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USERS MANUAL FOR THE NETWORK CONNECTIVITY ANALYSIS MODEL (NCAM)

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The OMNCS has been tasked by both Executive Order (EO) 12472 and National Security Decision Directive (NSDD) 97 to investigate the effects of EMP on the nation's National Security Emergency Preparedness (NSEP) telecommunication assets. A two-tiered network level approach has been implemented to drive the EMP Mitigation program. The first tier addresses the effects of EMP on selected network equipment types. The second tier is a computer based simulation of network performance, which uses the results of the equipment test programs. This tier is conducted by the NCAM model. This approach is referred to as network level because the results of the NCAM simulation predict the performance of the entire network following EMP exposure, as opposed to a specific set of equipment.

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USERS MANUAL FOR THE NETWORK
CONNECTIVITY ANALYSIS MODEL (NCAM)

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FOREWORD

The National Communications System (NCS) is an organization of the Federal Government whose membership is comprised of 22 Government entities. Its mission is to assist the President, National Security Council, Office of Science and Technology Policy, and Office of Management and Budget in:

- o The exercise of their wartime and non-wartime emergency functions and their planning and oversight responsibilities.
- o The coordination of the planning for and provision of National Security/Emergency Preparedness communications for the Federal Government under all circumstances including crisis or emergency.

In support of this mission the NCS has initiated and manages the Electromagnetic Pulse (EMP Mitigation Program). The major objective of this program is to significantly reduce the vulnerability of the U.S. telecommunications infrastructure to disabling damage due to nuclear weapon effects in direct support of the survivability and endurability objectives addressed by Executive Order 12472 and National Security Decision Directive 97. Nuclear weapon effects include EMP, magnetohydrodynamic EMP (MHD-EMP), and fallout radiation from atmospheric detonations. The purpose of this Technical Information Bulletin is to provide the reader with information relating to specific areas of EMP which are being investigated in support of the NCS EMP Mitigation Program.

Comments on this TIB are welcome and should be addressed to:

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T A B L E   O F   C O N T E N T S

LIST OF EXHIBITS

1.0 INTRODUCTION

The Network Connectivity Analysis Model (NCAM) is a tool developed by the Office of the Manager, National Communications System (OMNCS) for assessing the effects of Electromagnetic Pulse (EMP) on the nation's telecommunication capabilities. This model is a simulation package written in a combination of the Pascal and VAX macro computing languages using the Digital Equipment Corporation (DEC) VMS operating system. This NCAM User's manual is designed for two purposes, to provide insight into the model's applications and to show how to use the model.

1.1 BACKGROUND

The OMNCS has been tasked by both Executive Order (E.O.) 12472 and National Security Decision Directive (NSSD) 97 to investigate the effects of EMP on the nation's National Security Emergency Preparedness (NSEP) telecommunication assets. A two-tiered network level approach has been implemented to drive the EMP Mitigation program. The first tier addresses the effects of EMP on selected network equipment types. The OMNCS has available test data on the 5ESS and 1ESS switches; the TD-2 microwave, L4 carrier, T1 carrier, and FT3C fiber optic transmission facilities; and the D4 channel bank. In addition, present plans call for testing of the 4ESS and DMS-100 switches.

The second tier is a computer based simulation of network performance, which uses the results of the equipment test programs. This tier is conducted by the NCAM model. This approach is referred to as network level because the results of the NCAM simulation predict the performance of the entire network following EMP exposure, as opposed to a specific set of equipment. Network performance is quantified by the point-pair connectivity metric, which is a function of the post-attack versus pre-attack connections.

Initial network level analyses assessed the EMP effects of a hypothetical minimally connected network (reference 1). This effort was followed by analyses on a simulated PSN network, and later on a simulated Nationwide Emergency Telecommunications Service (NETS) network (references 2 and 3). A subsequent study (reference 4) addressed both the physical and logical connectivity of the actual PSN. Through successive studies the accuracy and usefulness of the network level results have increased. Improvements have been made through obtaining additional equipment EMP test data as well as using more accurate network topology information.

The most recent enhancement to the network level approach has been the development of the EMPEAK model (reference 5). This model predicts the EMP stress levels to which each network equipment is exposed to based on the weapons of a nuclear attack scenario. Analyses prior to this used a simplified approach which assumed that the entire network was exposed to one of three EMP stress level ranges.

1.3 PURPOSE

This user's manual describes how to access the Network Connectivity Analysis Model (NCAM), whose purpose is to simulate the degradation effects of EMP. NCAMs development has been evolutionary, and has been enhanced to incorporate more accurate input data as well as to run faster. NCAM was developed by the OMNCS to solve a technical problem -- to simulate network level EMP effects. Due to numerous updates, the fact that the users of the program have also been the software developers, and the requirement for fast processing times, the aspect of "user friendliness" has not always been incorporated into NCAM. However, in the course of developing this user's manual, NCAM has been modified to make it more user friendly. These modifications primarily include the use of more descriptive variable names and adding additional commenting of the code.

This user's manual provides the following information:

- The flow of the NCAM model
- Description of critical user oriented input variables
- Description of the required hardware and software
- Specification of the required input information
- Presentation of how to run the model.

1.3 ORGANIZATION

Section 2.0 provides background information on the network level approach and the network topology. Understanding these subject areas is necessary for comprehending the discussion about NCAM, which uses specific terminology.

A detailed presentation of the flow of NCAM is given in section 3.0. Included is a detailed discussion of the four modules which compose NCAM, as well as how the four modules interrelate with each other. In addition, the input and output information associated with each module is specified.

The hardware and software required to run NCAM is specified in section 4.0. This includes the settings of various system parameters which NCAM requires, a discussion of the required input files, and the record structures of the input files.

Section 5.0 illustrates user access of NCAM. This section provides a step by step procedure for running the model. Also included is a definition of user related variables, and the implications associated with changing these variables.

A summary of this report is contained in section 6.0. This section specifies efforts which are required to make NCAM easier to access from the perspective of the end-user. Also discussed is the required changes which would need to be developed for running NCAM on other network topologies. Such changes are expected to be minimal.

2.0 SUPPORTING INFORMATION

To understand the NCAM model, background information on the network level approach used by the EMP Mitigation Program is required. In addition, it is necessary to be familiar with the terminology used in describing the network topology. Providing these two sources of information is the focus of this section.

2.1 NETWORK LEVEL APPROACH

The network level approach can be conceptually viewed as four interrelated modules, as depicted in Exhibit 2-1. The upper left hand module represents the survivability of the network telecommunications equipment to EMP. This information is based on EMP test data which has been obtained through OMNCS sponsored testing programs, or test programs run by other government agencies. The findings of these testing programs are then analyzed and interpolated. This results in a uniform approach for assessing the EMP survivability of each equipment tested. This uniform approach yields the sample size of EMP tests and the number of survivals for each equipment tested over three EMP stress level ranges. These stress level ranges are often referred to as "bins." The format of the test results is as shown in Exhibit 2-2. In this example the equipment was tested at the low stress level nine times and survived eight times, when exposed at the medium level it survived six of eight exposures, and it survived only two of six exposures at the high level. All equipment test data are interpolated into a similar format as shown in Exhibit 2-2.

This data is then fed into a Bayesian Survivability Model which uses a noninformative prior distribution. This model develops a cumulative distribution function (CDF) survivability curve which represents the survivability of the equipment to EMP. For each equipment tested, three survivability curves are

EXHIBIT 2-1

Network Level Approach for Assessing EMP Effects

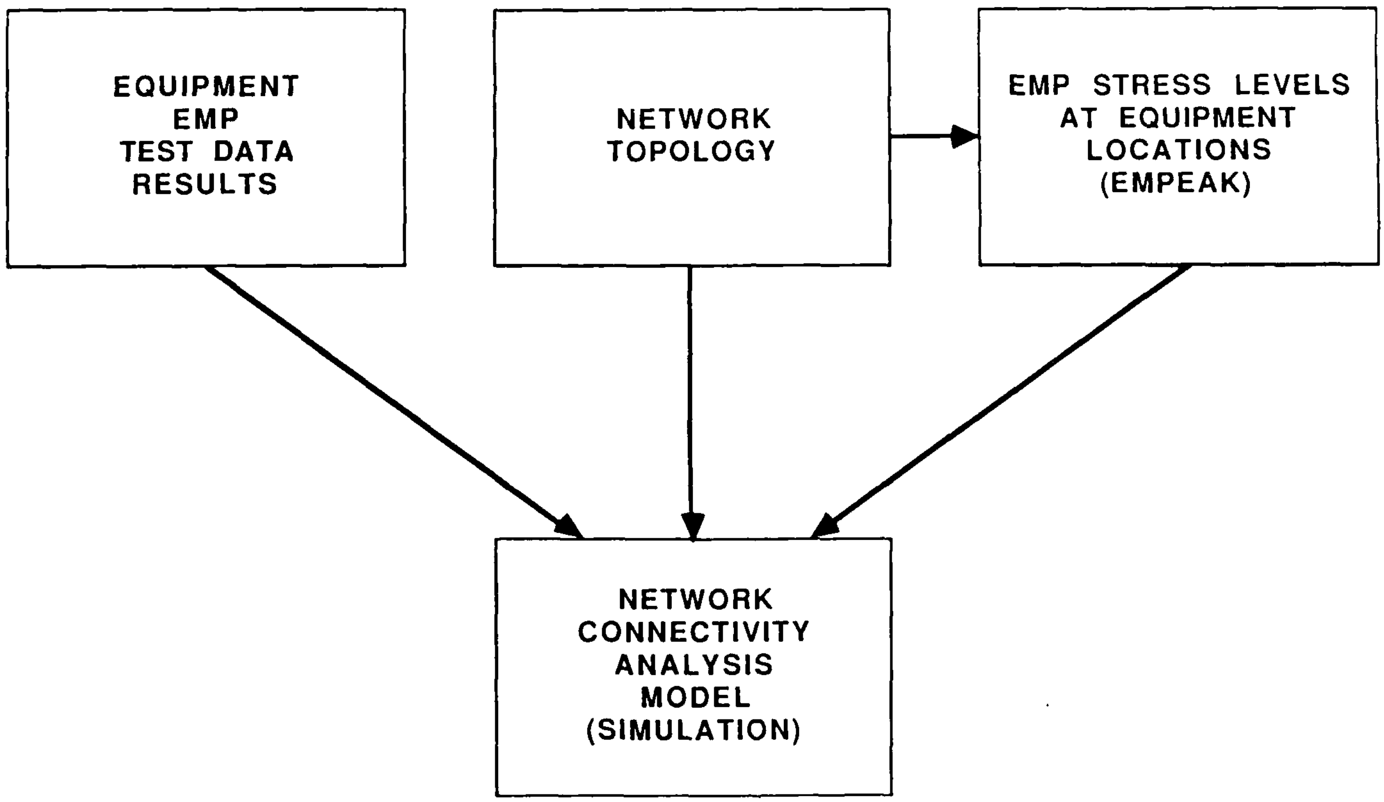


EXHIBIT 2-2

Format of Interpolated Test Results

EMP Stress Level:	Low	Medium	High
	10-30 kV/m	30-50 kV/m	50-70 kV/m
Sample Size	9	8	6
# of Survivals	8	6	2

developed, one for each stress level bin. Equipment types for which no EMP test data are available are assigned the survivability curves of the equipment type which they most technologically resemble that has been EMP tested. This assignment process, which is required due to a lack of complete test data, induces an unquantifiable source of error in the network level results.

The middle box depicts the network topology that is being analyzed. The OMNCS has obtained a description of the toll portion of the post-divestiture AT&T network to address this module. This description, which is in the form of a relational data base, is an accurate reflection of a major portion of the PSN from which to conduct network level analyses. Processing of the data base has yielded the following information:

- Switch locations
- Switch types (e.g. 4ESS and DMS-100)
- Transmission facility locations
- Transmission facility types (e.g. T1 carrier or microwave).

Understanding the network with this degree of fidelity supports probabilistic testing (from the EMP test data) of each network switch and transmission facility. Following the probabilistic testing, knowledge of the surviving telecommunications resources is known.

Specification of the EMP stress levels that the network equipment are exposed to is addressed by the upper right hand module. This requirement is conducted through the computer based EMPEAK model written in the Fortran programming language. The sole input to EMPEAK is a nuclear weapon attack scenario which must specify the following information for each weapon:

- Location (Latitude/Longitude)

- Height of burst

- Yield.

With this information the EMPEAK model can calculate the EMP stress level at any geographic location over the Continental United States (CONUS). By understanding the location of network switches and transmission facilities through the data base, the stress level that each equipment is exposed to can easily be derived.

The aforementioned described three modules are input into the NCAM simulation model. NCAM knows the stress level that each network equipment is exposed to, as well as the survivability (through EMP test data) of each equipment at its stress level. A probabilistic discrete event simulation is then performed on each equipment to determine whether it survived or failed the EMP exposure. The model is then left with the surviving telecommunications equipment. Based on the surviving resources the point-pair connectivity metric is calculated. This metric is calculated from both the physical and logical perspective.

2.2 DEFINITIONS

In addition to understanding the flow of the network level approach, it is also necessary to be familiar with many of the specific terms which are used. Therefore the following definitions are offered:

- Physical connectivity- implies that there is some path between two switches.

- Logical connectivity- switches are logically connected so long as they are physically connected and the network has the capability of supporting communications over the physical connection.

- Span- is a transmission facility over which the network sends communications.

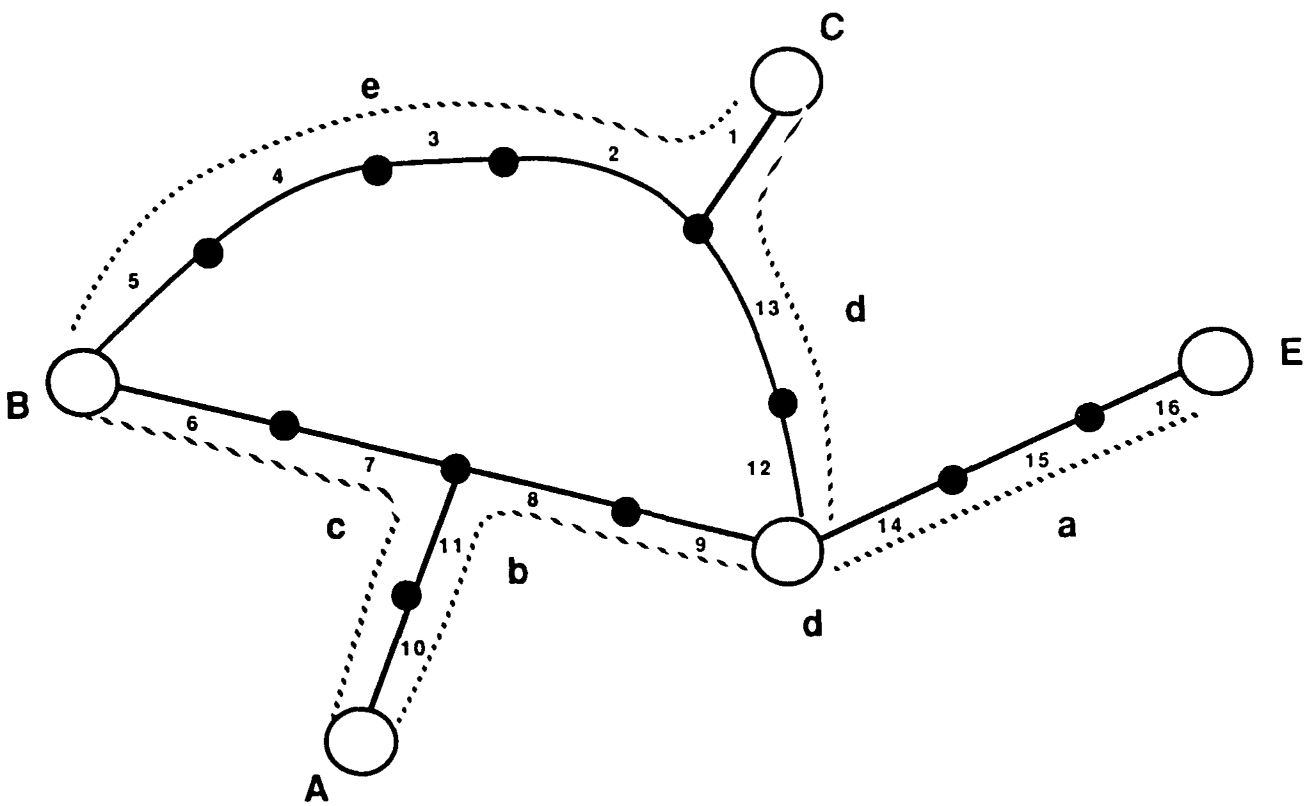
- ORIN- (Originating Route Identification Number) is comprised of a defined set of spans over which switches attain logical connectivity. When switches do not have direct ORINs between them, they attain logical connectivity by sequencing multiple ORINs.

- PSN Baseline- the logical connectivity that is available by the routing rules of the PSN. Generally, the PSN only supports two or three possible routes between switch pairs.

- NETS connectivity- the enhanced logical connectivity attained by providing additional routing capabilities, such as those supported by the proposed NETS system. This additional routing is obtained by allowing more diversified sequencing of ORINs between pairs of switches.

Additional insight into these terms is illustrated through the example shown in Exhibit 2-3. This hypothetical network contains five switches, five ORINs, and 16 spans. As shown switch A communicates with switch B over ORIN c, which is comprised of spans 6, 7, 10, and 11. Note how there is not any ORIN between switches A and C. These two switches must communicate by concatenating ORINs together, such as ORINs b and d. Finally, it is important to observe that spans are often shared by ORINs, as are spans 10 and 11 with ORINs b and c. If span 10 or 11 were to fail, then both ORINs b and c would go down. The structure of the network shown in this example is very similar to the network analyzed by NCAM, though the analyzed network is much more complex.

EXHIBIT 2-3
Network Structure



3.0 NETWORK CONNECTIVITY ANALYSIS MODEL (NCAM) DESCRIPTION

This section presents the approach used by the computer-based NCAM to estimate the effects of Electromagnetic Pulse (EMP) on network performance. In particular, the model is designed to estimate physical and logical connectivity among network switches under different EMP stress levels. Physical connections are defined as either direct connections between the switches or indirect connections that form a path between the switches via intermediary switches. The NCAM analysis uses the AT&T concept of ORINs in its assessment of logical connectivity. An ORIN, composed of spans, survives as long as all of its physical resources survive. As illustrated in Exhibit 3-1, NCAM is composed of four separate subprograms: Node and Span Damage module, Physical Connectivity Assessment module, ORIN Assessment module, and Logical Connectivity Assessment module. This section describes the logical flow, inputs/outputs, and functions of each of these four modules.

3.1 INTRODUCTION

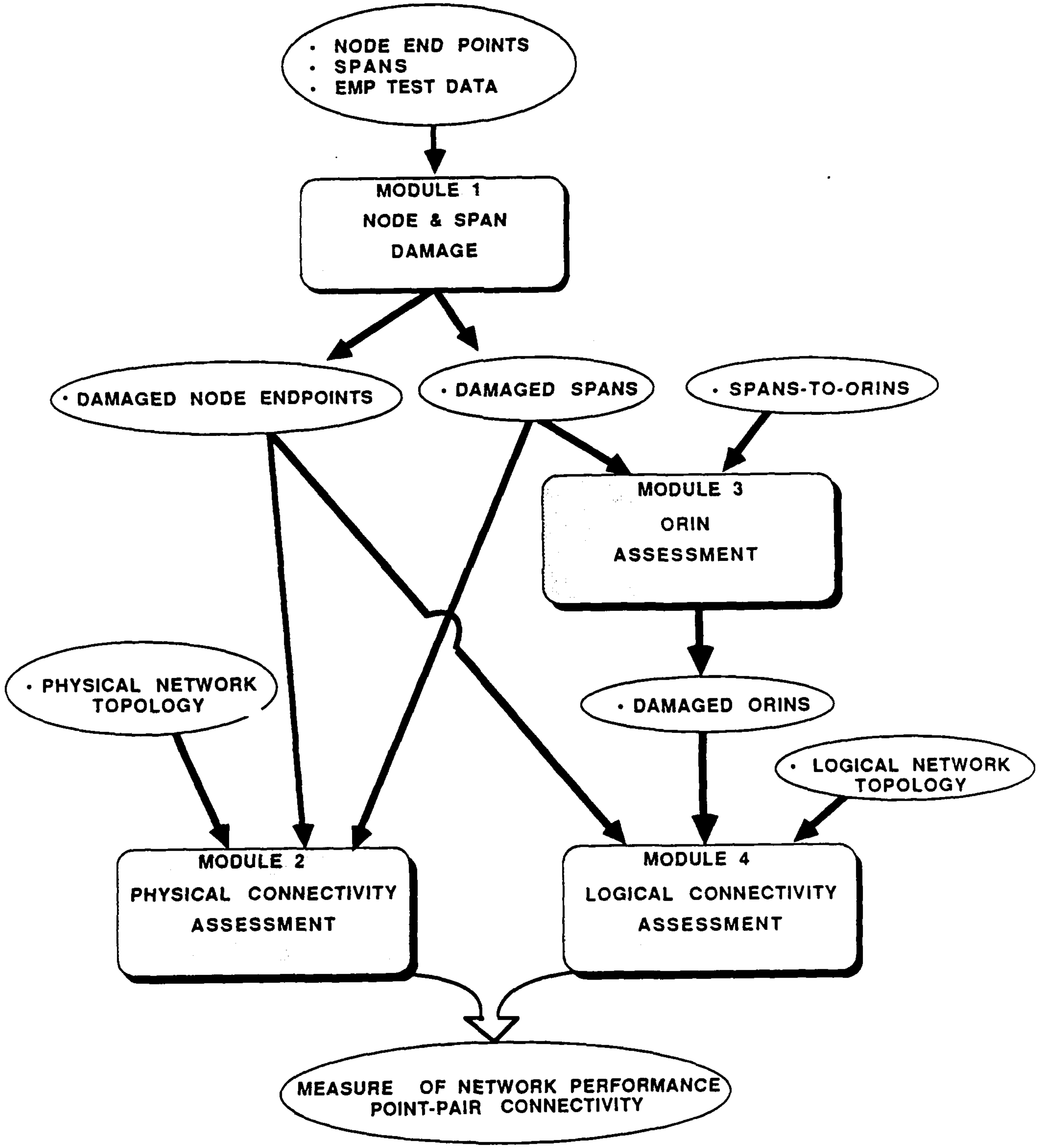
The first module assesses node and span damage. A node refers to a switch and a span refers to a transmission facility between two switches. In this document the terms node and switch are used interchangeably, as are the terms span and transmission facility. The subprogram used to determine node and span damage receives inputs consisting of node endpoints, spans, and EMP test data. The damage to nodes and spans is obtained and stored in a file using a matrix format. The output from this subprogram consists of a file of damaged spans and nodes.

The second module performs a physical connectivity analysis. The damaged spans, damaged node endpoints, and physical network

EXHIBIT 3-1

EMP NCAM

Top Level Flow Diagram



topology are used as inputs to the physical connectivity assessment module. This subprogram determines the physical connectivity of AT&T Point-Of-Presence (POP) switches, which function as the gateway to the toll network for the end offices. As POPs are the sole link for end-users into the toll network, POP connectivity is a true reflection of the overall network connectivity. Network connectivity is quantified by the point-pair connectivity metric which is calculated by the following equation:

$$\text{point-pair connectivity} = \frac{\text{\# of surviving connections}}{\text{\# of original connections}}$$

In the third module, an analysis is performed to determine which ORINs survive. The ORINs and damaged spans are input to the ORIN assessment subprogram. Survival of those spans which comprise the ORINs determines which ORINs survive. The ORIN assessment module outputs damaged ORIN information.

Fourth, the damaged ORINs, damaged node endpoints, and the logical network topology are input to the logical connectivity assessment module. This module performs a logical connectivity assessment of the post-attack network. The output of module 4 is the logical point-pair connectivity of the AT&T POPs.

NCAM is replicated fifty (50) times for the resulting stress level of the weapon laydown scenario. This approach is known as the Monte Carlo procedure. For each replication in the Monte Carlo procedure, the physical and logical point-pair network connectivity metrics are computed. At the conclusion of the Monte Carlo process, two primary statistics are calculated, the mean (average) and the standard deviation of the connectivity measures. The standard deviation provides insight into the amount of dispersion that is expected among the replications within the Monte Carlo procedure.

Subsections 3.2 through 3.5 present a detailed description of the four NCAM subprograms and their functions.

3.2 NODE AND SPAN DAMAGE

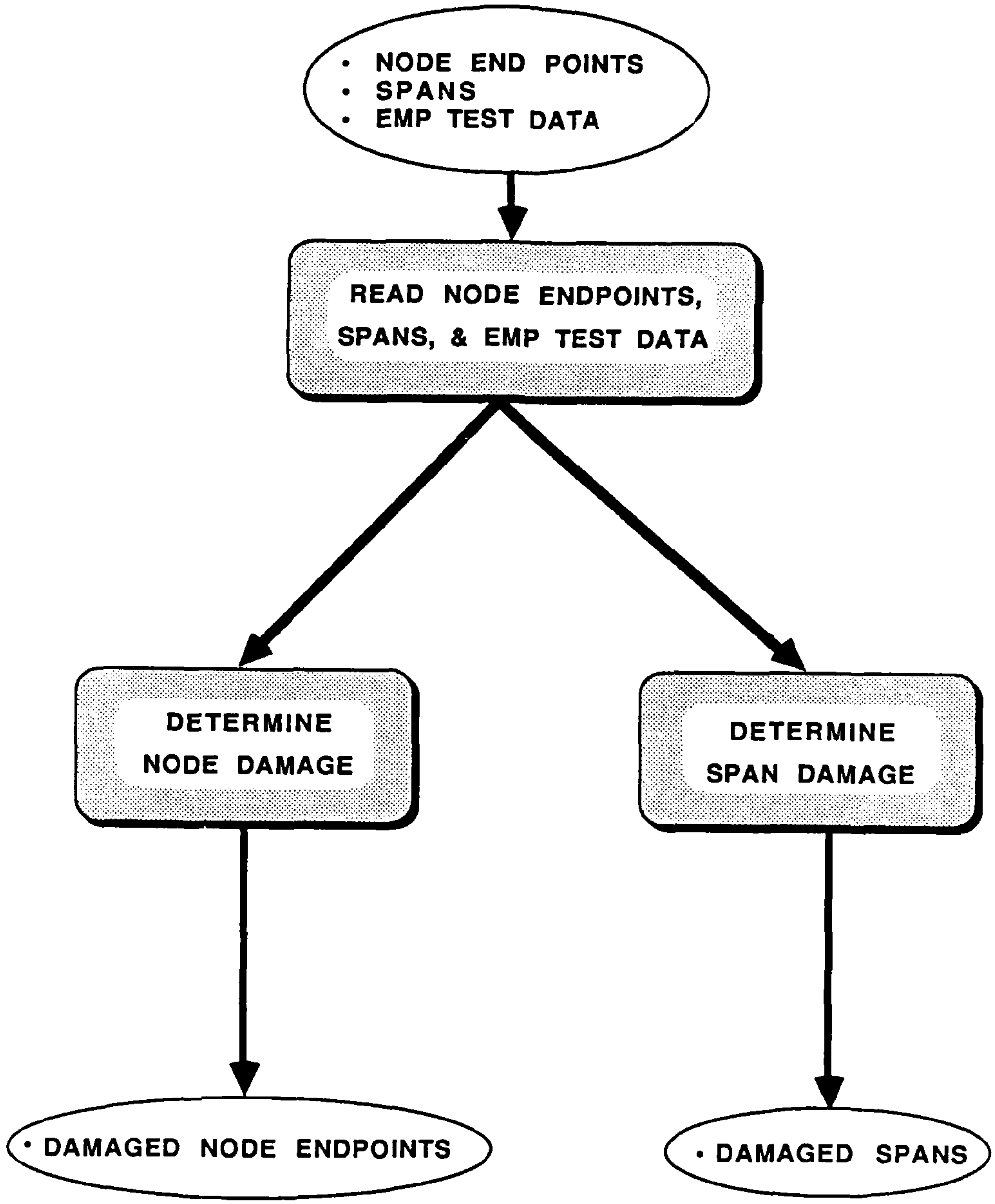
The NCAM begins with an analysis of the node and span damage as shown in Exhibit 3-2. The node and span damage module begins by reading the EMP test data file. The test data consists of Cumulative Distribution Function (CDF) curve values stored in a matrix. Before operating NCAM, a separate computer-based model predicated on Bayesian statistical theory was employed to generate these CDF curves that characterize the EMP-induced survival probabilities for different types of telecommunications equipment (network elements) over a range of stress values. Next, the span information is read from a file into an array of records. Each span record consists of an origin Common Language Location Identifier (CLLI) code, a destination CLLI code (the two span endpoints), and the span type. The CLLI codes identify the state, city, and building of a span termination. Finally, node end points (switches) are stored in a second array of records. Each node record contains the node CLLI code which identifies the state, city, type, and building of the switch.

Once the node and span information have been stored internally, damage is assessed by determining the span or node type. A random sample is taken from an appropriate CDF curve and is used as the survival probability for a particular equipment type at a particular stress level, low, medium, or high. Otherwise, NCAM assigns a predefined survival probability value to the equipment type under study. This second method is further explained in subsection 3.6 of this section. After the survival probability is determined, another random number is generated. If this ran-

EXHIBIT 3-2

EMP NCAM Module 1:

Node and Span Damage



dom number is less than the survival probability then the span or node survives, otherwise the span or node fails. This is a statistically valid method of assigning the survivability of the equipment based on EMP test data. For each equipment type and each stress level, the node and span damage module is replicated fifty (50) times.

In cases where there is a digital span with an analog node, a D4 channel bank is required and the survivability of the span is assessed by also taking into account the survivability of the channel bank. A D4 is an analog to digital (A/D) converter, and is operationally placed at the interface of an analog switch and digital transmission facility. Therefore, in this case, both the span and the channel bank must survive for the span to survive.

The node and span damage module creates two matrices for use in the other NCAM modules: a span damage and a node damage matrix. Finally, these matrices are written to a span and node data file. Following execution of this module, it is known which switches and spans have survived the EMP exposure.

3.3 PHYSICAL CONNECTIVITY ASSESSMENT

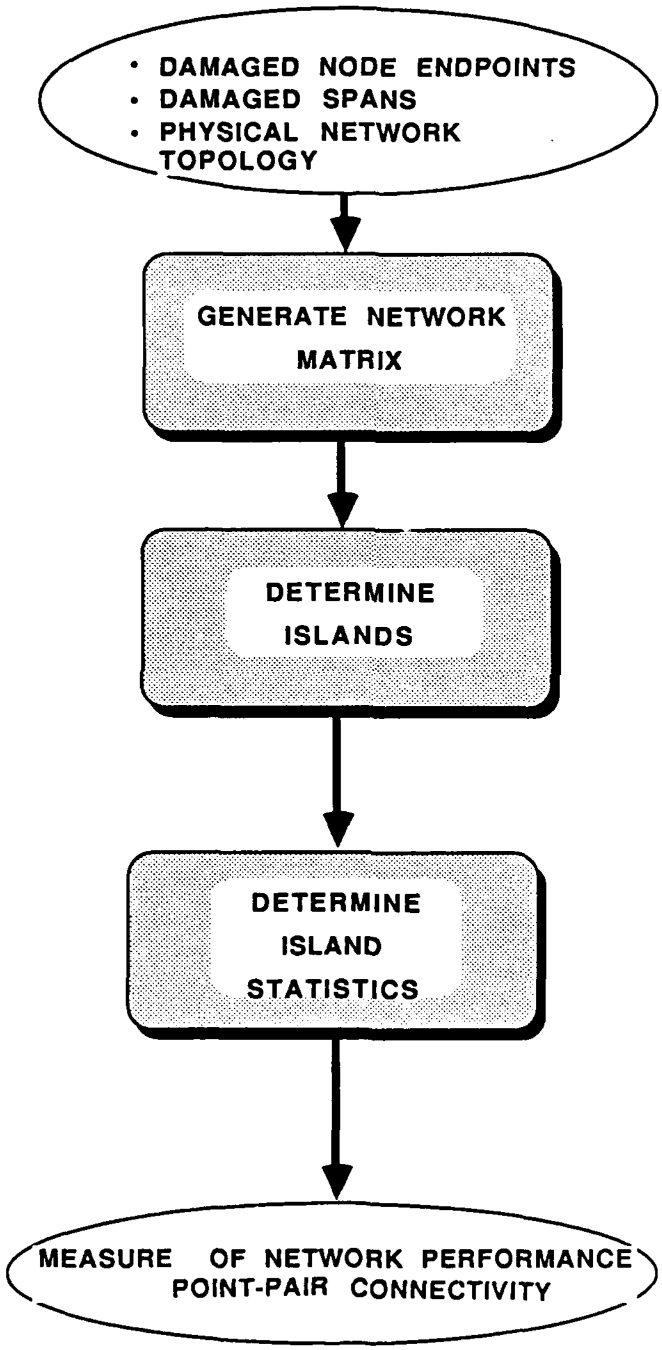
Following completion of the node and span damage module, the physical connectivity module, Exhibit 3-3, assesses the physical point-pair connectivity. The point-pair connectivity metric is used to quantify the telecommunications capability of the EMP exposed network. This module first reads the physical network topology into a matrix. Next, the damaged node endpoints and damaged spans are read into matrices. The physical connectivity assessment module is replicated fifty (50) times for the EMP stress levels.

For every replication of module 2, each node in the network topology is examined. If a node is found to be undamaged then a

EXHIBIT 3-3

EMP NCAM Module 2:

Physical Connectivity Assessment



depth first search of the span matrix follows. The depth first search is a recursive algorithm, based on graph theory, that is used to determine which other nodes are connected to this island. All nodes in the island are marked when visited. The network topology is checked for the next unvisited node and a depth first search is again performed. This process continues until all nodes have been visited. As a result, all interconnected islands of switches are identified.

Finally, after all the islands are stored in a matrix the island statistics are calculated. These statistics, which consist of the connectivity metrics, are retained and averaged for the fifty (50) iterations of the EMP stress level to determine the mean point-pair connectivity. The standard deviation is also calculated after each Monte Carlo procedure for the EMPEAK laydown stress levels. The results of the physical connectivity analysis are output to a storage file. Execution of this module produces the physical point-pair connectivity of the post-attack network, which represents the maximum telecommunications capability of the network.

3.4 ORIN ASSESSMENT

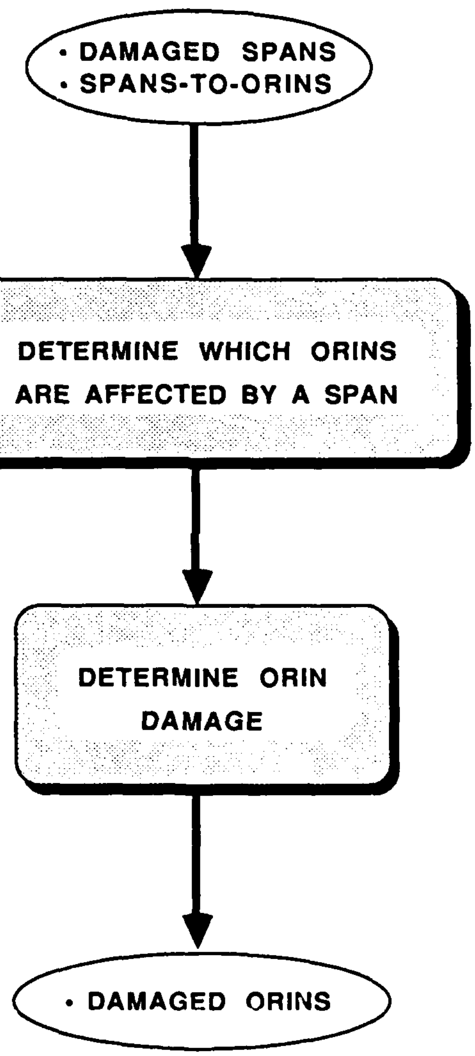
The ORIN assessment module, illustrated Exhibit 3-4, initially reads two input files: the damaged span matrices and the information on the ORINs for the logical network under study.

After these module inputs are stored in memory, the ORIN assessment begins. First, an array is created to store all the span numbers and their corresponding ORINs. Next, the surviving ORINs are determined. If a span fails, then the ORIN(s) of which that span is part of is deemed to fail. Therefore, for an ORIN to survive, all of its spans must survive and both of the switches that the ORIN connects to must also survive. ORIN survival information is stored in a matrix for each iteration of the Monte

EXHIBIT 3-4

EMP NCAM Module 3:

ORIN Assessment



Carlo procedure. Finally, the ORIN matrix is written to a file for use in the NCAM logical connectivity assessment module. In summary, this module specifies the surviving ORINs with which the network can support logical connections.

3.5 LOGICAL CONNECTIVITY ASSESSMENT

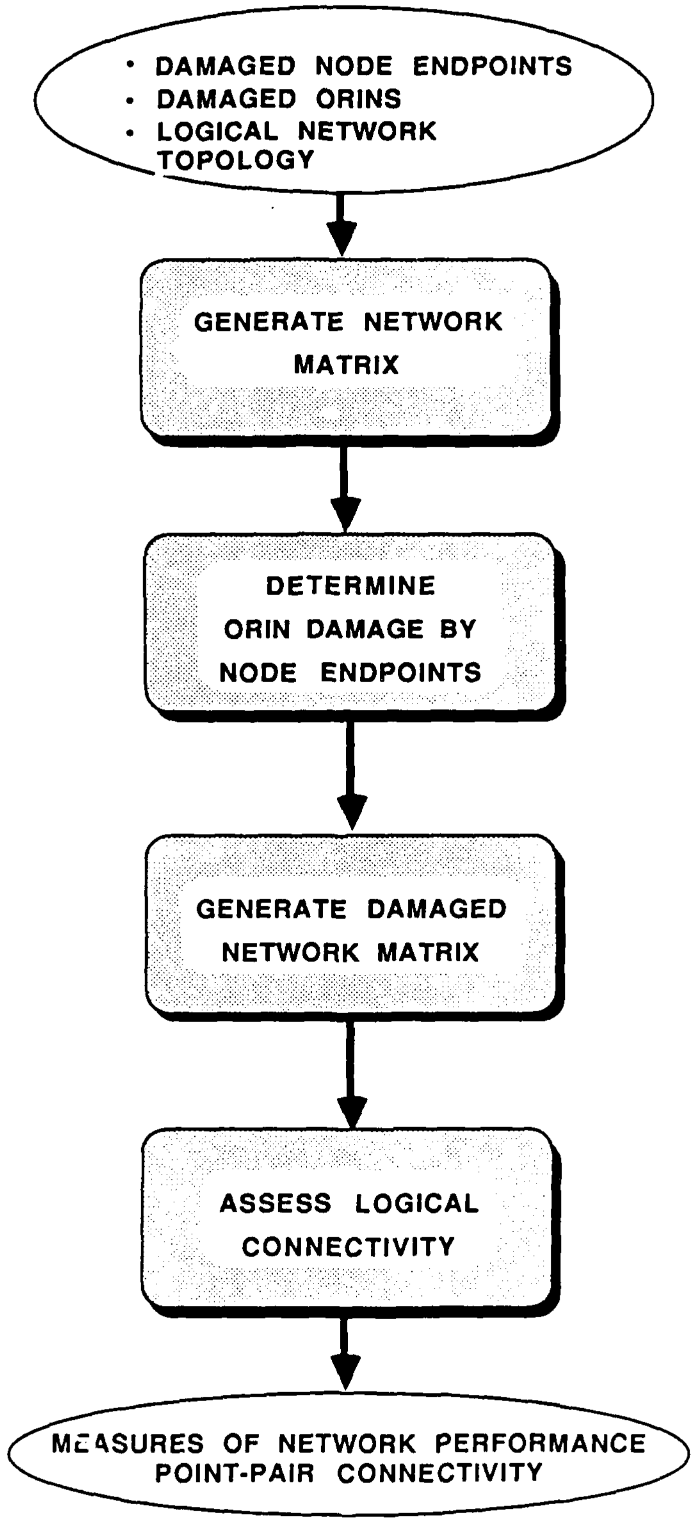
The inputs used in the fourth module are the POP switches, damaged node endpoints, damaged ORINs, and the logical network topology. The logical network topology may either be the NETS network or the baseline network. The baseline is a representation of the current PSN, which has limited routing alternitives between pairs of switches. Generally switches have only two or three possible logical paths over which to communicate. With NETS, the routing mechanism is enhanced by supporting additional logical paths between switches. The enhanced routing is attained by providing additional ORIN sequencing among switch pairs.

Exhibit 3-5 illustrates the Module 4 functional flow diagram. First the subprogram, reads POPs, nodes, ORINs, and network information into memory. Second, a matrix, composed of an array of POPs is generated. Each POP references all other POPs with which it has connectivity via an ORIN. Next, ORIN damage, span damage, and the array of POPs are used to generate a third matrix that stores all the remaining POPs which are connected. This process is accomplished using a Breadth First Search (BFS) algorithm. The BFS algorithm determines the POP to POP connectivity for a damaged network. For the NETS network, POPs are deemed logically connected so long as there is some path of ORINs between them. For the baseline network, only those POPs which are located within two (2) ORIN hops from one another are considered to be logically connected. Finally, the point-pair connectivity is determined from the resulting POP matrix generated by BFS for each of the fifty (50) replications of the logical connectivity assessment module at a particular stress

EXHIBIT 3-5

EMP NCAM Module 4:

Logical Assessment



level. This is the final module of NCAM. It provides the logical point-pair connectivity of the post-attack network, which represents the actual communication capabilities of network users.

3.6 SENSITIVITY STUDY

(U) An additional study can be performed to determine the sensitivity of the network (physical, baseline, and NETS) connectivity to the behavior of particular equipment types in the network. This analysis is typically conducted on equipment types, such as the 4ESS, D4, and microwave equipment types where little or no EMP test data are available to describe survivability. The procedure for the analysis is as follows. First, the element (node or span) addressed in the sensitivity study is assigned one of several discrete survivability values, which represents the probability that the element survives an EMP stress level. Second, module 1 determines which of the remaining elements survive the EMP stress level. Third, using modules 2, 3, and 4, the network connectivity for the simulated stress level is obtained. After the Monte Carlo procedure, the mean and standard deviation of the network connectivity are calculated.

(U) The network level sensitivity study is a tool used to assess survivability assumptions. The degree of sensitivity of network connectivity to the element under study is useful when determining critical communications facilities in a network. This provides a useful tool for prioritizing equipment EMP testing. For equipment types deemed by NCAM as being critical to network performance should be tested with the greatest amount of precedence.

4.0 REQUIRED RESOURCES

4.1 HARDWARE

The NCAM program was designed and developed on a Digital Equipment Corporation (DEC) VAX 11/750 minicomputer. The program has also been run on a DEC 8200 series minicomputer. The operating system used on both of these machines is VMS version 4.5. The NCAM program uses a very large matrix structure to perform network connectivity analyses. To accommodate processing of large amounts of data in the computers memory during program execution, the VAX SYSGEN working set parameter must be set to 10,000. To modify this parameter the user must have access to "systems-high" privileges. The size of the output files generated by NCAM must be considered when running the program. A full-blown run of NCAM creates output files which consume approximately 9,000 blocks of disk storage space. If this space is not available on the system, then the program run will be terminated.

The list of hardware equipment required to run NCAM includes:

- DEC VAX computer with VMS operating system 4.5
- VAX SYSGEN working set parameter equal to 10,000
- 9,000 blocks of disk space.

4.2 SOFTWARE

The NCAM program was written using VAX Pascal version 3.5. VAX Pascal is a standard implementation of Pascal except it allows VMS system service routines to be incorporated in the code. The only non-standard routines used by the NCAM program are calls to LIB$GET_SYMBOL which reads parameters which have been keyed into a command file. The LIB$GET_SYMBOL routine is from the VAX system service library and will automatically be included in the program during compilation. A command file is used to control the execution of the NCAM program.

In order to create an executable version of the NCAM program the source code must be compiled using the VAX Pascal compiler. When source code is error free and compiles, it creates a file with the extension "OBJ." The OBJ file is object code and must be converted to executable code using the LINK command. The VAX VMS LINK version 4.5 was used to create the current executable version of the NCAM program. To modify the existing source code, an editor must also be available. The existing source code was created using the VAX VMS EDT full screen editor.

The software elements necessary to run the NCAM program include:

- VAX Pascal version 3.5 (necessary for modifications)
- Knowledge of a VAX editor
- Input data files:
  - emp$span_type.ascii
  - emp$switch_nodes.ascii
  - emp$span_type.ascii
  - emp$cdf_table.ascii
  - endpts_np.ascii
  - swtchs_np.ascii
  - endpts_dn.ascii
  - swtchs_dn.ascii
  - emp$switch_nodes.ascii
  - emp$pops.ascii
  - emp$span_matrix.ascii
  - emp$orin_matrix_sb.ascii
  - emp$orin_matrix_bas.ascii
  - span_orin_direct.ascii

4.3 INPUT DATA

Numerous input files are necessary to run the NCAM program. These files can be divided into three categories, EMP test data, primary input data, and processed input data.

4.3.1 Equipment Test Data

The survivability of equipment to EMP effects is quantified by a CDF curve. For each equipment tested, three CDF curves are calculated, correlating to the three EMP stress level bins. Recall that in section 2.0 it was documented that all data between 10-30 kV/m was grouped together, data in the 30-50 kV/m was grouped together, and likewise for the 50-70 kV/m region.

In the NCAM model a digitized curve composed of 27 points is used to represent the equipment CDF curve at one of the three EMP stress level regions. The digitized CDF curves are stored in a file called "emp$cdf_table.ascii" with a record structure as shown in Exhibit 4-1. Note that each CDF curve is monotonically increasing in Exhibit 4-1 from left to right. This is the only information used by NCAM in assessing the survivability of network equipment.

4.3.2 Primary Input Files

There are three primary input files necessary to run the NCAM program. These files contain switch, span, and ORIN information about the telecommunications network to be tested. The record structures and the data contained in these files is described below.

The first primary input file contains data on the telecommunications switches in the network being analyzed. The data contained in this file is simply a listing of unique identifiers

EXHIBIT 4-1

CDF Curve Data

EMP$CDF_TABLE.ASCII:

Data Types	CDF curve values:					
Sample Records	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	Equipment Type #1 Stress Level Bin #1
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	0.0000000E+00	3.0000001E-07	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	1.7999999E-06	0.3422763	0.3422763	0.2924027	0.2924027	
	0.2924027	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.2308722	
	0.2308722	0.2308722				
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	Equipment Type #1 Stress Level Bin #2
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	0.0000000E+00	8.0000001E-07	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	5.5999999E-06	0.3900716	0.3900716	0.3324030	0.3324030	
	0.3324030	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.2605588	
	0.2605588	0.2605588				
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	Equipment Type #1 Stress Level Bin #3
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	0.0000000E+00	4.5000002E-06	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	6.3100000E-05	0.5034468	0.5034468	0.4295951	0.4295951	
	0.4295951	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.3342732	
	0.3342732	0.3342732				
	0.0000000E+00	1.0000000E-07	10000000E-07	0.0000000E+00	0.0000000E+00	Equipment Type #2 Stress Level Bin #1
	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	1.0000000E-07	7.0999999E-06	0.0000000E+00	0.0000000E+00	0.0000000E+00	
	1.1580000E-04	0.5344558	0.5344558	0.4569013	0.4569013	
	0.4569013	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.3555150	
	0.3555150	0.3555150				

for each switch in the network. A sample record structure for this file is shown in the first figure of Exhibit 4-2. The switch identifier in the sample record is an eleven or twelve character field. The first four characters denote a city name. The fifth and sixth characters are the state postal code. The seventh and eighth characters refer to the building identifier. The ninth character is the switch identifier. The remaining characters refer to the switch type. In some instances not all of this information is available and the missing information is not presented in the CLLI code. If damage is imposed on the network via an attack scenario, then the latitude and longitude of each switch would be necessary.

The second primary input file contains data on the telecommunications spans in the network being analyzed. The data contained in this file includes an originating CLLI code, a destination CLLI code, and the span type. The record structure of the span file is shown in the middle figure of Exhibit 4-2. The CLLI codes shown in the example contain the same information as the first eight characters of the switch identifier detailed in the previous paragraph. The span type refers to the transmission facility equipment used between the origination and destination CLLI codes. A span type of "R" might refer to Analog Microwave, type "L" might be an L-4 Analog Cable, and "T" might be a T4M carrier. If damage needs to be imposed on the spans then the latitude and longitude for each CLLI code (span endpoint) also needs to be included in this file.

The third primary input file contains data on the ORINs which comprise the network being analyzed, and has a record structure as shown in the third figure of Exhibit 4-2. The data contained in this file includes an originating switch identifier, the destination switch identifier, and a list of pointers to the span records which compose the ORIN. For example, the first record of the file specifies a span between CLLI location

EXHIBIT 4-2

Primary Input Files

EMP$SWITCH_NODES.ASCII:

Data Types	Switch ID
Sample Records	BWLGKYMAA5E ALBYGAMAADM2 AURRILARE

EMP$SPAN_TYPE.ASCII:

Data Types	CLLI code A	CLLI code Z	Span type
Sample Records	LWRNMACA	GRAYMEQ0	R
	WANDMAQ0	NBSCMAQ0	R

EMP$ORINS.ASCII:

Data Types	Switch ID	Switch ID	List of Span Records Which are Used
Sample Records	LWRNMACA	GRAYMEQ0	136 896 212 88 123 ...
	WANDMAQ0	NBSCMAQ0	548 321 917 256 17 ...

codes "LWRNMACA" and "GRAYMEQO." This ORIN is comprised of spans 136, 896, 212, 88, 123, etc. Each switch and span identifier must match one of the switches and spans in the files described above. The ORIN file will be used to create the network matrix which matches ORINs to their corresponding spans.

4.3.3 Processed Input Files

The NCAM program is designed to be as efficient as possible. Therefore, the primary input files must be preprocessed to create the necessary damage, and network matrix files used for simulation of EMP effects. These preprocessed files are briefly described below.

The damage assessment portion of the NCAM program uses files which give the probability of survival for various equipment types as derived through the EMPEAK program. These files contain data for two different damage scenarios with separate files for switches and endpoints. The damage files are named "endpts_np.ascii," "swtchs_np.ascii," "endpts_dn.ascii," and "swtchs_dn.ascii." Record structures for these files are shown in Exhibit 4-3. In order to analyze another telecommunications network, either a damage scenario must be provided, damaged switch and span files provided, or a common stress level assumed.

Separate network topology information is used for the physical and logical portions of the NCAM program. The physical network topology is composed of three files named "emp$switch_nodes.ascii," "emp$pops.ascii," and "emp$span_matrix.ascii" as described in Exhibit 4-4. The emp$switch_nodes.ascii file contains information on each switch in the network including the switch CLLI code, class, and equipment type. The emp$pops.ascii file contains information on all Point of Presence (POP) switches and the related equipment type. The emp_span$matrix.

EXHIBIT 4-3

Damaged Files

ENDPTS_NP.ASCII

Data Types	Endpoint ID	survival code
Sample Records	ANTPNDQ0	0
	ARKBMSQ5	1
	AHVLNCOH	1

SWITCHS_NP.ASCII

Data Types	Switch ID	survival code
Sample Records	ANTPNDQ0	0
	CLEVOHO2	0
	AHVLNCOH	1

ENDPTS_DN.ASCII

Data Types	Endpoint ID	survival code
Sample Records	ANTPNDQ0	1
	ANHMCA02	0
	ARKBMSQ5	0

SWITCHS_DN.ASCII

Data Types	Switch ID	survival code
Sample Records	AIKNSCMA	0
	BRHMALMT	1
	CLEVOH02	1

EXHIBIT 4-4

Network Files

EMP$SPAN_MATRIX.ASCII

Data Types	Switch ID	Number of Spans	Ptr. to Span #1	Ptr. to link info. #1	Ptr. to Span #2	Ptr. to link info #2.	. . .		
Sample Records	BWLGKYMAA5E	2	845	139	2860	458			
	ALBYGAMAADM2	0							
	AURRILARE	6	652	224	3049	214	4863	576	• • •

EMP$POPS.ASCII

Data Types	Switch ID	Equipment Type
Sample Records	AKRNOH2503T	1AE
	BKFDCA0140T	4E
	FRMNMAWA04T	5E

EMP$ORIN_MATRIX_SB.ASCII:

Data Types	Switch ID	Number of Orins	Ptr. to Orin #1	Ptr. to link info. #1	Ptr. to Orin #2	Ptr. tc link info #2.	. . .		
Sample Records	BWLGKYMAA5E	2	412	121	5660	321			
	BLNGMTOOACT A	0							
	AURRILARE	116	843	322	4309	231	4553	567	• • •

EMP$ORIN_MATRIX_BAS.ASCII:

Data Types	Switch ID	Number of Orins	Ptr. to Orin #1	Ptr. to link info. #1	Ptr. to Orin #2	Ptr. to link info #2.	. . .		
Sample Records	BWLGKYMAA5E	2	412	121	5660	321			
	BLNGMTOOACT A	0							
	AURRILARE	116	843	322	4309	231	4553	567	• • •

ascii file contains span data which connects the switches together to form a network.

The logical network topology is also composed of three files whose record structures are as shown in Exhibit 4-4. The first and second files of the logical network topology are matrix files called "emp$orin_matrix_sb.ascii" and "emp$orin_matrix_bas.ascii". These matrix files contain information which describe the logical connections between switches for the baseline and NETS network implementations. The third logical network file is called "span_orin_direct.ascii" and contains data which maps an ORIN to the physical spans which it uses.

4.4 SUMMARY

Currently the NCAM program is only used for the AT&T EMP analysis. However, NCAM was designed so that any telecommunications network could be analyzed for the effects of EMP damage. To perform analysis on other networks the following information is necessary:

- A switch file containing unique identifiers for each switch. If damage needs to be imposed on the switches then the latitude and longitude of each switch is necessary.

- A span file containing the originating and destination CLLI codes (or equivalent CLLI code type information), and the transmission facility equipment type. If damage needs to be imposed on the spans then the latitude and longitude of each span endpoint is also necessary.

- An ORIN file containing the origination and destination switch identifiers, as well as specification of the spans which comprise the ORIN.

- Either a damage scenario must be provided, damaged switch and span files provided, or a common stress level assumed.

Given the data listed above, the remainder of the input files necessary for running NCAM can easily be developed through data base processing.

5.0 RUNNING NCAM

5.1 INTRODUCTION

Due to the size and complexity of the NCAM simulation, the model is divided into four distinct modules. These modules are compiled and linked separately, then run according to the sequence specified in the command file called "emp.com." The names of the NCAM simulation modules are the following:

- emp_damage
- emp_span_orin
- emp_phys
- emp_mod.

Upon compilation of these files, executable code is produced to run the model.

The remaining text in this section includes both commands and instructions. Commands are those characters the computer user types on the terminal keyboard to properly run NCAM. Instructions are those lines of text in this section that instruct as to which commands should be typed. A few points of clarification are offered so that one may easily differentiate commands from instructions:

- Commands will be separated from the text
- Commands should be typed exactly as they appear in this section
- At the end of each command line the user must press the return key to activate the command.

5.2 PROCEDURE

Below is the step-by-step process necessary to run NCAM. In addition, sample runs will be illustrated. The sample runs show how to execute the model with and without sensitivity studies, and how to select between the two weapon laydown scenarios. Finally, typical output information is presented with a discussion on interpretting the information.

The following steps show the user how to set the parameters that specify which connectivity analysis the NCAM program performs. The aforementioned command file, emp.com, lists these parameters and stores their ranges and functions. The emp.com file, as shown in Exhibit 5-1, contains two primary variables to be modified as needed by the user. To modify this file enter the following VMS command:

```
edt emp.com
```

Step one sets the parameter variable that specifies the sensitivity study. This variable is named "sens_study" and has a range of four possible settings. Each setting specifies a sensitivity study for a specific equipment type. When "sens_study" is set to 1 the the NCAM runs in the normal mode, that is no sensitivity study is performed, when set to 2 a 4ESS sensitivity study is performed, when set to 3 a D4 channel bank sensitivity study is performed, and a sensitivity study on the microwave transmission facilities is conducted when set to 4. As mentioned earlier, sensitivity studies are used to quantify the importance of a particular equipment type's survivability to network performance.

- Setting a variable requires moving the cursor to the number and changing it to 1, 2, 3, or 4.

Exhibit 5-1
EMP.COM FILE
Complete NCAM Run

```
$!-------------------------------------------------------------
$!  SET THE VARIABLES BELOW
$!-------------------------------------------------------------
$ sens_study = 1      ! -Start sensitivity study:
$                     !                1 = nosens
$                     !                2 = 4ESS
$                     !                3 = D4 channel bank
$                     !                4 = Microwave Facility
$ sens_study_end = 4  ! -Set equal to the equipment type which is to
$                     !    be the last one run through the program
$ scenario = 1        ! -Start scenario number:
$                     !                1 = Nickel Plate
$                     !                2 = Dime Novel
$ scenario_end = 2    ! -Set equal to the scenario which is the last
$                     !    one to be run through the program
$!--------------------------------------------------------------
start1:
$   E = 0             !  4ESS sensitivity variable
$   D = 0             !  D4 Channel Bank sensitivity variable
$   M = 0             !  Microwave Facility sensitivity variable
$        if sens_study .eq. 1 then goto Nosens
$          if sens_study .eq. 2 then E = 1
$          if sens_study .eq. 3 then D = 1
$          if sens_study .eq. 4 then M = 1
start2:
$        run EMP_DAMAGE.EXE
$        run EMP_SPAN_ORIN.EXE
$        run EMP_PHYS.EXE
$        create/fdl = new_pas_file  matrix.ascii
$        run EMP_MOD.EXE
$        rename matrix.ascii  old_matrix.ascii
$        delete orin_dam.direct;
$        delete span_dam.direct;
$        delete node_dam.direct;
$        scenario = scenario + 1
$        if scenario .gt. scenario_end then goto exitpt
$        goto start2
Nosens:
$        run EMP_DAMAGE.EXE
$        run EMP_SPAN_ORIN.EXE
$        run EMP_PHYS.EXE
$        create/fdl = new_pas_file  matrix.ascii
$        run EMP_MOD.EXE
$        rename matrix.ascii  old_matrix.ascii
$        delete orin_dam.direct;
$        delete span_dam.direct;
$        delete node_dam.direct;
exitpt:
$        sens_study = sens_study + 1
$        if sens_study .lt. (sens_study + 1) then goto start1$
```

- In order to run only one sensitivity study the user must set the "sens_study" and the "sens_study_end" variables both equal to the appropriate number for the sensitivity study to be run. For example, if a sensitivity study of only the microwave transmission facilities is desired both variables should be set to 4.

- To run NCAM on all of the sensitivity studies set the "sens_study" variable equal to 1 and the "sens_study_end" variable to 4.

Step two sets the parameter variable named "scenario." This variable specifies one of two scenarios: "Nickel Plate" or "Dime Novel." If "scenario" is set at 1 then the model begins by running the Nickel Plate laydown scenario. If "scenario" is set at 2 the program runs the Dime Novel laydown scenario.

- To run only one laydown scenario the user must set both the "scenario" and the "scenario_end" variables to either 1 or 2.

- To run both laydown scenarios the user must set the "scenario" variable to 1 and the "scenario_end" variable to 2.

Step three selects one of three network analyses to be performed: the physical network analyses, the logical network analyses, or both. Specifying the type of network analysis is accomplished by commenting out lines. Commenting out a line renders that line inactive during the program run. To run the program solely on the physical network analysis portion of NCAM certain lines of code must be commented out. Comment out the following lines under both the "start2:" and the "nosens:" sections as displayed in Exhibit 5-2.

Exhibit 5-2
EMP.COM FILE
Physical, D4 Channel Bank, Nickel Plate Example

```
$!-------------------------------------------------------------
$!  SET THE VARIABLES BELOW
$!-------------------------------------------------------------
$ sens_study = 3     ! -Start sensitivity study:
$                    !                 1 = nosens
$                    !                 2 = 4ESS
$                    !                 3 = D4 channel bank
$                    !                 4 = Microwave Facility
$ sens_study_end = 3 ! -Set equal to the equipment type which is to
$                    !    be the last one run through the program
$ scenario = 1       ! -Start scenario number:
$                    !                 1 = Nickel Plate
$                    !                 2 = Dime Novel
$ scenario_end = 1   ! -Set equal to the scenario which is the last
$                    !    one to be run through the program
$!--------------------------------------------------------------
start1:
$   E = 0            !  4ESS sensitivity variable
$   D = 0            !  D4 Channel Bank sensitivity variable
$   M = 0            !  Microwave Facility sensitivity variable
$         if sens_study .eq. 1 then goto Nosens
$           if sens_study .eq. 2 then E = 1
$           if sens_study .eq. 3 then D = 1
$           if sens_study .eq. 4 then M = 1
start2:
$         run EMP_DAMAGE.EXE
$   !     run EMP_SPAN_ORIN.EXE
$         run EMP_PHYS.EXE
$   !     create/fdl = new_pas_file  matrix.ascii
$   !     run EMP_MOD.EXE
$   !     rename matrix.ascii  old_matrix.ascii
$   !     delete orin_dam.direct;
$         delete span_dam.direct;
$         delete node_dam.direct;
$         scenario = scenario + 1
$         if scenario .gt. scenario_end then goto exitpt
$         goto start2
Nosens:
$         run EMP_DAMAGE.EXE
$   !     run EMP_SPAN_ORIN.EXE
$         run EMP_PHYS.EXE
$   !     create/fdl = new_pas_file  matrix.ascii
$   !     run EMP_MOD.EXE
$   !     rename matrix.ascii  old_matrix.ascii
$   !     delete orin_dam.direct;
$         delete span_dam.direct;
$         delete node_dam.direct;
exitpt:
$         sens_study = sens_study + 1
$         if sens_study .lt. (sens_study + 1) then goto start1$
```

- Use an "!" in the emp.com file after the "$" character at the beginning of the line to comment out the following lines:

```
! run EMP_SPAN_ORIN.EXE
! create/fdl=new_pas_file matrix.ascii
! run EMP_MOD.EXE
! rename matrix.ascii old_matrix.ascii
! delete orin_dam.direct;
```

To run the program solely on the logical network comment out the following line of code under both the "start2:" and the "nosens:" sections of the emp.com file:

```
! run EMP_PHYS.EXE
```

To run the model for both types of analyses do not perform any commenting out of the EMP.COM file.

The final step is to run the NCAM model. Having set all the parameter variables, the user types the following command to run the program:

```
submit/log/notify/queue=fast emp
```

5.3 NCAM OUTPUT

After running the NCAM model the results must be examined. NCAM creates two types of output data files: physical, and logical (assuming both types of analyses are performed). The output file containing the physical connectivity statistics is called "physical_stats.ascii" and is shown in Exhibit 5-3. In this example the point pair connectivity is 97.7 percent with a standard deviation of 1.78 among the 50 runs.

Two output files contain logical connectivity statistics, "logical_stats.ascii" and "log_conn_history.ascii." These files,

EXHIBIT 5-3

Output Data File Structures

PHYSICAL_STATS.ASCII

Baran 98.84% Standev 0.898
Point Pair 97.70% Standev 1.778

LOGICAL_STATS.ASCII

Level 1 Network 1 Avg Point Pair 95.925% Standev 0.022
Level 1 Network 2 Avg Point Pair 96.426% Standev 0.020

LOG_CONN_HISTORY.ASCII

Point Pair Connectivity 95.069%
Point Pair Connectivity 94.945%
Point Pair Connectivity 98.320%
Point Pair Connectivity 93.361%
•
•
•

shown in Exhibit 5-3 contain two lines of statistics for each sensitivity study within a scenario. The first line of the logical_stats.ascii file shows statistics for the baseline network, the second line shows the NETS statistics. In this example the baseline has a point pair connectivity of 95.9 percent and the NETS network, which has more routing capabilities, has a point-pair connectivity of 96.4 percent. If NCAM is run on both scenarios for all four equipment types then there would be sixteen lines of statistics. The "log_conn_history.ascii" file contains an entry on the statistics calculated for each of the 50 iterations used in the Monte Carlo simulation process.

6.0 SUMMARY

This user's manual describes how to access the Network Connectivity Analysis Model (NCAM). NCAM is a tool developed by the OMNCS for assessing the effects of EMP on the nation's telecommunication capabilities. This model is a simulation package written in a combination of the Pascal and VAX macro computing languages using the Digital Equipment Corporation (DEC) VMS operating system. The NCAM user's manual is designed not only to show the operator how to use the model but also to provide insight into the model's applications.

NCAM was developed by the OMNCS to solve a technical problem -- the simlulation of network level EMP effects. NCAM's development has been evolutionary; the model has been enhanced to incorporate more accurate input data as well faster processing times. Due to numerous updates, the fact that the users of the program have also been the software developers, and the requirement for fast processing times, the aspect of "user friendliness" has not always been incorporated into NCAM. However, in the course of developing this user's manual, NCAM has been modified to make it more user friendly. These modifications primarily include the implementation of more descriptive variable names and providing additional commenting of the source code.

Numerous input files are necessary to run the NCAM program. These files can be divided into three categories, equipment types, EMP test data and damage information, and network topology. The input data files have not been packaged along with NCAM because they represent AT&T proprietary information. Further, some of the vulnerability test data on the network equipment is classified information. It is noteworthy that any network, such as MCI or US Sprint, can be analyzed so long as the input data is processed in a simlar manner to AT&T's input data.

In summary, this user's manual has provided the following information:

- The flow of the NCAM model
- Description of critical user oriented input variables
- Description of the required hardware and software
- Specification of required user input information
- Presentation of how to run the model.

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