals.

Return briefly to the earlier figure on the stages of the recovery process over time and superimpose the consideration of the functional elements of the system. *The formulation of goals has been described as a* depiction of a desired system at the end of the time horizon. If time horizons are determined by the transition of the economy from one stage to the next, that is, if goals are defined and programs are oriented toward a particular stage, the desired system state at the end of the time horizon forms the initial conditions for the system for the following phase. This is a rather complex way of indicating that even if programs are formulated for a particular phase of the recovery process, they impact on the achievement of goals in the recovered economy. Therefore an analysis of program effectiveness only in terms of short-run effectiveness, the achievement of immediate goals, is incomplete. [1/]

C. Programs and Policy Issues in Preparedness and Recovery

The National Plan for Emergency Preparedness, published by the Office of Emergency Planning in December 1964, while dated in terms of institutional approach, still provides a useful categorization of the required program elements for preparedness and recovery. These categories and their subelements include:

1/ It is also true that whatever the goals for the end of the time horizon, decisionmakers are not likely to be indifferent to the path taken between initial and final system states.

- Mitigation of Attack Effects
  - reduction of vulnerabilities (both of population and facilities)
  - provision of essential community services
- Economic Survival and Recovery
  - provision of essential resources
  - management of resources
  - economic stabilization
- Institutional Survival and Recovery
  - maintenance of civil order
  - continuity of government
  - protection of rights[1].

These broad classes of preparedness and recovery programs, both prior to and following this formulation of a plan for national action, have been addressed by the research community and government program planners. For the most part, however, what has been addressed is the feasiblility and cost-effectiveness of concrete proposals for accomplishing a limited spectrum of subtasks to provide for the continued functioning of the nation post-strike. In setting about establishing requirements for analytical systems, therefore, it is necessary to reexamine the set of issues which these systems will address in a comprehensive fashion.

1. Mitigation of Attack Effects

In the peacetime period, activities which relate to the reduction of vulnerability of population and the economic base to attack might include:

- crisis-relocation planning
- shelter construction
- industrial hardening

[1]Office of Emergency Planning, The National Plan for Emergency Preparedness, U.S.G.P.O., December 1964, pp. 8-9.

In regard to each of these activities both the physical and economic feasibility of programs, and the cost and effectiveness of various alternative measures are key issues. In the case of crisis relocation, the impact of implementation on the economy in case of a "false alarm" or limited attack also has been a concern in the evaluation of its potential effectiveness.

In regard to industrial hardening programs, analogous concerns are relevant: vulnerability of facilities, engineering feasibility of hardening a facility, cost of hardening measures. In considering the priority of a category of facilities in a program to reduce vulnerability, however, the additional parameter, the relative value of a facility of that category in the post-attack economy, should also be of concern. What then are the analytical elements in addressing the economic value of the facility or in other terms, the value associated with an additional unit of productive capacity in a given sector, in recovery? If the output of the facility is in abundant supply relative to the demand, given production possiblilites and production goals, then resources might better be utilized in hardening a different catagory of facility.

Therefore, as well as a strategic assessment of the objectives of the attack and an engineering assessment of the vulnerability and potential for reducing the vulnerability of a class of facilities, an economic assessment of the potential role of the facility in postattack recovery is required to establish the parameters of a program design. The elements of the economic assessment would include:

- the set of production end-use goals over time
- the set of production possibilities over time
- direct and indirect requirements for output of the sector in question
- the change in production possibilities with respect to a change in the output of that sector
- the value of that change given objectives

Thus, beyond the notion that more of a good (all other things being equal) is always preferred, the economic considerations involved in designing a hardening program involve not only the impact on the initial conditions for recovery, but also the functioning of the system and recovery objectives as well.[1]

The second subelement included under the category of mitigation of attack effects is the provision of essential community services. These are further defined as provision of survival amenities, basic utilities, and health, welfare and informational services. The basic analytical issues here are production possibilities (and production tradeoffs), demand for the service, and appropriate allocation mechanisms, given the initial conditions and goals. While subsistence levels for many of these items are dictated by biological and engineering considerations, any growth beyond these levels has an opportunity cost in terms of achievement of other goals and thus must be considered together (the impact on productivity of increased levels of these services may in fact decrease apparent opportunity costs). A gap between anticipated production possibilities at a point in time and desired levels of consumption may also have implications for stockpiling policies and provision for redundant facilities.

2. Economic Survival and Recovery

According to the National Plan:

> The elements in this category have as their objectives insuring efficient use of surviving resources, maintaining an economy capable of supporting national requirements, and insuring availability of resources for expanding, maintaining, or restoring production and distribution processes.[2]

Under provision of essential resources, one of three elements in this category, are envisioned the maintenance of reserves and the development of substitutes for critical resources, mobilizing productive capacity for defense needs, and exercising import and export controls. Management of resources, the second element, entails the planning and establishment of criteria for systems

1/ This is not to ignore the equally important social consequences of program actions which would be reflected in a truly comprehensive analysis. For example, the social consequences of selectively providing shelter via a hardening program.

2/ Office of Economic Preparedness, loc. cit.

for allocation and distribution of resources for production. Lastly, economic stabilization measures envisioned include control of wages, prices and rents, rationing of essential consumers' goods, and the maintenance of financial systems.

While specific program actions under these major elements would depend on imbalances in supply and demand for production inputs and the degree of damage to the infrastructure, criteria for preparedness and recovery planning relevant to these program elements can be developed via the application of analytical systems, under alternative potential environments. Clearly the analytical objectives would pertain to production possibilities and the identification of resource constraints on the ability to meet national requirements, as well as the evaluation of the effectiveness of control mechanisms and the development of guidelines for the settings of instruments to obtain desired system responses. The forms of control mechanisms incorporated into the analytical picture of the system would probably relate to the character of the emergency -- direct controls (rationing, etc.) being associated by planners with significant disruption of peacetime relationships, and to the phase of the recovery process under consideration. The meeting of national requirements, however, which the Plan directs policymakers to support, is not a purely single-period phenomena, and it is clear that actions taken in the early phase of recovery will impact on the capability of the recovered economy to meet national objectives. Thus, a dynamic picture of the system, responding to a set of control mechanisms evolving over time, would be required in order to respond to the letter of this directive.

3. Institutional Survival and Recovery

This program category of the National Plan includes the followng elements: maintenance of civil order (law inforcement by police and possibly, armed forces), continuity of government (providing for leadership succession, preservation of records, operational centers), and protection of rights (establishment of a civil justice system assuring limitation of rights does not exceed requirements of the emergency).

In the cases of the maintenance of law and order and the establishment of a justice system, it is not expected that the application of economic tools and techniques can provide guidance as to how to accomplish these objectives via program actions. Insights available from application of these tools, however, could include:

- Availability of material and manpower to meet requirements for these efforts, given resources, production possibilities and other objectives;
- Trade-offs with other activities
- The impact of alternative levels of achievement in these efforts in terms of system performance (labor productivity, accumulation of assets, pattern of demand for consumer goods, etc.) and hence an estimate of the contribution of these activities to social welfare.

The evaluation of requirements for and contribution to system capabilities of programs under the rubric of "continuity of government" would certainly benefit from the development of appropriate analytical systems. Preservation of records and information-gathering capabilities aid in assessment of resources and requirements and hence provide for an increased ability effectively to formulate goals, establish control mechanisms, and set the instruments in order to obtain anticipated system response. Increased effectiveness of these programs expands production possiblities for government services. As program design would vary with the anticipated profile of government services, evaluating the cost and the contribution of various categories of services to system performance can provide guidance in program design and for alternative recovery environments:

- comparative feasibility, cost, and effectiveness of local, regional, and national based services
- data requirements and the impact of the availability and reliability of information on system performance
- resource and infrastructure requirements of various profiles of services
- evolution of optimal levels and profile of operations over time.

Thus, again in this category, analytical objectives relate to production possibilities, control mechanisms and settings of instruments, and the formulation of goals.

D. Policy Issues and Analytical Objectives in Summary

It is evident that the policy areas explicitly identified in preparedness and recovery program planning relate to a subset of the activities enumerated in the conceptual framework of Section II above. The design of analytical systems must be related to the broader set of issues organized around that framework, since the policy concerns of this section are not pursued in isolation from other aspects of the system, nor can outcomes be evaluated on a narrow set of criteria. It is important, however, to identify analytical objectives with respect to policy concerns already enunciated in order to demonstrate that they are subsumed in addressing analytical issues within the conceptual framework and are appropriately handled by a total system approach. The approach via the conceptual framework is further elaborated in Section IV, in which analytical issues are coupled with appropriate techniques to arrive at a design for analytical systems.

Table 2 provides illustrative issues relating to the program categories and elements discussed above. These issues are associated in the table with analytical objectives in system assessment. In Section IV, the appropriateness of particular techniques for meeting these objectives is indicated so that techniques can be related to issues in the analysis in later sections. Neither the issues in the table immediately following, or in the elaboration of the conceptual framework, are regarded as exhaustive, but rather represent the spectrum of concerns involved in program design and assessment of system performance.

E. Key Issues and the Recovery Environment

The alternative levels of damage and stages of recovery which this study will consider have already been discussed above. It was also indicated that the character and time span of each of the stages will depend to a considerable extent on the level of damage. Because program elements and the key issues associated with them will serve as a guide in deriving specific design

Table [illegible]

Policy Issues and Analytical Objectives

Program Elements \ Analytical Objective	Goal Formation	Production Possibilities	Control Mechanisms	Settings of Instruments
● Mitigation of Vulnerability				
- Reduction of Vulnerability	Relation of goals to priorities for protecting industries	Impact of increased capital surviving by sector on production possibilities	Impact of vulnerability reduction on control mechanisms available.	Implication of increased survivability on settings of instruments and responses.
- Provision of essential community services	Definition of other fixed claims on resources	Availability of resources to provide these services	Appropriate allocational mechanisms	Implication of allocational policies for system performance
● Economic Survival and Recovery				
- Provision of essential resources	Establishment of targets and priorities for essential end-use categories	Resource requirements to meet end-use targets; Identification of effective resource constraints	Direct and indirect controls on resource allocation	System response to direct; indirect control
- Management of resources	Definition and prioritization of national requirements	Feasible production sets with alternative resource allocation	Direct and indirect controls on allocation of inputs; consumption and investment, etc.	Impact of controls on levels and composition of end-use
- Economic Stabilization	In addition to goals for system performance as above, establish operational definition of "stability"	Impacts of alternative policies on productivity, input mix, resource constraints, growth of capacity over time	Determination of instruments to effectively stabilize prices, wages, financial markets, etc.	Optimal settings to maintain stability given other objectives

Table 2 (Cont'd)

Program Elements / Analytical Objective	Goal Formation	Production Possibilities	Control Mechanisms	Settings Of Instruments
• Institutional Survival and Recovery				
- Maintenance of Civil Order	Establish relationship of civil order to accomplishment of objectives	Resource requirements, constraints, trade-offs with other activities	Impact of "civil order" on ability to exercise control mechanisms	Settings which reinforce incentives for "civil order"
- Continuity of Government	Prioritization of spectrum of government services	Resource requirements, constraints, trade-off with other activities; effect of government operations on production possibilities	Feasibility of control mechanisms given various levels and spectra of governmental operations	Impact of information availability, etc. on settings
- Protection of Rights	Priority of civil liberties relative to accomplishment of other objectives	Resource requirements, constraints, trade-offs, impact on labor productivity, accumulation of wealth, etc.	Trade-offs between control mechanisms and protection of rights	Impact of civil liberties on ability to pursue particular instrument settings

considerations and research priorities for analytical systems, it is useful to address here the impact of alternative environments on key issues.

1. The Light and Moderate Damage Cases

For the lighter damage environment, the survival/reorganization phase can be expected to be briefer, given less severe disruption of peacetime relationships. If an immediate external threat does not exist, key goals may be longer term in nature, with a more balanced approach to the growth of economic capabilities. Direct controls on resource allocation would probably be restricted to the immediate post emergency period. Peacetime information systems could be readily restored and augmented to reduce the uncertainty in decisionmaking.

Primary attention would be devoted to program elements in the category of Economic Survival and Recovery, particularly in regard to efficient management of scarce resources and economic stabilization. Production possibilities would reflect technology similar to that in the peacetime economy, but under the constraints of reduced capacity. Institutional survival would most likely not be a concern and the spectrum of government operations would approximate the peacetime pattern, within the levels dictated by the reduced availability of resources. Thus, meeting the analytical objectives in regard to the design of programs for this environment, following a relatively brief survival/reorganization phase, would approximate the same tasks for the peacetime economy and very similar analytical techniques are appropriate.

The moderate damage case can be viewed as an intermediate point in the spectrum between the familiar problems of peacetime analysis and the speculation on system capabilities and performance characteristics in a heavily damaged environment, about which even historical experience provides little guidance. Extraordinary measures to insure both economic and institutional survival and recovery will most certainly be required for a considerable period after the onset of the emergency. The particular profile of damage may be critical to production possibilities and fixed claims on output (national security, public health care, etc.) may severely limit the achievement of other objectives in the short-to mid-term. As survival is assured and reorganization provides the foundation for capacity expansion, a standard of living above subsistence levels and renewed inter-regional linkages, the analytical problem moves toward the light damage case for the recovering economy.

2. The Heavy Damage Case

This case presents analytical questions which tools developed for peacetime analysis are least able to answer in terms of the required picture of production possibilities which is lacking. The reestablishment of production units (outside of areas which escaped heavy damage and are highly self sufficient) may well come only after an extensive reconstruction effort. The feasibility of recovery would depend on the expansion of production capacity to exceed consumption (and other fixed claims) before inventories are depleted.[1] Provision of essential resources and efficient management of resources will be critical to assuring viability of the system. Problems of economic stability will be basic - remonetarizing the economy. Information on the state of the system will be at a premium, and early definition of goals will primarily be accomplished at the local and regional levels. Institutional patterns may develop that are very different from the peacetime mode, e.g., the public sector assuming roles reserved in peacetime for the private sector, and the priorities attached to some traditional areas of governmental operations may be relatively low.[2]

An innovative approach to the combination of analytical tools for application to this environment is therefore in order. The picture of the system these tools incorporate for the analysis will be postulated less on observations of

[1]See Sydney G. Winter, Jr., Economic Viability After Thermonuclear War: The Limits of Feasible Production, The Rand Corporation. (RM-3436-PR), September 1963.

[2]See Francis W. Dresch, Information Needs for Post-Attack Recovery Management, Stanford Research Institute, April 1968.

basic characteristics revealed by macroeconomic relationships and more on psychological and sociological predictions concerning individual and group behavior and notions of economic rationality under extreme uncertainty.

IV. Inventory of Tools and Techniques

Analysis of issues in preparedness and recovery is difficult and complex. Except at the most basic technical, engineering levels few of the problems are simple. Most involve consideration of trade-offs and assessment of impacts elsewhere within the system. For example, devoting resources to a specific purpose, such as military goods production, leaves lesser amounts of goods and services available for other uses. This in turn can impinge seriously on the ability to achieve other goals, on productivity and labor force control, and so forth. Finally, in turn, increasing devotion of resources to a specific use in the short run may erode capabilities to serve that need in the longer run. In other words, there is a cascade of effects, with feedbacks, both within the short-run periods (say a year) and across years.

The analytical problem is made even more complex by radical alterations in structure of the real world economic-political system. Such changes can occur either through vastly different initial positions from which recovery is to take place (that is, the extent of damage), marked shifts in institutional arrangements (such as revamped commercial, civil and criminal codes, substitution of direct allocation for market operation, etc.), or other elements that basically modify behavioral patterns and responses.

Given the complexity and diversity of analytical problems and the vast range of possible system responses, no single tool or technique can be used to answer satisfactorily the many recovery questions that are to be resolved. Included in those questions, of course, are issues of what resources are to be devoted to what purposes in what time frame at which locations, how the resource allocation is to be effected, how the system is to be monitored and controlled, and so forth. A variety of tools and techniques are needed for those purposes. Moreover, some are appropriate for specific problems and not for others. Also special adaptations are required in order to be able to analyze selected questions.

In what follows, some well-known tools and techniques are described and examples are given of their application to preparedness and recovery analysis. Included in the discussion are conceptual limitations of their use for those purposes.

The tools covered here are those involving extensive use of formal mathematical expressions (equations and inequalities) enabling analyses to be conducted in rigorous and reproducible fashion. Other disciplines and tools, such as sociology, psychology and organization theory, are sure to prove useful for recovery analysis, too. In general the latter involve greater emphasis on subjective assessments. This is a limitation, but not one which should be considered fatal to their useful application. Limitations of time prevent fuller discussion of those fields and methods in this report.

A. Econometrics

1. Description and Standard Application

Econometric analysis proceeds from the postulation of functional relationships among economic variables. The parameters of the relationships are then statistically estimated from empirical data. While a single functional relationship between two economic variables might be called an econometric model, large-scale models encompassing a description of complex economic systems can consist of hundreds of estimated equations. After a model is specified and estimated, it is typically subjected to system testing and calibrated. The model's error properties can be tested over the sample period, by comparing a model solution with observed data outside the sample, and by examining the response of endogenous variables to changes in inputted values of exogenous variables for consistency with a priori knowledge.

Standard applications of econometric models include forecasting, structural analysis, and policy analysis. The utility of the model for application depends on the stability of the estimated relationships. These relationships may be characteristic of technological, behavioral, or institutionally-determined causality among the variables. If the model is to be applied over a particular regime, these relationships should exhibit stability, i.e., give plausible results within those bounds. If system-testing reveals this is not the case, the model may be improperly specified, that is, key explanatory variables missing in the specification of some functional relationships, or the underlying structural relationships valid over the sample do not hold outside that sample.

An example of structural analysis using an econometric model is the examination of variation of capital intensities and capital-labor substitutability across industries. In an elaborated model of industrial production and markets for outputs and factor inputs, the analysis will involve not only the technological relationships of the production process, but also the economic behavior of producers facing market-determined prices, wages, the cost of capital, etc.

In the application of econometric models to forecasting, the judgment of the analyst is often a critical element in structuring the model solutions. The usual approach is to begin with a baseline forecast. The baseline will incorporate the analyst's assumptions about the most likely values for the exogenous variables in the model. For example, key exogenous assumptions for a macroeconometric model of a national economy today would include the rate of increase of the price of OPEC oil over the forecast period. This in turn impacts on the balance of payments, trade flows, rate of inflation and so on--repercussions which spread throughout the model. Variants of the forecast are then typically prepared with alternative sets of assumptions, indicating the sensitivity of economic variables of interest. The preparation of forecasts is often an iterative process, with the analyst intervening where the model-generated responses, in his judgment, understate or exaggerate movements that would be expected a priori.

Policy analysis is a similar process which can be performed over the forward period (in forecast mode) or over the historical period (counter-factual mode). The latter can be a useful starting point for sensitivity analysis because the baseline scenario is supplied by observed data. The variants of interest in these analyses relate to the set of exogenous variables which are instruments of economic policy. These policy instruments may have impacts which in turn vary with respect to exogenous variables that are not subject to manipulation by instrument-setters in question. Thus variants of policy may be prepared around alternative baselines. For instance, building on the example given above, the impact of alternative monetary policies, perhaps represented in the model by an exogenously set money supply, on the rate of growth of wholesale prices might be examined given three alternative assumptions about the increase in the average price of imported oil.

The design and implementation of an econometric model is necessarily closely related to its intended application. A model for long-term forecasting would not aim at capturing short-run responses reflected in variations in quarterly data. An econometric forecasting model for a particular region of the country would probably have only a minimal monetary sector, apart from the response of local activity to interest rates which are determined on a national basis.

Some of the major areas of application of econometric analysis have included the following:

- the impact on prospects for economic growth and the standard of living of economic policy and regulation, resource constraints, technological progress;
- impact on employment, prices, production and end-uses of alternative monetary and fiscal policies;
- impact of international trade and financial activity and domestic policies on foreign trade and payments positions;
- regional development prospects;
- impact of alternative policies on patterns of income distribution.

2. Suggested Applications for Preparedness and Recovery Analysis

In the analysis of economic recovery, econometrics offers a tool with which to address the performance of the economic system, production possibilities, and the response of that system to control mechanisms (including the peacetime concept of policy instruments). Elsewhere, we have resolved preparedness and recovery programs into two classes: mitigation, which aims to reduce the negative impact on production possibilities, and preparedness which aims to improve the responsiveness of the system to control mechanisms. Thus, to the extent that an econometric model can portray the functioning of the system and its response to instruments, it holds promise as an analytical tool. On the other hand, it is a positivistic tool. Econometric methods alone can not determine the desirability of outcomes that is involved in the setting of goals and instruments.

Assuming, then, that an econometric model provides a satisfactory description of system performance, and given initial conditions and the settings of instruments, the recovery analyst can ask the following sorts of questions:

- What are the trade-offs over time between military outlays and other end-uses of national product?

- What are the impacts on production possibilities of various sets of initial conditions?

- What levels and composition of consumption per capita can be supported over time given resources and other claims on output?

- What is the return to investment in terms of the growth of production implied by alternative sectoral patterns of investment?

- What would be the contribution of external economic flows in expanding production possibilities?

- What regional disparities could be expected with alternative sets of initial conditions and investment policies?

- What are the implications for output composition, economic growth, and income distribution of particular wage and price policies?

3. Conceptual Limitations

Apart from the fact that an econometric model alone cannot handle normative questions, the primary limitation in the application of econometric methods to preparedness and recovery analysis is the requirement for a significant sample of historical data from which to estimate the parameters of the system. If the functioning of the system is so altered by the change in the environment that inferences from historical experience are not likely to hold or data on similar experience is lacking, little faith can be placed in the picture of system performance and system response presented by an econometric model.

On the other hand, if the range of the damage to the economy is light-to-moderate, a significant degree of continuity of economic processes can be expected. Thus, an econometric model, with some modification of the peacetime specification, would prove a useful analytical tool for such a scenario. Assumptions are required about the applicability of technical and behavioral relationships estimated over the sample period, and thus care is necessary in interpretation of the results of model simulations. Analyst intervention may assume a more important role than in either standard forecasting or policy simulation.

4. Other Comments

Building and maintaining econometric models can involve substantial resources. Assembling data represents a significant effort for any good-sized model, while models based on time-series data, especially annual, are likely to find specification and estimation alternatives limited by data availability.

While econometric models alone cannot solve the questions of goal formulation and settings of instruments, they can usefully be combined with other techniques for these purposes. Econometric models can be incorporated as a system description (set of constraints or "laws of motion") in programming or control theory ("optimal control") approaches, although, computational problems may result for large systems.

B. Input-Output Analysis

1. Description and Standard Application

An input-output table indicates the flows of goods and services between the sectors of the economy at a point in time. The data involved in preparing a table may be derived from census-type information either via sampling or exhaustive reporting. By making certain assumptions, this information can be manipulated to examine alternative sets of outputs feasible with the technology prevailing (represented by a matrix of input coefficients--dollars of input x per dollar of output y). The key assumptions are that technology is linear--coefficients are fixed--and relative prices do not change. No substitution of one input for another can occur, or in other terms, if you don't have any paint, you can't produce any airplanes.[1] By means of matrix algebra, the matrix of direct input coefficients is manipulated to produce a matrix of direct plus indirect coefficients, so that for any specified set of final demands (gross values of output of the producing sectors less intermediate or interindustry uses), if the set is feasible, the required gross outputs of each sector can be determined. Thus, end-use requirements can be directly related to demands for sector output.

Input-output techniques are primarily used for structural analysis and in some cases short-term forecasting (although movements of coefficients over time can be modeled econometrically to extend the appropriate forecast horizon). While prevailing technological relationships are explicit in an input-output model, underlying behavioral and institutional relationships are only represented ex-post by their impact on the intersectoral flows. That is, decisions on output levels, input mixes, and the individual decisions which are aggregated into the set of final demands are the result of the response of decisionmakers to prevailing prices of outputs, inputs (including labor and capital services), levels of disposable income, tastes, etc.

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[1] Where an input is the output of one I/O sector, and all output of that sector is assumed to be homogeneous, or infinitely substitutable as an input to production.

Typically, input-output analysis is applied to questions such as the following:

- is the economy (national or regional) capable of producing a particular set of final demands?
- what would be the impact of specified resource constraints or capacity constraints on the set of feasible final demand vectors?
- what is the impact of changing composition of final demand on requirements for sectoral outputs?
- what is the relative importance of specified sectors (considering direct plus indirect requirements) in satisfying particular end-use requirements?

2. Suggested Applications in Preparedness and Recovery Analysis

As in the analysis of the peacetime economy, input-output techniques can be applied to very much the same types of questions presented above. Again strong assumptions about the prevailing technology must be made. Also, as we have seen, in order to answer any question about the dynamics of the system, some technique must be used to move the matrix of input-output coefficients over time. Care must be exercised in interpreting input output results with regard to the realism of the assumptions and the confidence that can be placed in the individual coefficients.

Because many issues related to the design of preparedness programs concern the importance of particular industrial sectors to the production possibilities and the sectoral composition of end-use requirements, a picture of the postattack economy in an input-output framework is a particularly useful tool. In fact many of the previous attempts to model the postattack economy have centered on input-output technology analysis. As in standard application, the input-output technology matrix can be used to examine the feasibility of various sets of final deliveries, the requirements for sectoral gross outputs given a set of final demands, or the implications of a particular capacity constraint for production possiblities. An input-output approach can be used as a means to describe production possibilities in combination with other tools to examine implications and compatability of goals and the settings of instruments.

3. Conceptual Limitations

Some of the limiting assumptions of input-output techniques have already been indicated above, but to restate them:

- An input-output table presents a static picture of the economy.
- The coefficients of an input-output technology matrix reflect
  - a particular mix of technologies corresponding to scale of production, etc.
  - a particular mix of products which are viewed as homogeneous in the I/O scheme
  - a particular set of relative prices
- No substitution between sectoral deliveries in production is allowed for, while within a sector all of the output is perfectly substitutable as an input to production or for final use.

One would speculate that, with any significant degree of disruption, the mix of technologies and composition of sectoral output would change considerably. Thus, the specification of the input-output coefficients would present considerable difficulty. Furthermore, the sectoral composition of end-uses, consumption, government expenditures, etc. could also be expected to differ significantly from peacetime.

Input-output analysis, per se, can only answer questions about production possibilities at a point in time. Input-output relationships, however, can be incorporated into an analytical system with other tools to address optimizing strategies. The implications of the assumptions of the input-output world, of course, would similarly apply.

4. Other Comments

While input-output techniques have been characterized as addressing a static picture of the economy, methodologies have been developed to move input-output coefficients over time. Linear extrapolation of coefficient changes from two or more benchmark tables are one approach, although without an understanding of why movements take place, confidence in the estimated coefficients is not great and the resulting matrices must be balanced. The

RAS technique is an approach to adjusting rows and columns iteratively based on some control figures that assures a balanced table will result in a table which is a plausible but not necessarily the correct input-output picture consistent with the control information obtained separately. The technique has been applied to Soviet input-output tables as reconstructed by the Foreign Demographic Analysis Division of the Commerce Department to develop a time series of input-output tables for use with the SRI-WEFA Econometric Model of the Soviet Union.[1] The LITM model developed for the Federal Preparedness Agency by DRI employs flexible input-output coefficients which respond to changes in the prices of primary inputs.[2] An attempt to model such changes in a post-attack environment could draw on these techniques, but would certainly be an ambitious and largely speculative effort.

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[1]See Donald W. Green, et al, The SRI-WEFA Econometric Model of the Soviet Union, Phase III Documentation, SRI Technical Note SSC-TN-2973-5, January 1977.

[2]See E. A. Hudson and D. Jorgenson, The Long-Term Industry Transaction Model, GSA/FPA, July 1979 (TR-109)

C. System Dynamics

1. Description and Standard Application

System dynamics is an approach to formulating a picture of the economy over time via a set of equations that are solved much like an econometric model. The major differences between this approach and econometric modeling lie in the specification of the model structure and the association of values with the model parameters.

A system dynamics model relies heavily on microeconomic relationships in specifying the structure of the economy, that is, a portrayal of individual and corporate decisionmaking which in the aggregate explain macroeconomic phenomena. For example, demands for primary factors are not derived either from aggregate production functions or from aggregate demand considerations, but rather production decisions might be represented by an ordering function which responds to order backlog for the factor, inventories, delivery delays, prices, expectations, desired production rates, etc.[1] Thus, while a system dynamics model would normally have equation blocks which correspond to those of a macromodel, the embodied statements of causal relationships may differ considerably.

The parameters of these relationships do not depend primarily on statistical estimation methods applied to historical data series. Parameters are set via the opinion of experts on the relationship of the dependent to the independent variables. This is not to say, however, that in some cases parameters derived from estimated relationships among historical data are not incorporated or at least considered in the setting of other parameters. Primary emphasis however is on reflecting the modeler's perception of key influences in decisionmaking, including the influence of psychological and sociological factors which may underlie but are not specifically treated in an econometric model.

[1]See for example Nathaniel J. Mass, "Introduction to the Structure of the System Dynamics National Model," Monograph, M.I.T., January 1979.

A system dynamics model is applied primarily for the purpose of long-term policy analysis rather than short-term forecasting. Policy-making processes may be incorporated in the structure of the model and the implications of alternative policymaking rules or modes derived via the altering of parameters in the equations describing policy response to state variables. Thus questions very much like those addressed by econometric models are also addressed in system dynamics models:

- impact on prospects for economic growth of alternative economic policies (or policy response modes) and resource constraints;
- impact on employment, production, prices, and end-uses of alternative policy environments and resource availability;
- impact of altered perceptions (expectations) of the future on economic decisionmaking and performance; and so on.

2. Suggested Application for Preparedness and Recovery Analysis

System dynamics offers a tool with which to examine the performance of the postattack system in terms of production possibilities and responses to settings of instruments. The control mechanisms can be partially endogenized as discussed above. Psychological and sociological factors can be explicitly handled in the model, which would reflect characteristics of the environment that should perhaps be explicitly incorporated in a consistent manner.

Such models could be applied as in the analysis of the peacetime economy above. While a search for optimal settings of instruments is possible via alternative simulations of the model, to the degree that instrument setting is endogenized, however, great care would need to be exercised to assure consistency of adjustments in policymaking modes.

3. Conceptual Limitations

While it was noted that econometric modeling required a significant sample of historical data from which to estimate parameters, system dynamics requires instead knowledge of decisionmaking behavior, primarily at the micro level. This knowledge should pertain not only to some base period, but also to the range of environments to be addressed by the model. In the case of analysis of recovery phenomena, such knowledge, even drawing on historical experience under emergency conditions, is not available. Rather, speculation must be relied on and heretofore, speculation has addressed primarily broad trends in psychological, sociological and economic behavior of individuals and groups that might be anticipated in a post-strike emergency.[1] Even the results of concrete psychological experiments in which great pains were taken to simulate postattack conditions (e.g. to examine behavior in shelters over considerable periods) have been questioned, given the inevitable lack of realism. It might be assumed that the less the disruption of the system, the closer to behavior with which there is accumulated experience. In some regards, however, even light damage may result from actions which severely alter the perceptions of individuals in the following period (a crisis of confidence, perhaps). Nevertheless, as in the case of econometric modeling, it should be expected that the light to moderate damage environments are those in which one would have greater confidence in the accuracy of the model relationships that guide system performance.

4. Other Comments

System dynamics, like econometrics, does not per se provide answers to normative questions. That is, such a model provides a picture of how the system performs (production, control mechanisms) but does not prescribe actions that should be taken. If a large enough number of simulations of the model are performed, varying the settings of instruments, given objectives and a methodology for evaluating outcomes, guidance for preferred settings can be derived. The system dynamic model can also serve as the "laws of motion" for an optimal control problem, and then optimal settings of instruments over time can be derived.

[1] See Bruce C. Allnut, "A Study of Consensus on Psychological Factors Related to Recovery from Nuclear Attack," Human Sciences Research, Inc. May 1971; and Raymond D. Gastil, "Scenario for Postattack Social Reorganization," Hudson Institute, August 1969 (HI-1188-RR).

D. Optimal Control

1. Description and Standard Application

Optimal control theory, first applied to the problem of engineering feedback control, is an approach to guiding a system over time so that, as closely as possible, certain criteria for the performance of the system are met. The elements of the optimal control problem are,

- a description of the system (in terms of relationships between rates of change of the variables, i.e. differential or difference equations);
- constraints on the variables;
- boundary conditions for the variables; and
- a cost function which is to be minimized.

In application to economic questions, the system is a model (based on an econometric model, etc.). The constraints are limits on the permissible variation in key levels (e.g. interest rates). The boundary conditions are the initial values for variables and desired values at the end of the time horizon. The cost function places values (national priorities, for example) on deviations of actual values from targeted values for key variables and aggregates them for each point in time. When all these relationships are specified together with the optimization conditions (derived from the application of the calculus of variations), the system of equations is solved backwards in time, and the optimal vectors of values for control variables over time are determined.

Optimal control approaches have been utilized in a number of planning problems:

- To determine optimal planning behavior for a centrally planned economy;
- To examine optimal stabilization policy for a mixed economy;
- To examine optimal investment/consumption allocation with growth models, particularly for developing countries;
- Planning production activity at the micro level.

2. Suggested Application for Preparedness and Recovery Analysis

Optimal control is a normative technique. That is, given a description of the system (an econometric or system dynamic model, etc.), objectives, and constraints, direct implications can be derived for the setting of control instruments. Therefore, optimal control is applicable to the following sort of questions about the postattack economy.

- Optimal settings of instruments (control variables, which in postattack environment may be more or less numerous than in peacetime such as monetary and fiscal policy instruments, price and wage policies, or extraordinary controls such as on per capita consumption)
- Optimal growth strategies, that is, optimal capital accumulation programs given time preferences
- Shadow prices for variables which describe the state of the system; that is, given objectives and boundary conditions, under optimal instrument settings, which aspects of the system state are most important in preventing the achievement of targets in each period.

Clearly optimal control techniques are directly applicable to policy questions both for optimizing recovery behavior and for preparedness programs.

3. Conceptual Limitations

From the foregoing discussion, it can be seen that the utility of optimal control would depend on an accurate picture of the "laws of motion" or dynamics of the system. Thus in adopting a particular econometric or system dynamics model, the assumptions and hence the limitations of that model would be in force.

Secondly, it may not be possible to incorporate into the optimal control problem all of the constraints on levels and variability of instrument settings in the particular environment. Thus, a particular program of policy setting might be infeasible for political, sociological, or psychological reasons while optimal from the point of view of the optimal control program. If in the particular model of the system these influences are appropriately incorporated as well as in the social "cost function," then the problem may be somewhat lessened.

Third, given the computational requirements of optimal control solutions and the current state of the art, non-linearities in the system model are to be avoided. While most large scale peacetime econometric models are highly linear or can be readily linearized, linear functional forms may well not be appropriate for various types of models of the postattack system--that is, a linear description of a particular subset of dynamic behavior may not be an acceptable approximation.

4. Other Comments

Optimal control solutions can prove to be very expensive in light of the computational requirements, particularly for complex systems. Therefore, applications are generally limited to small systems with relatively few instruments. Note that in the reformulation of econometric models for control problems, the lag structure if it is complex, multiplies many fold the number of state variables which must be treated.

E. Programming

1. Description and Standard Application

Programming is an approach to solving resource allocation problems in which the constraints are expressed as inequalities (for instance, the production of commodity x cannot exceed the capacity of a particular production unit). The problem is to allocate resources among activities such that a particular objective function is maximized (minimized) and the set of constraints are not violated. The algorithm which solves this problem is concerned with minimizing, as well, the set of possible allocations which need to be examined and the order in which these are examined, so that an optimal allocation is determined as rapidly as possible. A common formulation of the problem, computationally the least demanding, is the linear program. In this formulation, the operative constraints are represented as linear functions. One basic principle is that if there are m choice variables, the solution will occur when at least m of the constraints are met as an equality. That is, the solution will lie at an extreme point of the boundary of the feasibility space. The constraints are then solved as a set of simultaneous equations to identify the extreme points and these points are evaluated in a particular order to determine the optimal solution. Approaches have also been developed to handle non-linear constraints, and dynamic programming problems.

As the description indicates, the programming approach is applied to solve resource allocation problems, such as:

- optimal production-mix; outputs
- transportation planning
- stockpiling decisions
- optimal capacity decisions
- optimal inputs to production, etc.

2. Suggested Application in Preparedness and Recovery Analysis

Programming approaches would be useful in recovery analysis for establishing production possibilities and in obtaining settings of instruments. In examining production possibilities, the programming analysis would address the optimal production relations given the pattern of resource constraints. In regard to the setting of instruments, programming approaches are applicable to a wide variety of optimization problems. Thus, given objectives and constraints, optimal allocations of manpower, scarce resources, capacity (industrial, transportation, warehousing), etc. can be determined. Given time preferences, optimal allocations over time can also be derived.

3. Conceptual Limitations

The primary concern with the application of programming to a resource allocation problem is a large and complex feasibility space. In this situation, the number of possible optimum solutions (extreme points) is not readily handled by existing programming algorithms. Further, the optimum point in a programming problem may be determined to be a corner solution (the intersection of a constraint and an axis, which may also include, depending on the constraints, the origin). In this case, the recommendation of the program is that one, several, or all the activities not be undertaken at all. If this is not acceptable, the problem must be reformulated to provide an appropriate answer.

F. Decision Theory

1. Description and Standard Application

Decision theory provides a methodology for decisionmaking when alternative outcomes of the choices are uncertain. Decision analysis allows for the explicit treatment of subjective information in the assignment of probabilities to outcomes and the consideration of risk aversion. Applied to clearly structured problems with well-defined objectives, it is often termed operations research, while in the case of application to very complex systems for which structure and goals are only generally specified it is often called systems analysis.

The first step in a decision-analytical approach to a problem is to define the feasible sequences of actions (the decision tree) which result in the range of discrete possible outcomes. The sources of uncertainty of the occurrence of the outcome are identified and probabilities are assigned. The expected utility of each outcome is then assessed, at which point time-preferences and risk aversion are also incorporated. When an optimal outcome is selected, the decision tree can be analyzed to determine an optimal strategy. The process can be repeated assuming additional information is available to alter the assigned probabilities. By examining the sensitivity of expected utilities of dominant outcomes, the value of additional information-gathering can be weighed against the cost.

Standard applications of decision analysis include:

- inventory control, quality control, production scheduling, etc.
- cost-effectiveness analysis for weapons programs
- research and development planning
- investment planning

2. Suggested Application in Preparedness and Recovery Analysis

Decision theory can be used in recovery analysis in several alternative ways. It can be used to structure strategies for decisionmakers in goal formulation exercises. It can be used to aid in arriving at a specification of decisionmaking behavior in a system-dynamics approach to modeling performance based on micro-relationships. Lastly, it can be used in relating analytical results associated with the probability of a particular system state occuring to program design and policy actions.

3. Conceptual Limitations

The utility in applying decision analysis to a particular problem is diminished as the multiplicity of possible outcomes increases. It is often the case, however, that particular strategies are clearly preferable to others over the range of the underlying probabilities. The set of strategies which is thus dominated can then be eliminated and the problem reduced to a more manageable one. It is necessary, however that probability distributions of outcomes be known or assumed. Decisionmakers may be unable or unwilling to make such assumptions in the case of very unfamiliar environments. Furthermore, in the circumstances in which the decision is of extreme importance, risk aversion by decisionmakers may be such that only a very limited range of options would be considered in an operational context relative to a hypothetical exercise.

4. Other Comments

Decision theory is ascribed to by the Bayesian school of analysis. That is, intuition or subjective judgments are directly incorporated into the assignment of probability. There is an opposing school which feels that such judgments should not be incorporated into a formal analysis and furthermore that many key interpretive factors which should be used to apply a stylized analysis to the real world cannot be quantified. Thus in this view, the operational significance imputed to the results of decision analysis is misleading.

G. Game Theory

1. Description and Standard Application

Game theory describes the strategies of action of participants in an interchange, where each person acts according to his explicit preferences for joint outcomes. Each participant must decide his action on the basis not only of his preferences, but also his estimate of the other participants' actions (based on their preferences) because the outcomes are jointly determined. The rules of the game relate to the range of possible actions by a participant and the mapping of the set of actions by all participants into a particular outcome. Consider a game with two players. If the preferences of one player are diametrically opposed to those of the second, every gain in terms of the outcome for one player is a loss for the other. This is termed a zero-sum game because the gain in the total utility of the players in any outcome nets to zero. If this is not the case, a non-zero sum game, negotiation is possible to eliminate some strategies that are clearly dominated. Game theory is related to decision analysis in that it examines decisionmaking behavior under uncertainty. Game theory, however, is descriptive rather than prescriptive. It is neutral among participants in its insights. It is applied to examine possible strategies and outcomes given preferences of participants and the environment, and a preferred strategy for a potential participant in the real world must still be selected.

Gaming is applied to a wide class of problems in which it is necessary to examine the interaction of participants with conflicting objectives in a particular environment. Games often include role-playing by participants with computer simulation of outcomes, so that the players learn by experience the usefulness of particular strategies in light of the reactions of others. Alternatively, a team of players may be required to devise a strategy against a computer-generated reaction and outcomes are evaluated by some form of an autonomous control. Gaming is used to examine:

- politico-military strategies for potential environments
- military planning
- alternative outcomes of an oligopolistic situation for corporate planning
- development of management approaches

2. Suggested Application in Preparedness and Recovery Analysis

The primary application of gaming in recovery analysis would be the examination of the goal formation process. The examination would include:

- strategic interactions with adversaries and allies and implications for national security requirements, growth strategies, etc.
- integration of political, military, and economic factors in goal formulation
- impact of potential regional, urban-rural conflicts etc. on definition and attainment of national goals
- market behavior given varying levels of competition and regulation
- individual behavior in conflict situations.

3. Conceptual Limitations

Several problems arise when game theory is applied to complex real-world situations. As the number of players increases and the number of possible actions for each player multiplies, the analysis of alternatives becomes very costly and implications less clear, remembering that gaming is prescriptive and alternative strategies must still be evaluated. Second, evaluating the preferences of real-world participants may involve assumptions about consistent maximizing behavior that is not borne out in practice, e.g., at some points, corporate decisionmakers may be maximizing sales, staff-size, personal control, etc. rather than profit. Lastly, structuring the game so that that appropriate alternative choices of action are presented to participants and the rules of play are realistic may prove to be very challenging, particularly if experience with a particular environment is limited and the feasible set of actions is ill-defined, large, and constraints on actions are complex.

L. Information Theory

1. Description and Standard Application

Information theory provides a conceptual framework and methodology for the determination of informational efficiency of a system structure. It has important applications for the design of computer systems, automatically controlled production processes, etc. In application to economic systems, information theory is concerned with providing criteria for the evaluation of resource allocation mechanisms in particular environments. Two primary criteria have been developed in this regard. The first is informational efficiency. An allocation mechanism is informationally efficient if each decisionmaker receives neither more nor less information than he needs in order to make decisions optimally from the point of view of system objectives. The second criterion is information decentralization. A system incorporates allocation mechanisms which are effectively decentralized if a decisionmaker can arrive at optimal decisions only on the basis of information which pertains only to him and an aggregate set of information available to all decisionmakers. Thus in a perfectly competitive environment, market allocation is informationally decentralized because optimal decisions are arrived at by a producer with the knowledge of his own costs and relative market prices, similarly for a consumer who needs to know only his own income and preferences in addition to prevailing prices. Further, criteria for resource allocation mechanisms are developed concerning the ability to achieve equilibria with particular desirable chacteristics.

2. Suggested Application in Preparedness and Recovery Analysis

The methodological approach of information theory would provide important implications for the design of information systems for the recovery period which would be consistent with objectives, allocation mechanisms and the particular environment. Systems could be developed for the local, regional and national environments. In turn, the design of allocation mechanisms could be carried out in such a manner as to improve their informational efficiency and provide for a degree of decentralization concomitant with the orchestration of attainment of national objectives and the stringent informational constraints of the postattack period. These considerations would obviously become more critical with increasing degrees of disruption of preexisting structures and mechanisms, scarcity of information, and reduction of capabilities for information processing and dissemination.

3. Conceptual Limitations

There are several limitations in the application of information theory to this class of problems, given the current state of development. It is generally limited in application to small, relatively non-complex systems. It is also primarily oriented to competitive mechanisms in systems which tend to equilibrium. This may well not be the appropriate characterization of the postattack environment of interest. The approach, however, has been extended to a broader range of environments and does hold promise for further generalization which would have increased utility in application to recovery analysis.

I. Simulation

Simulation involves the repeated solution of a model of a system, while varying across solutions the settings of policy instruments or the values of variables which are determined outside the system. The sensitivity of solution values to this variation can thus be indicated. The preference for particular outcomes can then be evaluated, and conclusions drawn which relate desirable policy actions to alternative system states and environmental determinants of system performance outside the control of policymakers and exogenous to the system.

The technique is not separately evaluated here for applicability to preparedness and recovery analysis because the utility of this approach is determined only in relation to the model of the system with which it is undertaken. Thus it is discussed in conjunction with various modeling approaches described above.

J. Summary of Techniques

The following two tables present a tabulation of the applicability of the individual techniques under alternative analytical objectives and a brief summary of the character, capability, and limitations of the techniques. It will be useful for the reader to glance back at these summary tables at various points in the discussion in Section V in which key analytical issues are related to appropriate techniques.

TABLE 3:

TOOLS, TECHNIQUES AND THEIR APPLICATION

(Partial list of use and limitation of tools and techniques being addressed under Project)

	Goals and Prototypes	Production Possibilities	Control Mechanism and Instruments	Setting of Instruments
OPTIMAL CONTROL	✓	✓	✓	✓
SIMULATION	✓	✓	✓	✓
PROGRAMMING		✓		✓
SYSTEMS DYNAMICS	✓	✓	✓	✓
DECISION THEORY		✓	✓	✓
ECONOMETRICS		✓	✓	
INFORMATION THEORY	✓		✓	✓
INPUT-OUTPUT		✓		✓
GAME THEORY	✓		✓	✓

TABLE 4:

TOOLS AND TECHNIQUES--USES AND LIMITATIONS

TECHNIQUE NAME	TYPE	USE AND METHOD	LIMITATIONS
Optimal Control	Normative	Obtain control instrument settings given objective function and constraints	Computationally laborious, expensive Generally limited to small systems and few instruments
Simulation	Normative	Obtain response surface to exogenous change	Costly when performed with large nonlinear systems due to requirement for many iterations
Programming	Normative	Maximization of returns from allocation of inputs	Corner solutions. Costly and time consuming where feasibility space is large and complex
System Dynamics	Positivistic	Ascertain system response paths given initial state	Arbitrary selection of parameters; lack of maximizing rationale for behavioral limits. Validation often lackening
Decision Theory	Normative	Ascertain optimum behavior given uncertainty of outcomes	Generally limited to small sets of conditional possibilities; probability distributions must be known or assumed
Econometrics	Positivistic	Obtain descriptions of system structure and behavior via set of estimated equations	Needs for significant sample of consistent historical information to obtain system parameters
Information Theory	Normative	Obtain optimum network organization and information flow	Generally limited to small scale systems; highly complex in many applications
Input-output	Positivistic	Given outputs or inputs, obtain other quantities	Homogeneous of degree zero in system structure; often, coefficients are fixed
Game Theory	Normative	Obtain optimum strategy given uncertain response of opponent	Maximization and consistency assumptions Costly when feasibility space is large and game complex

V. Requirements for Analytical Systems

A. Choosing an Analytical Technique

Many of the elements involved in the choice of an analytical technique for application to a particular issue have been separately treated above. They include:

- identification of the analytical objectives; that is, is the issue a matter of examining
  - goal formulation,
  - production possibilities,
  - control mechanisms,
  - settings of instruments

  or the process in which these system functions are interrelated
- the environment in which the system operates
  - the degree of certainty with which one can describe system functions
  - the information that will be available to decisionmakers
  - the anticipated locus of decisionmaking
  - other environmental implications for system characteristics
- the spectrum of available techniques
  - information requirements
  - computational requirements
  - conceputal limitations
  - compatibility of techniques for application in hybrid analytical systems

The characteristics of individual techniques were treated in the preceding section, and the implications of three alternative environments were considered at the end of section III. The identification of key analytical issues and their relationship to analytical objectives was also begun in section III based on an examination of issues arising from a consideration of preparedness and recovery programs. A similar process was undertaken with the broader set of policy concerns developed in the conceptual framework.

The first and third categories of criteria indicated above, relating to analytical objectives and characteristics of techniques, were utilized to provide a set of candidate techniques for each of the analytical issues developed in the conceptual framework. In this section, the results of this process are reported, and then, making some assumptions about the nature of the environment, the second category of criteria are used to choose among these candidate techniques to formulate illustrative analytical systems.

B. Further Elaboration of the Conceptual Framework

Table 3 following presents, in essence, two more columns which can be appended to the conceptual framework in Section II. The first of these additional columns associates with each activity of the framework the key analytical issue or issues which must be addressed by decisionmakers concerned with the production of welfare in the society. These issues, as illustrated with a narrower set in Section III, can be assessed as to the analytical objectives in regard to system function.

The second of the additional columns is a result of an implicit consideration of the relevant analytical objectives as well as the capabilities and limitations of the individual tools and techniques assessed in Section IV. The candidate techniques appropriate for application to the relevant analytical issues are presented. The selection of a particular technique for incorporation into an analytical system as indicated above would depend on the particular environment and the compatibility with techniques applied to related aspects of system function. This is consistent with the theme that has guided all of the foregoing discussion, i.e., there is very limited utility in the analysis of any policy task in isolation from the total picture of system performance.

TABLE 5

ANALYTICAL ISSUES AND APPROPRIATE TECHNIQUES

Activity	Analytical Issues	Appropriate Techniques
<u>Non-Exclusive:</u> External Security ● Territorial Control	- defensibility of territory claimed	game theory, simulation
	- sufficiency of arable land, natural resources under control	input-output, econometrics, programming
	- viability of regional concentrations of population and economic assets as configured; optimal configurations	input-output, econometrics programming
	- requirement for dispersal of population and production for damage limitation in potential conflict; cost in terms of departure from optimal configuration	simulation, decision theory
● National Defense Forces	- requirements to meet current needs--personnel, armament, budgets	simulation, system dynamics, input-output
	- requirements to meet potential military contingencies	simulation, system dynamics, input-output
	- current-period opportunity costs of military expenditures	econometrics, input-output, programming
	- trade-off over time between military expenditures and economic growth	econometrics, programming
	- economic constraints on meeting specific defense-related objectives	input-output, econometrics, system dynamics
● Foreign Political/ Military Relations	- assessment of threat; comparative resources for and burdens of defense, current and projected	game theory; simulation, econometrics, system dynamics
	- feasibility and desirability of foreign economic relations--commodity composition and terms of trade	econometrics, programming

TABLE 5 (Con'd)

Activity	Analytical Issues	Appropriate Techniques
Demographic Change and Public Health		
• Population Profile	- impact on future demographic developments, societal patterns--tastes, mobility, requirements for social services	simulation, system dynamics, econometrics
	- impact on production possibilities--able-bodied participation rates, productivity, etc.	econometrics, input-output, programming
• Nutrients Available	- ability to produce subsistence levels	simulation, input-output, econometrics, programming
	- impact of consumption levels on productivity; variation in requirements by age and occupation	simulation, system dynamics econometrics
	- optimal mix of livestock and crop production	programming, simulation
	- opportunity costs of improving diet over time	econometrics, programming
• Public Health Status	- minimum expenditures to provide alternative levels of care (i.e. stabilize health status at designated levels)	programming, simulation, econometrics
	- return to additional investment in public health care	econometrics, system dynamics,
	- trade-offs with private health care	econometrics, system dynamics
Political-Economic System		
• Type of System	- impact on locus of decisionmaking	information theory, simulation
	- ability to mobilize resources to meet designated objectives	simulation, system dynamics, econometrics
• Concentration of Political Control	- pervasiveness of central priorities	information theory, control theory, system dynamics, econometrics
	- mobility of factors of production	(same as above)
	- impact on end-use composition of national product	(same as above)
	- impact on income distribution	(same as above)

TABLE 5 (Cont'd)

Activity	Analytical Issues	Appropriate Techniques
Political-Economic System (Continued)		
• Concentration of Economic Control	- desirability, feasibility of centralized planning--national, regional	information theory, simulation, control theory
	- design of policy instruments and controls--fiscal and monetary policy, wage and price controls	decision theory, econometrics, control theory
	- impact of controls on incentives	simulation, system dynamics
	- requirement for income redistribution	simulation, system dynamics
	- devolution of government control over time	simulation, system dynamics
	- implications of pattern of control for crisis mobilization	simulation, system dynamics
Government Services		
• General	- Resources required to maintain "law and order"	simulation, input-output
	- cost effectiveness of provision of services at local/regional vs. national level	information theory, simulation
• Social	- minimum vector of social services over time	simulation, system dynamics
	- cost effectiveness of providing services at local/regional vs. national level by public sector vs. private sector activity	information theory, simulation econometrics, system dynamics
	- impact of level of social services on productivity; on private consumption patterns	simulation, system dynamics, econometrics
	- opportunity cost over time of providing increased levels of social services	simulation, system dynamics, econometrics
• Commerce and Production	- efficiency of public sector activity relative to corresponding private sector activity	information theory, econometrics simulation
	- return to investment in infrastructure by public sector	econometrics, system dynamics, simulation

TABLE 5 (Cont'd)

Activity	Analytical Issues	Appropriate Techniques
Government Services (cont'd) • Natural Resources and Environment	- pattern of natural resources requirements, scarcities over time	input-output, econometrics, programming
	- ability of private sector to satisfy demand	econometrics, system dynamics, simulation
	- need to enforce central priorities in production and use, e.g., to provide for meeting potential military threat	control theory, econometrics, simulation
	- cost to repair, maintain environment at "acceptable" standards	econometrics, programming, simulation
Exclusive: Domestic Security • Basic Survival Amenities	- vectors of subsistence requirements over time: food, clothing, shelter, medical supplies	econometrics, system dynamics, simulation
	- production possibilities and inventories by region, over time	econometrics, input-output, programming, simulation
	- allocation mechanisms and distributional considerations	control theory, information theory, econometrics, simulation
	- impact of availability on incentives, productivity	econometrics, system dynamics, simulation
• Enhanced Survival Amenities	- production possibilities by region, over time	econometrics, input-output, programming
	- allocation mechanisms, distributional concerns	control theory, econometrics, system dynamics, simulation
	- impact on productivity	econometrics, system dynamics, simulation

TABLE 5 (Cont'd)

Activity	Analytical Issues	Appropriate Techniques
Domestic Security (cont'd) • Contingency of Personal Threat	- impact on productivity, asset accumulation, etc.	econometrics, system dynamics, simulation
	- impact on demand for private-sector goods and services	econometrics, system dynamics, simulation
• Personal Mobility	- impact on labor force by region and sector over time	econometrics, system dynamics, simulation
	- demand for transportation services	econometrics, programming
	- regional differences in standard of living	econometrics, simulation
• Private Health	- production possibilities by region over time	input-output, econometrics, programming
	- demand for private health services given alternative levels of public health care and health status	econometrics, system dynamics, simulation
Consumption and Leisure • Education and Training	- existing vs. desired mix of skills in labor force, by region, over time	input-output, econometrics, system dynamics
	- divergence of private vs. social costs and benefits of education and training	econometrics, programming
	- production possibilities by type	econometrics, system dynamics, programming
• Accumulation of Capital	- sufficiency of private capital formation to meet growth objectives	control theory, econometrics, system dynamics
	- operation of financial markets and impact on investment	decision theory, econometrics, system dynamics
	- relationship of private sector and public sector capital formation	control theory, econometrics, simulation
	- incentives for accumulation of human capital	econometrics, system dynamics

C. Recovery Environments and Analytical Systems

As the process is initiated here to design an analytical system appropriate for a particular environment it will be clear that some options will have to be left open. A choice among these options will depend on some very specific assumptions about the postattack environment that would be unfounded if based on the research undertaken here. In fact, in light of the very considerable cost of analytical system development, the speculative nature of much of the past research on the description of the environment provides an unsatisfactory basis for these choices. The environmental description which determines the design of an analytical system will in the end, of course, involve a probabilistic assessment of alternatives, but the band of uncertainty needs to be well understood and reduced if possible. Therefore, the environment descriptions employed here are quite incomplete and suggested analytical systems necessarily are only illustrative of design considerations.

1. The Light-Damage Environment

The key characteristic of this environment that guides design of an analytical system is the likelihood that the degree of disruption of the peacetime economic system after the immediate post-strike emergency will not be great. Let us first consider the problem of goal formulation. If the balance between national security and domestic concerns is not disturbed by a heightened state of international conflict, national objectives might be inferred from peacetime experience. This may well not be the case, however. The process of goal formulation may be represented via a gaming scenario in which the rules of the game are determined by the constraints on national decisionmakers anticipated in the light damage environment, that is, portraying a system much like the peacetime case.

Production possibilities could be examined via standard peacetime techniques, with some minor modification if necessary to handle special circumstances. Thus an econometric model would be an appropriate tool.

If recovery tasks varied significantly, due to spatial concentrations of damage, regional disaggregation within the model is called for. In order to identify key sectoral capacity constraints on system performance, a dynamic input-output system could be embedded in the econometric model, also on a regional basis if data permitted. Macro equation blocks would be required to represent all the various major elements of the system as in the peacetime model--production and factor supply and demand, end-use determination, wage and price determination, the financial sector etc.

Control mechanisms would be incorporated into the model specification. Except for early phases, when analyst intervention in model solutions would be of critical importance, control mechanisms would primarily be indirect, although somewhat enhanced over pre-emergency instruments. Thus, fiscal and monetary policies might be augmented by wage and price controls and increased activity by monetary authorities in regulating the financial sector.

The settings of instruments could be derived by the application of optimal control techniques. The macroeconometric model is reformluated as the system to be controlled. The cost function is defined via the results of the game. Targets for key state variables and constraints on the solution are similarly determined. The timing and levels of control instruments are then provided by the solution, as well as the deviation from the targeted trajectory.

Thus one may arrive at a possible analytical system for a particular environment. Informational requirements are seen to be time-series data for state variables. For instance, relevant dependent variables can be implied from the conceptual framework and from the specification of functional relationships which determine them. Both data collection and computational requirements for this system promise to be demanding.

2. The Moderate-Damage Environment

The moderate-damage environment entails significant disruption of peacetime processes, but the elements of the system, in terms of the locus of decisionmaking and production of welfare are likely to survive in some significant capacity. Regional and sectoral disparities in capabilities and even degree of viability are likely to be wide. Inputs for the maintenance of national security and domestic order may well be in short supply. Comparable capabilities of potential enemies will play an important role in determining requirements for defense activities. Information on production possibilities will remain difficult to obtain throughout the reconstruction process. As capabilities expand over time, the conditions will approach the light damage case but it is unlikely that as close an approximation of the preexisting system will be reconfigured. Goal formulation can not be easily inferred from peacetime or even prior emergency experience, and thus a game-theoretic approach then might be appropriate. A significant effort would be involved in designing the game to capture the elements of the decisionmaking environment.

Production possibilities would not be represented by an econometric model or input-output system based primarily on specifications and statistical estimation drawn from a peacetime period. Considerable modification of an econometric model would be required. New specifications could be based on previous emergency experience, on the implications of information theory and decision theory for the organization of production activity, and on the likely pattern of decisionmaking responses to system states under significant uncertainty. As greater modification of estimated relationships in the model takes place, it approaches system dynamics techniques. The tenets of macroeconomic theory, however, would probably not be completely discarded in the analysis of a moderate damage case.

If the regional disparities in levels and profile of economic activities are projected to be wide, a linked regional modeling approach may well be appropriate. Interregional ties would be dependent on notions of comparative advantage given surviving assets and on the capacity of transportation and communications networks. As the model or system of models takes shape, it could be apparent that particular industrial sectors will play a key role in constraining regional and/or national economic growth or in meeting the requirements for particular priority end-uses. For these sectors, then, the specific structure of operations may become critical to analysis of system performance. It is possible to develop a set of satellite industrial models, incorporating engineering and economic relationships, which would be linked to the core model.[1] The modeling approach for each industry would depend on particular conditions it faced in the recovery environment--complexity of technology, linkages to other sectors, spatial differentiation of processes, etc.

Control mechanisms to be incorporated in the family of models would be a mix of direct and indirect mechanisms evolving over time toward primary reliance on indirect controls, barring a repetition of emergency conditions. The design of control instruments and their impact on behavior would also draw heavily on decision theory and information theory. The amount of information available to policymakers would be a critical element in this design process.

Optimal control techniques could be applicable to the determination of settings of instruments in the moderate damage case as well. The nonlinearities and complexity of the system description, however, may limit this application. Alternative programming approaches to optimization, or repeated policy simulations may be required to provide guidance for settings of instruments in this environment.

3. The Very-Heavy-Damage Environment

In this environment, although it is assumed the rudiments of the national entity remain, the elements of the system that would prevail prior to a significant period of reorganization could not be expected to resemble in structure or function the preattack configuration. The meeting of requirements for national security, survival items, and domestic law and order would overshadow planning for a balanced recovery of prewar capabilities for a

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[1] Programming approaches to optimal production organization may prove useful for individual industry models.

considerable period. Regional and local concentrations of population would need to be as self-sufficient as possible and the reestablishment of production units would be accomplished with meeting local requirements as a primary goal. Areas which had suffered relatively little damage would have to shift resources into production of high-priority items and would have to replace flows from areas of heavy destruction. With severely reduced communications and transport facilities and a rudimentary financial sector at best, markets could not be relied on to allocate labor and scarce commodities. Key informational requirements would relate to inventories of essential resources and finished goods, fixed claims on those items (e.g., subsistence) and production start-up lead times and initial capacities. Again, a game-theoretic approach to goal formulation recommends itself. The goal formulation process should be analyzed at alternative levels--local, regional, and national and the integration of these sources of goal identification would consistute a major element of the analytical process.

Because the settings of instruments would most likely involve direct setting of production targets and allocation by rationing, the determination of production possibilities and instrument setting would form an integrated problem. A linear programming approach in which engineering considerations and biological requirements are primary in defining the feasibility space could prove to be one useful method for addressing this problem. When going from a static to a dynamic consideration of the problem, system dynamics approaches to moving the constraints through time could be employed. As sufficient reorganization and reconstruction takes place and the feasibility space becomes larger and more complex, a model of the system approaching the requirements of the moderate-damage environment could be envisioned. It should not be expected, however, that in time, the heavily damaged environment duplicates the moderate case because the radically altered system which takes shape in the earlier phases is unlikely to evolve into as close a replication of prewar relationships as in the case described in the preceding section.

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4. An Exemplar Analytical System

Initial reviewers of this study suggested the addition of an example of an analytical system developed to support analysis of a specific class of preparedness/recovery policy problems. This is attempted here in the interest of a clearer expostion rather than a recommendation for a research effort. As is indicated in later sections, it would be preferable to withhold the selection of items for a detailed research agenda until the formulation of a comprehensive research strategy is completed.

Given the discussion of the preceding sections, it is clear that the environment about which one might most readily speculate is the light damage case. Therefore the example of an analytical system will address issues in that environment. The class of policy problems will be that of damage mitigation--what categories of facilities are to receive high priority in an industrial hardening program. The key components of the analytical system can be suggested:

- a macroeconometric model which would provide for determination of demands and factors supplied (perhaps capital, labor, energy and material inputs) and would include blocks to determine prices, wages, financial flows, etc.
- an input-output system which would serve to impose detailed material input constraints on production
- an optimizing routine would maximize an objective function (with arguments being key endogenous variables of the macro-model to which are associated priority weights) subject to the input-output constraints.

Given initial conditions, and having established the relative priorities of various end-uses, the system can be simulated. The solution set will contain shawdow prices for sectoral outputs. Each shadow price will represent the increase in the value of the objective function which would result from relaxing the particular constraint one unit, i.e. the marginal utility of the sectoral output. This information would then serve to rank categories of industrial facilities with regard to the accomplishment of the stated objectives in the given environment.

The priority weights would need to be derived from outside this model. The model could be applied together with a game-theoretic model for this purpose or perhaps in a decisionmaking game with individuals playing the role of responsible officials. In the latter case, the results of model simulations provide decisionmakers with the consequences of their actions and can stimulate adaptive behavior in succeeding periods or iterations for a single period.

In the course of research, interregional flows or the characteristics of individual sectors may be identified as critical to the implications of results for program initiatives. Links to a set of regional models or satellite industry models with the macromodel are possible, and indeed these are features of models currently being developed for the peacetime economy. The preferred regional disaggregation, sectoral disaggregation, etc. are not obvious a priori. They are likely to depend on the nature of the environment and very much on data availability as well as the set of specific analytical questions which the model will be designed to address.

D. Preparation of a Research Strategy

The discussion of the preceding section was illustrative of design considerations for analytical systems based on a possible spectrum of recovery environments and a full range of analytical objectives. To undertake the development of a family of systems with which to meet such a broad variety of contingencies is certainly not feasible given development costs. Nor is the probability of success concomitant with the cost for developing each of these individual tools with regard to relevant application areas.

The task at hand is to couple careful assessments of the development costs and likelihood of obtaining a useful set of techniques with the probability of any particular environment occurring and the value of the availability of such tools for handling policy with regard to that environment. While such an effort is beyond the scope of this report, it is a manageable one and vital to the development of a comprehensive research strategy.

Second, a more consistent and comprehensive statement is needed of the missions in regard to preparedness and recovery with which central policymakers will be charged. This statement would relate not so much to the association of broad policy areas with an institutional structure, but rather to the operational concerns for the functioning of the socio-economic system. This definition of missions would also be a critical element in establishing priorities for a research strategy and perhaps for placing narrower bounds on requirements for analytical systems.

Third, analytical systems development must be carried out in concert with the design of information systems. It is clear that sufficient information for the evaluation of potential system performance in recovery or the operational guidance of the system during the recovery is not now collected in an appropriate format nor would be available given the lack of provision for such specific capabilities. The development of analytical systems would provide the requirements for information systems. These in turn are critical to the applicability of tools to particular classes of problems.

VI. Research Priorities and Design Considerations

A. Research Strategy

The magnitude and complexity of problems involved in formulating plans, procedures, and organizational structures for U.S. preparedness and recovery needs on first consideration appear to be overwhelming. If attention is limited to narrower issues, such as the hardening of industrial facilities or provision of adequate food supplies, the question is left open whether analytical results and program plans are consistent with overall welfare maximization and structural and behavorial interrelations between components of the system.

It is necessary, therefore, to conduct analysis within a total system framework which recognizes such interrelations and feedbacks to the extent practicable. A possible framework is presented in earlier sections of this study. This provides for comprehensive consideration of national objectives, trade-offs between these goals, identification of production possibilities, and segmentation of analytical issues.

Defining a research agenda within that framework requires a set of criteria for the establishment of analytical priorities. The key factors in arriving at priorities are the likely scenarios in which the results would be applied and the gains achieved by having prepared adequate plans and procedures, and of course, resource limitations (both cost and time) on the proposed research program. This process entails the assignment of the probabilities that particular environments might be encountered in light of military attack scenarios or potential natural phenomena. Further, given those alternative environments, it also requires the preliminary projection of benefits from proposed preparedness and recovery programs.

To arrive at a research design, not only the analytical requirements, but also the cost and feasibility of meeting those requirements must be addressed. Analytical techniques identified as appropriate for application to key issues in a given environment must be assessed in terms of cost, data, and time requirements, ease of implementation, degrees of confidence in and ability to validate predicted results, etc. A preferred research strategy then is formulated with due consideration of the results of the two preceding steps:

- priorities derived from estimates of the potential expected benefits from conducting and implementing results from various analytical studies,

- cost, time requirements and other characteristics of individual studies, as well as overall cost and time limitations.

When the expected results would be needed would influence the concrete research design as well. The research agenda would, of course, be subject to revision in light of subsequent findings and events, including the evolution of domestic conditions and international economic and political relations.

The prerequisite for the design of the detailed research agenda would be a refinement of the conceptual framework, of which this report has provided a prototype. The first step in that process is to arrive at an ordering by relative importance of an established set of national objectives in preparedness and recovery. As was attempted here, the segmentation of national performance into discrete activities is a second step. To each of these activities, characteristics of performance and appropriate indicators of achievement should be assigned. This effort should receive high priority, because from it will proceed the identification of principal analytical problems from which the detailed research agenda could be derived. It is not necessary, however, that the framework be fully elaborated before component problems can be addressed.

B. Recommendations

To reiterate, then, the step-by-step recommendations for the preparation and implementation of a detailed research strategy include:

Step 1: Prepare a statement of national objectives and supporting preparedness and recovery missions, i.e., refine the conceptual framework for the analysis to follow.

Step 2: Conduct a probabilistic assessment of potential reconstitution and recovery environments.

Step 3: Estimate the benefits to be derived from preparedness and recovery measures afforded by anticipated analytical capabilities.

Step 4: Structure candidate analytical systems and supporting information systems appropriate for given analytical tasks and environments.

Step 5: Assess the cost and time requirements for the development of the candidate systems.

Step 6: Based on priority ranking by expected potential benefit, individual system development requirements, and overall resource constraints, formulate a preferred research strategy.

Step 7: Implement the research plan, subject to revision in light of interim findings and the evolution of domestic and international events.

This multi-step approach to a research design is required although reasonable a priori expectations can be formed that selected tools will be among the set to be implemented for preparedness and recovery analyses. Clearly, econometrics, system dynamic, game-theoretic and other models will be among techniques which would rank high in priority. Without the initial steps of defining a framework and desired requirements in detail, however, launching research with particular forms of tools would be premature for a number of reasons:

- the highly specific nature of the applicability of particular tools with respect to alternative environments and analytical objectives;
- the dependence of analytical capability on the availablity of data,
- the potential utility of a tool may not be concomitant with the cost of development;
- the need to be highly selective in order to maximize the expected utility of the analytical systems developed, in light of what are likely to be stringent resource and time limitations
- even with the development of potentially useful analytical tools, the need for a total-system framework remains--are individual results consistent with national objectives and priorities, as well as with structural and behavioral determinants of system performance?

C. Contributions of This Analysis: Design Considerations

It is useful here to summarize what the authors of this report regard as the accomplishments of this research effort that will further the development of a comprehensive research design for analytical systems development. This study has:

- indicated the need for and defined, via the development of a prototype, a framework which relates the functioning of the socio-economic system to national objectives and trade-offs between those goals;

- provided an approach for the comprehensive identification of production possibilities and a taxonomy of analytical issues:
- examined a set of analytical tools and techniques and considered the capabilities and limitations of each with respect to recovery environments and analytical objectives;
- established the need to integrate individual techniques to meet analytical objectives and considered potential configurations of integrated techniques: and,
- recommended a step-by-step approach to formulating and implementing a research strategy for analytical system development.

The final section of this report will consider the state-of-the-art of model application to issues in economic recovery. This will serve to contrast the program proposed here with a research effort which has progressed rather fitfully over the past three decades.

VII. State-of-the-Art: Development of Analytical Systems for for Evaluation of U.S. Reconstition and Recovery Programs

A. Introduction

The succession of government agencies which have borne primary responsibility for the organization and coordination of U.S. preparedness programs and contingency planning over the past three decades have sponsored a number of research efforts aimed at the development of analytical tools with which to assess program requirements and effectiveness. On the whole, these research efforts have not resulted in new analytical capabilities directly applicable to a broad range of preparedness and recovery issues via an on-going long-term research program. Some of the reasons pertain, perhaps, to the shifting emphasis on and role envisioned for preparedness programs over that period. Secondly, conceptual and computational limitations recognized by both proponents and critics of those techniques called into question the advisability of relying on them to resolve detailed operational issues, such as concrete plans for resource management. Therefore, as indicated at the beginning of the preceding chapter, the primary research focus has been on limited issues in the absence of a total system framework for the analysis of performance.

The broader research which has been undertaken, it should be noted, has advanced the sophistication of analytical approaches to recovery analysis and provided insights into key recovery and preparedness issues that have altered the body of conventional wisdom which has guided the development of program initatives. Moreover, some modeling efforts have resulted in useful tools, primarily for application to issues of crisis mobilization and stockpiling, although falling short of broader requirements outlined in this report.

B. Addressing the Issue of Economic Viability

A primary motivation for the development of postattack economic models, especially in the late 1950's and early 1960's, was to address the question of whether the economy could function viably following a massive nuclear attack. The primary analytical tasks were to determine anticipated effective production capacities and thus the capability of supporting various levels of surviving population at or above subsistence levels. With a notable exception, the answer provided by these studies was that without doubt the economy would still be viable following an attack. Most of these studies shared some important shortcomings which they explicitly recognized:

- questions of organizational failures and social upheavals, even in the immediate post-attack period were assumed away·
- the use of historical values for key parameters was most likely inappropriate, both for technological relationships and establishment of end-use requirements;
- the principal technique employed was input-output analysis and results seemed to be very sensitive to the level of aggregation;
- the evaluation criterion, despite the quantitative analysis, was a very subjective measurement of viability.

The notable exception was the work undertaken at the RAND Corporation by Sideny Winter.[1] Winter formulated the recovery problem as one of reaching the point where production exceeds subsistence, fixed claims on output, and depreciation before surviving inventories are depleted. The specification was formalized in a highly aggregative growth model. Winter applied the model to a number of alternative sets of initial conditions to demonstrate that viability may not be assured. Despite the interesting results obtained by Winter, the approach was not further elaborated in later modeling efforts.

C. Resource Management Issues

A second focus of foregoing modeling efforts for the post-attack environment was the identification of guidelines for preparedness and recovery planning in regard to resource management. The work primarily proceeded from the notion that certain key production sectors could be identified which would be bottlenecks in post-attack recovery and would constrain the growth of the economy, given that the system was assumed to be viable. The standard approach was input-output analysis, usually with considerable sectoral detail. The issue of substitutability of inputs into production was handled primarily by alternative levels of aggregation and classification schemes, to which the

[1] op. cit.

results appeared to be quite sensitive. The substitution of final goods in deliveries to end-use was typically not addressed other than with a caveat.

The exception to the treatment of the problem without adequate consideration of these issues was represented by the PARM study.[1] PARM (Program Analysis for Resource Management), developed by the National Planning Association, was a set of computer models which were designed to interact via a set of decision-makers. Sets of input-output coefficients were replaced by factor files which accounted for lags between inputs and resulting output and functional relationships instead of fixed coefficients and could be altered to reflect substitution among inputs to production in order to break bottlenecks. Time-phased vectors of final demands were generated by a consumption submodel based on stipulations by responsible decision-makers. The input-output analysis was carried out iteratively with modifications in final demand requirements until a feasible plan was obtained. The PARM system was not optimizing, however, and while the end-result was a feasible plan, it was not necessarily the preferred feasible plan. As in the case of most of these exercises, no attempt was made to evaluate alternative outcomes, or only an assignment of some notion of priority for classes of activities guided the solutions. Another common problem was the lack of an appropriate data base which would enable an analysis to derive operational plans. A successor model which incorporated geographic disaggregation of activity was initiated, but the research effort was not continued beyond the prototypes for the system.

D. Operational Models

Despite conceptual and computational limitations inherent in the models described above, considerable experience with the application of mathematical models to economic analysis through a broad range of concurrent research could have served to expand the capabilities of further modeling efforts built on the earlier work. A refocusing of research priorities, however, resulted in shifting of effort toward narrower tasks--studies of industrial vulnerability, potential for crisis relocation of population, crisis mobilization and stockpiling, etc.

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[1] see M.K. Wood, "PARM - An Economic Programming Model," Management Science, Vol. II, No. 7, May 1965, pp. 619-680.

Over this period, a number of models were developed for and maintained by the Mathematics and Computation Laboratory of the Federal Preparedness Agency. While these models, as in the earlier resource management effort, are primarily input-output oriented, they exhibit the increased capabilities afforded by advances in computer technology and the application of mathematical models to economic analysis. Having recognized the problems of an appropriate database and lack of historical experience for the setting of key parameters, these models have been developed primarily to address disruptions of the peacetime economy rather than the post-attack environment. Applications, therefore, have included analysis of impacts of supply disruptions for key primary materials, stockpiling policy to support crisis mobilization, impact of emergency disruption and policy response, etc.

Two of the models, still in the development and testing phase, were anticipated to be applicable to analysis of a post-attack system. The Temcris model, developed by the Center for Planning and Research, is intended for the analysis of economic adjustments under emergency considtions, to include limited nuclear conflict. Demands are generated by a macroeconometric model and linked to an input-output model via a linear programming routine. The input-output system consists of fixed coefficients representing peacetime technology and the forecasts, moreover, are not normative.

The development of the DGEM (Dynamic General Equilibrium) Model was undertaken by Professor Dale Jorgenson of Harvard and intended to measure impacts of major emergencies--its possible applicability to catasrophic nuclear war remains to be explored. It combines a macro growth model with input-output analyses, in which the input-output coefficients are functions of relative prices and supply-demand relationships.

E. Observations

It is clear from the foregoing discussion that the state-of-the-art of the application of mathematical modeling to economic analysis and improvements in computational capabilities now offer considerably increased opportunity for new analytical approaches to recovery and preparedness issues. Moreover, insights derived from past approaches can be useful in developing new tools.

Even with the introduction of more sophisticated analytical techniques in the more recent research efforts, however, a key issue remains--the applicability of models incorporating peacetime relationships to environments which result from major disruptions of the socio-economic system. As this report has indicated, it is likely that alternative analytical techniques will be required to address environments which differ in the degree of disruption of peacetime relationships. The analytical framework which has been suggested, however, is intended to be applicable to the performance of the socio-economic system for whatever environment is appropriate to the evaluation of recovery and preparedness programs. Proceeding from that statement of analytical objectives, a total system analysis can be structured which will attempt to incorporate the relationships anticipated in the environment of interest. Thus, a continued research efforts holds the prospect of providing analytical capabilities which the earlier work reviewed had sought but not attained.

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DEVELOPMENT OF ANALYTICAL SYSTEMS FOR EVALUATION OF US RECONSTITUTION AND RECOVERY PROGRAMS (Unclassified)
SRI International, September 1980
DCPA01-78-C-0309, W.U. 4341D

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