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VULNERABILITY OF REGIONAL AND LOCAL ELECTRIC POWER SYSTEMS: NUCLEAR WEAPONS EFFECTS AND CIVIL DEFENSE ACTIONS

Brian K. Lambert, et al

Defense Electric Power Administration

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VULNERABILITY OF REGIONAL AND LOCAL ELECTRIC POWER SYSTEMS:

NUCLEAR WEAPONS EFFECTS AND CIVIL DEFENSE ACTIONS

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The application of the model to the electric power system in Orleans Parish, Louisiana is illustrative of a detailed evaluation technique which can be employed to assess local electric power system vulnerability and to relate it to the response of the larger, regional system. Aggregation of electric power system data from such local level analyses provides a relatively simple method for assessing the vulnerability of both the local and regional systems to disruptions caused by nuclear attack.

The analysis and evaluation reveals that a high degree of interconnection exists both within the region and with adjacent regions and, thus, only a widespread disaster could significantly affect the intraregional transmission network. However, a local system within this network can be completely disrupted. Generally, the conclusions may be stated as follows: (1) the regional electric power system can maintain its integrity when single nodes (generation) and associated links (transmission) are eliminated, (2) eliminations of combinations of components associated with a local electric power system results in reductions in regional system capacities and complete disruption of the local system. The report also contains a state-of-the-art discussion and an annotated bibliography.

DEFENSE ELECTRIC POWER ADMINISTRATION
DEPARTMENT OF THE INTERIOR
Washington, D.C. 20240

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by

Brian K. Lambert

Joseph E. Minor

FINAL REPORT
for

Systems Evaluation Division
DEFENSE CIVIL PREPAREDNESS AGENCY
Washington, D.C. 20301

Work Unit 4334B; Work Order OCD-PS-66-92

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FOREWORD

This technical report was directed by the Defense Electric Power Administration, Department of the Interior, under Work Order OCD-PS-66-92 with the Defense Civil Preparedness Agency, Washington, D. C., 20301. Texas Tech University, Lubbock, Texas, was retained by DEPA under Sub-contract No. 14-01-0001-1485 to assist in the investigative effort and to develop the report. Mr. Phillip Swart of DEPA served as project director, and Dr. Brian K. Lambert of the Industrial Engineering Faculty and Dr. Joseph E. Minor of the Civil Engineering Faculty at Texas Tech University served as principal investigators. The general objective of the program concerns studies and analysis of the effects of nuclear attack on regional and local electric power systems in order to provide improved methods, techniques, and technical information for the conduct of an electric power vulnerability analysis, and to obtain inputs to the definition of problems, the selection of objectives, and the analysis and selection of alternative future civil defense systems.

Penebaker

G. W. Penebaker
Administrator

ACKNOWLEDGMENTS

The comprehensive research program in resource systems vulnerability was perceived and implemented by Mr. George F. Divine of the Systems Evaluation Division, DCPA. The involvement of the Defense Electric Power Administration in a series of projects within the resource systems program has benefited both federal agencies, as well as the electric power industry. Mr. Divine's perception and direction regarding the conduct of this and previous efforts are gratefully acknowledged.

The authors also wish to acknowledge very helpful direct contributions made by electric power systems personnel who provided data and assistance: Mr. B. C. Hulsey of the Southwest Power Pool, Mr. Carlos O. Love of Texas Power and Light Company, and Mr. A. J. Bartlett of Middle South Services, Inc. Guidance and support provided by Mr. Phillip Swart, Mrs. Lori O'Neill, and Mr. George W. Penebaker of the Defense Electric Power Administration are also acknowledged.

ABSTRACT

A systems evaluation technique developed for the Systems Evaluation Division (Research) of DCPA is utilized in evaluating a specific local electric power system within the Louisiana-Southern Mississippi region. The model utilized in this evaluation is highly flexible and can be utilized for electric power systems of any magnitude from a local level to a national level. The general model concept employs the use of generation and demand nodes with transmission links, and includes an objective function which measures the response of a system to disruptions. Basically, the model is a constrained network flow model which is transformed into a modified transshipment linear programming format for analysis.

The application of the model to the electric power system in Orleans Parish, Louisiana is illustrative of a detailed evaluation technique which can be employed to assess local electric power system vulnerability and to relate it to the response of the larger, regional system. Aggregation of electric power system data from such local level analyses provides a relatively simple method for assessing the vulnerability of both the local and regional systems to disruptions caused by nuclear attack.

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S U M M A R Y

VULNERABILITY OF REGIONAL AND LOCAL ELECTRIC POWER SYSTEMS: NUCLEAR WEAPONS EFFECTS AND CIVIL DEFENSE ACTIONS

Defense Electric Power Administration
Department of the Interior

Work Order OCD-PS-66-92; Work Unit 4334B; July 1976; Final Report

Methodology and computer programs developed in previous DCPA sponsored efforts are employed in the work reported herein to assess the vulnerability of a local electric power system, and to relate system response to the functioning of the regional system of which the local system is a part. This procedure is built on the "triad" concept of inputs, thruputs, and outputs advanced by the Systems Evaluation Division as a basis for the conduct of systems evaluation studies. These conceptual formulations are made more specific in application to a specific, "area" size (county) electric power system.

The perspective for the evaluation determines the definition of the triadic terms. In the electric power system evaluation fuel becomes "input" and electric power is "output". This definition contrasts with the manufacturing system perspective which has both fuel and electric power serving as "crossflows". The systems evaluation proceeds along structured lines in which system inputs (fuels), thruputs (people, equipment, facilities), and crossflows (water, spare parts) are considered. Results are expressed as constraints on output in a format suitable for integration with outputs from other systems evaluation efforts.

Specific results of the illustrative example in which Orleans Parish in the Louisiana-Southern Mississippi Regional Model is impacted with a 5 MT weapon are: (1) the local electric power system cannot continue to function as a network as interconnect loops are completely disrupted, (2) the regional system retains its network integrity, although it suffers a 20 percent reduction in system capacity, and (3) demands in the affected region can be met with available power through the use of a CD planned and directed scheme of priorities for restoring transmission links to demand nodes (substations).

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I. INTRODUCTION

This report fits into a series of reports developed for DCPA which address the general topic of resource systems vulnerability. A general methodology built upon the "triad" concept advanced by FitzSimons (FitzSimons, n.d.)* is advanced in a manufacturing systems evaluation written by Lambert and Minor (1974). This general methodology is also employed in an electric power systems evaluation prepared for DEPA by Lambert and Minor (1973).

In this report, a computer oriented systems evaluation technique is applied to a local electric power system (Orleans Parish, Louisiana). This technique had been previously utilized in a regional analysis (Lambert and Minor, 1973). To make this document complete in itself, summaries of the "triad" concept and the previously developed systems evaluation methodology are presented (Section III). Results of the local systems evaluation are also related to reported results from the regional evaluation (Section IV). Civil defense (CD) actions indicated by this vulnerability evaluation are discussed in Section V. A state-of-the-art discussion (Section II) and an annotated bibliography (Appendix C) are also included in the report.

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*References in this document may be found by referring to the alphabetical List of References and finding author name and publication date, in that order.

II. ELECTRIC POWER SYSTEMS VULNERABILITY: STATE-OF-THE-ART

Considerable effort has been expended since the early 1960's to develop and apply techniques for assessing the vulnerability of electric power systems. The studies which have been conducted have ranged from "brick-by-brick" investigations to total systems analysis approaches. The major emphasis of the vulnerability research has been to develop recommendations to be used as guidelines for electric utilities to assist them in maintaining service during and after a nuclear attack. However, several other research objectives of importance have been achieved, including an analysis of the interactions of electric power systems with other resource systems. The following discussion is a detailed review of the state-of-the-art of vulnerability analysis of electric power systems.

An early study regarding the vulnerability of electric power systems was the "Power Area 7 - Project 1" study published by the Defense Electric Power Administration in 1961 (DEPA, 1961). The purpose of the study was the development of minimum recommendations to be used as guidelines for electric utilities to assist them in maintaining service during and after a nuclear attack. The approach utilized was to form three committees from the utility representatives in DEPA Area 7: Load Study Committee, Personnel Committee, and Facilities Committee. The Load Study Committee investigated three broad areas: (1) effect of fallout on load loss, (2) needed inter- and intra-system communications during and after an attack, and (3) adequacy of power systems interconnections. The Personnel Committee was concerned with developing plans for maintaining personnel on the job during and following a nuclear attack. The Facilities Committee studied three areas: (1) development of recommendations for physical facilities necessary for personnel protection, (2) development of recommendations for simplification of plant operations, and (3) development of recommendations for decontamination procedures.

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Although the recommendations presented by the committees were rather general, this study provided an insight to vulnerability problems that required additional study and also provided a potential starting point for further studies.

Further advancement in recommending procedures for maintaining service in the event of nuclear attack was made in the study, "Protection of Electric Power Systems," done by DEPA in 1962 (DEPA, 1962). This project had four major objectives: (1) determine to what extent greater protection can be attained, (2) recommend protective measures against sabotage, (3) examine industry stocks and inventories for adequacy following a nuclear attack, and (4) develop plans for dispersion of management. A survey type methodology was utilized with representative sampling of the industry. The representative sample included selecting power systems based on location, type of ownership, service area, and system size. In all, forty systems were sampled and these forty served 43 percent of the customers in the United States.

In general, the survey revealed that the companies in the industry have plans for continuing operation during emergency conditions. However, several further recommendations were made: (1) additional plans for security measures, (2) increase and disperse the inventory of spare parts, (3) more emphasis on radio communications, and (4) insure adequate fallout protection. The study also strongly emphasized the need for each utility to resolve its own emergency preparedness plans.

One of the first truly vulnerability oriented studies was performed by the Defense Electric Power Administration in 1962. This investigation, titled "Vulnerability of Electric Power Systems to Nuclear Weapons: Pilot Study - Region 1," was larger in scope than most previous efforts (DEPA, 1962a). Basically, the objective of the study was to develop and apply a methodology for determining the effects of nuclear weapons on a regional electric power system and to identify restrictive factors such as power service capability, interactions among essential resource systems, and resulting postattack problems. Essentially, the methodology which evolved can be summarized as follows: (1) determination of regional preattack resources, (2) assessment of damage to the system components (generation, transmission, population, and interconnections), (3) determination of postattack power capability, (4) estimation of postattack requirements, (5) identification of regional interconnected support, and (6) determination of power service vs. load requirements. A specific attack was used and damage assessments were made using two methods: (1) use of the National Resource Evaluation Center data, and (2) hand computed damage assessment. Based upon the postattack demand estimates and the postattack power system, the general conclusion was that the electric power industry met the drastically reduced requirements whenever the surviving transmission lines could reach the area of need.

The next major advancement in vulnerability of electric power systems was a joint effort between the Defense Electric Power Administration and the Office of Civil Defense (now the Defense Civil Preparedness Agency). This study was the most complete analysis made up to that time (1963) of an assumed full-scale nuclear attack on the entire electric power system of the nation (DEPA, 1963). Several important conclusions were made as a result of this study and are briefly described as follows: (1) the electric power industry has the capability to provide service during shelter confinement period and during the recovery period, (2) load denial resulted primarily from blast effects on transmission and distribution systems, (3) the generating capacity of the nation is at all times in excess of the load requirements, and (4) the major problem of the electric power industry is fallout and continued attention should be directed toward providing fallout protection for operating personnel. Although comprehensive and detailed, this study dealt with the effects of a specific attack rather than with the development of a general vulnerability evaluation procedure. In addition, no consideration was given to the systemic effects of a nuclear attack.

In 1963 the National Engineering Science Company proposed a step-by-step method for predicting electric power availability following a nuclear attack (NESC, 1963). Basically, the proposed method involved five steps: (1) predict the environment produced by a given attack, (2) determine and collect power system data, (3) define bomb damage tolerance criteria for the power system components, (4) determine substation power availability as a function of time, and (5) assess power availability to specific consumers. The study was not concerned with assessing vulnerability but considered a detailed procedure for estimating available electric power following a nuclear attack. Also contained in the report are useful overpressure - damage relationships for electric power system components.

The Defense Electric Power Administration conducted another regional electric power system vulnerability study in 1963 (DEPA, 1963a). The investigation concentrated on a nine state region, and the conclusions drawn from the analysis were similar to previous studies in that it was found that the amount of demand lost was considerably greater than the generating capacity lost.

In 1966, DEPA published a report which was aimed at aiding the electric power industry in the area of civil defense preparedness (DEPA, 1966). One section of the report addresses the problem of vulnerability and the attendant evaluation of facilities and services. The report provides management with checklists which provide a framework for specific tasks within six major objectives. The major objectives cover: (1) corporate continuity, (2) continuance of generation, transmission, and distribution, (3) reduced vulnerability of physical properties, (4) personnel protection and survival, (5) civil defense training and operation, and (6) relations with other organizations.

One of the first studies intended to develop a general methodology for assessing electric power system vulnerability was conducted by Stanford Research Institute (SRI, 1966). Three analytical techniques were developed for assessing the effects of nuclear weapons on electric power availability at the transmission level. One method is a rapid qualitative technique which can be applied for comparing effects over large geographic areas and several hypothetical attacks. The second method utilizes a linear programming model to assess the relationship of supply and demand and to provide an optimum solution for delivering power in a disrupted system. The third method provides for determining the amount of deliverable power and the size and location of the demand that can receive power. The study also included the development of procedures for estimating population related postattack demands for power at various points in time in the postattack period.

Several years of research effort resulted in the Defense Electric Power Administration publishing the Electric Power Emergency Operations Handbook (DEPA, 1967). The purpose of the handbook is "to outline the organization, define responsibilities, and describe those actions which can be anticipated under present mobilization planning to be performed by government and electric utilities in planning for and for operating during national defense emergencies."

The next significant vulnerability evaluation research effort to be undertaken was the Five City Study. This effort was the first attempt to bring together interactions between the component resource systems into a meaningful systems evaluation (OCD, 1965). With respect to electric power systems, "brick by brick" analyses were made for San Jose, California (DEPA, 1967a), Albuquerque, New Mexico (DEPA, 1969), and Detroit, Michigan (DEPA, 1970). These studies were highly detailed in nature and dealt primarily with the determination of the physical damage to various components of the electric power system of a given city for a given attack. Although detailed and informative, the Five City Study did not provide analyses of secondary intersystem responses, such as the effects of power system damage on the operation of manufacturing systems.

In the early 1970's the Defense Civil Preparedness Agency began a systems evaluation program which considered systemic interactions among various resource systems. This program was conceived and implemented by the Systems Evaluation Division (Research) under the direction of Mr. George F. Divine. A principal objective of this program was to overcome the lack of comprehensive system interaction analyses common to previous studies. With respect to electric power, a systems vulnerability evaluation was conducted by DEPA under DCPA sponsorship and the results were published in 1973 (Lambert and Minor, 1973). The model developed in this research can be utilized for electric power systems of any size ranging from a local level to a national level. The model employs the use of nodes, links and an objective function which indicates the response of a system to disruptions. The approach used involves a constrained network flow model which is transformed to a modified transhipment linear programming format for analysis. The model was utilized on a regional electric power system (Louisiana - Southern Mississippi) to determine the effects of several types of disruptions on the total system.

In addition to total systems analyses of the type conducted by Lambert and Minor, research is being conducted in the area of power system vulnerability to electro-magnetic pulse. One study conducted at Oak Ridge National Laboratory was concerned with assessing the possible effects on commercial electric power systems from the electromagnetic pulse (EMP) produced by high altitude nuclear detonations (Nelson, 1971). The study considers the type and probability of damage to various types of equipment from EMP effects and addresses countermeasures which will reduce disruption and effectively harden electric power systems. Another report published in July, 1972, entitled "EMP Protective Systems," presents a description of representative problems and solutions for providing protection against a nuclear electromagnetic pulse (DCPA, 1972). Protective information is provided for several different types of equipment, including antennas, telephones, power equipment, and controls.

In summary, vulnerability evaluations of electric power systems have progressed from detailed, specific analyses of particular systems reacting to a specific nuclear attack to general methods of evaluation using sophisticated modeling techniques. The next step necessary in the research effort is the development and utilization of a technique for evaluating: (1) how systems which interface with electric power systems actively influence the power system, and (2) how the electric power systems influence other resource systems, directly and indirectly. The first area (Item 1) is the topic of this report, while Item 2 (above) is considered in a report on resource systems vulnerability (Lambert and Minor, 1974).

III. GENERAL ANALYSIS PLAN AND THE ROLE OF ELECTRIC POWER SYSTEMS

A. General Systems Structure and Vulnerability Methodology

Considerable research on the vulnerability of resource systems has been completed (See List of References entries under Minor, Lambert, Boseman, Checchi, DEPA, Grigsby, Hamburg, Pryor, Stephens). Basically, the systems concept embraces the idea that any organization is a system made up of segments, each of which has its own function and goals. The utilization of system evaluation techniques implies that the entire system should be examined and that an understanding of the interrelationships among the various components which constitute the system should be obtained. In other words, simply examining the performance of each component of a system will not yield a reliable estimate of the performance of the entire system.

A resource system -- as defined by Lambert and Minor (1974) -- is considered to be composed of four major supporting systems: (1) electric power, (2) transportation, (3) oil and gas, and (4) water supply and sewerage; and one major producing system: manufacturing. Each of these major systems of the resource system contains several components, as depicted in Figure 1. These major resource systems are highly interrelated -- the functioning of each is dependent upon the performance and outputs of the others. Previous studies have examined in detail the characteristics and functioning of each of these subsystems as independent entities. The purpose of the research reported herein is to determine the vulnerability of electric power systems in a context which recognizes that the manufacturing, electric power, oil and gas, water supply and sewerage, and transportation systems act together as a single unified, interrelated system.

For the purpose of this investigation which emphasizes the electric power component, it is useful to consider the electric power system as the principal point of evaluation and to view the manufacturing, oil and gas, water supply and sewerage, and transportation systems as systems which interface with electric power systems.

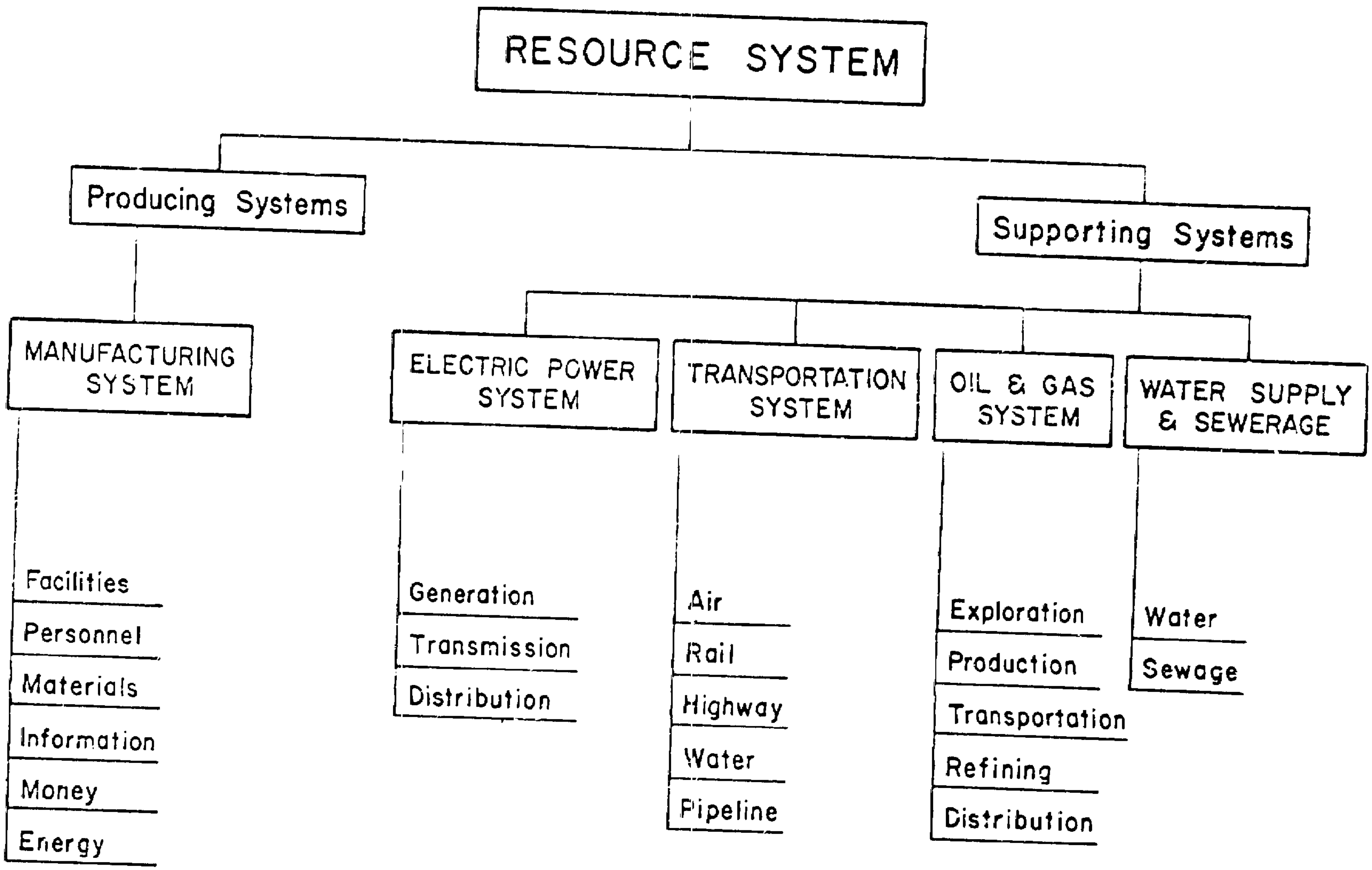

FIGURE 1. RESOURCE SYSTEM COMPONENTS

1. General Terminology and Methodology

A general method for evaluating systems has been proposed by FitzSimons (FitzSimons, 1972) and involves the use of triads. A triad is defined as the smallest functionable system and consists of three components: input, thruput, and output. Basically, as depicted in Figure 2, the thruput acts upon the input to produce output which is input that has been altered in form, function, state, status, or location. The triad concept can be utilized at any level desired: regional systems, specific industries (i.e., SIC major groups), individual manufacturing plants, or specific functions identified with electric power systems. The series of operations required to produce, transmit, and distribute electric power can be represented by a sequence of triads. Besides the elements of input, output, and thruput, another element, termed crossflow, may exist. According to FitzSimons, there may be flow into the thruput which is not transformed into output and, therefore, is not input; this type of flow is called crossflow. Examples of crossflow -- described in the context of an electric power system -- include fuel, water, transportation service and, where spare parts are concerned, manufacturing.

2. General Resource Systems Model

The first step in the vulnerability evaluation process involves structuring of a general model which can, in turn, be utilized in the evaluation of specific systems of interest. The general model structure advanced in this section of the report incorporates pertinent concepts and components of models previously advanced by FitzSimons (1972, n.d.) and by several DCPA contractors. Previously completed research efforts which address the modeling of resource systems in this context include Minor and Lambert, 1972; Lambert and Minor, 1973a; and Lambert and Minor, 1974.

Figure 3 shows a general schematic diagram of the resource system model and analysis methodology employed in the most recent resource system evaluation. Basically, the model characterized resource system response to a disruption (nuclear attack or other perturbation) by using a data base and three major analysis steps: (1) disruption

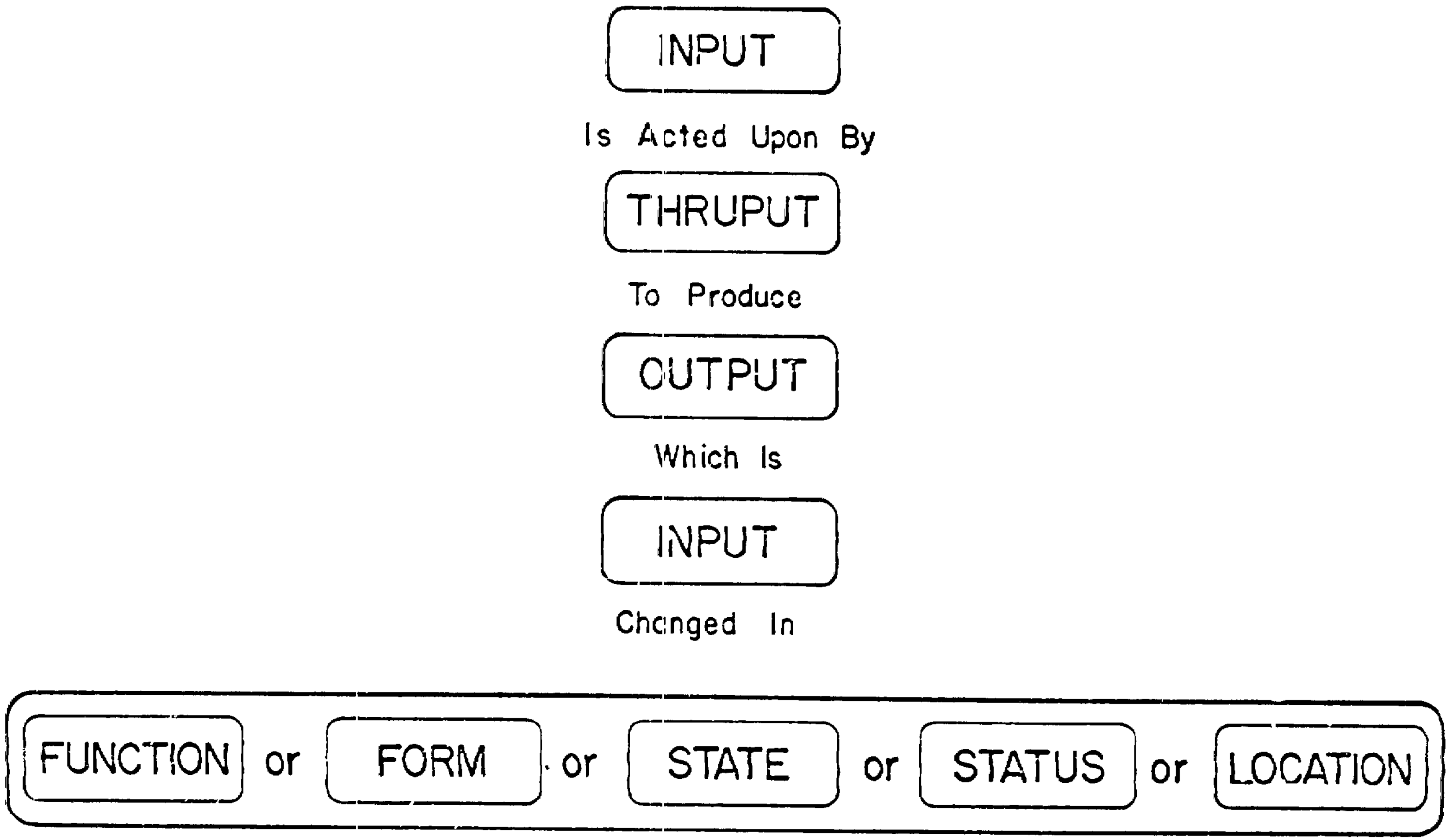

FIGURE 2. NATURE OF A TRIAD

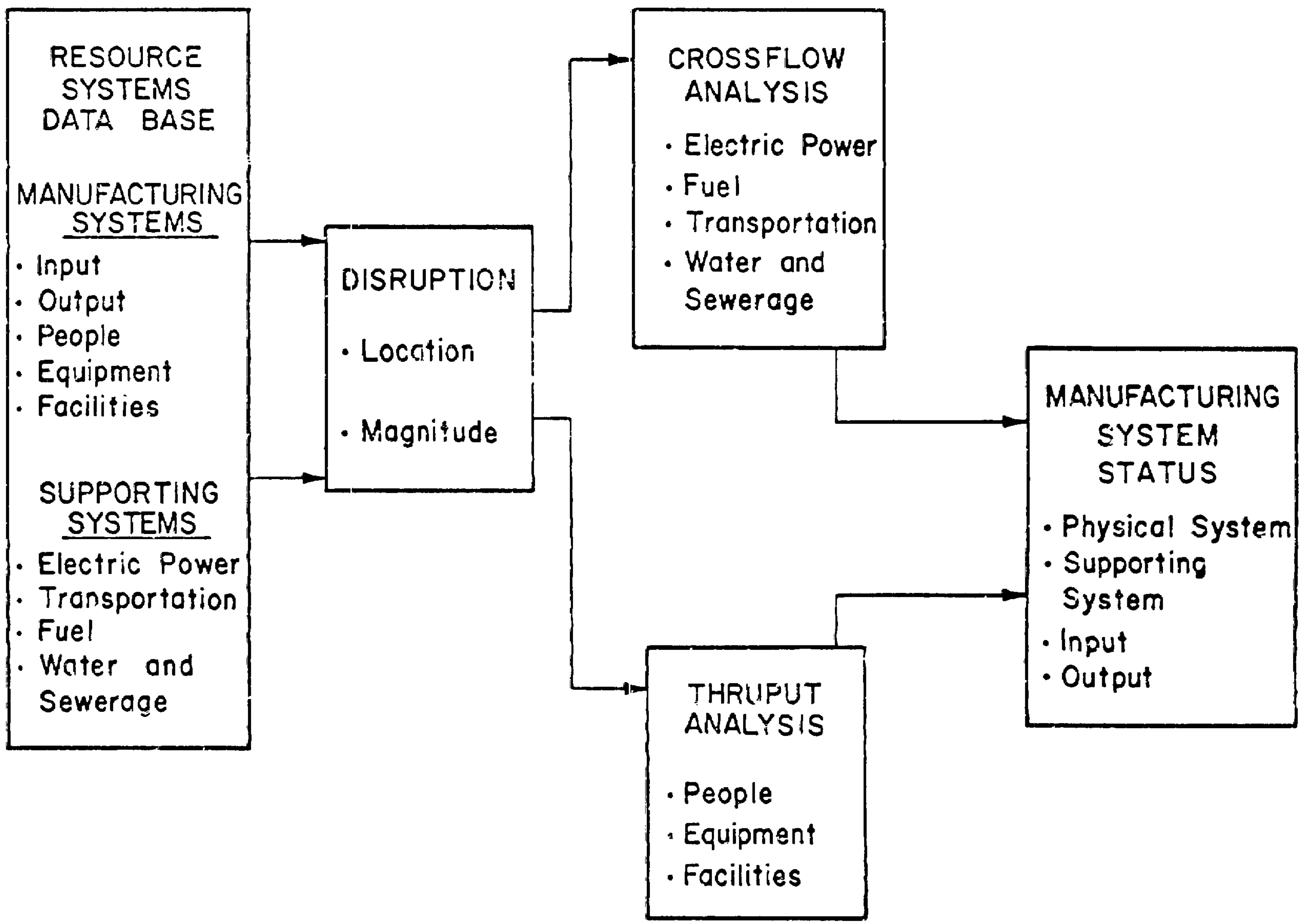

FIGURE 3. FLOW CHART OF RESOURCE SYSTEMS MODEL

imposition, (2) crossflow and thruput analyses, and (3) determination of manufacturing system status.

The manufacturing resource data base includes pertinent information regarding the manufacturing system for the particular region being considered. This information consists of identification of all SIC coded industries within the region, the number and size of such industries, the location of the industries, and major input requirements.

The crossflow and thruput analyses are concerned with the impact of a disruption on human resources, production and supporting equipment, and facilities. These analyses include examination of electric power, fuel, water supply and sewerage, and transportation systems.

Given the location and magnitude of a disruption, analyses of the inputs, thruputs, crossflows, and outputs of a particular SIC industry group results in a determination of the status of that industry in the immediate postattack period. By performing the same analysis on all SIC coded industry groups within the study region, and by aggregating the results, the status of the regional manufacturing system can be determined (Lambert and Minor,1974).

This general methodology -- developed initially for resource systems vulnerability evaluations -- can be applied to any one of the component systems. In the case of electric power system vulnerability evaluations, the principal system is the electric power network itself, with crossflows now consisting of fuel, water, and, to a certain extent, manufacturing. This electric power system model structure is described in detail in Section III.B.

B. Electric Power System Structure

The electric power system plays a supporting role in the general context of resource system operation (Ref. Fig. 1). To make a detailed evaluation of this role, it is necessary to look at the electric power system as the principal system, and to depict systems which interface with electric power as peripheral systems. This revised perspective is presented in terms of triads in Figure 4. Here, it may be seen that

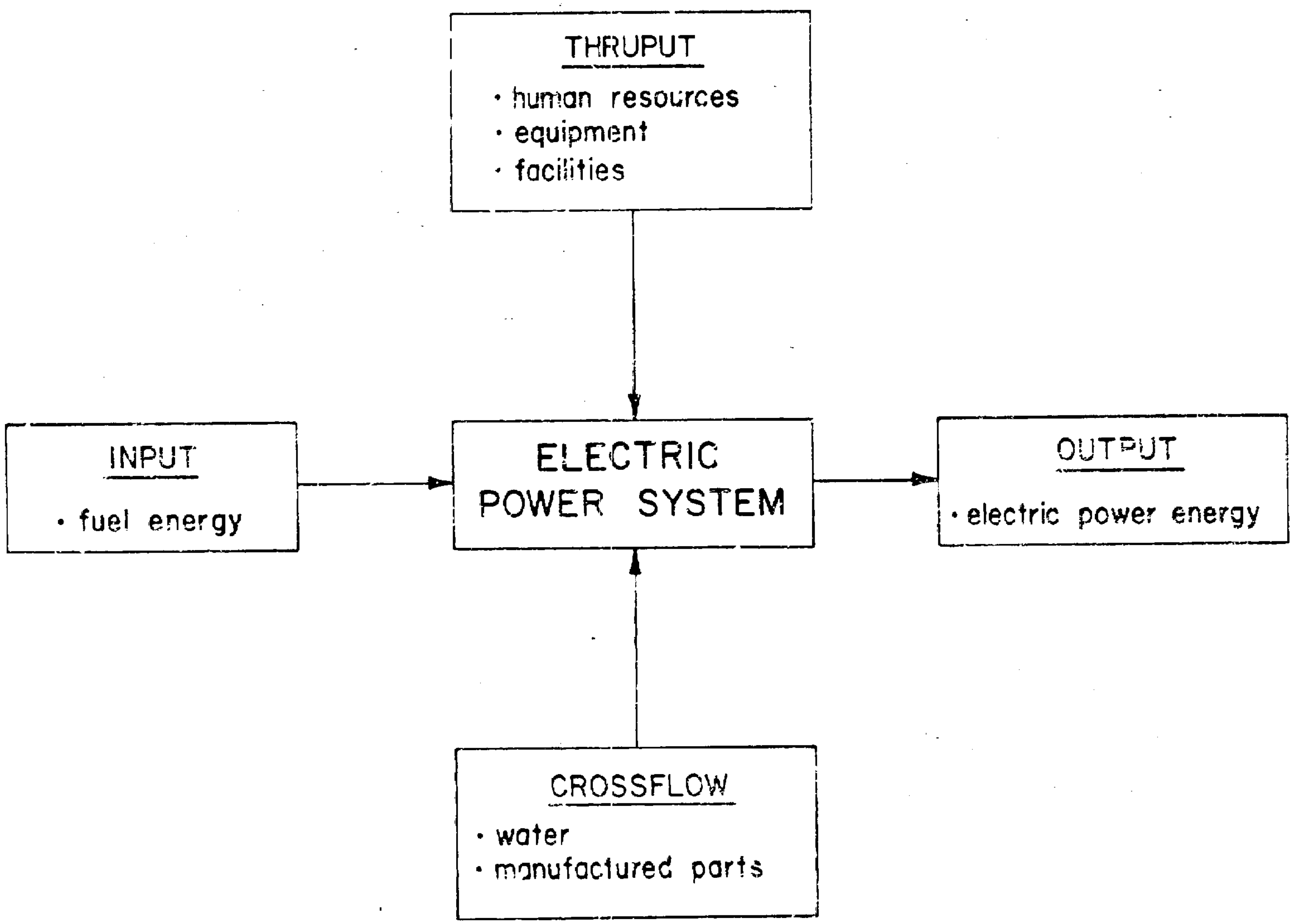

FIGURE 4. TRIADIC REPRESENTATION OF AN ELECTRIC POWER SYSTEM

input is fuel energy and output is electrical energy, crossflows include water and certain manufactured parts, and thruputs include people, equipment, and facilities. The change in perspective is evident when it is noted, for example, that in the case of a manufacturing operation, fuel is a crossflow and manufactured products are outputs (Lambert and Minor, 1974; Fig. 4).

Once this new viewpoint has been established, it remains only to place the electric power system into this context. Thus structuring of the electric power system can be done on a broad scale -- such as was done in the regional level in the Louisiana-Southern Mississippi study (Lambert and Minor, 1973), or on a smaller area scale such as is done for a specific area in New Orleans in Section IV of this report. The detailed model structure is presented in Section IV; it is sufficient to say at this point that the model structure involves three types of components: (1) generating nodes, (2) links, and (3) demand nodes. Generating nodes in the area scale model are generating stations, links are actual transmission lines, and demand nodes are substations. To provide a manageable model in the regional evaluation (Lambert and Minor, 1973) it was necessary to aggregate generation, transmission, and demand by parish; in the smaller area scale evaluation, the model involves only a few such aggregations -- involving, principally, the combining of adjacent substations into a single demand node.

IV. ELECTRIC POWER SYSTEM VULNERABILITY

The general procedure for evaluating the vulnerability of resource systems and the place of electric power in such evaluations was described in Section III. This section discusses in more detail the development and application of the vulnerability evaluation model to electric power systems. The procedure for assessing the vulnerability of electric power systems which has been developed is general in nature. The procedure can be applied to small scale systems (such as an individual city or county) or to large scale systems (such as a group of counties or a state). In addition, the method can be used to evaluate a series of small, area size systems (e.g. the system in a specific city). The results of several such evaluations can then be aggregated over a larger area.

A. General Vulnerability Evaluation Model

Figure 5 is a flow diagram which outlines the procedure utilized in the vulnerability evaluation of an electric power system. The input data includes the intact (pre-disruption) generating capacity, the locations of generating stations, the intact transmission network, and the location and magnitude of the disruption. The initial decision block in the procedure is concerned with whether or not the generating component of the electric power system is functional. This decision is determined for the generating stations by knowing the location of the disruption and by conducting a generating station damage analysis, a fuel supply analysis, a personnel availability analysis, and a supporting systems analysis. If it is found that the generating component is functional, then the next step is the determination of post-disruption output capacity at each generation station. If the output capability is 100 percent of the "system intact" level, the analysis proceeds to the transmission component. If the output capability is found to be less than the "system intact" value, then the generating capacities at each station are adjusted to show this reduction.

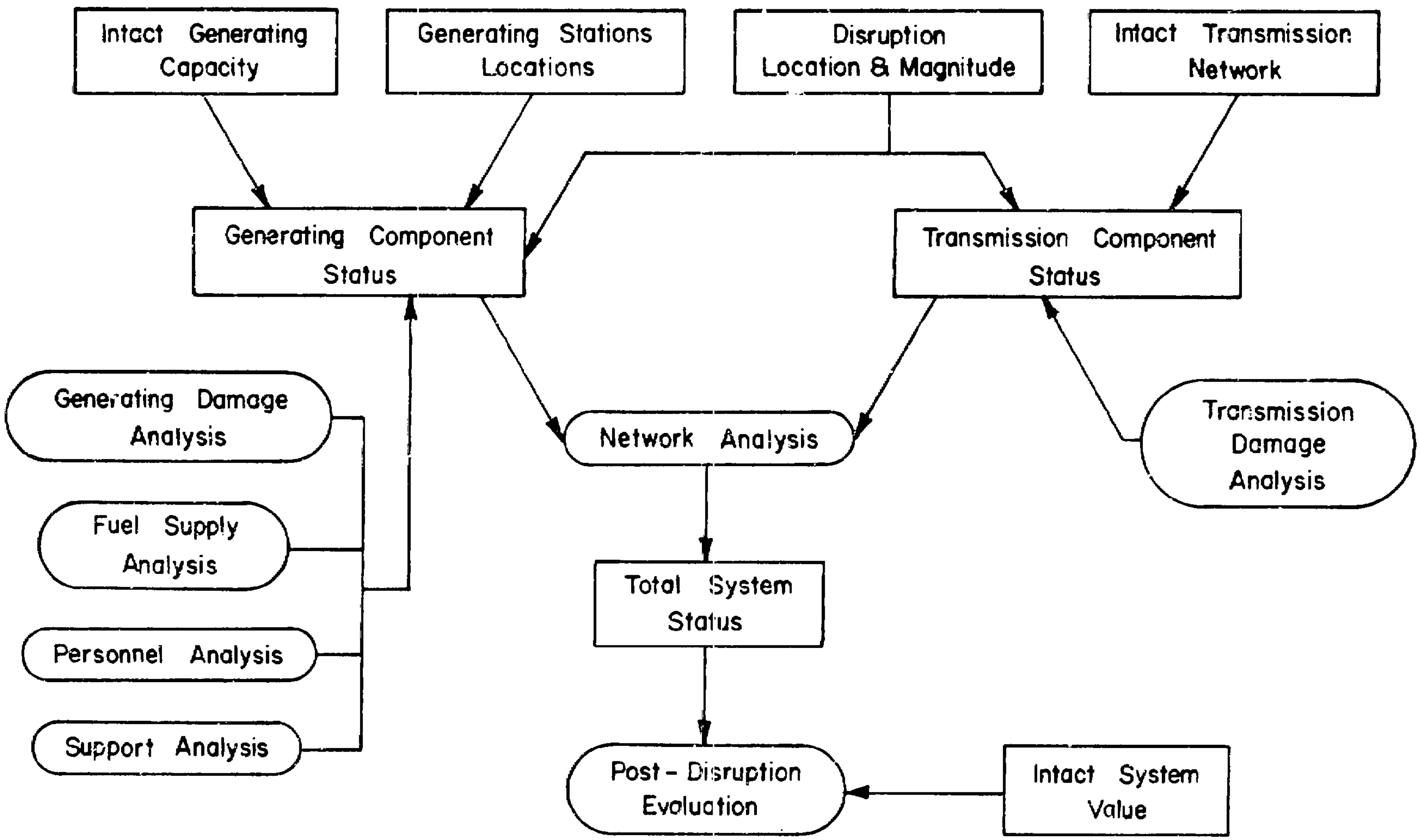

FIGURE 5. VULNERABILITY EVALUATION OF ELECTRIC POWER SYSTEM

The next step in the procedure is an evaluation of the status of the transmission component of the system. The initial decision block in this phase of the evaluation is concerned with the functional level of the transmission component. This determination is based upon the location and magnitude of the disruption, a transmission subsystem damage analysis, and a network analysis. If the transmission capabilities are found to be less than the system intact value, then the network is adjusted to reflect this reduction.

By combining any adjustments to the generating output and the transmission network, the adjusted or post-disruption electric power system can be defined. The end result of the analysis is the determination of how much, if any, electric power can be made available at a given node (demand point). This data can then be utilized to assess the impact of the disruption on the ability of the electric power system to perform. For example, available power can be compared with respect to the post-disruption demands at a given node. The following paragraphs present more detailed descriptions of the vulnerability model components.

1. Input Data

For any given electric power system being evaluated (i.e. regional or area), the basic input information includes the location and capacity of generating stations, the transmission network, system demand, and the location and magnitude of the disruption.

Information regarding the generating component of the system should include:

(1) Station name and coding,

(2) Capacity,

(3) Latitude and longitude,

(4) Type (steam, hydro, etc.), and

(5) County location (name, RSAC code designation, etc).

Additional information which might be useful to the evaluation includes percent of total regional or area generating capacity represented by a given node, the nearest urban node, a vulnerability rating of the generating node, and a criticality rating of the facility to the operating network (see FitzSimons, 1972). An example of a coding method for generating stations that has been designed for computer usage is described in Section IV.B.

The transmission network input data includes the capacity of each line and the nodes connected by the line. Additional useful information might include the type of structure of the line (e.g. steel tower, wood H structures). Each line may be identified by a single number, or by two numbers, which indicate the nodes connected by the lines.

The third set of basic input data to the model is the network demand. Demand information can be classified into three major categories: (1) manufacturing demand (SIC code groups 19 through 39), (2) residential or population demand, and (3) other demand. The latter classification consists of commercial energy use, municipal uses, agricultural demands and all other demands other than for manufacturing or residential purposes. By classifying demands in this manner more flexibility is possible in evaluating the impact of a disruption on the system. Analysis of disruption impacts can be based on total demand, manufacturing demand, residential demand, other demand, or any combination desired.

The last group of input data is concerned with the locations and magnitudes of disruptions. This information is necessary for use in damage assessment procedures which are integral parts of the evaluation procedure.

2. Generating System Node Damage Analysis

The initial step in the vulnerability evaluation procedure is to determine the functional level of the generating component of the electric power system under study. One of the factors in finding the output capacity after a disruption is a generating node damage analysis. This analysis is intended to determine the direct effects of a disruption on generating stations within the nodes defined for the model.

Assessment of damage to a generating station can be performed at various levels of detail. A very simple assessment method requires only the location of the weapon, the size of the weapon, and the type of burst. This simple method assumes that at an overpressure of 5 psi or greater the system component is unoperable and at levels of less than 5 psi the major system components are assumed to be 100 percent functional. This simple assessment method is used herein for illustrative purposes only; much more refined damage assessment techniques are used in actual vulnerability evaluations.

To utilize this damage assessment method, the distance of a facility from ground zero, the size of the weapon, and the height of burst must be known. The following information can then be used (derived from Glasstone, 1962):

Weapon Size (MT)	5 psi Radii	
	Surface	Optimum Burst Height
1	2.7 mi	4.3 mi
5	4.7 mi	7.3 mi
10	5.9 mi	9.2 mi

For example, this damage assessment procedure indicates that a 10 megaton surface burst would render any electric power component within 5.9 miles of ground zero inoperable. If the weapon was detonated at its optimum burst height any facility within 9.2 miles would be inoperable.

3. Fuel Supply Analysis

A second factor of importance in determining post-disruption generating capacities for each generation node is a fuel supply analysis. A major input to a generating station is the fuel to be converted into electrical energy; consequently, the status of the fuel supply is of considerable importance in assessing the vulnerability of the generating component of electric power systems. The fuel material can be coal, fuel oil, or gas, and, in some cases, more than one type of fuel can be used. In the event that the primary fuel source is not available, the type of alternative fuel and the days of operation that are possible by using the alternate fuel must be known.

Development of a total model for assessing the impact of nuclear weapon induced disruptions on the fuel supply system is beyond the scope of this research effort. However, two recent reports address the problem of the vulnerability of petroleum systems and natural gas systems (Stephens, 1973; Stephens and Golasinski, 1974). The results of these two studies could be formulated into a vulnerability evaluation model similar in format to the one shown in Figure 5, and the systemic effects of fuel supply disruptions on the electric power system could be determined.

4. Personnel Analysis

Another factor to be considered in determining the functional level of the generating component is the availability of operating personnel. For example, a 175 MW generating station has the personnel shown in Table I (DEPA, 1969). An initial phase of a personnel analysis would be to determine the minimum number of skills required to keep the generating plant operable for a given period of time. Next, an analysis to determine the availability of personnel after the disruption would be done. For estimating personnel casualties models such as TELOS (Test and Evaluation of Local Operating Systems) can be utilized (FitzSimons, 1971 and 1973).

5. Support Analysis

A fourth factor to be utilized in determining the post disruption generating capacity is termed support analysis. Numerous supporting systems are necessary to keep a generating station in operation. Such supporting systems include water supply, communications, maintenance equipment, control systems, spare parts supply systems, and many others. At the present time, little research has been done to evaluate the systemic effects of supporting system disruptions on the ability of electric power systems to function. Consequently, additional work should be done to examine the response of supporting systems to disruptions.

6. Network Analysis

After the post-disruption status of the generating component of an electric power system has been established (through the use of model components just described) the next step in the vulnerability evaluation is to assess the condition of the transmission system.

TABLE I.

175 MW GENERATING STATION PERSONNEL
(From: DEPA, 1969)

Skill	Number of Persons
Superintendent	1
Operators	8
Apprentice	6
Sr. Aux. Operator	2
Aux. Operator	2
Jr. Aux. Operator	1
Utility Helper	3
Mechanic Working Foreman	1
Mechanic	1
Mechanic Helper	1
Electrician Working Foreman	1
Apprentice Electrician	1
Control Instrument Working Foreman	1
Control Instrument Maintenance Man	2
Laborer	1
Clerk	1
Total Personnel	33

First, a transmission damage analysis is performed to identify those links which have been eliminated or damaged. A simplified procedure such as the one presented in the discussion of a generation node damage assessment can be used.

After damage to the transmission component of the system has been determined a network analysis is performed. The network analysis examines the status of generating nodes, links, and demand nodes (e.g. substations for the area model) to determine where and how much electric power is available. An example of such a network is shown in Figure 6.

A flow network such as the one shown in Figure 6 may be converted to a linear programming model for analysis purposes. Such a method of analysis allows for simultaneous assessment of the entire system under study. In the case of electric power systems the conversion from a flow network to a linear programming format results in a modified transhipment model. The transformation of the flow model to a linear programming format requires the development of a set of constraints for the generating nodes, demand nodes, and transmission lines. In addition, an objective function must be developed which will reflect the reaction of the system to disruptions. That is, some measure of effectiveness of the electric power system following a disruption must be available if post disruption system effectiveness is to be assessed.

For a generating node a constraint is necessary so that net outflow does not exceed the generating capacity of the node. The general form for such a constraint is given by:

$$\sum_{i=1}^{n} x_i = G$$

where the x_i's represent flow values and G is the nodal generating capacity.

For a substation, a constraint is necessary to insure that outflow equals inflow. Such a constraint implies that a substation does not function as a generation or demand node. The general form for such a constraint is given by:

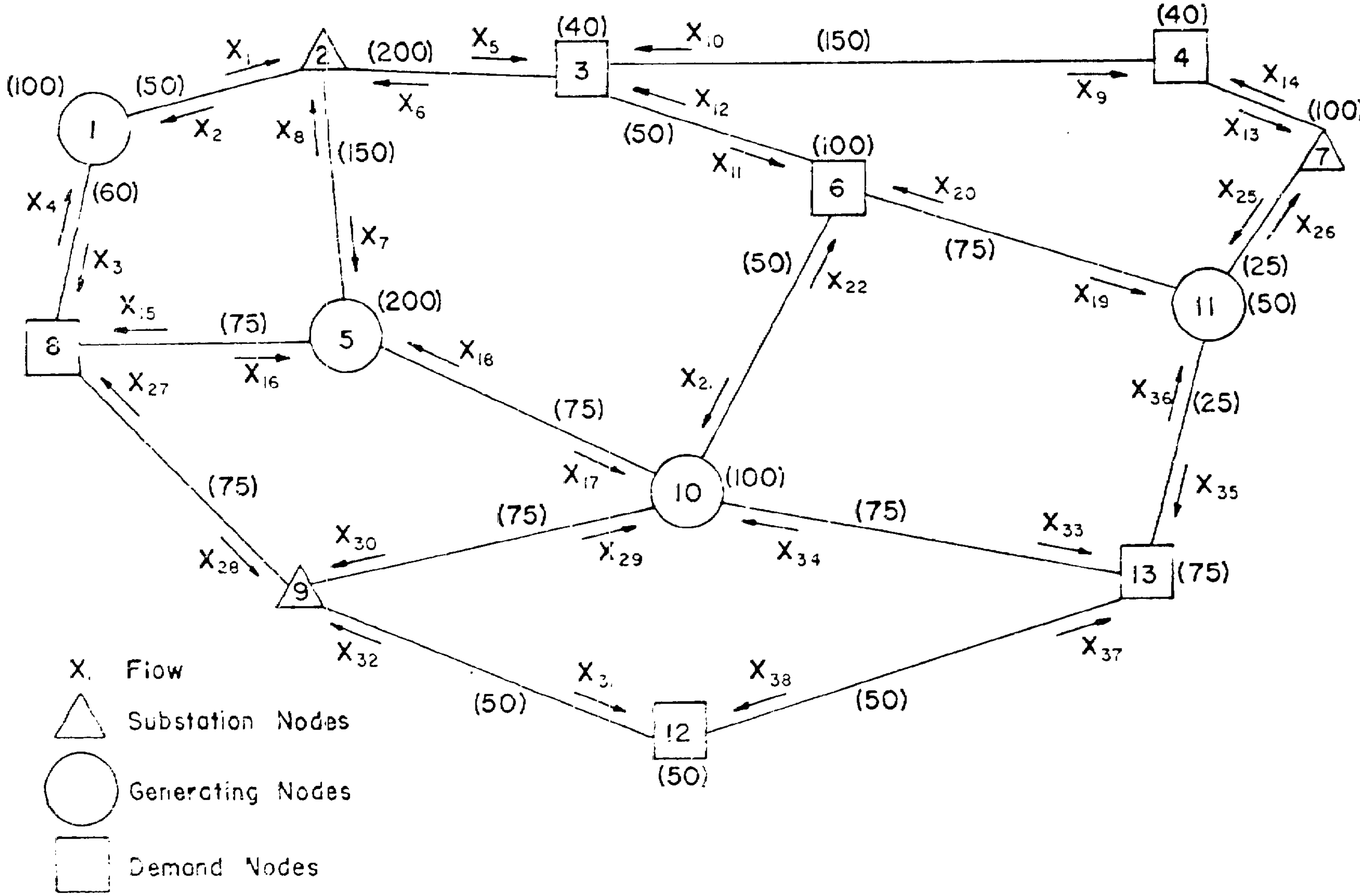

FIGURE 6. NODE AND LINK REPRESENTATION OF REGIONAL ELECTRIC POWER NETWORK.

$$\sum_{i=1}^{n} x_i = 0$$

Transmission lines between nodes require two constraints in order to keep power transmission from exceeding line capacity. Both constraints are necessary because the direction of flow is unknown until the final solution for a given disruption is known. For example, the constraints for a link would be expressed as:

$$x_i = x_j \leq C$$

$$-x_i + x_j \leq C$$

where C represents line capacity.

For each demand node, a constraint is needed so that the inflow minus the outflow is less than or equal to the demand for that node. Such a constraint will also allow the demand node to act as a transhipper if necessary. That is, although the demand requirements at the node might be eliminated it is possible that the node can act as a connection between links. The general format for a demand node constraint is given by:

$$\sum_{i=1}^{n} x_i \leq D$$

Where D is the nodal demand.

Several possibilities exist for the construction of an objective function to assess system performance under various disruptions. One method is to use a function which maximizes the sum of the products of node consumptions and node priorities. A node priority is a flexible quantity which can be adjusted according to the needs of the analysis. Priorities can be based on total demand requirements, manufacturing sector requirements, military demand, residential demand, etc. Such an objective function would appear as:

$$\text{Maximize } Z = \sum_{i=1}^{n} C_i P_i$$

where C_i is the consumption at the i^{th} node and P_i is the priority index at the i^{th} node.

Another potential objective function which may be utilized employs the concept of artificial power. In this case, each demand node is supplied with a source of artificial power and demand is satisfied by some combination of real and artificial power. The objective then becomes the minimization of the use of artificial power. To accomplish this objective a penalty cost is assigned for the use of artificial power. Then the objective becomes the minimization of the total penalty cost. Either objective function can be used to assess the relative effects of various disruptions on the system.

7. System Evaluation

The electric power system model described can be used to evaluate the vulnerability of the system to disruptions in any individual component or any combination of components. The model also can provide an indication of the criticality of any component to the functioning of the total system.

Disruptions in the electric power system can occur in many ways, both directly and indirectly. Direct disruptions include actual physical damage to any of the electric power system components: generating stations, substations, or transmission lines. Indirect disruptions include such items as fuel supply damage, lack of communications or control, inadequate operating personnel, etc. The evaluation procedure described in previous paragraphs is capable of handling highly localized disruptions or widespread disaster. Also, total or partial disruption of a functioning node or link is possible.

The initial step in the evaluation procedure is to determine the value of the objective function with the system intact with each demand node receiving its full demand. This procedure is done to determine the maximum value of the objective function for comparison purposes where the system is not intact due to disruptions.

The next step in the vulnerability evaluation is to impose disruptions on the system in order to determine the net effect on the total electric power system and thus evaluate the relative importances of certain system components and combinations of components.

B. Evaluation of Regional Power System

The region which was selected to demonstrate the use of the vulnerability evaluation model described in the previous section is the Louisiana-Southern Mississippi region. The characteristics of this regional system are described fully in a previous report (Lambert and Minor, 1973) and are briefly summarized in the following paragraphs.

1. System Description

The study region, shown in Figure 7 with county codes given in Table II, consists of Office of Business Economic Areas 132, 133, 138, and 139, and contains all 64 parishes in Louisiana and 13 counties in Mississippi. Louisiana and a portion of Mississippi are contained in Defense Electric Power Administration (DEPA) Area 10; however, two of the counties in Mississippi included in the study region are in DEPA Area 4. The State of Louisiana is contained in the Southwest Power Pool (SPP) which is one of nine National Electric Reliability Council Regions. Not all of the member systems of the SPP are directly involved in the study area. The member systems which are included in the regional study are: (1) Central Louisiana Electric Company, (2) Gulf States Utilities Company, (3) Louisiana Power and Light Company, (4) Mississippi Power and Light Company, and (5) New Orleans Public Service. The study region also contains several municipally owned systems and generating plants owned by industrial firms. Figure 8 is a schematic diagram of the region, including generating stations, major substations, and transmission lines of 115 Kv and larger.

The regional generating capacity is presented in Table III. System capacity is presented as a computer printout of generating stations in the region. Those stations listed in the printout have a generating capacity of one megawatt or more, and the total regional capacity is approximately 8535 megawatts. The generating capacities of the stations

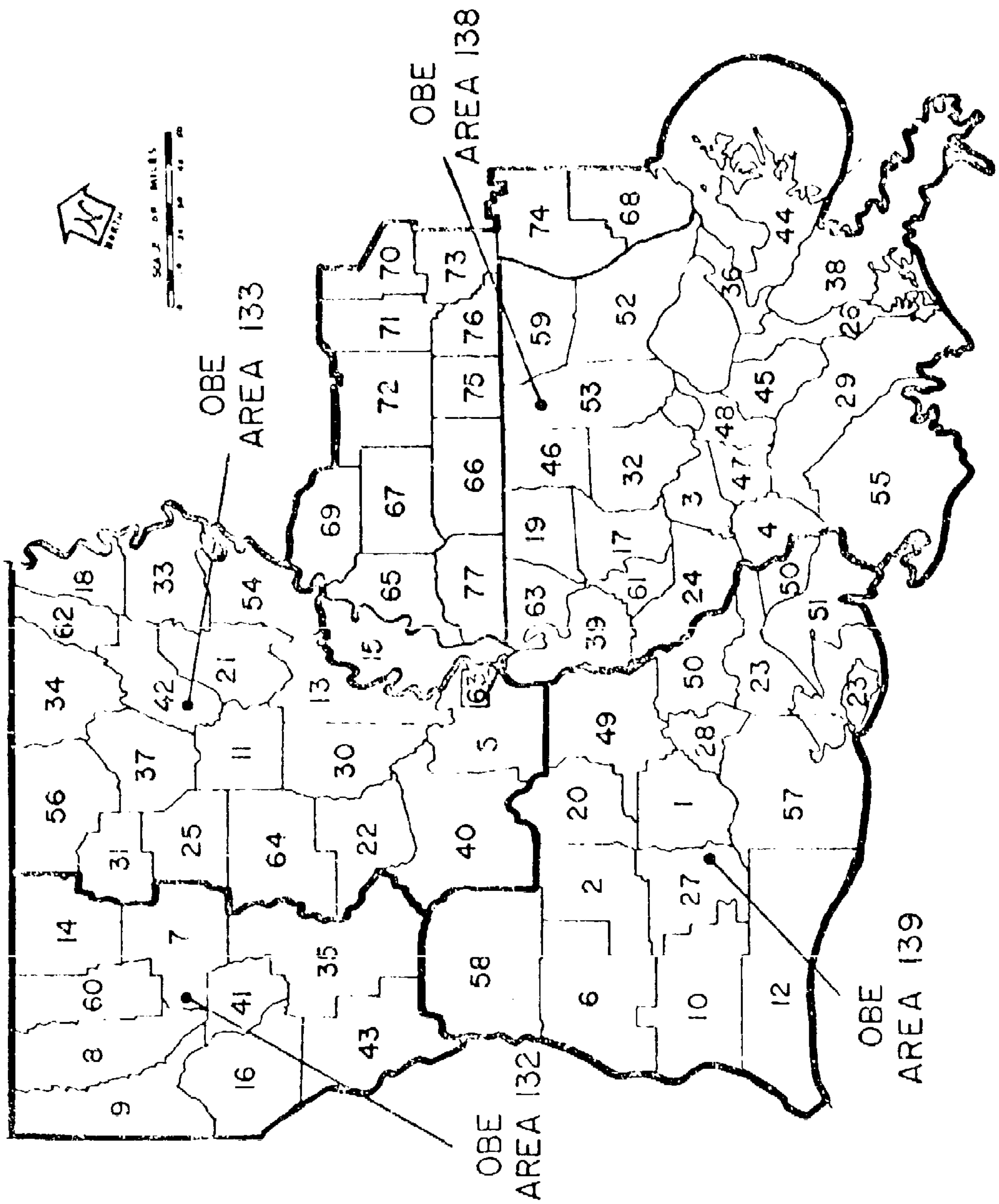

FIGURE 7. MAP OF STUDY REGION

TABLE II

COUNTY CODES: LOUISIANA - SOUTHERN MISSISSIPPI REGIONAL MODEL

County Code Number	PSAC Code* Number	County Name
	Louisiana	
1	52S1	Acadia
2	52S2	Allen
3	52T1	Ascension
4	52T2	Assumption
5	52R1	Avoyelles
6	52S3	Beauregard
7	52G1	Bienville
8	5251	Bossier
9	5252	Caddo
10	5221	Calcasieu
11	52R2	Caldwell
12	52S4	Cameron
13	52R3	Catahoula
14	52R4	Claiborne
15	52R5	Concordia
16	52G2	De Sota
17	5211	East Baton Rouge
18	52R6	East Carroll
19	52T3	East Feliciana
20	52S5	Evangeline
21	52R7	Franklin
22	5241	Grant
23	52S6	Iberia
24	52S7	Iberville
25	52R8	Jackson
26	5241	Jefferson
27	52S8	Jefferson Davis
28	52S9	Lafayette
29	52T4	Lafourche
30	52R9	La Salle
31	52RA	Lincoln
32	52T5	Livingston
33	52RB	Madison
34	52RC	Morehouse
35	52RD	Natchitoches
36	5242	Orleans
37	5231	Ouachita
38	5211	Plaquemines
39	52SA	Pointe Coupee
40	52J1	Rapides
41	52G3	Red River
42	52RE	Richland
43	52RF	Sabine
44	5243	St. Bernard
45	52T6	St. Charles
46	52T7	St. Helena
47	52T8	St. James
48	52T9	St. John the Baptist
49	52SB	St. Landry
50	52SC	St. Martin
51	52SD	St. Mary
52	52TA	St. Tammany
53	52TB	Tangipahoa
54	52RG	Tensas
55	52TC	Terrebonne
56	52RH	Union
57	52SE	Vermilion
58	52K1	Vernon
59	52TD	Washington
60	52G4	Webster
61	52S1	West Baton Rouge
62	52RI	West Carroll
63	52TE	West Feliciana
64	52RJ	Winn
	Mississippi	
65	34T1	Adams
66	34T2	Amite
67	34TB	Franklin
68	34G1	Hancock
69	34TC	Jefferson
70	34TD	Jefferson Davis
71	34TG	Lawrence
72	34TH	Lincoln
73	34TI	Marion
74	34TJ	Pearl River
75	34TL	Pike
76	34TP	Walthall
77	34TP	Wilkinson

*Region, State, Area, County Code used by the office of Emergency Preparedness

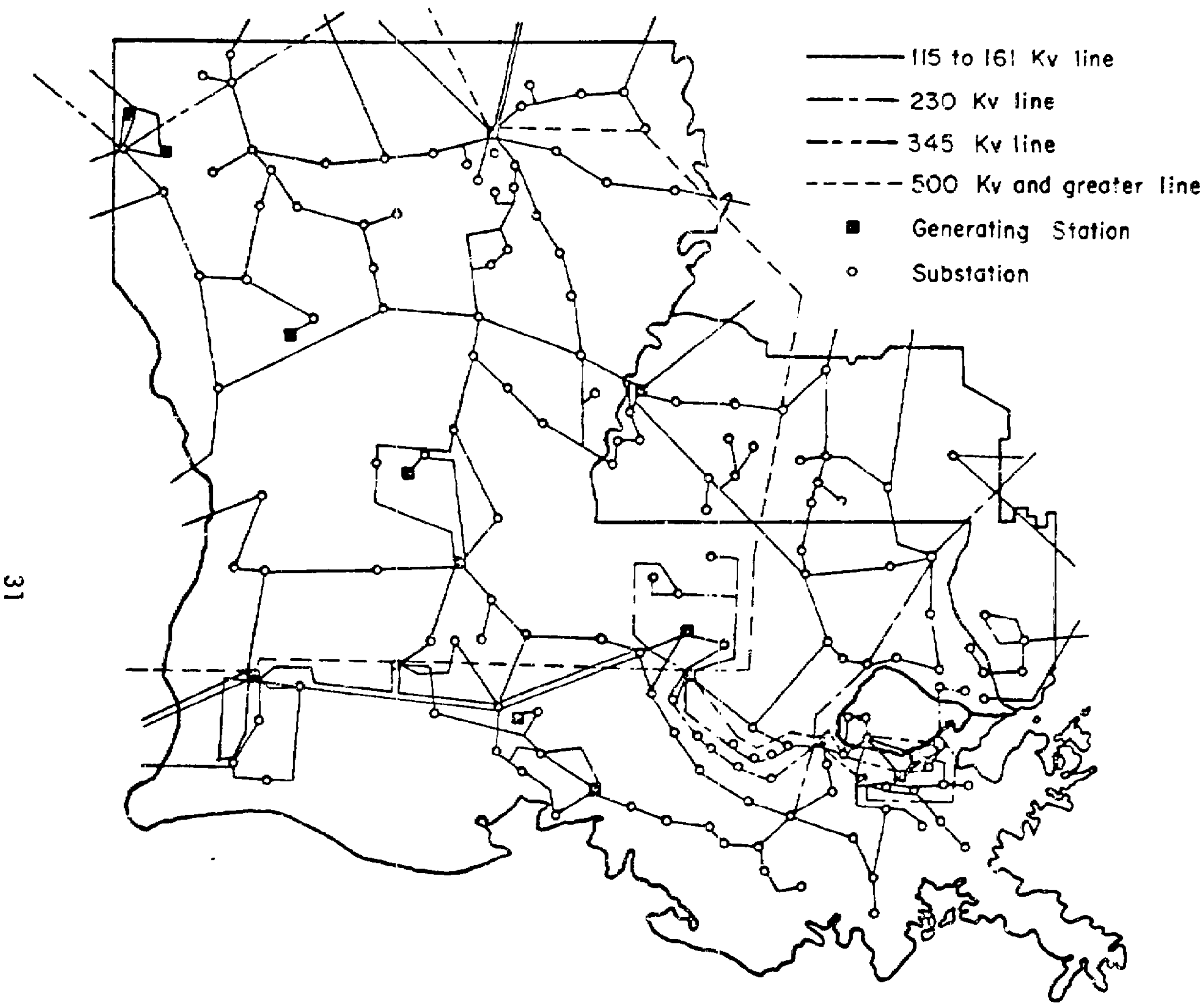

FIGURE 8. REGIONAL ELECTRIC POWER SYSTEM

TABLE III.

LATITUDES AND LONGITUDES OF GENERATION STATIONS IN LOUISIANA-SOUTHERN MISSISSIPPI

TTUN	NAME	CAP	LATN*	LONG*	TYPE	PARRISH	RSAC	TTUN	%
1	LITTLE GYPSY	242	3001	9001	1	ORLEANS	5242	36	2.84
2	ALEX 1	37.5	3119	9228	1	RAPIDES	52J1	40	.42
3	ARSENAL HILL	170	3231	9345	1	CADDO	5252	9	1.99
4	BERWICK	1	2960	9130	3	ST MARY	52S0	51	.01
5	COUGHLIN	483.3	3050	9215	1	AVOYELLES	52R1	5	5.66
6	CROWLEY	1.7	3020	9125	3	ACADIA	52S1	1	.02
7	FRANKLIN	9.1	2945	9130	3	ST MARY	52S0	51	.10
8	GRAND ESCAILLE	7.4	2922	8947	13	PLAQUEMIN	52I1	38	.08
9	HOMER	6.7	3247	9305	3	JACKSON	52R8	25	.08
10	HOUMA	42.7	2935	9043	123	TERREBONE	52TC	55	.48
11	JONESVILLE	1.7	3155	9175	3	CATAHOULA	52R3	13	.02
12	PINHOOK	48.5	3013	9200	13	LAFAYETTE	52S9	28	.55
13	L.CHARLES PPG	90	3013	9317	1	CALCASIEU	5221	10	1.05
	L.CHARLES CC	49.3	3010	9319	1	CALCASIEU	5221	10	.58
15	L.PROVIDENCE	8.8	3247	9111	3	E.CARROLL	52R6	18	.10
16	LIEBERMAN	277.3	3242	9357	1	CADDO	5252	9	3.25
17	LOUISIANA	201.6	3019	9114	1	E.BATON R	5211	17	2.36
18	MARKET ST	166.3	2955	9004	1	ORLEANS	5242	36	1.95
19	MELVILLE	1	3080	9175	3	P.COUPPE	52SA	39	.01
20	MICHOUD	959.3	3000	8956	1	ORLEANS	5242	36	11.24
21	BOGALUSA MILL	49	3047	8952	1	WASHING	52TD	59	.55
22	MINDEN	38.8	3235	9317	3	WEBSTER	52G4	60	.44
23	MONROE	182	3231	9207	12	QUACHITA	5231	37	2.13
27	NEW IBERIA	4.1	3000	9180	3	IBERIA	52S6	23	.05
28	NEW ROADS	7.5	3042	9126	3	WFELICIAN	52TF	63	.08
29	NINE MILE	1101	2956	9008	1	S CHARLES	52T6	45	12.91
30	OPELOUSAS	25.4	3032	9205	1 3	S LANDRY	52S8	49	.29
31	PLAQUEMINE	10.8	3030	9130	3	IBERVILLE	52S7	24	.12
32	POWER HOUSE 2	67	2990	9020	1 2	ORLEANS	5242	36	.79
33	RAYNE	7	3014	9216	3	ACADIA	52S1	1	.08
34	RAYVILLE	10.8	3240	9175	3	RICHLAND	52RE	42	.12
35	REA	6.1	3057	9211	3	AVOYELLES	52R1	5	.07
36	RIVERSIDE	166.2	3013	9316	1	CALCASIEU	5221	10	1.94
37	RUSTON	14.5	3232	9236	1 3	LINCOLN	52RA	31	.16
38	SPRINGHILL	49.3	3258	9327	1	CADDO	5252	9	.58
39	STERLINGTON	351.5	3241	9205	1	QUACHITA	5231	37	4.12
40	TECHE	79.4	2949	9132	1	IBERIA	52S6	23	.93
41	THIBODAUX 1	3.1	2947	9048	3	LA FOURCE	52T4	29	.04
42	CHALMETTE	398	2956	8958	1 3	STBERNARD	5243	44	4.66
43	ELIZABETH	13.5	3052	9248	3	RAPIDES	52J1	40	.15
44	LITTLE GYPSY	1229	3000	9028	1	SJOHNBAP.	52T9	48	14.4
45	WILLOW GLEN	994	3016	9107	1	EBATON R	5211	17	11.65
46	ALEX 2	97.5	3119	9228	1	GRANT	52H1	22	1.14
47	MCDONALD AV	41.4	3231	9235	1	LINCOLN	52RA	31	.7
48	DOC BONIN	143.3	3014	9202	1	LAFAYETTE	52S9	28	1.68
49	THIBODEAUX 2	24.5	2945	9047	3	LAFOURCE	52T4	29	.28
50	ALLIED CHEM	70.6	3029	9111	2	ASSUMPTION	52T2	4	.83
51	BURRAS	17.5	3000	9028	2 3	PLAQUE.	52I1	38	.20

*xx.xx degrees

range from one megawatt (Melville) to 1229 megawatts (Little Gypsy). The larger plants are generally steam turbine types using natural gas as a fuel supply and the smaller plants are usually internal combustion or gas turbine types. Additional information concerning the generating characteristics can be found in the report by Lambert and Minor (1973).

The regional transmission network is also shown in Figure 8 and may be described as being highly interconnected both within the region and with surrounding areas. The interconnections with surrounding areas are of considerable importance since civil defense planners are concerned with the problem of regional self-sustainment in the post-disruption period. A total of 29 transmission lines cross the study region boundaries, and these interconnections are well dispersed around the regional boundary. This wide dispersion indicates that complete isolation of the region would be difficult to achieve.

Regional demand characteristics can be classified into three major types: (1) manufacturing, (2) residential or population, and (3) other. The latter category includes commercial energy use, agricultural uses, and all other demands other than for manufacturing and residential purposes. The demand figures for the region were derived from "Fuels and Electric Energy Consumed," U.S. Bureau of the Census, and are given in Appendix A. Additional information regarding the demand characteristics of the region is contained in a 1973 DEPA report (Lambert and Minor, 1973).

2. Regional Vulnerability Evaluation

If all 77 parishes and counties and all 52 generating stations in the Louisiana-Southern Mississippi region were considered as individual demand or generating nodes, an extremely complex network of transmission lines, generators, substations, and demands would result. The transformation of such a large network to a linear programming format would result in thousands of flow variables and constraints. Such a problem would be unmanageable; consequently, the development of a workable regional model can be approached in one of two ways. The first method is to transform and condense the regional electric power system into a system model of manageable size. The second method involves evaluating relatively small areas within the region and then aggregating the results to determine the effects of disruptions on the total system. These two methods are described in the following paragraphs.

a. Condensation Method

The method for condensing regional data into a regional electric power system model of reasonable size was first proposed by Lambert and Minor (1973), and involves six major steps:

(1) ranking of parish demand and generating data,
(2) reduction of the number of nodes by elimination of very low demand and generation parishes,
(3) aggregation of parishes for further reduction of the number of nodes,
(4) determination of the aggregate generating and demand quantities for each node,
(5) determination of transmission links, and
(6) identification of interconnections where transmission lines intersect outside of nodal groups.

Application of this procedure to the electric power system of Louisiana-Southern Mississippi resulted in the regional network model shown in Figure 9. The parishes making up each of the 19 nodes are identified in Table IV. This network constitutes 91 percent of the total regional demand and approximately 92 percent of the total regional generating capacity. Thus, the condensation process eliminated only a small amount of demand and generation but provided a network model of manageable size.

The next phase of the procedure was the conversion of the network model to a linear programming format. This was accomplished by writing the necessary generating, demand, substation, and transmission constraints and developing an objective function as described in Section IV.A. The resulting linear programming problem has 145 constraints and 102 flow variables. The problem was programmed in Fortran IV for use on an IBM 370/145 computer. The program is contained in Appendix B. The model is highly flexible and can be used for single node or single link elimination or elimination of any combination of links and nodes. Also, any

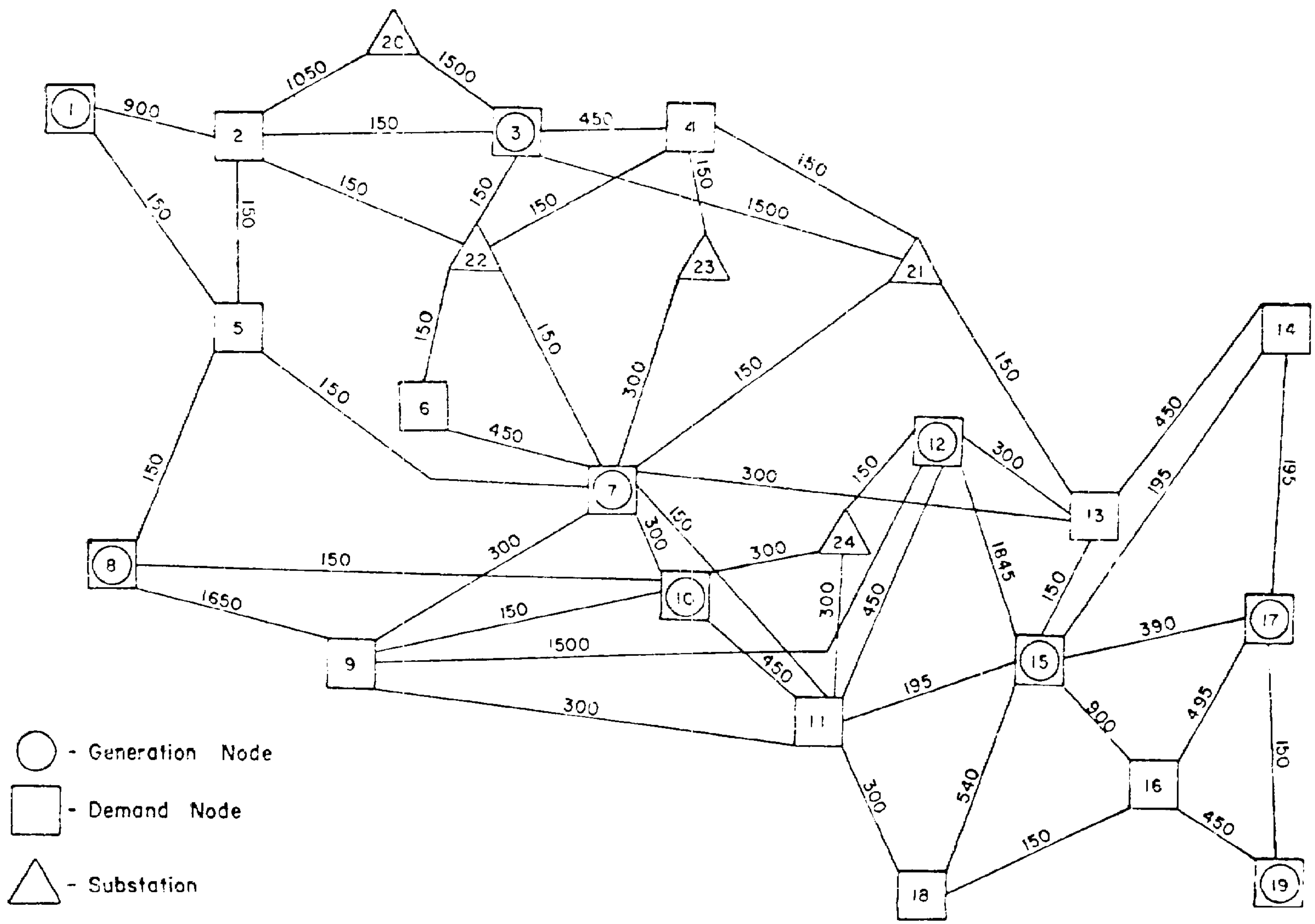

FIGURE 9. REGIONAL NETWORK MODEL

TABLE IV.

REGIONAL NODE IDENTIFICATION

Node Number	Constituent Parishes (Ref. Table II)	Demand (Mw)	Generation (Mw)
1	9	446	497
2	8,25,31,60	305	0
3	37	229	534
4	21,34,42	143	0
5	2,6,16,35,58	274	0
6	40	213	0
7	5,15,20,49,65	370	489
8	10	282	697
9	1,27,57	243	0
10	28	190	192
11	23,24,39,50,51	378	0
12	17	535	1196
13	32,53,72,75	295	0
14	52,59,73,74	283	0
15	3,45,47,48	241	2330
16	26	632	0
17	36	1121	1435
18	29,55	272	0
19	38,44	146	398

percentage reduction of capacity or demand can be done rather than total node elimination. The reaction of the total system to any given disruption is measured by the decrease in the objective function value as compared to the system intact value.

Previous research with the model just described includes single node analysis, single link analysis, and combination analysis (Lambert and Minor, 1973). The results of the single node analysis are presented in Table V. The analysis involved complete removal of the nodal demand or generation; however, the node was allowed to act as a transhipper of electric power.

The single link analysis was concerned with the removal of individual links connecting generating, demand, and substation nodes. Each of the 51 links in the network was removed individually and the system response was found. In all cases the removal of only one link between nodes had no effect on the total system response. Due to the high degree of nodal interconnection the regional electric power system was able to respond completely when only a single link was eliminated.

The combination analysis which was performed involved a combination of each possible type of analysis: (1) Generation-Transmission, (2) Demand-Demand, (3) Demand-Transmission, (4) Generation-Demand-Transmission, and (5) Generation-Generation. The specific combinations used and the results of the analyses are presented in Lambert and Minor (1973).

b. <u>Area Aggregation Method</u>

Several vulnerability evaluations have been accomplished by utilizing the condensed network model summarized in the previous paragraphs (Lambert and Minor, 1973). The method has proven useful in evaluating regional scale electric power systems. However, due to the condensation procedures utilized in this method, some degree of detail was necessarily sacrificed. Consequently, an additional procedure for vulnerability evaluation is proposed in this research; this new procedure will provide a useful supplement to the previous model.

The use of an area scale evaluation (smaller in size when compared with a region scale evaluation) followed by an aggregation procedure was

TABLE V.

SINGLE NODE ANALYSIS

Node No.*	Type	Objective Function Value (System Intact = 320.25)	% Change In Objective Function Value
1	Generation (497 Mw)	320.25	0
2	Demand (205 Mw)	310.95	2.90
3	Generation (534 Mw)	320.25	0
4	Demand (143 Mw)	318.21	.64
5	Demand (274 Mw)	312.74	2.35
6	Demand (213 Mw)	315.71	1.42
7	Generation (489 Mw)	320.25	0
8	Generation (697 Mw)	320.25	0
9	Demand (243 Mw)	314.32	1.85
10	Generation (192 Mw)	320.25	0
11	Demand (378 Mw)	305.96	4.46
12	Generation (1196 Mw)	320.25	0
13	Demand (295 Mw)	311.55	2.72
14	Demand (283 Mw)	312.24	2.50
15	Generation (2330 Mw)	320.25	0
16	Demand (632 Mw)	280.31	12.47
17	Generation (1435 Mw)	316.78	1.08
18	Demand (272 Mw)	312.85	2.31
19	Generation (398 Mw)	320.25	0
1A**	Demand (446 Mw)	300.36	6.21
3A	Demand (229 Mw)	315.01	1.63
7A	Demand (370 Mw)	306.56	4.27
8A	Demand (282 Mw)	312.30	2.48
10A	Demand (190 Mw)	316.64	1.13
12A	Demand (535 Mw)	291.63	8.94
15A	Demand (241 Mw)	314.44	1.81
17A	Demand (1121 Mw)	194.59	39.24
19A	Demand (146 Mw)	318.12	.66

*See Figure 9 and Minor and Lambert (1973) for identification, description, and location.

**Demand portion only.

considered advantageous because of the size of the total regional problem. Here, a region refers to a relatively large electric power system such as Louisiana-Southern Mississippi, and an area refers to a smaller system such as that contained in a single county. Counties were chosen to represent area size units because many of the other resource system models (such as manufacturing) are based on the use of counties as nodes. In a system as large and as complex as that of the study region, consideration of every generation and substation node and every transmission line connecting them produces a huge number of flow variables and constraint equations. Even if enough computer capacity were available to handle such a large problem, analysis of a system of such magnitude to a fine degree of detail would be very difficult. A more realistic approach to the problem is to evaluate an area in detail, and to aggregate the remaining regional system into several single nodes as was described in Section IV.B.2.a in the condensation method .

In utilizing the area procedure, two levels of detail are considered. For the specific area being studied the generating capacity of each station and the capacity of each transmission line joining facilities are included in the analysis. Use of the area method considered substations within the area as the point of final demand, since distribution beyond the substation level is considered to be another level of detail beyond the scope of this research. However, in going to the substation level within an area, considerable refinement in the degree of detail is achieved, when compared with previous methods.

Once the area is specified, the electric power system is converted to a network flow model and is then transformed into a linear programming format for analysis. The procedure used to evaluate the effects of disruptions on the area subsystem is the same as that shown in Figure 5. The end result of the analysis provides the amount and location of power within the area, any import requirements necessary, or any surplus available for export.

The second level of detail pertains to the remainder of the regional electric power system. The approach employed to characterize this portion of the system is similar to that used in the condensation method. That is, aggregation of generating capacities and demands is done to provide a reasonably sized nodal network. Also, transmission capacities between nodes are included on an aggregated basis. Thus, with the exception of the area being studied in detail, the remainder of the region consists of single generation and demand nodes as needed. As a result, demands for an area can be supplied by generation within the area of by importing power from the other nodes of the regional electric power system.

If widespread disruptions are to be considered (that is, several nodes undergoing disruptions simultaneously) then each node can be analyzed individually on an area subsystem basis and these results used as input to a regional analysis to assess the net effect of the various disruptions.

To illustrate the application of the general vulnerability evaluation procedure depicted in Figure 5 and the use of the area method, an example utilizing the New Orleans area subsystem is presented.

In the regional network model shown in Figure 9, Node 17 consists of Orleans Parish which contains four generating stations: Michoud, Patterson, Market Street, and Power House Number 2. The capacity, approximate latitude and longitude, type of station and other information for each of these plants is given on the computer printout presented as Table III. A systems map of the New Orleans area showing the generating plants, major substations, and the transmission network is presented in Figure 10. This subsystem was converted to the area network flow model shown in Figure 11 with the coding given in Table VI in order to facilitate conversion to a linear programming format for analysis. Substations were considered as final demand points and, for ease of analysis, the total nodal demand was allocated equally among these demand points. Utilizing the transhipment linear program model (computer program given in Appendix B) resulted in a system intact objective function value of 110.3. This value provides the basis of comparison for the relative effects of disruptions on the area system.

The information available at this point constitutes all of the input information required for the vulnerability evaluation method described in Figure 5, with the exception of the disruption location and magnitude.

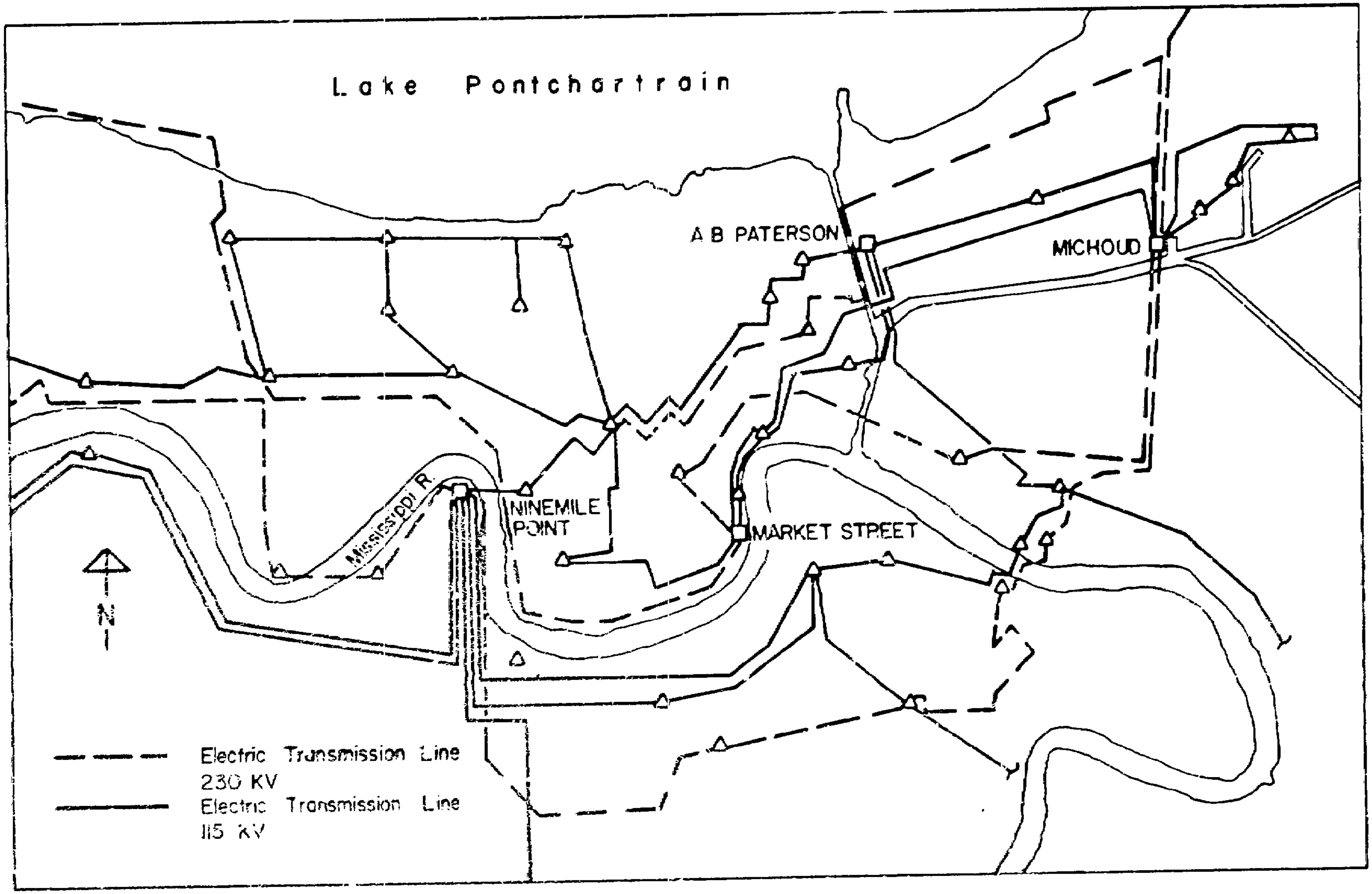

FIGURE 10. NEW ORLEANS AREA ELECTRIC POWER NETWORK

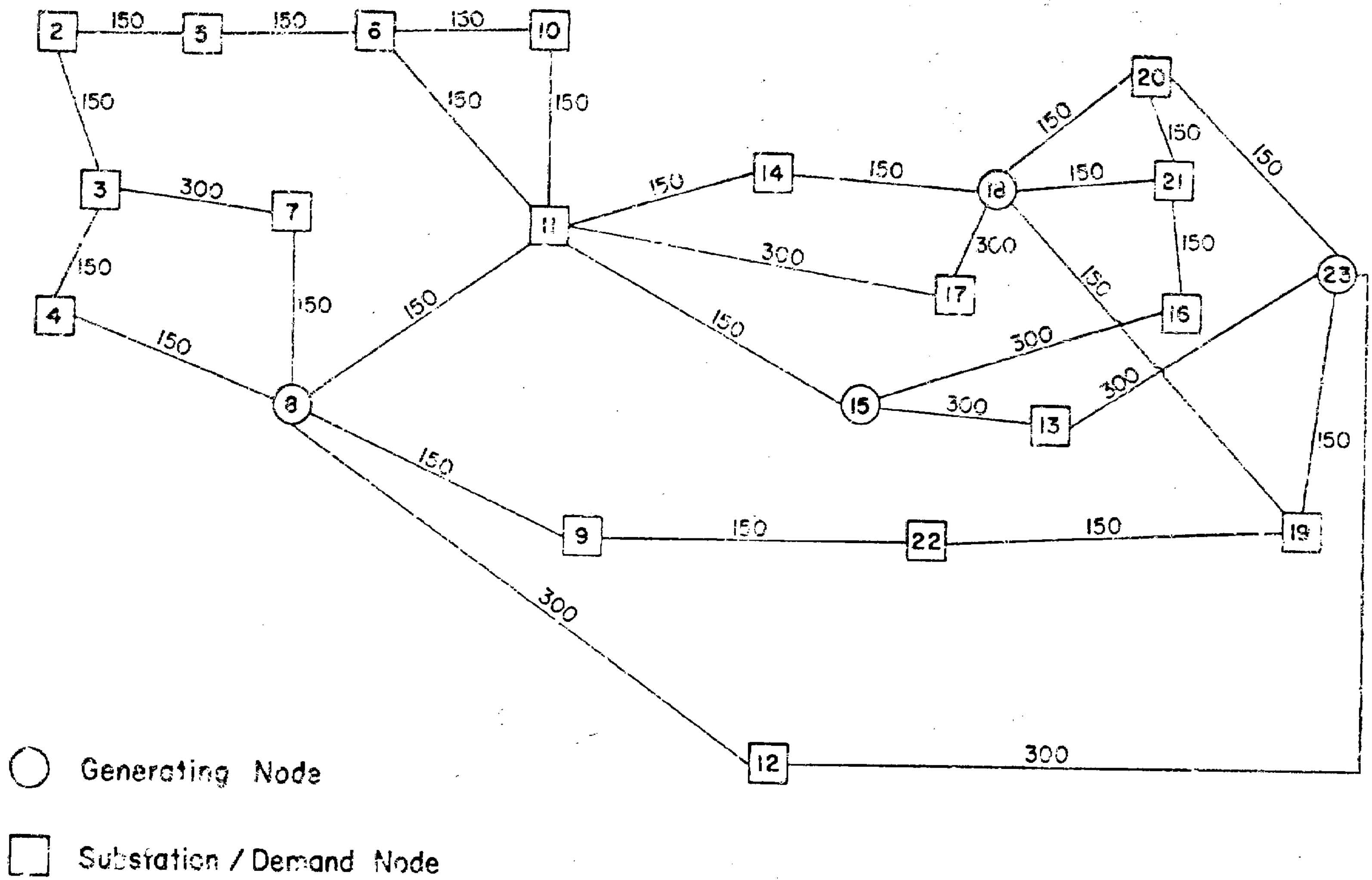

FIGURE 11. NEW ORLEANS AREA NETWORK FLOW MODEL

TABLE VI.

NEW ORLEANS AREA FLOW MODEL CODE

Node No.	Facility *	Node No.	Facility
2	Norco (SS)	13	Derbiguy (SS), Arabi (SS)
3	Destrehan (SS)	14	Pontchartrain Pk. (SS), Pauger (SS)
4	Luling (SS), Amer. Cyan. (SS)	15	Market Street (G)
5	Kenner (SS), Snake Farm (SS)	16	Claiborne (SS), Delta (SS)
6	Ponchartrain (SS), Lakeshore (SS), Cleary (SS), LaBarre (SS)	17	Almonaster (SS)
		18	A. B. Patterson (G)
7	Harahan (SS), Avondale (SS)	19	Kaiser (SS), Chalmette (SS), Gretna (SS), Holiday (SS)
8	Ninemile Point (G)		
9	Westwego (SS), Harvey (SS)	20	Sherwood Forest (SS)
		21	Florida (SS)
10	Paris (SS), Ave. C. (SS)	22	NASA West (SS), Gentilly Road (SS), Gulf Outlet (SS)
11	Dublin (SS), Valence (SS), Midtown (SS)	23	Michoud (G)
12	Peters Rd. (SS), Behrman (SS), Packenham (SS), Lower Coast (SS)		

*SS - Substation
G - Generation

For illustrative purposes, assume that the disruption is in the form of a 5 mt weapon (air burst) with ground zero being approximately equivalent to the location of the Market Street generating station. Such a detonation results in a 5 psi radius of 7.3 miles.

Now suppose that direct effects to generating stations and transmission lines -- as well as systemic effects caused by disruptions in fuel supply, personnel availability, and supporting systems -- result in the damage shown in Table VII. These disruptions were inputed to the transhipment computer program in order to perform the necessary network analysis.

The results of the network analysis indicate that the area subsystem can no longer function as a total system. Even though the remaining generating capacity slightly exceeds the surving demand, the widespread destruction of transmission capacity prohibits power movement to certain demand nodes. However, some of the remaining demand nodes can receive power from outside the area. For example, Demand Nodes 2, 3, 4, 5, 6, 7, and 10 could conceivably obtain sufficient power supply from the Little Gypsy plant located in St. Bernard Parish.

The next level of analysis involves determining the effects of the disruption on the total regional electric power system. By taking the results of the area subsystem analysis as input to the regional model, and be performing the network analysis, a drop in the objective function value to 255.68 (compared to a system intact value of 320.25) is seen. This corresponds to a 20.16 percent decrease in the objective function value. Thus, the total regional system cannot return to its "system intact" level of operation after the disruption to Node 17 (Orleans Parish).

This procedure can be repeated for as many nodes in the region as desired. That is, area network flow models could be developed for each county size area, disruptions could be imposed, and the resulting area evaluation outputs would provide the input to the regional electric power system model. Thus, not only would the response of small electric power systems (such as counties) be known, but also the resulting effects on larger sized systems, such as regions, can be determined.

TABLE VII.

DISRUPTION EFFECTS ON ORLEANS PARISH: GENERATION, TRANSMISSION, DEMAND

Generation	Transmission
Node 15 - Market Street: Destroyed	Link 15 - 11: Destroyed
Node 8 - Nine Mile Point: Destroyed	Link 15 - 16: Destroyed
Node 18 - Patterson: Destroyed	Link 15 - 13: Destroyed
Node 23 - Michoud: Reduced by 25%	Link 8 - 7: Destroyed
	Link 8 - 11: Destroyed
	Link 8 - 9: Destroyed
	Link 8 - 12: Destroyed
	Link 18 - 14: Destroyed
	Link 18 - 17: Destroyed

Demand	
Node 11:	Destroyed
Node 13:	Destroyed
Node 17:	Destroyed
Node 14:	Destroyed
Node 19:	Destroyed
Node 16:	Destroyed
Node 21:	Destroyed
Node 12:	Reduced by 50%
Node 10:	Reduced by 50%
Node 9:	Reduced by 50%
Node 6:	Reduced by 25%
Node 7:	Reduced by 25%

V. VULNERABILITY ASSESSMENT AND CIVIL DEFENSE ACTIONS

A. Vulnerability of Electric Power Systems

The two levels of vulnerability assessment which are made in the regional report (Lambert and Minor, 1973) and reported herein (Section IV) provide some very interesting insights into electric power system vulnerability. These insights provide important clues as to the nature of civil defense actions which should be planned for the region and area. The previous report (Lambert and Minor, 1973) indicated that the regional electric power system could continue to function following a major disruption in one or more county size nodes within the system. This conclusion was also reached herein, but it is also noted that the electric power network within the affected node (the area system) may cease to function as a system. Thus, the previous report indicated that the "region" would continue to function as a self supporting entity, while this report indicates that the affected "area" would be dependent upon the region for support.

B. Potential Civil Defense Actions

A principal objective of the research described herein is to assess systemic vulnerability of electric power systems relative to nuclear weapons effects, and to evaluate the roles of possible civil defense (CD) activities in reducing this vulnerability. Two general CD policies could be adopted, singly or in combination, if vulnerability reduction within the electric power system is a stated objective. The first policy would be directed at specific vulnerable points in the electric power system itself. The second policy might involve a more general plan such as that associated with Crisis Relocation Planning (CRP). The models and procedures described in this document and in related documents (Minor, Lambert and Smith, 1972; Lambert and Minor, 1973; Lambert and Minor, 1973a; Lambert and Minor, 1974) can be used to evaluate the effectiveness of these alternative policies.

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1. Civil Defense Actions applied to Electric Power Systems

Since we cannot expect the network within the affected node (county size electric power system) to function as a network, CD planning actions should be directed toward recognition of this probable eventuality. Steps should be taken on the part of the electric power systems to insure that previously developed procedures for "load shedding" the affected area are instituted so as to minimize losses to the functioning of the regional network. Furthermore, planning steps should be taken to identify the demand nodes (substations) in each area sized unit which should be reconnected first to the regional net in the event that generation and transmission in the area are destroyed. This latter planning effort is one which is the primary responsibility of the State and local government officials as stated in DMO Order 8500.1A (a copy of which is included as Appendix D.) The local CD planner is one who can assist in interpreting the established criteria for reconnection priorities. In this regard, it is noted that the CD planner is guided in this function by the results of manufacturing system vulnerability evaluations (Lambert and Minor, 1973a) and other research studies pertaining to critical services and emergency operations.

2. Crisis Relocation Planning as a Civil Defense Action

A vulnerability reducing CD action which is currently under intensive study within DCPA is Crisis Relocation Planning (CRP). This possible gereral policy is intended to reduce the vulnerability of the population, in general, as a deterrent to nuclear war. However, as suggested by the analysis conducted in this document, CRP can also produce a reduction in the vulnerability of electric power systems -- at least in the situations where potential damage to people is the fundamental cause of the projected reduction in output.

Although not accomplished as a part of the study effort described in this document, the model and procedures outlined herein could be used effectively to evaluate the effects of CRP on the operation of electric power systems during the relocation period. Reductions in the number of employees who operate the electric power systems will affect system output. A principal systems evaluation question which could be answered using the procedures outlined herein concerns the degree to which CRP operations would disrupt electric power production, or, more specifically, how much work force reduction can be allowed without harming the productivity of the electric power system.

C. Regional Self Sustainment and Civil Defense Actions

A final objective of the Work Unit 4334B effort concerns utilizing the results of the study to estimate the impact of CD actions on the region, with specific reference to the ability of the region (1) to be self sustaining in the postattack period and (2) to contribute to filling national needs in the same period.

Implications of the result of the vulnerability assessment advanced in Section IV are clear. If subjected to a nuclear attack which produces the disruptions outlined in Section IV, the electric power system at the area level would be severely damaged (through direct and systemic effects), but the region could be expected to sustain itself in the immediate postattack period. The imposition of CD actions could mitigate this situation, if appropriate steps were taken in the preattack time period. Direct CD actions involving planning of demand node reconnections could reduce postattack constraints on needed manufacturing and other operations, and personnel relocation actions (such as CRP) could relieve postattack constraints on human resources. CD actions which produce contributions of needed resources from outside of the region during the postattack period could be advanced as helpful activity as well, but such actions may not be feasible in light of comparable problems which may exist in adjacent areas.

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APPENDIX A
RANKING OF PARISHES BY TOTAL DEMAND

Rank	Parish No.	Mfg. Dem. Kw	Mfg. Dem. %	Resid. Dem. Kw	Resid. Dem. %	Other Dem. Mw	Other Dem. %	Total Dem. Mw	Total Dem. %	Total Cum. %
1	36	149,573	16.72	383,201	15.27	587.74	15.27	1,120.51	15.45	15.45
2	26	79,262	8.88	217,968	8.69	334.47	8.69	631.70	8.71	24.16
3	17	68,272	7.65	184,132	7.34	282.51	7.34	534.91	7.37	31.53
4	9	69,812	7.82	148,630	5.92	227.86	5.92	446.30	6.15	37.68
5	10	44,836	5.02	93,894	3.74	143.95	3.74	282.68	3.90	41.58
6	37	40,657	4.56	74,505	2.97	114.31	2.97	229.47	3.16	44.74
7	40	19,388	2.17	76,243	3.04	117.00	3.04	212.63	2.93	47.67
8	28	10,443	1.17	70,844	2.82	108.54	2.82	189.83	2.62	50.29
9	55	18,678	2.09	49,105	1.96	75.44	1.96	143.22	1.98	52.27
10	49	8,117	.91	51,891	2.07	79.67	2.07	139.68	1.93	54.20
11	29	16,303	1.83	44,515	1.77	68.12	1.77	128.94	1.78	55.98
12	8	20,561	2.30	41,660	1.66	63.89	1.66	126.11	1.74	57.72
13	51	15,965	1.79	39,228	1.56	60.04	1.56	115.23	1.59	59.31
14	52	11,391	1.28	41,057	1.64	63.12	1.64	115.57	1.59	60.90
15	53	7,276	.82	42,535	1.70	65.43	1.70	115.24	1.59	62.49
16	1	21,388	2.40	33,647	1.34	51.57	1.34	106.61	1.47	63.96
17	23	12,315	1.38	37,061	1.48	56.96	1.48	106.34	1.47	65.43
18	44	8,685	.97	33,050	1.32	50.80	1.32	92.54	1.27	66.70
19	58	1,046	.12	34,735	1.38	53.12	1.38	89.28	1.23	67.93
20	60	21,384	2.40	25,789	1.03	39.64	1.03	86.81	1.20	69.13
21	57	12,498	1.40	27,811	1.11	42.72	1.11	83.03	1.14	70.27
22	59	13,344	1.50	27,111	1.08	41.56	1.08	82.02	1.13	71.40
23	3	19,865	2.23	23,946	.95	36.56	.95	80.37	1.11	72.51
24	45	23,116	2.59	19,080	.76	29.25	.76	71.45	.99	73.50
25	65	7,509	.84	24,362	.97	37.33	.97	69.20	.95	74.45
26	5	6,286	.70	24,376	.97	37.33	.97	67.99	.93	75.38
27	32	6,102	.68	23,575	.94	36.18	.94	65.86	.90	76.28
28	75	6,252	.70	22,640	.90	34.64	.90	63.53	.87	77.15
29	35	4,741	.53	22,741	.91	35.02	.91	62.50	.86	78.01
30	34	8,868	.99	20,961	.84	32.33	.84	62.16	.85	78.86
31	24	8,709	.98	19,853	.79	30.40	.79	58.96	.81	79.67
32	50	5,349	.60	20,955	.84	32.33	.84	58.63	.80	80.47
33	31	2,441	.27	21,825	.87	33.48	.87	57.75	.79	81.26
34	20	2,849	.32	20,518	.82	31.56	.82	55.03	.75	82.01
35	38	12,158	1.36	16,288	.65	25.01	.65	53.46	.73	82.74

APPENDIX A (Cont'd.)
RANKING OF PARISHES BY TOTAL DEMAND

Rank	Parish No.	Mfg. Dem. Kw	Mfg. Dem. %	Resid. Dem. Kw	Resid. Dem. %	Other Dem. Mw	Other Dem. %	Total Dem. Mw	Total Dem. %	Total Cum. %
36	27	4,770	.53	19,083	.76	29.25	.76	53.10	.73	83.47
37	72	6,230	.70	17,278	.69	26.55	.69	50.06	.69	84.16
38	48	8,561	.96	15,376	.61	23.47	.61	47.41	.65	84.81
39	74	6,620	.74	14,471	.58	22.32	.58	43.41	.59	85.40
40	47	9,038	1.01	12,742	.51	19.62	.51	41.40	.57	85.97
41	6	4,339	.49	14,779	.59	22.70	.59	41.82	.57	86.54
42	73	3,644	.41	15,040	.60	23.09	.60	41.77	.57	87.11
43	21	2,094	.23	15,462	.62	23.86	.62	41.42	.57	87.68
44	2	6,938	.78	13,427	.54	20.78	.54	41.15	.56	88.24
45	42	3,518	.39	14,059	.56	21.55	.56	39.13	.53	88.77
46	39	2,517	.28	14,207	.57	21.93	.57	38.65	.53	89.30
47	16	1,574	.18	14,699	.59	22.70	.59	38.97	.53	89.83
48	15	486	.05	14,579	.58	22.32	.58	37.39	.51	90.34
49	25	8,369	.94	10,307	.41	15.78	.41	34.46	.47	90.81
50	4	956	.11	12,691	.51	19.62	.51	33.27	.45	91.26
51	43	2,053	.23	12,035	.48	18.47	.48	32.56	.44	91.70
52	56	2,039	.23	11,911	.47	18.09	.47	32.04	.44	92.14
53	19	3,028	.34	11,401	.45	17.32	.45	31.75	.43	92.57
54	14	3,132	.35	10,992	.44	16.93	.44	31.05	.42	92.99
55	64	3,478	.39	10,569	.42	16.16	.42	30.21	.41	93.40
56	61	2,280	.26	10,889	.43	16.55	.43	29.72	.40	93.80
57	7	1,190	.13	10,347	.41	15.78	.41	27.32	.37	94.17
58	68	3,691	.41	9,065	.36	13.85	.36	26.61	.36	94.53
59	66	810	.04	10,055	.40	15.39	.40	26.26	.36	94.89
60	33	242	.03	9,727	.39	15.01	.39	24.98	.34	95.23
61	22	964	.11	8,827	.35	13.47	.35	23.26	.32	95.55
62	76	666	.07	8,725	.35	13.47	.34	22.86	.31	95.86
63	30	908	.10	8,585	.34	13.08	.34	22.57	.31	96.17
64	18	1,542	.17	8,319	.33	12.70	.33	22.56	.31	96.48
65	70	208	.02	8,743	.35	13.47	.35	22.42	.30	96.78
66	62	439	.05	8,412	.34	13.08	.34	21.93	.30	97.08
67	63	3,256	.36	7,345	.29	11.16	.29	21.76	.30	97.38
68	77	0	0	8,546	.34	13.08	.34	21.63	.29	97.67
69	71	3,176	.36	6,596	.26	10.00	.26	19.77	.27	97.94

APPENDIX A (Cont'd.)
RANKING OF PARISHES BY TOTAL DEMAND

Rank	Parish No.	Mfg. Dem. Kw	Mfg. Dem. %	Resid. Dem. Kw	Resid. Dem. %	Other Dem. Mw	Other Dem. %	Total Dem. Mw	Total Dem. %	Total Cum. %
70	13	104	.01	7,599	.30	11.54	.30	19.24	.26	98.20
71	69	512	.06	6,549	.26	10.00	.26	17.06	.23	98.43
72	46	252	.03	6,416	.26	10.00	.26	16.67	.22	98.65
73	67	982	.11	5,996	.24	9.23	.24	16.21	.22	98.87
74	11	938	.11	6,040	.24	9.23	.24	16.20	.22	99.09
75	54	78	.01	6,284	.25	9.62	.25	15.98	.22	99.31
76	41	745	.08	5,957	.24	9.23	.24	15.93	.21	99.52
77	12	739	.08	5,291	.19	7.31	.19	13.34	.18	99.70
Totals		892,572		2,509,253		3849.		7250.82		

APPENDIX B

COMPUTER PROGRAM FOR NETWORK ANALYSIS OF REGIONAL AND AREA ELECTRIC POWER SYSTEMS

```
C THIS IS THE MAIN PROGRAM
C VARIABLE DEFINITIONS:
C A1=ARRAY CONTAINING THE RHS OF CONSTRAINTS
C B1=ARRAY CONTAINING THE SIGN OF THE CONSTRAINT
C ICC1=ARRAY CONTAINING THE JTH SUBSCRIPT IN THE ITH CONSTRAINT
C ICC2=ARRAY CONTAINING THE SUBSCRIPT OF THE  JTH SUBSCRIPT ABOVE
C NODE=ARRAY DEFINING THE  SUBSCRIPTS CORRESPONDING TO NODE CONSTRAINTS
C ARRAY DEFINING THE SUBSCRIPTS CORRESPONDING TO GENERATION NODES
      INTEGER*2 ICC1,ICC2
      DIMENSION A1(150),B1(150),ICC1(150,100),ICC2(150,100),L(150)
      DIMENSION NODE(50),NODEG(20)
C   READ NUMBER OF CONSTRAINTS,VARIABLES, INDEX
      READ(5,1321)NC1,NV1,INDX5
 1321 FORMAT(3I4)
      NC1A=NC1+1
C     READ CONSTRAINTS OF OBJECTIVE FUNCTION*******
      DO 1351 I=1,NC1A
      READ(5,1322) L1,A1(I),B1(I),(ICC1(I,J),ICC2(I,J),J=1,L1)
 1322 FORMAT(I2,F8.0,F10.0,19I4/(20X,19I4))
      L(I)=L1
 1351 CONTINUE
C     READ NODE DEFINITION ARRAY
      READ(5,1323)NIG,(NODE(I),I=1,NIG)
 1323 FORMAT(I4,19I4/20I4)
C     READ GENERATION ARRAY**********
      READ(5,1323) IGEN,(NODEG(I),I=1,IGEN)
C     ELIMINATE NODES ONE BY ONE******************
      DO 1357 K=1,NIG
      J1=NODE(K)
      TEMP5=A1(J1)
      TEMP6=B1(J1)
      WRITE(6,1324)J1
 1324 FORMAT(1H1,'THE  NODE ELIMINATED IS:',I4,';  THE RESULTS ARE;')
      A1(J1)=0.0
      B1(J1)=0.0
C    CALCULATE POST ATTACK GENERATING CAPACITY
      CALL CRT1(NODEG,IGEN,A1,GRT)
C     PUT THE DATA ON DISK FOR USE WITH THE L-P ALGORITHM
      REWIND 3
      WRITE(3) GRT,NC1,NV1,INDX5
      ENDFILE 3
C       THE ABOVE INFORMATION IS AVAILABLE ON LOGIC FILE THREE
      REWIND 2
      DO 1358 I=1,NC1A
      L1=L(I)
```


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```
      WRITE(2) I,A1(I),B1(I),(ICC1(I,J),ICC2(I,J),J=1,L1)
 1358 CONTINUE
      ENDFILE 2
C     THE PREVIOUS INFORMATION IS AVAILABLE ON LOGIC FILE TWO
      CALL DEPA
      A1(J1)=TEMP5
      B1(J1)=TEMP6
 1357 CONTINUE
      CALL EXIT
      END
```

```
      SUBROUTINE GRT1(NODEG,IGEN,A1,GRT)
      DIMENSION NODEG(20),A1(150)
      SUM=0.0
      DO 1 I=1,IGEN
      J1=NODEG(I)
      SUM=SUM+A1(J1)
    1 CONTINUE
      GRT=SUM
      RETURN
      END
```

```
      SUBROUTINE DLPA
      INTEGER*2 INC,IVAL
      DIMENSION A(150,115),X(260),IY(260),T(260),INC(100),IVAL(100)
      DIMENSION AVAL(1CC),UP(260)
      CCMMCN IC,IR,INCX
      REWIND 3
      READ(3)GRT,IR,N,NI
      NV=IR+N
      IPO=N+3
      IC=IR+1
      INDX=IC+1
C     *********** INITIALIZATION ****************************
      DC 10 J=1,NV
      X(J)=C.0
      IY(J)=1
   1C CCNTINUF
      DO 15 I = IO,INDX
      DO 15 J = 1,3
   15 A(I,J) = ).0
C     *********   READ ALL DATA   *************************
      CO 1000 I=1,IO
      DC 1000 J=4,IPC
      K=J-3
      UP(K)=GRT
 100C A(I,J)=0.C
      REWINC 2
      DC 1200 I=1,IO
      READ(2)L,A(I,3),A(I,2),(IND(J),IVAL(J),J=1,L)
      DO 1200 J=1,L
      JIND=IND(J)+3
      AVAL(J)=IVAL(J)
 1200 A(I,JIND)=AVAL(J)
      DO 30 J=4,IPC
   30 A(INCX,J)=J-3
      DO 50 I=1,IR
      NS=N+I
      IF(A(I,2))42,44,46
   42 UP(NS)=99999.
      X(NS)=A(I,3)
      A(I,1)=NS
      GC TC 5C
   44 UP(NS)=0.0
      X(NS)=A(I,3)
      A(I,1)=NS
      GO TO 50
   46 UP(NS)-99999.
      X(NS)=-A(I,3)
      DC 47 J=3,IPC
```

```
   47 A(I,J)=-A(I,J)
      A(I,1)=NS
   50 CONTINUE
C     ******  CHANGE SIGN OF X-C ROW  **********************
      DO 60 J=4,IPO
   60 A(IO,J)=-A(IO,J)
C     ******* WRITE THE TABLEAU ****************************
      ITAB=1
      GO TO 80
   70 IF(NI)80,80,75
   75 CALL OUTPUT(ITAB,IPO,NV,IY,X,A)
C     ******* CHECK FOR PRIMAL  ****************************
   80 ICHECK=1
      DO 160 J=4,IPO
      IF(A(IC,J))82,160,160
   82 IF(ABS(A(IO,J))-0.0001)160,83,83
   83 JEC=J
      ICHECK=0
      TMIN=999999.
      DO 100 I=1,IR
      IF(A(I,JEC)*A(I,3))84,86,94
   84 T(I)=99999.
      GO TO 96
   86 IF(A(I,JEC))88,88,92
   88 T(I)=99999.
      GO TO 96
   92 T(I)=0.0
      GO TO 96
   94 T(I)=A(I,3)/A(I,JEC)
   96 IF(TMIN-T(I))100,100,98
   98 TMIN=T(I)
      IER=I
  100 CONTINUE
      IF( ABS(TMIN-99999.)-0.01)120,120,110
  110 CALL PIVCT(A,IER,JEC,IPC,X,UP)
      ITAB=ITAB+1
      GO TO 70
  120 JUP=A(INDX,JEC)
      IF(UP(JUP)-90000.)130,160,160
  130 DO 140 I=1,IR
      A(I,JEC)=-A(I,JEC)
      A(I,3)=A(I,3)+(UP(JUP)*A(I,JEC))
      IBAS=A(I,1)
  140 X(IBAS)=A(I,3)
      A(IC,JEC)=-A(IO,JEC)
      A(IO,3)=A(IC,3)+(UP(JUP)*A(IC,JEC))
      IY(JUP)=IY(JUP)+1
      GO TO 70
```

```
160 CONTINUE
    IF(ICHECK)200,200,400
200 DO 300 I=1,IR
    IF(A(I,3))210,210,300
210 IER=I
    TMIN=999999.
    DO 270 J=4,IPC
    IF(A(IER,J))220,250,250
220 IF(A(IC,J))250,230,230
230 T(J)=-A(IO,J)/A(IER,J)
    GO TO 255
250 T(J)=99999.
255 IF(TMIN-T(J))270,270,258
258 TMIN=T(J)
    JEC=J
270 CONTINUE
    IF( ABS(TMIN-99999.)-0.01)300,300,280
280 CALL PIVCT(A,IER,JEC,IPC,X,UP)
    ITAB=ITAB+1
    GO TO 70
300 CONTINUE
    DO 350 I=1,IR
    IBAS=A(I,1)
    IF(UP(IBAS)-99990.)310,350,350
310 A(I,3)=A(I,3)-UP(IBAS)
    DO 320 J=3,IPC
320 A(I,J)=-A(I,J)
    X(IBAS)=A(I,3)
    X(BAS)=A(I,3)
    IY(IBAS)=IY(IBAS)+1
    GO TO 70
350 CONTINUE
    GO TO 9999
390 II=1
400 DO 500 I=1,IR
    IF(A(I,3))405,500,500
405 IF(ABS(A(I,3))-0.0001)500,410,410
410 IER=I
    TMIN=999999.
    DO 470 J=4,IPO
    IF(A(IER,J))420,450,450
420 IF(A(IC,J))450,430,430
430 T(J)=-A(IO,J)/A(IER,J)
    GO TO 455
450 T(J)=99999.
455 IF(TMIN-T(J))470,470,458
458 TMIN=T(J)
    JEC=J
```

```
470 CONTINUE
    IF( ABS(TMIN-99999.)-0.01)9999,9999,480
480 CALL EIVCT(A,IIR,JEC,IPC,X,UP)
    ITAB=ITAB+1
    IF(NL)390,390,485
485 CALL OUTPUT(ITAB,IPC,NV,IY,X,A)
490 GO TO 390
500 CONTINUE
    DO 540 I=1,IR
    IBAS=A(I,1)
    IF(X(IBAS)-UP(IBAS))540,540,510
510 A(I,3)=A(I,3)-UP(IBAS)
    DO 520 J=3,IPC
520 A(I,J)=-A(I,J)
    X(IBAS)=A(I,3)
    IY(IBAS)=IY(IBAS)+1
    GO TO 400
540 CONTINUE
    WRITE(6,3001)ITAB
3001 FORMAT(1H0,///,15X,'****  SOLUTION OPTIMUM*****',5X,'NUMBER OF TABL
   EAUS=',2X,I4)
    DO 600 J=1,N
    IF(IY(J)/2*2-IY(J))600,560,560
560 X(J)=UP(J)-X(J)
600 WRITE(6,3002)J,X(J)
3002 FORMAT(20X,'X',I3,4X,'=',F12.5)
    WRITE(6,3003)Z(IC,2)
3003 FORMAT(1X,//,'  OPTIMUM VALUE CF THE COJECTIVE FUNCTION  =',F15.6)
    GO TO 9999
9999 WRITE(6,3004)
3004 FORMAT(10X,' THE SOLUTION IS INFEASIBLE')
    CALL OUTPUT(ITAB,IPC,NV,IY,X,A)
9999 RETURN
    END
```

```
      SUBROUTINE PIVOT(A,IER,JEC,IPO,X,UP)
      DIMENSION A(150,115),X(260),UP(260)
      COMMON IO,IR,INDX
      CR=A(IER,JEC)
      DO 100 I=1,IO
      IF(I-IER)10,100,10
   10 DO 100 J=3,IPO
      IF(J-JEC)20,100,20
   20 A(I,J)= (A(I,J)*CR-A(I,JEC)*A(IER,J))/CR
  100 CONTINUE
      DO 120 J=3,IPO
  120 A(IER,J)=A(IER,J)/CR
      DO 130 I=1,IO
  130 A(I,JEC)=-A(I,JEC)/CR
      A(IER,JEC)=1./CR
      ITEMP=A(IER,1)
      A(IER,1)=A(INDX,JEC)
      A(INDX,JEC)=ITEMP
      X(ITEMP)=0.0
      DO 200 I=1,IR
      JJ=A(I,1)
  200 X(JJ)=A(I,3)
      IF(UP(ITEMP)-1.01)300,400,400
  300 IPO=IPO-1
      IF(JEC-IPO)330,330,400
  330 DO 350 J=JEC,IPO
      DO 350 I=1,INDX
  350 A(I,J)=A(I,J+1)
  400 RETURN
      END


      SUBROUTINE OUTPUT(ITAB,IPO,NV,IY,X,A)
      DIMENSION A(150,115),X(260),IY(260)
      COMMON IO,IR,INDX
      WRITE(6,3001)ITAB
 3001 FORMAT(1H0,'TABLEAU NUMBER',I4)
      DO 100 I=1,INDX
  100 WRITE(6,3002)A(I,1),A(I,2),A(I,3),(A(I,J),J=4,IPO)
 3002 FORMAT(1H0,2(F4.0,1X),F15.3,2X,10(F8.2,1X)/(27X,10F9.2))
      DO 200 J=1,NV
      IF(IY(J)/2*2-IY(J))150,180,180
  150 WRITE(6,3003)J,X(J)
 3003 FORMAT(10X,'X',I3,'    =     ',F12.5)
      GO TO 200
  180 WRITE(6,3004)J,X(J)
 3004 FORMAT(10X,2HX',I3,4X,'=',F12.5)
  200 CONTINUE
      RETURN
      END
```

APPENDIX C

SELECTED ANNOTATED BIBLIOGRAPHY

The following annotated bibliography contains only those references which are considered to be the most pertinent and timely with respect to resource systems vulnerability analysis. Additional annotated bibliographies may be found in Minor, Lambert, and Smith (1972), Lambert and Minor (1973), Lambert and Minor (1973a), and Lambert and Minor (1974).

Ayers, R. W., "Methodology for Postattack Research," Hudson Institute, HI-647-RR, New York, OCD Work Unit 3522 A (AD 639 751) (1966).
Annotation Statement: Discussions of the use of models for postattack research as contrasted to scenarios, games, case histories, and metaphors.

Ayers, R. W., "Models of the Postattack Economy," Hudson Institute, Report No. HI-648-RR, New York (Ad 639 713) (1966).
Annotation Statement: State-of-the-art summary of current programs related to postattack economy.

Bear, D. B. T. and Clark, P. G., "The Importance of Individual Industries for Defense Planning," Rank P-2093, Santa Monica, California (1960).
Annotation Statement: Analysis of individual industries intended as a guide to peacetime defense preparations, plausible supplies, and demands in the U. S. Economy after a nuclear war.

Bickley, L. J., Concentrations of the Manufacturing Industries, Research Report for OCD Contract # PS 66 113.
Annotation Statement: Industries classified at the 4 digit SIC level and individual plants identified by city location. Number of persons employed used as a measure of industrial activity. Study indicates potentially vulnerable concentrations within manufacturing industries.

Bickley, Leonard J., The Spectrum of Characteristics of the Manufacturing Industry and Derivation of Industrial Family Groupings, Research Report for OCD Contract # PS-66-113, Subtask 4115A.
Annotation Statement: Reports on the spectrum of characteristics of industries and divides industries into families.

Bickley and Sachs, Industrial Hardening Classification: A Methodology for Simplifying the Evaluation of Hardening Costs, Institute for Defense Analyses Study S-263 (1966).
Annotation Statement: Sets forth a method for handling the large mass of data required to develop an estimate of the cost of hardening economic resources against nuclear attack.

Black, R. H. and Van Horn, W. H., Development of Procedures for Assessment of Local Industrial Productive Capacity Following Nuclear Attack. URS Research Company, Report URS 753-6 Feb., 1970.
Annotation Statement: Assessment of productive capacity considered in 3 steps: (1) damage assessment, (2) repair effort estimation, (3) estimation of potential productive capacity.

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Boesman, W. C., Grigsby, J. and Manly, R., *Vulnerability of the Petroleum Distribution System Detroit, Michigan, Checchi and Company, Report 7023*, July 1970.
Annotation Statement: Study covers vulnerability of Petroleum distribution system in Detroit including gasoline, diesel fuel, liquified petroleum gas and other petroleum products. Results give estimated values of post attack capacities.

Boesman, William C., Robert P. Manley and Richard A. Ellis, *Total Resource System Vulnerability: Development and Application of a General Model*, DCPA Work Unit 4342A, Checchi and Co., Washington D. C., 1972.
Annotation Statement: Develops a total economic resource system vulnerability model for CD problems.

Brown, S. L., "Industrial Recovery Techniques," SRI MU-4949-350, Menlo Park, California. OCD Work Unit 3331 B (AD 636 947) (1966).
Annotation Statement: Generalized concepts concerning industrial models, industrial vulnerability to nuclear attack, industrial recovery requirement, and industrial recovery procedures.

Carter, Anne P., "The Economics of Technological Change," *Scientific American*, Vol. 214, No. 4 (April 1966).
Annotation Statement: Use of input-output methodology to determine the effects of technological change on the economy.

Chenoweth, J. M., et. al., *A Method for Predicting Electrical Power Availability Following a Nuclear Attack*, National Engineering Science Co., April, 1963.
Annotation Statement: Considers a detailed procedure for estimating available electric power following a nuclear attack.

Clark, P. G., "Vulnerability and Recuperation of a Regional Economy," Rand RM-1809, Santa Monica, California (AD 123 549) (1956).
Annotation Statement: Methodological contribution to analysis of consequences of bombing attacks on a region of the nation. Report notes that "it is not easy to construct a scheme of assumptions that will reveal the existence of potential bottlenecks."

DCPA, *EMP Protection for Emergency Operating Centers*, Defense Civil Preparedness Agency, Publication # TR-61A, July 1972.
Annotation Statement: A description of a nuclear electromagnetic pulse and provides an unclassified guide for incorporating EMP protection into Emergency Operation Centers.

DCPA, *EMP Protective Systems*, Defense Civil Preparedness Agency, Publication # TR-61-B, July 1972.
Annotation Statement: A description of representative problems and solutions providing protection against a nuclear electromagnetic pulse.

DEPA, Civil Defense Preparedness in the Electric Power Industy, Defense Electric Power Administration, March 1966.
Annotation Statement: Management guide covering (1) CD planning for the power industry, (2) government organization and planning for protection and restoration of the power industry, (3) essentials of electric power industry preparation and readiness, and (4) civil defense preparedness and readiness check lists for the power industry.

DEPA, Civilian Defense and Emergency Operation Plan. U. S. Dept. of Interior DEPA, September 1961.
Annotation Statement: A proposed plan by which to promote continuity of community services during emergency conditions.

DEPA, Protection of Electric Power System, Defense Electric Power Administration, Research Project No. 4405, June 1962.
Annotation Statement: Results of power industry survey to determine the ability of power companies to survive the attack and continue operation. Recommendations for improving ability to survive and operate.

DEPA, Recommendations To Be Used as a Guide To Assist Electric Utilities in Maintaining Service During and Following a Nuclear Bombing Attack, Defense Electric Power Administration, Power Area 7-Project No. 1, September 1961.
Annotation Statement: Results of a DEPA committee study to serve as a guide for electric utilities during and following a nuclear attack.

DEPA, Vulnerability Analysis of Electric Power Distribution Systems Detroit, Michigan. U. S. Dept. of Interior DEPA, Research Report for OCD work order # PS-66-92, Work Unit 4334-B.
Annotation Statement: An analysis of the effects of a hypothetical nuclear attack directed at the city of Detroit, Michigan.

DEPA, Vulnerability of Electric Power Systems to Nuclear Weapons, U. S. Dept. of Interior DEPA. Research Report for OCD Work Order # OS-63-53.
Annotation Statement: An analysis of the effects of an assumed full-scale nuclear attack on the nation's electric power industry.

DEPA, Engineering Study - "Vulnerability of Electric Utilities to Nuclear Attack," Defense Electric Power Administration, Electric Power Area 12, October 1, 1963.
Annotation Statement: Analysis of area 12 electric utility system to withstand nuclear attack and to continue to produce power after attack.

Doll, John P., et. al., Method for Evaluating the Effects of Nuclear Attack on the Ability of Power Systems to Meet Estimated Postattack Demands, Stanford Research Institue, Sept., 1966.
Annotation Statement: Development of three methods for assessing vulnerability including a rapid, qualitative technique, a linear programming method, and a non-computer method for determining amount of deliverable power and size and location of demand.

Dynes, Russell R., E. L. Quarantelli, and Gary A. Kreps, A Perspective on Disaster Planning, TR-77, Defense Civil Preparedness Agency. December 1972.
Annotation Statement: Study of relationship between emergency planning and the manner in which people in the disaster area react to the disaster. Directed at natural disasters.

Faucett Associates. Applications of Network Analysis to Civil Defense Operations. Prepared for Office of Civil Defense, Work Unit 4114, August 1971.
Annotation Statement: Application of mathematical programming and network theory to the allocation of resources to meet post-disaster needs.

Faucett, Jack and Grace J. Kelleher, Economic Relationships in the New Orleans Metropolitan Area. Research Report for OCE Contract PS-66-113. Subtask 4131A.
Annotation Statement: Presents 1963 interindustry transaction data for analysis of results derived for New Orleans using input-output data for CD planning.

FitzSimons, Neal, A Geographic Framework for Systems Evaluation, Office of Civil Defense, Systems Evaluation Division, Washington, D. C., 1972.
Annotation Statement: Description of the structure and uses of the Geographic Nodal Network.

FitzSimons, Neal, Notes on the Use of Triads to Model Systems, Research Directorate, OCD, 1972.
Annotation Statement: A guide to researchers working under Systems Evaluations Division, Research Directorate, OCD in the modeling of systems for studies involving survival and recovery in event of a nuclear war.

Fogot, Carl R. and William H. Van Horn, Availability and Use of Emergency Power Sources in the Early Postattack Period, URS Research Company, URS 710-4, OCD Work Unite 3311B, August 1969.
Annotation Statement: Study concerned with identification and use of emergency power sources, both conventional and unconventional, in the early postattack period.

Grisby, J. W., R. P. Manly, W. C. Boesman and J. M. Johnson, Vulnerability of the Local Petroleum Distribution System--Albuquerque, New Mexico. Checchi and Company, OCD Work Unit 4361 A, June, 1968.
Annotation Statement: Examines vulnerability of petroleum distribution system including product storage facilities.

Grimm, Bruce T., Estimation of CES Production Functions for U. S. Manufacturing by Input-Output Sector. Institute for Defense Analyses, Research Paper P-525, July 1969.
Annotation Statement: Estimates are made of the production functions for 52 manufacturing input-output sectors using the equilibrium condition for labor demand. Results indicate that there exists a limited but significant ability to substitute capital and labor for one another in manufacturing.

Hall, R. W., Vulnerability of Local Transportation Systems--Albuquerque, New Mexico. Stanford Research Institute, OCE Work Unit 4334 A, July 1969. Annotation Statement: Developes an inventory of resources by quantity and location for each transportation mode. Estimates of damage are made for each mode and the capability of residual systems to perform transportation services is examined.

Hamburg, W. A., Transportation Vulnerability Research: Review and Appraisal 1959-1969, Stanford Research Institue, Jan. 1969. Annotation Statement: Review of past research in transportation systems. Includes a summary of data requirements and likely sources for all modes.

Hamburg, William A., Vulnerability of a Zonal Transportation System, Stanford Research Institute, Menlo Park, California. Annotation Statement: Represents the starting phase of research on the vulnerability of the transportation systems in a specified zonal area to the effects of a nuclear attack.

Hamburg, W. A. and Hall, R. W., Vulnerability and Serving Capability of the Nation's Transportation Systems: Development and Test of Methodology. Stanford Research Institute, March 1970. Annotation Statement: Examination of two possible methodologies; generalized model and scenario approach.

Hirshleifer, J., "Economic Recovery." Rand, Santa Monica, California (AD 626 605) (1965). Annotation Statement: A general discussion of the theory that economic recovery is feasible after thermonuclear war when considered with reference to past disasters.

Input-Output Bibliography, 1960-1963, New York: Statistical Office, Department of Economic and Social Affairs. United Nations, 1964. Annotation Statement: Bibliography of input-output techniques and applications.

Isard, Walter, Methods of Regional Analysis: An Introduction to Regional Science. M. I. T. Press, Cambridge, Mass. 1960. Annotation Statement: Purports to improve the spatial and regional frameworks of the social science disciplines, especially economics, through the development of a more adequate general theory of location and space-economy.

Isard, Walter and Thomas W. Langford, Regional Input-Output Study: Recollections, Reflections, and Diverse Notes on the Philadelphia Experience. Department of Regional Science, University of Pennsylvania and Regional Science Research Institute, 1971. Annotation Statement: A detailed description of the application of the theoretical "input-output" concept to the economy of metropolitan Philadelphia.

Isard, W., Schooler and Vietorisz, Industrial Complex Analysis and Regional Development. Annotation Statement: Regional input-output analysis of petro-chemical industries in Puerto Rico. Identifies activities for which Puerto Rico would be a favorable location.

Lambert, B. K. and Minor, J. E., Vulnerability of Regional Electric Power Systems to Nuclear Weapons Effects, DEPA, May 1973.
Annotation Statement: Describes the development of a conceptual model for assessing power system vulnerability. A constrained network flow structure is utilized. Includes an application to a particular region.

Lambert, B. K., and J. E. Minor, Vulnerability of Regional Manufacturing and Resource Systems to Nuclear Weapons Effects, Texas Tech University, August 1973 (publication pending by DCPA).
Annotation Statement: Development of a method for assessing vulnerability of resource systems. Incldues the development of a composite vulnerability index and an application to a specific region.

Leontief, W. W., "Input-Output Economics," Scientific Amer., Vol 185, #4 (Oct. 1951).
Annotation Statement: Concerning a method which can portray both an entire economy and its fine structure by plotting the production of each industry against its consumption from every other (7 pages).

Leontief, W. W., "The Economic Effects of Disarmament," Sc. Amer., Vol. 204 (1961), p. 47, April 1961.
Annotation Statement: The technique of "input-output" analysis is here adapted to facilitate forecasting the effect on sales and jobs of the reallocation of the funds now expended for military purposes.

Leontief, Wassily, "The Structure of Development" Scientific American, Sept., 1963.
Annotation Statement: Analysis of an economy by the input-output method revealing its internal structure and mapping out its growth.

Leontief, W. W., "The Structure of the U. S. Economy," Scien. Amer., Vol. 212, #4, (Apr. 1965).
Annotation Statement: The input-output tables divide the economy into 81 sectors and list the transactions among them. The numbers are the constants of the technological relations among the sectors (11 pages).

McGraw-Hill, "Plant Census: S-1 Format and L-1 Format" Hightstown, New Jersey (1967).
Annotation Statement: Employed in 4351 A methodology; excellent method for four-digit industrial plant identification.

McFadden, Fred R. and Charles D. Bigelow, Development of Rapid Shutdown Techniques for Critical Industries. Stanford Research Institute, OCD Work Unit 2321A, January 1966.
Annotation Statement: A study of problems of rapid shutdown in the petroleum and steel industries. Basic operation and shutdown procedures are described. Consequences of rapid shutdown and measures for reducing shutdown vulnerability are presented.

Manly, R. P., Lerner, H. A., and Grigsby, J. Petroleum Distribution, Gross National Product, and System Vulnerability: Methods of Analyses Checchi and Co., Washington, D. C., Oct. 1970.
Annotation Statement: Principal attention given to four areas of analysis: gross national product analysis, national needs analysis, spatial interaction analysis and network boundary flow analyses.

Minor, Joseph E., Brian K. Lambert, and Milton L. Smith, Vulnerability of Regional Manufacturing Systems to Nuclear Weapons Effects, Texas Tech University, Contract No. DAHC20-70-C-0382, Work Unit 4352A, May 1972.
Annotation Statement: Report contains three major presentations: development of a general model concept for simulating a regional manufacturing system, utilization of the model to simulate a specific economic region, and exercise of the model to demonstrate its usefulness in vulnerability evaluations and other types of systems studies.

Minor, J. E., A. J. Pryor, G. E. Commerford, and R. C. Dehart, Evaluation of Industrial Systems Interrelationships and Vulnerability to Nuclear Attack, Southwest Research Institute, August 1969.
Annotation Statement: General methodology developed for defining and evaluating manufacturing systems. The model developed includes: (1) inventory and network definition of systems, (2) characterization of manufacturing systems and interrelationships, (3) identification of essential industries, (4) vulnerability analysis and evaluation. Report is specifically concerned with the Detroit SMSA.

Nevin, R. L., Vulnerability of the Detroit Water Supply System, Stanford Research Institute, Sept. 1970.
Annotation Statement: Estimated damage to facilities and personnel as well as estimates of post-attack capabilities of the system are discussed.

Nevin, R. L., Vulnerability of the Albuquerque Sanitary Sewerage and Storm Drainage System, Stanford Research Institute, June 1969.
Annotation Statement: Probable damage to facilities and personnel are considered as well as possible loss of support from interrelated systems. Post-attack capabilities estimated as nil.

Nevin, R. L. and Pickering, E. E., Water, Sewerage, and Storm Drainage Systems Staff Vulnerability--San Jose, California, Stanford Research Institute, May 1969.
Annotation Statement: Analysis of casualties to management, maintenance and operation staffs and assessment of surviving staff capabilities.

Norton, J. W., Economic Activities and Resources: Classification and Data Inventory, National Planning Association, Washington, D. C., Nov. 1968.
Annotation Statement: Classification of areas, activities, and objects suitable for use in an economic model for planning the survival and recovery of a single city following nuclear attack.

OCD, A Framework for Evaluation of Survival and Recovery Systems, Transactions of an OCD Research Symposium, March 1970.
Annotation Statement: Of interest are the following papers: (1) Vulnerability assumptions; (2) A Matrix for System Descriptions; (3) The Final Product.

OCD, EMP Protection for AM Radio Broadcast Stations, Department of Defense/Office of Civil Defense, Publication # TR-61-C, May 1972.
Annotation Statement: A description of nuclear electromagnetic pulse effect on AM broadcast stations.

OCD, EMP Threat and Protective Measures, Department of Defense/Office of Civil Defense, Publication # TR-61, Aug. 1970.
Annotation Statement: A technical report presenting a description of a nuclear electromagnetic pulse effect on civil defense activities.

OCD, Reducing the Vulnerability of Industrial Plants to the Effects of Nuclear Weapons, Office of Civil Defense, PSD-PG 80-8, October 1963, Professional Guide Series.
Annotation Statement: Guide to assist architects and engineers in developing constructive measures for protection of industrial plants against the effects of nuclear attack.

Orcutt, G. H., "Simulation of Economic Systems," American Economic Review, Vol. 50, # 5.
Annotation Statement: Discusses use of simulation in studying economic systems. Discusses past research dealing with simulation studies. Mainly discusses methodology of simulation rather than any specific application to economic system.

Pendleton, W. W., "A Study of Personnel Demands and Availabilities for Postattack Counter Measure Systems," Human Science Research Inc., (AD 637 833) June 1966.
Annotation Statement: The use and assignment of manpower are examined. Several principles for assigning manpower are suggested.

Petersen, D. L. and Schmidt, L. A., Arrangements of U. S. Population by Urban and Rural Geometrical Clusters. Institute for Defense Analyses, Paper P-706, Sept. 1970.
Annotation Statement: Describes structuring of the U. S. population based on aggregations of natural clusters of people into nodes; development of the National Nodal Network. Results indicate that considerable simplification is possible in describing a county.

Pryor, A. J., G. E. Commerford, and J. E. Minor, Vulnerability of Industries Critical to National Survival in a Postattack Environment, Southwest Research Institute, January 1968.
Annotation Statement: Assesses national needs in postattack environment and developes critical industry selection criteria. Detailed analysis performed on a plant in San Jose, California.

Rand McNally, Commercial Atlas and Marketing Guide-99th Edition (1968).
Annotation Statement: Shows population distribution, total personal income, industrial and commercial area as map overlays. Data can be used after an industrial complex is defined.

Redmond, John H., "Industry Planning for Continuity of Production," Pub. # L57-121 Industrial College of the Armed Forces, Washington D. C., 1957.
Annotation Statement: Speech discussing status of industrial planning for continuity of production to the Industrial College of the Armed Forces.

Reliability and Adequacy of Electric Power Within Southwest Power Pool 1970-1980, A Report to the Federal Power Commission, September 1, 1970.
Annotation Statement: Study showing additional capacity planned for the power pool to meet increased load projected for the period 1970 to 1980.

Research on Evaluation of Civil Defense Systems, Briefing at IDA for Canadian Director General of Emergency Measures Organization, October 1969.
Annotation Statement: Summaries of papers. Of interest are the following: (1) Development of a Structure for Evaluating CE Systems, (2) Sector Analysis, (3) Network Analysis, (4) Dynamic Evaluation of CE operational systems.

Richford, M. A. and Davis, W. E., Vulnerability of Gas Utilities to Nuclear Attack--Detroit, Michigan, U. S. Department of Interior, Office of Oil and Gas, July 1971.
Annotation Statement: Concludes that post-attack transmission system capacity is ample and physical facilities are adequate for post-attack repair.

Rockett, F. C. and Brown, W. M., "Crisis Preparation for Postattack Economy Recovery," Hudson Institute Report No. HI-661-RR, New York (AD 639 387) (1966).
Annotation Statement: Report reviews and describes the effectiveness of a "relocation" and "protection" civil defense methodology utilizing transportation resources.

Sachs, Abner and Timmermans, J. A., Economic Structure of the U. S. Using the County as a Functional Base, Institute for Defense Analyses, Research Paper P-511, April 1969.
Annotation Statement: Presents resource data using the county as the geographic unit. Economic measures include value added, number of plants, employment, sales, and others.

Schmidt, L. A., A Study of National Travel Requirements for Strategic Evacuation. Institute for Defense Analyses, Paper P-702, March 1970.
Annotation Statement: Calculations were made of travel requirements from large urban centers to rural areas.

Smith, Caleb A., Methods Used in Developing Input-Output Tables for the Providence Standard Statistical Area, 1963. Research Report for OCD work order # PS-66-113, by the Department of Economics, Brown University.
Annotation Statement: Describes methods used in developing the input-output tables for the Providence, Rhode Island, Metropolitan Area.

Smith, Caleb and Dale L. Moody, Economic Relationships in the Providence, Rhode Island, Metropolitan Area. Research report for OCD work order # PS-66-113, Subtask 4131A.
Annotation Statement: Presents interindustry transaction data and coefficients for the Providence, Rhode Island, Standard Metropolitan Statistical Area.

Stephens, Maynard M., Minimizing Damage to Refineries from Nuclear Attack, Natural and Other Disasters. Research Report for OCD work order DAHC 20-68-C-0097, by The Office of Oil and Gas, The Dept. of Interior, 1970.
Annotation Statement: A handbook reviewing potential hazards that could affect petroleum refinery operations in times of war and peace.

Truppner, W. C., "Nuclear Blast Effects on a Metropolitan Economy," IDA S-209 Arlington, Virginia (AD 631 026), OCD Work Unit 4113C (1965).
Annotation Statement: Study of weapons effects on Houston, Texas, SMSA in terms of economic output, property values, and population characteristics.

U. S. Technical Committee on Industrial Classification: (1) Standard Industrial Classification Manual (1957), (2) Supplement to 1957 Edition, Standard Industrial Classification Manual (1958), (3) Supplement to 1957 Edition, Standard Industrial Classification Manual (1963); Executive Office of the President, Bureau of the Budget.
Annotation Statement: Basic manual governing SIC coded industry identification.

Wetzler, Elliot, The Structure of the IDA Civil Defense Economic Model, Institute for Defense Analyses, Paper P-674, August 1970.
Annotation Statement: Development of an I/O model with CES production functions to assess viability of the postattack economy given a variety of alternate CD plans.

Winter, S. G., "Economic Viability after Thermonuclear War: The Limits of Feasible Production," Rand RM-3436-PR. Santa Monica, California (AD 426 906) (1963).
Annotation Statement: A study of the technological features of the problem of achieving viability. Surviving resources, scarcities, and alternate paths are considered.

Yamada I., Theory and Application of Inter-Industry Analysis, Kinokuniya Bookstore, Tokyo, 1961.
Annotation Statement: Mathematical treatment of input-output analysis. Portions of this work on regional input-output may be applicable.

APPENDIX D

DEFENSE MOBILIZATION ORDER 8500.1A

APPENDIX D

Defense Mobilization Order 8500.1A
November 4, 1964

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF EMERGENCY PLANNING
Washington, D. C. 20504

DMO 8500.1A—GUIDANCE ON PRIORITY USE OF RESOURCES IN IMMEDIATE POSTATTACK PERIOD

1 *Purpose.* This Order (1) states the policy of the Federal Government on use of resources in the period immediately following a nuclear attack on the United States, (2) provides general guidance for Federal, State, and local government officials on activities to be accorded priority in the use of postattack resources, and (3) lists those items essential to national survival in the immediate postattack period.

2. *Cancellation.* Defense Mobilization Order 8500.1, Guidance on Priority Use of Resources in Immediate Postattack Period, dated April 1, 1964 (29 F.R. 5796) is hereby superseded.

3 *General policy.* In an immediate postattack period all decisions regarding the use of resources will be directed to the objective of national survival and recovery. In order to achieve this objective, postattack resources will be assigned to activities concerned with the maintenance and saving of lives, immediate military defense and retaliatory operations, and economic activities essential to continued survival and recovery.

This guidance is designed to achieve a degree of national equity in the use of resources and to assign and conserve resources effectively in the immediate postattack period. Until more specific instructions are available, these are the general guidelines within which managerial judgment and common sense must be used to achieve national objectives under widely differing emergency conditions.

4 *Responsibilities.* As stated in The National Plan for Emergency Preparedness, the direction of resources mobilization is a Federal responsibility. However, in the period immediately following an attack, certain geographical areas may be temporarily isolated, and State and local governments will assume responsibility for the use of resources remaining in such areas until effective Federal authority can be restored. State and local governments will not assume responsibility for resources under the jurisdiction of a Federal agency where the Federal agency is able to function.

As soon as possible after an attack and until specific national direction and guidance on the use of resources is provided, Federal, State, and local officials will determine what resources are available, to what needs they can be applied, how they are to be used, and the extent to which resources are deficient or in excess of survival needs. They will base determinations as to the relative urgency for use of resources primarily upon the importance of specific needs of defense, survival, and recovery.

5. *Priority activities in immediate postattack period.* The following activities are to be accorded priority over all other claims for resources. There is no significance in the order of the listing—all are important. The order in which and the extent to which they are supported locally may vary with local conditions and circumstances. If local conditions necessitate the establishment of an order of priority among these activities, that order shall be based on determinations of relative urgency among the activities listed, the availability of resources for achieving the actions required, and the feasibility and timeliness of the activities in making the most rapid and effective contribution to national survival.

a. The immediate defense and retaliatory combat operations of the Armed Forces of the United States and its Allies: This includes support of military personnel and the production and distribution of military and atomic weapons, materials and equipment required to carry out these immediate defense and retaliatory combat operations.

b Maintenance or reestablishment of Government authority and control to restore and preserve order and to assure direction of emergency operations essential for the safety and protection of the people. This includes:

(1) Police protection and movement direction;

(2) Fire defense, rescue and debris clearance;

(3) Warnings;

(4) Emergency information and instructions;

(5) Radiological detection, monitoring and decontamination.

c Production and distribution of survival items and provision of services essential to continued survival and rapid recovery. (For list of survival items, see Appendix 1 to this order.) These include:

(1) Expedient shelter;

(2) Food, including necessary processing and storage;

(3) Feeding, clothing, lodging, and other welfare services;

(4) Emergency housing and community services;

(5) Emergency health services, including medical care, public health and sanitation,

(6) Water, fuel, and power supply;

(7) Emergency repair and restoration of damaged vital facilities.

d Essential communications and transportation services needed to carry out the above activities.

e. Provision of supplies, equipment, and repair parts to produce and distribute goods needed for the above activities.

6 *Assignment of resources.* Resources required for essential uses including manpower, will be assigned to meet the emergency requirements of the priority activities indicated above. The principal objectives are to use available resources to serve essential needs promptly and effectively, and to:

a Protect and to prevent waste or dissipation of resources prior to their assignment to priority activities;

b Support production of essential goods. Other production will be permitted to continue only from inventories on hand and when there is no emergency requirement for the resources vital to this production.

c Support construction for emergency repair and restoration, construction of facilities needed for survival, or the conversion of facilities to survival use, where this can be accomplished quickly. Other construction already under way should be stopped, and no new construction started unless it can be used immediately for essential purposes upon completion.

Dated: November 4, 1964.

Effective date. This order is effective the date of issuance.

EDWARD A. MCDERMOTT,
Director,
Office of Emergency Planning.

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