# NATIONAL BUREAU OF STANDARDS REPORT

10 093

## A COMPUTER MODEL FOR THE EVALUATION OF FIRE STATION LOCATION

in East Lansing

[illegible] & Berlin

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

# NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards [1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

**THE INSTITUTE FOR BASIC STANDARDS** provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

> Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics [2]—Radio Engineering [2]—Time and Frequency [2]—Astrophysics [2]—Cryogenics.[2]

**THE INSTITUTE FOR MATERIALS RESEARCH** conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

> Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Physical Chemistry.

**THE INSTITUTE FOR APPLIED TECHNOLOGY** provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

> Engineering Standards—Weights and Measures — Invention and Innovation — Vehicle Systems Research—Product Evaluation—Building Research—Instrument Shops—Measurement Engineering—Electronic Technology—Technical Analysis.

**THE CENTER FOR RADIATION RESEARCH** engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center consists of the following divisions:

> Reactor Radiation—Linac Radiation—Nuclear Radiation—Applied Radiation.

**THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY** conducts research and provides technical services designed to aid Government agencies in the selection, acquisition, and effective use of automatic data processing equipment; and serves as the principal focus for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

> Information Processing Standards—Computer Information — Computer Services — Systems Development—Information Processing Technology.

**THE OFFICE FOR INFORMATION PROGRAMS** promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

> Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information [3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

# NATIONAL BUREAU OF STANDARDS REPORT

**NBS PROJECT** 4314121

August 1969

**NBS REPORT** 10 093

## A COMPUTER MODEL FOR THE EVALUATION OF FIRE STATION LOCATION

Louis C. Santone and Geoffrey N. Berlin

Technical Analysis Division



NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

## Acknowledgment

We would like to express our appreciation to John McGrath, Sharon Rose, and Neil Gallagher of the National Bureau of Standards for their technical assistance and to John Patriarche, William Costick, Michael Conlisk, and Phil Patriarche in East Lansing for their effort in developing and implementing the computer model.

# ABSTRACT

Increasing awareness of the applicability of systems analysis to urban problems results in a program to develop concepts which are relevant to locational problems in various urban areas. The goal of this project is the development of a model to provide the urban decision maker with quantitative information regarding alternative choices in determining public service facility locations. In the case of fire station location, this model evaluates possible location sites by testing sensitivity to demographic and structural developments in the area served by the facilities.

# A Computer Model for Evaluating Fire Station Location

# A Computer Model for Evaluating Fire Station Location

## I. Summary

In January 1968, the International City Managers' Association (ICMA) sponsored a symposium to discuss the application of systems analysis to the resolution of urban problems. The symposium generated interest in a program to evaluate the applicability of systems analysis to specific problems. Program sponsorship was under the auspices of the ICMA, the American Society of Planning Officials, the Fels Institute of Local and State Government of the University of Pennsylvania, and the Technical Analysis Division of the National Bureau of Standards.

This report is addressed to one project done within the constraints of the program. This project provided a means for analyzing the location of public service facilities. East Lansing, Michigan, was selected as the participant city for study and the Technical Analysis Division was designated to serve as "technical coach" for the work to be done. The goal of the project was to generate information that could be used by the urban decision maker in the process of locating fire stations according to present and future protection requirements of the city.

In the case study work done for East Lansing, the specific objectives were defined as:

- to evaluate fire protection needs of the city in the static situation of the present environment and to determine the optimal number and location of fire stations requisite to meet these needs;

- to determine the protection needs of the city as of a future date (1980) and to ensure that fire stations which are adequate today will continue to meet the protection requirements of the changing environment.

The city staff of East Lansing and TAD analysts cooperated in the development of a simulation model to accomplish these objectives. In the process, it was demonstrated that systems analysis can be applied to a city problem at a reasonable cost and that the analysis can be performed by the city staff. It is hoped that city staffs in other regions of the country who face similar public service facility location problems will be able to utilize this model with little modification.

As a result of the work done in East Lansing, the coverage area of a fire station, located on the Michigan State University campus, is being expanded; a second station is being relocated north of the central business district; and a new station will be constructed in the Southeast Section of the city (see figure 3). It was determined that these three fire stations will afford adequate protection for the changing city, now and during the coming decade.

The procedure in East Lansing consisted of analyzing trial locations known to be reasonable, based on land availability, land cost, and citizen consent. A systematic analysis of the results met the prime objectives of the study.

## II. THE MODEL

The model is designed to evaluate the effectiveness of an existing or trial station location. Mathematically, the model is structured around a shortest-path algorithm, which calculates response time, and a "weighting function," which quantifies or measures the fire hazard of each structure. The various members of the Project Team agreed that response time and fire hazard are the two most relevant factors in determining station location.

The present criteria for locating fire stations are determined by the American Insurance Association. The distance criterion establishes maximum limits in terms of travel distance to either high value or residential areas.[1/] This distance criterion is most applicable to those cities where high value construction is in the central business district surrounded by a symmetric development of residential homes.

This is an unrealistic view of the structural and demographic characteristics of cities today. Also, present transportation systems do not lend themselves to a simple correlation between distance and time. That is to say, a one-mile drive on an expressway obviously requires less travel time than a one-mile drive in a central business district. There is need for the criteria to be sensitive to today's environmental conditions.

---

[1/] "The Grading of Municipal Fire Protection Facilities," The National League of Cities.

## A. Shortest-Path Algorithm

To utilize the shortest-path algorithm, first it is necessary to develop an adequate representation of the street network (that configuration of streets comprising the given urban area). The network is represented by a uniquely numbered series of nodes and links. A node indicates each street intersection worthy of representation, i.e., it is not necessary to represent small street intersections. A link represents the distance and travel time between each pair of nodes.

In many parts of the country, the city, county, or state highway department has coded the street network for present and future years. This representation is usually prepared according to a Bureau of Public Roads format. The data listed include distance between intersections (links between nodes), off-peak, peak, and posted speed to traverse each link, width of roadway, etc.

In the East Lansing study, the Tri-County Highway Department had coded the East Lansing street network for 1965 and 1975.

Having adequate network representation, the algorithm was used to calculate the minimum time path from one node, representing a trial fire station location, to all other nodes. The East Lansing Fire Department indicated that the travel time for their engines, between any pair of nodes, was well approximated by dividing the distance by the posted speed, and neglecting any change of speed at an intersection. However, there are two continually congested intersections in East Lansing and a half-minute of travel time was added to all trips traversing either of these intersections.

### B. The "Weighting Function"

Appraisal of the shortest-path times affords one means for evaluating potential fire station locations. However, some properties are more important than others in terms of potential damage. This variation in fire hazard is measured by a "weighting function." The "weighting function" may be defined as a heuristic function which quantifies a judgment of the East Lansing Project Team. This judgment concerns the relative significance of each of the structural and human factors as related to the hazard of a potential fire on a given property.

The rationale for such a "weighting function" is clearly seen when considering the protection requirements of an empty lot vs. a lot containing a school. Thus, the East Lansing Project Team decided that the "weighting function" should be a combination of the following factors:

- the land use type;
- the potential danger to human life; and
- the potential loss of the structure.

These factors contain a number of variables which had to be identified, their interrelationships defined, and their value quantified. The

Project Team identified the critical variables as:

1) number of persons endangered;

2) number of stories in each building;

3) construction type;

4) age of structure; and

5) square area of each floor.

The "weighting function" was devised by systematically correlating structural and demographic characteristics of all land use types with the statistical results of an analysis of the city's fire history data. The explicit physical characteristics of each structure, as well as implicit characteristics according to land use classification, were quantified as they related to the need for fire protection. The final product, (Eq. 1) provides a definite correlation between the measurable, structural and demographic characteristics and frequency of fire. The frequency of fire is the percentage of fire by occupancy type in proportion to the total number of structures of that land use type. The close correlation between the frequency of fire and the total points assessed for the various occupancy types experimentally suggests the validity of the penalty point system as a quantitative description of the fire hazard (see Chart 1). The formulation of the "weighting function" is:

$$\text{Structure} = \text{population (1)} + \text{height in stories (2)} + \text{construction type (3)} + \text{age (4)} + \text{area in square feet (5)} \qquad \text{(Eq. 1)}$$

$$\text{Weighting function} = \text{structure X occupancy type (6).} \qquad \text{(Eq. 2)}$$

Chart 1 - The Weighting Function

| LAND USE | NUMBER OF PEOPLE | HEIGHT | CONSTRUCTION TYPE | AGE | AREA | Σ | FREQUENCY | LAND USE VALUE |
|---|---|---|---|---|---|---|---|---|
| One Family | 3 | 2 → 0 | 4 | 15 → 1.5 | 800 → .8 | 8.3 | 10 | 1.0 |
| Two Family | 6 | 2 → 0 | 4 | 10 → 1.0 | 100 → 0.1 | 11.1 | 0 | 1.0 |
| Fraternity | 35 | 3 → 3 | 4 | 15 → 1.5 | 400 → 0.4 | 43.9 | 37 | 1.0 |
| Apartment | 60 | 3 → 3 | 4 | 7 → 0.7 | 500 → .5 | 68.2 | 29 1/ | 1.0 |
| Dormitory | 600 | 16 → 10 | 1 | 7 → 0.7 | 2000 → 2.0 | 613.7 | 500 | 1.0 |
| School | 400 | 2 → 0 | 1 | 10 → 1.0 | 3000 → 3.0 | 405.0 | 240 | 0.33 |
| Church | 400 | 1 → 0 | 3 | 15 → 1.5 | 3000 → 3.0 | 407.5 | 29 | 0.33 2/ |
| Commercial | 8 | 1 → 0 | 3 | 20 → 2.0 | 4000 → .4 | 13.4 | 22 | 1.0 |

Note: Structure value was not directly accounted for, but it will be indirectly express by the high density of people in the commercial area.

---

1/ Since all the apartments are new, it was felt that the data did not describe the frequency of fire that will occur in the near future.

2/ Churches are being used more as schools, and therefore, given the same land use value.

(1) Population is the number of persons who actually occupy the dwelling. Apartments and single-family dwelling units have been given an average population per household of 2.5 and 3, respectively.

(2) Height in stories has been penalized as follows: One and two stories, 0 points; three and four stories, 2 points; five and six stories, 4 points; seven and over, 10 points.

(3) Construction type of each structure is placed on a weighted scale with a range of four penalty points. The critical end of the scale is 4, and all single-family dwelling units have been assigned a "4" rating.

(4) Age of structure has been penalized as follows: 0 to 10 years, 1 point; 11 to 20 years, 2 points; 21 to 30 years, 3 points; 31 to 40 years, 4 points ...

(5) Area in square feet has been multiplied by 1/1000 in order to bring the extremely large numbers into perspective with the other weighted categories.

(6) Occupancy types, the multiplicative factor in Eq. 2, have a value of one (1.0), except for schools and churches, which have been assigned the value of one third (.333).

The link between the physical description of the city and its socio-economic description is achieved by multiplying the value of the "weighting function" for a structure by the length of time it takes an emergency vehicle to reach that structure. (See Appendix B for mathematical formulation.)

East Lansing provided the Project Team with data on all actual and potential fires within the city for the past 10 years. These records contain the node number location of each fire, the date, day of the week, hour, responding station, response distance, fire duration, number of persons endangered, cause, structure type, occupancy type, height of building, year building constructed, fire rating of structure, amount of damage to structure, amount of damage to contents, and address of structure (see Appendix A).

### C. Districting

The designation of districts, or station coverage areas, is presently a manual operation. To evaluate a trial location, it is necessary to input the coverage area for the location. Recognizing that the area of a district is reflected in the model evaluation, it is necessary to reassess the district after each effectiveness rating. In the East Lansing application, isochronal boundaries of 2 1/2 to 3 minutes were used to outline the first district for each trial location. Thus, the Project Team studied various location plans through the manipulation of districts.

### D. Assumptions

A basic assumption in this model is that all factors influencing the location of a fire station can be expressed in terms of a common utility scale. For example, in simulating the street network, probabilistic measurement of variables such as draw-bridges and railroad crossings must be expressed through the impedance value associated with the appropriate link. However, the way in which these points are introduced into the evaluation remains flexible.

Time is used as the metric for analyzing the highway network. The time associated with each link is calculated by dividing the distance in miles by the posted speed in miles per hour. The travel time to each destination is the sum of the travel times for those links comprising the shortest time path. It is assumed that any speed variation within a block or at an intersection approximates the posted speed. This assumption was validated in East Lansing by matching the computer-calculated time with the actual response times to fires.

A third assumption concerns the aggregation of the "weighting functions" for each land use to the node in the lower right-hand corner of each neighborhood. Such an aggregation is necessary to solve the problem with the existing computer hardware. It was the opinion of the East Lansing Project Team that such an aggregation did not significantly affect the sensitivity of the model.

## E. Evaluation

The effectiveness measure for each possible site is achieved by taking the product of response time and "weighting function" and summing it for all points in the district. By comparing the sum total for each trial site, a ranking of locations is obtained.

The final selection of a location site is based on several criteria:

1) a measure of effectiveness which is not significantly affected by proposed development plans;

2) a districting plan which minimizes excessive overlapping of coverage areas as additional stations are required; and

3) a satisfactory trade-off between an acceptable level of effectiveness and the financial and political constraints.

By satisfying these three conditions, the city provides both effective and efficient fire protection.

## III. THE PROGRAM

The basic input for the program is a highway network (see Appendix C) and a structural data index (see Appendix D). The network consists of nodes and links. Each node corresponds to an arbitrarily numbered intersection on a map of the city. In the central business district, every intersection is coded; while in the less densely populated residential area, every second or third intersection is coded. Each link represents a street segment between two intersections and is identified by the two nodes. The link is characterized by travel direction (one-way or two-way) posted speed, and distance.[2/] Travel time is calculated accordingly to distance and posted speed.

The form of the data is expanded by a pre-processing routine, so that each link is identified by a unique pair of ordered nodes. This ordering makes it possible for travel time in one direction to differ from travel time in the opposite direction. Since fire equipment will not normally travel against traffic, it is important to identify one-way streets. This pre-processing routine also sequentially renumbers the expanded list of links, which is necessary for the computer analysis of the network. These node numbers are referred to hereafter as the renumbered node numbers.

---

2/ Other characteristics, such as width of roadway, speed at peak and off-peak hours, etc., are available from an "Inventory Summary for Selected Streets and Highways in the Tri-County Region," prepared by the Lansing, Michigan Tri-County Planning Organization. These characteristics were not used in this analysis.

The building index is a listing of all land use classifications, i.e., buildings and vacant lots in East Lansing. Each structure is characterized by height, construction type, structural age, and square footage per floor. Each building in a neighborhood defined by the intersection of three or more links is associated with the node in the lower right-hand corner of that neighborhood. These two inputs are usually read from magnetic tape.

The data tape is created by the two programs, DATAT and STRUCT (see Appendix E). DATAT creates the network tape in a form fitted for the input requirement of program RANK. STRUCT creates the structural index file following the network information. Consequently, only one tape is used to input information. The logical unit number of the tape drive is specified by the variable TAP. The logical unit numbers of the card reader (for input) and printer (for output) are designated by the parameters R and P, respectively.

The card input which identifies trial sites and districts is divided into three sections. The first section identifies which program options are selected, sets the searching limits of the shortest-path algorithm, and initializes other boundary constraints. The second section specifies those changes in structural development being considered; and the third section identifies the coverage area for each set of trial locations.

### A. Section 1 - Parameters and Options

This section contains eleven (11) cards. The first card identifies four options:

NRUNS - the number of passes through the model;

OPT1 - optional output display of distance and time from origin to all destinations;

OPT2 - optional output listing of all nodes and the summed value of the "weighting function" associated with each node; and

FUTURE - option to consider future development.

Based on a particular highway network and structural index a single run of the program evaluates a number of origins associated with a districting plan. The variable, NRUNS, is both the number of passes through the model and the number of districts. For each node chosen as an origin, two arrays are calculated by the shortest-path algorithm. In the first array, each element is the shortest-path travel time from an origin to all other destinations. Each element in the second array gives the distance from an origin to all destinations when traveling along the least-time path. When OPT1 is triggered, the program will print the subsequent arrays for all nodes selected as trial origins (see Section 3). OPT2 is both an optional printout of two lists of nodes and the summed value of the "weighting function" associated with each node. One list is the renumbered node numbers used during the execution of the program; the second list contains the original node numbers which appear on the work map of the city. The fourth option, FUTURE, signals a decision to consider future structural developments. When this option is triggered, the program will read data concerning proposed structural development and change.

The second card in this section assigns values for three variables:

MAX - the limit on the number of links the algorithm will search to determine a shortest time path.

NNODE - the number of nodes in the network.

NLINK - the number of unique links in the network.

In the arithmetic "weighting function," land use is a multiplicative factor. The alphanumeric land use classifications are contained in the list ICODE. Presently, the program reads 64 land use classifications. The numeric values assigned with each land use type are in the list, ASSIGN, and are referenced by the same subscript as the corresponding variable name.

The final card in this section defines the parameter values for the "weighting function." These values are contained in List A.

## B. Section 2 - Future Development

This section modifies the information from the structural index tape to incorporate future structural development and change. When the option, FUTURE, is used, the analyst has the ability to exclude structures contained on the index list, and to include additional structures that will exist in the future. The program will delete any number of structures of a particular land use type from the neighborhood. At present, the program can delete four different types of structures from ten different neighborhoods. The first card in this section gives the general list of land use classifications to be removed as future development occurs. The variable name of this list is NSTR. Each of the 10 cards following this one identifies the original node number from which structures are to be removed, and the number of structures to be removed of each land use type. The variable, DETROY, identifies the list containing the nodes from which structures are to be removed. LIMIT is the list containing the number of structures to be removed.

Following the 11 cards described previously, the deck of cards containing the proposed structures completes the data (see Appendix D). Any number of cards describing future development will be read at this time. At the end of the deck, there must be End-of-File card. If future development is not to be considered in the analysis, this section of the program is omitted entirely.

## C. Section 3 - Service Districts

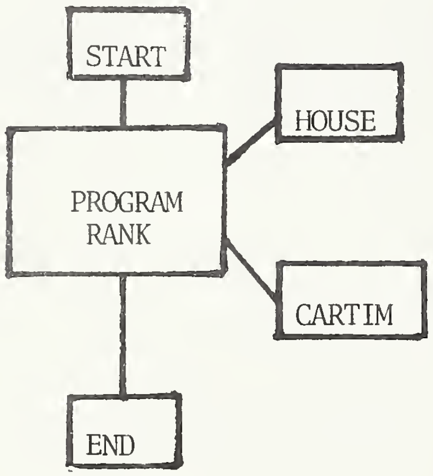
The third section is concerned with the identification of service areas. The information in this section can be repeated a number of times (NRUNS times). The first card is the title card, identifying the area under consideration. The next card concerns identification of the trial locations. The selection of nodes to be evaluated as test sites is contained in the list ICK. An option exists to printout the series of links comprising the shortest time path. The user selects any number of nodes from the subset of nodes chosen as test origins. This set of nodes is contained in the list ICHO. The program will enumerate the paths from the selected node to all other nodes in the city designated in the list IDEST. This information is useful for validating the highway network.

In this section, the first option, JSS, allows the user to select a specific area of coverage. Variations in existing equipment and manpower are reflected in the analysis by selecting districts which are proportional to available equipment and manpower. If JSS is activated, it is followed by cards designating all nodes within the service area. The list containing these selected nodes is called JSID.

When evaluating possible locations for a fire station having prime responsibility for a specific district, it may be desirable to include some fractional proportion of responsibility for protecting an area not encompassed in the home district. This option to consider secondary coverage is triggered by the variable NPOL. If this option is desired, the percentage of secondary coverage is specified by the variable POLICY. Following triggering of this variable, the nodes in the area under secondary coverage protection are enumerated in the list IPOL. If NPOL is not triggered, the run terminates.

IV. USER'S MANUAL

The model is basically a single program developed around the shortest-path algorithm. Although the program contains two subroutines (CARTIM and HOUSE), they do not perform a single unique operation; and consequently, the discussion of the model will refer to the model as one program.




The program has two types of inputs: tape and card. The tape contains the coded highway network and the existing structural index (see Appendix E). The card input initializes the parameters and identifies various model options and printout options.

The activation of an option or the selection of a node is accomplished by placing a one in the proper column. The consequences of not triggering an option is discussed at the same time as the capabilities of the option.

In the case of node selection for the lists JSID and IPOL, a node is designated by punching a one in the column corresponding to the renumbered node identification. Thus, the program sequentially reads in columns on (NNODE/80) cards. Otherwise, nodes are designated by the number appearing on the work map of the city.

The card input is divided into three sections for discussion purposes only. The "parameters and options" section identifies the program options and sets parameter values. This section contains 11 cards.

| No. of Cards | Column (or Format) | Description |
|---|---|---|
| 1 | 1-3 | NRUNS - the number of consecutive iterations of the program changing areas of coverage and/or policy decisions. |
| | 6* | IOPT1 - the option to print time and distance arrays associated with each origin. |
| | 9* | IOPT2 - the option to print a dictionary of all nodes along with the weighting function value for each node. |
| | 12* | FUTURE - the option to consider future structural development. |
| 1 | 1-5 | MAX - the maximum number of links investigated to build a path. |
| | 6-10 | NNODE - the number of nodes in the network. |

*Place a one in proper column to trigger option.

| No. of Cards | Column (or Format) | Description |
| --- | --- | --- |
| | 11-15 | NLINK - the number of links in the network. |
| | 16-17 | TAP - logical unit number of data tape. |
| | 18-19 | R - logical unit number of the card reader. |
| | 20-21 | P - logical unit number of the printer. |
| 4 | 16A4 | ICODE - the list of land use categories. |
| 4 | 16F4.2 | ASSIGN - the numerical value assigned to each land use. |
| 1 | 9F6.3 | A - the list of coefficients for the weighting function. |

The number of cards in the following two sections is a function of the choice of options activated in section I.

Section II specifies the changes in structural development that are to be considered. If there are no changes, this section is omitted. When additional structural development is to be considered (triggered by assigning FUTURE = 1), then include the following cards:

| No. of Cards | Column (or Format) | Description |
| --- | --- | --- |
| 1 | 3A4 | NSTR - a list of the land use types to be removed when future development takes place. |
| 10 | 16, 1X | DETROY - the node from which structures are to be removed (original node number). |

| No. of Cards | Column (or Format) | Description |
|---|---|---|
| | 313 | LIMIT - the number of structures of each land use type in NSTR to be removed (start column 8). |

Place future development deck of cards here, followed by an End-of-File card.

The "service districts" section identifies the set of trial origins and their respective coverage areas for each pass. The following cards are changed according to the number of passes (NRUNS) during a single run of the program.

| No. of Cards | Column (or Format) | Description |
|---|---|---|
| 1 | 12A6 | TITLE - identification of the coverage area. |
| 1 | 10(I5) | ICK - nodes chosen to be origins (original node number). |
| 1 | 10(4X, I1)* | ICHO - nodes chosen from which to enumerate paths to all destinations. |
| 1 | 10(I5) | IDEST - nodes chosen as path destinations (original node number). |
| 1 | 3* | JSS - option to consider a specific area rather than the entire city. If zero, skip to NPOL. |
| 6 | 80I1 | JSID - nodes within the specified area. |
| 1 | 3 | NPOL - option to consider an area of secondary coverage. If zero, this is the end. |
| 1 | F4.2 | POLICY - the percentage of secondary coverage. |

*Place a one in proper column to trigger option.

| No. of Cards | Column (or Format) | Description |
| --- | --- | --- |
| 6 | 8011* | IPOL - nodes considered under policy percentage of secondary coverage. |

For another pass, the next card following this section will be another title card. Of course, the subsequent cards would then follow.

The computer program has been implemented in East Lansing, Michigan. The program is written in FORTRAN IV for the CDC 3600 at MSU and FORTRAN V for the UNIVAC 1108 at NBS. Run on the CDC 3600 to evaluate a network of 432 nodes, 1400 links, and 1500 structures, the program evaluated 10 trial sites in each of three districts in approximately 3 1/2 minutes.

---

*Place a one in proper column to trigger option.

# V. LEXICON

## I. Programs

DATAT - computer program to transfer street network to the data tape.

RANK - computer program which evaluates the effectiveness of trial fire locations.

STRUCT - computer program to transfer structural and demographic information to the data tape.

## II. Single Parameters

FUTURE - the option to consider future structural development

JSS - the option to consider a specific service area.

MAX - the maximum number of links investigated by the shortest-path algorithm to build a least-time path.

NLINK - the number of unique links in the street network.

NNODE - the number of nodes in the network.

NPOL - the option to consider an area of secondary coverage.

NRUNS - the number of consecutive iterations of the program.

OPT1 - the option to print time and distance arrays.

OPT2 - the option to print a dictionary of all nodes along with the weighting function value for each node.

P - the logical unit number of the printer.

R - the logical unit number of the card reader.

TAP - the logical unit number of the data tape.

III. Lists

A - the coefficients for thw weighting function.

ASSIGN - the numerical value assigned to each land use.

DETROY - the nodes from which structures are to be removed.

ICHO - the nodes chosen from which to enumerate paths from trial origins to selected destinations.

ICK - the nodes chosen to be origins.

ICODE - the land use categories.

IDEST - the nodes selected as destinations.

IPOL - the nodes under secondary coverage.

JSID - the nodes within the specified service area.

LIMIT - the number of structures of each land use type to be removed.

NSTR - the land use types to be removed when future development takes place.

POLICY - the percentage of secondary coverage.

TITLE - the identification of the coverage area.

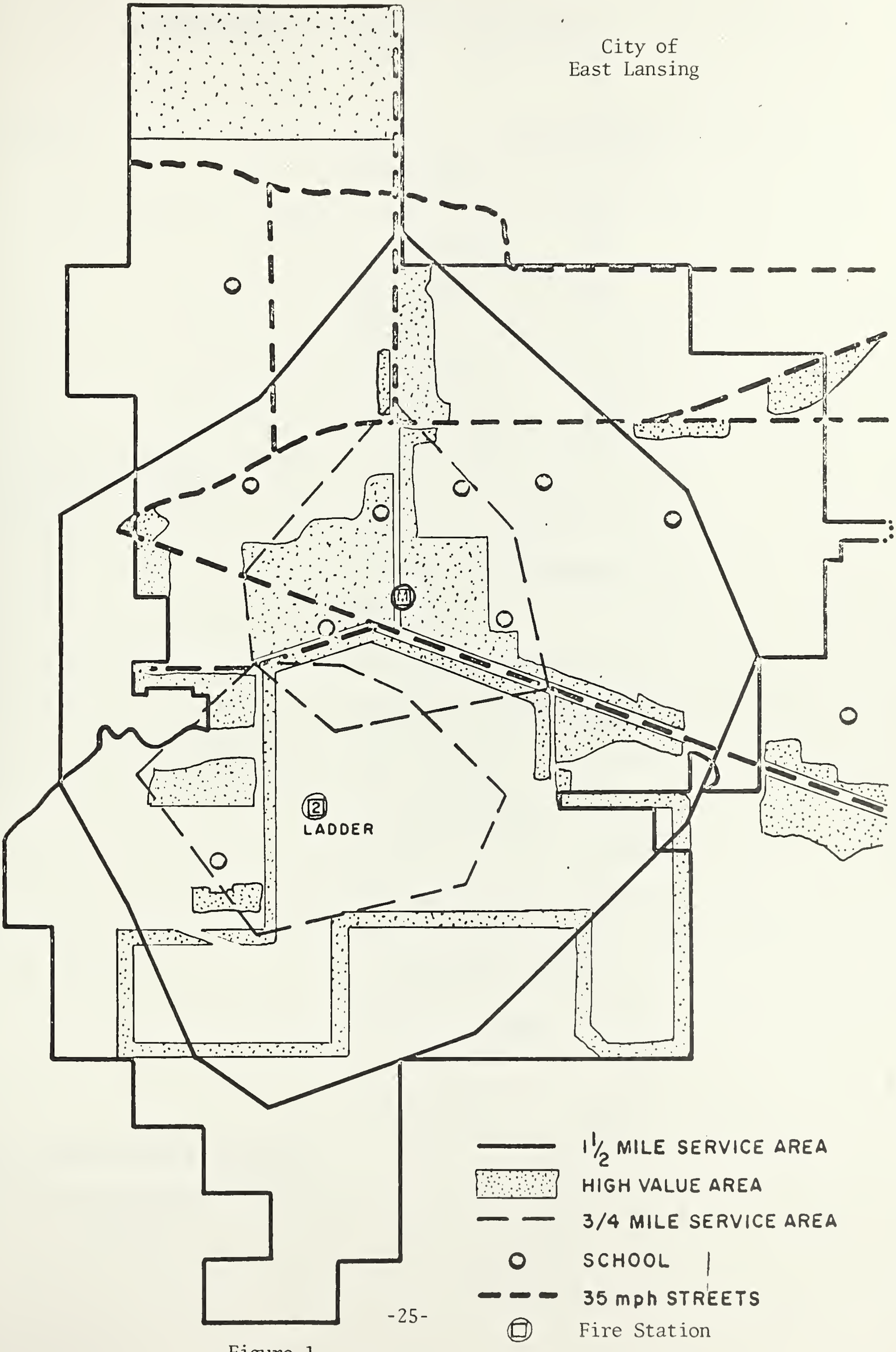

City of
East Lansing
2
LADDER
1 1/2 MILE SERVICE AREA
HIGH VALUE AREA
3/4 MILE SERVICE AREA
SCHOOL
35 mph STREETS
Fire Station

Figure 1

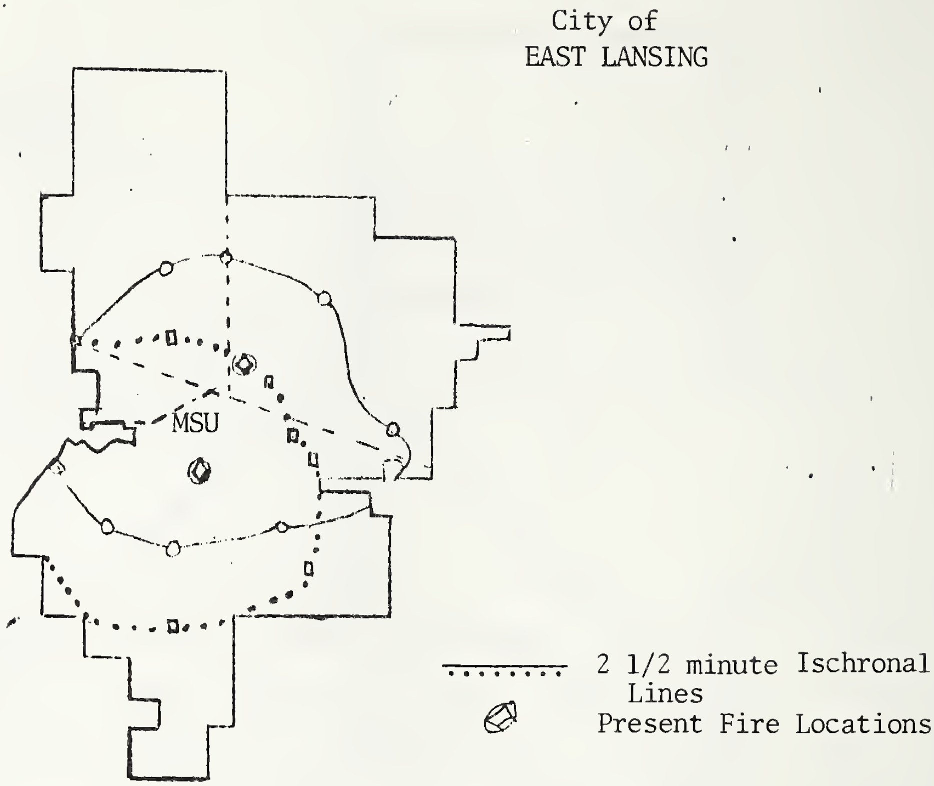



Figure 2

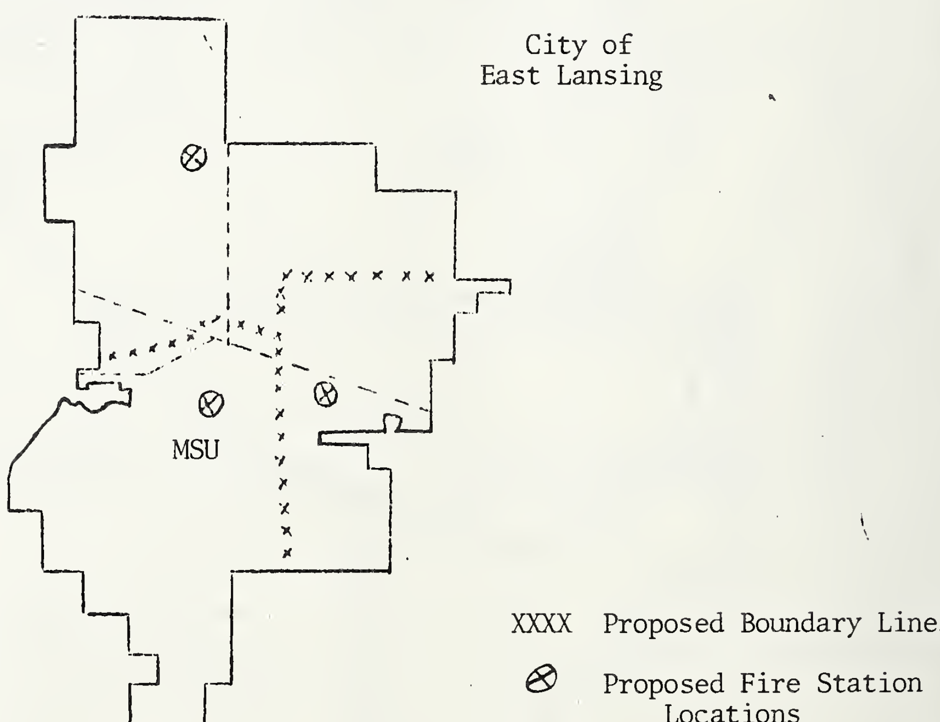





Figure 3

## Appendix A - Fire Record Code Format

| Column | Information |
|---|---|
| 2 - 5 | Node Number |
| 8 - 12 | Date (8-month; 9 & 10-day of month; 11 & 12-year) |
| 13 | Day of Week |
| 14 | Hour (nearest) |
| 15 | a.m. or p.m. |
| 17 | Station first responding |
| 19 - 20 | Distance in 10ths of a mile |
| 23 - 25 | Duration of fire in minutes |
| 27 - 30 | Number of persons endangered |
| 32 | Cause |
| 34 - 35 | Structure occupancy type |
| 39 - 40 | Height of building (number of stories) |
| 42 - 43 | Year building constructed |
| 45 | Fire rating of structure |
| 49 - 55 | Amount of damage to structure |
| 59 - 65 | Amount of damage to contents |
| 73 - 80 | Address (73-77 structure number; 78-80 street code) |

## Appendix B - Mathematical Formulas

1) The weighting function $\omega_{(k,j)}$ for each building k associated with node j can be expressed as:

$$\omega_{(k,j)} = \ell_k \sum_{i=1}^{5} \alpha_i \, x_i \, (k,j)$$

where

$\ell_k$ = a factor depending on land use

$\alpha_i$ = coefficient of $i^{th}$ category

$x_{i(k,j)}$ = $i^{th}$ structural characteristic of building (k/,j)

2) The aggregated value $W_j$ associated with node j is:

$$W_j = \sum_{k=1}^{m} \omega_{(k,j)}$$

where

n = number of buildings identified with node j

3) The objective function $F_\beta$ for origin $\beta$

$$F_\beta = \sum_{j=1}^{N} t_{\beta j} \, W_j$$

where

$t_{\beta j}$ = shortest path time from node $\beta$ to node j.

N = number of nodes in the coverage district.

## Appendix C - Highway Network Format

| Column | Information |
| --- | --- |
| 1 - 5 | NODE A |
| 8 - 12 | NODE B |
| 15 - 18 | DISTANCE |
| 21 | DIRECTION |
| 24 - 25 | POSTED SPEED |

1. NODE A - the first node used to identify a link ☐☐☐☐☐
2. NODE B - the second node required to identify a link ☐☐☐☐☐
3. DISTANCE - link distance in hundredths of a mile ☐.☐☐
4. DIRECTION - [0] - if one way in the opposite direction

   [1] - if one way street

   [2] - if link is a two way street 1/

---

1/ 3 was used instead of 2 for two way streets in the 1975 forecasted network.

## Appendix D - Structural Data Format

| Column | |
|---|---|
| 1 - 7 | Structural value in thousands ☐☐☐☐☐.☐ |
| 9 - 13 | Land value in thousands 2/ ☐☐☐.☐ |
| 18 - 21 | Land use ☐☐☐☐ |
| 25 - 28 | Structural age ☐☐☐☐ |
| 31 - 35 | Square footage in thousands 3/ ☐☐☐.☐ |
| 39 - 42 | Height of building ☐☐.☐ |
| 47 - 49 | Structure rating ☐☐☐ |
| 51 - 55 | Number of people ☐☐☐☐☐☐ |
| 76 - 80 | Node number ☐☐☐☐☐ |

Example:

1. Structural Value

Structural value will be recorded in hundreds and will, therefore, require five columns.

| Examples: | |
|---|---|
| $1,337,800.00 | 1 3 3 7 8 |
| $ 3,200.00 | 0 0 0 3 2 |

2. Land Value

Land values will be designated in hundreds and will require four columns

Example: $1,400.00 | 1 4 |

---

2/ Land values are assessed at 1/3 of real value

3/ The number of square feet given in each case is only for the ground floor

3. Land Use/Occupant Type

Two columns for recording type corresponding to Uniform Building Code occupancy type list.

Example: Student Dormitory | H | 3 |

Coding list consists of the following types of land use and also the standard building code contained in this appendix section.

Types of Land Use

| | |
|---|---|
| 1-F | one family |
| 2-F | two family |
| 3-F | three family |
| M-F | multiple family |
| SOR | sorority |
| FRT | fraternity |
| COM | commercial |
| CHH<br>CHR | church |
| GAR | garage |
| SCH | school |
| APT | apartment |
| LOT | parking lot |
| COP | co-op |
| HAL | hall |
| FIR | fire station |
| SEW | sewage treatment plant |
| RGS | regulation station |
| STD | students |
| LIB | library |
| PRK | park |
| OFF | office |
| NUR | nursing home |
| POF | post office |
| WTP | water plant |
| POL | state police post |
| MOT | motel |
| UTL | utility |

4. Age of Structure

Two columns to record year of original construction

Example: 1948 | 4 | 8 |

5. Square Footage

Square feet of buildings will be designated in hundreds and will require four columns.

Example: 1200 sq. ft. | | | 1 | 2 |

The number of square feet given in each case is only for the ground floor. To get total square footage of a structure, square feet must be multiplied by the number of stories.

6. Number of Stories

Two columns to record actual height.

Example: 17 story building | 1 | 7 |

Notice that the number of stories is broken down into fractions, i.e., 1 1/4, 1 1/2, 1 3/4, etc. Bi-level homes account for this breakdown. For purposes of this study anything over 1 story, such as 1 1/2 stories, would be considered 2 stories.

7. Structural Rating

Requires one column.

Example: Single family home | 4 |

8. Number of Persons Endangered

Four columns recording actual number of persons in structure.

Example: 3 persons | | | | 3 |

9. Node

Five columns recording node will be recorded with the first column designating the political jurisdiction using the following key:

| | |
|---|---|
| A = 1 | East Lansing City Limits |
| L = 2 | City of Lansing |
| M = 3 | Meridian Township |
| T = 4 | Lansing Township |
| U = 5 | University Property in East Lansing |
| X = 6 | University Property outside of East Lansing |

Example: M 0003 | 3 | 0 | 0 | 0 | 3 |

| GROUP | DESCRIPTION OF OCCUPANCY |
| --- | --- |
| A | Any assembly building with a stage and an occupant load of 1000 or more in the building. |
| B | 1-Any assembly building with a stage and an occupant load of less than 1000 in the building. |
| | 2-Any assembly building without a stage and having an occupant load of 300 or more in the building |
| | 3-Any assembly building without a stage and having an occupant load of less than 300 in the building, including such buildings used for school purposes less than eight hours per week. |
| | 4-Stadiums, reviewing stands, and amusement park structures not included within Group A nor Divisions 1, 2, and 3, Group B Occupancies. |
| C | Any building used for school or day-care purposes more than eight hours per week, involving assemblage for instruction, education, or recreation, and not classified in Group A or Divisions 1 and 2, Group B, Occupancies. |
| D | 1-Mental hospitals, mental sanitariums, jails, prisons, reformatories, houses of correction, and buildings where personal liberties of inmates are similarly restrained. |
| | 2-Nurseries for full-time care of children under kindergarten age. Hospitals, sanitariums, nursing homes with nonambulatory patients, and similar buildings (each accommodating more than five persons). |
| | 3-Nursing homes for ambulatory patients, homes for children of kindergarten age or over (each accommodating more than five persons). |
| E | 1-Storage and handling of hazardous and highly inflammable or explosive materials other than flammable liquids. |
| | 2-Storage and handling of Class I, II, and III flammable liquids, as specified in U.B.C. Standard No. 9-1-64; dry cleaning plants using flammable liquids, paint stores with bulk handling; paint shops and spray painting rooms and shops. |

| GROUP | DESCRIPTION OF OCCUPANCY |
| --- | --- |
| | 3-Woodworking establishments, planning mills and box factories; shops, factories where loose, combustible fibers or dust are manufactured, processed, or generated; warehouses where highly combustible material is stored. |
| | 4-Repair garages. |
| | 5-Aircraft repair hangar |
| F | 1-Gasoline and service stations, storage garages where no repair work is done except exchange of parts and maintenance requiring no open flame, welding, or the use of highly flammable liquids. |
| | 2-Wholesale and retail stores, office buildings, drinking and dining establishments having an occupant load of less than 100, printing plants, municipal police and fire station, factories and workshops using material not highly flammable or combustible, storage and sales rooms for combustible goods, paint stores without bulk handling. |
| | 3-Aircraft hangars where no repair work is done except exchange of parts and maintenance requiring no open flame, welding, or the use of highly flammable liquids. |
| G | Ice plants, power plants, pumping plants, cold storage and creameries, factories and workshops using incombustible and nonexplosive materials. Storage and sales rooms of incombustible and nonexplosive materials. |
| H | Hotels and apartment houses. Convents, monasteries (each accommodating more than 10 persons). |
| | 1-Apartments |
| | 2-Frat., sor., coop. |
| | 3-Student dormitories |
| | 4-Hotels, motels |
| I | Dwellings and lodging houses. |
| | 1-Single family |

| GROUP | DESCRIPTION OF OCCUPANCY |
|---|---|
| | 2-Rooming house |
| | 3-Duplex |
| J | 1-Private garages, sheds and minor buildings used as accessories only when not over 1000 square feet in area. |
| | 2-Fences over 6 feet high, tanks and towers. |

(From Uniform Bldg. Code, 1964 Edition Pg. 46-48, Table No. 5-A.)

```
C     THIS PROGRAM CREATES NETWORK TAPE
C     THIS PROGRAM ENUMERATES ALL LINKS
      COMMON NODEA(3000),INODE(3000),NODEB(3000),JNODE(3000),DIST(3000),
     1DIS(3000),NEXT(3000),LOC(1500),IDIC(1500)
      INTEGER TAP,R,P
      R=5
      P=6
      TAP=7
      L=0
110   L=L+1
      READ (R,280,END=115)INODE(L),JNODE(L),DIS(L)
      K=L+1
      INODE(K)=JNODE(L)
      JNODE(K)=INODE(L)
      DIS(K)=DIS(L)
      L=K
      GO TO 110
C     THIS PROGRAM SORTS ALL LINKS
115   IFIRST=1
      NLINK=L-1
      LAST=1
      DO 120 I=1,L
120   NEXT(I)=0
      DO 200 I=2,NLINK
      ICOUNT=0
      M=IFIRST
130   IF (INODE(I)-INODE(M)) 170,140,180
140   IF (JNODE(I)-JNODE(M)) 170,150,180
150   IF (M.NE.LAST) NEXT(I)=NEXT(M)
160   IF (M.EQ.LAST) LAST=I
      NEXT(M)=I
      GO TO 200
170   IF (M.NE.IFIRST) NEXT(J)=I
      IF (M.EQ.IFIRST) IFIRST=I
      NEXT(I)=M
      GO TO 200
180   IF (M.EQ.LAST) GO TO 160
      ICOUNT=ICOUNT+1
      IF (ICOUNT.LE.I) GO TO 190
      WRITE (P,350) I,M,IFIRST,LAST,(NEXT(J),J=1,I)
      STOP
190   J=M
      M=NEXT(M)
      GO TO 130
200   CONTINUE
      M=IFIRST
      DO 210 I=1,NLINK
      NODEA(I)=INODE(M)
      NODEB(I)=JNODE(M)
      DIST(I)=DIS(M)
      M=NEXT(M)
210   CONTINUE
C     THIS PROGRAM RENUMBERS ALL LINKS
      K=1
      LONODE=NODEA(1)
      IDIC(1)=LONODE
      LOC(1)=1
      NODEA(1)=1
```

```
      DO 230 I=2,NLINK
      K=K+1
      IF (NODEA(I).EQ.LONODE) GO TO 220
      LONODE=NODEA(I)
      NODEA(I)=K
      IDIC(K)=LONODE
      LOC(K)=I
      GO TO 230
220   K=K-1
      NODEA(I)=K
230   CONTINUE
      DO 260 I=1,NLINK
      DO 240 J=1,K
      IF (NODEB(I).EQ.IDIC(J)) GO TO 250
240   CONTINUE
250   NODEB(I)=J
260   CONTINUE
      NNODE=K
      WRITE (P,360)
      WRITE (P,370) (IDIC(I),I=1,K)
      WRITE (P,320)
      KK=K+1
      LOC(KK)=NLINK+1
      WRITE (P,370) (LOC(I),I=1,KK)
      WRITE (TAP) (LOC(I),I=1,KK)
      WRITE (TAP) (IDIC(I),I=1,K)
      WRITE (P,330)
      WRITE (P,340)
      DO 270 I=1,NLINK
      IB=NODEB(I)
      IC=NODEA(I)
      WRITE (P,290) IDIC(IC),IDIC(IB),DIST(I)
      WRITE (TAP) NODEA(I),NODEB(I),DIST(I)
270   CONTINUE
      END FILE 7
      WRITE (P,300) NLINK
      WRITE (P,310) NNODE
      STOP
C
280   FORMAT (29X,I4,2X,I4,32X,F5.2)
290   FORMAT (1X,I5,2X,I5,6X,F5.2)
300   FORMAT (1H022HTHE NUMBER OF LINKS ISI5)
310   FORMAT (1H022HTHE NUMBER OF NODES ISI5)
320   FORMAT (1H1,23HVALUES OF LOC TO FOLLOW)
330   FORMAT (1H1,41HLISTING OF RENUMBERED LINK DATA TO FOLLOW)
340   FORMAT (1H0,2X,6HNODE A,2X,6HNODE B,2X,10HLINK DIST.)
350   FORMAT (22H ERROR IN SORTING-I = ,I4,9HIFIRST = ,,I4,8H,LAST = ,I4
     1/35H THE VALUES OF NEXT ARE AS FOLLOWS-/(25I5))
360   FORMAT (1H1,30HVALUES OF DICTIONARY TO FOLLOW)
370   FORMAT (1H0,20I6)
      END
```

```
C       THIS PROGRAM CREATES STRUCTURE INDEX
        DIMENSION DUM(9)
        INTEGER P,R,TAP
        R=5
        P=6
        TAP=7
        ICOUNT=0
110     READ (R,140,END=115) (DUM(1),DUM(2),JDUM,(DUM(J),J=4,8)),IOLD
        WRITE (TAP,140) (DUM(1),DUM(2),JDUM,(DUM(J),J=4,8)),IOLD
        ICOUNT=ICOUNT+1
        GO TO 110
115     END FILE 7
        WRITE (P,130) ICOUNT
        WRITE (P,120)
        STOP
C
120     FORMAT (20X,26HTHE JOB HAS BEEN DONE WELL)
130     FORMAT (25H  THE VALVE OF ICOUNT IS ,I5)
140     FORMAT (F7.1,1X,F5.1,4X,A4,3X,F4.0,2X,F5.1,3X,F4.1,4X,F3.0,1X,F6.0
       1,19X,I5)
        END
```

```
C     THIS PROGRAM EVALUATES SITES FOR THE LOCATION OF A FIRE STATION.
      COMMON MAX,NNODE,NLINK,IRROR,IOPT1,IOPT2,NUNITS,JDUM,ITAPE,IOLD,NO
     1DE(1500),TM1(1500),DIST(1500),XX(500,9),DUM(9),ICODE(70),LOC(500),
     2IDICT(500),X(500,9),A(9),F(500),TOTF(500),DETROY(10),TRITI(500),KP
     3ATH(500),SEQNOD(150),TOTG(500),LIMIT(10,10),NPATH(150),NBACK(150),
     4ICK(10),ICHO(10),TITLE(12),IPOL(500),DISTA(500),Y(500),YY(500),ASS
     5IGN(70),TOTDIS,SUMTIM,IDEST(10),NSTR(3),ISUM(10,10),JSID(500),IMAX
      INTEGER P,R,FUTURE,DETROY,TAP
      R=5
      P=6
      READ (R,410) NRUNS,IOPT1,IOPT2,FUTURE
      READ (R,420) MAX,NNODE,NLINK,TAP
      READ (R,470) (ICODE(I),I=1,64)
      READ (R,480) (ASSIGN(I),I=1,64)
      READ (R,490) (A(I),I=1,9)
      WRITE (P,500)
      DO 110 I=1,60
      WRITE (P,510) ICODE(I),ASSIGN(I)
110   CONTINUE
      DO 120 I=1,NNODE
      Y(I)=0.0
      DO 120 J=1,9
120   X(I,J)=0.0
      ND=NNODE+1
      READ (TAP) (LOC(KO),KO=1,ND)
      READ (TAP) (IDICT(KK),KK=1,NNODE)
      ITAPE=0
      NUNITS=1
      IF (FUTURE.NE.1) GO TO 150
      DO 130 I=1,10
      DO 130 J=1,3
130   ISUM(I,J)=0
      READ (R,450) (NSTR(I),I=1,3)
      DO 140 I=1,10
140   READ (R,460) (DETROY(I),(LIMIT(I,J),J=1,3))
      NR=0
150   NR=NR+1
      READ (TAP,660,END=160) NODA,NODE(NR),DIST(NR),TM1(NR)
      GO TO 150
C     THIS SET OF INSTRUCTIONS DELETES STRUCTURES FROM CONSIDERATION
160   READ (TAP,640,END=235) (DUM(1),DUM(2),JDUM,(DUM(IDUM),IDUM=3,7)),
     1IOLD
      IF (FUTURE.NE.1) GO TO 210
      DO 170 ID=1,10
      IF (DETROY(ID).EQ.IOLD) GO TO 180
170   CONTINUE
      GO TO 210
180   DO 190 JJ=1,3
      IF (JDUM.EQ.NSTR(JJ)) GO TO 200
190   CONTINUE
      GO TO 210
200   ISUM(ID,JJ)=ISUM(ID,JJ)+1
      IF (LIMIT(ID,JJ).LT.ISUM(ID,JJ)) GO TO 210
      GO TO 160
210   DUM(8)=1.0
      IF (DUM(3).LT.80) GO TO 220
      DUM(3)=180-DUM(3)
      GO TO 230
```

```
220   DUM(3)=80-DUM(3)
230   ITAPE=ITAPE+1
      CALL HOUSE
      GO TO 160
235   IF (FUTURE.NE.1) GO TO 250
240   READ (R,700,END=250) (DUM(1),NUNITS,JDUM,(DUM(IDUM),IDUM=3,7)),
     1IOLD
      DUM(8)=1.0
      ITAPE=ITAPE+1
      CALL HOUSE
      GO TO 240
250   WRITE (P,580)
      WRITE (P,540) NNODE,NLINK
      WRITE (P,600) ITAPE
      WRITE (P,650)
      WRITE (P,670)
      DO 260 I=1,NNODE
      WRITE (P,680) I,(X(I,J),J=1,9)
260   CONTINUE
      WRITE (P,690) (A(I),I=1,9)
      DO 360 NSTATN=1,NRUNS
      DO 270 I=1,NNODE
      TOTG(I)=0.0
      TOTF(I)=0.0
270   F(I)=0.0
      DO 280 NK=1,NNODE
      YY(NK)=Y(NK)
      DO 280 KN=1,9
280   XX(NK,KN)=X(NK,KN)
      READ (R,440) (IMAX,TITLE(I),I=1,12)
      WRITE (P,430) (TITLE(I),I=1,12)
      WRITE (P,580)
      READ (R,630) (ICK(IB),IB=1,IMAX)
      READ (R,610) (ICHO(IK),IK=1,IMAX)
      READ (R,630) (IDEST(ID),ID=1,IMAX)
      WRITE (P,570)
      DO 290 IRIGIN=1,IMAX
290   WRITE (P,590) IRIGIN,ICK(IRIGIN)
      READ (R,560) JSS
      IF (JSS.EQ.0) GO TO 320
      READ (R,620) (JSID(JS),JS=1,NNODE)
      DO 310 JS=1,NNODE
      IF (JSID(JS).EQ.1) GO TO 310
      YY(JS)=0.0
      DO 300 I=1,9
300   XX(JS,I)=0.0
310   CONTINUE
320   READ (R,560) NPOL
      IF (NPOL.EQ.0) GO TO 350
      READ (R,550) POLICY
      DO 340 INEW=1,NNODE
      READ (R,620) IPOL(INEW)
      IF (IPOL(INEW).EQ.0) GO TO 340
      DO 330 IDUM=1,9
330   XX(INEW,IDUM)=POLICY*XX(INEW,IDUM)
340   CONTINUE
350   CALL CARTIM
360   CONTINUE
      WRITE (P,580)
      IF (IOPT2.EQ.1) GO TO 370
      GO TO 400
```

```
370   WRITE (P,520)
      DO 380 IDT=1,NNODE
      DO 380 IX=1,8
      F(IDT)=F(IDT)+(X(IDT,IX)*A(IX))
380   CONTINUE
      DO 390 I=1,NNODE
390   WRITE (P,530) I,IDICT(I),F(I)
400   STOP
C
410   FORMAT (I3,3(2X,I1))
420   FORMAT (3I5,I2)
430   FORMAT (1H1,30X,12A6)
440   FORMAT (I5,10X,12A6)
450   FORMAT (3A4)
460   FORMAT (I6,1X,3I3)
470   FORMAT (16(A4))
480   FORMAT (16F4.2)
490   FORMAT (9F6.3)
500   FORMAT (20H   LAND USE    VALUE)
510   FORMAT (5X,A4,5X,F4.2)
520   FORMAT (2X,10HDICTIONARY,5X,16HWEIGHTING FACTOR)
530   FORMAT (2X,I3,3X,I5,5X,F10.2)
540   FORMAT (10X,19HTHE NO. OF NODES IS,I6,25H, AND THE NO. OF LINKS IS
     1,I7)
550   FORMAT (F4.2)
560   FORMAT (I3)
570   FORMAT (36H NODES CHOSEN FOR POSSIBLE LOCATIONS)
580   FORMAT (1H0,///)
590   FORMAT (1H ,I5,1X,1H(,I5,1H))
600   FORMAT (11H  THERE ARE,I6,28H STRUCTURES BEING CONSIDERED)
610   FORMAT (10(4X,I1))
620   FORMAT (80I1)
630   FORMAT (10(1X,I4))
640   FORMAT (F7.1,1X,F5.1,4X,A4,3X,F4.0,2X,F5.1,3X,F4.1,4X,F3.0,1X,F6.0
     1,19X,I5)
650   FORMAT (1H1,40X,16HPARAMETER VALUES)
660   FORMAT (2I5,2F4.2)
670   FORMAT (11X,44HSTR VAL LAND VAL  STR AGE    SQ FT   STORIES,40H
     1RATING   PEOPLE   CONSTANT   LAND USE)
680   FORMAT (2X,I4,2X,8(F9.0),5X,F6.2)
690   FORMAT (8H WEIGHTS,3X,9(F6.3,3X))
700   FORMAT (F7.1,2X,I6,4X,A4,2X,F5.1,2X,F5.1,3X,F4.1,4X,F3.1,1X,F4.0,1
     19X,I5)
      END
      SUBROUTINE CARTIM
C     THIS SUBROUTINE IS THE SHORTEST PATH ALGORITHM
      COMMON MAX,NNODE,NLINK,IRROR,IOPT1,IOPT2,NUNITS,JDUM,ITAPE,IOLD,NO
     1DE(1500),TM1(1500),DIST(1500),XX(500,9),DUM(9),ICODE(70),LOC(500),
     2IDICT(500),X(500,9),A(9),F(500),TOTF(500),DETROY(10),TRITI(500),KP
     3ATH(500),SEQNOD(150),TOTG(500),LIMIT(10,10),NPATH(150),NBACK(150),
     4ICK(10),ICHO(10),TITLE(12),IPOL(500),DISTA(500),Y(500),YY(500),ASS
     5IGN(70),TOTDIS,SUMTIM,IDEST(10),NSTR(3),ISUM(10,10),JSID(500),IMAX
      INTEGER SEQNOD,ANODE,P,R,TAP
      N=NNODE
      DO 130 IA=1,IMAX
      DO 110 IC=1,NNODE
      IF (ICK(IA).EQ.IDICT(IC)) GO TO 120
110   CONTINUE
      WRITE (P,560) IA
      GO TO 130
120   ICK(IA)=IDICT(IC)
```

```
130   CONTINUE
      DO 410 IO=1,IMAX
      IRIGIN=ICK(IO)
      DO 140 J=1,NNODE
      TRITI(J)=9000.
140   KPATH(J)=0
      TRITI(IRIGIN)=0.
      DO 150 MM=1,MAX
      SEQNOD(MM)=0
150   NPATH(MM)=0
      NODEA=IRIGIN
      IPUT=1
      IGET=1
      ICOUNT=0
      ATIME=0.0
C     THIS SET OF INSTRUCTIONS SEARCHES ALL LINKS LEADING FROM A NODE.
160   NBR=LOC(NODEA)
      NEXT=LOC(NODEA+1)-1
      DO 180 JJ=NBR,NEXT
      IF (NODE(JJ).EQ.IRIGIN) GO TO 180
      NODEB=NODE(JJ)
      TIME=ATIME+TM1(JJ)
      IF (TIME.GE.TRITI(NODEB)) GO TO 180
      TRITI(NODEB)=TIME
      KPATH(NODEB)=NODEA
      SEQNOD(IPUT)=NODEB
      ICOUNT=ICOUNT+1
      IF (ICOUNT.LE.MAX) GO TO 170
      WRITE (P,520) ICOUNT
      GO TO 410
170   IPUT=IPUT+1
      IF (IPUT.EQ.MAX+1) IPUT=1
180   CONTINUE
      IF (ICOUNT.EQ.0) GO TO 190
      NODEA=SEQNOD(IGET)
      ATIME=TRITI(NODEA)
      ICOUNT=ICOUNT-1
      IGET=IGET+1
      IF (IGET.EO.MAX+1) IGET=1
      GO TO 160
190   SUMTIM=0.0
      DO 200 J=1,NNODE
      IF (TRITI(J).GE.9000.) GO TO 200
      IF (J.EQ.IRIGIN) GO TO 200
      SUMTIM=SUMTIM+TRITI(J)
200   CONTINUE
      DO 320 J=1,NNODE
      IF (IRIGIN.EQ.J) GO TO 320
      IB=MAX
      MPATH=J
      NPATH(IB)=J
210   IB=IB-1
      IF (IB.GT.0) GO TO 220
      IRROR=274
      WRITE (P,500) IRROR
      GO TO 320
220   NPATH(IB)=KPATH(MPATH)
      IF (NPATH(IB).EO.IRIGIN) GO TO 230
      MPATH=NPATH(IB)
      GO TO 210
230   IF (ICHO(IO).EO.0) GO TO 280
```

```
      DO 240 IDD=1,IMAX
      IF (IDICT(J).EQ.IDEST(IDD)) GO TO 250
240   CONTINUE
      GO TO 280
250   DO 260 LQ=1,MAX
260   NBACK(LQ)=0
      DO 270 LK=IB,MAX
      JK=NPATH(LK)
      INT=IDICT(JK)
270   NBACK(LK)=INT
      WRITE (P,580) IRIGIN,J
      WRITE (P,570) (NBACK(JQ),JQ=IB,MAX)
280   IF (IOPT1.EQ.0) GO TO 380
      DISTA(J)=0.
      TOTDIS=0.0
      NMAX=MAX-1
      DO 310 IX=IB,NMAX
      ANODE=NPATH(IX)
      NTRY=LOC(ANODE)
      LIMIT1=LOC(ANODE+1)-1
      DO 290 JQ=NTRY,LIMIT1
      IF (NPATH(IX+1).EQ.NODE(JQ)) GO TO 300
290   CONTINUE
      IRROR=277
      WRITE (P,500) IRROR
      GO TO 310
300   DISTA(JQ)=DIST(JQ)+DISTA(J)
310   CONTINUE
320   CONTINUE
      DO 330 J=1,NNODE
330   TOTDIS=TOTDIS+DISTA(J)
      IRGN=IDICT(IRIGIN)
      WRITE (P,480)
      WRITE (P,440) IRIGIN,IRGN
      JR=1
      JM=15
340   WRITE (P,450) (TRITI(JB),JB=JR,JM)
      JP=JR+15
      JM=JM+15
      IF (N-JM) 350,350,340
350   WRITE (P,450) (TRITI(JB),JB=JR,NNODE)
      WRITE (P,540) IRIGIN,IDICT(IRIGIN),SUMTIM
      WRITE (P,470)
      WRITE (P,460) IRIGIN,IRGN
      JR=1
      JM=15
360   WRITE (P,450) (DISTA(MB),MB=JR,JM)
      JR=JR+15
      JM=JM+15
      IF (N-JM) 370,370,360
370   WRITE (P,450) (DISTA(MB),MB=JR,NNODE)
      WRITE (P,550) IRIGIN,IDICT(IRIGIN),TOTDIS
380   TOTF(IRIGIN)=0.0
      TOTG(IRIGIN)=0.0
      DO 390 IDT=1,NNODE
      F(IDT)=0.0
      DO 390 IX=1,8
390   F(IDT)=F(IDT)+(X(IDT,IX)*A(IX))
      DO 400 IDT=1,NNODE
      IF (TRITI(IDT).GE.9000.0) GO TO 400
      TOTF(IRIGIN)=TOTF(IRIGIN)+(F(IDT)*TRITI(IDT))
```

```
      TOTG(IRIGIN)=TOTG(IRIGIN)+(YY(IDT)*TRITI(IDT))
400   CONTINUE
410   CONTINUE
      WRITE (P,510)
      WRITE (P,490)
      DO 430 I=1,NNODE
      IF (ICK(I).EQ.0) GO TO 430
      NEXT=I
      NNEXT=NEXT+1
      DO 420 J=NNEXT,NNODE
      IF (ICK(J).EQ.0) GO TO 420
      IF (TOTF(J).LT.TOTF(NEXT)) NEXT=J
420   CONTINUE
      WRITE (P,530) NEXT,IDICT(NEXT),TOTF(NEXT),TOTG(NEXT)
      TOTF(NEXT)=2.0**35-1
430   CONTINUE
      RETURN
C
440   FORMAT (40X,1H0,26HVALUES OF TIME FROM ORIGIN,1X,I5,1X,1H(,I5,1H),
     1/)
450   FORMAT (1H ,6X,15(F5.2,2X))
460   FORMAT (40X,1H0,30HVALUES OF DISTANCE FROM ORIGIN,1X,I5,1X,1H(,I5,
     11H),/)
470   FORMAT (1H0,/)
480   FORMAT (1H0,///)
490   FORMAT (16X,59HRENUMBERED   ORIGINAL   WEIGHTED TIMES        SUMMED
     1   TIMES)
500   FORMAT (42H ERROR CONDITION FOUND AT STATEMENT NUMBER,I5,29H.  PRO
     1CESSING CANNOT PROCEED.)
510   FORMAT (45H LISTING OF WEIGHTED SUMS TO ALL DESTINATIONS)
520   FORMAT (46H THE SEQUENCE TABLE CAPACITY HAS BEEN EXCEEDED/10H ICOU
     1NT = ,I4)
530   FORMAT (1H ,15X,I5,8X,I5,3X,F14.2,8X,F14.2)
540   FORMAT (1H0,22HTOTAL TIME FROM ORIGIN,1X,I5,1H(,I5,1H),1X,2HIS,F10
     1.2,1X,7HMINUTES)
550   FORMAT (1H0,26HTOTAL DISTANCE FROM ORIGIN,1X,I5,1H(,I5,1H),1X,2HIS
     1,F10.2,1X,5HMILES)
560   FORMAT (20X,19HTHE LOCATION OF THE,I3,25HTH ORIGIN CANNOT BE FOUND
     1)
570   FORMAT (1H ,20(I5,1X)/1H ,20(I5,1X)/1H ,20(I5,1X))
580   FORMAT (17H0PATH FROM ORIGIN,I3,15H TO DESTINATION,I4)
      END
      SUBROUTINE HOUSE
      COMMON MAX,NNODE,NLINK,IRROR,IOPT1,IOPT2,NUNITS,JDUM,ITAPE,IOLD,NO
     1DE(1500),TM1(1500),DIST(1500),XX(500,9),DUM(9),ICODE(70),LOC(500),
     2IDICT(500),X(500,9),A(9),F(500),TOTF(500),DETROY(10),TRITI(500),KP
     3ATH(500),SEQNOD(150),TOTG(500),LIMIT(10,10),NPATH(150),NBACK(150),
     4ICK(10),ICHO(10),TITLE(12),IPOL(500),DISTA(500),Y(500),YY(500),ASS
     5IGN(70),TOTDIS,SUMTIM,IDEST(10),NSTR(3),ISUM(10,10),JSID(500),IMAX
      INTEGER P
      DO 120 I=1,NNODE
      IF (IDICT(I).EQ.IOLD) GO TO 110
      GO TO 120
110   INEW=I
      GO TO 130
120   CONTINUE
      WRITE (6,250) IOLD
      WRITE (P,240) ITAPE
      GO TO 230
130   DO 150 I=1,60
      IF (ICODE(I).EQ.JDUM) GO TO 140
```

```
      GO TO 150
140   DUM(9)=ASSIGN(I)
      GO TO 160
150   CONTINUE
      WRITE (P,260) JDUM
      WRITE (P,240) ITAPE
      GO TO 230
160   IF (DUM(5).LT.3) GO TO 170
      IF (DUM(5).LT.5) GO TO 180
      IF (DUM(5).LT.7) GO TO 190
      DUM(5)=10.0
      GO TO 200
170   DUM(5)=0.0
      GO TO 200
180   DUM(5)=2.0
      GO TO 200
190   DUM(5)=4.0
200   DO 210 I=1,8
210   DUM(I)=NUNITS*DUM(I)*DUM(9)
      Y(INEW)=1.0
      DO 220 I=1,9
      X(INEW,I)=X(INEW,I)+DUM(I)
220   CONTINUE
230   RETURN
C
240   FORMAT (10X,40HTHE MISTAKE OCCURS ON STRUCTURE CARD NO.,I6)
250   FORMAT (24H   THE LOCATION OF IOLD,I6,17H CAN NOT BE FOUND)
260   FORMAT (27H   THE VALUE FOR LAND USE ',A4,18H  CAN NOT BE FOUND)
      END
```