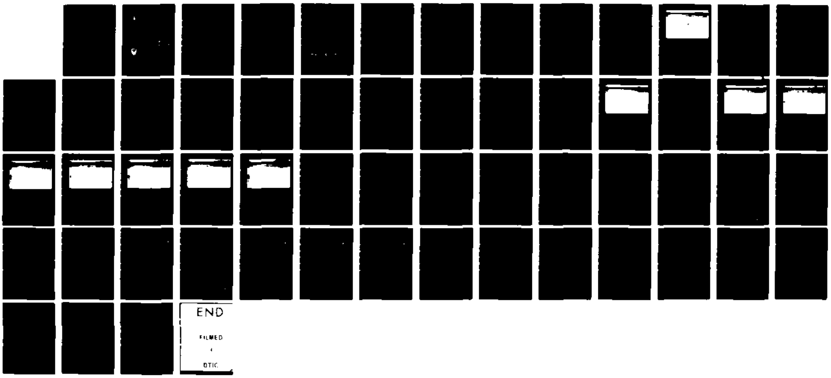
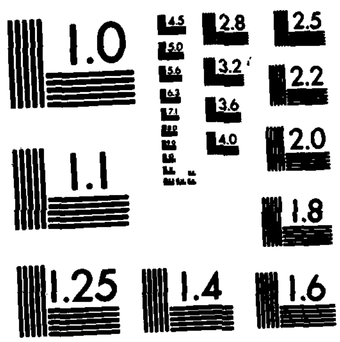
AD-A125 333 BATTLEFIELD SYSTEMS POWER NETWORK OPTIMIZATION(U) GEORGIA INST OF TECH ATLANTA ENGINEERING EXPERIMENT STATION L G CALLAHAN ET AL. OCT 82 DRSMI/RD-CR-83-3 DAAH01-81-D-A003 1/1

UNCLASSIFIED F/G 10/2 NL






MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-E950 348

(12)

AD A125333

TECHNICAL REPORT RD-CR-83-3

# BATTLEFIELD SYSTEMS POWER NETWORK OPTIMIZATION
## FINAL SUMMARY REPORT


Prepared by:
Leslie G. Callahan, Jr. and Robert L. Davis
Georgia Institute of Technology. Engineering Experiment Station
Atlanta, Georgia


Prepared for:
System Simulation Directorate
US Army Missile Laboratory
Redstone Arsenal, Alabama



October 1982

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898

Approved for public release; distribution unlimited.



83 02 025 001

## DISPOSITION INSTRUCTIONS



## DISCLAIMER



## TRADE NAMES

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

**1. REPORT NUMBER**
RD-CR-83- 3

**2. GOVT ACCESSION NO.**
AD-A125 333

**3. RECIPIENT'S CATALOG NUMBER**

**4. TITLE (and Subtitle)**
"Battlefield Systems Power Network Optimization"

**5. TYPE OF REPORT & PERIOD COVERED**
Final Summary Report

**6. PERFORMING ORG. REPORT NUMBER**
12/9/81 - 9/30/82

**7. AUTHOR(s)**
Leslie G. Callahan Jr. and Robert L. Davis

**8. CONTRACT OR GRANT NUMBER(s)**
DAAH01-81-D-A003
Delivery Order No. 035

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
Commander, USAMICOM ing
ATTN: DRSMI-RDF
Redstone Arsenal, AL 35898

**10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS**

**11. CONTROLLING OFFICE NAME AND ADDRESS**
Commander, USAMICOM
ATTN: DRSMI-RPT .1
Redstone Arsenal, AL 35898

**12. REPORT DATE**
~~Nov.~~ OCT. 1982

**13. NUMBER OF PAGES**
51

**14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)**

**15. SECURITY CLASS. (of this report)**
unclassified

**15a. DECLASSIFICATION/DOWNGRADING SCHEDULE**

**16. DISTRIBUTION STATEMENT (of this Report)**
Approved for Public Release ; distribution unlimited.

**17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)**

**18. SUPPLEMENTARY NOTES**

**19. KEY WORDS (Continue on reverse side if necessary and identify by block number)**
Battlefield Electrical Power Distribution, Decision Support Systems, Optimization of Power Network

**20. ABSTRACT (Continue on reverse side if necessary and identify by block number)**
This research project studies an alternative system for power distribution in a tactical environment whose goal is to improve overall reliability while reducing the total cost of generating power. As a means of accomplishing this end, we explore the concept of "common users" of generators in order to reduce system down time and optimize generator distribution.

Our approach was to develop a computer-assisted, interactive decision model which is both portable and user friendly. The computer we chose was the Chromatics Colorgraphics system which both aids in clarifying the problem CONTINUED

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

20. ABSTRACT (continued)

and promoting user interest. The problem we studied was fairly basic. Given an arc of operations, there are x units on the ground at given locations, interconnected by a road network. Some number of these units require varying amounts of power to be functional. Distance is used as a basis for determining the cost of providing this power.

The decision support system we developed to aid the user in finding solutions to this problem is based on solving the k-best, minimum weight spanning trees for the network. It displays these k-trees in a tabular form which the user can then superimpose on a map and then utilizing any additional information he may possess, decide upon a best solution. The model is easily expandable to larger, more complex situations and is equally useful in non-tactical applications. At the end of the report, we have suggested further possible applications and expansions for this system.

TABLE OF CONTENTS

## SUMMARY

This research project studies an alternative system for power distribution in a tactical environment whose goal is to improve overall reliability while reducing the total cost of generating power. As a means of accomplishing this end, we explore the concept of "common users" of generators in order to reduce system down time and optimize generator distribution.

Our approach was to develop a computer-assisted, interactive decision model which is both portable and user friendly. The computer we chose was the Chromatics Colorgraphics system which both aids in clarifying the problem and promoting user interest.

The problem we studied was fairly basic. Given an arc of operations, there are x units on the ground at given locations, interconnected by a road network. Some number of these units require varying amounts of power to be functional. Distance is used as a basis for determining the cost of providing this power.

The decision support system we developed to aid the user in finding solutions to this problem is based on solving the k-best, minimum weight spanning trees for the network. It displays these k-trees in a tabular form which the user can then superimpose on a map and then, utilizing any additional information he may possess, decide upon a best solution.

The model is easily expandable to larger, more complex situations and is equally useful in non-tactical applications. At the end of the report, we have suggested further possible applications and expansions for this system.

# CHAPTER I

# INTRODUCTION

## A. Background

Continuous technological advances have made the modern battlefield highly sophisticated and lethal. Everything from target acquisition and engagement systems, to communications equipment, to the First Sergeant's coffee pot and electric razor are dependent on some form of electricity to operate. A weapons system capable of engaging multiple targets simultaneously is worthless if we cannot supply it with enough power to remain operational.

A possible solution, the use of commercially produced power, is not feasible. On the one hand, we cannot depend on such a source being available in a wartime environment. Commercial power plants will be prime targets early on in any hostilities. Additionally, today's systems operate on a variety of voltages which further complicates the issue. Finally, more often than not, units can expect to be operating in remote regions where commercial power is unavailable.

The solution has been and still is <u>generators</u>. However, system proliferation and variation have made the types and number of generators a complex, frustrating problem. Looking at the generators required by the Heavy Division 10 the Division 86 studies (see Appendix A-1), one sees everything from .5 kilowatts to 100 kilowatts, 28 volts to 240 volts, 60 hertz to 400 hertz and one phase to three phase generators, in skid-mounted and trailer-mounted configurations. The quantities are staggering. Looking only at the requirements for 60 hertz, 120 volt power generator equipment, one filds the figures displayed in Appendix A-2; a total of 938 generator sets producing 4,943.5 kilowatts of power.

Associated with this vast number of generators are the further requirements for the operators, mechanics, and repair parts necessary to run and maintain these pieces of equipment.

Realizing the inherent difficulties associated with our current system, the U.S. Army Construction Engineering Research Laboratory studied the issues and presented their findings in the Electrical Power Generation Distribution (EGAD) Report in December 1975 [13]. The study essentially recognized the need for systematic optimization of electrical systems and the development of planning, design, and construction capabilities for such systems. Their recomendations were addressed toward non-tactical applications, however, we feel the ideas expressed are compatible with tactical power generation.

Presently, another option which the Corps of Engineers is researching is the possibility of providing a standard family of power generation equipment which through the use of transformers can be adapted to all systems currently found on the battlefield. It is along this vein that this study progresses toward a possible alternative to the existing doctrine.

## B. Purpose of Research

The purpose of this research project is to study an alternative system for power distribution in a tactical environment which improves overall reliability while reducing the total cost of generating power. Additionally, we explore the concept of "common users" of generators as a means of reducing system down time and optimizing generator distribution.

## C. Approach

Our approach was to develop a computer-assisted, interactive decision model which is both portable and user friendly. To aid in clarity and to enhance the interest of possible users of this system, it was developed on a color-graphics computer system.

Our problem to be studied was this: Given an area of operations, there are x units on the ground at given locations. These locations can be readily identified on a map and are interconnected by a road network. Some number, n, of these units have a need for K kilowatts of power. The cost of providing this power is the distance between the units. What is needed is a system to optimize the location of a "common user" generator or a bank of generators in order to minimize the distances necessary to run power lines.

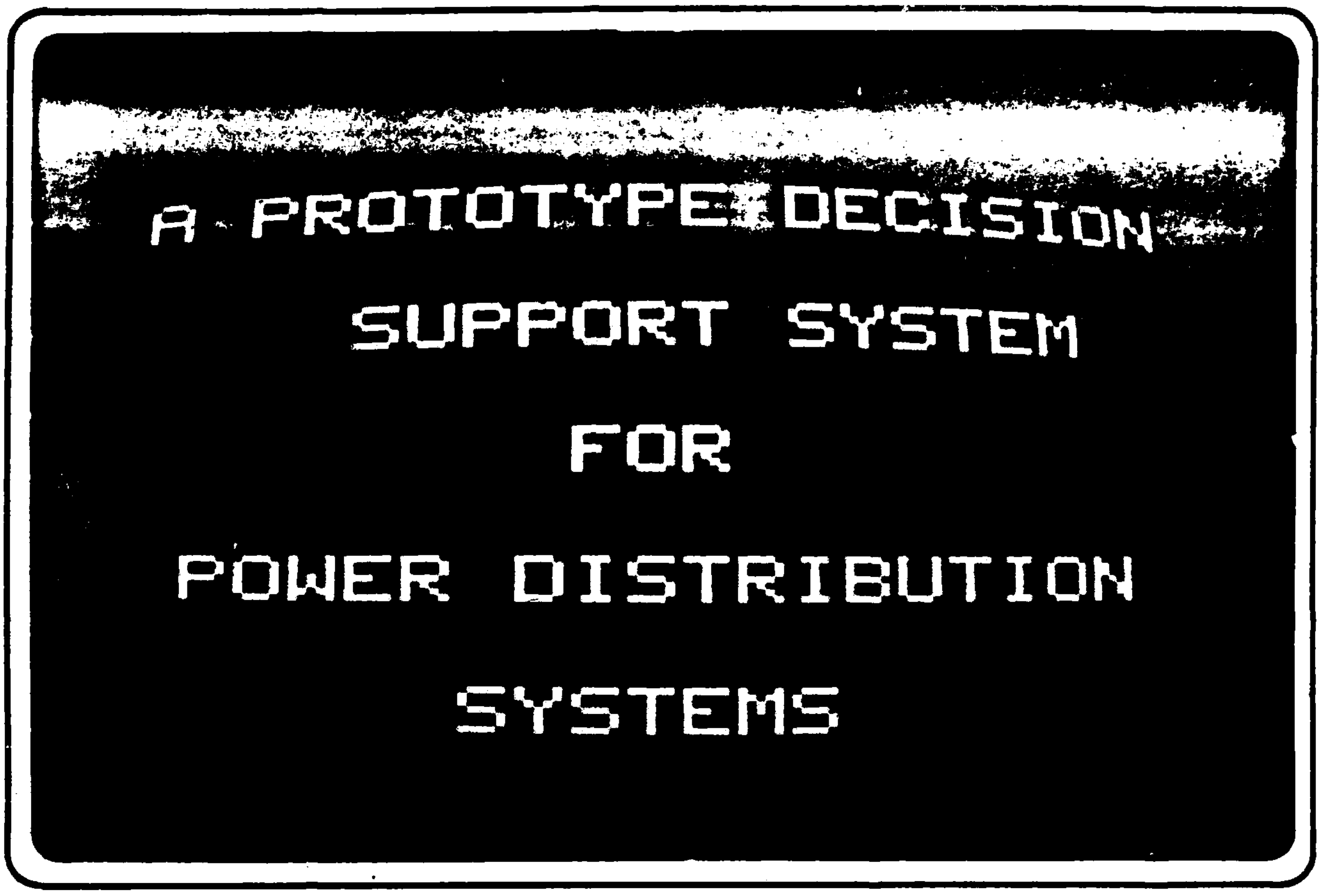



Figure 1. - Example of Graphic Display

# CHAPTER II

# ASSUMPTIONS AND MATHEMATICAL FORMULATION

## A. Assumptions

In formulating this model, it was necessary to make/impose a number of assumptions:

(1) The cost of providing "common user" power is proportional to the total distance of transmission lines necessary. It should be noted that whenever two or more nodes are connected by existing power transmission lines, these can be incorporated into the model by assigning those arcs a minimal cost or no cost.

(2) All needed data is available to the decision maker. Information required is a map of the area, present unit locations, unit demand in kilowatts, existing transmission lines if any, and priority of units in case total demand exceeds total supply.

(3) There is no additional fixed cost associated with providing power to one site over another.

(4) Locations and demands are considered to be relatively static. Once a generator location is chosen, it is not expected to have to be moved daily.

(5) The "common user" generators will be located at a node. That is they will be co-located with one of the demand points. This has intuitive appeal as the operators and maintenance personnel will require rations, fuel, etc.

(6) That the generator requirements shown in the unit TOE's is necessary to remain fully operational. No attempt was made to try and ascertain how much of each TO&E was safety margin and how much was actually required.

(7) It will be aasumed that all transmission lines will run alongside existing roads. This has intuitive appeal in that existing power lines are most likely to be found along existing road networks. Also, if lines must be constructed, it would be much easier and quicker to run them along existing roads.

B. Mathematical Formulation

The mathematical formulation which comes closest to representing the Power Distribution System problem is the shortest path problem [2]. Consider a network with m nodes and n arcs and a cost $C_{ij}$ associated with each arc in the network. The shortest path problem is: Find the shortest (least costly) path from node 1 to node m in the network. The cost of the path is the sum of the costs on the arcs in the path.

To formulate the problem, set up a network in which we wish to send a single unit of flow from node 1 to node m at minimal cost. Thus $b_1 = 1$, $b_m = -1$, $b_i = \emptyset$ for $i \neq 1$ or m. The mathematical formulation comes from [2], page 483:

$$\text{Minimize} \quad \sum_{i=1}^{m} \sum_{i=1}^{m} C_{ij} X_{ij}$$

$$\text{Subject to} \quad \sum_{j=1}^{m} X_{ij} - \sum_{k=1}^{m} X_{ki} = \begin{cases} 1 \text{ if } i = 1 \\ \emptyset \text{ if } i \neq 1 \text{ or } m \\ -1 \text{ if } i = m \end{cases}$$

$$X_{ij} = \emptyset \text{ or } 1 \quad \text{for } i,j = 1,2,\ldots,m$$

The constraints $X_{ij} = \emptyset$ or 1 indicates that each arc is either in the path or not.

In order to solve this problem, we have utilized an algorithm to find k minimum weight spanning trees for the newtork. The user determines the value of k, the number of minimum weight spanning trees he wishes to see, up to five. That is, the algorithm will select the spanning tree with the least cost, the second smallest cost, etc. until it has found the five best solutions.

A spanning tree is a nondirected tree defined as follows [6]:

(i) A connected graph of n vertices and (n-1) links

or (ii) A connected graph without a circuit

or (iii) A graph in which every pair of vertices is connected with one and only one elementary path.

The minimum weight or shortest spanning tree is that nondirected tree which minimizes the sum of the arcs. The shortest spanning tree of a graph has obvious applications in cases where roads (gas pipelines, electric power lines, etc.) are to be used to connect n points together in such a way so as to minimize the total length of road that has to be constructed [6, pp. 124-125].

C. The K Tree Algorithm

The algorithm implemented used the general approach suggested in Gabow's paper, "Two Algorithms for Generating Weighted Spanning Trees in Order" [24, pp. 140-147]. It utilized a three phase approach.

Step 1. The first step formed the minimum weight spanning tree by Prim's method [24, pp. 138-139]. This algorithm produces the shortest spanning tree by growing one subtree $T_S$ containing more than a single vertex and considering the remaining vertices to form one subtree each. Subtree $T_S$ is then grown continuously by adjoining that link $(X_{ij})$, $X_i \epsilon T_S$, $X_j \epsilon T_S$ with the minimum cost $C_{ij}$ until (n-1) links are added and $T_S$ becomes the required shortest spanning tree. This step is incorporated in lines 6500-6799 of Program SOL( Appendix C).

Step 2. Step 2 found the minimum weight exchange link subject to a set of membership constraints. A link, $X_{ij}$, not a member of spanning tree K, is eligible to enter and replace link $X_{i,k}$, an existing member of the spanning tree, provided link $X_{ij}$ is not restricted from entering and link $X_{i,k}$ is not restricted from leaving. The minimum cost replacement for all candidate entering/departing link combinations is selected. This is accomplished by lines 6800-6990 of Program SOLVE (Appendix C).

Step 3. The minimum cost new spanning tree is selected from all candidate new trees. Two disjoint sets of restrictions are generated:

(i) The parent tree has the restriction imposed that existing arc must be retained for all future candidate spanning trees generated from the parent (in additionto any previously imposed restrictions).

(ii) The offspring tree has the restriction imposed that the existing link may not enter any future candidate trees generated from this tree (in addition to any previously imposed restrictions on the parent tree).

This step is implemented by lines 6155-6165 of Program SOLVE (Appendix C).

# CHAPTER III

## THE DECISION MAKING PROCEDURE

### A. Existing System

The existing decision making process for location of generators can be summarized as follows:

(1) Following established rules and regulations, the organization divisions of the directorate of Combat Developments allocates generators of various types to each unit according to their equipment requirements and power needs.

(2) Built into these figures are certain allowances for extra generators in case the primary means of power becomes nonoperational.

(3) In a field environment, as generators are lost through mechanical vailure or battlefield losses, the unit commander shifts his assets according to his own established priorities.

(4) If he should reach a point whereby he is no longer capable of accomplishing his mission, the unit commander requests additional support from his superior organization.

(5) If no additional power genration equipment is available, the unit becomes ineffective.

### B. Proposed System

The Decision Support System we propose would modify this as follows:

(1) When writing the TOE's, the developers should only meet the unit's base requirements and not add all the "additional" or "safety factor" generators.

(2) In the field environment, the location of each unit requiring additional power is plotted on a scaled map no larger than eleven inches by eleven inches. This map is taped to the BITPAD, input into the computer, and stored on a disk according to the directions given by the program NTRACE. (If the network is already on disk, that disk is mounted on disk drive #2.)

(3) The decision maker knows the power requirements of each unit, the unit's priority and through some means of reporting such as readiness reports, he knows how many generators are down. He also knows how much "common user" capability is available to supply those units which are in need.

(4) If the supply cannot meet the demand, he must reduce or eliminate units according to his priorities until such time as the demand can be met.

(5) Once he has determined that his supply is adequate to meet his demand, he utilizes the program SOLVE to produce up to the five best possible routes to take to supply the needed power.

(6) Here is where the decision maker interacts with the computed solutions. He can take the five (or however many he requested) best solutions and lay them out on his map to select the best solution. The human is capable of looking at the terrain, obstacles, the present tactical situation, anticipated actions, etc., and taking this knowledge into account, select the best solution.

(7) Onec the decision has been made, the units are connected to the "common" source and the system is monitored and changes are made as needed by following the same procedure.

(8) The user also selects the best location for the power plant(s). Again, utilizing the map and his knowledge of the units located at each point, he is able to select that unit which is best able to support the power plant and co-locates his teams with them. Due to the nature of power distribution this can be any of the points in the network. It does not have to be at the

median or center. Again, here is where the interaction between the user and the computer becomes valuable. Figure 2 depicts a flowchart of user actions.

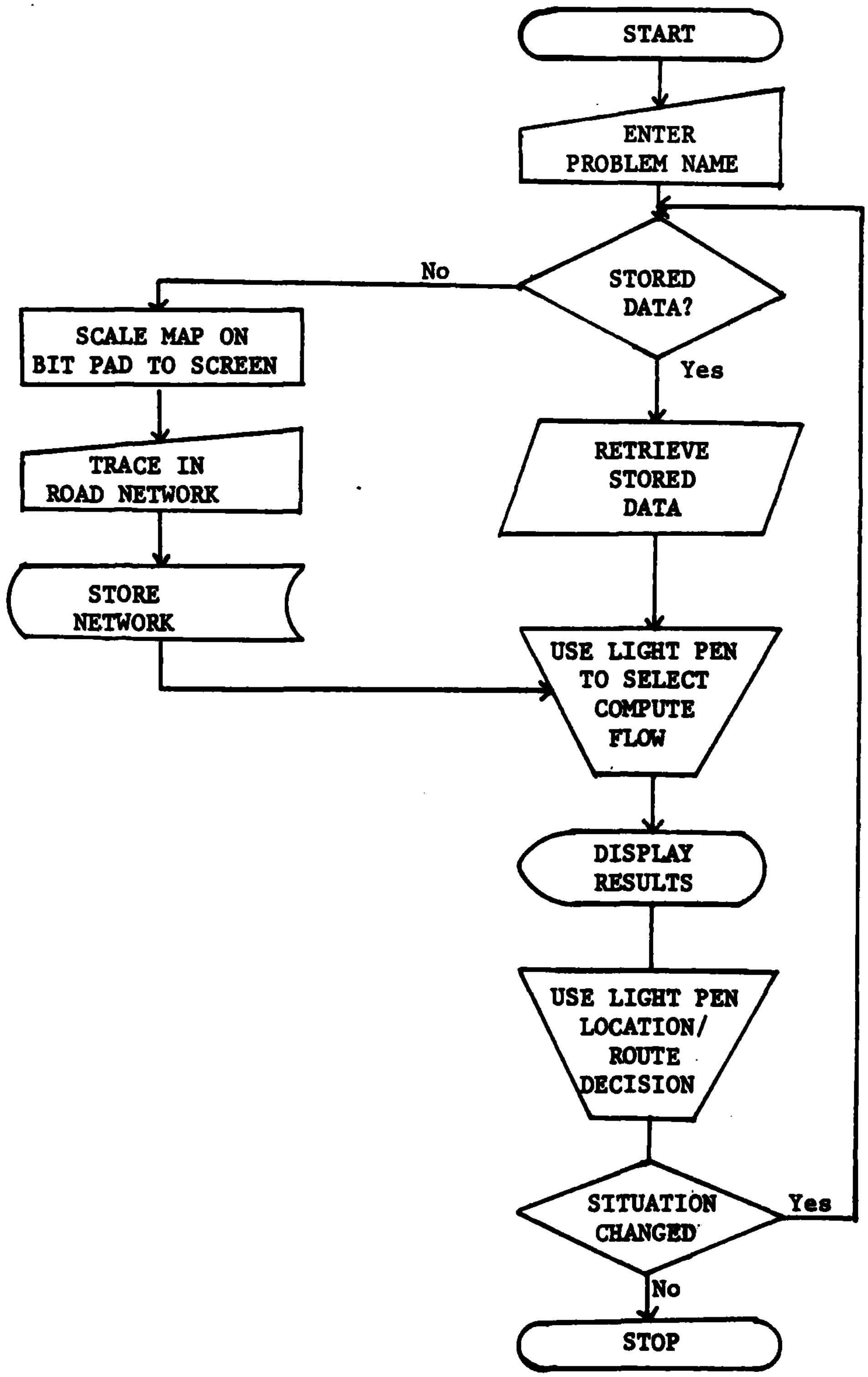



Figure 2. Flowchart of User Actions

# CHAPTER IV

# IMPLEMENTATION AND DOCUMENTATION

## A. Instrumentation and Equipment

The primary item of equipment utilized in this model is the Chromatics color graphics minicomputer [32]. It is a wholly self-contained, high resolution (512 by 512 dot matrix) color graphics terminal with an integral Z-80 microprocessor, attached floppy disk drives and 64 k bytes of random access memory. It's high resolution screen provides a choice of from one to eight colors and automatically generates geometric figures as well as graphs and bar charts.

As an additional feature, the terminal is equipped with a light pen. This is a device which is capable of detecting light on the screen and relaying a signal back to the terminal. This signal is then used to pinpoint the location of the light pen relative to the screen. This is the primary device for controlling program execution.

A digitizer pad is utilized to input the nodes and arcs into the computer while displaying a visual representation of the network on the screen. This accessory to the terminal converts graphic information into a digital form suitable for use by the Z-80 microprocessor. It is operated by positioning the crosshairs or touching a stylus to any position on a map which is affixed to the pad's surface. The x,y coordinates of that position are then transformed into their digital equivalents and transmitted to the terminal for processing.

## B. Implementation and Documentation

All programming was accomplished using Chromatics Basic Language [7]. The primary blocks are: (i) map data input, (ii) menu selection control, (iii) general purpose data input, (iv) data manipulation, (v) computations execution and (vi) display of the results.

The program NTRACE is a modification of Monte Anderson's [1] program which he used for his thesis work. It is used primarily to trace in the networks and control the switching to the program SOLVE. The similarity between this model and the Water Point Model created by Cpt. Anderson constitutes the beginnings of a library of decision support systems which could be available to a Division Engineer to improve his support and assessment capabilities. NTRACE provides light pen selection of menu items to add nodes or arcs, stop program execution, save data, restart, or solve the problem which has been input into the system. A selection of menu items COMPUTE FLOW or DISPLAY ANALYSIS while under the control of program NTRACE results in all accumulated data being saved on disk automatically and program SOLVE being retrieved from the disk and execution initiated.

Program solve performs all calculations and controls the display of the results. The results of the calculations are not saved on the disk. Both programs were designed to be as user friendly as possible. The procedure for tracing a network is accompanied by detailed instructios to provide a step-by-step routine. The intent is to make it possible to operate the entire program with no background as to what the correct solution procedure should be. For further documentation of the program NTRACE, see Monte Anderson's Master's Thesis [1].

The program SOLVE is even easier to use than NTRACE. SOLVE first explains to the user that it can handle up to sixty nodes and asks the user to type in the number of nodes in his network. This accomplished, it then explains that no node can have more than twenty arcs incident to that node and prompts the user to input the maximum number of arcs incident to any node in the networks. Next, SOLVE explains that the maximum number of arcs that memory will allow is 1200 and asks the user to input the total number of arcs in the network.

SOLVE now has all the data necessary to begin to solve the k minimum weight spanning tree problem. Finally, it asks the user how many trees he would like to see (5 or less). Once this value is input, the problem is solved for the stated number of minimum weight trees as explained in Chapter II and the results are displayed in tabluar form.

## CHAPTER V

## TEST PROBLEM AND RESULTS

### A. Test Problem

In order to demonstrate the procedure, consider the network shown in Figure 3. It depicts the locations of eight units requiring addition power and the road network which connects them. It has been entered on the BITPAD using the program NTRACE.

The corresponding costs associated with the twelve arcs are shown in Table 1. The proper procedure for inputing this network is first to input the

| Arc | Starting-Ending Node | Costs |
|---|---|---|
| 1 | 1-2 | 4 |
| 2 | 1-3 | 6 |
| 3 | 1-4 | 3 |
| 4 | 2-4 | 2 |
| 5 | 4-5 | 5 |
| 6 | 3-5 | 2 |
| 7 | 4-6 | 5 |
| 8 | 2-6 | 4 |
| 9 | 5-8 | 6 |
| 10 | 4-8 | 6 |
| 11 | 7-8 | 3 |
| 12 | 6-7 | 2 |

Table 1. Arcs With Associated Costs

eight nodes in order. Each time the blue button is depressed, it will increment the node counter by one. Then, beginning with node number 1, input arc number 1 by touching the cursor to node one, depressing the green button and tracing the road to node number 2. The computer will automatically record the arc number, the beginning and ending nodes, and will computer the cost (distance) of the arc traced. The entire network was input in this manner an is now ready to be solved by switching control to program SOLVE.

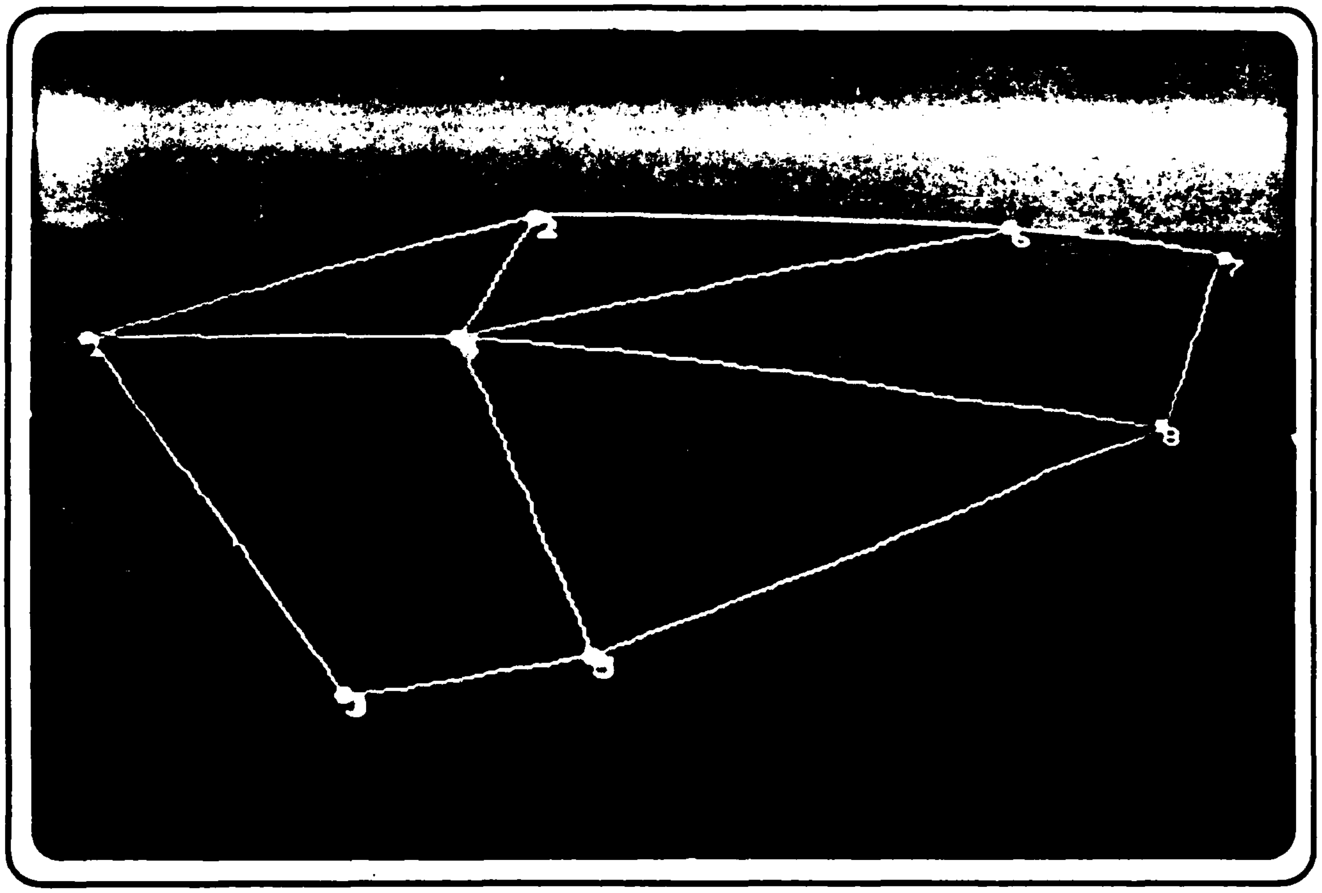


Figure 3. Test Network

## B. Results

The test problem was solved for the five best minimum weight spanning trees and the results as they actually appeared on the cathode ray tube of the chromatics colorgraphics terminal are shown in Tables 2 and 3. At this point the decision maker has all the necessary information to make his selection of the best possible location(s) for his "common user" generators. He takes the five best solutions and plots them on his map. Then, utilizing his knowledge of the situation as well as the previously discussed variables, he selects his site. The five best possible solutions for the test problem are shown as Figures 4 through 8.

THE KTH MINIMUM WEIGHT SPANNING TREE FOR K= 1

| SP ARC | NODE#1 | NODE#2 | COST | ARC# |
|---|---|---|---|---|
| 1 | [illegible] | [illegible] | [illegible] | [illegible] |
| 2 | 2 | 4 | [illegible] | [illegible] |
| 3 | 4 | 5 | 5 | 5 |
| 4 | 3 | 5 | 2 | 6 |
| 5 | 2 | 6 | 4 | 8 |
| 6 | 7 | 8 | 3 | 11 |
| 7 | 6 | 7 | 2 | 12 |

[illegible] SPANNING TREE IS 21

THE KTH MINIMUM WEIGHT SPANNING TREE FOR K= 2

| SP ARC | NODE#1 | NODE#2 | COST | ARC # |
|---|---|---|---|---|
| 1 | 1 | 2 | 4 | 1 |
| 2 | 2 | 4 | 2 | 4 |
| 3 | 4 | 5 | 5 | 5 |
| 4 | 3 | 5 | 2 | 6 |
| 5 | 2 | 6 | 4 | 8 |
| 6 | 7 | 8 | 3 | 11 |
| 7 | 6 | 7 | 2 | 12 |

[illegible] THIS SPANNING TREE IS 22

THE KTH MINIMUM WEIGHT SPANNING TREE FOR K= 3

| SP ARC | NODE#1 | NODE#2 | COST | ARC # |
|---|---|---|---|---|
| 1 | 1 | 3 | 6 | 2 |
| 2 | 1 | 4 | 3 | 3 |
| 3 | 2 | 4 | 2 | 4 |
| 4 | 3 | 5 | 2 | 6 |
| 5 | 2 | 6 | 4 | 8 |
| 6 | 7 | 8 | 3 | 11 |
| 7 | 6 | 7 | 2 | 12 |

22

Table 2. Test Results for k = 1,2,3.

THE KTH MINIMUM WEIGHT SPANNING TREE FOR K=

| SP ARC | NODE#1 | NODE#2 | COST | ARC # |
|---|---|---|---|---|
| 1 | 1 | 4 | 3 | 2 |
| 2 | 2 | 4 | 2 | 4 |
| 3 | 4 | 5 | 3 | 5 |
| 4 | 3 | 5 | 2 | 6 |
| 5 | 4 | 6 | 3 | 7 |
| 6 | 7 | 8 | 3 | 11 |
| 7 | 6 | 7 | 2 | 12 |

[illegible] THIS SPANNING TREE IS 22

THE KTH MINIMUM WEIGHT SPANNING TREE FOR K= 5

| SP ARC | NODE#1 | NODE#2 | COST | ARC # |
|---|---|---|---|---|
| 1 | 1 | 2 | 4 | 1 |
| 2 | 1 | 4 | 3 | 3 |
| 3 | 4 | 5 | 3 | 5 |
| 4 | 3 | 5 | 2 | 6 |
| 5 | 2 | 6 | 4 | 8 |
| 6 | 7 | 8 | 3 | 11 |
| 7 | 6 | 7 | 2 | 12 |

[illegible] THIS SPANNING TREE IS 23

Table 3. Test Results for k = 4,5.

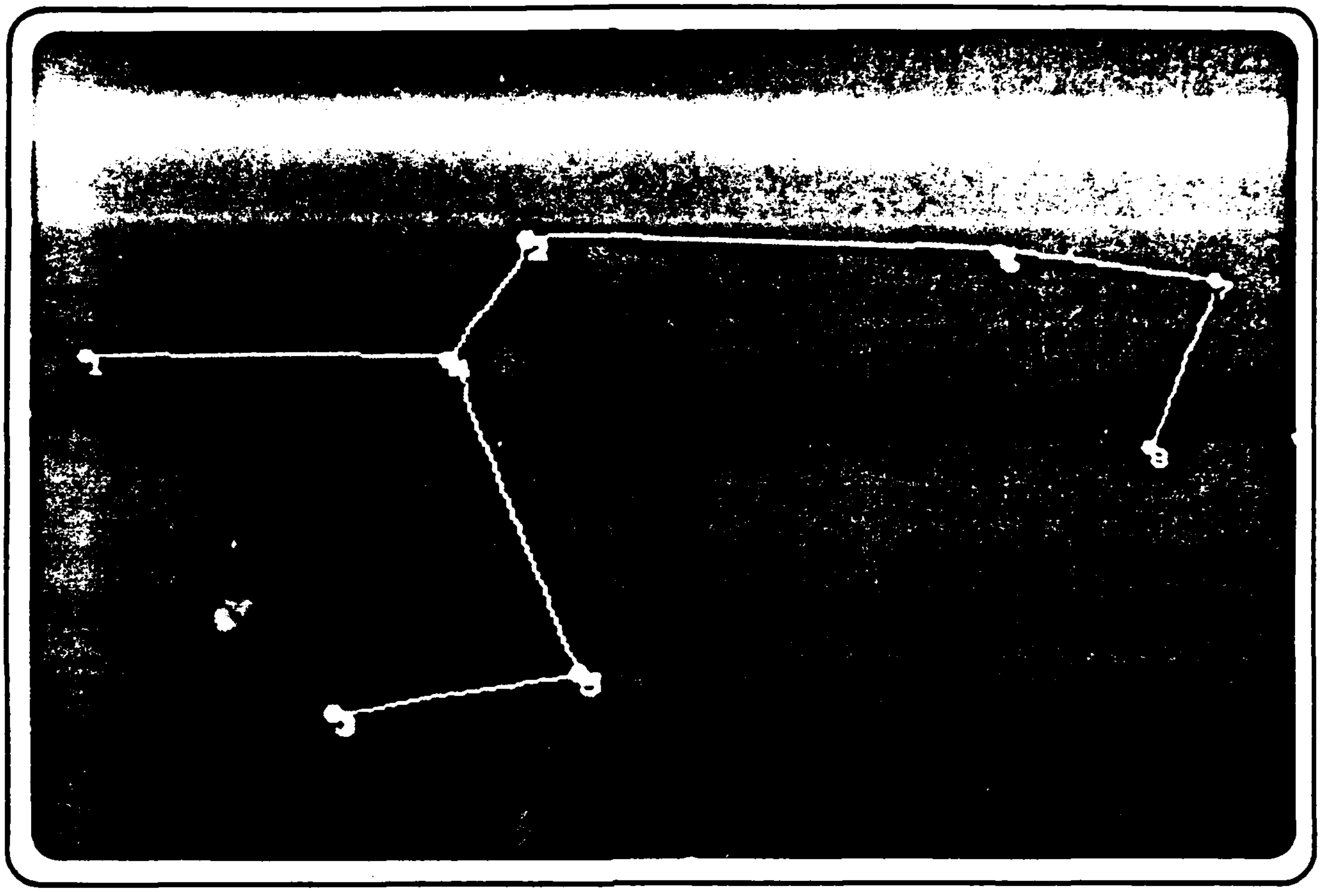


Figure 4. Resulting Network for k = 1.

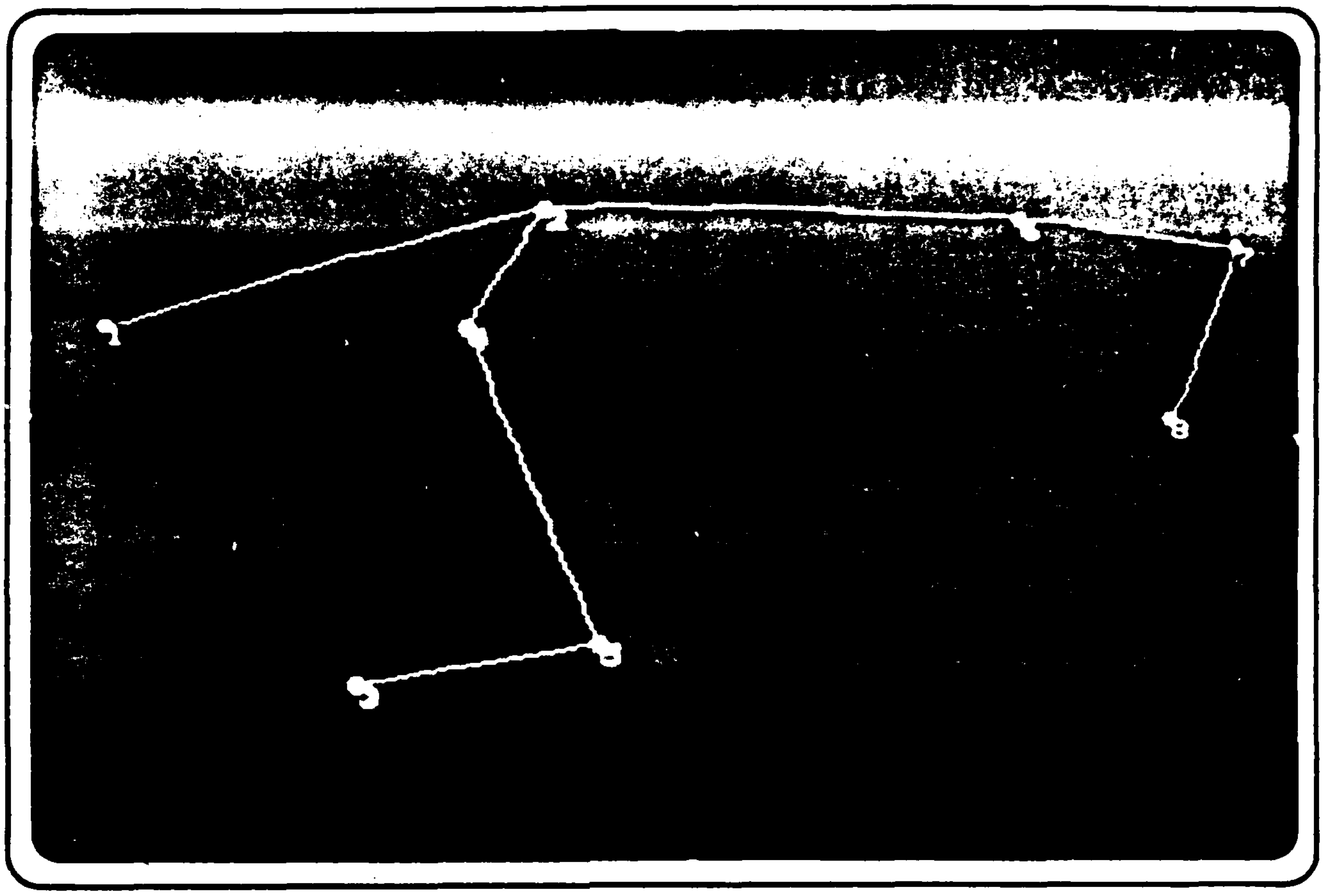


Figure 5. Resulting Network for k = 2.

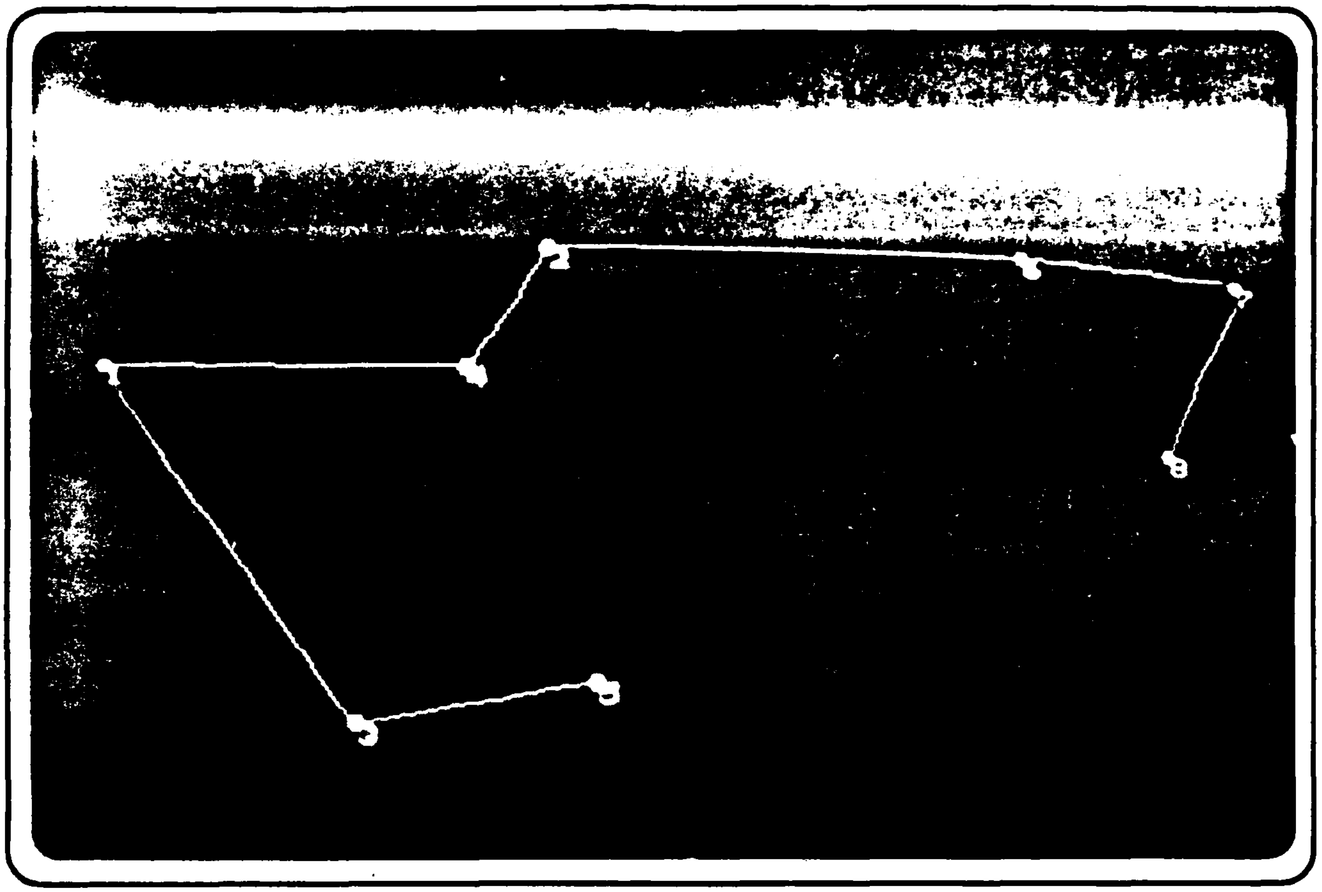


Figure 6. Resulting Network for k = 3.

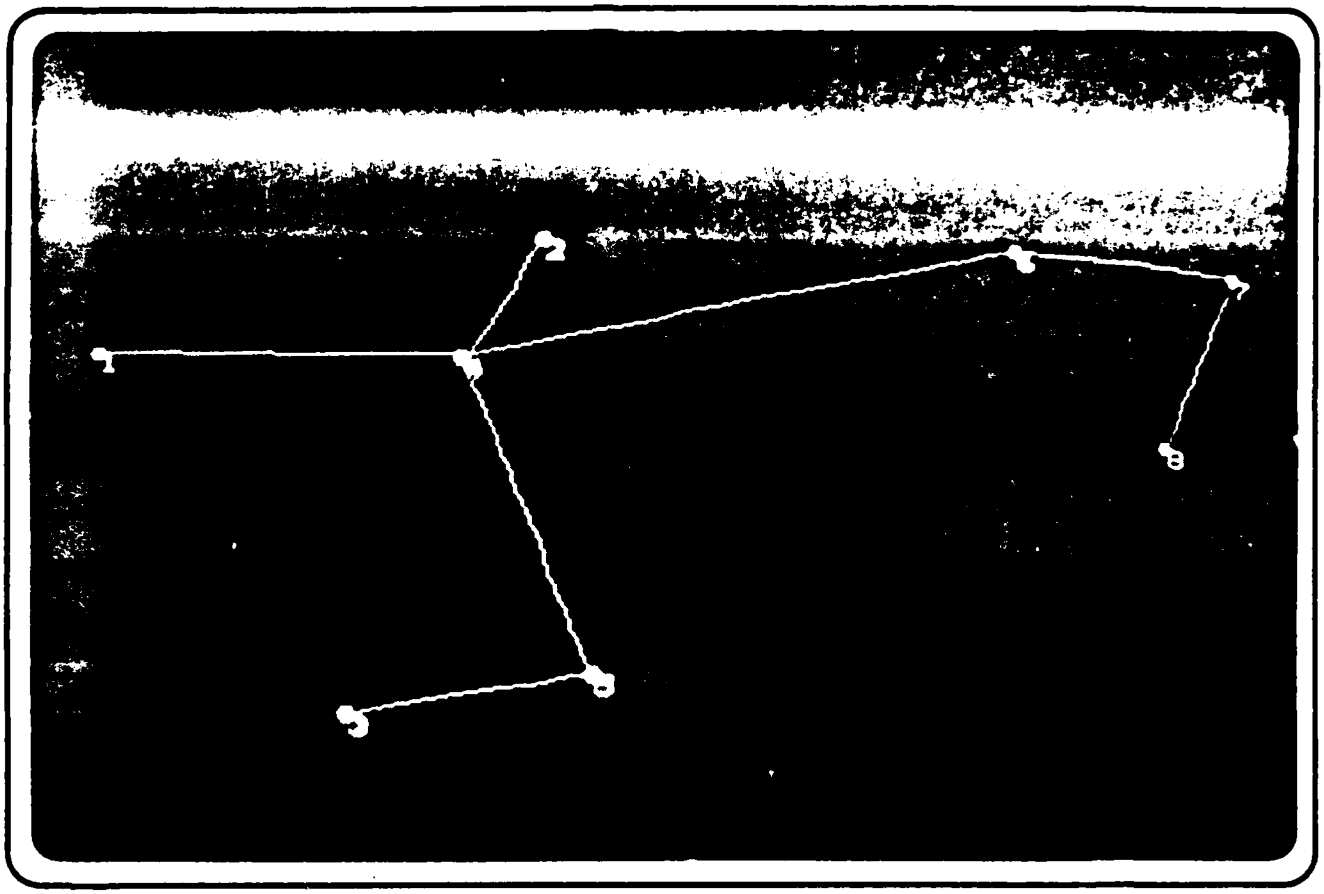



Figure 7. Resulting Network for k = 4.

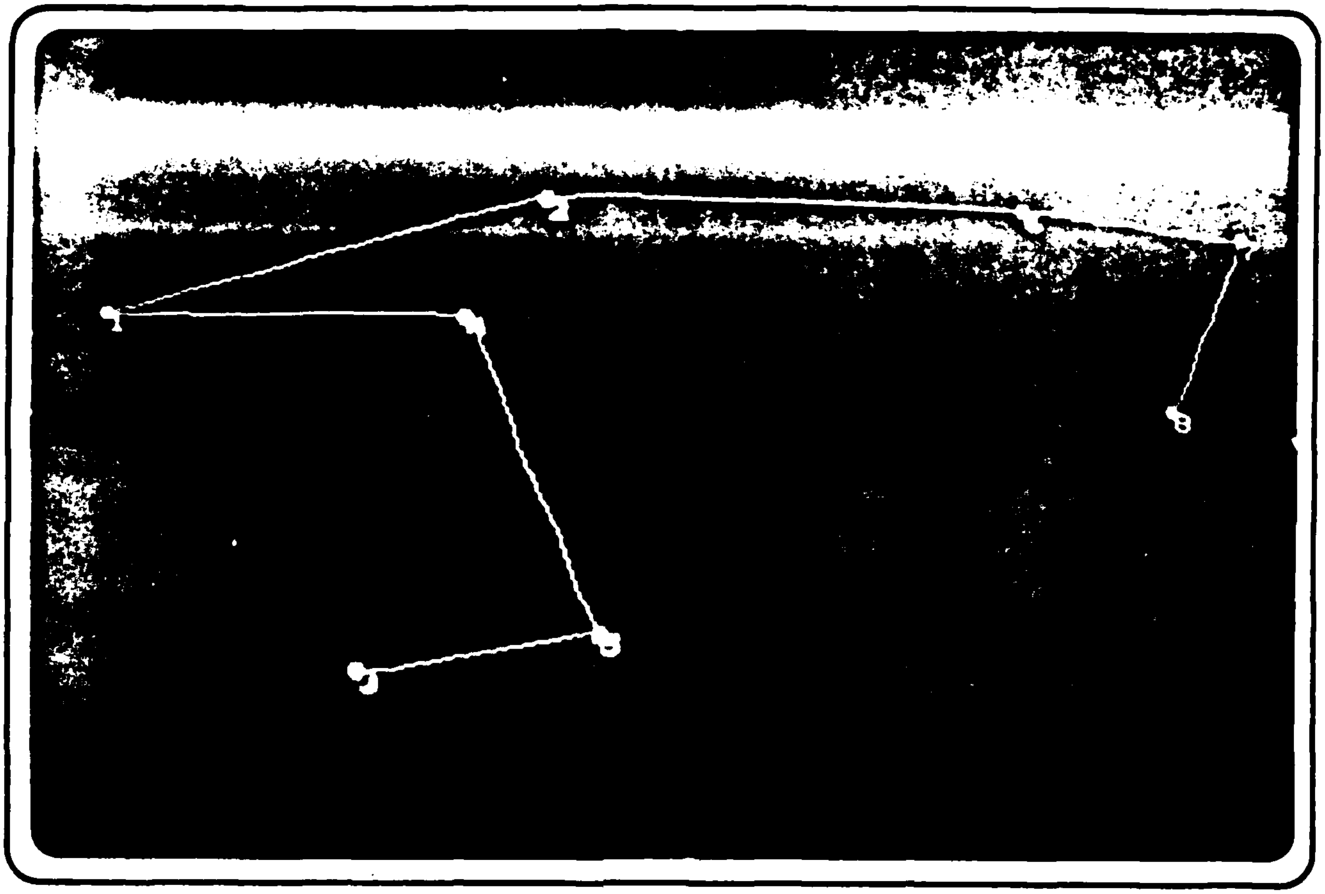


Figure 8. Resulting Network for k = 5.

## CHAPTER VI

## CONCLUSIONS AND RECOMMENDATIONS

### A. <u>Conclusions</u>

We realize that this is quite a departure from conventional thinking as far as power distribution systems are concerned. As this concept is delved into further, it may result in the conclusion that this is impractical and inveasible in a constantly moving tactical environment, particularly the closer the units are to the front. However, it should be noted that the idea of "common users" of generators and "power plant teams" is not new in a non-tactical situation.

The Corps of Engineers has both power plant operation and maintenance, and power line teams. These are depicted in Appendices D-1 and D-2. Their concept and mission would be particularly suited to the decision support system described here.

Although this system was originally designed with Division 86 units and their requirements in mind, it is easily extrapolated to Corps and Theater Army levels with only minimal effort. Possibly once you get as high as theater level, you may exceed the memory capability of the Z-80 microprocessor. There are processors available with greater memory capabiliteis and so this thinking need not be limited by the computer hardware.

Another application of this system would be with the concept of cellular division and corps headquarters. The thought here is that a division headquarters would occupy an area roughly 10 kilometers square (Corps, 15 kilometers). Within this area the various headquarters elements, although dispersed, could be connected by transmission lines to a common source of power. The optimum location of the power plant(s) could easily be determined by our decision support system.

Another concept which the Corps of Engineers is researching is that of power conditioners. As mentioned earlier, there are numerous different sizes, voltages and cycles of power generation equipment in a given unit. When an item requires, say 6 kilowatts to operate, it must use a 10 kilowatt generator (the next larger size). When you multiply this by the number of that piece of equipment in the unit, the excess power becomes even larger. Now expand that over all other items and you'll find there exists a significant overkill.

A power conditioner is a "black box" which can convert cycles, voltages, etc. so that a common source of power can drive any of the diverse systems and thereby reduce the numbers of generator, operator, repair parts, and overall cost to the system. Here again would be an excellent situation where our decision support system could be utilized.

These are but a few possible applications of our system. The possibilities are many and varied.

B. Recommendations

(1) We recommend that this area be further explored to determine possible expanded applications of the process considered here. Military pipeline systems would be readily adaptable to such a decision system.

(2) Time and manpower precluded making this system any more sophisticated than presented here but there are several improvements which could be made to increase it's value.

(a) The minimum operating power requirements for each unit could be stored in computer memory. The user could take readiness and casualty/damage reports and constantly monitor each unit's present status. Thus shortages would be detected sooner to reduce system down time.

(b) Voltage losses through transmission lines could be calculated by inputing formulas to account for drops due to distances and wire sizes.

(c) Priority for each unit could be stored in computer memory thus eliminating the need for the user to manually monitor these.

# APPENDIX A

## GENERATOR REQUIREMENTS FOR DIVISION 86 UNITS

Appendix A-1.

| | | | | | | |
|---|---|---|---|---|---|---|
| J35492 | A GEN ST DSL ENG TM: 15KW 60HZ MTD ON M-200A1 PU-405 | 19 | 19 | 19 | 19 | |
| J35492 | B GEN ST DSL ENG TM: 15KW 60HZ MTD ON M-200A1 PU-405 | 14 | 14 | 14 | 14 | |
| J35629 | A GEN ST DSL ENG TM: 60KW 60HZ MTD ON M-200A1 PU-650 | 3 | 3 | 3 | 3 | |
| J35680 | A GEN ST DSL ENG TM: 60KW 400HZ MTD ON M-200A1 PU-707 | 2 | 2 | 2 | 2 | |
| J35801 | A GEN ST DSL ENG TM: 100KW 60HZ MTD ON M353 PU-495 | 2 | 2 | 2 | 2 | |
| J35813 | A GEN ST DSL ENG: 5KW 60HZ 1-3PH AC 120/208 120/240V TAC UTIL | 16 | 16 | 16 | 16 | |
| J35813 | B GEN ST DSL ENG: 5KW 60HZ 1-3PH AC 120/208 120/240V TAC UTIL | 9 | 9 | 9 | 7 | |
| J35825 | A GEN ST DSL ENG: 10KW 60HZ 1-3PH AC 120/208 120/240V TAC UTIL | 12 | 12 | 12 | 20 | |
| J36109 | A GEN ST DSL ENG: 30KW 60HZ 3PH AC 120/208 240/416V 50HZ TAC UTIL | 1 | 1 | 1 | 1 | |
| J36303 | A GEN ST DSL ENG TM: 30KW 60HZ MTD ON M-200A1 PU-406 | 5 | 5 | 5 | 5 | |
| J36725 | A GEN ST DSL ENG: 30KW AC 120/208 240/416V 3PH 400HZ TAC PRECISE | 5 | 5 | 5 | 5 | |
| J37205 | A GEN ST DSL ENG TM: 45KW 60HZ MTD ON M-200A1 PU-551 | 5 | 5 | 5 | 5 | |
| J37205 | B GEN ST DSL ENG TM: 45KW 60HZ MTD ON M-200A1 PU-551 | 4 | 4 | 4 | 4 | |
| J38301 | A GEN ST DSL ENG: 60KW 60HZ 3PH AC 120/208 240/416 50HZ TAC UTIL | 1 | 1 | 1 | 1 | |
| J41452 | A GEN ST GAS ENG TM: 10KW 400HZ MTD ON M103 PU-304/MPQ-4 | 2 | 2 | 2 | 2 | |
| J42100 | A GEN ST GAS ENG TM: 10KW 60HZ 1-3PH AC 120/240 120/208V PU-619/M | 72 | 72 | 72 | 57 | |
| J42100 | B GEN ST GAS ENG TM: 10KW 60HZ 1-3PH AC 120/240 120/208V PU-619/M | 3 | 3 | 3 | 3 | |
| J42976 | B GEN ST GAS ENG: 0.5KW 60HZ 1PH AC 120/240V SHOCK MTD TAC UTILITY | 1 | 1 | 1 | 1 | |
| J43027 | A GEN ST GAS ENG: 0.5KW 400HZ 1PH AC 120/240V SKD SHK TAC UTILITY | 11 | 11 | 11 | 11 | |
| J43918 | A GEN ST GAS ENG: 1.5KW 60HZ 1PH 2 WIRE AC 120V SHOCK TAC UTILITY | 129 | 129 | 129 | 123 | |
| J43918 | B GEN ST GAS ENG: 1.5KW 60HZ 1PH 2 WIRE AC 120V SHOCK TAC UTILITY | 195 | 195 | 194 | 192 | |
| J44055 | A GEN ST GAS ENG: 1.5KW DC 28V SHOCK TACTICAL UTILITY | 73 | 71 | 71 | 80 | 1 |
| J44055 | B GEN ST GAS ENG: 1.5KW DC 28V SHOCK TACTICAL UTILITY | 138 | 138 | 131 | 117 | |
| J45699 | A GEN ST GAS ENG: 3KW 60HZ 1-3PH 120/240 120/208V SKD TAC UTILITY | 19 | 19 | 19 | 11 | |
| J45699 | B GEN ST GAS ENG: 3KW 60HZ 1-3PH 120/240 120/208V SKD TAC UTILITY | 34 | 34 | 34 | 34 | |
| J45836 | A GEN ST GAS ENG: 3KW 400HZ 1-3PH AC 120/208/240V TAC UTIL | 54 | 54 | 54 | 54 | |
| J45836 | B GEN ST GAS ENG: 3KW 400HZ 1-3PH AC 120/208/240V TAC UTIL | 14 | 14 | 14 | 14 | |
| J46110 | A GEN ST GAS ENG: 3KW DC 28V SKD-SHK TBLR FRAME MTD TAC UTILITY | 27 | 27 | 27 | 28 | |
| J46110 | B GEN ST GAS ENG: 3KW DC 28V SKD-SHK TBLR FRAME MTD TAC UTILITY | 78 | 78 | 78 | 78 | |
| J46252 | A GEN ST GAS ENG TM: 3KW 60HZ 2 EA MTD ON M101 PU-625 | 54 | 50 | 42 | 50 | |
| J46252 | B GEN ST GAS ENG TM: 3KW 60HZ 2 EA MTD ON M101 PU-625 | 1 | 1 | 1 | 1 | |
| J46304 | A GEN ST GAS ENG TM: 3KW 60HZ 2 EA MTD ON M101 PU-617 | 14 | 14 | 14 | 10 | |
| J46392 | A GEN ST GAS ENG TM: 5KW 60HZ 2EA MTD ON M103 PU-629 | | | | 1 | |
| J46692 | A GEN ST GAS ENG: DC 5KW 28V FRAME-SHOCK MTD TACTICAL UTILITY | 6 | 6 | 6 | 1 | |
| J46692 | B GEN ST GAS ENG: DC 5KW 28V FRAME-SHOCK MTD TACTICAL UTILITY | 1 | 1 | 1 | 1 | |
| J47068 | A GEN ST GAS ENG: 5KW 60HZ 1-3PH AC 120/240 120/208V SKD TAC UTIL | 4 | 4 | 4 | 4 | |
| J47068 | B GEN ST GAS ENG: 5KW 60HZ 1-3PH AC 120/240 120/208V SKD TAC UTIL | 6 | 6 | 6 | 6 | |
| J47068 | C GEN ST GAS ENG: 5KW 60HZ 1-3PH AC 120/240 120/208V SKD TAC UTIL | 2 | 2 | 2 | 2 | |
| J47480 | A GEN ST GAS ENG TM: 5KW 60CY 1-3PH AC 120 240 120/208V PU-618/M | 3 | 3 | 3 | 3 | |
| J47617 | A GEN ST GAS ENG TM: 5KW 60HZ 2EA MTD ON M116 PU-620 | 80 | 79 | 76 | 78 | |
| J47617 | B GEN ST GAS ENG TM: 5KW 60HZ 2EA MTD ON M116 PU-620 | 26 | 26 | 26 | 25 | |
| J48713 | A GEN ST GAS ENG: 5KW 400HZ 1-3PH AC 120/240 120/208 SKD TAC UTIL | 10 | 10 | 10 | 10 | |
| J49055 | A GEN ST GAS ENG: 7.5 KW DC 28.5 V WHL MTD | 2 | 2 | 2 | 2 | |
| J49055 | B GEN ST GAS ENG: 7.5 KW DC 28.5 V WHL MTD | 7 | 7 | 7 | 7 | |
| J49398 | A GEN ST GAS ENG: 10KW 60HZ 1-3PH AC 120/240 120/208V TAC UTILITY | 19 | 19 | 19 | 21 | |
| J49398 | B GEN ST GAS ENG: 10KW 60HZ 1-3PH AC 120/240 120/208V TAC UTILITY | 8 | 8 | 8 | 8 | |
| J49466 | A GEN SET GAS ENG: 10KW 400HZ 1-3PH AC 120/240 120/208V TAC UTIL | 5 | 5 | 5 | 4 | |
| J49809 | A GEN ST GAS ENG TM: 10KW 60HZ MTD ON M101 PU-332 | 6 | 6 | 6 | 6 | |
| J49809 | B GEN ST GAS ENG TM: 10KW 60HZ MTD ON M101 PU-332 | 1 | 1 | 1 | 1 | |
| J61505 | A GEN ST GAS TURB ENG: 60KW AC 120/240 208/416V 3PH 400CY SKD MTD | 6 | 6 | 6 | 3 | |

# Appendix A-2

## Unit Generator Requirements

| | .5 | 1.5 | 3 | 5 | 10 | 15 | 30 | 45 | 60 | 100 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/1 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 2/1 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 3/1 Mech | | 8 | | | | | | | | | 12.0 |
| 1/2 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 2/2 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 3/2 Mech | | 8 | | | | | | | | | 12.0 |
| 1/3 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 2/3 Armor | | 3 | 1 | | | | | | | | 7.5 |
| 3/3 Mech | | 8 | | | | | | | | | 12.0 |
| 4/3 Mech | | 8 | | | | | | | | | 12.0 |
| Engr. Bn | | 13 | 16 | | | | | | | | 64.5 |
| Mil Intel Bn | | 5 | | 41 | 12 | 1 | | | | | 347.5 |
| Signal Bn | | 8 | 136 | 82 | 7 | | | | | | 900.0 |
| MP Company | | 3 | | | | | | | | | 4.5 |
| NBC Company | | 5 | | | | | | | | | 7.5 |
| HHC 1st Bde | | 4 | 2 | 4 | | | | | | | 32.0 |
| HHC 2nd Bde | | 4 | 2 | 4 | | | | | | | 32.0 |
| HHC 3rd Bde | | 4 | 2 | 4 | | | | | | | 32.0 |
| ADA Bn | | 50 | 1 | | | | | | | | 78.0 |
| HHB, Divarty | | 6 | | 24 | 3 | | | | | | 159.0 |
| TGT Aqn Bty | | 3 | | | | | | | | | 4.5 |
| 1st Bn, 155 mm | | 12 | 1 | 4 | | | | | | | 41.0 |
| 2nd Bn, 155 mm | | 12 | 1 | 4 | | | | | | | 41.0 |
| 3rd Bn, 155 mm | | 12 | 1 | 4 | | | | | | | 41.0 |
| 8 inch Bn | | 8 | | | | | | | | | 32.0 |
| HHT, ACAB | | 7 | | 6 | | | | | | | 40.5 |
| SBT SPT AVN BN | 1 | 28 | 11 | 7 | 2 | | | | 3 | | 310.5 |
| CAV. SQDN. | 1 | 6 | | 2 | | | | | | | 19.0 |
| 1st Atk Bn | | 6 | | 4 | 2 | | | | | | 49.0 |
| 2nd Atk Bn | | 6 | | 4 | 2 | | | | | | 49.0 |
| HHC STP CMD | | | | | | 4 | | | | 2 | 260.0 |
| DMMC, SPT CMD | | | | 3 | | 7 | | | | | 120.0 |
| AG Co. | | 2 | 1 | | | 3 | | | | | 51.0 |
| MED Bn. | | 3 | 1 | | 7 | | | | | | 77.5 |
| Maint Bn | | 22 | 12 | 8 | 19 | 2 | 3 | 9 | 1 | | 884.0 |
| S&T Bn | | 3 | 1 | 6 | 5 | | | | | | 87.5 |
| 1st Bde Spt Bn | | 16 | | 7 | 18 | 4 | 1 | | | | 329.0 |
| 2nd Bde Spt Bn | | 16 | | 7 | 18 | 4 | 1 | | | | 329.0 |
| 3rd Bde Spt Bn | | 18 | | 7 | 19 | 4 | 1 | | | | 342.0 |
| HHC, Dvy Div. | | 2 | 1 | 4 | | 4 | | | | | 86.0 |
| | 1 | 334 | 195 | 240 | 114 | 33 | 6 | 9 | 4 | 2 | 4943.5 |

TOTAL NUMBER 60 HZ, 120 V Generators = 938

# APPENDIX B

## PROGRAM NTRACE

```
10 '************************************************************************
20 '*PROGRAM-NTPACE "PREPARES DATA INPUT FOR PROGRAM COMPUTE"
30 '*A PROTOTYPE DECISION SUPPORT SYSTEM FOR WAREHOUSE LOCATION  ON A ROAD NETWORK.
40 '*FOR DOCUMENTATION SEE MASTERS THESIS BY MONTY J. ANDERSON, CPT. USA
50 '*GEORGIA INSTITUTE OF TECH., PROF DONOVAN YOUNG, CHAIRMAN
55 '*MODIFIED BY CPT ROBERT L. DAVIS, APRIL 1982
56 '************************************************************************
60 HT=0:TR=0
65 PRINT CHR$(27);"R1C";CHR$(27);"OE5";CHR$(27);"IE5";'ESTABLISH COMMUNICATIONS WITH BITPAD
67 PRINT#4;"H"
70 IF B1 AND B2 THEN B1=0:B2=0:GOSUB 660:GOTO 4300      'CHANGE SUPPLY/DEMAND IF CHAINED FROM COMPUTE
80 IF B1 THEN GOSUB 660:GOTO 4850                      'MINOR RESTART IF CHAINED FROM COMPUTE
90 IF B2 THEN GOSUB 660:GOTO 4710                      'MAJOR RESTART IF CHAINED FROM COMPUTE
100 CLEAR:DEFINT A,I,J,N,B,S,Z                          'INITIALIZE VARIABLES IF NOT CHAINED FROM COMPUTE
110 PRINT CHR$(12);"~X2,~Y2,~C6~B5";
120 PRINT"ENTER PROBLEM NAME"
130 LINE INPUT"(For Disk Storage of Data):  ~C5";A$
140 IF LEN(A$)=0 THEN 100                               'REPROMPT IF NULL ENTRY
150 DIM NN(30)                                          'GENERAL PURPOSE STORAGE ARRAY
160 'NN(0)=ACTUAL # OF NODES IN PROBLEM;NN(16)=MAXIMUM # OF NODES ALLOWED IN PROBLEM; NN(13)=FLAG FOR NEW COST MATRIX
170 'NN(1),NN(4),NN(2),NN(5)=LOWER LEFT AND UPPER RIGHT X&Y BITPAD SCALING POINT COORD RESPECTIVELY
180 'NN(3),NN(6)=COMPUTED X&Y SCALING CONSTANTS FROM ABOVE VALUES
190 'NN(7),NN(8)=# OF SOURCES AND SINKS IN PROBLEM;NN(9),NN(10),NN(15)=CONSTANT VALUESFROM SUBROUTINE 2600
192 DIM A1(100),A2(100),DEG(60),NARC(60,20),C(100)
200 DIM DX(1,1),NX(1),NY(1),NS(1),NT(1),AL(1)           'DIM ARRAYS FOR NETWORK DATA
210 DIM SR(1),SK(1),IS(1),B(1)                          'ARRAYS FOR SUPPLY/DEMAND
220 DIM SD(1),SP(1),NI(1),IC(1,1)                       'ARRAYS FOR SHORTEST PATH
230 DIM ID(1),NF(1),ND(1),NR(1),NU(1),IU(1),ZP(1)       'ARRAYS FOR TRANSP ALGORITHM
240 DIM NP(1),X(1),Y(1)                                 'ARRAYS FOR GRAPHING
250 PRINT CHR$(12);
260 PRINT"IS THERE DATA PRESENTLY STORED UNDER NAME:                 ~C4";A$
270 LINE INPUT"~C6              Yes=Y or No=N  ~C5";Z$
280 IF LEFT$(Z$,1)="Y" THEN GOSUB 2700:GOSUB 660:GOTO 1000 'RETRIEVE STORED DATA
290 PRINT CHR$(12);:GOSUB 2100                          'INPUT CONSTANT VALUES FOR NEW PROBLEM
320 PRINT CHR$(12);"~C6~Y2 ~C YOU MAY NOW ENTER A NETWORK FOR STORAGE IN DISK FILE:~C4  ";A$
330 PRINT CHR$(10);"~C7HIT ~C5CARRIAGE RETURN~C7 AND"
340 PRINT" FOLLOW TRACING INSTRUCTIONS"
350 PRINT CHR$(10);"~C1DO YOU WANT INSTRUCTIONS: ~C5~1YES=Y OR NO=N~2~C1~J ";
360 LINE INPUT S$:IF LEFT$(S$,1)<>"Y" THEN 480         'SKIP ALL INSTRUCTIONS IF S$<>"Y"
370 PRINT CHR$(12);"~=~C4~U001300";
380 PRINT"YOU SHOULD NOW PREPARE TO ENTER THE DESIRED NETWORK.";
390 PRINT"THE AREA ON THE MAP OF CONCERN   MUST BE NO MORE THAN 10 INCHES BY 10 ";
400 PRINT"INCHES.  CENTER THE IDENTIFIED AREA ON THE      BITPAD AND SECURE IT IN PLACE ";
410 PRINT"WITH TAPE.  IDENTIFY A POINT IN BOTH THE LOWER LEFT     CORNER AND UPPER ";
420 PRINT"RIGHT CORNER THAT IS NO MORE THAN 1/4 INCH OUTSIDE BOTH THE X AND Y AXIS ";
430 PRINT"BOUNDRIES OF THE IDENTIFIED AREA. "
440 PRINT CHR$(10);"~X002~Y002~C6THESE TWO POINTS WILL BE USED BY ";
450 PRINT"YOU TO   SCALE THE SIZE OF THE IDENTIFIED ";
460 PRINT"AREA TO  THE FULL SIZE OF THE SCREEN."
470 LINE INPUT"~C5HIT RETURN WHEN YOU ARE READY TO BEGIN.~C7~G+0,0,511,511";Z$
480 PRINT CHR$(12);"~=~U1,100~C4~K";
490 PRINT "TOUCH LOWER LEFT SCALE POINT WITH STYLUS OR DEPRESS ANY BUTTON ON THE CURSOR"
500 PRINT "AFTER IT IS CENTERED ON THE SCALE POINT.  LISTEN FOR A BELL.~U001255~C8"
510 PRINT "IF YOU DO NOT HEAR A BELL THEN YOU ARE OUTSIDE OF THE SENSITIVE AREA "
520 PRINT "ON THE BITPAD.  DECREASE THE SIZE OF THE AREA TO BE TRACED."
530 INPUT#4;X,Y,F$:IF F$="1" OR F$="3" OR F$="4" OR F$="8" THEN NN(1)=X:NN(4)=Y ELSE 530
540 PRINT CHR$(12);"~U001500~C4";CHR$(7);
```

```
570 PRINT "IF YOU DO NOT HEAR A BELL THEN YOU ARE OUTSIDE OF THE SENSITIVE AREA ON "
580 PRINT "THE BITPAD.  DECREASE THE SIZE OF THE AREA TO BE TRACED.";
590 F$="0":PRINT"~7020"
600 INPUT#4;X,Y,F$:IF F$="1" OR F$="3" OR F$="4" OR F$="8" THEN NN(2)=X:NN(5)=Y ELSE 600
610 NN(3)=(NN(2)-NN(1))/512:NN(6)=(NN(5)-NN(4))/412
620 PRINT CHR$(12);"~C4~U001450";CHR$(7);:IF LEFT$(S$,1)<>"Y" THEN HT=5:GOSUB 850:GOTO 4100
630 PRINT"YOU HAVE FINISHED THE SCALING OF THE MAP.  YOU ARE NOW READY TO INPUT THE"
640 PRINT "LOCATIONS OF~C6 ALL~C4 ROAD INTERSECTIONS~C6 AND ROAD END POINTS~C4 THAT EITHER:  "
650 PRINT CHR$(10);"1)  LEAVE THE EDGE OF THE AREA THAT WAS SCALED EARLIER."
660 PRINT CHR$(10);"2)  TERMINATE AT ANY POINT INSIDE OF THE SCALED AREA."
670 PRINT CHR$(10);"TO DESIGNATE A POINT AS A NODE YOU NEED ONLY";
680 PRINT "POSITION THE CURSOR OVER IT AND PRESS THE ~C1BLUE~C4 BUTTON.  ";
690 PRINT "A BELL WILL SOUND INDICATING THAT THE   NODE WAS ACCEPTED AND A~C1 BLUE~C4  ";
700 PRINT "CIRCLE WILL APPEAR ON THE SCREEN.  ~C6TAKE CARE TO ENTER AS MANY NODES ";
710 PRINT "AS YOU CAN IDENTIFY.  ALL CONNECTING ROADS ";
720 PRINT "MUST START AND END AT A NODE."
730 LINE INPUT"~C5~X003~Y003HIT RETURN TO CONTINUE.";Z$'PLAIN WAIT FOR CARRIAGE RETURN
738 '*
740 HT=5:GOSUB 850:GOTO 4100                        'BRANCH TO DIGITIZER ROUTINE
840 '***THIS SUBROUTINE PRINTS THE MENU AND SETS INITIAL WINDOW CONDITIONS
850 PRINT "~=";CHR$(12);
860 PRINT CHR$(27);"OA1~=~W300,1005110,~R~B5";CHR$(12);
870 PRINT CHR$(27);"OA0~=~K~C3~F~G";
880 PRINT "*25,50,10,07550,10,12550,10,17550,10,";
890 PRINT "22550,10,27550,10,~L";CHR$(21);
900 PRINT "~U016060ADD~U1,030NODE/ARC";
910 PRINT "~U054080STOP OR~U061030SAVE~U061020DATA";
920 PRINT "~U107060CHANGE~U107030SUPPLY/~U107020DEMAND";
930 PRINT "~U154080COMPUTE~U163030FLOW";
940 PRINT "~U204060DISPLAY~U201030ANALYSIS";
950 PRINT "~U254060RESTART";
960 RETURN
998 '*
1000 '***THIS IS THE INFINATE LOOP SECTION TO WAIT FOR A LIGHT PEN HIT
1010 TR=1:ON ERROR#2 GOTO 2000:OUT&H80,0            'ACTIVATE LIGHT PEN INTERRUPT
1020 PRINT CHR$(27)"OA1~C6LIGHT PEN ACTIVATED~C7~K"
1030 PRINT CHR$(10);CHR$(27);"OA0~K";
1040 GOTO 1040
1098 '*
1100 '***THIS SECTION CONTROLS THE INPUT SIGNAL FROM THE 4 BUTTON CURSOR WITH DIGITIZER PAD
1110 TR=1:ON ERROR#2 GOTO 2000:OUT&H80,0
1120 PRINT#4;"J":PRINT CHR$(27);"OA0";              'SET BITPAD A 10 COORD/SEC
1130 'RECEIVE COORD PLUS FLAG FROM BITPAD; IGNOR IF F$ IS NOT "4" OR "8" FOR BLUE AND GREEN BUTTON RESPECTIVELY
1140 INPUT#4;X,Y,F$:IF F$="4" OR F$="8" THEN 1150 ELSE 1140
1150 IF X<=0 OR Y<=0 THEN 1140                      'REJECT INPUT IF ZERO
1160 XP=FNPX(X):YP=FNPY(Y)                          'SCALE BITPAD COORD TO SCREEN
1170 IF XP<0 OR YP<0 OR XP>511 OR YP>511 THEN 1140  'REJECT COORD IF OUTSIDE SCALED AREA
1180 IF F$="4" THEN GOSUB 1400                      'IF BLUE BUTTON THEN ESTABLISH A NODE
1190 IF F$="8" THEN GOSUB 1500                      'IF GREEN BUTTON THEN DRAW AN ARC
1200 GOTO 1140
1299 '*
1400 '***THIS SUBROUTINE INCREMENTS THE NODE COUNTER
1410 SH=5:GOSUB 1600:IF SH<>5 THEN 1440             'IGNOR NODE REQUEST IF DISTANCE IS < 5 DOTS
1420 PRINT CHR$(7);:N=N+1:CL=N:NN(0)=N
1430 NX(N)=XP:NY(N)=YP:PRINT "~C3";:GOSUB 1800      'RECORD NODE COORD; PLOT ON SCREEN
1440 RETURN
1499 '*
1500 '***THIS SUBROUTINE DRAWS THE ARCS BETWEEN THE NODES
1510 PRINT#4; "I"
```

```
1520 SH=25:GOSUB 1600                                'FIND DISTANCE TO CLOSEST NODE
1530 IF SH=25 THEN GOSUB 1400:SH=0:CL=NN(0) ELSE PRINT CHR$(7);'ESTABLISH NODE IF DISTANCE > 25 DOTS
1540 PRINT "~1~K~F~C2~G+";
1550 PLOT NX(CL),NY(CL),2                            'PLOT BLINKING GREEN CIRCLE
1560 PRINT "~2~L(";:PLOT NX(CL),NY(CL)               'PLOT CONCATENATED VECTOR
1570 PLOT XP,YP:XO=XP:YO=YP:S=CL                     'REMEMBER OLD VALUES
1580 INPUT#4;X,Y,F$
1590 XP=FNPX(X):YP=FNPY(Y)
1600 DI=ABS(XP-XO)+ABS(YP-YO)
1610 IF DI>100 THEN 1580
1620 PLOT XP,YP
1630 IF F$<>"8" THEN 1660
1640 XO=XP:YO=YP:SU=SU+DI                            'SUM DISTANCE FROM LAST COORD
1650 GOTO 1560
1660 SH=25:GOSUB 1600
1670 IF SH=25 THEN GOSUB 1400:SH=0:CL=NN(0)
1680 SU=SU+SH:PLOT NX(CL),NY(CL)
1690 PRINT"~F~C3+";:PLOT NX(S),NY(S),2
1700 PRINT"~L";CHR$(21);
1702 L=L+1:AN=L:NN(21)=L
1704 A1(L)=S:A2(L)=CL:C(L)=SU
1710 DX(S,CL)=SU:DX(CL,S)=SU:SU=0                    'RECORD TWOWAY ARC
1712 FOR J2=1 TO NN(16)
1714 IF J2=S THEN 1716 ELSE 1716
1716 DEG(J2)=DEG(J2)+1:NARC(J2,DEG(J2))=L
1718 IF J2=CL THEN 1719 ELSE 1720
1719 DEG(J2)=DEG(J2)+1:NARC(J2,DEG(J2))=L
1720 NEXT J2
1722 RETURN
1799 '*
1800 '***THIS SUBROUTINE FINDS THE CLOSEST NODE TO THE LIGHT PEN HIT
1810 FOR J=1 TO NN(0)
1820      DI=ABS(NX(J)-XP)+ABS(NY(J)-YP)
1830      IF DI<SH THEN SH=DI:CL=J
1840 NEXT
1850 RETURN
1899 '*
1900 '***THIS SUBROUTINE PLOTS THE NODE NUMBER AND A CIRCLE AT THE NODES COORD
1910 PRINT "~U";:PLOT NX(CL),NY(CL)
1920 PRINT CHR$(21);
1930 IF CL<10 THEN PRINT USING "#";CL; ELSE PRINT USING "##";CL;
1940 PRINT "~K~F~G+";:PLOT NX(CL),NY(CL),2
1950 RETURN
1998 '*
2000 '***THIS SECTION CONTROLS THE BRANCHING TO THE APPROPRIATE SECTION AFTER A LIGHT PEN HIT
2005 IF ERR=24 THEN 2010 ELSE ON ERROR#0 GOTO 0
2010 IF HT=0 THEN 2080                               'IGNOR ALL LIGHT PEN HITS
2020 XP=CURSX(4):YP=CURSY(4)                         'RECEIVE LIGHT PEN HIT COORD
2030 ON HT GOTO 2040,3335,3635,3000,4100,4165        'IF HT<>1 THEN BRANCH TO APPROPRIATE SECTION
2040 XO=25:FOR I=1 TO 6                              'SEARCH THROUGH MENU FOR CLOSEST POINT
2050 DI=ABS(XP-XO)+ABS(YP-50)
2060 IF DI<20 THEN PRINT CHR$(7);:ON I GOTO 4100,4200,4300,4400,4500,4600
2070 XO=XO+50:NEXT
2080 OUT&H50,0:RESUME 1020
2098 '*
2100 '***THIS SECTION INPUTS CONSTANT VALUES FOR CALCULATION OF CAPACITIES & DEMANDS
2110 PRINT"~C6THE MAXIMUM NUMBER OF NODES MEMORY WILL   ALLOW IS 60."
```

```
2280 RETURN
2299 '*
2300 '***THIS SUBROUTINE ALLOWS FOR THE MANUAL CHANGING OF A SPECIFIC ARC LENGTH
2310 PRINT CHR$(12);"~2";
2320 LINE INPUT"~C7DO YOU WANT TO CHANGE A SPECIFIC   ARC LENGTH~C5~1?~2~C7  Yes=Y or No=N  ~J~C5";Z$
2330 IF LEFT$(Z$,1)<>"Y" THEN 2420 ELSE PRINT CHR$(12);
2340 S=0:INPUT"~C7ENTER THE START NODE #~C5";S:PRINT
2350 T=0:INPUT"~C7ENTER THE FINISH NODE #~C5";T
2360 IF S<1 OR S>NN(0) OR T<1 OR T>NN(0) THEN PRINT CHR$(12);"~C4~1ERROR ON INPUT~2~C7":GOTO 2300
2370 PRINT CHR$(12);"~C7THE PRESENT ~C4~1ONEWAY~2~C7 LENGTH OF THE   ARC FROM NODE#~C3";S;"~C7TO NODE#~C3";T;"~C7IS:  ~C4";DX(S,T)
2380 PRINT"~C6ENTER THE NEW DISTANCE."
2390 INPUT"~C7A Carriage Return ALONE RESULTS IN NO CHANGE.~1~C5";DX(S,T)
2400 NN(13)=0
2410 GOTO 2300
2420 RETURN
2499 '*
2500 '***THIS SUBROUTINE SAVES THE DATA INPUT
2510 PRINT "THIS IS THE FILE SAVE ROUTINE.":PRINT
2520 PRINT "TO SAVE DATA TYPE ~C5''~1STOP~2''~C7 THEN        ~C6RETURN.~C4~J  ";
2530 LINE INPUT Z$:IF Z$ <> "STOP" THEN 2620
2540 PRINT CHR$(27);"GA0"="~K~H0,1005110,";CHR$(12);
2549 '*
2550 '***THIS SUBSECTION SAVES DATA WITHOUT PROMPTING THE USER
2560 IF NN(7) THEN 2570 ELSE 2580
2570 DOS"ARYSAVE "+A$+"SR SR":DOS"ARYSAVE "+A$+"IS IS"
2580 IF NN(6) THEN 2590 ELSE 2600
2590 DOS"ARYSAVE "+A$+"SK SK"
2600 IF NN(7) OR NN(8) THEN DOS"ARYSAVE "+A$+"G G"
2610 NN(16)=MA:DOS"ARYSAVE "+A$+"NN NN"
2620 RETURN
2699 '*
2700 '***THIS SUBROUTINE RETRIEVES PREVIOUSLY SAVED DATA
2710 PRINT"~=~K";CHR$(12);
2720 DOS"REFRESH "+A$:DOS"ARYLOAD "+A$+"NN NN":KY=NN(13):MA=NN(16)
2730 ERASE NX:DIM NX(MA):DOS"ARYLOAD "+A$+"NX NX"
2740 ERASE NY:DIM NY(MA):DOS"ARYLOAD "+A$+"NY NY"
2750 IF NN(7) THEN ERASE SR,IS:DIM SR(NN(7)+1),IS(NN(7)+1):DOS"ARYLOAD "+A$+"SR SR":DOS"ARYLOAD "+A$+"IS IS" ELSE 2770
2760 PRINT"~C6";:FOR I=1 TO NN(7):CL=SR(I):GOSUB 1800:NEXT
2770 IF NN(6) THEN ERASE SK:DIM SK(NN(8)+1):DOS"ARYLOAD "+A$+"SK SK" ELSE 2780
2780 PRINT"~C1";:FOR J=1 TO NN(6):CL=SK(J):GOSUB 1800:NEXT
2790 ERASE G:DIM G(MA)
2800 IF NN(7) OR NN(6) THEN DOS"ARYLOAD "+A$+"G G"
2810 PRINT CHR$(21);
2820 HT=1:RETURN
2899 '*
4000 '***THIS SUBROUTINE COMPUTES THE LINKLIST DATA ARRAYS FROM THE D(I,J) MATRIX
4005 ERASE NS,NT,AL:DIM NS(MA+1),NT(5*MA),AL(5*MA)
4010 PRINT CHR$(27);"OA1";CHR$(12);
4015 PRINT "NOW COMPUTING LINKLIST DATA ARRAYS FOR PROBLEM:  ";A$
4020 PRINT"~C5~X002~Y002PLEASE WAIT~C7~X001~Y001~K"
4025 FOR I=1 TO N:FOR J=1 TO N
4030 IF DX(I,J)>0 THEN A=A+1:NT(A)=J:AL(A)=DX(I,J)
4035 NEXT J:NS(I+1)=A:NEXT I
4040 PRINT CHR$(12);CHR$(7);"PROBLEM ";A$;" HAS";NS(N+1);"ARCS."
4045 PRINT"~X2,~Y2,~C6NOW SAVING DATA~X1,~Y1,";
4050 DOS"ARYSAVE "+A$+"D DX":DOS"ARYSAVE "+A$+"NS NS"
4055 DOS"ARYSAVE "+A$+"NT NT":DOS"ARYSAVE "+A$+"AL AL"
4056 DOS"ARYSAVE "+A$+"A1 A1":DOS"ARYSAVE "+A$+"A2 A2"
4057 DOS"ARYSAVE "+A$+"NARC NARC":DOS"ARYSAVE "+A$+"DEG DEG"
```

```
4058 DOS"ARYSAVE "+A$+"C C"
4060 RETURN
4098 '*
4100 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE BITPAD DATA INPUT
4105 DEF FNPX(X)=FIX((X-NN(1))/NN(3)+.5)
4110 DEF FNPY(Y)=FIX((Y-NN(4))/NN(6)+.5)+100
4115 N=NN(0)
4120 PRINT CHR$(27);"OA1";CHR$(12);
4125 ERASE DX,NX,NY:DIM DX(MA,MA),NX(MA),NY(MA)
4130 IF NN(0) THEN PRINT""X2,"Y2,"C6RETRIEVING DATA"X1,"Y1,"K":DOS"ARYLOAD "+A$+"D DX" ELSE ERASE G:DIM G(MA):GOTO 4155
4135 DOS"ARYLOAD "+A$+"NX NX":DOS"ARYLOAD "+A$+"NY NY"
4140 GOSUB 2300:PRINT CHR$(12);
4145 LINE INPUT""C7DO YOU WANT TO USE THE DIGITIZER   PAD"C5"1?"2"C7  Yes=Y or No=N   ";Z$
4150 IF LEFT$(Z$,1)<>"Y" THEN 4160
4155 HT=6:PRINT CHR$(12);""C2DIGITIZER ACTIVATED"K";CHR$(7);
4160 IF NN(0) THEN OUT&H50,0:RESUME 1100 ELSE GOTO 1100
4165 PRINTCHR$(27);"OA0"K"W0,1005110,";CHR$(12);
4170 DOS"PICTURE "+A$:NN(13)=0:DOS"ARYSAVE "+A$+"NN NN"
4175 DOS"ARYSAVE "+A$+"NX NX":DOS"ARYSAVE "+A$+"NY NY"
4180 GOSUB 860:GOSUB 4000:PRINT CHR$(12);
4185 HT=1:IF TR THEN OUT&H50,0:RESUME 1020 ELSE GOTO 1000
4198 '*
4200 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE STOPPING OF PROGRAM EXECUTION
4210 PRINT CHR$(27);"OA1"K";CHR$(12);
4220 GOSUB 2500:PRINT""=";CHR$(12);:CLEAR:END
4230 OUT&H80,0:RESUME 1020
4298 '*
4300 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE INPUT OF DATA
4310 PRINT CHR$(27);"OA1";CHR$(12);:GOSUB 3000
4320 PRINT CHR$(12);""X2,"Y2,"C6SAVING DATA"X1,"Y1,"K":GOSUB 2550
4330 PRINT CHR$(12);""K"C2"1ALL DATA HAS NOW BEEN ENTERED."2"C7"
4340 HT=1:IF TR THEN OUT&H80,0:RESUME 1020 ELSE TR=1:GOTO 1000
4398 '*
4400 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE CALCULATION OF FLOW
4410 PRINT CHR$(27);"OA1"K";CHR$(12);
4420 PRINT""X2,"Y2,"C2PLEASE WAIT"X1,"Y1,";
4440 IF NN(8) THEN 4470
4450 PRINT CHR$(12);""C7YOU CAN NOT COMPUTE FLOW UNTIL THE NODES HAVE BEEN DESIGNATED.  YOU"
4455 PRINT"MUST "C5CHANGE SUPPLY/DEMAND"C7 FIRST."
4460 GOTO 4490
4470 OUT &H80,0:RESUME 4480
4480 DOS"CHAIN COMPUTE"
4490 OUT&H80,0:RESUME 1020
4498 '*
4500 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE DISPLAY OF ANALYSIS
4510 PRINT CHR$(27);"OA1";CHR$(12);
4520 IF NN(7) AND NN(8) THEN 4560
4530 PRINT""C6YOU CAN NOT DISPLAY AN ANALYSIS    UNTIL THE SUPPLY/DEMAND HAS BEEN   ENTERED."
4540 PRINT"YOU MUST "C5CHANGE SUPPLY/DEMAND"C6 FIRST."
4550 GOTO 4580
4560 OUT &H80,0:RESUME 4570
4570 DOS"CHAIN COMPUTE"
4580 OUT&H80,0:RESUME 1020
4598 '*
4600 '***THIS SECTION CONTROLS THE MENU SELECTION FOR THE RESTART FUNCTION
4610 PRINT CHR$(27);"OA1";CHR$(12);
4620 PRINT""C7#"C51"C7=''"C6COMPLETE RESTART"C7.''"
4630 PRINT""C7#"C52"C7=''"C6MAJOR RESTART"C7.''"
4640 PRINT""C7#"C53"C7=''"C6MINOR RESTART"C7.''"
```

# APPENDIX C

## PROGRAM SOLVE

```
5 '*************************************************************************
10 '*PROGRAM - SOLVE "K-MINIMUM WEIGHT SPANNING TREE PROBLEM WITH INTERACTIVE
12 '*                    GRAPHIC SOLUTIONS"
14 '*FOR DOCUMENTATION SEE SPECIAL PROJECT BY CPT ROBERT L. DAVIS
16 '*GEORGIA INSTITUTE OF TECHNOLOGY,APRIL 1982. DR L.G. CALLAHAN - ADVISOR
18 '*************************************************************************
19 '*
20 CLEAR:DEFINT A,B,C,D,F,N,M,S,O,I,J,K,L
22 DIM NN(30), AS(10,100),IN(10,100),OU(10,100),SET(5,60)
24 DIM FRM(60),CD(5),BI(5),BO(5)
25 PRINT CHR$(12);"~X2,~Y2,~C5~85";
30 PRINT"ENTER PROBLEM NAME"
35 LINE INPUT "~C5                    ";A$
40 IF LEN(A$)=0 THEN 5
41 PRINT"~U000256"
42 PRINT"~C6THE MAXIMUM NUMBER OF NODES MEMORY WILL    ALLOW IS 60"
43 PRINT"~C3HOW MANY NODES WILL BE IN PROBLEM~C4 ";A$;"~C5~J";:MA=0:INPUT MA
44 IF MA<1 OR MA>60 THEN 42 ELSE NN(16)=MA:PRINT CHR$(12);
45 PRINT"~C6 THE LIMIT OF THE NUMBER OF ARCS INCIDENT TO ONE NODE IS 20"
46 PRINT"~C3WHAT IS THE MAXIMUM IN PROBLEM~C4  ";A$;"~C5~J";:MB=0: INPUT MB
47 IF MB<1 OR MB>20 THEN 45 ELSE NN(15)=MB:PRINT"~U000256"
48 PRINT"~C6 THE LIMIT ON THE TOTAL NUMBER OF ARCS IS 1200"
49 PRINT"~C3HOW MANY ARCS ARE IN PROBLEM~C4  ";A$;"~C5~J";:MC=0: INPUT MC
50 IF MC<0 OR MC>1200 THEN 48 ELSE NN(21)=MC
75 '*** THIS SECTION RETRIEVES THE NETWORK AND DATA
80 PRINT"~=~K";CHR$(12);
85 DOS"REFRESH "+A$:DOS"ARYLOAD "+A$+"NN NN":KY=NN(13)
90 DIM NX(MA):DOS"ARYLOAD "+A$+"NX NX"
95 DIM NY(MA):DOS"ARYLOAD "+A$+"NY NY"
100 DIM A1(MC+1),A2(MC+1):DOS"ARYLOAD "+A$+"A1 A1":DOS"ARYLOAD "+A$+"A2 A2"
105 DIM DEG(MB+1),NARC((MA+1),(MB+1))
110 DOS"ARYLOAD "+A$+"DEG DEG":DOS"ARYLOAD "+A$+"NARC NARC"
115 DIM C(MC+1):DOS"ARYLOAD "+A$+"C C"
120 GOSUB 6000
130 END
5180 '*
6000 '***THIS SUBROUTINE SOLVES THE K MINIMUM WEIGHT SPANNING TREES
6001 '------------------------------------------------------------
6010 '*
6020 '------------------------------------------------------------------------
6030 '                    VARIABLES
6032 'AS(K,J)= 1 IF ARC J IS AN ELEMENT OF THE KTH TREE; 0 OTHERWISE
6034 'A1(J)= NODE 1 OF ARC J
6036 'A2(J)=NODE 2 OF ARC J
6038 'C(J)= COST OF ARC J
6040 'IN(K,J)= 1 IF ARC J MUST BE A MEMBER OF THE KTH TREE; 0 OTHERWISE
6042 'OU(K,J)= 1 IF ARC J CANNOT BE A MEMBER OF THE KTH TREE; 0 OTHERWISE
6044 'SET(K,I)= 1 IF NODE I IS CONNECTED TO THE KTH TREE; 0 OTHERWISE
6046 'DEG(I)= DEGREE OF NODE I
6048 'NARC(I,J)= DESIGNATION OF THE JTH ARC CONNECTING NODE I
6050 'N= NUMBER OF NODES
6052 'M= NUMBER OF ARCS
6054 'K= KTH TREE
6056 'KTH= THE HIGHEST NUMBER KTH TREE
6058 'KMAX= NUMBER OF MINIMUM WEIGHT TREES DESIRED
6060 'CD(K)= MINIMUM WEIGHT REPLACEMENT FOR THE KTH TREE
6062 'BI(K)= BEST INCOMING REPLACEMENT FOR THE KTH TREE
6064 'BO(K)= BEST OUTGOING REPLACEMENT FOR THE KTH TREE
6066 '*
```

```
6067 '-----------------------------------------------------------------------
6068 '*
6070 M=NN(21):N=NN(16)
6072 PRINT CHR$(12);
6075 PRINT"~C5HOW MANY MINIMUM WEIGHT TREES WOULD YOU LIKE TO SEE? (5 OR LESS)";:MD=0:INPUT MD
6080 IF MD<1 OR MD>5 THEN 6075 ELSE KM=MD
6115 FOR K=1 TO KM
6120 FOR J=1 TO M: IN(K,J)=0: OU(K,J)=0
6125 NEXT J
6130 NEXT K
6135 K=1:KTH=1:MEAS=0:SPT=0:GOSUB 6500
6137 IF KM=1 THEN 6890 ELSE GOSUB 6600
6140 MI=888
6145 FOR I=1 TO KTH
6150 IF CD(I)<MI THEN MI=CD(I):TEMP=I:NEXT
6155 KTH=KTH+1
6160 FOR J=1 TO M:IN(KTH,J)=IN(TEMP,J):OU(KTH,J)=OU(TEMP,J):AS(KTH,J)=AS(TEMP,J):NEXT
6165 OU(KTH,BO(TEMP))=1:AS(KTH,BO(TEMP))=0:IN(TEMP,BO(TEMP))=1:AS(KTH,BI(TEMP))=1
6170 PRINT"~C2  THE KTH MINIMUM WEIGHT SPANNING TREE FOR K= ";KTH
6175 PRINT"    -----------------------------------------------------"
6180 PRINT"     "
6185 PRINT"   SP ARC    NODE#1    NODE#2    COST    ARC #"
6195 PRINT"   ------    ------    ------    ----    -----"
6200 PRINT"     "
6205 I=0:CO=0
6210 FOR J=1 TO M
6215 IF AS(KTH,J)=1 THEN I=I+1:CO=CO+C(J) ELSE 6225
6220 PRINT"    ";I;"    ";A1(J);"    ";A2(J);"    ";C(J);"    ";J
6225 NEXT J
6230 PRINT"~C4 THE COST OF THIS SPANNING TREE IS  ~C1";CO
6235 IF KTH=KM THEN 6245
6236 K=TEMP:GOSUB 6600
6240 K=KTH:GOSUB 6600
6242 GOTO 6140
6245 PRINT"SUMMARY"
6450 RETURN
6498 '*
6500 'THIS SUBSECTION SOLVES THE MINIMUM WEIGHT SPANNING TREE
6501 '-----------------------------------------------------
6510 K=1:FOR I=1 TO N
6520 SET(K,I)=0
6530 NEXT I
6532 AR=0:FOR J=1 TO M
6534 AS(K,J)=0
6536 NEXT J
6540 SET(K,1)=1
6550 CM=888
6560 NEXARC=0:FOR I=1 TO N
6570 IF SET(K,I)=1 THEN 6580 ELSE 6640
6580 FOR IL=1 TO DEG(I)
6590 SPT=SPT+1:A=NARC(I,IL)
6600 IF (SET(K,A1(A))+SET(K,A2(A)))=1 THEN SPT=SPT+1 ELSE 6630
6610 IF C(A)<CM THEN CM=C(A):NEXARC=A ELSE 6630
6620 IF CM=1 THEN GOTO 6650
6630 NEXT IL
6640 NEXT I
6650 AS(K,NEXARC)=1
6660 SET(K,A1(NEXARC))=1:SET(K,A2(NEXARC))=1:AR=AR+1
```

```
6700 PRINT"     "
6710 PRINT"   SP ARC    NODE#1    NODE#2    COST    ARC#"
6720 PRINT"   ------    ------    ------    ----    ----"
6730 PRINT"     "
6740 I=0:CO=0: FOR J=1 TO M
6750 IF AS(K,J)=1 THEN I=I+1:CO=CO+C(J) ELSE 6770
6760 PRINT"     ";I;"     ";A1(J);"     ";A2(J);"     ";C(J);"     ";J
6770 NEXT J
6780 PRINT"~C4THE COST OF THE SPANNING TREE IS ~C1";CO
6790 RETURN
6798 '*
6800 'THIS SUBSECTION COMPUTES THE BEST ARC EXCHANGE
6801 '-----------------------------------------------
6805 MW=999
6810 FOR J=1 TO M
6815 IF AS(K,J)=0 THEN IF OU(K,J)=0 THEN 6820 ELSE 6862 ELSE 6862
6820 FOR I=1 TO N: FRM(I)=0:NEXT
6825 H1=A1(J):H2=A2(J):FRM(H2)=H1
6830 FOR I=1 TO N
6835 IF FRM(I)<>0 THEN 6840 ELSE 6880
6840 FOR L=1 TO DEG(I): ARC=NARC(I,L)
6845 IF AS(K,ARC)=1 THEN 6848 ELSE 6875
6848 IF FRM(A1(ARC))>0 THEN IF FRM(A2(ARC))>0 THEN 6875
6850 IF A1(ARC)=I THEN 6855 ELSE 6860
6855 MEAS=MEAS+2:FRM(A2(ARC))=I: GOTO 6865
6860 MEAS=MEAS+2:FRM(A1(ARC))=I
6865 IF A1(ARC)=H1 THEN 6890
6870 IF A2(ARC)=H1 THEN 6890
6875 NEXT L
6880 NEXT I
6885 GOTO 6830
6890 DI=C(J)-C(ARC)
6895 IF IN(K,ARC)=0 THEN IF DI<MW THEN MW=DI:CI=J:CT=ARC ELSE 6905 ELSE 6905
6900 IF MW=0 THEN 6965
6905 IF A1(ARC)=H1 THEN K1=A1(ARC) ELSE K1=A2(ARC)
6910 K2=FRM(K1):K1=K2
6915 FOR I=1 TO DEG(K1): TEMP=NARC(K1,I)
6920 IF AS(K,TEMP)=1 THEN MEAS=MEAS+1 ELSE 6960
6925 IF A1(TEMP)=FRM(K1) THEN IF A2(TEMP)=K1 THEN 6935
6930 IF A2(TEMP)=FRM(K1) THEN IF A1(TEMP)=K1 THEN 6935 ELSE 6960 ELSE 6960
6935 DI=C(J)-C(TEMP)
6940 IF IN(K,TEMP)=0 THEN IF DI<MW THEN 6945 ELSE 6955 ELSE 6955
6945 MEAS=MEAS+1:MW=DI:CI=J:CT=TEMP
6950 IF MW=0 THEN 6965
6955 IF FRM(K1)=H2 THEN 6962 ELSE 6910
6960 NEXT I
6962 NEXT J
6965 CO=0
6970 FOR J2=1 TO M
6975 IF AS(K,J2)=1 THEN CO=CO+C(J2)
6980 NEXT J2
6985 CD(K)=MW+CO:BI(K)=CI:BO(K)=CT
6986 PRINT"~C6 CD= ";CD(K);" BI= ";BI(K);" BO= ";BO(K);"~C1"
6987 PRINT "KTH=  ";KTH;" TEMP=  ";TEMP
```

# APPENDIX D

## POWER PLANT AND POWER LINE TEAMS

Appendix D-1

g. Team HG, Power Plan Operation and Maintenance

(1) Capabilities. Operates and maintains installed electrical power plants of at least 900 KW capacity, of up to 3 generators having combined capacity of 900 to 7,500 KW capacity.

(2) Basis of Allocation. One per electric power generating plant of 900 to 7,500 KW capacity.

(3) Mobility.

(a) This unit is authorized by TOE 16 personnel and approximately 1,900 pounds (100 cubic feet) of equipment requiring transportation. Non-equipment and supplies constitute approximately 1,200 pounds (50 cubic feet).

(b) On a move to a new location using one lift by organic assets, the unit can move approximately two personnel and 1,500 pounds (150 cubic feet)1/ of equipment and supplies.

TOE 05-530H6 — TABLE OF ORGANIZATION AND EQUIPMENT — TOE 05-530H6

CHANGE 06 — SECTION II: PERSONNEL ALLOWANCES — CHANGE 06

[illegible]

| INDEX | | DESCRIPTION | CHANGE NUMBER | [illegible] | [illegible] | [illegible] | STRENGTH LEVELS | | | | | | [illegible] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | | | | | | 1 | 2 | 3 | A | B | C | 1 | 2 | 3 |
| a | b | c | | d | e | f | g | h | i | j | k | l | m | n | o |
| | | SRC 05530H6NG | | | | | | | | | | | | | |
| | | PWR PLANT OP/MAINT TEAM | | | | | | | | | | | | | |
| 01 | 02 | POWERPLANT OP | 04 | E-6 | 52F30 | | 3 | | | | | | | | |
| | 03 | EXTERIOR ELEC | 03 | E-5 | 51R20 | NC | 1 | | | | | | | | |
| | 04 | POWERPLANT OP | 03 | E-5 | 52E20 | | 1 | | | | | | | | |
| | 05 | PWR GEN & WHEEL MECH | 03 | E-5 | 63B20 | NC | 2 | | | | | | | | |
| | 06 | POWERPLANT OP | 04 | E-5 | 52E20 | | 4 | | | | | | | | |
| | 07 | DELETE | 03 | | | | | | | | | | | | |
| | 08 | PWR GEN & WHEEL MECH | 03 | E-4 | 63B10 | | 2 | | | | | | | | |
| | 09 | DELETE | 03 | | | | | | | | | | | | |
| | 10 | DELETE | 04 | | | | | | | | | | | | |
| | 11 | PWR GEN & WHEEL MECH | 03 | E-3 | 63B10 | | 2 | | | | | | | | |
| | | PARA TOTAL | | | | | 16 | | | | | | | | |
| | | SRC TOTAL | | | | | 16 | | | | | | | | |

| [illegible] | LIN | ERC | DESCRIPTION | CHANGE NUMBER | EQUIPMENT LEVEL 1 | 2 | 3 | 4 | 5 | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| a | b | | c | | d | e | f | g | h | i |
| | | | SRC 05530HNA6 | | | | | | | |
| | | | PWR PLANT OP/MAINT TEAM | | | | | | | |
| 06 | [illegible] | B | MASK CBR: PROTECTIVE FIELD | 02 | 16 | | | | | |
| | [illegible] | B | MULTIMETER: AN/USM-223 | 02 | 3 | | | | | |
| | [illegible] | A | RADIACMETER: IM-93/UD | 02 | 1 | | | | | |
| | [illegible] | B | RADIACMETER: IM-174/PD | 02 | 1 | | | | | |
| | [illegible] | B | RIFLE 5.56 MILLIMETER: M/E | 02 | 16 | | | | | |
| | [illegible] | B | SERVICE KIT-POWER PLANT MAINTENCE: OPRTG MAINTENANCE TEAM OAMF | 02 | 1 | | | | | |
| | [illegible] | B | TOOL KIT MECHANICS: LIGHT WEIGHT | 02 | 6 | | | | | 212 |
| | [illegible] | B | TOOL KIT CARPENTERS: ENGINEER PLATOON W/CHEST | 02 | 1 | | | | | |
| | [illegible] | B | TOOL KIT ELECTRICIANS: SET NO 1 | 02 | 3 | | | | | 213 |
| | [illegible] | B | TORCH OUTFIT CUTTING AND WELDING: SET 2 | 02 | 1 | | | | | |
| | [illegible] | B | TRUCK CARGO: TACTICAL 1-1/4 TON 4X2 W/E | 02 | 1 | | | | | |

Appendix D-2

i. <u>Team HI, Power Line</u>

(1) Capabilities. Installs and maintains up to 60 miles of high voltage electrical power lines.

(2) Basis of Allocation. One per two electric power generating plants of 900 to 7,500 KW capacity. Normally attached to an Engineer Facilities Engineer Group, TOE 5-203.

(3) Mobility.

(a) This unit is authorized by TOE 14 personnel and approximatley 7,200 pounds (950 cubic feet) of equipment requiring transportation. Non-TOE equipment and supplies constitute approximately 1,000 pounds (50 cubic feet).

(b) On a move to a new location using one lift by organic assets, the unit can move approximately 14 personnel and 7,540 pounds (730 cubic feet)1/ of equipment and supplies.

TOE 05-530H6 TABLE OF ORGANIZATION AND EQUIPMENT TOE 05-530H6

CHANGE 06 SECTION II: PERSONNEL ALLOWANCES CHANGE 06

| Index Para | Index Line | Description | Change Number | Grade | MOS | Branch | Strength 1 | Strength 2 | Strength 3 | Alt A | Alt B | Cadre C | Remarks 1 | Remarks 2 | Remarks 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a | b | c | | d | e | f | g | h | i | j | k | l | m | n | o |
| | | SRC 05530H6HI- | | | | | | | | | | | | | |
| | | POWER LINE TEAM | | | | | | | | | | | | | |
| 01 | 02 | ELEC TM CH | 03 | E-6 | 51R30 | NC | [illegible] | | | | | | | | |
| | 03 | DELETE | 03 | | | | - | | | | | | | | |
| 02 | 04 | EXTERIOR ELEC | 03 | E-5 | 51R20 | NC | 3 | | | | | | 02 | | |
| | 05 | EXTERIOR ELEC | 03 | E-4 | 51R10 | | 3 | | | | | | 02 | | |
| | 06 | EXTERIOR ELEC | 03 | E-3 | 51R10 | | 6 | | | | | | | | |
| | | | PARA TOTAL | | | | 14 | | | | | | | | |
| | | | SRC TOTAL | | | | 14 | | | | | | | | |

| PARA | LINE ITEM | ERC | DESCRIPTION | CHANGE NUMBER | EQUIPMENT LEVEL | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 | 2 | 3 | CAD A | TYPE B | |
| a | b | | c | | d | e | f | g | h | i |
| | | | SRC 05530HOH1 | | | | | | | |
| | | | POWER LINE TEAM | | | | | | | |
| 01 | [illegible] | B | CHARGER RADIAC DETECTOR: PP-1578/PD | 02 | 1 | | | | | |
| | [illegible] | B | MASK CBR: PROTECTIVE FIELD | 02 | 14 | | | | | |
| | [illegible] | B | MULTIMETER: AN/USM-223 | 02 | 3 | | | | | |
| | [illegible] | B | RADIACMETER: IM-93/UD | 02 | 2 | | | | | |
| | [illegible] | B | RADIACMETER: IM-174/PD | 02 | 1 | | | | | |
| | [illegible] | A | RIFLE 5.56 MILLIMETER: W/E | 02 | 14 | | | | | |
| | [illegible] | B | SERVICE KIT POWER LINE MAINTENANCE: TRANSMISSION LINE TEAM OSHE | 02 | 1 | | | | | |
| | [illegible] | A | TRUCK MAINTENANCE: TELEPHONE/UTILITY CONST 36000GVW 6X4 W/WN W/E | 04 | 1 | | | | | |
| 01 | W44248 | B | TOOL KIT LINEMANS: RAILWAY SET NO 1 | 02 | 12 | | | | | |
| | W60952 | B | TOOL SET ELECTRIC POWER TRANSMISSION COMPANY: RAILWAY MAINT | 02 | 1 | | | | | |
| | W95263 | B | TRAILER CABLE REEL: 3-1/2 TON 2 WHEEL W/E | 02 | 1 | | | | | |
| | W95811 | B | TRAILER CARGO: 1-1/2 TON 2 WHEEL W/E | 02 | 1 | | | | | |
| | X39429 | B | TRUCK CARGO: TACTICAL 1-1/4 TON 4X2 W/E | 02 | 2 | | | | | |
| | X39735 | | DELETED | 01 | | | | | | |
| | X40009 | A | TRUCK CARGO: 2-1/2 TON 6X6 W/E | 02 | 1 | | | | | |
| | X53903 | | DELETED | 04 | | | | | | |
| | Y14309 | B | VOLTMETER: PTBL AC CIRCUIT TEST | 02 | 1 | | | | | |

# BIBLIOGRAPHY

# BIBLIOGRAPHY


1. Anderson, M. J., "A Prototype Decision Support System for the Location of Military Water Points," Masters Thesis, Georgia Institute of Technology, Atlanta, GA, (1980).

2. Bazaraa, Mokhtar and John J. Jarvis, Linear Programming and Network Flow, John Wiley andSons, 1977.

3 Beale, E. M. L., Editor, Applications of Mathematical Programming Techniques, The English Universities Press LTD, St. Paul's House, Warlick Lane, London E.C. 4, 1971.

4. Bit Pad One User's Manual, Summagraphics Corporation, Manual #64, 35 Brentwood Avenue, Fairfield, Connecticut, 06430, with Revision A, August 30, 1979.

5. Changes Made from CG BASIC Version 1.0 to CG FILE HANDLING BASIC Version 3.0, Chromatics, Inc., 3923 Oakcliff Industrial Court, Atlanta, Georgia 30340, 1979.

6. Christofides, Nicos, Graph Theory, An Algorithmic Approach, Academic Press, Inc., 1975.

7. Chromatics CG BASIC Reference Manual, Chromatics, Inc., 3923 Oakcliff Industrial Court, Atlanta, Georgia 30340, 1978.

8. Department of the Army, Army FAcilities Components Systems - Designs, TM 5-302-2, September 1973.

9. Department of the Army, Division 86 Final Report (ACN 36801) October 1981.

10. Department of the Army, Electrical Design - Electric Power Supply and Distribution, TM 5-411, 1965.

11. Department of the Army, Electrical Facilities Exterior Lighting, Repairs and Utilities, TM 5-680E, December 1947.

12. Department of the Army, Electrical Facilities, Generating Plants, Repairs and Utilities, TM 5-680-G, April 1947.

13. Department of the Army, Electric~l Power Generation Distribution, (EGAD), Volume IV, December, 1975.

14. Department of the Army, Electrical Power Transmission and Distribution, TM 5-765, June 1970.

15. Department of the Army, Electric Power Generation in the Field, TM 5-766, September, 1972.

16. Department of the Army, Electric Power Supply and Distribution, TM 5-811-1, July 1965.

17. Department of the Army, Outside Utilities for Emergency Construction, Electric Power Supply and Distribution, TM 5-884-1, January 1963.

18. Department of the Army, Overhead Distribution Systems, TM 5-780-C, September, 1963.

19. Dial, R., F. Glover, D. Karney, and D. Klingman, "A Computational Analysis of Alternative Algorithms and Labeling Techniques for Finding Shortest Path Trees," Research Report CCS 291, Center for Cybernetic Studies, University of Texas at Austin, 1977.

20. Dearing, P. M., R. L. Francis, and T. J. Lowe, "Convex Location Problems on Tree Networks," Operations Research, Vol. 24, No. 4, pp. 628-642, July-August, 1976.

21. Disk Software Reference Manual CG 1999, Chromatics Inc., 3923 Oakcliff Industrial Court, Atlanta, Georgia 30340, 1978.

22. Elam, Joyer, D. Klingman and J. Mulvey, "An Evaluation of Mathematical Programming and Minicomputers," European Journal of Operation Research, Vol. 3, No. 1, pp. 30-39, 1979.

23. Gabow, Harold N., "Two Algorithms for Generating Weighted Spanning Trees in Order," SIAM Journal on Computing, Vol. 6, No. 1, March 1977.

24. Geffrion, A. M., "A Guide to Computer-Assisted Methods for Distribution Systems Planning," Sloan Management Review, Vol. 16, pp. 17-42, 1975.

25. Glover, Fred and Darwin Klingman, "Real World Applications of Network Related Problems and Breakthroughs in Solving Them Efficiently," ACM Transactions on Mathematical Software, Vol. 1, No. 1, pp. 47-55, March, 1975.

26. Handler, G. K. and P. B. Mirchandini, Location on Networks, Theory and Algorithms, The MIT Press, 1979.

27. Keen, Peter G. W. and Michael S. Scott Morton, Decision Support Systems: An Organizational Perspective, Addison-Wesley Publishing Company, 1978.

28. McGinnis, Leon F., "A Survey of Recent Results for a Class of Facilities Location Problems," AIIE Transactions, Vol. 9, pp. 11-18, 1977.

29. Moder, J. J., and S. E. Elmaghraby Editors, Handbook of Operations Research, Van Nostrand Reinold Company, 1978.

30. Pierce, A. R., "Bibliography on Algorithms for Shortest Path, Shortest Spanning Tree, and Related Circuit Routing Problems (1956-1974)," Networks, Vol 5, pp. 129-143.

31. Preliminary Operators Manual CG 1999, Chromatics, Inc., 3923 Oakcliff Industrial Court, Atlanta, Gerogia 30340, Revised November 1978.

32. Proctor, E. K., E. C. Wood, R. D. Williams, Power Generation and Support Systems, Standford Research Institute, October 1970.

33. Wendell, Richard E. and Arthur P. Hunter, Jr., "Optimal Locations on a Network," Transportation Science, Vol. 7, No. 1, pp. 18-33, February 1973.

## DISTRIBUTION

| Addressee | No. Copies |
|---|---|
| Dr. L. G. Callahan, Jr.<br>School of Industrial & Systems Engineering<br>Georgia Institute of Technology<br>Atlanta, GA 30332 | 10 |
| DRSMI-RDF, Mr. Hallum | 1 |
| DRSMI-LP, Mr. Voigt | 1 |
| DRSMI-RPR | 15 |
| DRSMI-RPT, Record Copy | 1 |

END

FILMED

3-83

DTIC