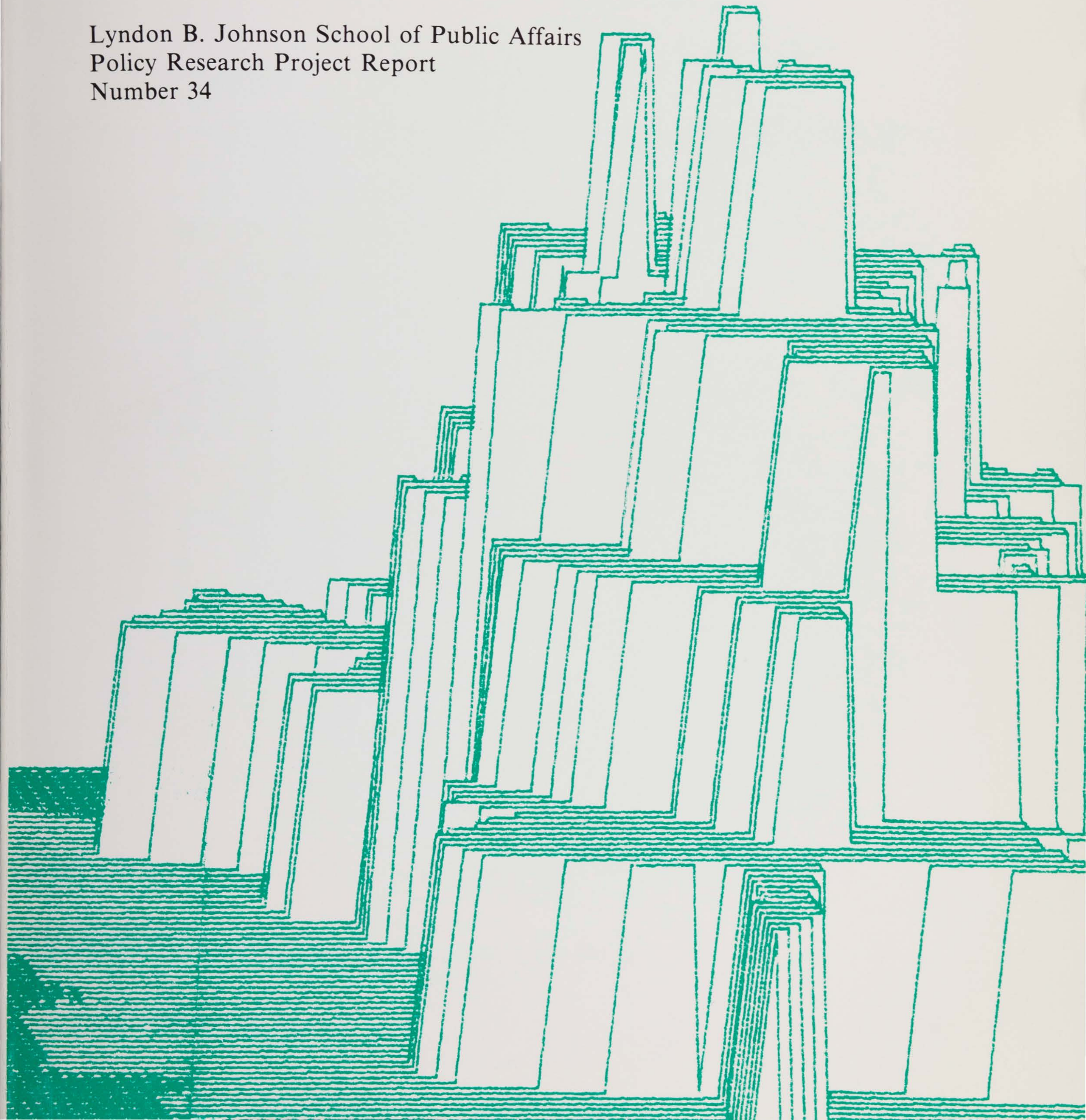
# Location Techniques for Emergency Medical Service Vehicles

## Volume I

## An Analytical Framework for Austin, Texas

Lyndon B. Johnson School of Public Affairs
Policy Research Project Report
Number 34



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# Location Techniques for Emergency Medical Service Vehicles

## Volume I
## An Analytical Framework for Austin, Texas

A report by
The Emergency Medical Services Policy Research Project
Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin
1979

**Library of Congress Card Number: 79-90645**

**ISBN 0-89940-631-9**



Front Cover:

The illustration is a map of the EMS vehicle service pattern in Austin, Texas. The relative height indicates that zero (base), one, two, three, or four (peak) vehicles can reach the associated enclosed area within 10 minutes of travel from the set of EMS vehicle bases existing in December 1979.

# Foreword

The Lyndon B. Johnson School of Public Affairs has established interdisciplinary research on policy problems as the core of its educational program. A major part of this program is the nine-month policy research project, in the course of which two or three faculty members from different disciplines direct the research of ten to twenty graduate students of diverse backgrounds on a policy issue of concern to an agency of government. This "client orientation" brings the students face to face with administrators, legislators, and other officials active in the policy process, and demonstrates that research in a policy environment demands special talents. It also illuminates the occasional difficulties of relating research findings to the world of political realities.

This report was produced by a policy research project in the academic year 1978-79. The study, funded by the City of Austin, the Ford Foundation, and the Henry J. Kaiser Family Foundation, has developed a series of techniques to assist the City of Austin to locate emergency medical service vehicles.

This volume is a summary report of the computer methods developed by the EMS Policy Research Project. It also reports on initial illustrations of the use of these techniques in analysis of deployment options for EMS vehicles in the City of Austin.

It is the intention of the LBJ School both to develop men and women with the capacity to perform effectively in public service and to produce research which will enlighten and inform those already engaged in the policy process. The project which resulted in this volume has helped to accomplish the former; it is our hope and expectation that the report itself will contribute to the latter.

Elspeth Rostow
**Dean**

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# Contents

# Chapter One
# Executive Summary

This volume reports on the status of a cooperative effort by staff members of departments of the City of Austin and students and faculty at The University of Texas at Austin to develop a plan for deployment of emergency medical service (EMS) vehicles in Austin, Texas. This work was carried out during the 1978-79 school year in a Policy Research Project (PRP) at the Lyndon B. Johnson School of Public Affairs with the financial support of The University of Texas at Austin, the City of Austin, and the Ford Foundation. This summary briefly describes the four volumes of materials developed by the PRP members.

## EMS SERVICES IN AUSTIN

Although ambulances have operated in Austin for many years, a City-managed emergency medical service is of recent origin. The City of Austin created a Department of Emergency Medical Services as a separate administrative unit through an ordinance passed by the City Council on January 16, 1975. The purpose of the new department is:

> . . . to provide on a twenty-four hour a day basis necessary emergency medical personnel, facilities, and equipment to effectively respond to individual needs in the City of Austin for immediate medical. . . . (1)

The ordinance also created an Emergency Medical Services Quality Assurance Team to serve as an advisory body to the City Countil. The team periodically advises

> . . . the City Manager, the Director of the Department of Emergency Medical Services, and the City Council concerning planning, reviewing, and evaluating the operations, performance, and procedures of the Department of Emergency Medical Services and is privileged to recommend professional performance standards for the Department. (2)

On July 31, 1975, the Austin City Council reaffirmed its commitment through a motion supporting a separate EMS Department. The Council authorized the City Manager to implement the motion as quickly as possible.

After a brief transition period from private Austin ambulance services, the Department of Emergency Medical Services began full city-wide operation on January 1, 1976. The EMS Department also provided assistance to private ambulance companies in surrounding Travis County. On May 1, 1977, the City of Austin entered into an agreement with Travis County to provide EMS coverage in Travis County.

Austin's EMS Department currently provides advanced emergency care utilizing mobile life support equipment, such as a cardiac monitor defibrillator and telemetry system. The EMS Department operates a program to train basic and advanced emergency medical technician classifications to skill levels that exceed the standards of both the State of Texas and the U.S. Department of Transportation. Two thirds of the approximately seventy persons who deliver EMS services have achieved paramedic certification (3).

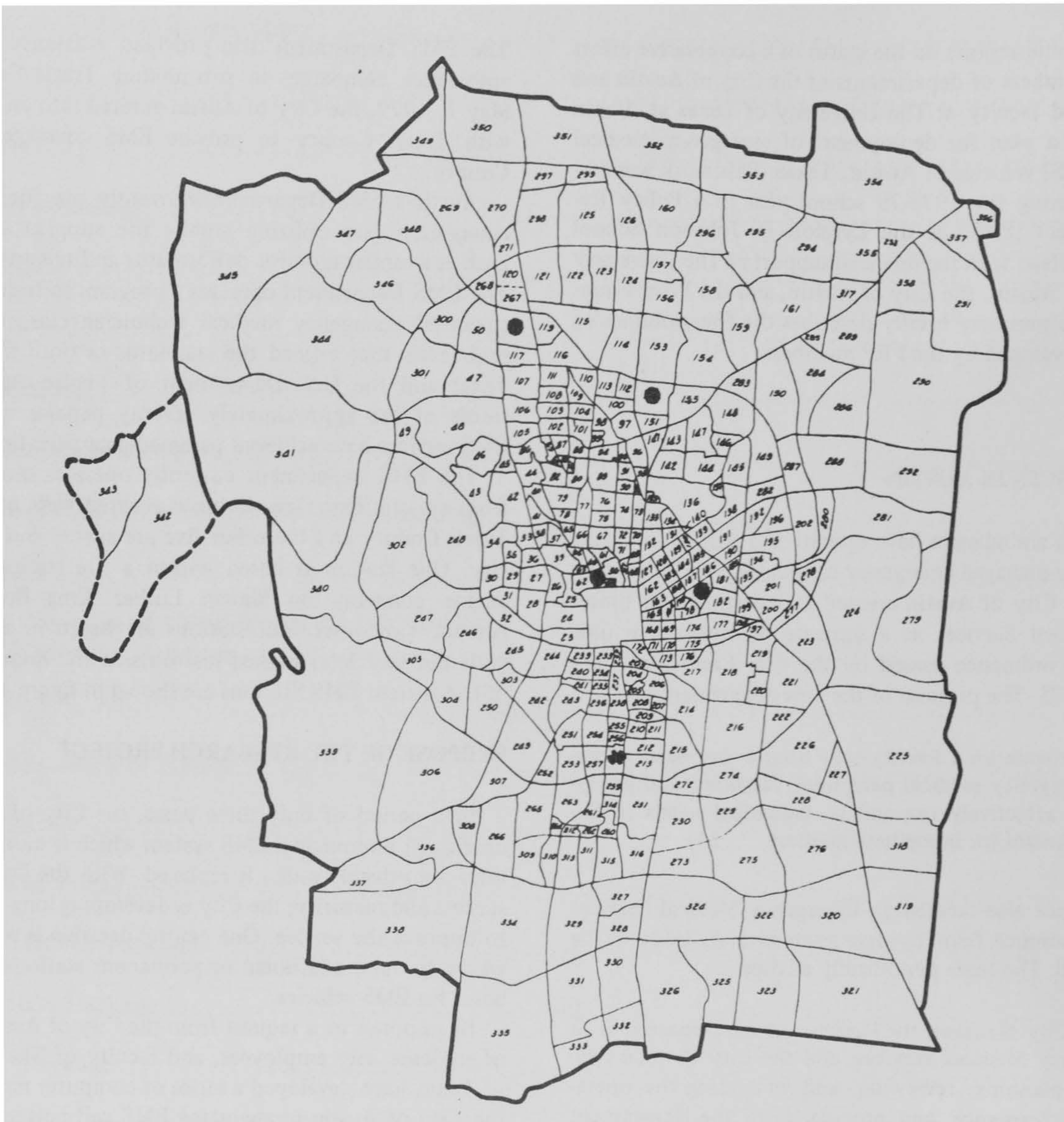
The EMS Department currently operates seven vehicles from six stations. One station is located west of Austin in Travis County and the other five are spread out within the city. One station is based within a fire station (with an engine company on Martin Luther King Boulevard in Austin. The other four stations are based in apartments, with the vehicle(s) parked just outside the door. The sites of the current EMS Stations are shown in figure 1-1.

## PURPOSE OF THE RESEARCH PROJECT

In a period of only three years, the City of Austin has developed a municipal EMS system which is more advanced than the private system it replaced. With the Department's success and maturity, the City is developing long-range plans to improve the service. One central decision is whether and where to build additional or permanent stations to serve as bases for EMS vehicles.

In response to a request from the City of Austin, a team of students, city employees, and faculty of The University of Texas have developed a series of computer models to aid the City of Austin in analyzing EMS call patterns or alternative EMS station sites, and to display such results in mapped form. These models incorporate such criteria as response time to the scene of an emergency, the frequency of calls in different sections of the city, and distribution of calls throughout the city. One program allows users to analyze historical EMS call data by site of occurrence and by several levels of time intervals. Two techniques allow determination of possible EMS location sites that maximize the number of calls accessible to EMS vehicles within a specified response time and minimize the overall response time of the EMS system to all calls. Three computer map-

## FIGURE 1-1: CURRENT EMS LOCATIONS IN THE AUSTIN TRANSPORTATION STUDY AREA†



Key

. site of a single EMS vehicle

* site of two EMS vehicles

†One EMS vehicle is based in Travis County outside the Austin Transportation Study Area. This location is not depicted in the map.

ping programs have been adapted to illustrate the results of the techniques mentioned above. In addition, the project members have collected information to serve as a data base for EMS location analysis in Austin.

## VOLUME ONE – METHODS

After a review of the published literature on analysis of emergency medical services (see Appendix A), the project members either developed or implemented four computer-based techniques that can be used by the City to evaluate alternate EMS vehicle locations. The computer techniques are: (a) the Call History Analysis Package (CHAP); (b) the CALL/CZSR location analysis program; (c) the CLASGAS location analysis program; and (d) three mapping programs called SYMAP, SYMVU, and CALFORM.

### Call History Analysis Package (CHAP)

The Call History Analysis Package (CHAP) is a collection of computer programs that can analyze records of the location and nature of calls for EMS assistance and the responses of the EMS system to these calls. One program, CAP, can be used to aggregate call data by geographical zones and by several levels of time intervals. A second program, RAP, calculates both the relative and cumulative frequencies of calls for all days and weeks for which data is supplied. The ZAP program calculates both the relative and cumulative frequencies of calls for geographical locations. These programs use historical call data for the City of Austin as an input and can generate useful summary statistics regarding these calls as an output.

The two inputs to CHAP are a list of historical calls to the EMS system and a set of computer instructions selected by the analyst. The EMS call data, obtained from dispatcher records, includes: (a) the site (serial zone), time (day, date, hour, minute), and nature of each call; (b) the base and identity of the responding EMS unit; and (c) the time (hour and minute) when an EMS vehicle arrives at the call scene, leaves the call scene, arrives at the hospital, and leaves the hospital.

The user can choose to aggregate calls by either specific geographical areas or time intervals. An analyst can instruct CHAP to group calls for all of Austin, a particular site, or a group of sections of the city. The program allows a user to distinguish three types of time intervals: the period (the full week, particular days, or groups of days of the week); hour intervals (the entire 24-hour day or integer factors of 24); and a time range (specified months and dates). The purpose for collecting and analyzing this EMS data is to determine temporal or spatial patterns in EMS calls. To assist such evaluation, CHAP programs can generate tables of statistics for the specified time intervals and areas of Austin. The summary statistics include frequency counts, averages, variances, standard deviations, and percentages of calls.

Some tentative results from applying CHAP to a limited set of Austin EMS call data suggest that some areas of the city are busier than others. For example, the frequency of calls in the Central Business District is greater than might be suggested on the basis of its size or its resident population alone. Also, for the entire City some time periods are busier than others. The periods 3 p.m. to 6 p.m. (Monday, Tuesday, and Wednesday) and 9 p.m. to midnight (Thursday, Friday, Saturday, and Sunday) are significantly busier than other times of the day. In general, the period from 3 p.m. to 3 a.m. is busier than 3 a.m. to 3 p.m.

### The CLASGAS Program

CLASGAS is a computer procedure which identifies sites for EMS stations that provide maximum accessibility of vehicles to emergency calls within some predetermined maximum response time. The program uses two procedures, GAS and GA, to try to find the fewest vehicle sites that cover the largest fraction of EMS calls subject to an upper bound on response time. The GA procedure starts with no facilities and then adds one at a time the best facility sites. The best facility site in a given iteration is defined to be that site which covers at least as large a fraction of the EMS calls as any other site. This program is a variant of the algorithm implemented in reference (4) to solve the maximal covering location problem (5). The GAS algorithm seeks to improve the GA solution at each iteration by replacing each facility one at a time with an unused site if coverage can be increased.

As a basis for analysis, the CLASGAS program requires information on the relative frequency of EMS calls for zones in the city and the shortest time of travel from any zone to any other zone. The user must also supply an upper limit on response time and a statement of any sites that either require a station or that cannot serve as a base for EMS vehicles. CLASGAS can identify the tradeoffs between the fraction of calls covered, the number of vehicle sites, and the time standard used to represent quality of service.

CLASGAS was applied to Austin using an incomplete set of EMS call frequencies and a travel time matrix for 358 serial zones in the city of Austin and surrounding areas. Both GA and GAS programs were run to determine the "best" locations for as many as seven EMS vehicles. These locations were defined as those sites which would reach the largest fraction of calls for service in less than four minutes. Using six vehicles, both GA and GAS found sites that were accessible to approximately three quarters of the calls within four minutes. The GA routine appears to be more cost effective in screening sites for EMS vehicles.

CLASGAS can be a valuable tool both for identifying initial sites that are accessible to calls and for analyzing incremental EMS bases. CLASGAS can be used to quantify the increased call coverage possible from establishing and operating additional EMS vehicle bases.

### The CALL/CZSR Program

CALL/CZSR is an analytical computer model composed of two routines, CALL and CZSR, that can identify good sites for locating emergency medical vehicles. The CALL routine calculates the EMS system's mean response time for a given set of vehicle locations. The contiguous zone search routine (CZSR) tries to substitute other sites as vehicle locations if they reduce the system's average response time of vehicles to calls. This approach (6) is a variant of the model described in reference (7).

CALL/CZSR requires information concerning initial sites for EMS station locations, sites of hospital(s), the mean number of calls per day, mean EMS vehicle time at scene, mean transfer time of a patient at hospital(s), and probability of transport. The frequency of calls occurring in each zone is used as a measure of the potential need for emergency medical service. The program also requires information on the minimum time to travel between one zone and any other zone.

The CALL/CZSR model begins by calculating the average response time of vehicles to EMS calls, using a trial set of vehicle sites. If a shift of EMS vehicle locations could improve performance of the system, the CZSR program will search among the zones contiguous to the current locations for those replacement sites. The model will continue to shift EMS vehicle locations until tests of possible replacement sites indicate that significant additional reductions in average response time are not possible. If particular sites should be fixed (for political or other reasons), or if some zones should not be considered as potential EMS bases, the user can either fix these locations or remove them from consideration.

The output of CALL/CZSR allows a user to determine sites that minimize average call response time. The sites that minimize average system response time also reduce the likelihood of excessive response times of vehicles to calls. Another result is a smoothing of EMS vehicle workloads, since reduced average response times are brought about by a more equitable sharing of the volume of calls by all vehicles.

### Mapping Programs

Project members have adapted SYMAP, SYMVU, and CALFORM computer programs (originally described in references 8, 9, and 10) to produce several kinds of maps that display the spatial distribution of census data, calls for EMS service, and location analysis results.

The mapping programs adopt a user-identified study area as a source map. In this case the study area is the city of Austin, as divided into 358 transportation serial zones. To implement these programs, the user first specifies serial zone boundaries in terms of points defined by (y,x) coordinates. The user can then assign values either to the coordinate locations of data points or to serial zones. Using points, zones, and values, these mapping programs can generate three types of maps through combinations of certain computer subroutines. The type of map selected will depend on the type of data to be displayed and the purpose of the map.

The three types of maps are called "contour," "conformant," and "proximal." A contour map is a series of closed curves known as contour lines which connect all points having the same numerical value. A familiar example is a topographic map, which shows area elevation. Contour maps can be used to display such continuous information as population density and age distribution. An example of a conformant map is a map of political boundaries. Variables of interest can take on values associated with all the points within a zone. Conformant maps can be used to illustrate discrete data, such as minimum response time (in minutes) of EMS vehicles to specific serial zones. The data points themselves define a proximal map; zone boundaries are created by the computer, equidistant from adjacent points to which data values have been assigned. A proximal map can be used to depict the primary service area covered by a particular EMS vehicle base.

The three computer programs that generate these maps are called SYMAP, SYMVU, and CALFORM. SYMAP can be used to plot any of the three types of maps via a standard remote job entry terminal printer. A second mapping program, called SYMVU, uses SYMAP data and a pen plotter to produce three-dimensional oblique view contour, conformant, or proximal maps. The basic input to a SYMVU program is a SYMAP program that is stored on tape. To obtain a SYMVU map, the user runs a SYMAP program with certain changes and then a separate SYMVU deck. This SYMVU program accesses the SYMAP data on tape and plots a three-dimensional equivalent of the SYMAP map. The third mapping program, CALFORM, can instruct a pen plotter to create two-dimensional conformant maps. Maps drawn on a pen plotter are neater in appearance, easier to read, and can be used to make higher quality reproductions than the conformant maps produced by SYMAP. The preparation of a CALFORM map is similar to the procedure for generating a SYMAP map. These programs allow planners to manage large volumes of information and arrange it in inexpensive visual displays.

## DATA VOLUMES TWO THROUGH FOUR

Project members collected data for applying the computer models to Austin. These data include travel time information, EMS call data, and statistics on housing and population of the serial zones (see table 1-1).

**TABLE 1-1: DATA COLLECTED BY EMS PROJECT**

| CALL DATA INFORMATION | POPULATION AND HOUSING INFORMATION |
|---|---|
| Site (serial zone) in which call originated | Vacant rental housing units |
| Day of the week | Vacant owned housing units |
| Date | Housing units vacant year-round |
| Hour | Owner-occupied housing units |
| Minute past the hour | Renter-occupied housing units |
| Type of call | Living units in structure |
| Identity number of the responding unit | Mobile homes |
| Serial zone the unit responded from | Housing value |
| Time (hour and minute) the responding unit arrives at the call scene | Number of persons per unit |
| | Total population |
| Time the responding unit leaves the call scene | Black population |
| Time the responding unit arrives at the hospital | Spanish population |
| Time the responding unit leaves the hospital | Population in group housing |
| | Population under 18 years of age |
| TRAVEL TIME INFORMATION | Population 62 years and over |
| The minimum expected travel time from any of 358 serial zones to any other | |

### Volume Two–Travel Time Information

The source of information regarding the times of travel between serial zones in Austin was an Austin Transportation Study Office (ATSO) study completed in conjunction with the Texas Highway Department. This report, identified as the 95-95-3 study, was completed in 1977.

The ATSO partitioned the study area of the city of Austin into 358 serial zones. Based on various assumptions, the ATSO calculated the minimum travel time from each zone to any other. These travel time projections are based on assumptions regarding the structure of Austin in the year 1995, the nature of vehicular travel, and the rationale behind individual driver decisions. The travel time matrix is listed in volume two and is used as an input to the various computer models.

### Volume Three–EMS Call Data Information

Volume three contains a description of EMS calls that project members used to represent the "demand" for EMS services. These calls consist of all requests for service recorded by City of Austin EMS Department dispatchers during December 1976 and February, June, July, and August 1977.

The record for each call includes both time and place information. EMS vehicle dispatchers recorded temporal information on cards inserted into a punch time-clock. It includes: the time the call was received; the time the ambulance arrived at the scene; the time the ambulance left the scene; time the ambulance arrived at the hospital (if the patient was transported); and the time the ambulance left the hospital. The event/place information includes the address of each call, the identification number of the responding ambulance, its base, and the type of incident.

### Volume Four–Population and Housing Information

Volume four lists seven population and eight housing variables that were used as input for some of the computer programs. These data were adapted from a data base from the 1976 Special Census of Travis County, Texas conducted by the Bureau of Census of the U.S. Department of Commerce. Items utilized by the study include eight housing and seven population variables. The data were collected by census tracts or enumeration districts, areas that are different in size from the ATSO transportation serial zones. In order to utilize the Bureau of Census information, it was necessary for project members to develop a "table of equal areas" to aggregate census block data to transportation serial zones, the basic unit of analysis of the EMS project. In areas that lie outside the region for which the Bureau of Census collected information by census block, census data were aggregated to serial zones by interpreting data that were originally collected for enumeration districts.

**RECOMMENDATION**

This report describes the uses and limitations of computer methods for assisting in the planning of the emergency medical service system in Austin. Project members have collected all the necessary data for these techniques to be applied for EMS planning in Austin. We recommend that the models be applied to help develop a list of priority bases for EMS vehicles in Austin.

# References

(1) City of Austin, Texas, City Ordinance #750116-D, part 1, January 16, 1975.

(2) City of Austin, Texas, City Ordinance #750116-D, part 5, January 16, 1975.

(3) Austin Department of Emergency Medical Services, unpublished memorandum of October 11, 1978.

(4) David Eaton, Richard L. Church, Vivienne L. Bennett, Bryan L. Hamon, Luis G. Valencia Lopez, and Rodrigo Bustamante Alvarez, "On Deployment of Health Resources in Rural Valle del Cauca, Colombia," in *Planning and Development Processes in the Third World,* edited by Wade Cook (New York: North Holland Publishing Co., 1979 (forthcoming).

(5) Richard L. Church, and Charles S. ReVelle, "The Maximal Covering Location Problem," *Papers of the Regional Science Association* 32, no. 101 (Fall 1974): 101-18.

(6) James A. Fitzsimmons, and Bellur N. Strikar, "An Approach to Locating Urban Services," *Proceedings of the Ninth AIDS Conference* (St. Louis: AIDS, November 1978), pp. 252-54.

(7) ——. "A Methodology for Emergency Ambulance Deployment," *Management Science* 19, no. 6 (October 1971): 491-99.

(8) Laboratory for Computer Graphics and Spatial Analysis, *CALFORM Manual* (Version 1.1) (Cambridge, Mass.: Graduate School of Design, Harvard University, December 1972).

(9) ——. *SYMAP User's Reference Manual* (fifth edition), (Cambridge, Mass: Graduate School of Design, Harvard University, September 1975).

(10) ——, *SYMVU Manual* (third edition), (Cambridge, Mass.: Graduate School of Design, Harvard University, July 1977).

# Chapter Two
# Techniques for the Analysis of Emergency Medical Calls

Estimating the demand for emergency medical services is an integral part of developing procedures to determine the proper bases for EMS vehicles. Members of the EMS Policy Research Project have developed four computer programs that aggregate and array historical call data. The programs have been collected into CHAP, the Call History Analysis Package.

The primary purpose of this section is to discuss the purpose of CHAP and illustrate its use in analysis of EMS call information. The presentation will include information on program capabilities, the control and parameter cards, default values, and output information of each of the four programs. To facilitate an understanding of the use of CHAP, the project members have applied it to an incomplete set of Austin EMS call records.

## THE CALL HISTORY ANALYSIS PACKAGE (CHAP)

CHAP is designed to analyze historical call data, based upon dispatcher's records of the calls received by the Emergency Medical Service Department of the City of Austin. Depending upon the user's interests, any combination of the following four programs may be executed:

- Call Analysis Program (CAP)
- Response Analysis Program (RAP)
- Zonal Aggregation Program (ZAP)
- Generation of Additional Data Program (GAP)

One program (GAP) allows the user to generate additional data relating to EMS calls. GAP instructs the computer to calculate and store three items of information not collected by the City of Austin for each EMS call: the day of the week in which the call was received, the number of the week in which the call was received, and a code number 0 or 1 to signify whether or not the call occurred within a week for which all calls were recorded. After this information has been added to the call data, the computer tape which stores the data is rewritten. The user may request output in the form of computer cards, each of which will contain information (including the recent additions) on one EMS call.* GAP need only be executed when additional data are added to the data set.**

*Special instructions (not described in this manual) must be used to generate a new set of computer cards bearing this information.
**GAP is a special purpose routine based on the data available on June 1, 1979. Minor changes to GAP may be required before it is executed using additional EMS call information.

The other three programs—CAP, RAP, and ZAP—generate summary statistics from a historical record of EMS calls. The Call Analysis Program (CAP) aggregates historical call data by geographical location and by time interval. The frequency of calls that it subsequently computes can be printed out in a distribution matrix. The Response Analysis Program (RAP) permits the user to calculate a historical frequency distribution of calls for response time, on scene time, transport time to the hospital, and time at the hospital. If the user is interested in computing the total number of calls for each city serial zone, then the Zonal Aggregation Program (ZAP) would be executed. As with CAP, the frequency distribution of calls by zones can be presented in the form of a distribution matrix.

### Coded Call Information

The CHAP package is built around computer cards with information on the time, date, site, and treatment of incoming EMS calls. The format specification for each card is shown in Table 2-1. Dispatcher records are the source of this information, except the data of columns 21-24, which are derived by the GAP program.

All this EMS information was obtained from punch-clock records (in whole minute) of 4,024 incoming calls to EMS recorded in December of 1976 and January, June, July, and part of August of 1977 (1).* The EMS Policy Research Project treats this set of 4,024 calls as an incomplete expression of EMS demand in Austin because some of these records are known to be incorrect.

Most of the CHAP subroutines are capable of identifying call data cards with unacceptable values. For example, if the hour of the call on a card exceeds 23 (e.g., 26th hour of the day), the card would be flagged as unacceptable. Each subroutine will print out the nature of the error and the relative position of the computer card in the data deck. Errors in the specifications of the geographical area and the time interval are also identified by a CAP subroutine.

The user of such EMS call information implicitly makes a number of assumptions concerning its validity, completeness, and consistency. The user must assume that the EMS Department recorded and reported this call data accurately and in a consistent pattern. In other words, the assumption is that all incoming calls to EMS were recorded and that

*This data is different from the coded call data described in reference (2).

TABLE 2-1: FORMAT SPECIFICATION FOR CALL DATA

| Columns | Definition |
|---|---|
| 1-4 | zone number where call originates |
| 5-6 | month of call |
| 7-8 | date of call |
| 9-10 | time of call, hour (0-23) |
| 11-12 | time of call, minutes (0-59) in that hour |
| 13-14 | time of arrival on scene, minutes in an hour (0-59) |
| 15-16 | time of departure from scene, minutes in an hour (0-59) |
| 17-18 | time of arrival at hospital, minutes in an hour (0-59) |
| 19-20 | time of departure from hospital, minutes in an hour (0-59) |
| 21* | day of week (1-7, Monday=1) |
| 22-23* | rank order of the week in which the call occurred |
| 24* | 0 (if data exists for the full week in which the call occurs) |
| | 1 (if data does not exist for the full week in which the call occurs) |
| 25-26 | reference number of dispatched ambulance |
| 27-29 | zone from which ambulance was dispatched |
| 30-32 | code number for the type of call |

*These data are added by the GAP program.

there are no coding errors in the call data. If a user plans to forecast calls on the basis of this historical record, the implicit assumption is that future calls will mimic the geographical and temporal patterns in the limited historical record of calls.

RAP computes averages and standard deviations for call-related information in decimal fractions of minutes. The computation of statistics implicitly assumes that all times coded as X minutes are uniformly distributed within minute periods. In other words, there is no way to determine whether a call recorded as occurring in the third minute of an hour is more likely to have occurred in the first 15 seconds or the last 15 seconds of the minute.

**A Sample Problem**

Throughout the following sections, reference will be made to table 2-2, which depicts a sample problem. This problem is to calculate the number of EMS calls that occur during Mondays in the entire city of Austin over all months of data. The calls are to be aggregated into twelve two-hour intervals. In addition, assume that the user is interested in executing all the programs except GAP.

TABLE 2-2: A SAMPLE PROBLEM

| | |
|---|---|
| Zones | all |
| Days of the Week | Monday |
| Hourly Interval | two hours |
| Time Period | all months |
| Programs to be run | CAP,RAP,ZAP |

To solve such a CHAP problem, the user would need nine job control cards and various parameter cards. The blocks of parameter cards are illustrated in table 2-3.

TABLE 2-3: PARAMETER CARD BLOCKS

| Block | Description | Maximum number of cards in each block |
|---|---|---|
| A | program selection cards | five |
| B | zonal parameter cards | fourteen |
| C | period parameter cards | nine |
| D | interval parameter cards | two |
| E | time parameter cards | two |
| F | GOMAN card | one |
| G | CONTINUE or RESTART card | one |

Block A parameter cards are used to select program options. The control cards are shown in figure 2-1. The remaining blocks, B through G, apply only to the CAP program and will be discussed in later sections.

In the event that a user does not include certain parameter cards, the CHAP program has been provided with the built-in default values identified in table 2-4. Further attention to the use of default values will be given in the section concerned with the CAP program. In multiple analyses, the user can override the built-in default values by using the CONTINUE card.* If CONTINUE is employed, the values of parameters most recently executed become the current default values for subsequent runs.

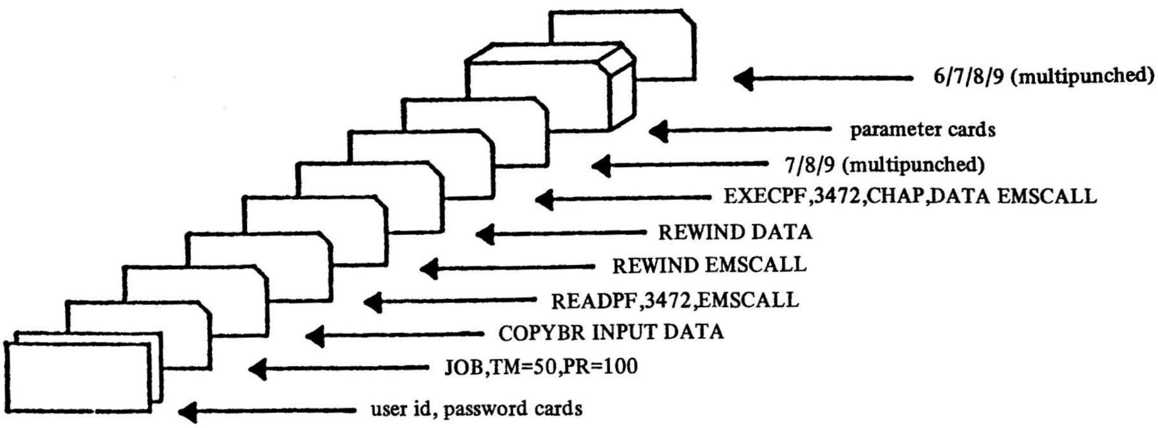
TABLE 2-4: CAP DEFAULT VALUES

| Block | Description | Default condition |
|---|---|---|
| B | zonal parameters | all zones |
| C | period parameters | WEEK option |
| D | interval parameters | six hours |
| E | time parameters | entire data set |
| F | GOMAN | NOPRINT option |

Blocks B, C, D, and E must be followed by blocks F and G. Within each block, the parameter cards must appear in the order they will appear in the appropriate sections.

*For a further discussion of RESTART and CONTINUE, see the discussion of block G cards below.

FIGURE 2-1: CONTROL CARDS FOR CHAP




**Block A (Program Selection Cards)**

The parameter cards specify whether or not to run the four programs in the CHAP package. Table 2-5 indicates the command needed to select each of the four programs as well as the QUIT command used to terminate execution of the CHAP package. It should be pointed out that QUIT must be the last card in the CHAP input deck before the 6/7/8/9 multipunch card.

TABLE 2-5: PARAMETER CARDS FOR PROGRAM SELECTION

| Variable* | Program Selected |
|---|---|
| ANALYZE | Call Analysis Program |
| FREQUENCY | Response Analysis Program |
| AGGREGATE | Zonal Aggregation Program |
| ADD | Generation of Additional Data Program |
| QUIT | Terminates execution of CHAP |

*Begin to keypunch each of these variables in column one.

Within a single run of the CHAP package, the user can execute several of these programs by selecting all appropriate block A parameter cards. For example, to execute all of the programs except GAP, a user would include the parameter cards shown in table 2-6. The ZAP, RAP, and GAP programs do not require parameter cards other than the block A cards.

TABLE 2-6: BLOCK A PARAMETER CARDS FOR THE SAMPLE PROBLEM

| Variable | Description |
|---|---|
| ANALYZE | executes CAP |
| FREQUENCY | executes RAP |
| AGGREGATE | executes ZAP |
| QUIT | terminates CHAP |

**ZAP and RAP Output Information**

Tables 2-7 and 2-8 illustrate the summary statistics that can be generated by the ZAP and RAP programs, respectively. Table 2-7, which is read from left to right, shows the average number of daily calls from each of the 358 city serial zones. Row 1 identifies the ten columns. The second row of numbers (i.e., 1, .536, 1.601, 0.000, . . ., 0.000) states the largest zone number previously listed (zone zero) and the relative frequency of calls in the next ten zones, zones 1 through 10. For example, over the five-month period, 1.601 EMS calls would arrive per day from zone two. The third row again lists the largest previous zone

(zone 10) and the average calls per zone for zones 11 through 20.*

times that an EMS vehicle responded to a call in the associated amount of time. The third row (FREQ) states the relative frequency response in that number of minutes. For example, the second row of data indicates that EMS units responded to 858 calls (21.3 percent of all recorded calls) in two minutes. The figure under the cumulative frequency column (CUM) indicates the total percentage of recorded calls that resulted in an emergency vehicle on the scene within the amount of time. In row two, the number .332 in

## TABLE 2-7: AVERAGE NUMBER OF DAILY CALLS PER ZONE (ZAP Program)

ZONAL DAILY AVERAGES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .536 | 1.601 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 10 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20 | 0.000 | 0.000 | .145 | 0.000 | .116 | .029 | .101 | .109 | .051 | .022 |
| 30 | .036 | .058 | .014 | .029 | .007 | .036 | .043 | .065 | .145 | .051 |
| 40 | .159 | .036 | .058 | .051 | .051 | .043 | .174 | .087 | 0.000 | .116 |
| 50 | 0.000 | .007 | 0.000 | 0.000 | 0.000 | .167 | .043 | .029 | .130 | .152 |
| 60 | .036 | .080 | .072 | .029 | .232 | .246 | .225 | .036 | .087 | .058 |
| 70 | .036 | .101 | .138 | .145 | .145 | .174 | .087 | .051 | .109 | .080 |
| 80 | .014 | .043 | .007 | .058 | .094 | .065 | .101 | .181 | .181 | .014 |
| 90 | .101 | .014 | .123 | .087 | .065 | .065 | .159 | .138 | .029 | .109 |
| 100 | .116 | .116 | .130 | .051 | .094 | .109 | .188 | .029 | .087 | .203 |
| 110 | .065 | .203 | .145 | .312 | .457 | .304 | .159 | .217 | .051 | .007 |
| 120 | .014 | .058 | .167 | .029 | .022 | .036 | .094 | .080 | .246 | .080 |
| 130 | .116 | .065 | .051 | .036 | .022 | .109 | .043 | .058 | .036 | .065 |
| 140 | .138 | .167 | .080 | .065 | .174 | .051 | .181 | .138 | .051 | .014 |
| 150 | .007 | .167 | .072 | .029 | .065 | .080 | .007 | 0.000 | .014 | 0.000 |
| 160 | .022 | .167 | .297 | .254 | .152 | 0.000 | .007 | .203 | .362 | .152 |
| 170 | .130 | .167 | .254 | .507 | .058 | .145 | .058 | .254 | .065 | .261 |
| 180 | .094 | .283 | .181 | .159 | .101 | .268 | .051 | .130 | .145 | .101 |
| 190 | .181 | .123 | .058 | .051 | .181 | .043 | .080 | .022 | .051 | .014 |
| 200 | .058 | .043 | .123 | .058 | .058 | .138 | .087 | .130 | .087 | .051 |
| 210 | .145 | .080 | .065 | .268 | .159 | .072 | .145 | .014 | .065 | .283 |
| 220 | .159 | .080 | .080 | .167 | .051 | .022 | 0.000 | .007 | 0.000 | .087 |
| 230 | .196 | .109 | .072 | .116 | .072 | .275 | .152 | .232 | .058 | .152 |
| 240 | .167 | .123 | .304 | .022 | .022 | .014 | .014 | 0.000 | .072 | 0.000 |
| 250 | .174 | .072 | .246 | .167 | .123 | .065 | .087 | .196 | .087 | .087 |
| 260 | .196 | 0.000 | .210 | .022 | .188 | .007 | .101 | .014 | .268 | .007 |
| 270 | 0.000 | .036 | .058 | .043 | .022 | .007 | .058 | 0.000 | .014 | .007 |
| 280 | .022 | .058 | .007 | .014 | 0.000 | .029 | .022 | .065 | 0.000 | 0.000 |
| 290 | 0.000 | 0.000 | 0.000 | 0.000 | .007 | 0.000 | 0.000 | .014 | 0.000 | .072 |
| 300 | .036 | 0.000 | .007 | 0.000 | 0.000 | 0.000 | .029 | .014 | .138 | .022 |
| 310 | .022 | .029 | .094 | .065 | .072 | .051 | 0.000 | 0.000 | 0.000 | 0.000 |
| 320 | 0.000 | 0.000 | 0.000 | .181 | 0.000 | 0.000 | .043 | .014 | .058 | .007 |
| 330 | 0.000 | 0.000 | 0.000 | .036 | .007 | 0.000 | .007 | .007 | .007 | 0.000 |
| 340 | .036 | 0.000 | 0.000 | 0.000 | .022 | 0.000 | .051 | .036 | 0.000 | 0.000 |
| 350 | .007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 2-8 (RAP output) identifies the relative and cumulative frequency of the "response time" for EMS calls. The first column (INTERVAL) lists minutes, from one to sixty. The second column (DIST) shows the number of

*This table is illustrative and does not portray the correct number of daily EMS calls in serial zones in Austin over the study period.

# TABLE 2-8: FREQUENCY TABLES (RAP Program)

FREQUENCY TABLFS

| | RESPONSE TIME | | | TIME AT SCENE | | | TRANSPORT TIME | | | TIME AT HOSPITAL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INTERVAL | DIST | FREQ | CUM. | DIST | FREQ | CUM. | DIST | FREQ | CUM. | DIST | FREQ | CUM. |
| 1 | 479 | .119 | .119 | 94 | .023 | .023 | 16 | .006 | .006 | 5 | .002 | .002 |
| 2 | 858 | .213 | .332 | 88 | .022 | .045 | 86 | .031 | .037 | 4 | .001 | .003 |
| 3 | 963 | .239 | .572 | 73 | .018 | .063 | 170 | .061 | .098 | 20 | .007 | .010 |
| 4 | 699 | .174 | .745 | 94 | .023 | .087 | 207 | .074 | .172 | 19 | .007 | .017 |
| 5 | 432 | .107 | .853 | 134 | .033 | .120 | 215 | .077 | .250 | 24 | .009 | .026 |
| 6 | 269 | .067 | .919 | 161 | .040 | .160 | 256 | .092 | .342 | 39 | .014 | .040 |
| 7 | 141 | .035 | .955 | 229 | .057 | .217 | 240 | .086 | .428 | 43 | .015 | .055 |
| 8 | 68 | .017 | .971 | 283 | .070 | .287 | 232 | .083 | .512 | 57 | .021 | .076 |
| 9 | 48 | .012 | .983 | 286 | .071 | .358 | 249 | .090 | .601 | 66 | .024 | .100 |
| 10 | 15 | .004 | .987 | 272 | .068 | .426 | 223 | .080 | .682 | 68 | .024 | .124 |
| 11 | 14 | .003 | .991 | 273 | .068 | .494 | 178 | .064 | .746 | 74 | .027 | .151 |
| 12 | 10 | .002 | .993 | 244 | .062 | .555 | 167 | .060 | .806 | 101 | .036 | .187 |
| 13 | 7 | .002 | .995 | 250 | .062 | .618 | 129 | .046 | .852 | 93 | .033 | .221 |
| 14 | 3 | .001 | .996 | 204 | .051 | .668 | 113 | .041 | .893 | 105 | .038 | .258 |
| 15 | 2 | .000 | .996 | 193 | .048 | .716 | 77 | .028 | .920 | 115 | .041 | .300 |
| 16 | 3 | .001 | .997 | 163 | .041 | .757 | 52 | .019 | .939 | 107 | .039 | .338 |
| 17 | 2 | .000 | .997 | 127 | .032 | .788 | 40 | .014 | .954 | 123 | .044 | .383 |
| 18 | 1 | .000 | .998 | 120 | .030 | .818 | 33 | .012 | .965 | 121 | .044 | .426 |
| 19 | 1 | .000 | .998 | 106 | .026 | .844 | 28 | .010 | .976 | 128 | .046 | .472 |
| 20 | 0 | 0.000 | .998 | 79 | .020 | .864 | 11 | .004 | .979 | 117 | .042 | .514 |
| 21 | 1 | .000 | .998 | 77 | .019 | .883 | 8 | .003 | .982 | 119 | .043 | .557 |
| 22 | 0 | 0.000 | .998 | 54 | .013 | .897 | 10 | .004 | .986 | 125 | .045 | .602 |
| 23 | 0 | 0.000 | .998 | 48 | .012 | .909 | 7 | .003 | .988 | 119 | .043 | .645 |
| 24 | 0 | 0.000 | .998 | 52 | .013 | .921 | 3 | .001 | .990 | 101 | .036 | .681 |
| 25 | 0 | 0.000 | .998 | 58 | .014 | .936 | 6 | .002 | .992 | 88 | .032 | .713 |
| 26 | 0 | 0.000 | .998 | 40 | .010 | .946 | 4 | .001 | .993 | 96 | .035 | .747 |
| 27 | 0 | 0.000 | .998 | 29 | .007 | .953 | 3 | .001 | .994 | 79 | .028 | .776 |
| 28 | 0 | 0.000 | .998 | 25 | .006 | .959 | 2 | .001 | .995 | 84 | .030 | .806 |
| 29 | 1 | .000 | .998 | 25 | .006 | .964 | 1 | .000 | .995 | 54 | .019 | .825 |
| 30 | 0 | 0.000 | .998 | 15 | .004 | .968 | 1 | .000 | .996 | 55 | .020 | .845 |
| 31 | 0 | 0.000 | .998 | 11 | .003 | .971 | 2 | .001 | .996 | 46 | .017 | .862 |
| 32 | 0 | 0.000 | .998 | 8 | .002 | .973 | 2 | .001 | .997 | 40 | .014 | .876 |
| 33 | 1 | .000 | .999 | 11 | .003 | .976 | 0 | 0.000 | .997 | 44 | .016 | .892 |
| 34 | 0 | 0.000 | .999 | 7 | .002 | .977 | 0 | 0.000 | .997 | 38 | .014 | .906 |
| 35 | 0 | 0.000 | .999 | 7 | .002 | .979 | 1 | .000 | .997 | 29 | .010 | .916 |
| 36 | 0 | 0.000 | .999 | 5 | .001 | .980 | 0 | 0.000 | .997 | 23 | .008 | .924 |
| 37 | 0 | 0.000 | .999 | 5 | .001 | .982 | 2 | .001 | .998 | 25 | .009 | .933 |
| 38 | 0 | 0.000 | .999 | 9 | .002 | .984 | 0 | 0.000 | .998 | 27 | .010 | .943 |
| 39 | 0 | 0.000 | .999 | 4 | .001 | .985 | 0 | 0.000 | .998 | 25 | .009 | .952 |
| 40 | 0 | 0.000 | .999 | 4 | .001 | .986 | 1 | .000 | .999 | 12 | .004 | .956 |
| 41 | 1 | .000 | .999 | 4 | .001 | .987 | 0 | 0.000 | .999 | 20 | .007 | .964 |
| 42 | 1 | .000 | .999 | 5 | .001 | .988 | 1 | .000 | .999 | 17 | .006 | .970 |
| 43 | 1 | .000 | .999 | 9 | .002 | .990 | 1 | .000 | .999 | 10 | .004 | .973 |
| 44 | 0 | 0.000 | .999 | 1 | .000 | .991 | 1 | .000 | 1.000 | 11 | .004 | .977 |
| 45 | 0 | 0.000 | .999 | 5 | .001 | .992 | 1 | .000 | 1.000 | 8 | .003 | .980 |
| 46 | 0 | 0.000 | .999 | 6 | .001 | .993 | 0 | 0.000 | 1.000 | 5 | .002 | .982 |
| 47 | 0 | 0.000 | .999 | 2 | .000 | .994 | 0 | 0.000 | 1.000 | 4 | .001 | .983 |
| 48 | 1 | .000 | 1.000 | 2 | .000 | .994 | 0 | 0.000 | 1.000 | 4 | .001 | .985 |
| 49 | 0 | 0.000 | 1.000 | 4 | .001 | .995 | 0 | 0.000 | 1.000 | 4 | .001 | .986 |
| 50 | 0 | 0.000 | 1.000 | 2 | .000 | .996 | 0 | 0.000 | 1.000 | 8 | .003 | .989 |
| 51 | 0 | 0.000 | 1.000 | 3 | .001 | .997 | 0 | 0.000 | 1.000 | 6 | .002 | .991 |
| 52 | 1 | .000 | 1.000 | 3 | .001 | .997 | 0 | 0.000 | 1.000 | 7 | .003 | .994 |
| 53 | 1 | .000 | 1.000 | 1 | .000 | .998 | 0 | 0.000 | 1.000 | 5 | .002 | .996 |
| 54 | 0 | 0.000 | 1.000 | 2 | .000 | .998 | 0 | 0.000 | 1.000 | 2 | .001 | .996 |
| 55 | 0 | 0.000 | 1.000 | 1 | .000 | .998 | 0 | 0.000 | 1.000 | 0 | 0.000 | .996 |
| 56 | 0 | 0.000 | 1.000 | 3 | .001 | .999 | 0 | 0.000 | 1.000 | 4 | .001 | .998 |
| 57 | 0 | 0.000 | 1.000 | 2 | .000 | 1.000 | 0 | 0.000 | 1.000 | 4 | .001 | .999 |
| 58 | 0 | 0.000 | 1.000 | 1 | .000 | 1.000 | 0 | 0.000 | 1.000 | 0 | 0.000 | .999 |
| 59 | 0 | 0.000 | 1.000 | 1 | .000 | 1.000 | 0 | 0.000 | 1.000 | 2 | .001 | 1.000 |
| 60 | 0 | 0.000 | 1.000 | 0 | 0.000 | 1.000 | 0 | 0.000 | 1.000 | 0 | 0.000 | 1.000 |
| TOTAL CALLS= | 4024 | | | 4024 | | | 2779 | | | 2779 | | |

STATISTICS

| RESPONSE TIME | TIME AT SCENE | TRANSPORT TIME | TIME AT HOSPITAL |
|---|---|---|---|
| AVERAGE= 3.649 | AVERAGE= 13.056 | AVERAGE= 8.959 | AVERAGE= 21.177 |
| VARIANCE= 7.498 | VARIANCE= 63.370 | VARIANCE= 23.601 | VARIANCE= 95.311 |
| STD DEVIATION= 2.738 | STD DEVIATION= 7.961 | STD DEVIATION= 4.858 | STD DEVIATION= 9.763 |

PERCENT OF CALLS TRANSPORTED=69.13

TOTAL CALLS=4020

the fourth column indicates that ambulances arrived on scene in two minutes or less in 33.2 percent of all calls. Table 2-8 shows the raw data, relative frequency, and cumulative distribution of time at scene, transport time, and time at hospital for incoming EMS calls, as expressed in whole minutes.

## THE CALL ANALYSIS PROGRAM (CAP)

### Introduction

The CAP program allows a user to specify a geographical area and a time interval and calculate the relative frequency of calls for that place and period. The program will compute summary statistics (i.e., frequency counts, averages, variances, standard deviations, and percentages) for these specifications.

The allowable specifications for the geographical area include: all zones of the city; ranges of city zones; individual zones; and combinations of ranges and individual zones. A city zone (or city serial zone) is a geographic area used by the Transportation Study Office and the Transportation Department of the City of Austin for study purposes. In Austin there are 358 city zones which approximately aggregate to census tracts and planning areas.

The time interval options, as previously listed in table 2-3, include: (a) the months or weeks under analysis (the TIME cards); (b) the days under analysis (the PERIOD cards); and (c) the hour interval (the INTERVAL cards). The first two options are used to select a subset of EMS calls for the analysis. When the user specifies the months or weeks of interest, the beginning and ending months and dates may be defined on control cards. The user can generate relative frequency information for various periods in a week: the full week, particular days of the week, or groups of days. The hour option is used to specify one level of aggregation (hour interval) of calls. The CAP program can generate a relative frequency of calls for 1, 2, 3, 4, 6, 8, 12, and 24 hour intervals (any integer factor of 24).

This CAP section describes both the parameter cards and the output of the program. The discussion will include consideration of the circumstances under which the parameter cards would be required and the default values that would be used if certain cards are not included in the input deck. Examples of keypunching formats will refer to the sample problem.

### Block B (Zonal Parameter Cards)

Block B specifies the city zones for which call data should be aggregated. As many as fourteen parameter cards are required if a user wishes to specify particular zones. If a user is interested in all city zones, then only one zonal parameter card need be included in the parameter deck; the remaining cards are unnecessary and should be omitted.

The first parameter card specifies the geographical area of interest. This area can be the entire city (all city zones), ranges of city zones, or particular zones of the city. The card is punched according to the specifications in table 2-9.

TABLE 2-9: FIRST ZONAL PARAMETER CARD

| Columns | Variable | Definition |
|---|---|---|
| 1-4 | ZONE | - |
| 11-16 | ALL | all city zones are specified |
| | RANGE | ranges of city zones are specified |
| | NUMBER | particular city zones are specified |

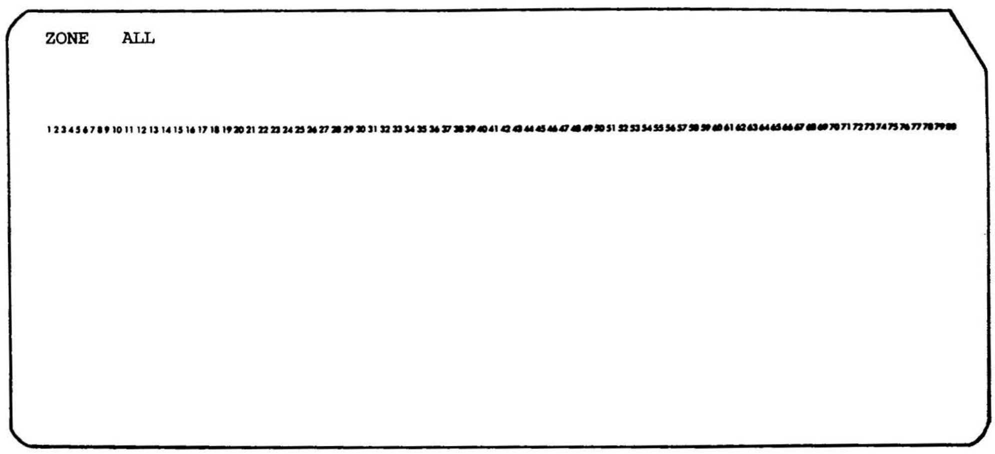
To run the sample problem, the user would punch "ZONE" in columns 1-4 and "ALL" in columns 11-13 on the first parameter card. This information informs the computer that the entire city has been specified as the area for geographical analysis. All alphabetic values must begin in the first column of the field, as illustrated in figure 2-2. If the user does not provide a block B parameter card, then CAP will use the current default value.

A parameter card or set of cards identifies either the range of city zones or the individual zones which the user wishes to consider. For illustrative purposes, assume that a user is interested in the frequencies of calls in city zones 1 through 24. In this case, the first parameter card has "ZONE" punched in columns 1-4 and "RANGE" in columns 11-15. The second parameter card is punched according to the specifications in table 2-10.

TABLE 2-10: FORMAT FOR POSSIBLE SECOND ZONAL PARAMETER CARD

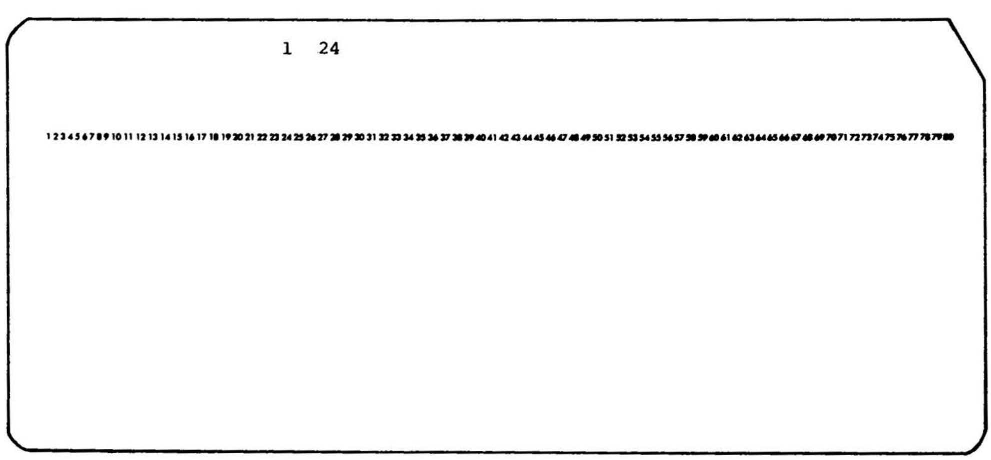
| Columns | Specification |
|---|---|
| 21-24 | lowest zone number of range |
| 25-28 | highest zone number of range |

FIGURE 2-2: FIRST ZONAL PARAMETER CARD




More than one card following this format may be used. A maximum of five ranges may be specified, with one range per computer card. All zone numbers must be right-justified in their fields as shown in figure 2-3.

FIGURE 2-3: POSSIBLE SECOND ZONAL PARAMETER CARD

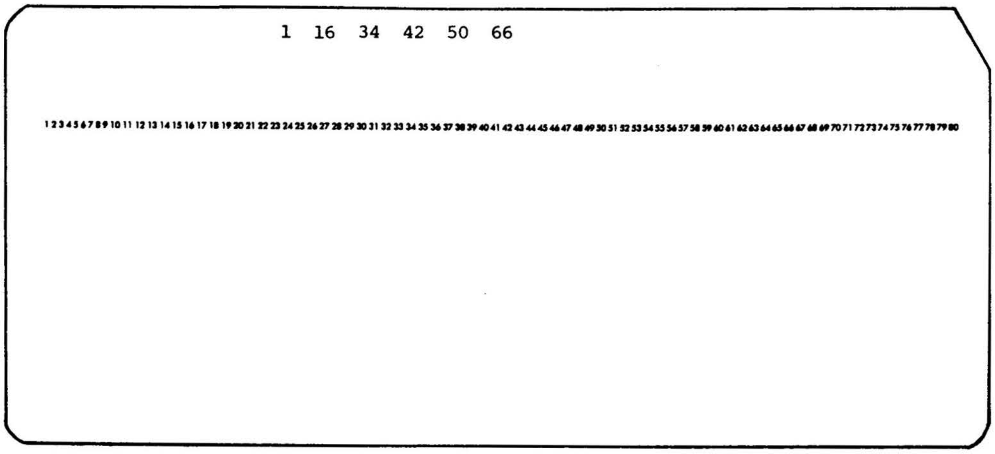



If individual city zones are specified as part of the geographical area, each zone is punched in sequential four-column blocks, beginning with columns 21 through 24. If four zones are the area of interest, the first zone number is entered in columns 21-24, the second in columns 25-28, the third in columns 29-32, and the fourth in columns 33-36. The parameter card containing this information would follow another zonal parameter card with "ZONE" punched in columns 1-4 and "NUMBER" punched in columns 11-16. Using groups of four columns, a maximum of ten city zones can be punched on each card. A user may specify as many as five of these cards, or fifty zones. Figure 2-4 illustrates how a card should be punched if a user wishes to specify six individual city zones (i.e., zones 1, 16, 34, 42, 50, and 66) as the geographical area. Punch only the columns of the cards necessary to specify the selected zones, with ZONE numbers right-justified in their fields.

A final parameter card, with "END" punched in columns one through three, signals an end to the geographical specifications. It is used whenever ranges of the city zones or individual city zones are specified as part of the geographical area.

A combination of ranges and particular city zones may be analyzed by the CAP program during one run. If the user

FIGURE 2-4: SECOND ZONAL PARAMETER CARD FOR INDIVIDUAL ZONES




is interested in specifying an area of this nature, then two sets of block B parameter cards would be required. One set would describe the range of zones and the other the particular city zones of interest.

### Block C (Period Parameter Cards)

Block C indicates the time period of interest. If the user wishes to perform an analysis of weekly call data, then only one parameter card need be used as input to the CAP program. As many as nine parameter cards could be included in a card deck if a user is interested in analyzing specific days of the week.

The first parameter card specified whether the whole week or particular days of the week are to be analyzed. "PERIOD" is always punched in columns 1 through 6. If the user is interested in analyzing the entire week, then columns 11 through 14 will contain the word "week." If particular days are of interest, such as Mondays in the sample problem, the word "DAYS" is punched in columns 11 through 14 (see figure 2-5). Whenever the block C parameter cards are omitted, the CAP program utilizes its current default value as the period option.

The second parameter card or deck of cards is necessary if DAYS appears on the first parameter card. One day can be punched on each card; thus the "second parameter card" could be a deck of up to seven cards. The first four letters of the name of the day should be punched in columns 1 through 4. For the sample problem, "MOND" would be punched in these columns (see figure 2-6), to indicate that

FIGURE 2-5: FIRST PERIOD PARAMETER CARD

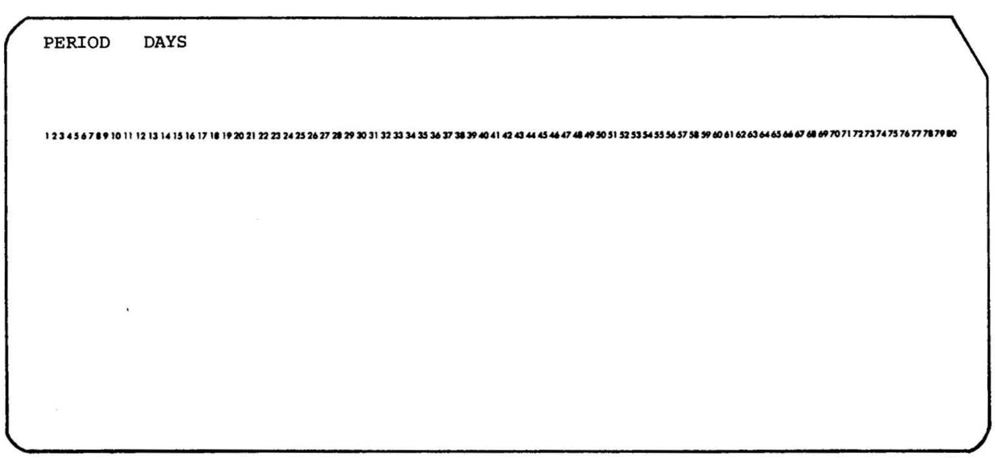
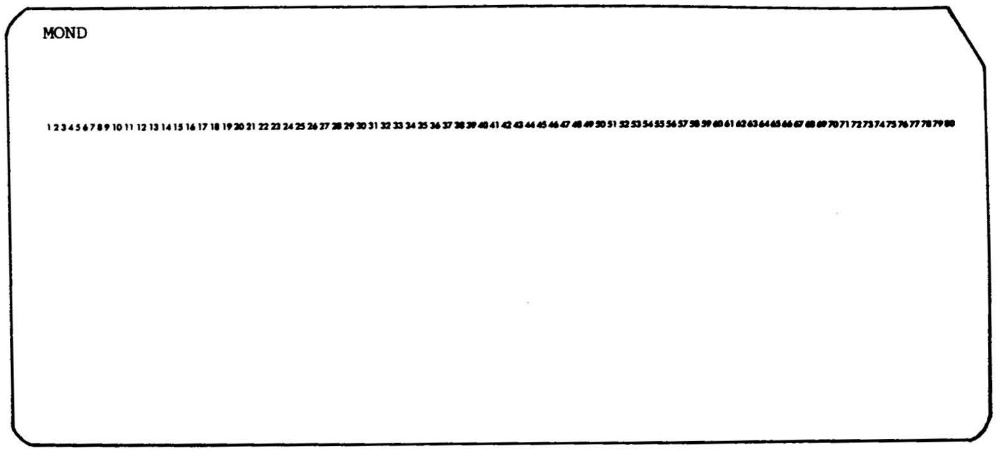


FIGURE 2-6: SECOND PERIOD PARAMETER CARD




the user wishes to analyze only Monday call data.

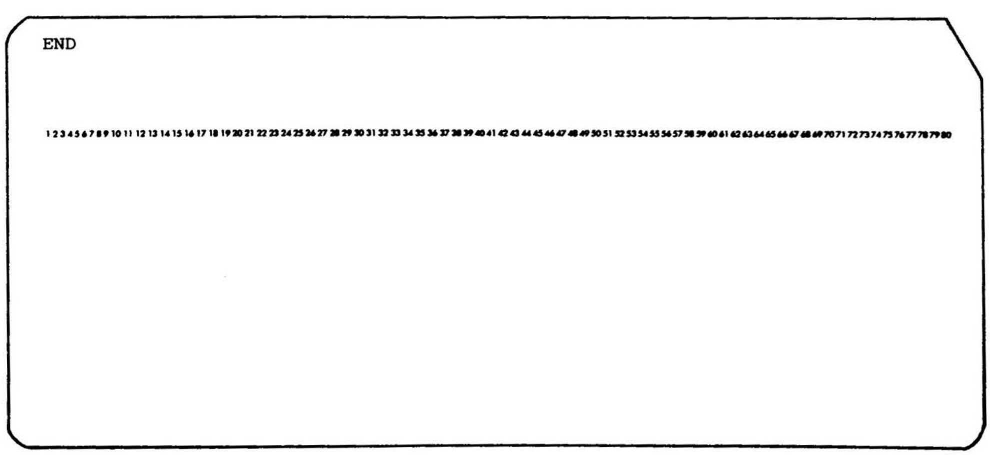
All seven days of the week can be analyzed by either the WEEK or the DAYS option. Although both runs would analyze all seven days of the week, they would produce different numerical results. When the WEEK option is utilized, the CAP program analyzes call data only for those weeks in which data for seven days are available. Under this option, the number of Mondays is equal to the number of Tuesdays, and so on. If the DAYS option is selected, the program will include a larger number of EMS calls, since the number of Mondays may differ from the number of Tuesdays, etc. Although the DAYS option includes a larger number of calls, it is not as consistent a set of data. Thus, "WEEK" is recommended over "DAYS" for analyzing calls from all seven days of the week.

A final parameter card terminates block C information. "END" is punched in columns one through three of the third card, as illustrated in figure 2-7. In the sample problem, the user must include parameter card three, since Monday is the day of interest. If the user had selected the WEEKS option, then this third period parameter card would not be required.

**Block D (Interval Parameter Cards)**

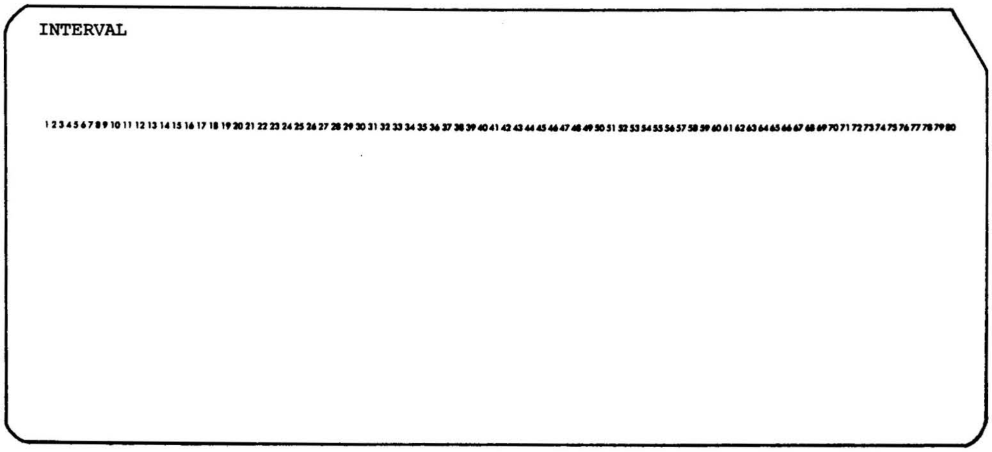
The two parameter cards of block D specify the number of hours into which EMS calls are to be aggregated. Both cards are required whenever the user specifies an hour inter-

FIGURE 2-7: THIRD PERIOD PARAMETER CARD



val other than the current default value. The word "INTERVAL" is punched in columns 1 through 8 of the first parameter card, as in figure 2-8, to indicate that the subsequent card contains the interval length.

FIGURE 2-8: FIRST INTERVAL PARAMETER CARD




The second parameter card specifies the exact "number of hours" interval to be used in aggregating the call data. Any integer factor of 24 (i.e., 1, 2, 3, 4, 6, 8, 12, and 24) can be punched right-justified in columns 1 through 3. For the sample problem, which is concerned with aggregating call data by two hour intervals, the use would punch a "2" in column 3 (see figure 2-9).

**Block E (Time Parameter Cards)**

Block E indicates the length of the historical record of EMS calls to be included in the analysis. If a user is concerned with the relative frequency of calls over all months, as in the sample case, then block E parameter cards can be omitted. If the CAP user is interested in call data for a specific range of calendar dates (e.g., some subset of the total historical record), then block E cards are required.*

***If the length of the historical record to be analyzed is identical to the current default value for this block, then block E cards may be omitted.**

FIGURE 2-9: SECOND INTERVAL PARAMETER CARD

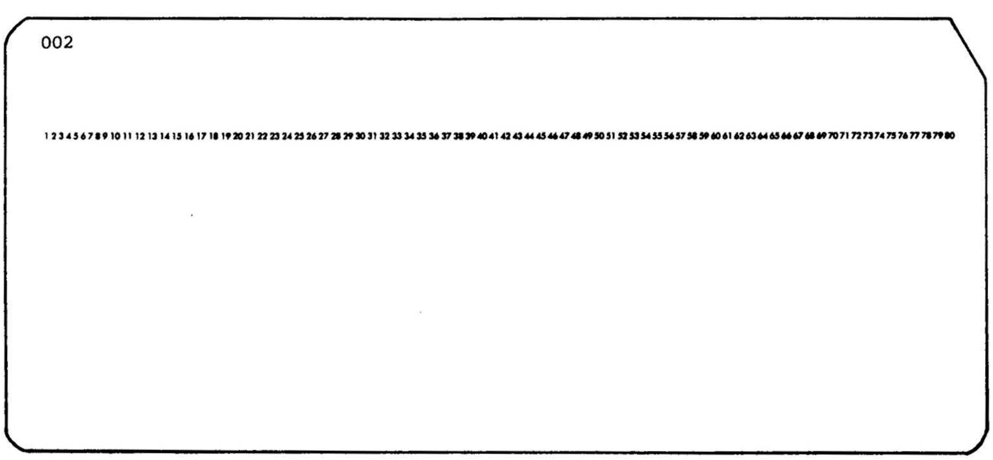
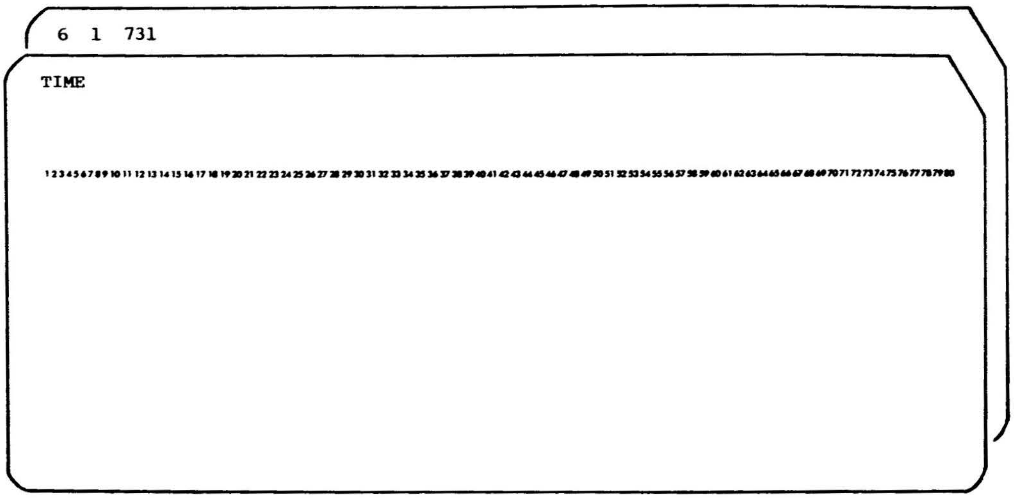


FIGURE 2-10: FIRST TWO TIME PARAMETER CARDS




The first parameter card contains the word "TIME" punched in columns 1 through 4. The second parameter card indicates the limits of the period from which call data are to be aggregated. Figure 2-10 illustrates these two cards.

Consider a hypothetical situation in which data representing two of five months of calls (June 1 through July 31) are of interest. The user should follow certain conventions for this data. The number of the beginning month must be less than or equal to the number of the ending month. If the initial and final months are the same, then the beginning date must be less than or equal to the ending date. The format specifications are outlined in table 2-11.

TABLE 2-11: FORMAT FOR SECOND TIME PARAMETER CARD

| Columns | Specifications |
|---|---|
| 1-2 | number of the beginning month |
| 3-4 | beginning date |
| 5-6 | number of the ending month |
| 7-8 | ending date |

**Block F (GOMAN Card)**

Block F contains one parameter card which is required for each CAP analysis. This card initiates the analysis and should follow all the parameter cards needed to describe the analysis. The options PRINT and NOPRINT (see table 2-12) specify whether CAP should print (or not print) the matrix of frequencies of calls for the selected time interval, day of the week, period of the data, and zone of the city. Figure 2-11 illustrates the keypunch format to print the matrix.

TABLE 2-12: THE FORMAT FOR THE GOMAN PARAMETER CARD

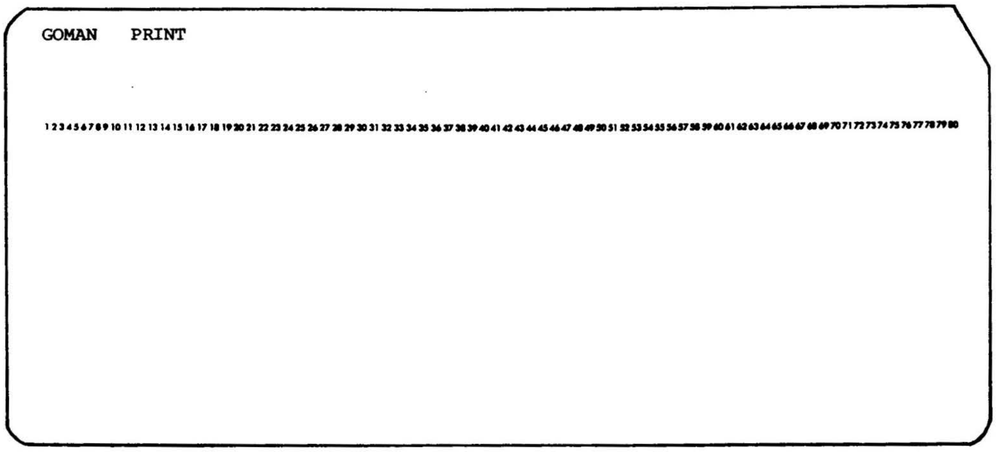
| Columns | Variable | Definition |
|---|---|---|
| 1-5 | GOMAN | identifies end of parameter set |
| 11-15 | PRINT | prints the distribution matrix |
| | NOPRINT | does not print the distribution matrix |

**Block G (Program Continuation Cards—CONTINUE and RESTART)**

Block G contains those parameter cards which allow the user to execute multiple analyses with a single CAP run. The format specifications for these parameter cards require that either the word "CONTINUE" or the word "RESTART" be keypunched in columns 1 through 8. Only one of these two variables should be used after each analysis.

The user may wish to perform subsequent analyses that

FIGURE 2-11: GOMAN PARAMETER CARD




make only minor modifications to the previous run. For example, assume that a user has completed the sample problem and now wishes to change the hour time interval from two to four hours. In this circumstance, the CONTINUE command would direct the CAP program to use the most recent parameter values, rather than the built-in default options of the CAP program. An illustration of the required parameter cards for this additional analysis is shown in figure 2-12.

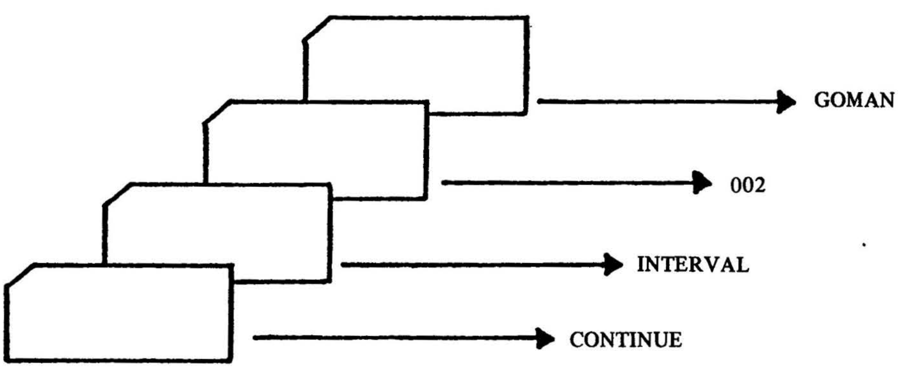
Alternatively, the user may wish to perform a subsequent analysis that differs significantly from the previous analysis. In such a case, the built-in CHAP default options may be more convenient. For example, imagine that a user seeks information on the number of calls in all zones for four-hour periods in all days of the week. In this case, the user could use the CHAP default options, changing only the time interval (from six- to four-hour periods). The RESTART command will instruct the computer to use these built-in options and any specified "number of hours" interval (see figure 2-13).

Figure 2-14 is an illustration of a complete set of parameter cards for the CHAP package. The order of the parameter cards required to perform additional analysis on the EMS call data is also depicted in this illustration.

## CAP Output Information

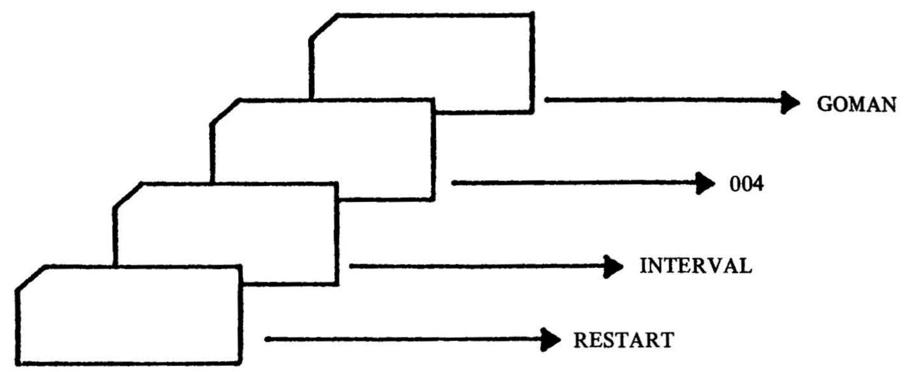
Four types of CAP output information for the sample problem are represented in this section. One type of output, shown in table 2-13, is a set of error summaries—a list

FIGURE 2-12: EXAMPLE USE OF CONTINUE OPTION




Note: Begin all cards in column one.

FIGURE 2-13: EXAMPLE USE OF RESTART OPTION

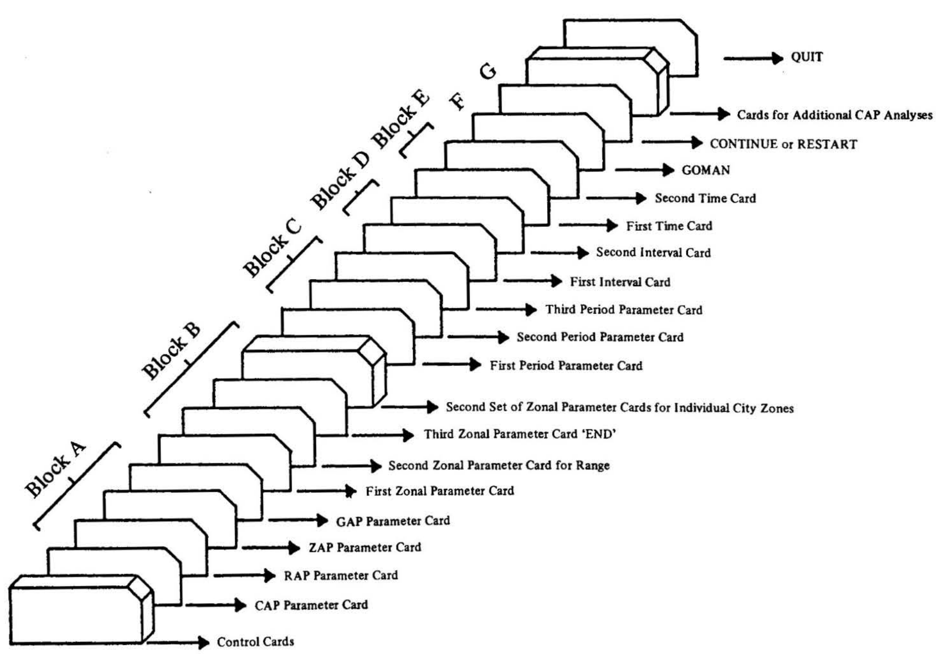



Note: Begin all cards in column one.

of unacceptable call data or parameter card values. A second output, illustrated in table 2-14, is a listing of the geographical areas and the time intervals which have been selected by the user. For the sample problem, this information would be identical to table 2-2. Table 2-15, a table of summary frequency statistics of calls in the selected time intervals, is a third type of printed result. Each of these results is printed for all CAP runs.

Table 2-16 illustrates a fourth possible output, the distribution matrix, which is obtained only if the PRINT option on the GOMAN is in effect. To illustrate the interpretation of the distribution matrix, imagine that the user wishes to determine the number of calls throughout the entire city between 6 a.m. and 8 a.m., during the tenth week of the call data. The information is shown as the circled number "2" in table 2-16 under week 10 and across from

FIGURE 2-14: INPUT DECK FOR CAP, RAP, ZAP, AND GAP



## TABLE 2-13: ERROR SUMMARIES

```
***INPUT*** INVALID TIME PERIOD. RESETTING TO ENTIRE DATA SET.

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12    2   16   20   22   32   38   59    4    1    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12    5   12   13   19   34   52    7    7    1    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12    8   13   20   28   11    0    0    3    2    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   11   19   23   30   54    5   23    6    2    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   12   11   13   17   30   38   57    7    2    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   16   10   12   17    0    0    0    4    3    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   17   19   31   33   52    7   29    5    3    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   20    3   56    2   28   37    7    1    3    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   21   15    2    4    6    0    0    2    3    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0   12   22    9   40   47    4   20   38    3    4    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0    2    3    7   58    3   27   35    3    4    6    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0    6    1   14   31   35   39    0    0    3   10    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0    6    5   13   31   36   49    0   23    7   10    0

***RUNIT*** ZONE EXCEPTION...WARNING...CALL DATA FOLLOWS
   0    6   21    0    0    4   15   26   33    2   12    0
```

## TABLE 2-14: SELECTED GEOGRAPHICAL AREAS AND TIME INTERVALS

```
ZONES        ALL

DAYS OF WEEK
                    MON

INTERVAL WAS    2 HOURS.

PERIOD WAS          ALL 5 MONTHS

**********************************************************************************

WARNING

          FOR RESTRICTED DATASET ANALYSES THE NUMBER OF WEEKS
          USED TO COMPUTE INTERVAL AVERAGES AND VARIANCES
          MAY BE ARTIFICIALLY LOW.  THE WEEKS MAY NOT
          CORRESPOND TO CALENDAR WEEKS IN THESE CASES.
          USE WITH CAUTION.

**********************************************************************************
```

## TABLE 2-15: SUMMARY FREQUENCY STATISTICS

| INTERVAL | COUNT | AVERAGE | VARIANCE | STD. DEV. | PERCENT |
|---|---|---|---|---|---|
| 1 | 33. | 1.74 | 2.65 | 1.63 | 5.92 |
| 2 | 28. | 1.47 | 1.93 | 1.39 | 5.03 |
| 3 | 23. | 1.21 | 1.40 | 1.18 | 4.13 |
| 4 | 19. | 1.00 | 1.00 | 1.00 | 3.41 |
| 5 | 40. | 2.11 | 2.77 | 1.66 | 7.18 |
| 6 | 57. | 3.00 | 3.33 | 1.83 | 10.23 |
| 7 | 54. | 2.84 | 2.58 | 1.61 | 9.69 |
| 8 | 76. | 4.00 | 5.78 | 2.40 | 13.64 |
| 9 | 76. | 4.00 | 5.67 | 2.38 | 13.64 |
| 10 | 53. | 2.79 | 3.84 | 1.96 | 9.52 |
| 11 | 46. | 2.42 | 2.15 | 1.46 | 8.26 |
| 12 | 52. | 2.74 | 3.43 | 1.85 | 9.34 |

***TOTAL DEMAND ANALYZED WAS 557. CALLS.

| WEEK | COUNT | AVERAGE | VARIANCE | STD. DEV. | PERCENT |
|---|---|---|---|---|---|
| 1 | 33. | 2.75 | 2.02 | 1.42 | 5.92 |
| 2 | 39. | 3.25 | 4.39 | 2.09 | 7.00 |
| 3 | 22. | 1.83 | 2.15 | 1.47 | 3.95 |
| 4 | 18. | 1.50 | .82 | .90 | 3.23 |
| 5 | 24. | 2.00 | 1.09 | 1.04 | 4.31 |
| 6 | 14. | 1.17 | .88 | .94 | 2.51 |
| 7 | 28. | 2.33 | 4.97 | 2.23 | 5.03 |
| 8 | 22. | 1.83 | 3.42 | 1.85 | 3.95 |
| 9 | 33. | 2.75 | 1.66 | 1.29 | 5.92 |
| 10 | 42. | 3.50 | 3.91 | 1.98 | 7.54 |
| 11 | 29. | 2.42 | 2.27 | 1.51 | 5.21 |
| 12 | 34. | 2.83 | 5.97 | 2.44 | 6.10 |
| 13 | 24. | 2.00 | 5.45 | 2.34 | 4.31 |
| 14 | 30. | 2.50 | 3.18 | 1.78 | 5.39 |
| 15 | 23. | 1.92 | 1.90 | 1.38 | 4.13 |
| 16 | 45. | 3.75 | 6.75 | 2.60 | 8.08 |
| 17 | 18. | 1.50 | 3.00 | 1.73 | 3.23 |
| 18 | 38. | 3.17 | 7.97 | 2.82 | 6.82 |
| 19 | 41. | 3.42 | 5.36 | 2.31 | 7.36 |

***TOTAL DEMAND ANALYZED WAS 557. CALLS.

period 4. Since the two-hour intervals begin at midnight, period 4 represents the 7th and 8th hours of the day (between 6 a.m. and 8 a.m.) in the 10th week.

### AUSTIN APPLICATION OF CHAP*

The purpose of this section is to discuss the ways in which CHAP programs can be used to analyze historical calls for emergency medical service in Austin. Whenever the CAP program is executed, it aggregates EMS calls by geographical location and time interval. It then generates the relative frequency of calls for these selected places and periods in Austin. The RAP program generates the cumulative frequency distribution of call-response time, on-scene time, transport time to the hospital, and time at the hospital.

#### EMS Calls

Table 2-17 is an incomplete list of the total number of EMS calls in each of 358 transportation serial zones in Austin during the five-month period.* Figure 2-15 represents a graph of the average number of calls per two-hour intervals in the city of Austin, graphed for different hours of the day. The horizontal axis lists each of twelve two-hour intervals on Mondays beginning with midnight to 2 a.m. and ending with 10 p.m. to midnight of Tuesday. The largest volume of calls on Mondays occurred during 2 p.m. to 6 p.m., in which four calls were received during each of the two-hour intervals.

*These results do not accurately reflect the historical record of EMS calls in Austin as shown in reference (1). A correct set of calls is listed in reference (2).

#### Response Time

The RAP program is able to calculate both the relative and cumulative frequency of response times for all calls in the data set. These frequency graphs are shown in figures 2-16 and 2-17, respectively. Both figures indicate that the EMS system's dispatched vehicles arrived on the scene ten minutes or less in nearly all cases. Approximately 74 percent of EMS calls result in emergency treatment in four minutes or less. Almost half of the sites of incoming calls are reached by EMS vehicles in 2.5 minutes or less.

#### Time on Scene and Transport Time

Figure 2-18 illustrates the cumulative frequency of time-on-scene for all recorded calls in the data set. Half the recorded calls required at least twelve minutes of EMS staff time-on-scene.

The cumulative frequency of transport times is depicted by the graph in figure 2-19. According to this graph, the transport time from the scene of the emergency to the

## TABLE 2-16: DISTRIBUTION MATRIX*

| PERIOD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 1 | 1 | 1 | 1 | 0 | 1 | 2 | 1 | 3 | 2 | 0 | 1 | 1 | 5 | 1 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33. |
| 2 | 0 | 1 | 2 | 0 | 2 | 0 | 2 | 0 | 3 | 2 | 0 | 2 | 5 | 2 | 2 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28. |
| 3 | 2 | 3 | 2 | 3 | 3 | 2 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23. |
| 4 | 2 | 1 | 1 | 1 | 1 | 3 | 0 | 3 | 2 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19. |
| 5 | 4 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 4 | 4 | 3 | 1 | 1 | 3 | 2 | 4 | 5 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40. |
| 6 | 3 | 3 | 2 | 1 | 4 | 1 | 5 | 3 | 4 | 3 | 1 | 6 | 0 | 2 | 1 | 7 | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 57. |
| 7 | 4 | 3 | 2 | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 4 | 2 | 1 | 4 | 1 | 6 | 0 | 3 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 54. |
| 8 | 5 | 8 | 1 | 2 | 2 | 0 | 5 | 6 | 2 | 7 | 2 | 9 | 5 | 5 | 4 | 4 | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76. |
| 9 | 3 | 3 | 2 | 2 | 2 | 1 | 6 | 3 | 5 | 6 | 3 | 3 | 1 | 6 | 4 | 7 | 2 | 9 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76. |
| 10 | 3 | 6 | 6 | 2 | 2 | 1 | 4 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 1 | 0 | 8 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 53. |
| 11 | 2 | 4 | 2 | 1 | 3 | 2 | 0 | 1 | 3 | 5 | 3 | 2 | 1 | 3 | 4 | 5 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46. |
| 12 | 4 | 2 | 1 | 3 | 2 | 1 | 2 | 0 | 3 | 5 | 5 | 3 | 7 | 1 | 1 | 5 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52. |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |
| 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. |

*The distribution matrix contains zero for periods 58-168.

hospital was less than twenty-eight minutes for all calls. In fifty percent of the cases, the EMS vehicle required less than eight minutes to transport the patient from the scene of the emergency to the hospital.

### Time at Hospital

Figure 2-20 presents a graph of the cumulative time at the hospital. In 50 percent of the cases, the EMS vehicle remained at the hospital for eighteen or more minutes.

### Policy Analysis

Some of the CHAP package results could affect present City EMS policies. One subroutine was used to analyze the relative frequency of calls by two-hour periods through the entire week for all full weeks of data. The results indicated that some periods are busier than others and some areas are busier than others.

The results of the CHAP package indicate that the frequency of calls in the Central Business District (CBD) is higher than that of calls occurring outside the area. Under these circumstances of high call colume, more EMS sites may be justified in or near the CBD than might be suggested on the basis of its size alone.

The periods of 3 p.m. to 6 p.m. (Monday, Tuesday, and Wednesday) and 9 p.m. to midnight (Thursday, Friday, Saturday, and Sunday) are much busier than other times of

## TABLE 2-17: TOTAL EMS CALLS BY SERIAL ZONE

SUMMARY OF ZONE COUNTS

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 74 | 221 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 20 | 0 | 16 | 4 | 14 | 15 | 7 | 3 |
| 30 | 5 | 8 | 2 | 4 | 1 | 5 | 6 | 9 | 20 | 7 |
| 40 | 22 | 5 | 8 | 7 | 7 | 6 | 24 | 12 | 0 | 16 |
| 50 | 0 | 1 | 0 | 0 | 0 | 23 | 6 | 4 | 18 | 21 |
| 60 | 5 | 11 | 10 | 4 | 32 | 34 | 31 | 5 | 12 | 8 |
| 70 | 5 | 14 | 19 | 20 | 20 | 24 | 12 | 7 | 15 | 11 |
| 80 | 2 | 6 | 1 | 8 | 13 | 9 | 14 | 25 | 25 | 2 |
| 90 | 14 | 2 | 17 | 12 | 9 | 9 | 22 | 19 | 4 | 15 |
| 100 | 16 | 16 | 18 | 7 | 13 | 15 | 26 | 4 | 12 | 28 |
| 110 | 9 | 28 | 20 | 43 | 63 | 42 | 22 | 30 | 7 | 1 |
| 120 | 2 | 8 | 23 | 4 | 3 | 5 | 13 | 11 | 34 | 11 |
| 130 | 16 | 9 | 7 | 5 | 3 | 15 | 6 | 8 | 5 | 9 |
| 140 | 19 | 23 | 11 | 9 | 24 | 7 | 25 | 19 | 7 | 2 |
| 150 | 1 | 23 | 10 | 4 | 9 | 11 | 1 | 0 | 2 | 0 |
| 160 | 3 | 23 | 41 | 35 | 21 | 0 | 1 | 28 | 50 | 21 |
| 170 | 18 | 23 | 35 | 70 | 8 | 20 | 8 | 35 | 9 | 36 |
| 180 | 13 | 39 | 25 | 22 | 14 | 37 | 7 | 18 | 20 | 14 |
| 190 | 25 | 17 | 8 | 7 | 25 | 6 | 11 | 3 | 7 | 2 |
| 200 | 8 | 6 | 17 | 8 | 8 | 19 | 12 | 18 | 12 | 7 |
| 210 | 20 | 11 | 9 | 37 | 22 | 10 | 20 | 2 | 9 | 39 |
| 220 | 22 | 11 | 11 | 23 | 7 | 3 | 0 | 1 | 0 | 12 |
| 230 | 27 | 15 | 10 | 16 | 10 | 38 | 21 | 32 | 8 | 21 |
| 240 | 23 | 17 | 42 | 3 | 3 | 2 | 2 | 0 | 10 | 0 |
| 250 | 24 | 10 | 34 | 23 | 17 | 9 | 12 | 27 | 12 | 12 |
| 260 | 27 | 0 | 29 | 3 | 26 | 1 | 14 | 2 | 37 | 1 |
| 270 | 0 | 5 | 8 | 6 | 3 | 1 | 8 | 0 | 2 | 1 |
| 280 | 3 | 8 | 1 | 2 | 0 | 4 | 3 | 9 | 0 | 0 |
| 290 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 10 |
| 300 | 5 | 0 | 1 | 0 | 0 | 0 | 4 | 2 | 19 | 3 |
| 310 | 3 | 4 | 13 | 9 | 10 | 7 | 0 | 0 | 0 | 0 |
| 320 | 0 | 0 | 0 | 25 | 0 | 0 | 6 | 2 | 8 | 1 |
| 330 | 0 | 0 | 0 | 5 | 1 | 0 | 1 | 1 | 1 | 0 |
| 340 | 5 | 0 | 0 | 0 | 3 | 0 | 7 | 5 | 0 | 0 |
| 350 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TOTAL NUMBER OF DATA POINTS ANALYZED = 4010
AVERAGE PER ZONE = 11.2640
VARIANCE ABOUT AVERAGE = 263.76
STANDARD DEVIATION = 16.2407

FIGURE 2-15: CALL FREQUENCY FOR SAMPLE PROBLEM

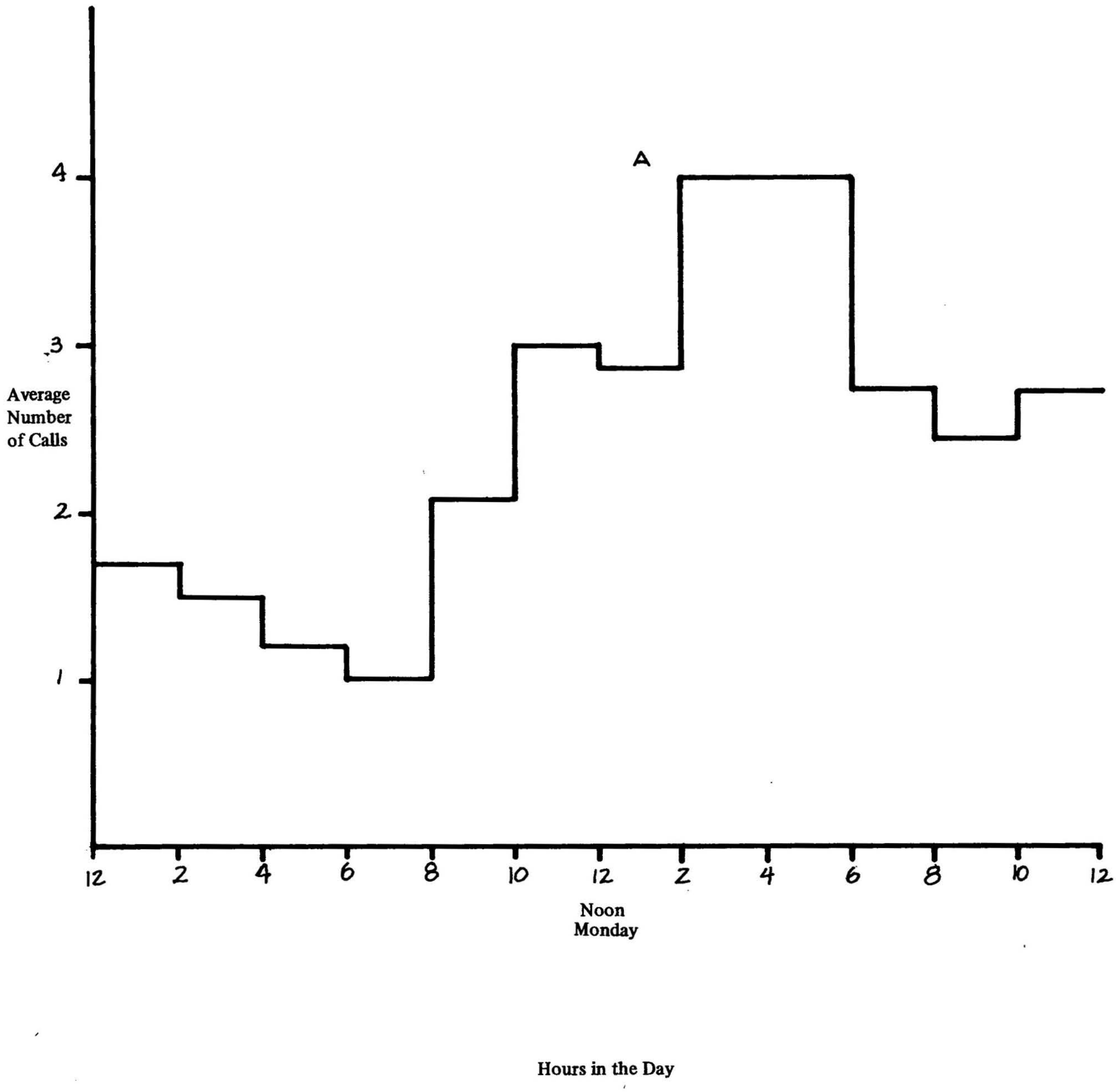


FIGURE 2-16: HISTORICAL RESPONSE TIMES OF EMS VEHICLES

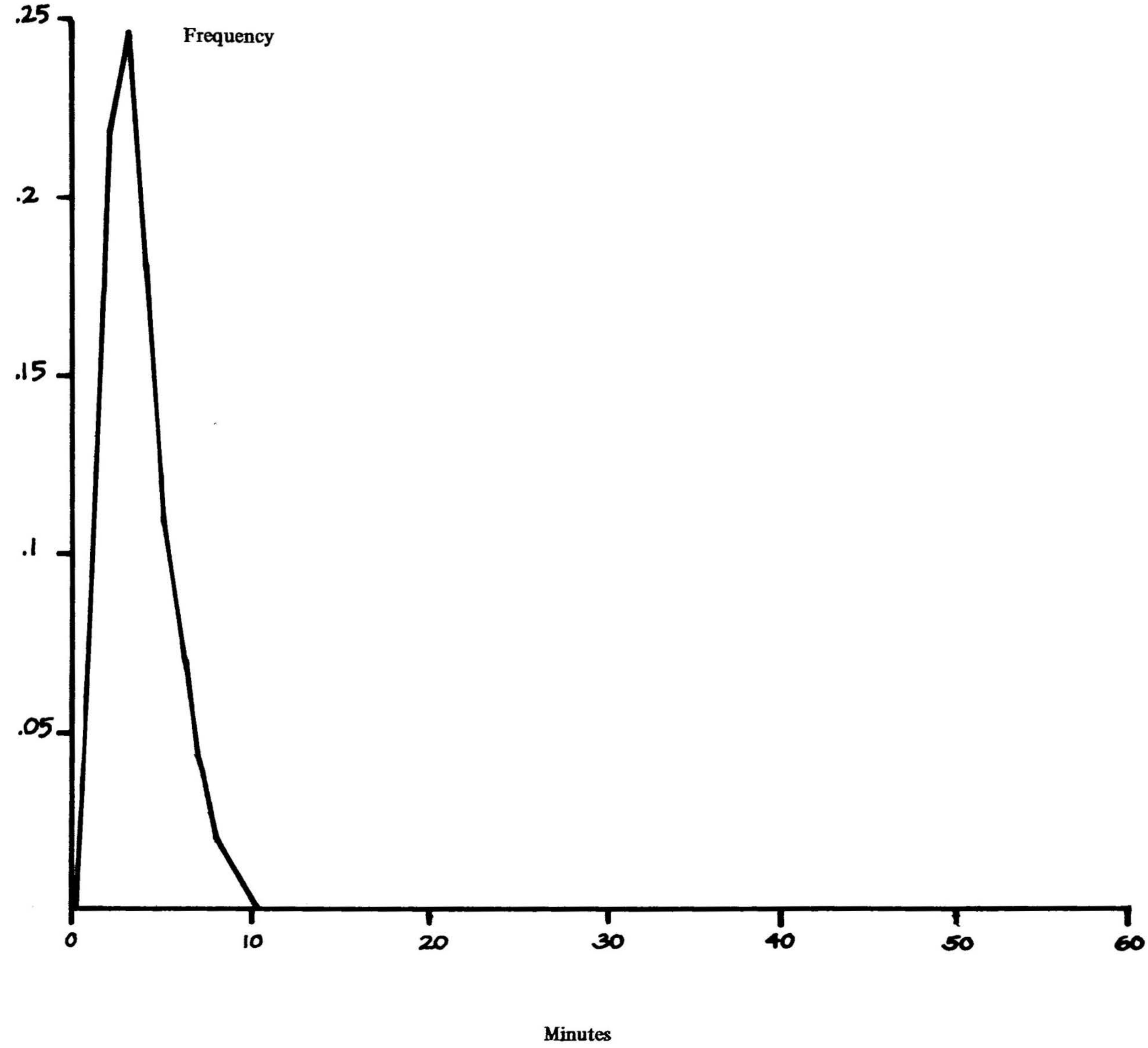


FIGURE 2-17: CUMULATIVE FREQUENCY OF HISTORICAL RESPONSE TIMES OF EMS VEHICLES

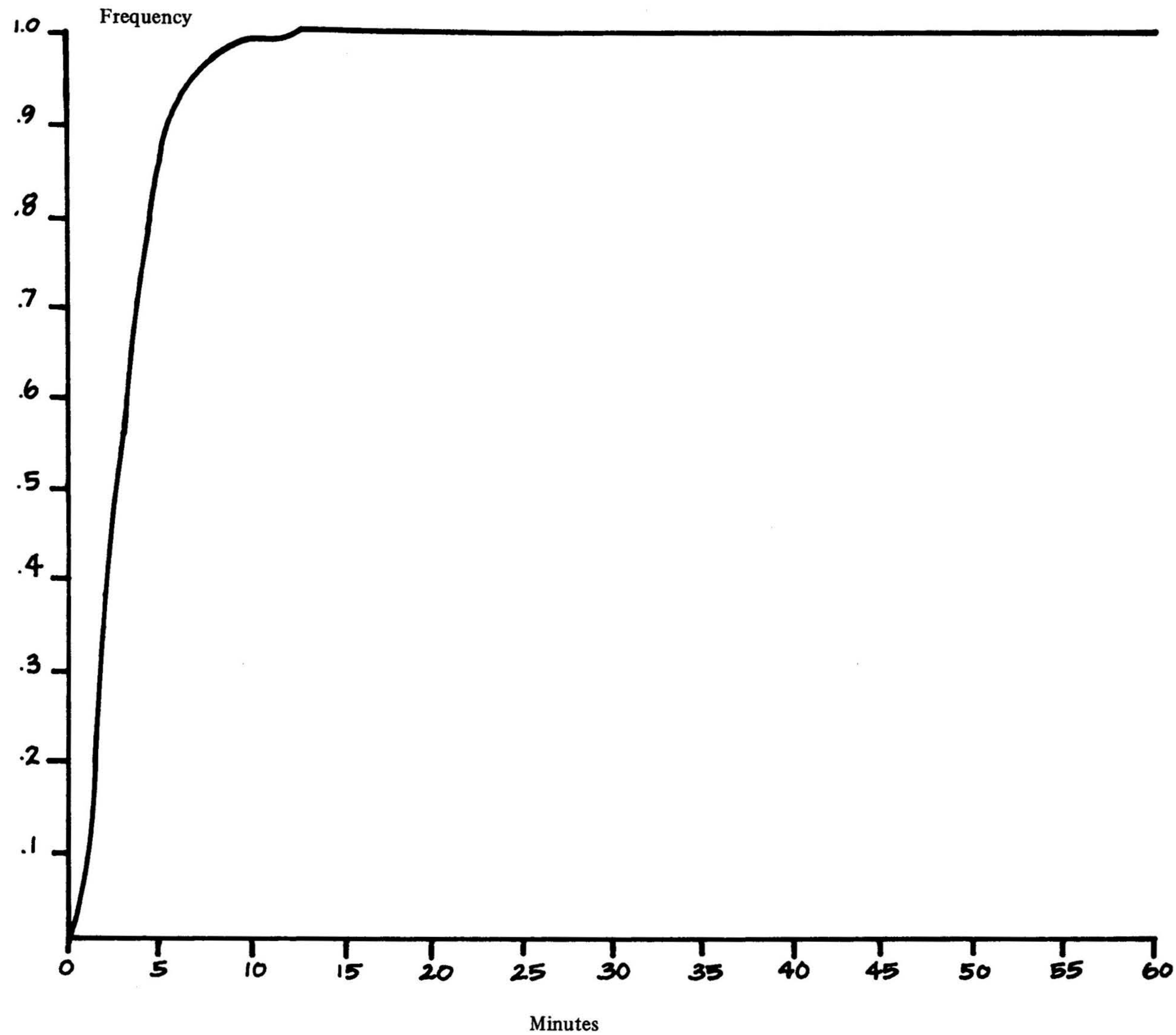


FIGURE 2-18: CUMULATIVE TIME AT SCENE

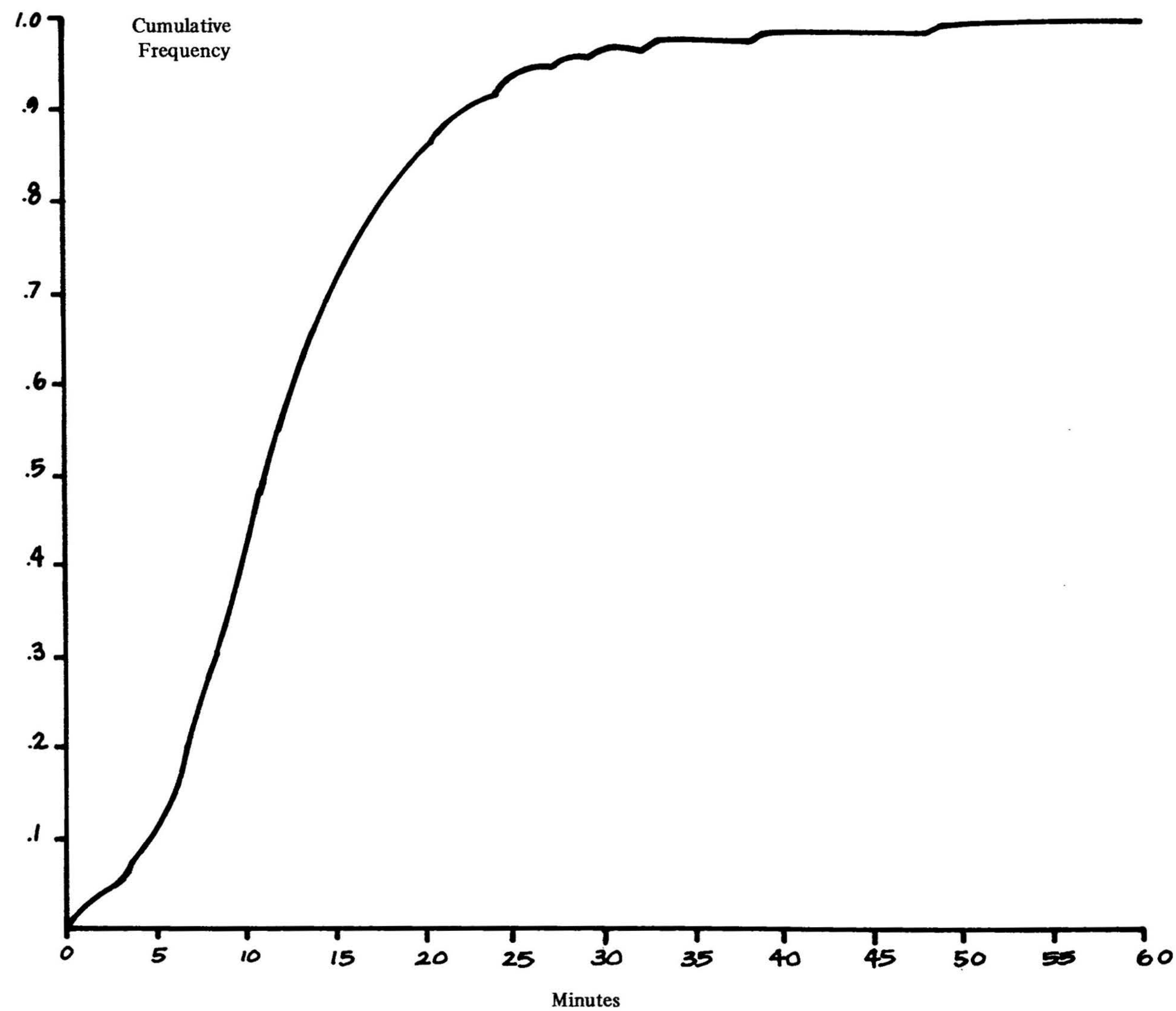


FIGURE 2-19: CUMULATIVE TRANSPORT TIME

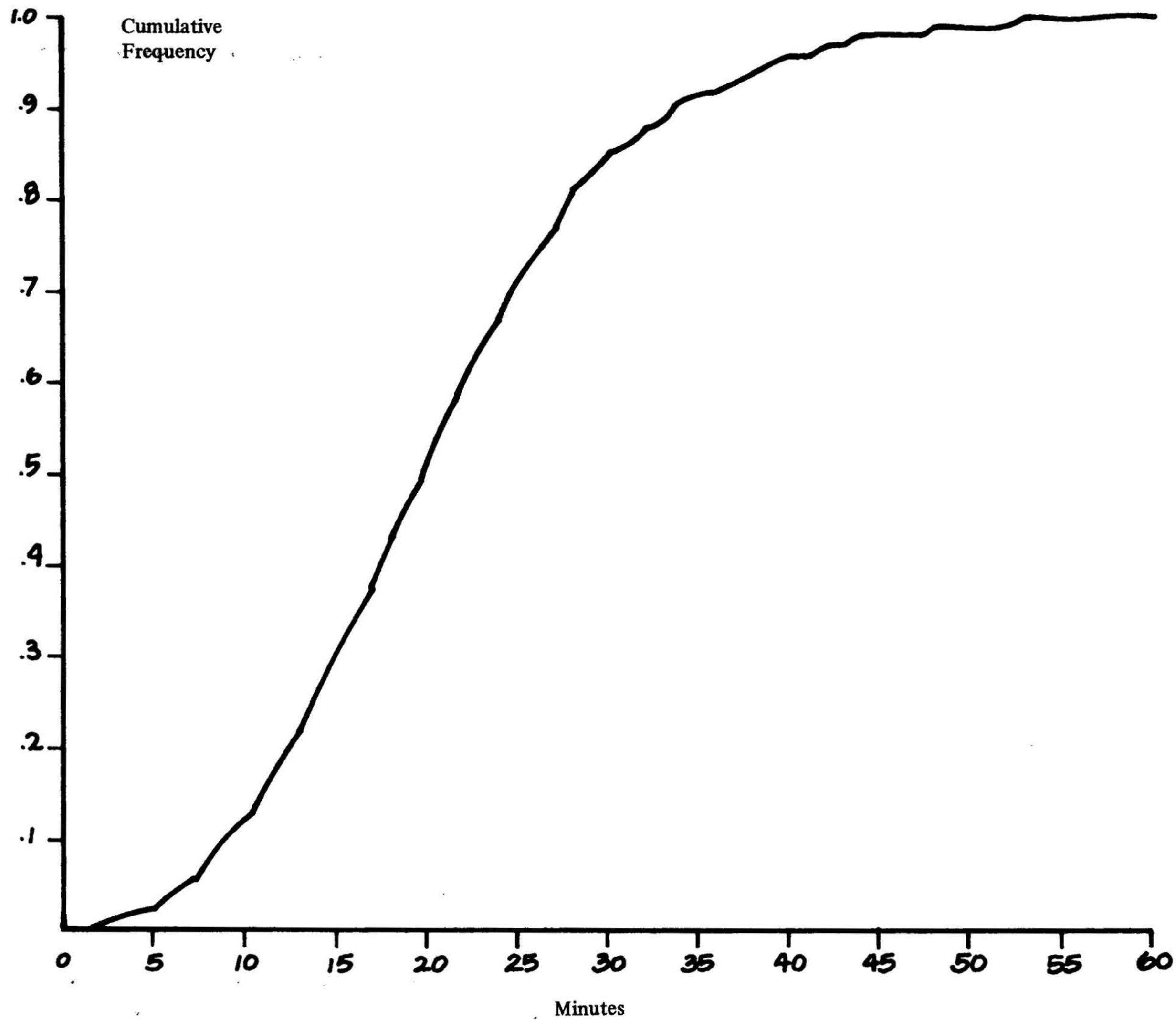


FIGURE 2-20: CUMULATIVE TIME AT HOSPITAL

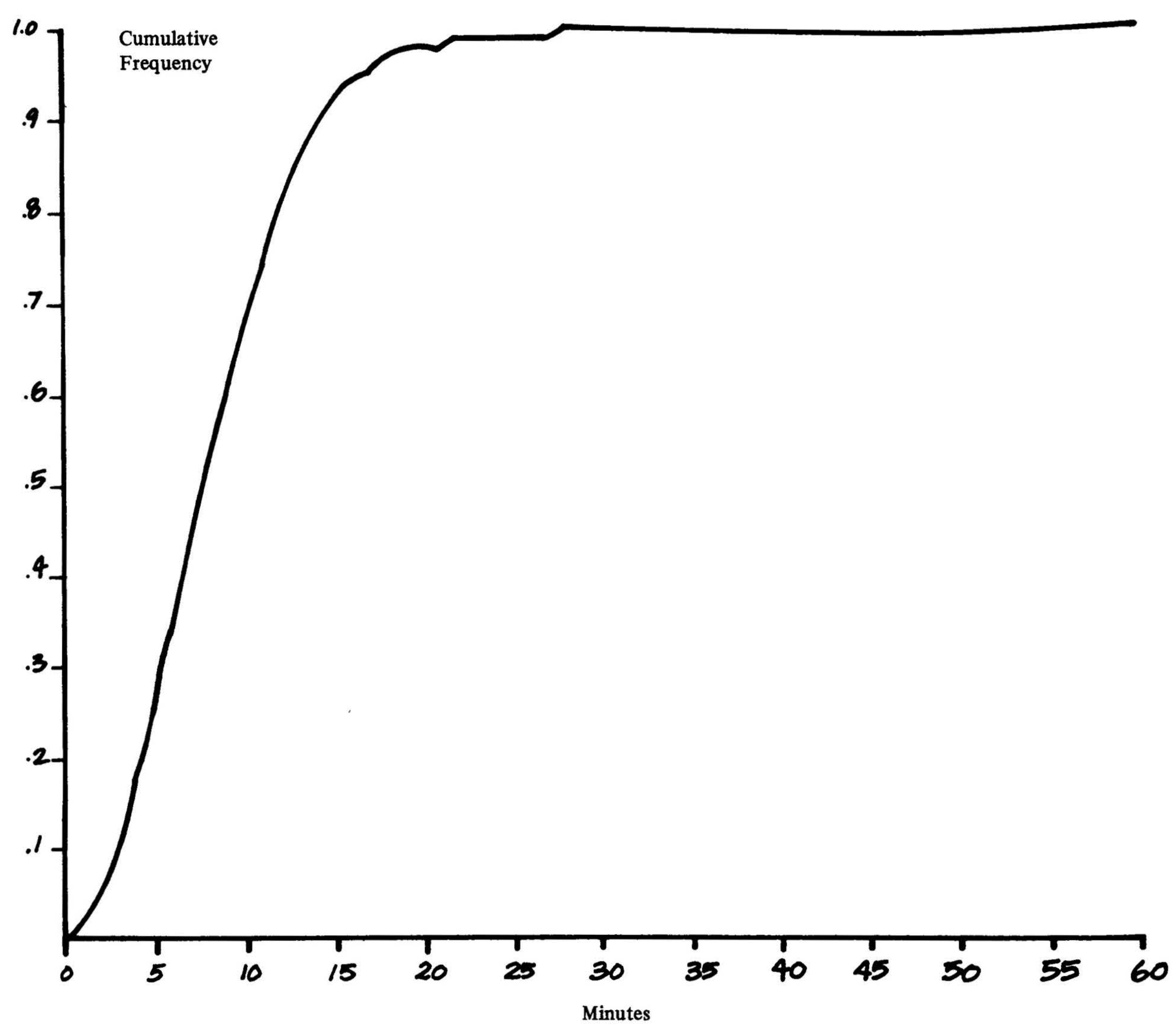
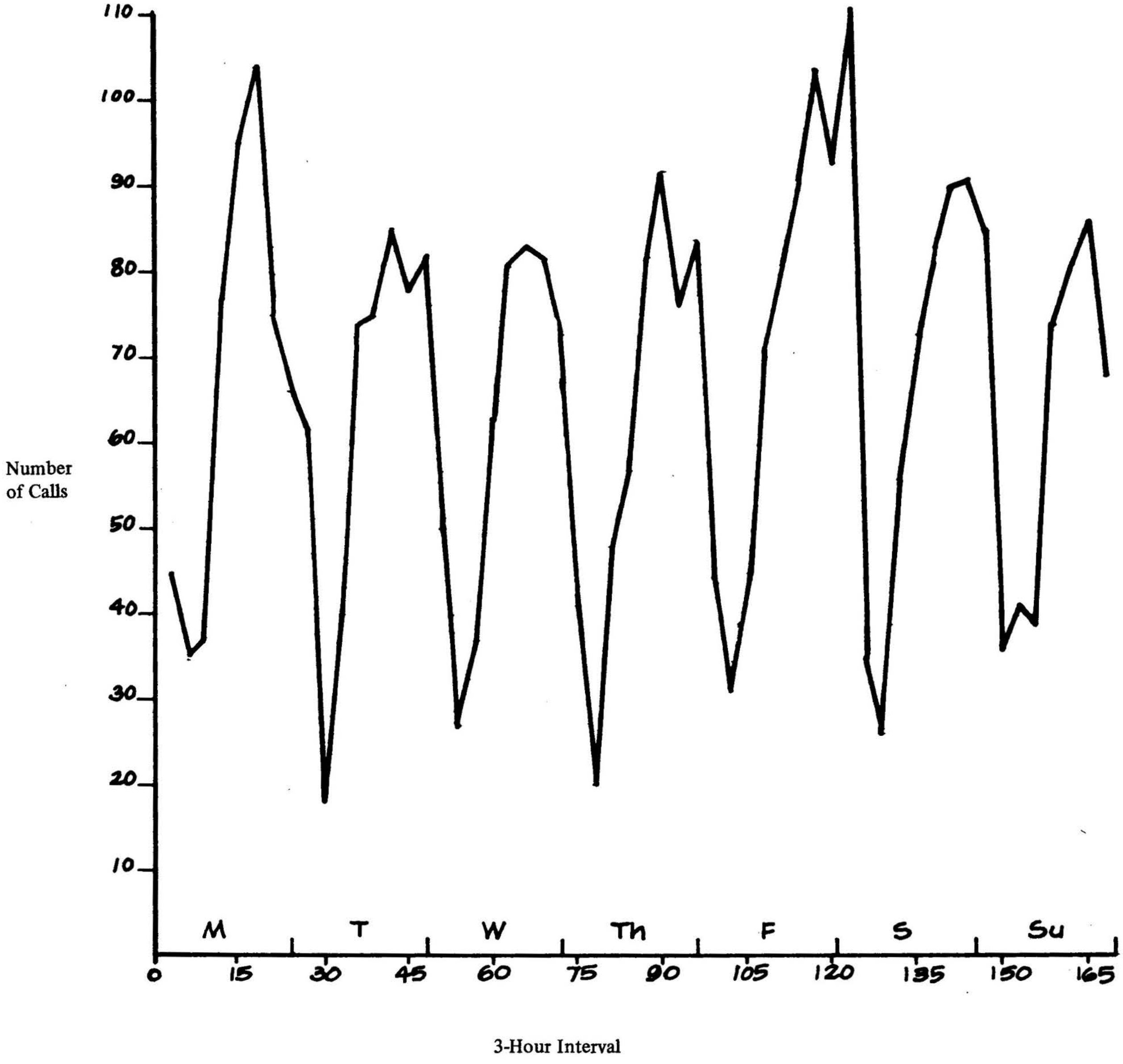


FIGURE 2-21: CALL FREQUENCY FOR ENTIRE CALL DATA



the day (see table 2-18 and figure 2-21). On all days, the period of 3 p.m. to 3 a.m. is far busier than the period of 3 a.m. to 3 p.m. These results suggest questions for EMS planners, such as:

- Should the deployment of EMS vehicles shift in response to the relative number of calls at times and places in the city?
- Should consideration be given to a change from the current forty-eight-hour EMS medic shift to a shorter shift, such as a twelve-hour shift?

**SUMMARY**

This chapter has described the subroutines within CHAP and how they may be applied to analyze Austin EMS call data. The relative complexity of the CAP program vis-a-vis the other programs required a more elaborate discussion of its capabilities and the underlying control and parameter cards. A sample problem utilizing actual (although incorrect) Austin EMS call data was used to illustrate the application of CAP, RAP, and ZAP in analyzing historical call data.

TABLE 2-18: BUSIEST TIME PERIOD OF EACH WEEKDAY

| | |
|---|---|
| Monday | 3 p.m. to 6 p.m. |
| Tuesday | 3 p.m. to 6 p.m. |
| Wednesday | 3 p.m. to 6 p.m. |
| Thursday | 9 p.m. to midnight |
| Friday | 9 p.m. to midnight |
| Saturday | 9 p.m. to midnight |
| Sunday | 9 p.m. to midnight |

# References

(1) City of Austin Emergency Medical Service Department, Partial List of EMS Calls in Austin, Texas during December 1976, and January, June, July, and August 1977.

(2) Emergency Medical Service Policy Research Project, *Location Techniques for Emergency Medical Service Vehicles, Volume III: Emergency Medical Service Calls in Austin—Description and Assumptions* (Austin, Texas: LBJ School of Public Affairs, The University of Texas at Austin, 1979).

# Chapter Three
# The Use of Maximal Covering Analysis in EMS Vehicle Deployment

This chapter describes the use of the CLASGAS program and illustrates its use in the evaluation of alternate sites for emergency medical vehicle bases in the city of Austin. The chapter is divided into six sections. The first describes the basic assumptions underlying the CLASGAS model. The second section discusses the general format for input information, and the third specifies the keypunch formats for specific input cards. The fourth section uses hypothetical data to illustrate maximal covering location analysis. The fifth section is an application of CLASGAS to the deployment of EMS vehicles in the city of Austin.

CLASGAS is the name of a computer program that is designed to solve several forms of the Maximal Covering Location Problem, which was originally introduced by Church and ReVelle in 1974 (1). The Maximal Covering Location Problem (MCLP) can be defined in an EMS context in the following way:

> Maximize the fraction of emergency medical service calls that can be covered within a desired response time S by locating a fixed number of EMS vehicle sites.

A solution to an MCLP is a set of vehicle locations that serve the largest possible percentage of the calls for emergency medical service within a specified response time standard.

The CLASGAS program is a heuristic computer procedure that identifies good if not optimal solutions to MCLP. The program offers two algorithms, Greedy Adding (GA) and Greedy Adding with Substitution (GAS), to achieve maximal cover solutions. The GA algorithm starts with an empty solution set and then adds to this set one at a time the best facility sites. The best facility site in a given iteration is defined to be that site which covers at least as much of the existing uncovered demand as any other site. The GAS algorithm, like GA, adds new facilities; however, in addition, GAS seeks to improve the solution at each iteration by attempting replacement of a current site by an unused site if coverage increases. Thus, this second heuristic can remove "no longer justified" sites from the final solution set.

## CLASGAS ASSUMPTIONS

GLASGAS is a computer procedure that identifies sites for EMS vehicle stations that can reach a maximum percentage of EMS calls within some maximum response time limit. Implicit in this problem structure are assumptions related to the geography of the study area, calls for emergency medical service, EMS vehicle response, and the measure of effectiveness of an EMS system. Table 3-1 lists these assumptions.

### Basic Assumptions

The CLASGAS model uses a network to represent the study area. The study area is divided into discrete districts; points within each district (called centroids) symbolize a concentration of district activity. These centroids are connected by network links that represent fixed estimates of minimum travel times from any district to any other. The scale of districting (census tracts, transportation serial zones, etc.) can be specified by the user of the model.

"Demand" for EMS can be represented by a variety of surrogates (such as historical call frequency or call forecasts) concentrated at district centroids. The relative frequency of calls is used to weight each district as a measure of the potential need for EMS.

Other assumptions relate to the existence and performance of emergency medical vehicles. The CLASGAS model assumes that all vehicles are identical in terms of the speed of response and the sophistication of the emergency staff and equipment. Vehicle dispatch always occurs from the location that is closest to the call for service. The model does not simulate calls in real time; it implicitly assumes that there will always be an available vehicle at each base to respond to a call.

The CLASGAS model measures EMS system performance by the fraction of the calls for service that can be "covered" by the system. "Coverage" is defined as the provision of EMS service within a specified response time from a fixed number of vehicles. The model incorporates a limit to response time because the length of time a patient must wait for treatment is related to the likelihood of successful treatment (2).

Three computational approaches can be used to find EMS vehicle sites that maximize coverage. The Greedy Adding (GA) algorithm starts with no EMS vehicles and locates vehicles one at a time at sites that cover the most uncovered demand until either all demand can be served within a specified response time or the limit on vehicles is reached. The Greedy Adding with Substitution (GAS) algorithm uses the additive procedure, but substitutes locations if a new

TABLE 3-1: ASSUMPTIONS OF THE CLASGAS LOCATION MODEL

| Subject | Assumption |
|---|---|
| **Geographical** | |
| study area | a set of discrete districts represented by central points connected by discrete travel times |
| potential vehicle sites | at nodes on the network |
| **Demand** | |
| origin of calls | points that represent a population concentration |
| representation of EMS needs | the number of calls from a district in a period of time |
| **Supply** | |
| characteristics of service | emergency medical vehicles are identical |
| vehicle dispatch | always allocates a vehicle from the closest location to the call for service |
| **Criteria** | |
| effectiveness of EMS system | maximum coverage of demand within specified limit on response time |

site improves the call coverage. An analyst can also test, with a separate linear programming step, whether GA or GAS solutions can be improved.

### User Options

The user of CLASGAS has several options that can both complicate the analysis and make it more realistic. Table 3-2 lists these options.* Locations can either be removed from the set of potential sites or fixed as necessary sites by appropriate labeling. The coverage of particular demand points can be eliminated by labeling those demand weights as zero. The limit on maximal time to service and the number of vehicles in the system can be easily changed by the user. The user also has the choice of computational approach. With multiple runs, all three program approaches can identify the tradeoffs between call coverage, the number of vehicles, and the time standard used to represent quality of service.

*Detailed keypunch information for implementing the user options is described in reference (3).

## INPUT INFORMATION

The CLASGAS program uses two basic sets of information, "demand" data and "locational" data. The number of calls that are expected to occur in regions of geographical space represent the demand to be "covered" by the siting of facilities. These demand points are locationally fixed as either points on a grid [(x,y) coordinates] or as nodes on a network (a shortest distance matrix representation).

The parameters important to the operation of the CLASGAS program include the number of facilities to be located and the maximal service time. By varying these numbers, a user can measure the tradeoffs between the number of vehicles, the maximal service time, and the amount of covered demand.

The input cards for CLASGAS include a card relating demand parameters, a set of cards giving demand figures, a set of cards giving either distances or locational coordinates, a name card, a card providing the number of facilities and service time parameters, and two blank cards to signify termination of input. The CLASGAS input deck should

TABLE 3-2: USER OPTIONS FOR THE CLASGAS MODEL

| Subject | Option |
|---|---|
| vehicle location | user can fix a vehicle at a particular site |
| | user can limit the number of vehicles |
| | user can eliminate a site as a potential facility |
| | user can specify some factor to eliminate locations as potential sites |
| demand | user can exclude demand points from consideration by labeling demand weights as zero |
| | user can employ total population or population data as surrogates for EMS demand |
| response time | user specifies the maximum response time |
| computational approach | user can choose to use GA, GAS and/or linear programming to find and test solutions |

conform to the structure in figure 3-1. The control cards needed to run the CLASGAS program should conform to the deck structure depicted in figure 3-2.

Some comment should be made concerning the FORTRAN formats used in punching the input deck. CLASGAS requires the use of either the "I" format or the "F" format when punching input numbers on an eighty-column computer card. When the "I" format is designated, an integer or whole number is expected by the program. Thus, if CLASGAS requires a figure to be punched according to the (I10) format, the number should be punched as an integer right-justified in a field of ten columns. ("Right-justified" means that the number should be punched so that the last digit appears in the farthest right column of the field.)

When an "F" format is designated, a "floating point," or a number with a decimal, is expected. Thus, if CLASGAS requires a number to be punched according to a (F10.0) format, the number should be punched as a decimal number right-justified in a field of ten columns.* Note that the digit to the right of the decimal point in the format statement reserves the number of farthest-right columns in the field for decimal places. Thus, in the example of (F10.0), no decimal places are reserved within the field of ten columns. If the format statement read (F10.3), then the three farthest-right columns in the field of ten columns would be reserved as decimal places.

*Although the procedure is not the only way to keypunch, a user unfamiliar with FORTRAN programming should follow this quide.

FIGURE 3-1: CLASGAS INPUT DECK

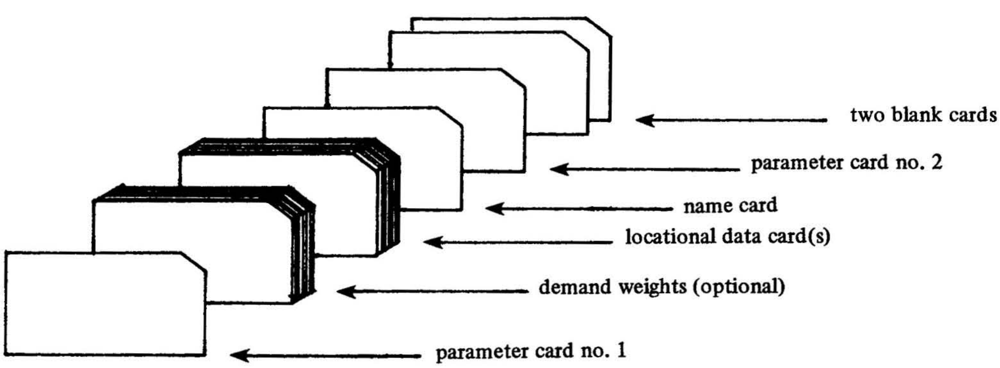
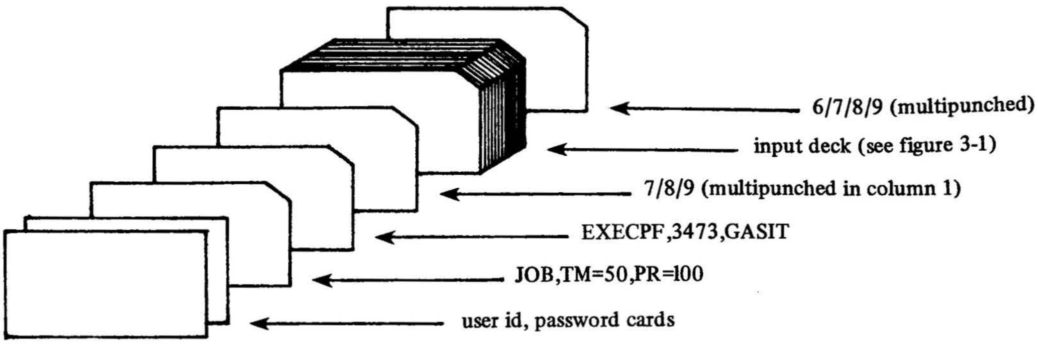


FIGURE 3-2: CONTROL CARDS FOR CLASGAS




One other feature of FORTRAN formats should be noted–the multiple field format. If the program requires an input of three fields-of-ten integers, then the format statement of this input may be written as either (I10, I10, I10) or (3I10). These two representations are equivalent statements, but the latter is often preferred for the sake of clarity and convenience.

In the following section, reference will be made to figure 3-3, a sample problem, for the purposes of illustrating specific card formats. Note that the example consists of a six node problem, with (x,y)-coordinates and demand weights as given. The node numbering system is arbitrary.

## CARD PUNCH INFORMATION

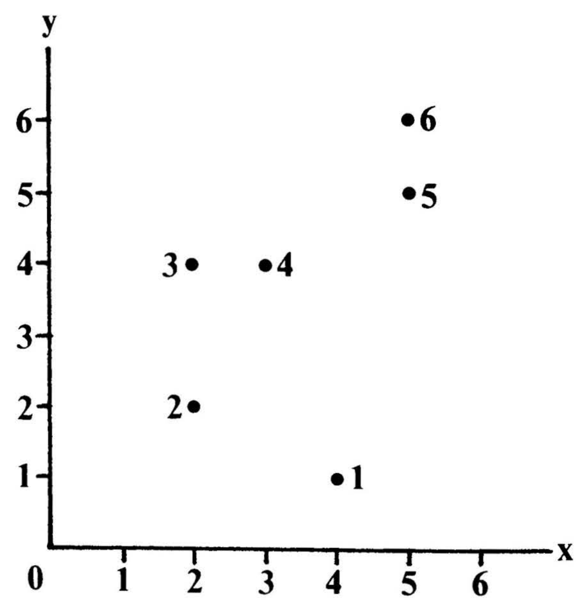
### Parameter Card No. 1

This card communicates to the program how many demand points are to be covered, whether or not to expect demand weights, and whether to expect distances or locational coordinates. The card is punched to the specifications in table 3-3. In reference to the example problem in figure 3-3, this card would have a "6" punched in column 5, a "1" punched in column 23, and a "0" punched in column 26. This information tells the program that the problem has six demand points, demand weights are to be read, and locational coordinates fix these points in space. For an example of this punching format, see figure 3-4.

### Demand Weights (OPTIONAL)

These weights are punched in some designated numerical order cards in the format (10F8.2). In terms of the example, these weights would be punched in fields of eight on one card. That is, the weight for node 1 (600) would be punched in the first eight columns, the weight for node 2 (300) would be punched in the second eight columns, etc. An example of this punching for the sample problem can be found in figure 3-5. Note that the seventh and eighth columns in each field are reserved for the decimal component of each weight.

FIGURE 3-3: SAMPLE PROBLEM

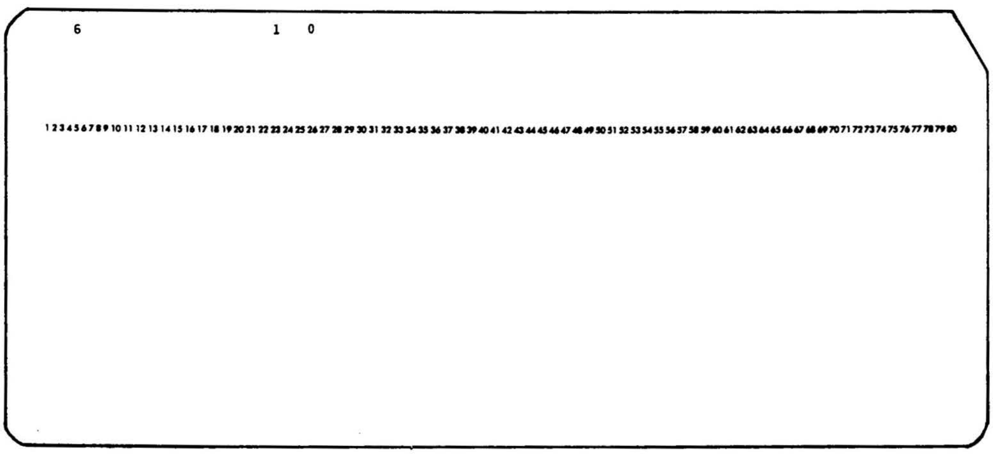



| Node Number | (x,y)-Coordinates | Population |
|---|---|---|
| 1 | (4,1) | 600 |
| 2 | (2,2) | 300 |
| 3 | (2,4) | 200 |
| 4 | (3,4) | 150 |
| 5 | (5,5) | 325 |
| 6 | (5,6) | 350 |

TABLE 3-3: PARAMETER CARD NO. 1 FORMAT

| Columns | Value | Definition | Format |
|---|---|---|---|
| 1-5 | variable | number of demand points | (I5) |
| 23 | 1 | demand weights are read | (I1) |
| | 0 | demand weights are not read | (I1) |
| 26 | 1 | time/distance matrix is read | (I1) |
| | 0 | (x,y) -coordinates of demand points are read | |

FIGURE 3-4: PARAMETER CARD NO. 1




### Locational Data—Distances or Coordinates

If a distance matrix is read, the first card has the "from" node number in the format (15) followed by the minimum distances to all nodes from that node (including the original "from" node) in numerical order. See reference (3) for details of the keypunch format.

When (x,y)-coordinates are to be read, they should be punched in corresponding pairs in the numerical order of the demand nodes, according to the (10F8.2) format. The coordinates for the problem of figure 3-3 would be punched on two cards, with the x-coordinate for node 1 in the first eight columns, the y-coordinate for node 1 in the second eight columns, the x-coordinate for node 2 in the third eight columns, the y-coordinate for node 2 in the fourth eight columns, etc. Figure 3-6 illustrates these cards.

### Name Card

This card contains any information the user wishes to use for identification of the problem run (see figure 3-7). If no information is desired, a blank card must be submitted in place of the name card.

### Parameter Card No. 2

This card includes parameters for the number of facilities to be sited, the maximal response time, a secondary response time,* whether to execute the GAS algorithm or the GA algorithm, and what detail of statistics should be printed. The card is punched to the specifications in table

*Secondary response time is some user-defined limit on response time. The program calculates (but does not try to maximize) the coverage within the secondary response time.

FIGURE 3-5: DEMAND DATA CARD

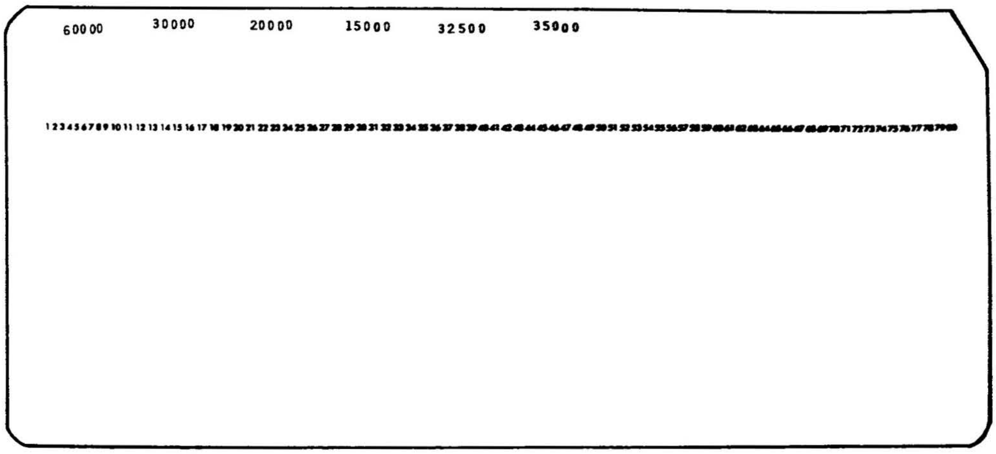
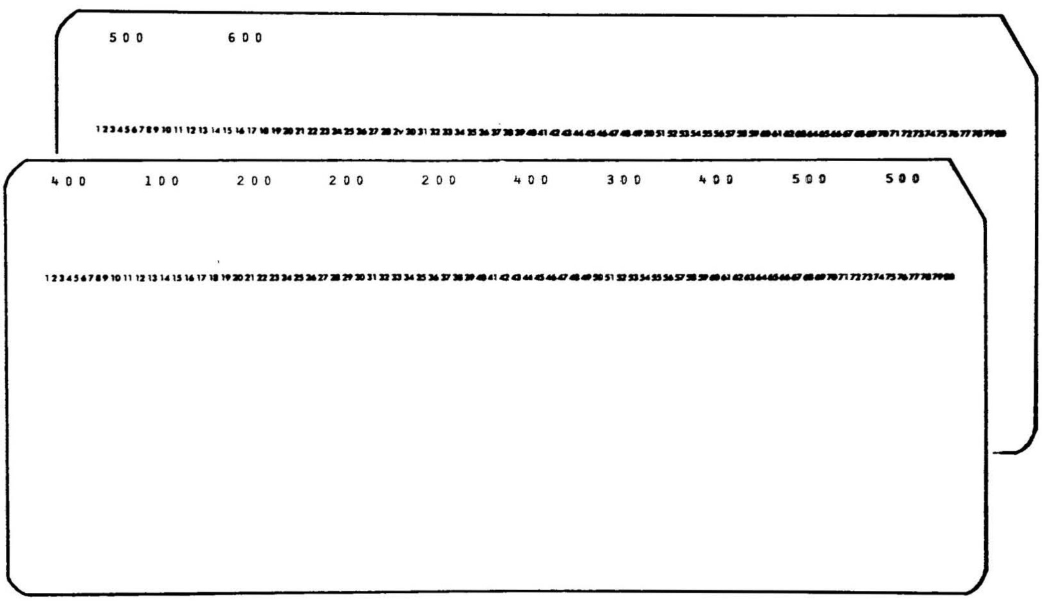



FIGURE 3-6: (X,Y)-COORDINATE DATA CARDS




3-4. If we assume that a primary limit on response time is 1.0 minutes, a secondary upper bound on response time is 2.0 minutes, and there are three facilities to be sited, then this card should have a "3" in column 5, "1.0" in columns 6-15, "2.0" in columns 16-25, "1" in column 26, and "0" in column 27.** Figure 3-8 illustrates such a punched card.

**In this example, 1.0 could represent either time (1.0 minute) or distance (1.0 mile or kilometer).

**Termination Cards**

To signify termination of input to the CLASGAS program, two blank cards must follow Parameter Card No. 2.

**OUTPUT**

Figure 3-9 is an example of CLASGAS computer output

FIGURE 3-7: NAME CARD

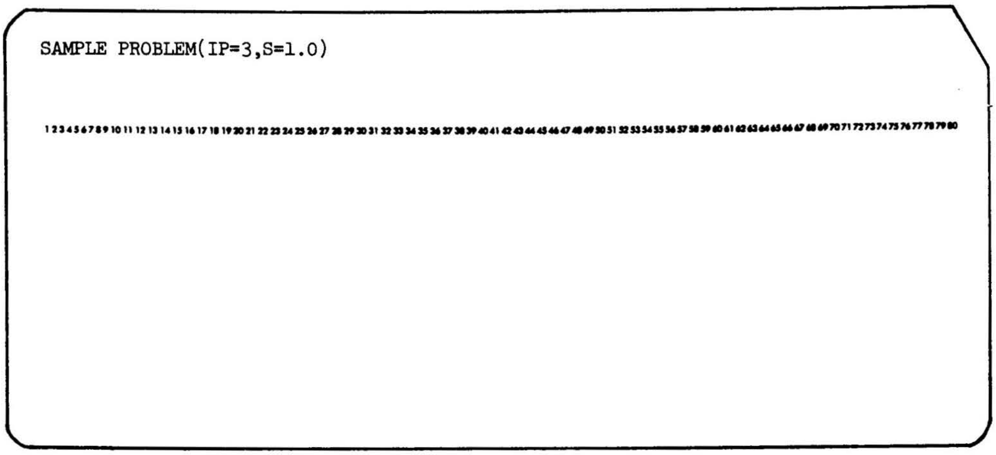



TABLE 3-4: PARAMETER CARD NO. 2 FORMAT

| Columns | Value | Definition | Format |
|---|---|---|---|
| 1-5 | variable | number of facilities to be sited | (I5) |
| 6-15 | variable | maximal service distance | (F10.5) |
| 16-25 | variable | secondary service distance | (F10.5) |
| 26 | 1 | GAS algorithm is executed | (I1) |
| | 0 | GA algorithm is executed | (I1) |
| 27 | 1 | all statistics are printed | (I1) |
| | 0 | only Iteration Number, Amount of Coverage, and Facility Placement are printed for intermediate solutions | |

for the sample problem. In the first iteration, the GAS algorithm selects node 5 as the first site; no other site covers more of the demand within the 1.0 minute response time limit.* A vehicle at node 5 could reach 35.06 percent of the demand within 1.0 minutes. All nodes are placed in the node 5 "partition"; the partition is defined as the set of demand nodes which are closer to the facility in question than to any other facility at that iteration. Thus, if a node is closer to facility A than to facility B, that node will be found in the partition of facility A.

Figure 3-10 is an illustration of the first iteration. Primary coverage is denoted by dotted lines and secondary coverage by dashed lines. The solid lines enclose the partition of a facility, which is indicated by a star.

Iteration 2 adds a facility at node 1 and redefines the facility partitions. Nearly two-thirds of all calls could be reached within 1.0 minutes by vehicles based at the two sites. Nodes 3, 4, and 2 are allocated to their respective partitions, but these demand points remain outside both primary and secondary coverage. The second iteration solution is mapped in figure 3-11.

In the third iteration GAS sites a facility at node 3, increasing primary coverage to 84.42 percent of demand. The node 3 facility now covers itself and node 4 within a 1.0 minute response time, and covers node 2 within 2.0 minutes. Figure 3-12 shows the coverage pattern at this stage.

The CLASGAS solution procedure adds new facilities until all demand is covered, or until the program reaches the limit on the number of facilities to be sited. In this case, the limit of three facilities was reached. Three vehicle sites cover 84.42 percent of EMS calls within a 1.0 minute re-

*Note that node 6 covers the same amount of demand.

FIGURE 3-8: PARAMETER CARD NO. 2

```
  3   100000    20000010

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
```

FIGURE 3-9: CLASGAS COMPUTER OUTPUT

```
     POPULATION DATA
----------------------------------------------------------------------------------------------------
  1  600.00*  2  300.00*  3  200.00*  4  150.00*  5  325.00*  6  350.00*
----------------------------------------------------------------------------------------------------
```

```
ITERATION NUMBER,     1

NUMBER OF FACILITIES    1
SERVICE DISTANCE =      1.000

NEW FACILITY LOCATION NUMBER       5

FACILITIES ARE LOCATED AT      5,
------------------------------------------------------------------------------------------
POPULATION SERVED      675.00          PERCENT OF TOTAL POPULATION SERVED    35.06
------------------------------------------------------------------------------------------
```

```
SAMPLE PROGRAM(NUMBER OF FACILITIES=3,SERVICE TIME=1.0

FACILITIES ARE LOCATED AT     5,
PRIMARY DISTANCE   =  1.00
SECONDARY DISTANCE =  2.00
******************************************************************************************************
         *         *PRIMARY*SECONDARY*POPULATION*POPULATION*LARGEST.*      *WT.DIST*WT.DIST. *WT.DIST* TOTAL  *
PARTITION*FACILITY*SERVED * SERVED  * OUTSIDE  *    IN    *TRAVELED* NODE *PRIMARY*SECONDARY*OUTSIDE*WEIGHTED*
 NUMBER  * NUMBER *  POP. *  POP.   *SECONDARY *PARTITION *DISTANCE*NUMBER*COVERED* COVERED *PRIMARY*DISTANCE*
    1         5    675.00     0.00    1250.00    1925.00      4.2     2      0.0       0.0  4710.5   4710.5
******************************************************************************************************
                   675.00     0.00    1250.00    1925.00                     0.0       0.0  4710.5   4710.5
PARTITION  1  FACILITY   5
**   1 D=  4.12**   2 D=  4.24**   3 D=  3.16**   4 D=  2.23**   5 D=  0.00**   6 D=  0.00
```

```
ITERATION NUMBER,     2

NUMBER OF FACILITIES    2
SERVICE DISTANCE =      1.000

NEW FACILITY LOCATION NUMBER       1

FACILITIES ARE LOCATED AT      5,     1,
------------------------------------------------------------------------------------------
POPULATION SERVED     1275.00          PERCENT OF TOTAL POPULATION SERVED    66.23
------------------------------------------------------------------------------------------
```

(FIGURE 3-9, continued)

```
SAMPLE PROGRAM(NUMBER OF FACILITIFS=3,SERVICE TIMF=1.0

FACILITIES ARE LOCATED AT     5,   1,
PRIMARY DISTANCE    =  1,00
SECONDARY DISTANCE =  2.00
****************************************************************************************************
     *         *PRIMARY*SECONDARY*POPULATION*POPULATION*LARGEST,*      *WT.DIST*WT.DIST. *WT.DIST* TOTAL  *
PARTITION*FACILITY*SERVED * SERVED  * OUTSIDE  *    IN    *TRAVELED* NODE *PRIMARY*SECONDARY*OUTSIDE*WEIGHTED*
 NUMBER  * NUMBER *  POP. *  POP.   *SECONDARY *PARTITION *DISTANCE*NUMBER*COVERED* COVERED *PRIMARY*DISTANCE*
    1        5     675.00      0.00     350.00    1025.00      3.2     3     0.0       0.0   966.5    966.5
    2        1     600.00      0.00     300.00     900.00      2.2     2     0.0       0.0   669.0    669.0
****************************************************************************************************
                  1275.00      0.00     650.00    1925.00                    0.0       0.0  1635.5   1635.5
PARTITION  1  FACILITY   5
**   3 D=  3.16**   4 D=  2.23**   5 D=  0.00**   6 D=  0.00**
PARTITION  2  FACILITY   1
**   1 D=  0.00**   2 D=  2.23**
```

```
ITERATION NUMBER,      3

NUMBER OF FACILITIES    3
SERVICE DISTANCE =     1.000

NEW FACILITY LOCATION NUMBER       3

FACILITIES ARE LOCATED AT     5,     1,     3,
----------------------------------------------------------------------------------------------------
POPULATION SERVED     1625.00           PERCENT OF TOTAL POPULATION SERVED    84.42
----------------------------------------------------------------------------------------------------
```

```
SAMPLE PROGRAM(NUMBER OF FACILITIES=3,SERVICE TIME=1.0

FACILITIES ARE LOCATED AT     5,   1,   3,
PRIMARY DISTANCE    =  1.00
SECONDARY DISTANCE =  2.00
****************************************************************************************************
     *         *PRIMARY*SECONDARY*POPULATION*POPULATION*LARGEST,*      *WT.DIST*WT.DIST. *WT.DIST* TOTAL  *
PARTITION*FACILITY*SERVED * SERVED  * OUTSIDE  *    IN    *TRAVELED* NODE *PRIMARY*SECONDARY*OUTSIDE*WEIGHTED*
 NUMBER  * NUMBER *  POP. *  POP.   *SECONDARY *PARTITION *DISTANCE*NUMBER*COVERED* COVERED *PRIMARY*DISTANCE*
    1        5     675.00      0.00       0.00     675.00      0.0     6     0.0       0.0     0.0      0.0
    2        1     600.00      0.00       0.00     600.00      0.0     1     0.0       0.0     0.0      0.0
    3        3     350.00    300.00       0.00     650.00      2.0     2   150.0     600.0   600.0    750.0
****************************************************************************************************
                  1625.00    300.00       0.00    1925.00                  150.0     600.0   600.0    750.0
PARTITION  1  FACILITY   5
**   5 D=  0.00**   6 D=  0.00**
PARTITION  2  FACILITY   1
**   1 D=  0.00**
PARTITION  3  FACILITY   3
**   2 D=  2.00**   3 D=  0.00**   4 D=  1.00**
THIS SOLUTION WAS GENERATED BY THE GAS ALGORITHM
```

sponse time and 100 percent coverage of the area within the secondary response time of 2.0 minutes.

Although the program terminated with an optimal configuration for the sample problem, it has not identified all possible optimal solutions. One should note that this example problem has several alternate optima, at sites (6,1,3), (6,1,4), and (5,1,4).

## A FORTY-NODE ILLUSTRATION

This section will identify a number of characteristics of CLASGAS analysis by illustrating its use in evaluating vehicle deployment in a hypothetical study area. Figure 3-13 shows a network of forty nodes representing districts in an urban area. The nodes are ordered and identified by (x,y)-coordinates on a Cartesian plane (see table 3-5). The relative frequencies of EMS calls in the districts are represented by the demand weight assigned to each node. Using these data, a user can solve the MCLP to determine the set of EMS vehicle bases that can best reach calls within one or two minutes.

### Service within Two Minutes

To maximize call coverage within two minutes, CLASGAS would locate one vehicle at node 25. A single EMS vehicle base at node 25 can reach 62.18 percent of the EMS calls within two minutes (see table 3-6). This location is selected either by the GA or GAS algorithm.

A second iteration of the GA adds node 3 as the site for a second facility, increasing coverage to 86.15 percent. Although the second iteration of GAS adds node 3, it also substitutes node 31 for node 25, increasing calls coverage by vehicles at the two facilities to 91.44 percent. After additional substitutions (node 8 for node 3, node 30 for node 31, and node 13 for node 8), vehicles based at the final GAS sites (nodes 30 and 13) can reach 99.30 percent of the calls within two minutes. This GAS solution is 13.15 percent better than the best GA solution for two sites.

The third iteration for GA adds a third facility at node 29. Vehicles at the three sites (nodes 25, 3, and 29) can cover 100 percent of EMS calls within the two-minute time standard. Since all demand is covered, GA does not

FIGURE 3-10: MAP OF ITERATION 1 SOLUTION

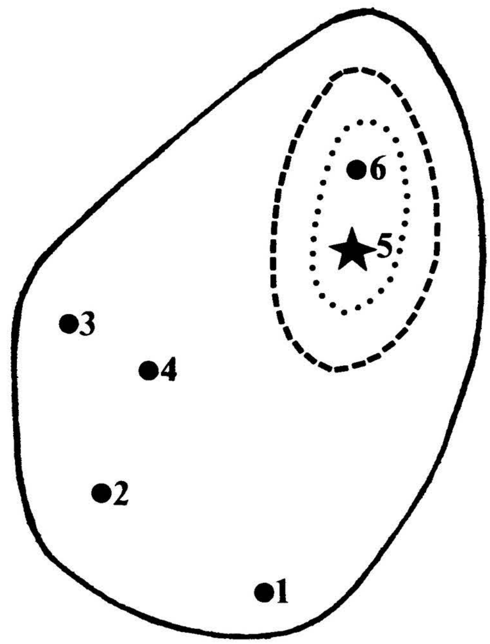



FIGURE 3-11: MAP OF ITERATION 2 SOLUTION

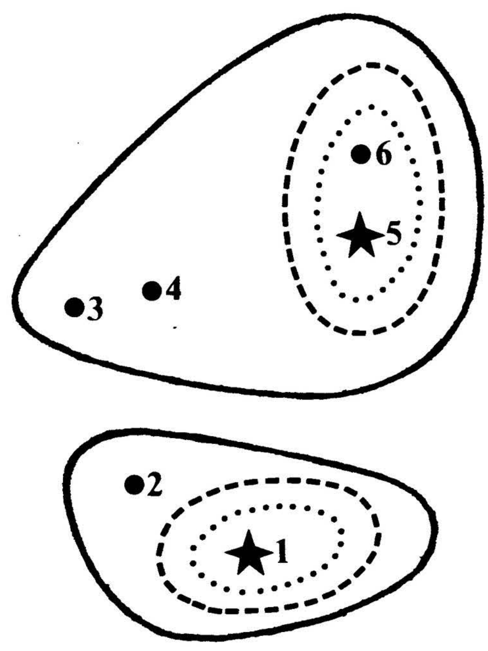


FIGURE 3-12: MAP OF ITERATION 3 SOLUTION

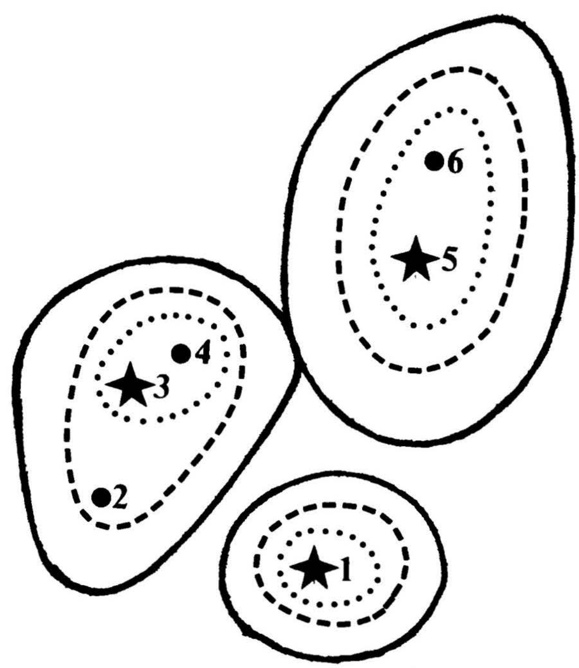
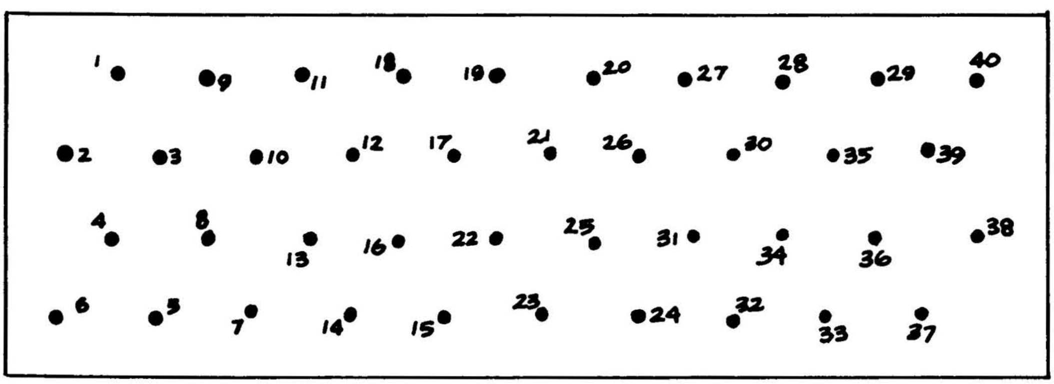



FIGURE 3-13: FORTY NODE NETWORK




continue to a fourth iteration. The third iteration of GAS adds another facility at node 1. The final GAS solution set (nodes 30, 13, and 1) provides 100 percent coverage.

Note that both GAS and GA find sites that are accessible to all calls in three iterations, yet the solution sets involve different facility locations. Although GAS substitution does improve intermediate solutions, the existence of alternate optima can lead both GA and GAS to identify the same number of vehicle sites in final solutions where all demand is covered within the time standard.

**Service within One Minute**

The output generated by CLASGAS for a one-minute maximum response time is listed in table 3-7. GA and GAS select the same initial three sites in the first three iterations. GAS makes one substitution in the fourth iteration, none in the fifth, and one in the sixth. By the completion of the sixth iteration, GAS has nearly the same solution set as GA (nodes 22, 24, 8, 36, 18, 27 versus 22, 34, 8, 36, 18, 27). The one site difference (node 24 in GAS versus node 34 in

TABLE 3-5: DATA ASSIGNED TO FORTY NODE NETWORK

| Point Number | X-Coordinate | Y-Coordinate | Demand Weight |
|---|---|---|---|
| 1 | 4.85 | 2.35 | 35 |
| 2 | 5.50 | 2.00 | 79 |
| 3 | 5.50 | 2.75 | 150 |
| 4 | 6.15 | 2.40 | 81 |
| 5 | 6.80 | 2.75 | 70 |
| 6 | 6.80 | 2.00 | 55 |
| 7 | 6.80 | 3.50 | 155 |
| 8 | 6.15 | 3.15 | 139 |
| 9 | 4.85 | 3.10 | 75 |
| 10 | 5.50 | 3.50 | 109 |
| 11 | 4.85 | 3.85 | 51 |
| 12 | 5.50 | 4.25 | 145 |
| 13 | 6.15 | 3.90 | 95 |
| 14 | 6.80 | 4.25 | 111 |
| 15 | 6.80 | 5.00 | 193 |
| 16 | 6.15 | 4.65 | 204 |
| 17 | 5.50 | 5.00 | 118 |
| 18 | 4.85 | 4.60 | 110 |
| 19 | 4.85 | 5.35 | 82 |
| 20 | 4.85 | 6.10 | 65 |
| 21 | 5.45 | 5.75 | 150 |
| 22 | 6.15 | 5.40 | 250 |
| 23 | 6.80 | 5.75 | 213 |
| 24 | 6.75 | 6.50 | 197 |
| 25 | 6.15 | 6.15 | 184 |
| 26 | 5.45 | 6.50 | 131 |
| 27 | 4.85 | 6.85 | 79 |
| 28 | 4.85 | 7.65 | 78 |
| 29 | 4.85 | 8.35 | 49 |
| 30 | 5.45 | 7.25 | 220 |
| 31 | 6.10 | 6.90 | 172 |
| 32 | 6.75 | 7.25 | 110 |
| 33 | 6.75 | 8.00 | 164 |
| 34 | 6.15 | 7.65 | 158 |
| 35 | 5.45 | 8.00 | 100 |
| 36 | 6.10 | 8.40 | 125 |
| 37 | 6.75 | 8.75 | 285 |
| 38 | 6.10 | 9.10 | 150 |
| 39 | 5.45 | 8.85 | 57 |
| 40 | 4.85 | 9.10 | 30 |

GA) would allow vehicles based at the six GAS sites to cover roughly 4 percent more of the EMS calls within a one-minute response time.

Note how the tempo of substitution increases in the eighth iteration. GA locates an eighth facility at node 1, achieving the same percentage of coverage (95.12) achieved by GAS in the seventh iteration. GAS adds a facility in the eighth iteration at node 7, and goes through a number of substitutions which result in eight facility sites (at nodes 15, 24, 3, 36, 18, 26, 29, and 7) being accessible to 98.91 percent of demand.

The ninth iteration of GAS sites an EMS vehicle at node 4, and terminates, since the set of vehicle sites can reach all calls within one minute. GA goes through ninth, tenth, and eleventh iterations prior to reaching 100 percent coverage.

In this case, only nine GAS iterations were necessary to determine sites from which EMS vehicles could reach all calls within one minute. The nine GAS sites include five of the eleven sites selected by GA. This example illustrates a key difference between the GA and GAS routines. Although both GA and GAS may find the locations that cover all demand within some response time, GAS may require

TABLE 3-6: CLASGAS SOLUTION SETS FOR TWO MINUTE TIME STANDARD

| GAS | | | GA | | |
|---|---|---|---|---|---|
| Iteration | Facilities | Coverage % | Iteration | Facilities | Coverage % |
| 1 | (25) | 62.18 | 1 | (25) | 62.18 |
| 2 | 25,(3) | 86.15 | 2 | 25,(3) | 86.15 |
| | [31], 3 | 91.44 | | | |
| | 31, [8] | 95.48 | | | |
| | [30], 8 | 95.76 | | | |
| | 30, [13] | 99.30 | | | |
| 3 | 30,13,(1) | 100.00 | 3 | 25, 3, (29) | 100.00 |

Code

○ facility site added per iteration

□ facility site selected to substitute for previous location

fewer vehicle bases. In this case, the difference (nine versus eleven sites) is significant.

**Analysis of Output**

GAS does do a better job than GA in finding those sites from which EMS vehicles can best cover calls for EMS service. However, differences in coverage between the two algorithms are small, as illustrated in figure 3-14.

For a maximal service time of two minutes and with one or three facility locations, GA and GAS reach an identical fraction of calls for service. At the two-EMS-vehicle site solution, the GAS solution (unbroken line) provides coverage for over 99 percent of demand, while the GA solution (broken line) covers only 86 percent of demand. GA and GAS selected the same initial facility. The final solution involved the same number of sites, although GA chose different sites (nodes 25, 3, 29) than GAS (nodes 31, 13, 1).

The difference in coverage is evident in the middle iteration; GAS, with its substitution feature, provides greater accessibility to calls. Vehicles based at the GAS-selected two sites can reach 99 percent of the calls for service; this fraction of coverage is close to the GA three-sites solution (100 percent).

Similar patterns emerge for the one-minute response time, although the differences in coverage between GA and GAS are even smaller. The GAS solution is an improvement over the GA solution set beginning with the fourth iteration. The difference in percent coverage between GA and GAS is not great (6.35 percent) and is reduced each iteration through the ninth. With the ninth iteration, vehicles based at the GAS-generated sites can reach all calls for service versus only 97 percent coverage by nine GA facilities.

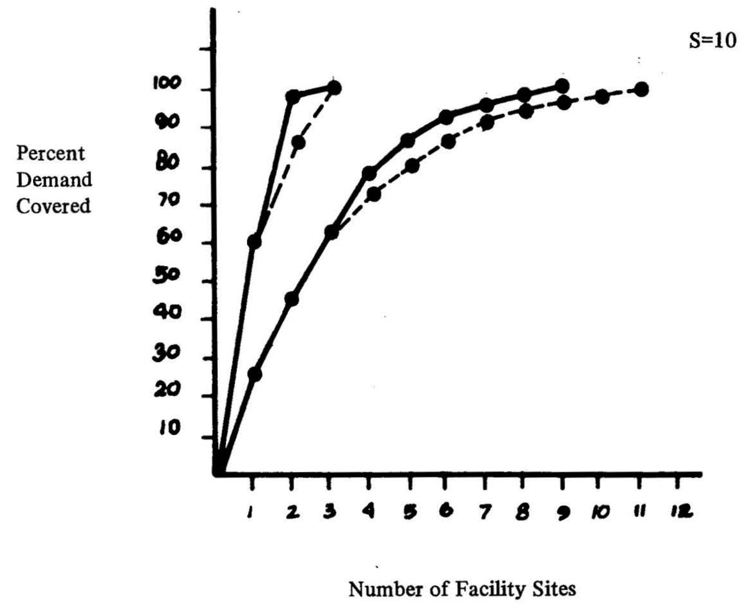
An inspection of facility location solution sets produced by GAS and GA for a range of maximal response time values (from S = 0.50 through S = 4.0) is informative. As table 3-8 illustrates, if shortened response times are required, only an increase in the number of vehicle sites can maintain 100 percent coverage of demand. This relationship is illustrated in figure 3-15; the number of facilities increase as "acceptable" response time is reduced.

**AUSTIN EMS APPLICATION**

The purpose of this section is to extend the previous example to show how the CLASGAS program can be useful in evaluation of EMS vehicle deployment in the city of Austin. The steps involved in preparation of this example are identical to those outlined in the 40-node problem.

The first step is to construct a map of the relative locations of areas in the city of Austin. The EMS project used estimates of the travel time from any of the 358 transportation serial zones in the city to any other serial zone based upon 1995 projections of population and the transporta-

FIGURE 3-14: COMPARISON OF GA AND GAS COVERAGE OF CALLS ONE AND TWO MINUTE RESPONSE TIMES




Code

GAS = unbroken line

GA = broken line is where GA solution deviates from GAS solution

S = maximum response time

TABLE 3-7: CLASGAS SOLUTION SETS FOR ONE-MINUTE SERVICE STANDARD

| | GAS | | GA | |
|---|---|---|---|---|
| Iteration | Facilities | Coverage (%) | Facilities | Coverage (%) |
| 1 | (22) | 26.11 | (22) | 26.11 |
| 2 | 22, (34) | 46.99 | 22, (34) | 46.99 |
| 3 | 22, 34, (8) | 62.90 | 22, 34, (8) | 62.90 |
| 4 | 22, 34, 8, (36) | 72.69 | 22, 34, 8, (36) | 72.69 |
| | 22, 31, 8, 36 | 79.22 | | |
| 5 | 22, [31], 8, 36, (18) | 86.94 | 22, 34, 8, 36, (18) | 80.41 |
| 6 | 22, 31, 8, 36, 18, (27) | 91.36 | 22, 34, 8, 36, 18, (27) | 87.44 |
| | 22, [24], 8, 36, 18, 27 | 91.36 | | |
| 7 | 22, 24, 8, 36, 18, 27, (1) | 95.12 | 22, 34, 8, 36, 18, 27, (23) | 91.36 |
| 8 | 22, 24, 8, 36, 18, 27, 1, (7) | 97.33 | 22, 34, 8, 36, 18, 27, 23, (1) | 95.12 |
| | 22, 24, [3], 36, 18, 27, 1, 7 | 97.33 | | |
| | 22, 24, 3, 36, 18, 27, [29], 7 | 98.91 | | |
| | 22, 24, 3, 36, 18, [26], 29, 7 | 98.91 | | |
| | [15], 24, 3, 36, 18, 26, 29, 7 | 98.91 | | |
| 9 | 15, 24, 3, 36, 18, 26, 29, 7, (4) | 100.00 | 22, 34, 8, 36, 18, 27, 23, 1, (7) | 97.33 |
| 10 | | | 22, 34, 8, 36, 18, 27, 23, 1, 7, (29) | 98.91 |
| 11 | | | 22, 34, 8, 36, 18, 27, 23, 1, 7, 29, (4) | 100.00 |

Code

○ facility sites added per iteration

□ facility sites selected to substitute for previous location

FIGURE 3-15: TRADEOFF BETWEEN RESPONSE TIME STANDARD AND REQUIRED EMS VEHICLES

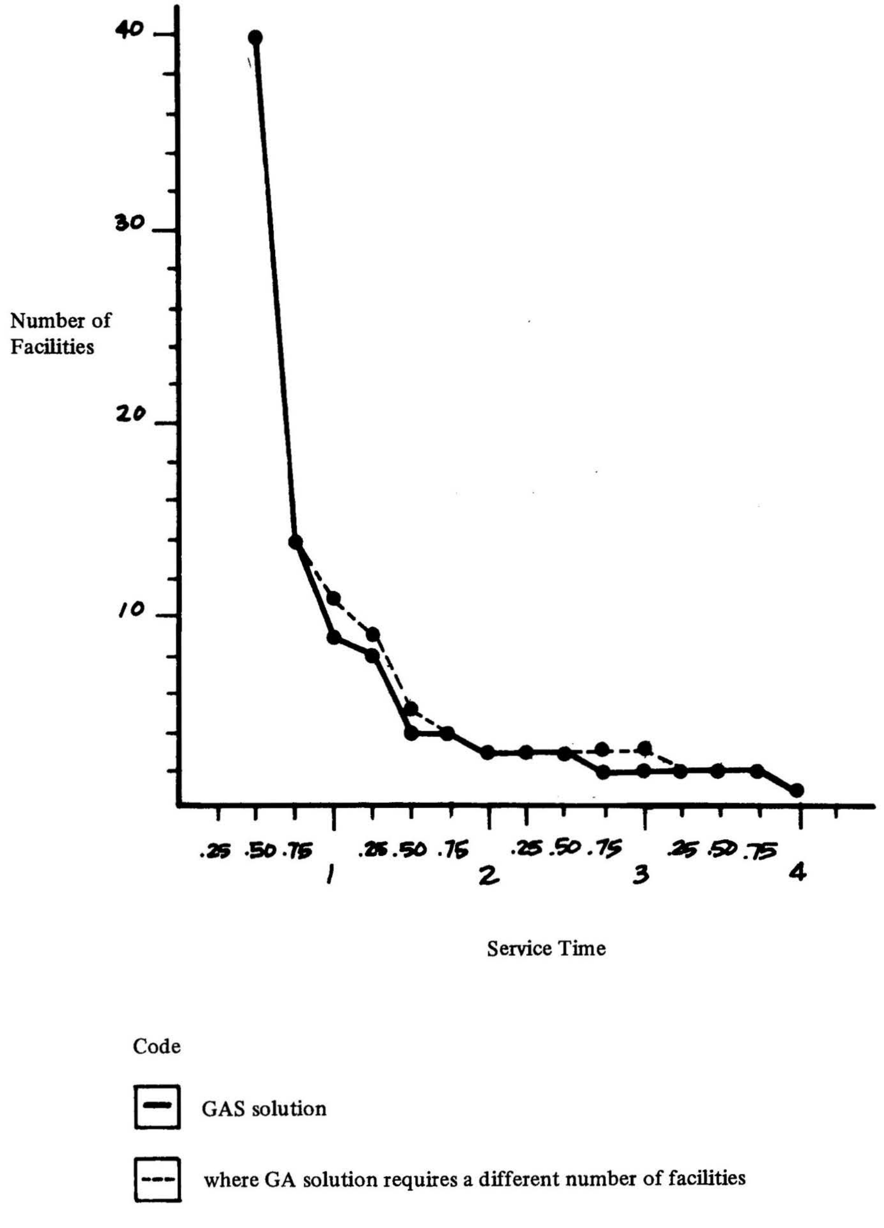


TABLE 3-8: GAS AND GA FACILITY SITE SOLUTION SETS
FOR 100 PERCENT COVERAGE OF DEMAND

| Time Standard (Minutes) | GAS | GA |
|---|---|---|
| *4.00 | 19 | 19 |
| *3.75 | 22, 19 | 22, 19 |
| *3.50 | 21, 1 | 21, 1 |
| *3.25 | 25, 1 | 25, 1 |
| 3.00 | 26, 1 | 25, 1, 20 |
| 2.75 | 26, 1 | 25, 1, 26 |
| *2.50 | 31, 3, 27 | 31, 3, 27 |
| *2.25 | 31, 3, 27 | 31, 3, 27 |
| 2.00 | 30, 13, 1 | 25, 3, 29 |
| 1.75 | 34, 16, 2, 28 | 25, 10, 35, 2 |
| 1.50 | 35, 10, 22, 2 | 25, 10, 35, 11, 2 |
| 1.25 | 14, 36, 3, 18, 27, 24, 4, 29 | 22, 34, 8, 18, 27, 39, 1, 7, 4 |
| 1.00 | 15, 24, 3, 36, 18, 26, 29, 7, 4 | 22, 34, 8, 36, 18, 27, 23, 1, 7, 29, 4 |
| * .75 | 16, 31, 37, 10, 20, 23, 5, 29, 1, 7, 11, 38 | 16, 31, 37, 10, 20, 23, 5, 29, 1, 7, 11, 38 |
| * .50 | (all demand nodes are needed) | (all demand nodes are needed) |

Code

* GAS and GA solution sets for these values are identical

tion system for Austin (4).

A second step is to represent demand for EMS. The EMS project obtained a record of historical calls for service in the city of Austin (5). This limited record of calls should not be used as a representative measure of serial zone EMS demand.*

A third step is to assume that there will be a given number of vehicles and some numerical response time standard. Assume that the goal of the EMS system is to reach a large fraction of calls for service in less than four minutes. Let seven sites be the upper limit on the number of EMS vehicle bases for Austin.

**Results**

Based on the preceding information, GA and GAS can be used to generate sites for EMS vehicles in Austin. Table 3-9 shows that, for three iterations, GA and GAS produce similar sites and comparable EMS call coverage. In the first iteration, both GA and GAS locate one EMS vehicle site at zone 166. A vehicle based in this zone could reach the location of 26.24 percent of the EMS calls in four minutes or less. In the second iteration, GA and GAS add a vehicle to zone 255. GAS substitutes zone 188 for 166. These two sites increase coverage to 38.64 percent of the city. The third iteration of both GA and GAS add a vehicle to zone 99. Vehicles based at the three sites selected by either algorithm are accessible to about half the Austin EMS calls in four minutes or less.

In the fourth iteration, GAS adds a site at zone 66 and goes through four substitutions (zone 179 for 188; 100 for 19; 65 for 66; and 188 for 179). The best GAS coverage achieved by four vehicle bases is 59.65 percent of the calls, which is 3 percent better than the four-vehicle GA solution of 56.50 percent.

The fifth, sixth, and seventh iterations follow similar patterns. After four substitutions, the fifth GAS solution set can reach only 1.7 percent more of the EMS calls than the associated GA solution. Indeed, the initial sixth GAS solution is even inferior to the sixth GA set of sites. The fraction of population covered by the initial fifth, sixth, and seventh GA and GAS solutions are rather comparable; later GAS iteration solution improvement reflects the substitution algorithm.

The final solutions generated by GAS and GA are summarized in table 3-10. The seven sites selected by GAS and GA can reach 75.68 and 73.04 percent of the Austin EMS calls in four minutes. GAS provides coverage that is only 2.64 percent better than the GA procedure.

Whereas GAS uses 578 seconds ($27.68) of computer time, GA uses only 95 seconds ($4.55). The higher GAS costs reflect the expense of fourteen substitutions. Four zones are elements of both the final sets of the seven GAS and GA sites (zones 116, 189, 255, and 264).

Table 3-11 is a comparison of the computation costs at various iterations of GA and GAS. GAS uses much more computer time to achieve only slightly improved call coverage. GA appears to be a more cost-effective approach to the screening of sites for EMS vehicles for a large multi-vehicle system.

This example run illustrates how GAS substitutes a location not in the current solution set for a present site. Compare the sites of table 3-9 with the Austin Transportation Study Serial Zone Map (figure 3-16). Most of the substitution steps involve neighboring serial zones. This pattern is similar to the built-in substitution rules of the CALL/CZSR program discussed in chapter four.

Figure 3-17 and table 3-11 illustrate how costs increase with the number of vehicle sites under consideration. As vehicle sites are added by the GA procedure, each added vehicle location appears to increase computer costs linearly. GAS computation costs appear to increase exponentially per added vehicle. This suggests that the GAS procedure becomes less cost effective as the number of vehicles increases.

The example run does indicate that GA or GAS can be valuable in identifying the added coverage performance of incremental EMS bases. As the number of vehicle sites is increased, the percentage of incremental calls covered per site decreases (see figure 3-18). At some point the benefits from increased coverage will be outweighed by the costs of establishing and operating an additional EMS vehicle base.

Although an Austin example with call frequencies that reflect demand for EMS service would be more valuable than this hypothetical case, it does illustrate the application of CLASGAS to a realistic problem. This case indicates the form of output information that is generated, and the costs of computer solutions.

It is interesting to compare the solution generated by GAS in the Austin application to current City of Austin EMS vehicle station locations and districts. Table 3-12 identifies these stations by serial zone location and area of coverage. Figure 3-19 illustrates the coverage of current EMS vehicle sites.

The seven current EMS vehicles are based in five city locations and one county location. Two vehicles are based in site one (serial zone 258), and provide coverage for districts one and two. Coverage for the west area of Austin is provided by the county vehicle (not shown in figure 3-19). Station three covers the Central Business District and a small area south of the Colorado River. Station four covers East Austin and station six covers Northeast Austin.

Figure 3-20 illustrates the five-facility GAS solution, indicating each site location and the serial zones covered per location. There are interesting differences between the current and the GAS-generated EMS vehicle districts. South Austin is not divided in half in the GAS solution. Southeast Austin is served by the East Austin site location and South-

*This record of calls is different from the data in reference (6).

# TABLE 3-9: EMS VEHICLE SITE SELECTION IN AUSTIN FOUR-MINUTE MAXIMUM RESPONSE TIME

| | GAS | | GA | |
|---|---|---|---|---|
| Iteration | Facilities | Coverage (%) | Facilities | Coverage (%) |
| 1 | 166 | 26.24 | 166 | 26.24 |
| 2 | 166, (255) | 38.04 | 166, (255) | 38.04 |
| | [188], 255 | 38.64 | | |
| 3 | 188, 255, (99) | 49.99 | 166,255, (99) | 49.39 |
| 4 | 188, 255, 99, (66) | 57.17 | 166, 255, 99, (189) | 56.50 |
| | [179], 255, 99, 66 | 57.62 | | |
| | 179, 255, [100], 66 | 59.21 | | |
| | 179, 255, 100, [65] | 59.37 | | |
| | [188], 255, 100, 65 | 59.65 | | |
| 5 | 188, 255, 100, 65, (18) | 63.66 | 166, 255, 99, 189, (116) | 63.01 |
| | [187], 255, 100, 65, 18 | 63.86 | | |
| | 187, [256], 100, 65, 18 | 64.09 | | |
| | 187, 256, 100, 65, [10] | 64.38 | | |
| | [186], 256, 100, 65, 10 | 64.73 | | |
| 6 | 186, 256, 100, 65, 10, (116) | 68.60 | 166, 255, 99, 189, 116, (65) | 69.22 |
| | 186, 256, [95], 65, 10, 116 | 70.09 | | |
| | 186, 256, 95, [41], 10, 116 | 70.42 | | |
| 7 | 186, 256, 95, 41, 10, 116, (264) | 73.09 | 166, 255, 99, 189, 116, 65, (264) | 73.04 |
| | 186, [255], 95, 41, 10, 116, 264 | 74.01 | | |
| | 186, 255, 95, 41, [5], 115, 264 | 74.01 | | |
| | [189], 255, 95, 41, 5, 116, 264 | 75.68 | | |

Code

○ facility sites added per iteration

□ facility sites selected to substitute for previous locations

TABLE 3-10: COMPARISONS OF BEST GA AND GAS SEVEN SITE SOLUTIONS
FOUR-MINUTE RESPONSE TIME

| | Primary Coverage (Percent) | Computer Time (Seconds) | Time Costs (Dollars) |
|---|---|---|---|
| GAS | 75.68 | 578 | 27.68 |
| GA | 73.04 | 95 | 4.55 |

GAS Vehicle Sites (Zones): 5, 41, 95, 116, 189, 255, 264

GA Vehicle Sites (Zones): 65, 99, 116, 166, 189, 255, 264

TABLE 3-11: COMPUTATION COST COMPARISON FOR GA AND GAS
FOUR-MINUTE RESPONSE TIME

| | GA | | GAS | |
|---|---|---|---|---|
| Facilities | Time Seconds | Time Costs | Time Seconds | Time Costs |
| 1 | 47.88 | $2.29 | 47.79 | $ 2.29 |
| 2 | 55.56 | $2.66 | | |
| 3 | 63.73 | $3.05 | | |
| 4 | 70.97 | $3.40 | 207.18 | $ 9.92 |
| 5 | 78.67 | $3.76 | | |
| 6 | 85.55 | $4.14 | | |
| 7 | 94.98 | $4.55 | 577.79 | $27.68 |

west Austin is served by the Central Business District vehicle site. North Austin is not divided into Northeast and Northwest Austin; the entire area is covered by a vehicle located at serial zone 100.

Despite the differences in partitioning, there are notable similarities between the current system and the five-facility GAS solution. Table 3-13 lists the serial zones of the best GAS five-facility EMS vehicle sites. Station one, covering East and Southeast Austin is located at serial zone 186. Referring to figure 3-19, one can see that this serial zone is contiguous with the current East Austin station located at serial zone 180. Station two, which provides coverage for South Austin, is adjacent to the current South Austin station located at serial zone 258. Station three covering North Austin is contiguous with the current EMS station covering Northeast Austin. Station five is located within the Central Business District; the current station covering this area is adjacent to it. The greatest difference in site location between the GAS five-site solution and the current system is GAS site four located at serial zone 65 (versus serial zone 118 in the current system). All the GAS sites tend to cluster in the center of the city.

Figure 3-21 shows the GAS six-facility site solution and associated EMS vehicle districts. The partitions containing South Austin and East Austin are very similar to the GAS five-facility partitions (see figure 3-20). The greatest differences in the two GAS solutions are in the north and the west parts of Austin. North Austin is divided into Northeast and Northwest Austin, with boundaries roughly similar to the current EMS districts (see figure 3-19). The Central

FIGURE 3-16: AUSTIN TRANSPORTATION STUDY SERIAL ZONE MAP

FIGURE 3-17: TRADEOFF BETWEEN COSTS AND NUMBER OF SITES

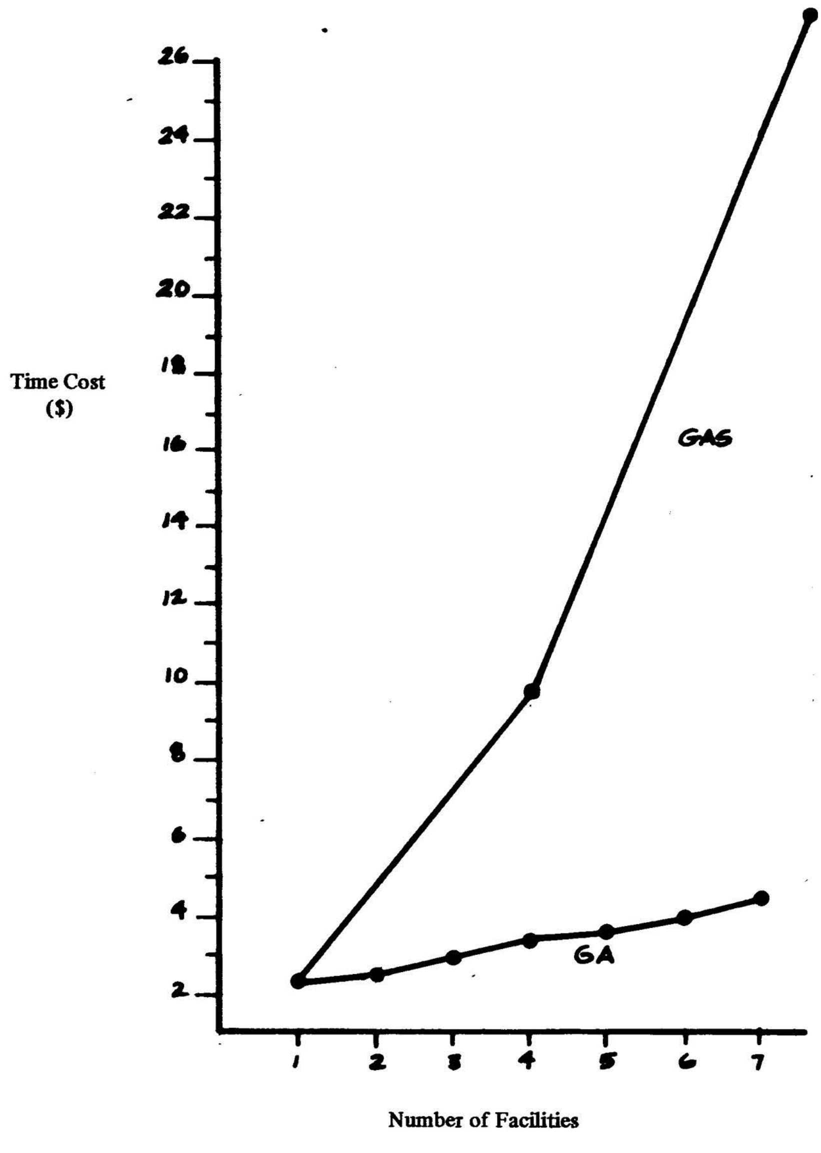


FIGURE 3-18: COMPARISON OF GAS AND GA INCREMENTAL IMPROVEMENT IN CALL COVERAGE

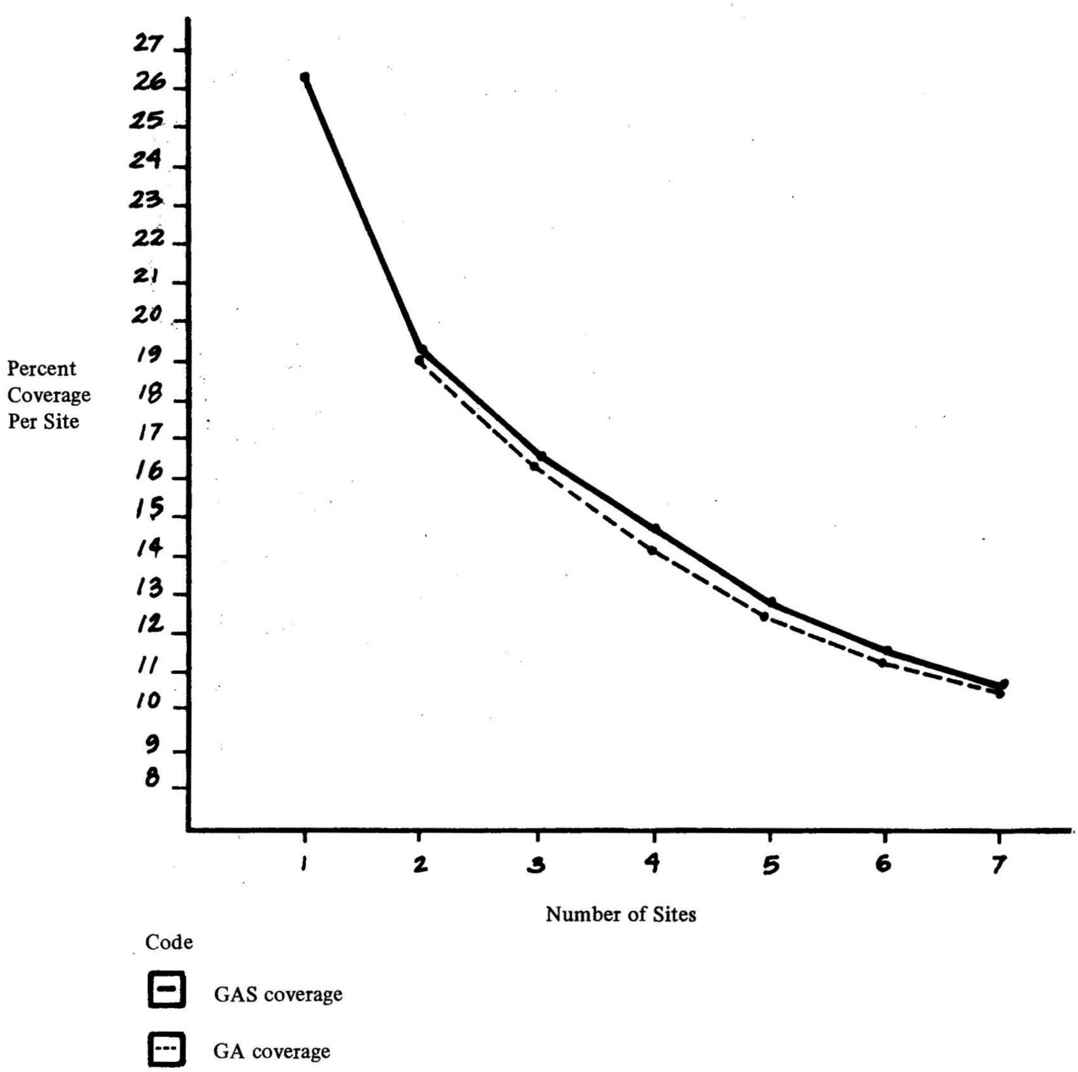


FIGURE 3-19: CURRENT EMS VEHICLE STATION LOCATIONS AND EMS DISTRICTS

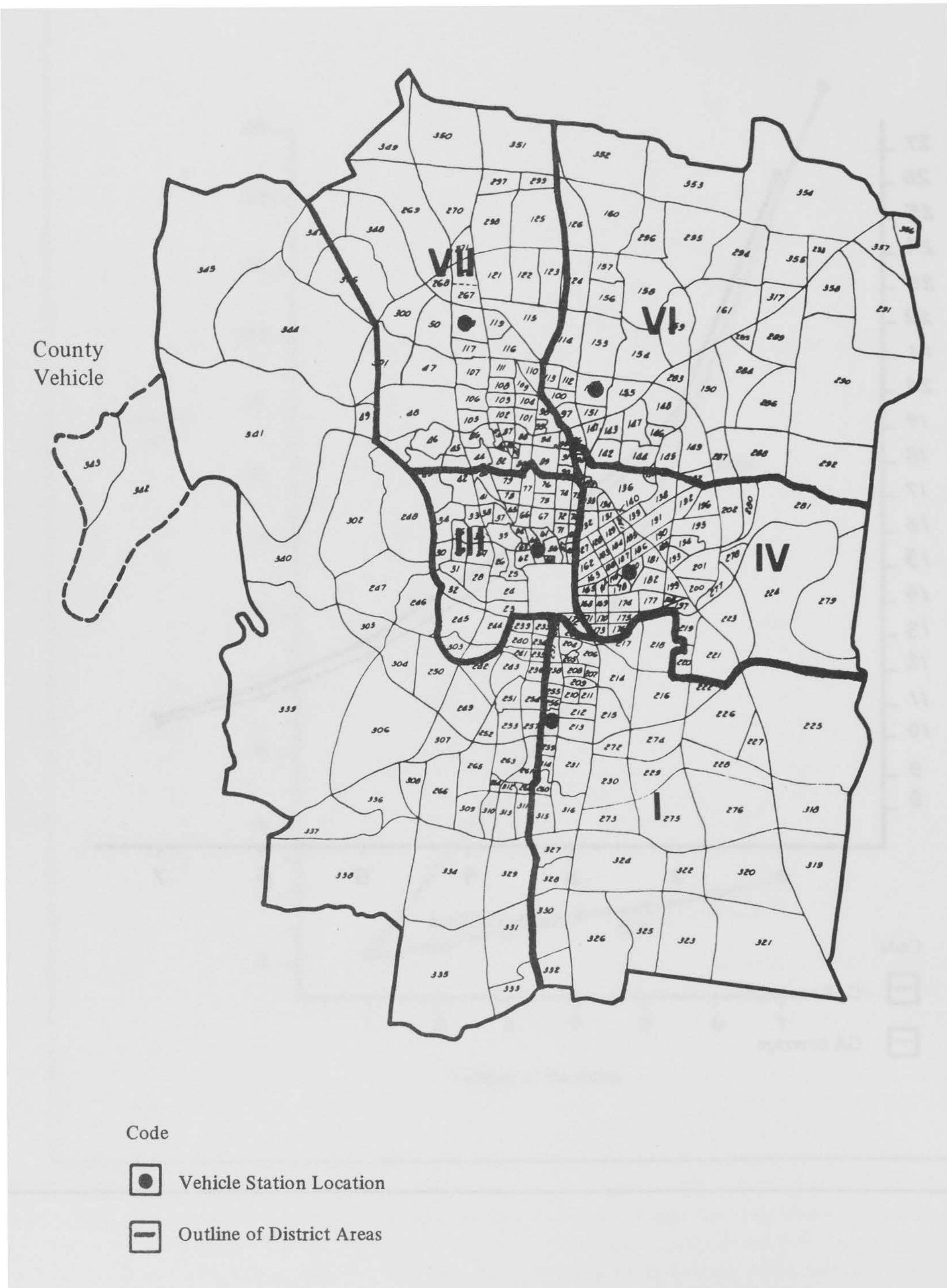


FIGURE 3-20: MAP OF 5 FACILITY GAS SOLUTION AND EMS DISTRICTS

FIGURE 3-21: MAP OF 6 FACILITY GAS SOLUTION AND EMS DISTRICTS

TABLE 3-12: CURRENT EMS LOCATION SITES

| Station | Serial Zone Location | Area of Coverage |
|---|---|---|
| one | 258 | South Austin |
| three | 59 | Central Business District (CBD) |
| four | 180 | East Austin |
| six | 152 | Northeast Austin |
| seven | 118 | Northwest Austin |
| county | outside of study area | County |

TABLE 3-13: GAS FIVE FACILITY LOCATION SITES

| Station | Serial Zone Location | Area of Coverage |
|---|---|---|
| one | 186 | East and Southeast Austin |
| two | 256 | South Austin |
| three | 100 | North Austin |
| four | 65 | Central and West Austin |
| five | 10 | CBD and Southwest Austin |

TABLE 3-14: GAS SIX FACILITY LOCATION SITES

| Station | Serial Zone Location | Area of Coverage |
|---|---|---|
| one | 186 | East and Southeast Austin |
| two | 256 | South Austin |
| three | 95 | Northeast Austin |
| four | 41 | West Austin |
| five | 10 | Central Business District |
| six | 116 | Northwest Austin |

Business District vehicle serves a compact area. Coverage for West Austin is provided by a sixth vehicle located at serial zone 41.

Comparing table 3-14 and figure 3-19, one can see similarities and differences between the GAS six-facility solution sites and the current EMS sites. The station locations for East Austin and South Austin are contiguous; the station locations for the Central Business District are closely related, since the EMS station in serial zone 59 is adjacent to the area. The GAS site covering Northwest Austin is contiguous to the current Northwest Austin serial zone location. The site serving Northeast Austin is located closer to the central area of Austin than the current station serving the same area. GAS provides an additional location covering West Austin. Presently, this area is served by the county location or the locations covering Northwest, Central, and South Austin.

# References

(1) Richard L. Church and Charles S. ReVelle, "The Maximal Covering Location Problem," *Papers of the Regional Science Association:* 32, no. 101 (Fall 1974), pp. 101-18.

(2) P.G. Gaal, "Cardiac Arrest and Resuscitation," in *Early Management of Acute Trauma,* ed. A.M. Hahum (St. Louis: C. V. Moxby, 1966), pp. 53-63.

(3) Richard L. Church, *An Introduction and Guide to the Location of Public Facilities Utilizing the "GAS" Program* (Austin, Tex.: LBJ School of Public Affairs, The University of Texas at Austin, 1979).

(4) Emergency Medical Services Policy Research Project, *Location Techniques for Emergency Medical Service Vehicles, Volume II: Travel Time Data—Description and Assumptions* (Austin, Tex: LBJ School of Public Affairs, The University of Texas at Austin, 1979).

(5) City of Austin, Emergency Medical Service Department, Partial List of EMS Calls in Austin, Texas during

December of 1976 and January, June, July, and August of 1977.

(6) Emergency Medical Service Policy Research Project, *Location Techniques for Emergency Medical Service Vehicles, Volume III: Emergency Medical Service Calls in Austin–Description and Assumptions* (Austin, Tex.: LBJ School of Public Affairs, The University of Texas at Austin, 1979).

# Chapter 4
# The Use of CALL/CZSR in Analyzing Alternate EMS Vehicle Locations

This chapter describes and illustrates the use of the CALL/CZSR computer routine for analysis of alternate EMS vehicle sites. Included is a user-oriented description of appropriate assumptions and the necessary computer control cards to run the program. This chapter also illustrates the routine's use with a sample 34-zone problem and a large scale (358 zone) application of CALL/CZSR for evaluating EMS vehicle bases in Austin.

CALL/CZSR is actually two routines that work together to determine good sites for EMS vehicles. CALL (Computerized Ambulance Location Logic) uses queuing theory to evaluate average system response time for a system, given a distribution of EMS calls and a trial deployment of service vehicles. CZSR (Contiguous Zone Search Routine) attempts to substitute neighboring zones as EMS vehicle bases for the set of trial locations. Subsequent repetitions of the CALL and the CZSR routines allow CALL/CZSR to find a set of sites that reduce the system mean response time and balance out EMS workloads.

## CALL/CZSR ASSUMPTIONS

The CALL/CZSR model is a computer procedure that determines EMS vehicle sites on the basis of a minimum average response time. The CALL routine measures system performance by calculating mean response time for a given set of vehicle locations. Figure 4-1 shows the relationship of response time to the various activity components of emergency medical service. Response time is the time delay between the reporting of an emergency and the time an EMS vehicle arrives at the scene. The CZSR portion of the model systematically shifts vehicle sites to reduce the average response time for EMS vehicles to serve all calls.

The purpose of this section is to list and describe the model assumptions relating to system geography, EMS demand, EMS supply, and measures of effectiveness of an emergency medical service. Table 4-1 lists the assumptions associated with each category.

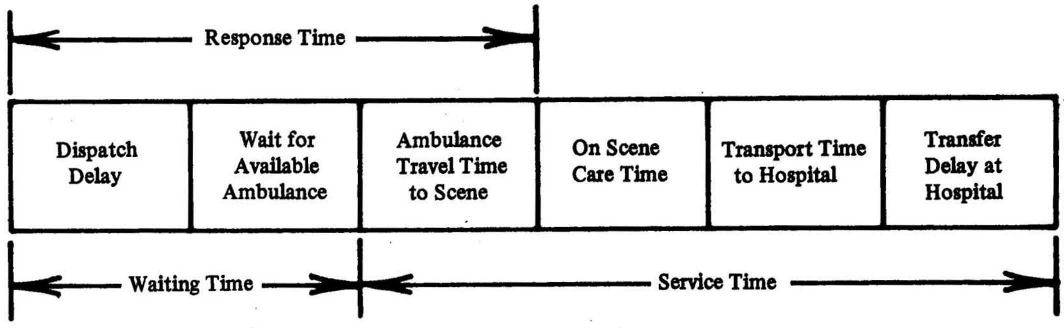
### Basic Assumptions

The CALL/CZSR model implicitly uses a set of nodes connected by links to represent the study area. The study area is divided into discrete zones, with each zone represented by a node placed at the centroid of zone activities. The relative position of each zone in the study area is described to CALL/CZSR by the zones contiguous to it. The user may choose census tracts, serial zones, etc., as possible study area divisions.

The CALL/CZSR routine begins with a user-supplied set of trial EMS vehicle sites. Computer procedures will shift vehicle locations if such changes improve performance of the total system. Potential replacement sites at any iteration are defined as any zone contiguous to a current trial site.

The CALL/CZSR model assumes that calls for EMS service occur at district centroids. Average demand from each district can be represented by a call rate for service based

FIGURE 4-1
SEQUENCE OF EVENTS IN PATIENT SERVICE



## TABLE 4-1: ASSUMPTIONS OF THE CALL/CZSR LOCATION MODEL

| Kind | Subject | Assumption |
|---|---|---|
| Geographical | City or area structure | A set of discrete districts represented by central points that are connected by travel time links |
| | Potential vehicle sites | At district centroids only |
| Demand | Origin of calls for EMS | From district centroids representing population concentration |
| | Demand for EMS | Rate of calls for service as defined by a Poisson distribution |
| | | Defined by the number of calls from a district in a period of time |
| Supply | Characteristics of service | Emergency vehicles are identical |
| | Vehicle dispatch | There will always be an available vehicle that can respond to a call |
| | | The closest available vehicle is dispatched |
| Criteria | Effectiveness of EMS system | Minimize average system response time |
| | Workload | Smooth workload for purposes of equity and training of EMS personnel |
| | Probability of excessive response time | Minimize the occurrence of extreme response times because of life-threatening consequences |

upon historical or forecasted call data. The number of calls for service from a district is approximated by a Poisson probability distribution. A Poisson distribution assumes that events occur independently of each other at random intervals.

Once a call for service occurs, the model calculates a response time based on a $M/G/\infty$ queuing model. The queuing model predicts the availability of EMS vehicles (i.e., the number of vehicles busy when the call is received), given parameters representing (a) the arrival rate and distribution of calls for service, (b) the average EMS service time and its distribution, and (c) the number of EMS vehicles. The notation "$M/G/\infty$" indicates by "M" that the call arrival rate is a Poisson distribution. The "G" represents service times of a general distribution. The "$\infty$" is used to denote an infinite number of vehicles; that is, no call for service need wait. Even if in reality the number of emergency medical vehicles is finite, the CALL/CZSR routine assumes that the probability of all vehicles being busy at one time is essentially zero.

Other assumptions relate to the existence and performance of emergency medical vehicles. All vehicles are identical in terms of speed of response, length of time for on-scene care, sophistication of equipment and EMS personnel, and transfer delay at the hospital. The time that elapses between the dispatch of a vehicle and its arrival at the scene is based upon estimated minimum travel times between districts provided by the user to the model. The user must also provide estimates of the average time for on-scene care and transfer delay.

EMS vehicles are dispatched only from a district centroid, rather than from any point within a district. Also, the closest available vehicle will be dispatched to serve a call. If a call occurs in a district where the "first-in" vehicle is busy, the next closest available vehicle will respond.

The CALL/CZSR model measures effectiveness of the EMS system by the average system response time. Response time is used as a performance criterion because the likelihood of patient death or permanent disability from trauma is related to the length of delay prior to treatment.

The number of ambulances and their deployment directly affects an EMS system's response time. The CALL/CZSR model tries to find EMS vehicle deployments that minimize the average response time of the entire system. Two other measures of system effectiveness, the likelihood of excessive response times (i.e., response times greater than some limit) and the workload range, may or may not be improved by minimizing mean response time. The workload range measures the workload differential between the busiest and the least busy EMS vehicles.

### User Options

CALL/CZSR has several options that allow a user to represent existing site restrictions. A user can specify the number of hospitals that will receive emergency medical cases, and the program will direct the EMS vehicle to the nearest hospital. The user must specify the number of vehicles that will be available and their initial trial locations within the study area. Districts inappropriate for EMS facility use (e.g., parks, industrial areas, etc.) can be removed from the list of potential facility sites.

## A CALL/CZSR USER'S MANUAL

This section develops a manual for running the CALL/CZSR program on the computer. Initial sections present the theory and logic of the CALL and CZSR routines. The manual then goes through a card-by-card description of the data requirements for batch entry on University of Texas at Austin system.

### The CALL Program

Figure 4-1 illustrated the sequence of events involved in serving a patient in an EMS system. Identifying some of the events as waiting and others as service suggests that the EMS system can be thought of as a queuing or waiting line system with one or more ambulances as servers. The CALL (Computerized Ambulance Location Logic) program uses this queuing framework to evaluate the system's mean response time for a given number and spatial location of ambulances (1).

Intrinsic to the model is the assumption that response time can be approximated by travel time to the scene. The dispatch delay component of response time is considered a constant unaffected by EMS vehicle deployment. The time spent waiting for a busy ambulance to become available has been assumed to be essentially zero. Austin call data analysis shows this assumption to be appropriate, although incidents have occurred in which all the ambulances were busy (2).

The response to a particular call will reflect the state of the system when the call is received. Often when a medical emergency occurs, the ambulance that would normally be assigned may be busy; therefore an idle but more distant ambulance is dispatched. Thus response time is dependent on the number and identity of the ambulances busy when a call is received. The value of mean response time for the system will be more accurate if calculations account for this dynamic phenomenon.

CALL represents the EMS vehicle system as being in various states of utilization. System states are identified by the number of ambulances busy when a call is received (i.e., states in which 0, 1, 2, . . . , n vehicles are busy). The mean response time for an ambulance system is then calculated by (a) determining the conditional mean response time for each system state, and (b) weighting each by the probability of that state occurring, as shown by the first term in equation 4-1.* If all ambulances are busy when a call is received, the next available ambulance will most likely respond from the hospital. The last term in equation 4-1 accounts for this possibility.

Equation 4-1

$$RBAR = \sum_{i=0}^{n-1} P(i)\,R(i) + \left[1 - \sum_{i=0}^{n-1} P(i)\right] RH$$

where

RBAR = system mean response time, minutes
P (i) = probability of "i" busy EMS vehicles
R (i) = conditional response time given "i" busy vehicles
n = number of EMS vehicles in the system
i = number of busy servers

For a queuing system in which there is no waiting, the likelihood of a certain state of the system occurring (i.e., the number of busy servers) follows the probability distribution shown in equation 4-2. Only two parameters are required, the mean call rate (e.g., five emergency calls per hour on the average), and the expected number of patients to be served per hour. For example, an average of thirty minutes per patient would result in a service rate of two patients per hour.

Equation 4-2

$$P(i) = \frac{e^{-(a/s)}\,(a/s)^{i}}{i!}$$

where P (i) and i are as previously defined and where

a = mean call rate with Poisson distribution
s = mean service rate per ambulance
e = base of the natural logarithms (2.71828)

Equation 4-2 assumes a Poisson call distribution. This assumption can be verified by applying a Chi-square goodness-of-fit test on the call data. A number of empirical studies of emergency systems have found that EMS calls do follow a Poisson distribution (4).

The use of this queuing model as an approximation to an EMS system means that emergency ambulance utilization

*Equations 4-1 through 4-3 originally appeared in reference (3).

must be low to insure that the probability of all ambulances being busy is insignificant. Equation 4-3 can be used to estimate the probability that a call must wait.

Equation 4-3

$$p(i \geqslant n) = 1 - \left[ \sum_{k=0}^{n-1} \frac{e^{-(a/s)} (a/s)^k}{k!} \right]$$

Figure 4-2 provides a flowchart of the calculations made in the computer version of the ambulance flowchart model. The input to the model consists of data identifying the locations of ambulance stations, hospitals, and districts that partition the service area into sources of demand. Additional required information includes the expected number of calls per day, expected time at scene, expected transfer time between each district pair and the relative frequency of calls occurring in each district is also required.

From this data, the model calculates the expected response time from the hospitals and the expected retrieval time to the hospitals. These values are calculated initially because they do not change with vehicle deployment. Based on a trial set of vehicle stations, a dispatch preference (first-in) list is established for each district assuming the closest idle ambulance will respond. Using this priority list and the probabilities of incidents occurring in each district, the mean response time is calculated for the system state when all ambulances are idle. The mean response for the system state when one vehicle is busy is similarly determined, based on the probability that the first ambulance of choice may be busy. The mean response times for the remaining system states (i.e., when 2, 3, 4, . . . , n-1 vehicles are busy) are estimated by Monte Carlo simulation methods because the number of combinations of busy vehicles associated with each system state is large. Because the estimates of mean response time and mean service time are interrelated (see figure 4-1), the CALL program is designed to cycle through the process of estimating mean response time until the value is stabilized. Finally, the distribution of system response time is estimated. The average number of daily calls served by each ambulance and many other features of the system are reported in Appendix B.

### Contiguous Zone Search Routine (CZSR)

One of the required inputs to the CALL/CZSR program is a trial deployment of emergency vehicles. This deployment may perform well in terms of average system response time, or it may not. Hence it is useful to be able to search for some set of vehicle sites that minimizes the mean response time of the system.

The CZSR search routine starts with an initial deployment. Successive vehicle site moves are tested to see whether system average response time is reduced by the move. The testing of potential vehicle locations continues until new moves do not produce significant reductions in the system mean response time.

To perform these moves, CZSR requires as input a list of contiguous zones for each zone or district in the service area. This list of contiguous zones completely describes the map of the region in a logical and computer-recognizable fashion. CZSR selects potential moves by attempting all possible substitutions of nearest neighbor zones for any of the zones currently serving as trial sites.

Figure 4-3 shows a descriptive flowchart of the contiguous zone search logic (5). The search routine uses the response model CALL as a subroutine to evaluate RBAR, the system mean response time, for a particular deployment. The response model is first called to evaluate the system performance for the initial vehicle locations. The CZSR search routine then proceeds to move vehicles systematically one at a time to neighboring zones, checking each move with the response model to evaluate system performance for the trial location. For each vehicle site, a search is made around its contiguous zones for an improvement in the system mean response time. The best move for each vehicle and the combined effect of simultaneously moving all ambulances to their best trial location is recorded. If there is a move that improves upon the previous set of locations, then that move becomes the new trial deployment. This new deployment may represent a change in one or all vehicle locations, depending on the outcomes of the separate and simultaneous moves.

During the search for the best vehicle deployment pattern, either a new set of locations may be established and the search repeated, or the search is terminated. Termination of CZSR occurs when no significant improvement in system mean response time is possible, or when the search evaluations have exceeded a user-specified upper limit on the number of evaluations.

Because it is likely that some areas within a city, such as parks or lakes, will be inappropriate for facility location, CZSR has an option where the user can select only certain contiguous zones for search. This is most commonly done by omitting the inappropriate zone from the contiguous zone lists.

### Data Requirements for CALL/CZSR

Figure 4-4 shows the deck structure for the CALL/CZSR program. There are four types of data cards in the input deck—two system parameter cards (one for integer parameters, one for real parameters), emergency medical facility cards, and emergency medical vehicle cards. Zone contiguity data cards would be a fifth type of data; however,

FIGURE 4-2: FLOWCHART OF "CALL," THE EMS VEHICLE RESPONSE MODEL

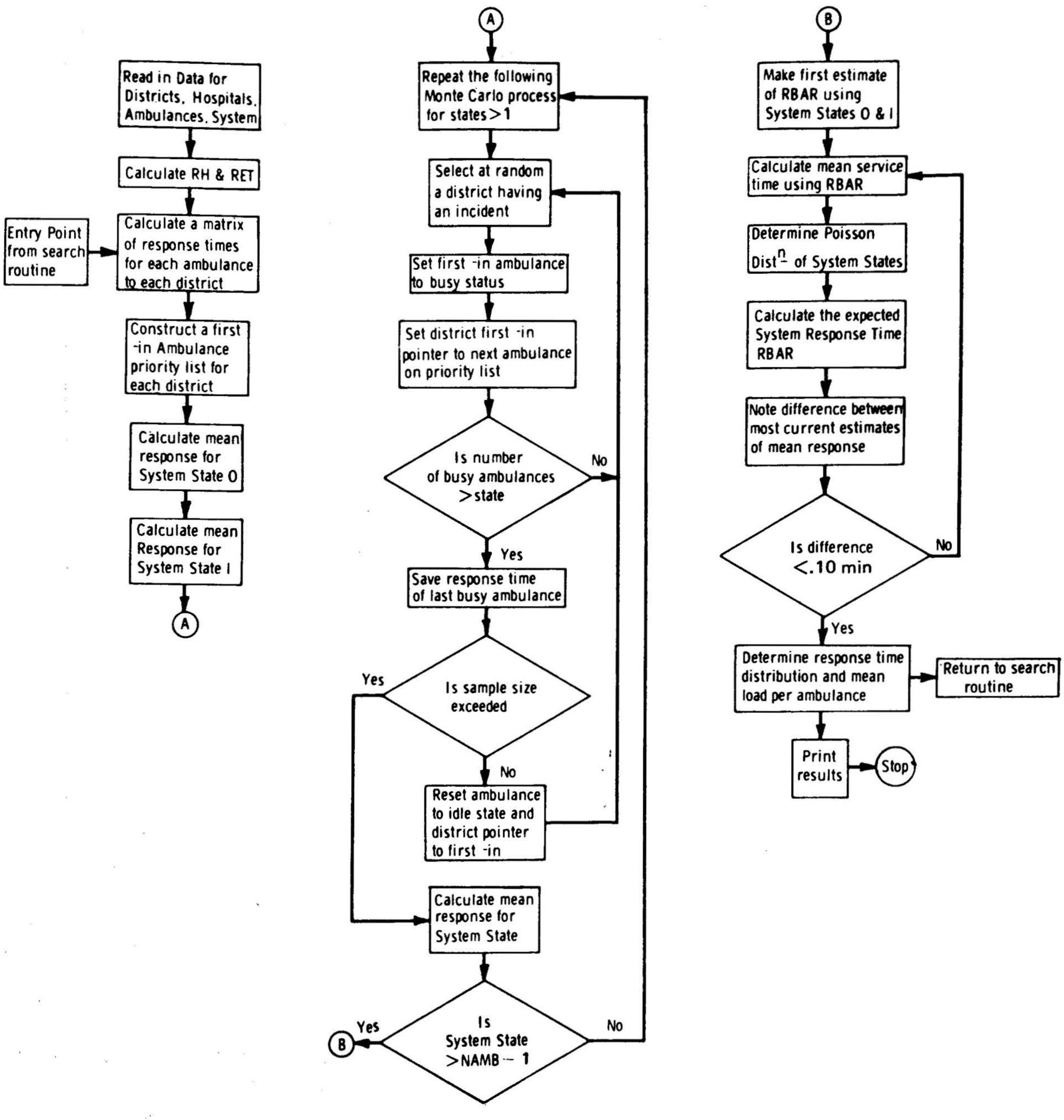
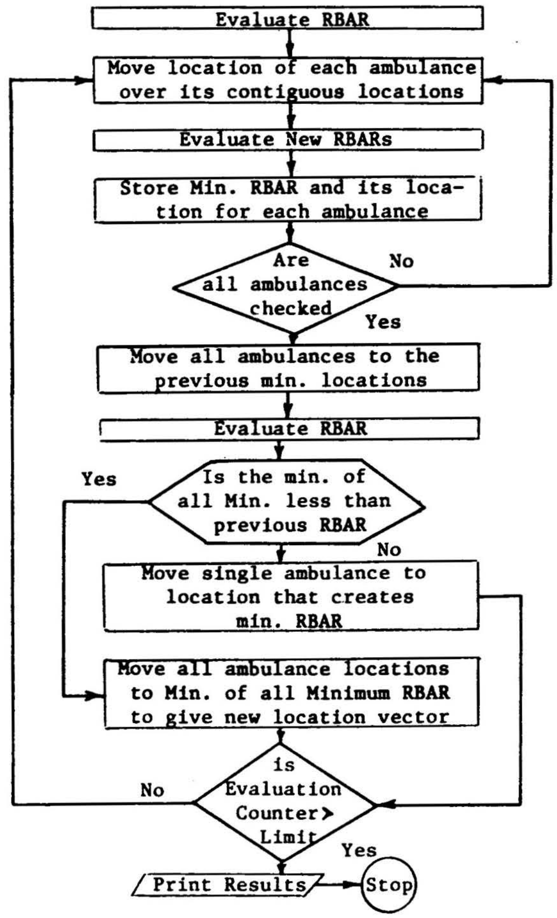


FIGURE 4-3: FLOWCHART OF "CZSR," THE CONTIGUOUS ZONE SEARCH ROUTINE




as such information can be great, these cards are usually replaced by a reference to a tape file.

Each card type will be fully explained, with keypunching instructions and sample values. The sample values are part of a hypothetical problem, and may be compared with a sample input deck shown in this section and the sample output which appears as Appendix B.

The hypothetical analysis is based on Austin's thirty-four census tracts. A census tract map, shown in figure 4-5, is used to illustrate the process of districting a city. Table 4-2 renumbers each census tract as a zone, and uses the map to develop the list of contiguous zones. Any zone not appropriate for ambulance location (i.e., a park area, lake, etc.) will be omitted from the list of contiguous zones. It is assumed that vehicle sites will be at the centroid of the zone.

The emergency medical system is described by two parameter cards. These cards, described by tables 4-3 and 4-4, indicate the nature of the input data and the format for keypunching it on computer cards. The format for keypunching cards is specified as floating (for decimal format), integer, or alphanumeric format. An example of a floating format is "F8.3," which indicates an eight-column width field with decimal places in the last three columns. "I5" is an example of an integer format. It indicates a five-column field with only integer inputs. The alphanumeric format "A4" indicates a field of characters. The expression "3X" is a skip specification. Nothing should be punched in the three-column field denoted by "3X," since the computer will skip reading these columns. An integer in front of any expression in parentheses, such as "6(I5)," denotes several consecutive fields with the same type of input format.

FIGURE 4-4

GENERAL CALL/CZSR DECK STRUCTURE

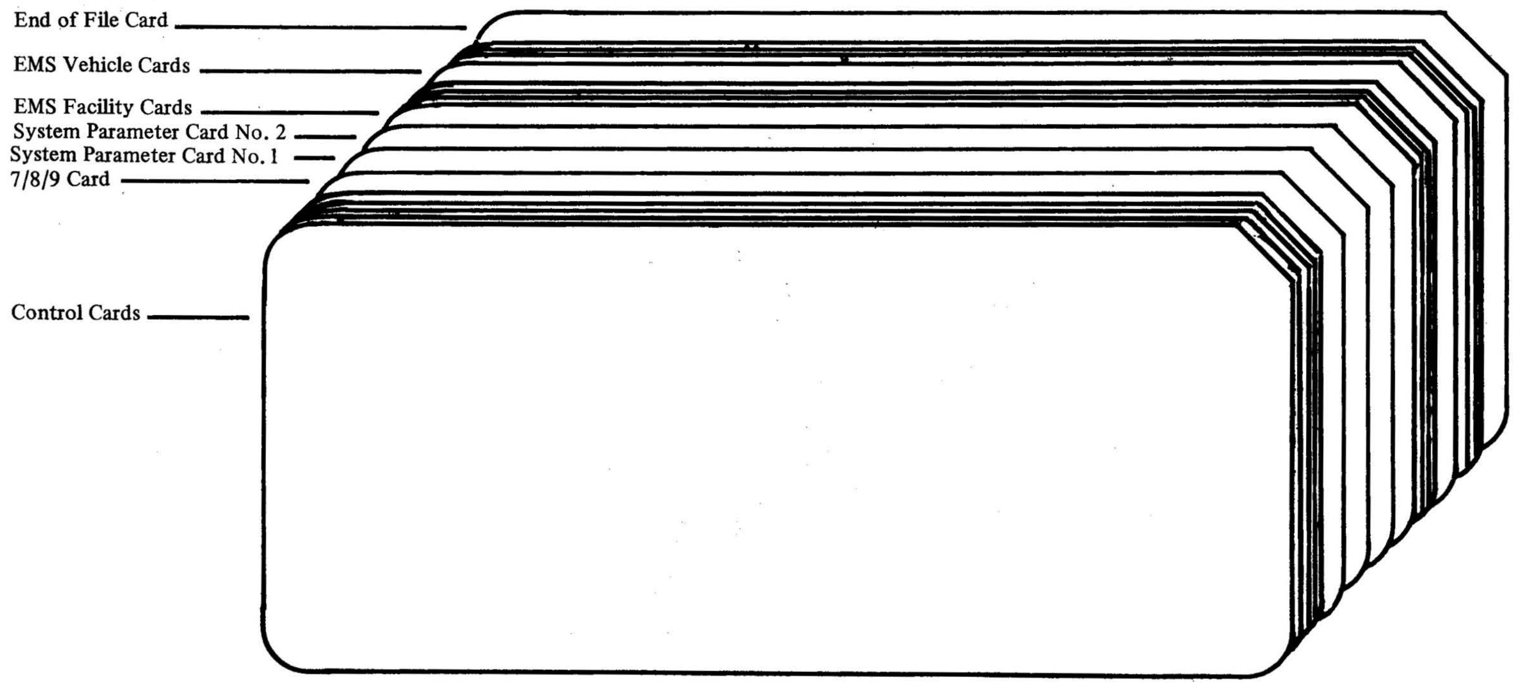


FIGURE 4-5: CENSUS TRACT MAP OF AUSTIN, TEXAS

"6(I5)" describes six consecutive five-column width fields with only integer inputs.

The decimal points in parameter card 1 can be keypunched anywhere within the appropriate field. All data for parameter card 2 must be right-justified within each field. For example, NHOSP, which has a sample value of 1, can have the 1 punched only in column 21. The sample values in tables 4-3 and 4-4 can be compared with the illustration of an input deck (see figure 4-6).

The parameter LIMIT, shown in table 4-4, is used to terminate the computer search after an arbitrary number of evaluations. If LIMIT is set to a large value (e.g., 999), the search routine should terminate prior to evaluation 999. CALL/CZSR will not undertake a new evaluation if the difference between the present deployment's mean response time differs from the previous deployment's by less than 1/100 of a minute. LIMIT is used as an upper bound on search evaluations to insure against excessive computer processing time. If LIMIT is set equal to one, then a search for optimal deployment will not be attempted, and a single evaluation for the existing system will be made.

The values of the other variables can likewise be adjusted to reflect the user's situation. NAMB, the number of ambulances in the system, is often adjusted to affect system

## TABLE 4-2: SUMMARY OF CONTIGUOUS ZONES FOR AUSTIN, TEXAS

| Census Tract Number | Zone Number | Contiguous Zones |
|---|---|---|
| 1 | 1 | 2, 19, 27, 16, 21 |
| 2 | 2 | 1, 16, 17, 18, 3, 5, 19 |
| 3 | 3 | 2, 18, 28, 29, 45 |
| 4 | 4 | 3, 5, 6, 7, 8, 29 |
| 5 | 5 | 2, 3, 4, 6 |
| 6 | 6 | 4, 5, 19, 7, 2 |
| 7 | 7 | 4, 6, 19, 11, 8, 12 |
| 8 | 8 | 4, 7, 11, 9, 29 |
| 9 | 9 | 8, 11, 10, 32, 29 |
| 10 | 10 | 9, 11, 15, 31, 32, 29 |
| 11 | 11 | 7, 12, 13, 14, 15, 10, 9 |
| 12 | 12 | 7, 9, 20, 26, 13, 14, 11 |
| 13.01 | 13 | 12, 26, 27, 14, 11 |
| 13.02 | 14 | 11, 12, 13, 27, 31, 15 |
| 14 | 15 | 11, 14, 31, 10 |
| 15.01 | 16 | 21, 1, 2, 17, 25 |
| 15.02 | 17 | 25, 16, 2, 18, 23 |
| 15.03 | 18 | 17, 2, 3, 28, 24, 23, 25 |
| 16.01 | 19 | 1, 2, 6, 7, 12, 20 |
| 16.02 | 20 | 19, 12, 26 |
| 17.01 | 21 | 1, 16, 25 |
| 17.02 | 22 | 26, 27, 34 |
| 18.01 | 23 | 25, 17, 18, 30 |
| 18.02 | 24 | 23, 18, 28, 30 |
| 18.03 | 25 | 21, 16, 17, 23 |
| 19 | 26 | 20, 12, 13, 27, 22 |
| 20 | 27 | 26, 22, 34, 31, 14, 13 |
| 21.01 | 28 | 23, 18, 3, 29, 30 |
| 21.02 | 29 | 3, 4, 8, 9, 32, 30 |
| 22 | 30 | 23, 24, 28, 29, 32 |
| 23.01 | 31 | 34, 27, 14, 15, 10, 32 |
| 23.02 | 32 | 10, 31, 33, 30, 29 |
| 23.03 | 33 | 32, 24, 30 |
| 24 | 34 | 27, 31, 33 |

response. NHOSP, the number of hospitals in the area with the capabilities for emergency treatment, should reflect existing facilities.

Information on the sources of calls and zones consists of three sets of ordered data describing their characteristics. First, the zones with their contiguous zones must be specified. The second data set consists of the expected number of calls from each zone, beginning with the first zone. The third set of data consists of a series of numbers indicating the time tables for each EMS vehicle to travel from each zone to any other zone. Input details and variable descriptions are given in table 4-5.

The sources of the data in table 4-5 require some explanation. IZONE is generally obtained from a map, such as figure 4-5. The expected number of calls from each zone, NUMCALL, may be available either from historical data or a predictive model. The number of calls is used in CALL/CZSR to calculate the probability of receiving a call from each zone. For ITRVEL, the user may obtain an interzonal travel time matrix from the files of the local state highway department. In order to avoid zero-valued travel times within a traffic zone, intrazone travel times in the array (i.e., 1 to 1, 2 to 2, etc.) can be estimated. In the sample problem, intrazone trips are assumed to be one-half the time required to travel from the centroid to a boundary of the zone.

Tables 4-6 and 4-7 give information about the EMS facility and the EMS vehicle cards respectively. Each hospital and each vehicle requires an identification card in the input deck.

## TABLE 4-3: SYSTEM PARAMETER CARD ONE (PUNCHED IN AN 8 (F8.3) FORMAT)

| Card Column | Variable | Sample Value | Definition | Comments |
|---|---|---|---|---|
| 1-8 | LAMBDA | 35.0 | Average number of calls per day | |
| 9-16 | CARE | 15.0 | Average time on scene | Given in minutes |
| 17-24 | TRSFR | 20.0 | Average transfer time at hospital | Given in minutes |
| 25-32 | TRANS | 0.63 | Percent of calls necessitating transport to hospital | Given in decimal form |
| 33-40 | DECI | 1.0 | Conversion factor from an integer travel time representation to an actual value, using a power of ten | As an example, if travel time is to be expressed in hundredths of a minute, a value of 100.0 should be used |

## TABLE 4-4: SYSTEM PARAMETER CARD (PUNCHED IN AN (I5,3X) FORMAT)

| Card Column | Variable | Sample Value | Definition | Comments |
|---|---|---|---|---|
| 1-5 | LIMIT | 999 | Maximum number of search evaluations | If set to 1, no search for improved locations will be made |
| 9-13 | NAMB | 5 | Number of ambulances in fleet | Maximum value = 10 |
| 17-21 | NHOSP | 1 | Number of emergency medical facilities | Maximum value = 10 |
| 25-29 | NDIST | 34 | Number of districts (zones) in the service area | Maximum value = 400 |
| 33-37 | NFRAC | 30 | Number of one-minute class intervals for response distribution | Distributions generated for relative and cumulative frequencies Maximum value = 40 |

## TABLE 4-5: ZONE DATA CARDS

| Data Set | Variable | Format | Definition | Comments |
|---|---|---|---|---|
| I | IZONE | 16(I5) | The zone number followed by the numbers of its contiguous zones | Each zone requires one IZONE card<br>If a zone cannot accommodate an ambulance, it will not appear as a contiguous zone on any card |
| II | NUMCALL | 16(I5) | The number of calls expected from each zone | |
| III | ITRVEL | 20(I4) | The travel time between zones | Read as a "from-to" matrix (i.e., zone 1 to itself and to all other zones, followed by zone 2 to zone 1, itself, and all other zones, etc.)<br>Expressed in integer values |

FIGURE 4-6
SAMPLE CALL/CZSR DECK FOR A 34-ZONE ANALYSIS

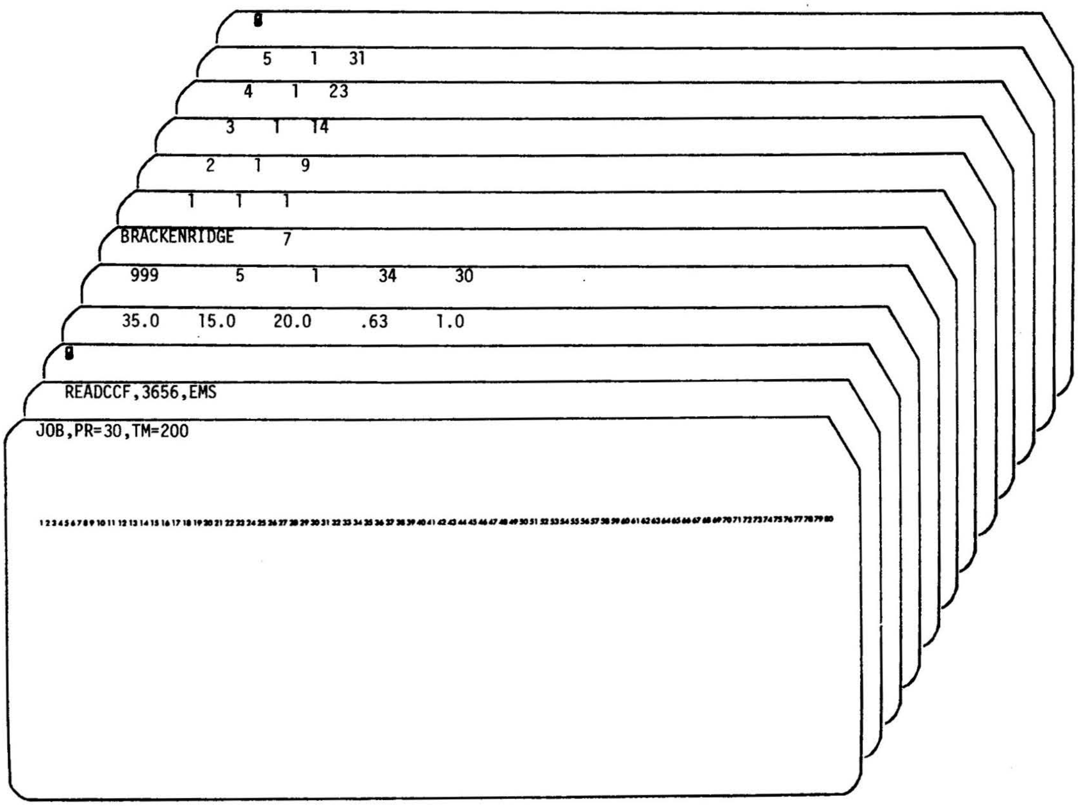



TABLE 4-6: EMERGENCY MEDICAL FACILITY CARDS
(PUNCHED IN A 3 (A4), I5 FORMAT)

| Card Column | Variable | Sample Value | Definition |
|---|---|---|---|
| 1-12 | EMF | BRACKENRIDGE | The emergency medical facility name |
| 13-17 | HOSLOC | 7 | The number of the zone in which the facility is located |

TABLE 4-7: EMERGENCY MEDICAL VEHICLE CARDS
(PUNCHED IN A 4 (I5) FORMAT)

| Card Column | Variable | Definition | Comments |
|---|---|---|---|
| 1-5 | AMBNO | The identification number for the emergency medical vehicle | |
| 6-10 | TYPE | The vehicle type | A "1" indicates a surface vehicle<br>A"2" indicates an air vehicle |
| 11-15 | AMBSITE | The number of the zone in which the ambulance is originally located | |

TABLE 4-8: SAMPLE EMS VEHICLE VALUES

| Card Number | AMBNO Values | TYPE Values | AMBSITE Values |
| --- | --- | --- | --- |
| 1 | 1 | 1 | 1 |
| 2 | 2 | 1 | 9 |
| 3 | 3 | 1 | 14 |
| 4 | 4 | 1 | 23 |
| 5 | 5 | 1 | 31 |

TABLE 4-9: CALL/CZSR CONTROL CARD REQUIREMENTS*

USER IDENTIFICATION CARD

PASSWORD CARD

JOB, PR=30, TM=200

---

for a 34-zone analysis: READCCF 3656 EMS

for a 358-zone analysis: READCCF B635 EMS2**

---

7/8/9 (multipunch)

System Description Cards

Emergency Medical Facility Cards

Emergency Medical Vehicle Cards

6/7/8/9 (multipunch)

---

* At the University of Texas at Austin computer system.

**Note: EMS2 is a macro containing the following operations:

```
READPF B635 CONTIG MATT
READPF 7816 TRAVELT
RENAME CONTIG=TAPE7
RENAME MATT=TAPE8
RENAME TRAVELT=TAPE9
READPF 2075 MOTI
RFL 220000
MNF I=MOTI, B=MOTIX, L=LI
MOTIX
```

Table 4-8 contains several sample values for the variables in table 4-7. These values are illustrated in the CALL/CZSR deck illustration in figure 4-6.

**Input Deck Structure**

Figure 4-6 illustrates a sample CALL/CZSR input deck that has been used on the University of Texas at Austin computer system. The figure shows the proper keypunching of the sample values listed in tables 4-3, 4-4, 4-6, 4-7, and 4-8. Because of the great volume of the contiguous zone, travel time, and call frequency data, those items can be stored as tape files.

Necessary control cards for the system are described in table 4-9. Note that different control cards are necessary for running the 34-zone analysis described above and the 358-zone analysis presented below.

## AN ILLUSTRATION OF CALL/CZSR ANALYSIS USING CENSUS TRACT DATA

This section illustrates the use of the CALL/CZSR program with data from the City of Austin as a means of verifying the program's value in analyzing EMS vehicle deployment. This first analysis uses hypothetical EMS call data for the thirty-four census tract zones in Austin. Interzonal travel times were estimated using rectangular distances between zone centroids.

To test the performance of the algorithm, CALL/CZSR was run several times, varying the number of ambulances (NAMB), the expected number of cases per day (LAMBDA), and the initial sites for ambulances. NAMB was varied from 2 to 7 in the analysis. NAMB was then fixed at 5 vehicles, and LAMBDA was varied from 25 to 45. Finally, with NAMB and LAMBDA set equal to 5 and 35 respectively, several initial deployments were attempted.

If the EMS call rate is held constant (at 35 calls per day) and the initial set of sites is fixed, the analyst can observe how the results change with respect to the number of vehicles. Table 4-10 indicates that the larger the number of vehicles, the shorter the average system response time. Incremental improvements in mean response time decrease with each added vehicle. This effect is illustrated in figure 4-7.

Figure 4-8 shows the frequency with which responses to calls are observed to be within particular time intervals, holding LAMBDA constant at 35. The "decreasing returns" effect of added vehicles is substantial; the curves level off as the number of vehicles reaches 6 or 7. In other words, as the number of vehicles increases beyond 7, the marginal improvement (from one added vehicle) in the chance that a call will be served within five or ten minutes will be relatively small.

If both initial vehicle sites and the number of vehicles are fixed (at 5 vehicles), a change in the number of calls per day does affect system performance (see table 4-11). These results are depicted in figure 4-9. Up to about 40 cases per day, system mean response time does not change much. As the number of cases per day increases beyond 40, system mean response time increases, indicating the five-ambulance system is reaching a point of congestion in an attempt to serve all calls.

Mean response time increases when more calls are received because vehicles are more likely to be busy when a call is received. A "second-in," and more distant, vehicle may respond in place of a busy first-in vehicle in zones with particularly heavy demand. This is also the reason for a slightly different deployment being a "best" deployment when calls reach 45 per day, as shown in table 4-11 (i.e.,

TABLE 4-10: EFFECT OF NUMBER OF EMS VEHICLES ON AVERAGE RESPONSE TIME

| Number of Vehicles | | Vehicle Locations (census tract) | System Mean Response Time (minutes) |
|---|---|---|---|
| 2 | initial: | 1, 6 | 9.596 |
| | final: | 3, 29 | |
| 3 | initial: | 1, 6, 17 | 7.088 |
| | final: | 3, 13, 29 | |
| 4 | initial: | 1, 6, 17, 21 | 5.310 |
| | final: | 3, 8, 23, 29 | |
| 5 | initial: | 1, 6, 17, 21, 30 | 3.448 |
| | final: | 3, 8, 23, 29, 31 | |
| 6 | initial: | 1, 6, 10, 17, 21, 30 | 3.245 |
| | final: | 3, 8, 17, 23, 29, 31 | |
| 7 | initial: | 1, 6, 10, 17, 21, 28, 30 | 2.848 |
| | final: | 3, 8, 17, 19, 23, 29, 31 | |

FIGURE 4-7: EFFECT OF NUMBER OF EMS VEHICLES ON SYSTEM MEAN RESPONSE TIME

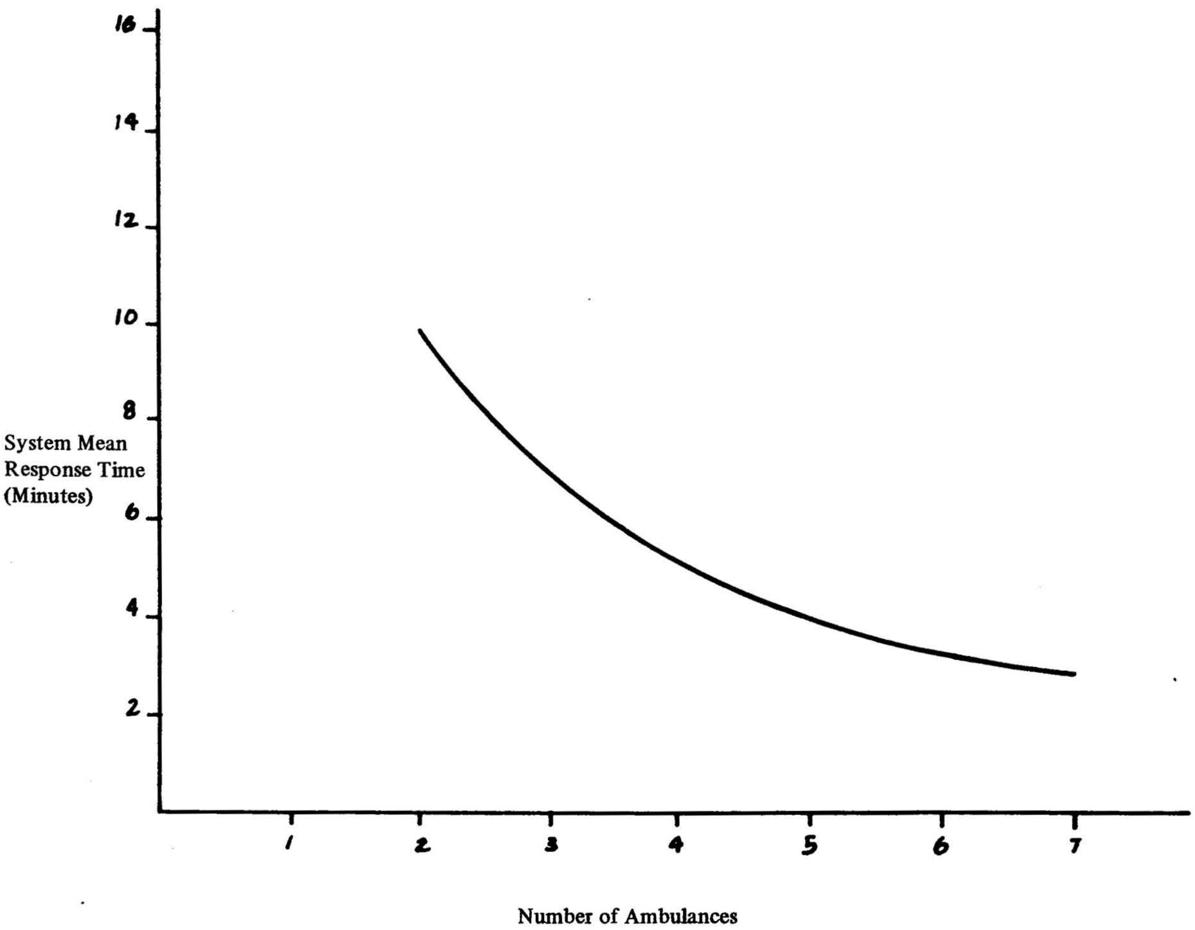
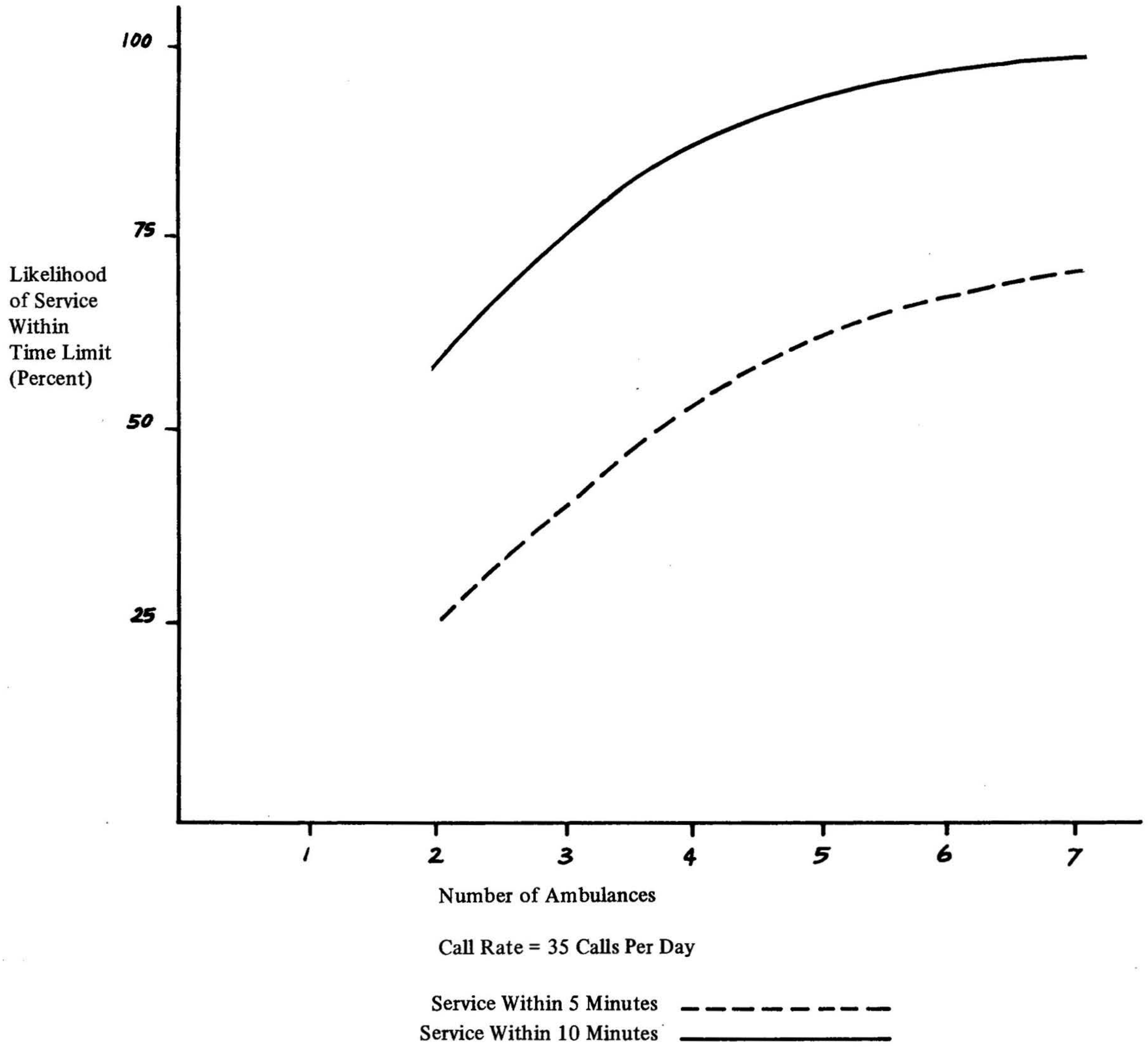



TABLE 4-11: EFFECT OF CHANGE IN CALL FREQUENCY UPON EMS

| Number of Calls Per Day | Vehicle Location (Census Tract) | System Mean Response Time (minutes) |
|---|---|---|
| | initial: 1, 6, 17, 21, 30 | |
| 25 | final: 3, 8, 23, 29, 31 | 3.227 |
| 30 | final: 3, 8, 23, 29, 31 | 3.334 |
| 35 | final: 3, 8, 23, 29, 31 | 3.448 |
| 40 | final: 3, 8, 23, 29, 31 | 3.647 |
| 45 | final: 3, 8, 23, 29, 31 | 4.338 |

FIGURE 4-8: EFFECT OF NUMBER OF EMS VEHICLES UPON THE LIKELIHOOD OF SERVICE WITHIN 5 OR 10 MINUTES




census tract 13 is substituted for 31).

When the number of ambulances and the number of calls per day are fixed (i.e., NAMB = 5 and LAMBDA = 35), the set of sites selected as "best" by CALL/CZSR varies with the initial set provided to the algorithm. Table 4-12 illustrates how the final sites vary. Note that certain locations (e.g., zone 29) appear in all cases.

The changes in final sites and in system mean response time reflect the fact that this algorithm searches contiguous zones rather than all zones. The different configurations of vehicle bases may be useful to planners as a basis for additional study of land availability within tracts and costs of vehicle base construction.

This illustration of CALL/CZSR analysis using census tract data revealed the following results that analysts are likely to observe in more realistic studies:

- There is a point reached where adding EMS vehicles achieves diminishing marginal benefits with respect to mean response time.
- The "best" vehicle deployment is dependent on the call rate because of the effects of congestion.
- Final vehicle deployment is dependent upon initial vehicle sites.

The limitations of this example are related to the size of

FIGURE 4-9: EFFECT OF CHANGE IN CALL FREQUENCY UPON SYSTEM MEAN RESPONSE TIME

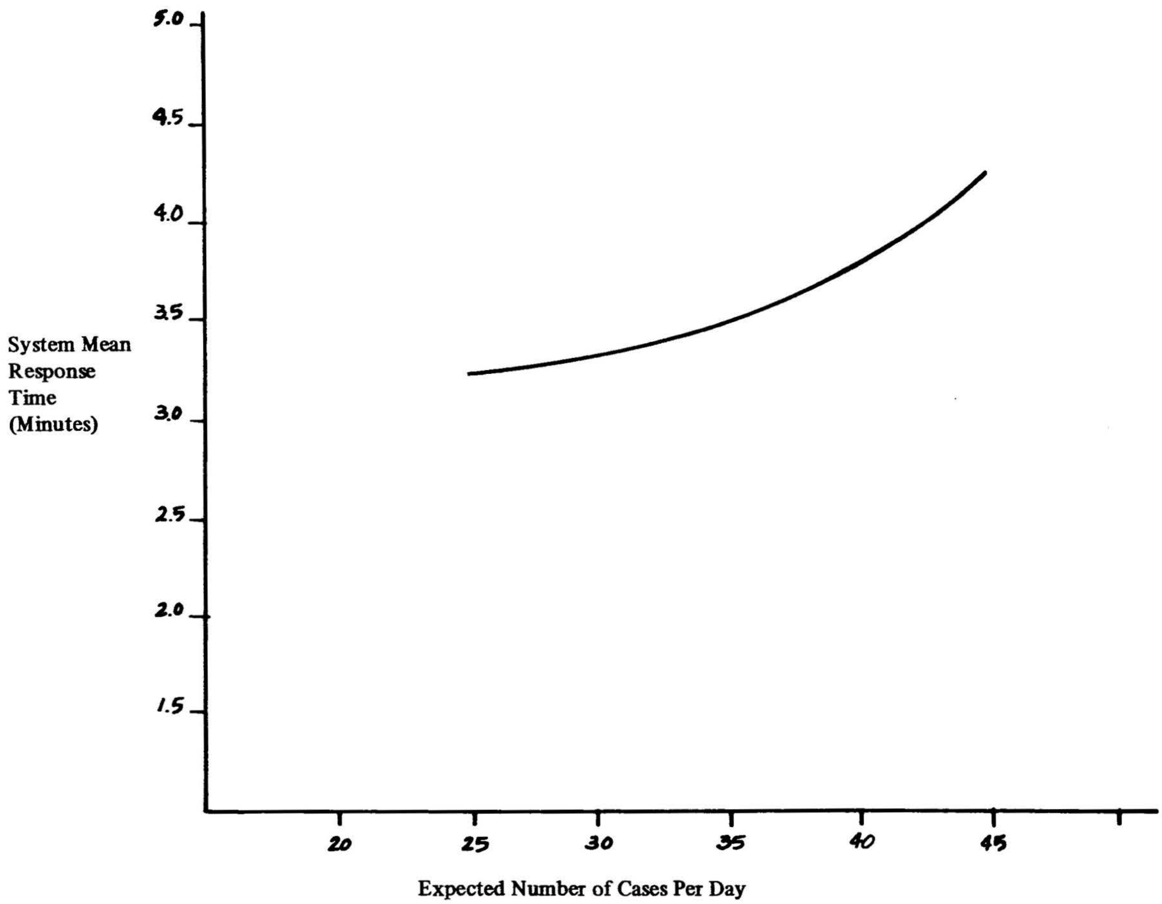



TABLE 4-12: EFFECT OF INITIAL SITES ON FINAL VEHICLE DEPLOYMENT

| Attempt | Vehicle Locations (census tract) | System Mean Response Time (minutes) |
|---|---|---|
| 2 | initial: 1, 2, 8, 6, 21, 29<br>final: 3, 8, 13, 23, 29 | 3.935 |
| 3 | initial: 6, 10, 15, 18, 33<br>final: 3, 8, 23, 29, 31 | 3.533 |
| 4 | initial: 1, 2, 6, 18, 30<br>final: 3, 4, 8, 13, 29 | 4.125 |
| 5 | initial: 6, 10, 15, 17, 21<br>final: 4, 17, 23, 29, 31 | 4.118 |

the zones, the response time estimates, and the meaning of vehicle sites. In this illustration, each of the census tracts are at least several square miles in area. The model implicitly sites EMS vehicles and the points of demand for EMS services at census tract centroids. This assumption leads to rather inaccurate response time estimates. In addition, the aggregation of the call data to such a large area suppresses the geographical variability of calls. Although this example does define some of the general characteristics of CALL/CZSR, it will be useful to illustrate the technique with a larger and more realistic system structure.

## AN APPLICATION OF CALL/CZSR TO THE CITY OF AUSTIN

This section describes the results of a CALL/CZSR analysis of alternate EMS vehicle stations in Austin using serial zones. The city of Austin was partitioned into 358 traffic serial zones (see figure 4-10). The time of travel between zones, a matrix of interzone travel times, was obtained from the Austin Transportation Study Office. Based on this data, the EMS Policy Research Project developed a list of contiguous serial zones. Hypothetical information on call frequency was compiled by the City of Austin's Emergency Medical Service Department. The EMS Department also estimated average vehicle time on scene, vehicle time at hospital, and the likelihood of patient transport.

This section uses the CALL/CZSR routine to analyze and compare several alternative sets of EMS vehicle sites in terms of three measures of EMS system performance: the system mean response time, the likelihood of service within specified time intervals, and the range of vehicle workloads. Table 4-13 summarizes the parameter values used in this set of CALL/CZSR runs.

The first step of the analysis was to determine good vehicle sites and the associated levels of average system response time for various numbers of EMS vehicles. These results are reported in table 4-14, which lists both initial and final locations by serial zone and the system mean response time for systems of two to ten vehicles.

No effort was made to assess the case of a one-EMS-vehicle system, because queuing theory analysis shows that a one-ambulance system is infeasible. The following condition is a prerequisite for standard queuing analysis: the rate of service must exceed the rate of arrivals for a feasible service system to exist (i.e., supply must exceed demand). The City of Austin analysis used a call arrival rate of 35 calls per day (one call per 41 minutes) on the average. The service time for any call is the sum of response time, on-scene care time, transport time, and transfer time. Although response time is dependent on ambulance deployment, the other three items were fixed in this hypothetical illustration. On-scene care, transport, and transfer times were assumed to be 15, 27.3, and 20 minutes, respectively. Using a response time of 7.4 minutes (the 2-ambulance result) and a 0.63 probability of transport, an average service time would be 52.2 minutes. This average service time exceeds the expected interval between EMS calls. The system is infeasible because the service time exceeds the time between arrivals; in queuing theory terminology, the system will never reach steady state. Thus, we find that it is impossible for one ambulance to serve Austin.

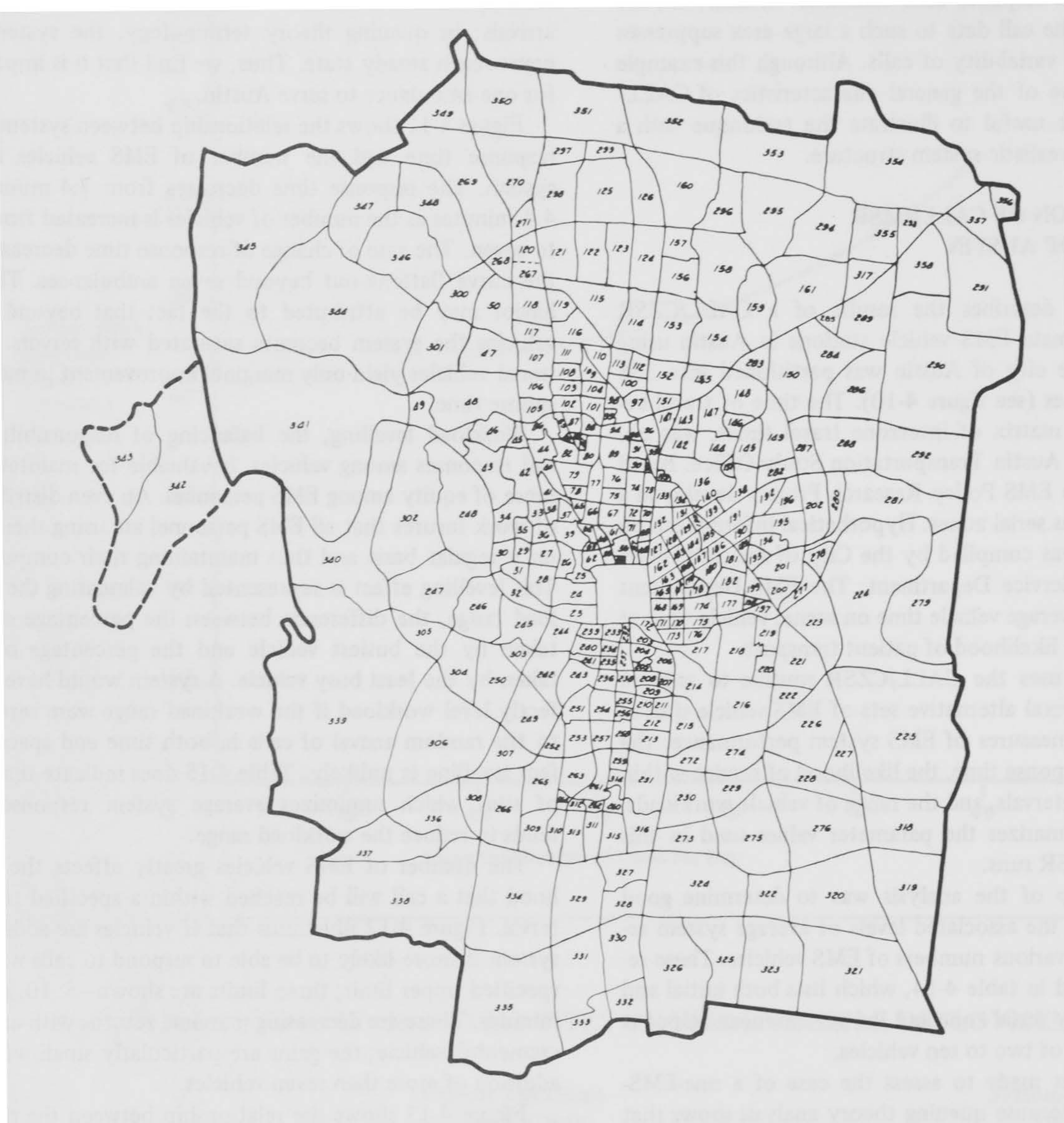
Figure 4-11 shows the relationship between system mean response time and the number of EMS vehicles in the system. The response time decreases from 7.4 minutes to 4.4 minutes as the number of vehicles is increased from two to seven. The rate of change of response time decreases and the curve flattens out beyond seven ambulances. This behavior may be attributed to the fact that beyond seven vehicles the system becomes saturated with servers. Additional vehicles yield only marginal improvement in mean response time.

Workload levelling, the balancing of responsibility for call responses among vehicles, is valuable for maintaining a sense of equity among EMS personnel. An even distribution of work insures that all EMS personnel are using their skills on a regular basis and thus maintaining their competence. This levelling effect is represented by calculating the workload range, the difference between the percentage of calls taken by the busiest vehicle and the percentage of calls taken by the least busy vehicle. A system would have a perfectly level workload if the workload range were zero. Due to the random arrival of calls in both time and space, perfect levelling is unlikely. Table 4-15 does indicate that a set of sites which minimizes average system response time tends to reduce the workload range.

The number of EMS vehicles greatly affects the likelihood that a call will be reached within a specified time interval. Figure 4-12 illustrates that if vehicles are added, the system is more likely to be able to respond to calls within a specified upper limit; three limits are shown—5, 10, and 15 minutes. There are decreasing marginal returns with each incremental vehicle; the gains are particularly small with the addition of more than seven vehicles.

Figure 4-13 shows the relationship between the number of vehicles and the fraction of a day that all ambulances are idle. The probability of all EMS vehicles being free increases with an increasing number of vehicles. It is interesting to note that although the number of vehicles increases from two to ten, the likelihood of all ambulances being idle is stable within a range of 0.33 to 0.37. The CALL/CZSR model indicates that all vehicles in the city would be idle about one-third of the time, regardless of the number of ambulances. In other words, when a call is received, the odds are two to three that one or more vehicles are busy.

FIGURE 4-10: A SERIAL ZONE MAP OF AUSTIN, TEXAS



NOTE: Map numerals indicate serial zone reference numbers.

## TABLE 4-13: PARAMETERS FOR ILLUSTRATIVE CALL/CZSR ANALYSIS

| System Parameter | Value |
|---|---|
| Average time of care on-scene (minutes) | 15.0 |
| Average transfer time at hospital (minutes) | 20.0 |
| Fraction of calls transported | 0.63 |
| Average number of calls per day | 35.0 |
| Number of zones | 358 |
| Number of hospitals | 1 |

## TABLE 4-14: SUMMARY OF CZSR RESULTS FOR AUSTIN CITY DATA (358 ZONES)

| Number of Vehicles | | Vehicle Location (Serial Zone) | System Mean Response Time (minutes) |
|---|---|---|---|
| 2 | initial: | 166, 225 | 11.81 |
| | final: | 3, 178 | 7.472 |
| 3 | initial: | 99, 166, 225 | 9.49 |
| | final: | 99, 166, 299 | 7.09 |
| 4 | initial: | 99, 166, 189, 225 | 7.714 |
| | final: | 99, 166, 190, 222 | 6.39 |
| 5 | initial: | 99, 116, 166, 189, 225 | 6.808 |
| | final: | 6, 80, 113, 190, 222 | 5.702 |
| 6 | initial: | 65, 99, 116, 166, 189, 225 | 6.031 |
| | final: | 65, 95, 116, 166, 190, 210 | 4.731 |
| 7 | initial: | 65, 99, 116, 166, 189, 225, 264 | 5.139 |
| | final: | 59, 88, 116, 166, 190, 222, 256 | 4.444 |
| 8 | initial: | 65, 99, 116, 166, 189, 208, 225, 264 | 4.622 |
| | final: | 41, 94, 110, 166, 190, 221, 238, 258 | 4.274 |
| 9 | initial: | 65, 99, 116, 140, 166, 189, 208, 225, 264 | 4.447 |
| | final: | 65, 99, 116, 140, 166, 189, 208, 221, 264 | 4.213 |
| 10 | initial: | 65, 99, 116, 140, 166, 189, 199, 208, 225, 264 | 4.361 |
| | final: | 41, 55, 101, 115, 134, 177, 186, 221, 238, 265 | 4.105 |

FIGURE 4-11: RELATION BETWEEN NUMBER OF EMS VEHICLES AND SYSTEM MEAN RESPONSE TIME

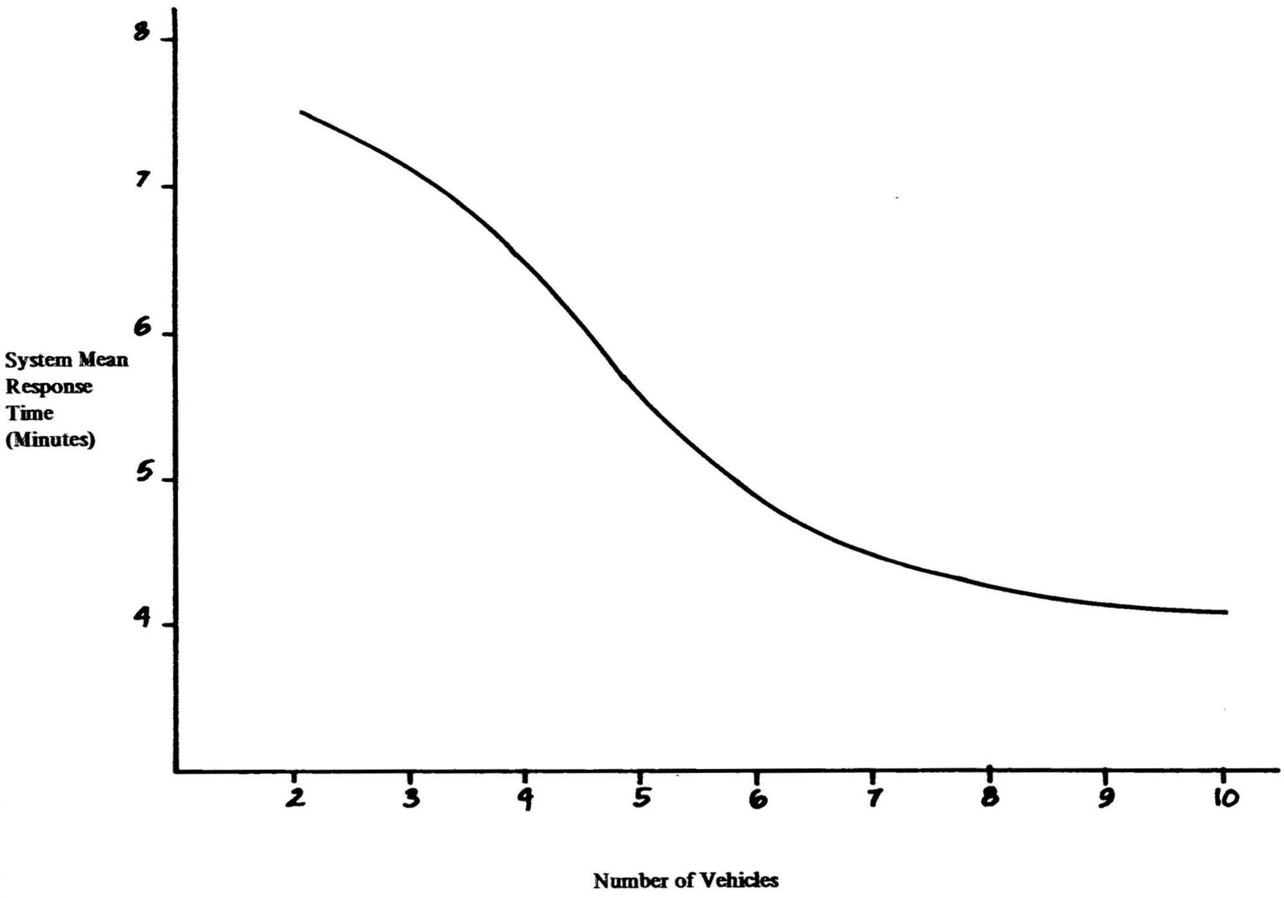


TABLE 4-15: AN ILLUSTRATION OF WORKLOAD LEVELLING

| Number of Vehicles | Difference in Activity of Busiest and Most Idle Vehicle (expressed in percent of calls serviced) | |
|---|---|---|
| | Initial Sites | Final Sites |
| 2 | 40.0 | 17.36 |
| 3 | 3.0 | 3.0 |
| 4 | 24.87 | 17.08 |
| 5 | 27.2 | 15.98 |
| 6 | 26.5 | 12.58 |
| 7 | 27.85 | 18.47 |
| 8 | 26.07 | 19.74 |
| 9 | 22.34 | 16.73 |
| 10 | 20.0 | 17.26 |

TABLE 4-16: PAST AND PRESENT EMS VEHICLE BASES

| | Serial Zone Locations | | | | |
|---|---|---|---|---|---|
| Vehicle Number | December 1976 | January to May 1977 | June 1977 | July to August 1977 | Present Location (September 1979) |
| 901 | 255 | 255 | 255 | 255 | 255 |
| 902 | 214 | 214 | 215 | 215 | 255 |
| 903 | 166 | 166 | 166 | 52 | 59 |
| 904 | 129 | 187 | 187 | 187 | 187 |
| 905 | 37 | 37 | 40 | 40 | * |
| 906 | 147 | 147 | 147 | 147 | 155 |
| 907 | 116 | 116 | 118 | 118 | 118 |

* Vehicle removed from service October, 1978.

Note: "Best" sites, as selected by a CALL/CZSR solution include serial zones 59, 88, 116, 166, 190, 222, and 256.

FIGURE 4-12: LIKELIHOOD OF CALL RESPONSE WITHIN PARTICULAR UPPER TIME BOUNDS

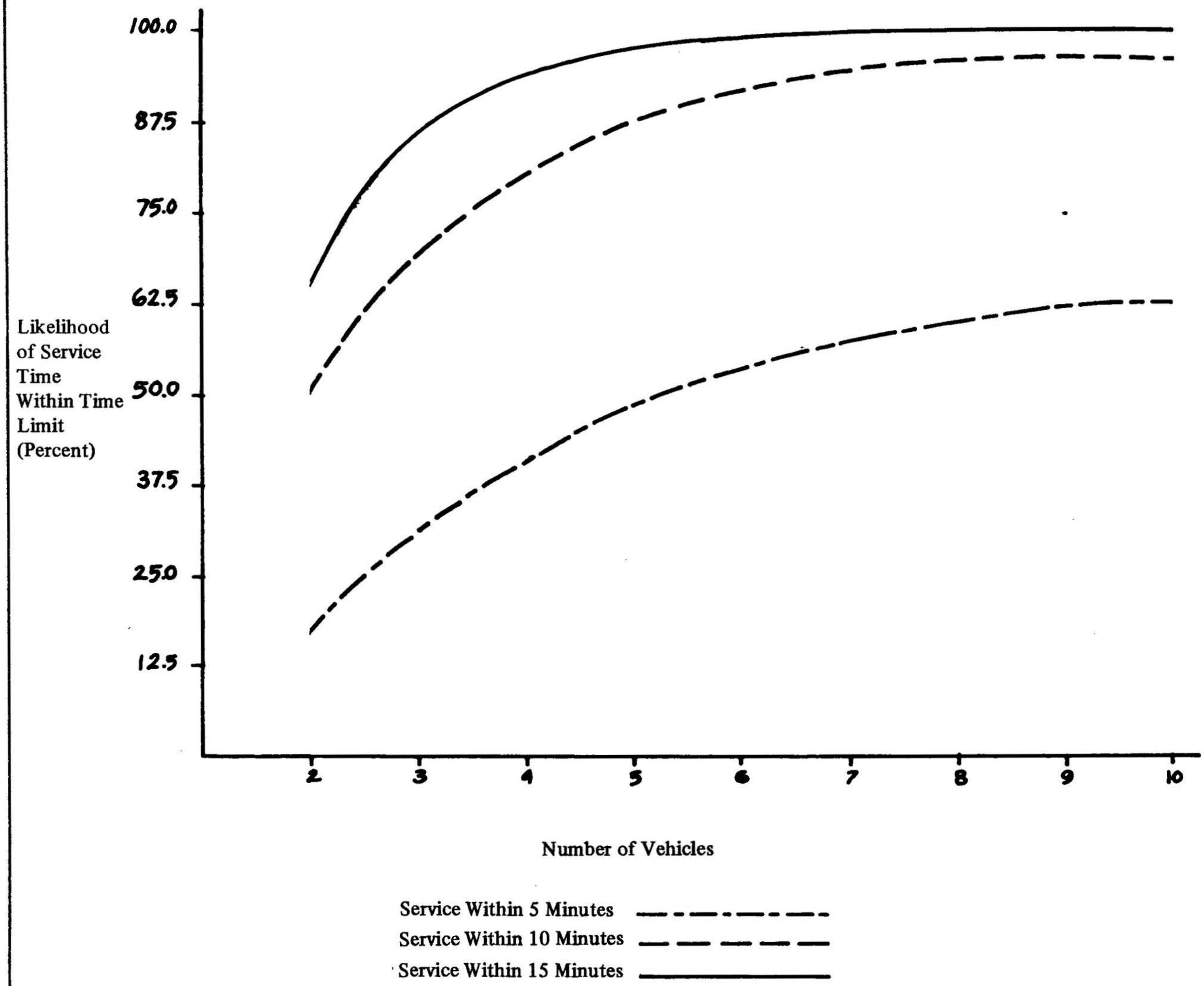


FIGURE 4-13: LIKELIHOOD THAT ALL VEHICLES ARE IDLE

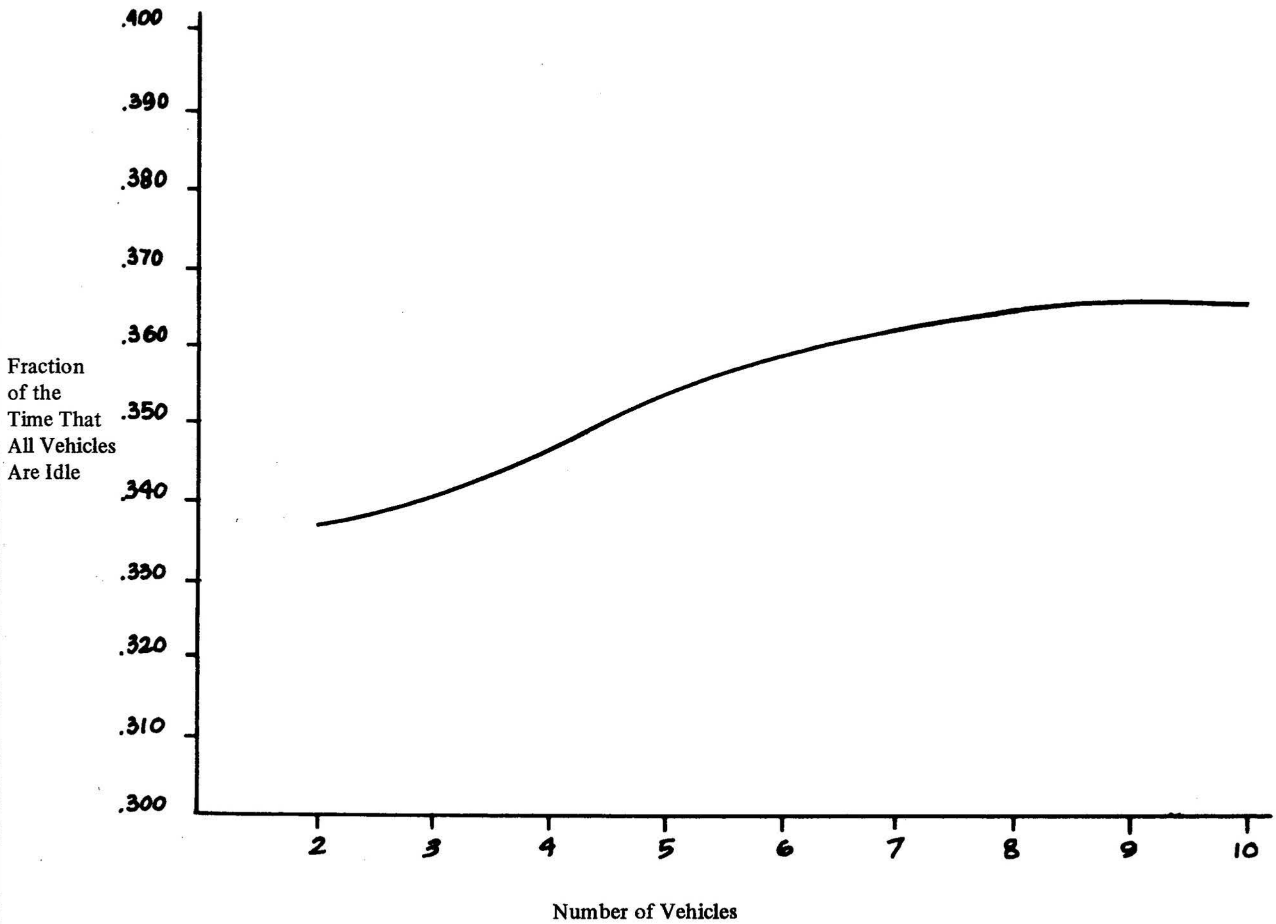


TABLE 4-17: COMPARISON OF PERFORMANCE OF EMS VEHICLE SITE CONFIGURATION

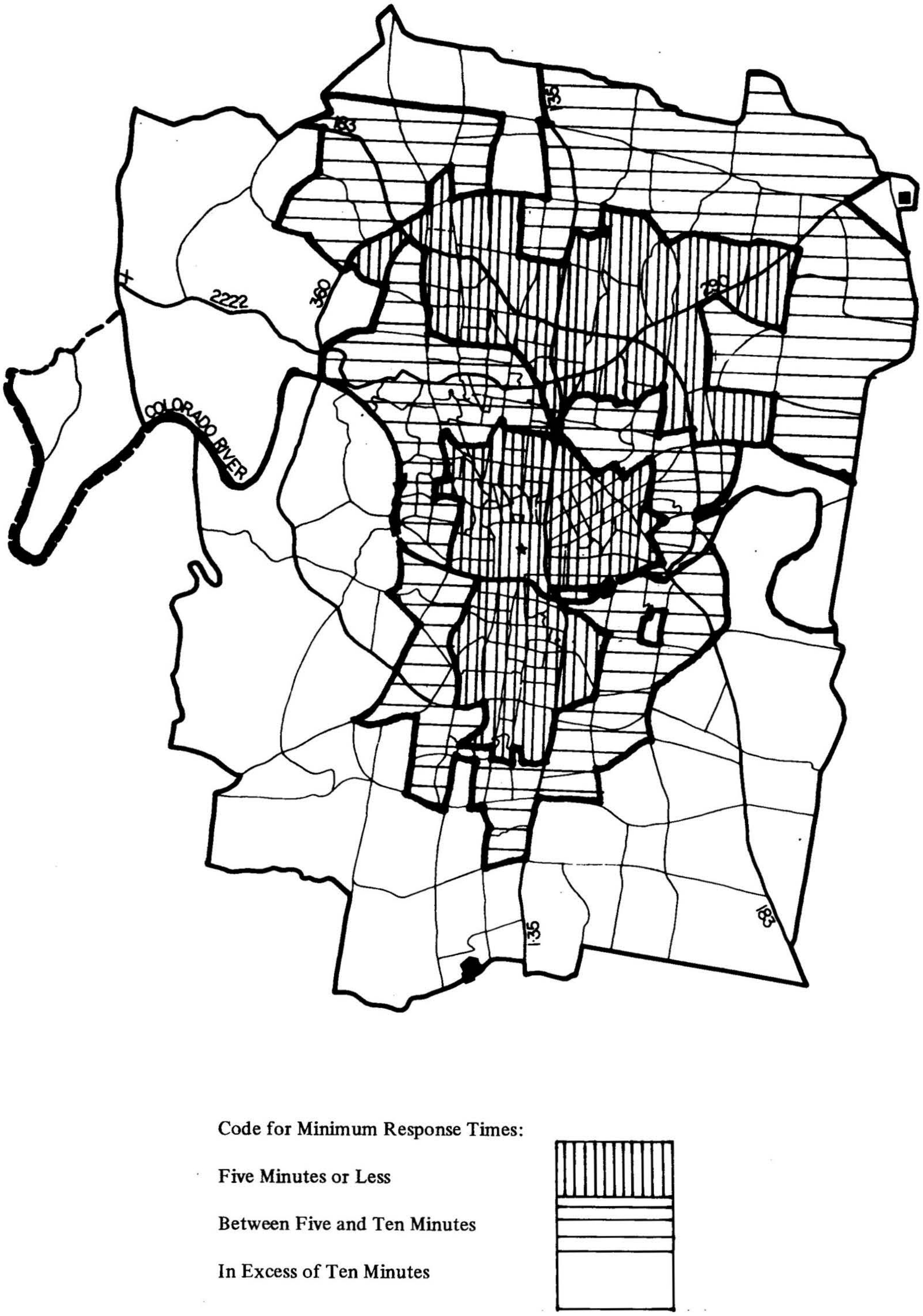
| Performance Criteria | Site Configurations | | | | | |
|---|---|---|---|---|---|---|
| | December 1976 | January to May 1977 | June 1977 | July to August 1977 | Present Location* | 7-Vehicle "Best" Site |
| System Mean Response Time | 4.649 | 4.650 | 4.852 | 4.922 | 5.317 | 4.444 |
| Workload Range | 15.66 | 16.72 | 19.61 | 18.91 | 18.55 | 18.47 |
| Fraction of Calls Served in Less Than: | | | | | | |
| 5 minutes | 0.5650 | 0.5659 | 0.4967 | 0.4975 | 0.4576 | 0.5803 |
| 10 minutes | 0.9519 | 0.9518 | 0.9642 | 0.9613 | 0.9343 | 0.9515 |
| 15 minutes | 0.9896 | 0.9896 | 0.9896 | 0.9898 | 0.9860 | 0.9961 |
| Likelihood of All EMS Vehicles Idle | 0.4089 | 0.4089 | 0.4069 | 0.4052 | 0.4023 | 0.3626 |

* The configuration of six EMS vehicles located in zones 255 (two vehicles), 59, 187, 155, and 188.

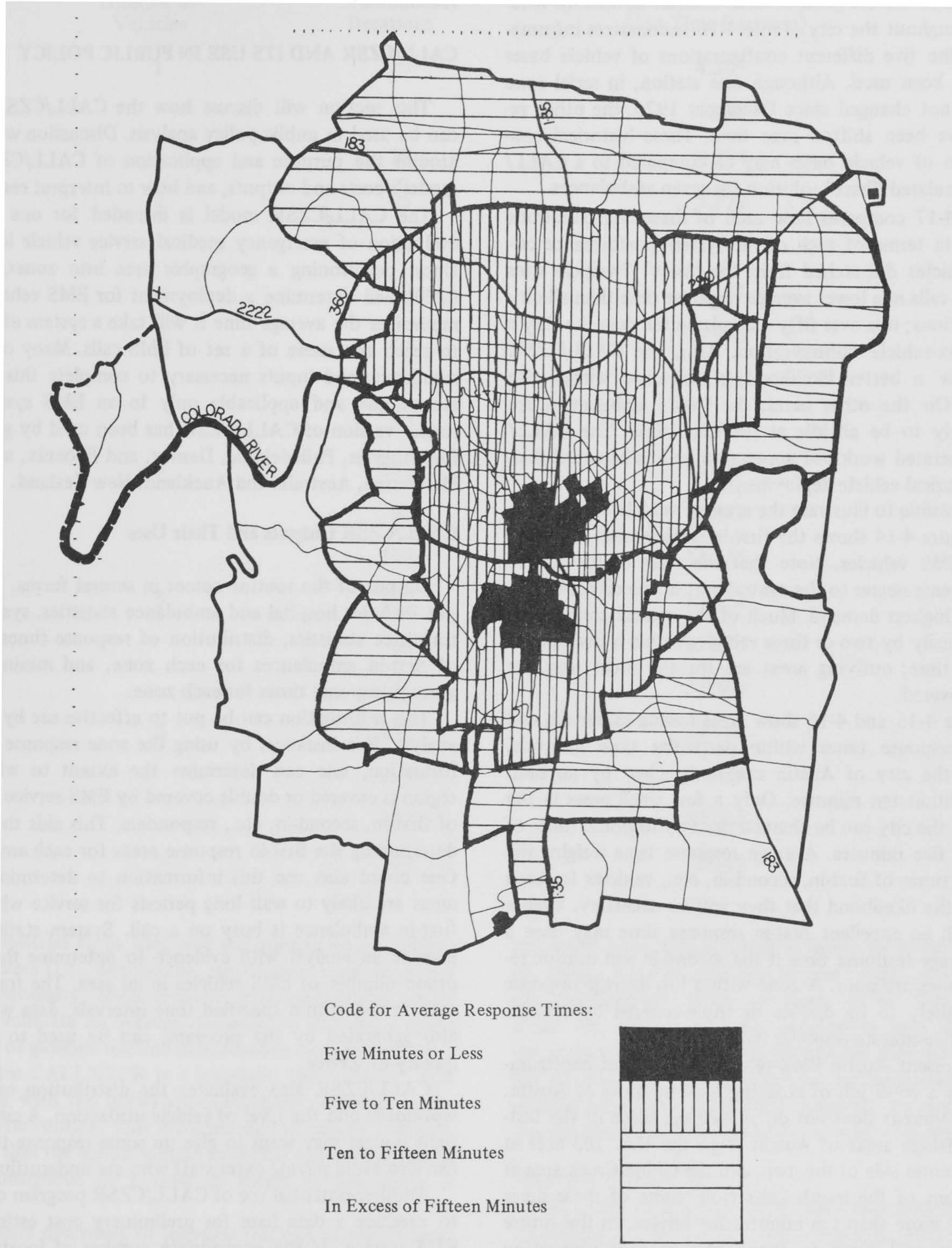
FIGURE 4-14: FIRST-IN SERVICE AREAS OF THE SIX EMS VEHICLES IN AUSTIN


Boldface numbers correspond to the designated number of the EMS vehicle.

FIGURE 4-15: A MAP OF RESPONSE TIME BY EMS FIRST-IN VEHICLES



## FIGURE 4-16: AVERAGE RESPONSE TIME OF EMS VEHICLES IN AUSTIN



### Assessment of Actual Austin EMS Vehicle Locations

Since December of 1976, the City of Austin has operated an EMS service with several vehicles at various locations throughout the city. Table 4-16 summarizes information on the five different configurations of vehicle bases that have been used. Although one station, in serial zone 155, has not changed since December 1976, the other vehicles have been shifted over time. These historical configurations of vehicle bases may be compared to a CALL/CZSR-calculated "best" solution for seven ambulances.

Table 4-17 compares how each of these configurations performs in terms of each of the system performance criteria. Vehicles dispatched from the "best" 7-vehicle sites can reach calls in a lower average response time than all city configurations; it is over fifty seconds better than the City's present six-vehicle configuration. Also, the CALL/CZSR sites allow a better likelihood of response within five minutes. On the other hand, the City's ambulances are more likely to be all idle at the same time. The CALL/CZSR-generated workload appears to be less balanced than some historical vehicle deployments.

It is possible to illustrate the areas of vehicle coverage on maps. Figure 4-14 shows the first-in service areas of the six current EMS vehicles. Note that the sizes of the service areas decrease nearer to the central part of the city, the area with the highest demand. Much of the central area can be covered easily by two or three vehicles within a five-minute response time; outlying areas are for the most part not double-covered.

Figures 4-15 and 4-16 show areas having minimum and average response times within particular time intervals. Most of the city of Austin can be reached by an EMS vehicle within ten minutes. Only a few small areas in the center of the city can be characterized by response times of less than five minutes. Average response time weights the response times of first-in, second-in, etc., vehicles for each zone by the likelihood that they will be necessary. Even a zone with an excellent first-in response time may have a poor average response time if the second-in and third-in response times are poor. A zone with a low average response time is likely to be double or triple-covered by vehicles within a five-minute response limit.

The present Austin EMS vehicle deployment configuration does a good job of covering built-up areas of Austin. The deployment does not do as well for some of the fast-growing fringe areas of Austin (e.g., the U.S. 183 area at the left center side of the map, and the Onion Creek area at the bottom of the map). Calls from some of these areas may wait more than ten minutes for service. In the future these areas will come to represent a growing proportion of the total demand.

This section has illustrated how CALL/CZSR can be used to study EMS vehicle deployments. The following section will develop some ideas about the strengths and weaknesses of this approach for determining sites in the city of Austin.

## CALL/CZSR AND ITS USE IN PUBLIC POLICY

This section will discuss how the CALL/CZSR model can be used in public policy analysis. Discussion will center around the purpose and application of CALL/CZSR, the model's costs and outputs, and how to interpret results.

The CALL/CZSR model is intended for one use, the evaluation of emergency medical service vehicle locations. Upon partitioning a geographic area into zones, CALL/CZSR will determine a deployment for EMS vehicles that minimizes the average time it will take a system of vehicles to reach the scene of a set of EMS calls. Many of the assumptions and inputs necessary to complete this analysis are unique and applicable only to an EMS system. An earlier version of CALL/CZSR has been used by groups in Los Angeles, Philadelphia, Denver, and Phoenix, as well as Melbourne, Australia and Auckland, New Zealand.

### CALL/CZSR Outputs and Their Uses

Output of the routine comes in several forms. The output includes hospital and ambulance statistics, system performance statistics, distribution of response times, a table of first-in ambulances for each zone, and minimum and average response times for each zone.

This information can be put to effective use by a policy analyst. For instance, by using the zone response time information, one can determine the extent to which the region is covered or double-covered by EMS service in terms of first-in, second-in, etc., responders. This aids the user in determining the first-in response areas for each ambulance. One could also use this information to determine which areas are likely to wait long periods for service when their first-in ambulance is busy on a call. System statistics can provide an analyst with evidence to determine the appropriate number of EMS vehicles in an area. The fraction of calls served within specified time intervals, data which are also generated by the program, can be used to evaluate quality of service.

CALL/CZSR also evaluates the distribution of vehicle workloads and the level of vehicle utilization. A city with a tight budget may want to give up some response time if it can also avoid paying extra staff who are underutilized.

Another potential use of CALL/CZSR program output is to produce a data base for preliminary cost estimates of EMS service. If the appropriate number of locations has been chosen, maintenance costs can be estimated. Personnel costs can be estimated by taking into account the number

TABLE 4-18: COMPUTER COSTS FOR CALL/CZSR SOLUTIONS OF A SMALL PROBLEM

| Number of Vehicles | Number of Iterations | Computer Central Processing Unit Time (seconds) |
|---|---|---|
| 1 | 13 | 4.267 |
| | 16 | 4.700 |
| | 18 | 4.254 |
| 2 | 25 | 5.172 |
| | 24 | 5.476 |
| | 52 | 6.161 |
| 3 | 70 | 6.945 |
| | 38 | 5.231 |
| | 52 | 6.281 |
| 4 | 137 | 15.070 |
| | 96 | 11.857 |
| | 100 | 12.148 |
| 5 | 117 | 19.353 |
| | 85 | 15.272 |
| | 142 | 22.566 |
| 6 | 131 | 29.156 |
| | 213 | 49.385 |
| | 373 | 77.042 |
| 7 | 275 | 76.112 |

of EMS vehicles to be used and the number of administrative workers (i.e., dispatchers, supervisory staff, etc.) that will be necessary. Mean response time information can be used to estimate an average distance per call and a rough estimate of gasoline use and maintenance costs per vehicle.

Because CALL/CZSR is a heuristic, the "chosen" sites may vary with the initial set of locations provided by the user to the routine. This inconsistency of results is due to the fact that the search routine is limited to looking only at zones contiguous to a zone in which an ambulance is located.

The tests described in previous sections of this chapter also indicate that alternative vehicle sites may not greatly differ in their mean system response times. These tests have also shown that if various sets of sites are selected as the initial sites, CALL/CZSR is likely to select as "best" (a) several sites in common between runs, and (b) other site combinations which are likely to be close together. While this introduces some uncertainty into the results, the analyst may find among the various alternatives a number of good choices. Information on land availability or existing structures as possible locations for vehicles may prompt specific final deployment recommendations.

### Costs of CALL/CZSR

The costs of running CALL/CZSR vary with the number of iterations the program must evaluate. The number of iterations is in turn related to the initial locations of the EMS vehicles, the number of EMS vehicles, and the response surface of a given system. If the response surface of

## TABLE 4-19: COMPUTER COSTS FOR CALL/CZSR SOLUTIONS OF A LARGE PROBLEM

| Number of Vehicles | Number of Iterations | Computer Central Processing Unit Time (seconds) |
|---|---|---|
| 1 | 9 | 38.470 |
| 2 | 126 | 48.880 |
| 3 | 54 | 41.425 |
| 4 | 99 | 54.873 |
| 5 | 144 | 76.820 |
| 6 | 374 | 180.479 |
| 7 | 308 | 188.715 |
| 8 | 382 | 272.699 |
| 9 | 116 | 123.421 |
| 10 | 217 | 232.210 |

the system is not smooth (i.e., if there are many small areas of high demand surrounded by low demand areas), then it takes many more iterations to determine the final solution.

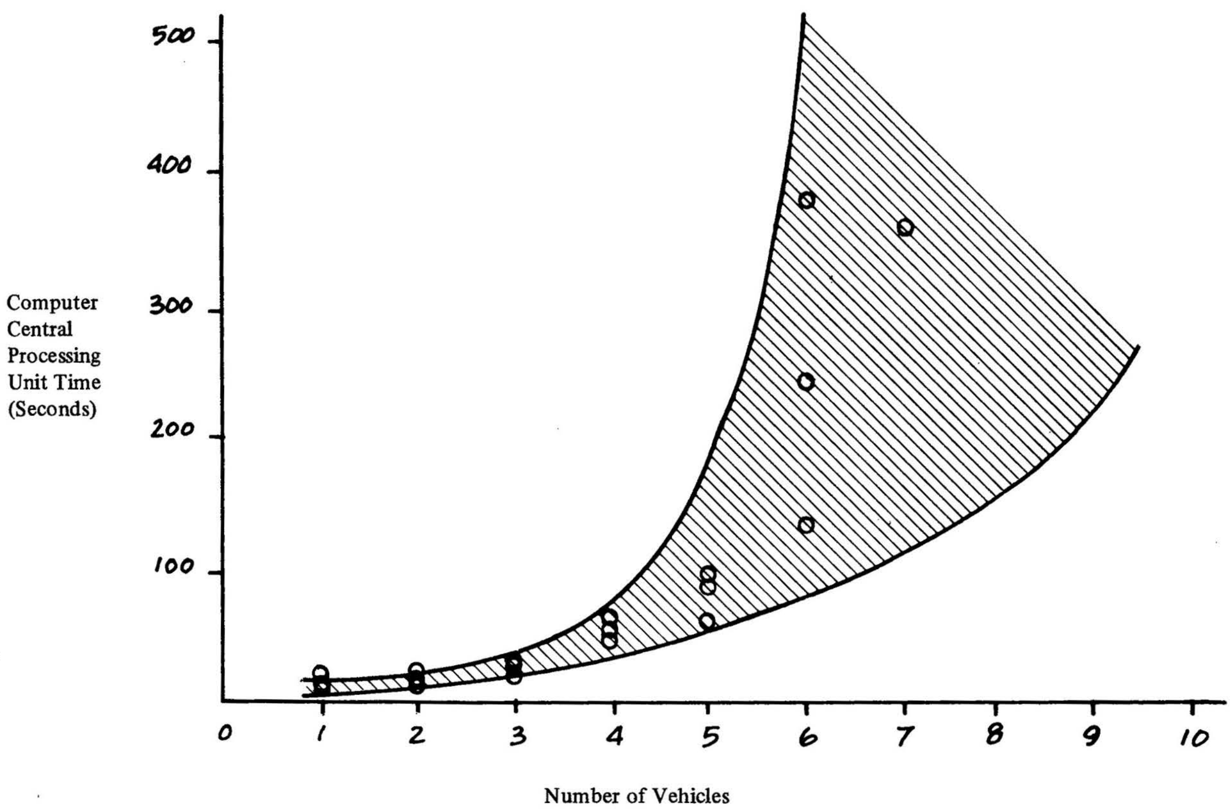
Table 4-18 gives some representative central processing unit costs given a number of iterations and a number of EMS vehicles, based on a test of the CALL/CZSR model using the 34 census tracts for the city of Austin. Figure 4-17 is a graphic representation of this data. Note that a region more accurately specifies the trend, rather than a line through the points.

Table 4-19 shows a similar comparison taken from tests using the 358 serial zones in Austin. These figures are representative of the far greater storage and computational requirements of a complex system.

Computer time is usually valued at a certain rate per CPU time unit, with rates varying between installations. The University of Texas system, on which these tests were done, values time at approximately 6.3 cents per second. Thus, CALL/CZSR computer analyses cost between twelve and fifteen dollars per run for the 358-zone example.

Analysis of figure 4-17 indicates that the required amount of computer time increases greatly with the complexity of the system and increases exponentially with the number of vehicles. This suggests that costs for vehicle deployment analyses for a small to medium-sized city (eight to ten vehicles) will be far less expensive than those for large urban areas with many EMS stations.

FIGURE 4-17: HOW CALL/CZSR COMPUTATION COSTS INCREASE WITH ADDED VEHICLES




# References

(1) James A. Fitzsimmons, "A Methodology for Emergency Ambulance Deployment," *Management Science* 19, no. 6 (February 1973): 627-36.

(2) Bill Bulloch, Director, Emergency Medical Service Department, City of Austin, personal communication to the EMS Policy Research Project, November 1978.

(3) James A. Fitzsimmons, "A Methodology."

(4) Alvin W. Drake, Ralph L. Keeney, and Philip M. Morse, *Analysis of Public Systems* (Cambridge, Mass.: MIT Press, 1972).

(5) James A. Fitzsimmons, "A Methodology."

# Chapter Five
# The Use of SYMAP to Map Information about the City of Austin

Relationships between economic, demographic, or health variables may not be evident when data is represented in tabular or matrix form. Computer mapping can generate pictures of the distribution of these factors. Four basic requirements are necessary to construct contour, proximal, or conformant maps. These are:

- a source map of the study area to be displayed;
- a variable which is distributed within each proximal region, contour zone, or data zone;
- value ranges (intervals) for the distribution of the variables; and
- a shading pattern (symbolism) to be associated with each value range.

SYMAP is a computer program that uses coordinate locations of points and values assigned to those points to produce contour, proximal, or conformant maps. The purpose of this chapter is to describe how SYMAP can access these four types of data and construct maps for evaluating options for EMS vehicle deployment in the city of Austin. This chapter describes only the basic principles of computer map generation. For additional information the reader should consult reference (1).

Figure 5-1 is an example geographic area which will be used throughout this chapter to illustrate mapping procedures. The appearance of a study area can be expressed in terms of (y,x)-coordinates. The location of a point in the study area can be specified by (a) the number of distance units down from the top border (the y-coordinate); and (b) the number of distance units across from the left map border (the x-coordinate). For example, to find the location of point A in figure 5-1, start from the top map border and move down the y-axis and stop parallel to point A, at 1.0 on the y-axis. Read across the x-axis and stop at the point parallel to A, in this case 1.8. To specify the point for SYMAP use, first write the y-coordinate and then the x-coordinate; point A is (1.0, 1.8). To describe a point, C, read down again along the y-axis (1.4 units distance). Refer to the x-axis to find point C at 3.6 units distance. When specifying the y- and then the x-coordinates, point C becomes (1.4, 3.6).

## CONSTRUCTING MAPS

The SYMAP program is a collection of seven computer subroutines that allow a user to create contour, proximal, or conformant maps (see table 5-1) (2). Observe how the set of points [A,B,C, and E] define the outline of the map's top side. These points and all the others that define the outline of zones are used to construct the contour and proximal maps. Point F is not on the boundary of zone one, but can be used to represent it.

### The Contour Map

A contour map consists of closed curves known as contour lines which connect all points having the same numerical value or weight. The A-OUTLINE package defines the complete outline of the study area and the B-DATA POINTS package specifies the location of data points. The E-VALUES package lists the values or weights to be associated with each data point. The F-MAP package constructs the map of the desired form.

Figure 5-2 illustrates the card deck for a contour map and figure 5-3 is the contour map derived from use of the data of figure 5-1. A number is printed on this map at a location of a data point. Note how a contour map uses white spaces to separate the contour zones and one weighted point (if one exists) to represent all the points in a contour zone.

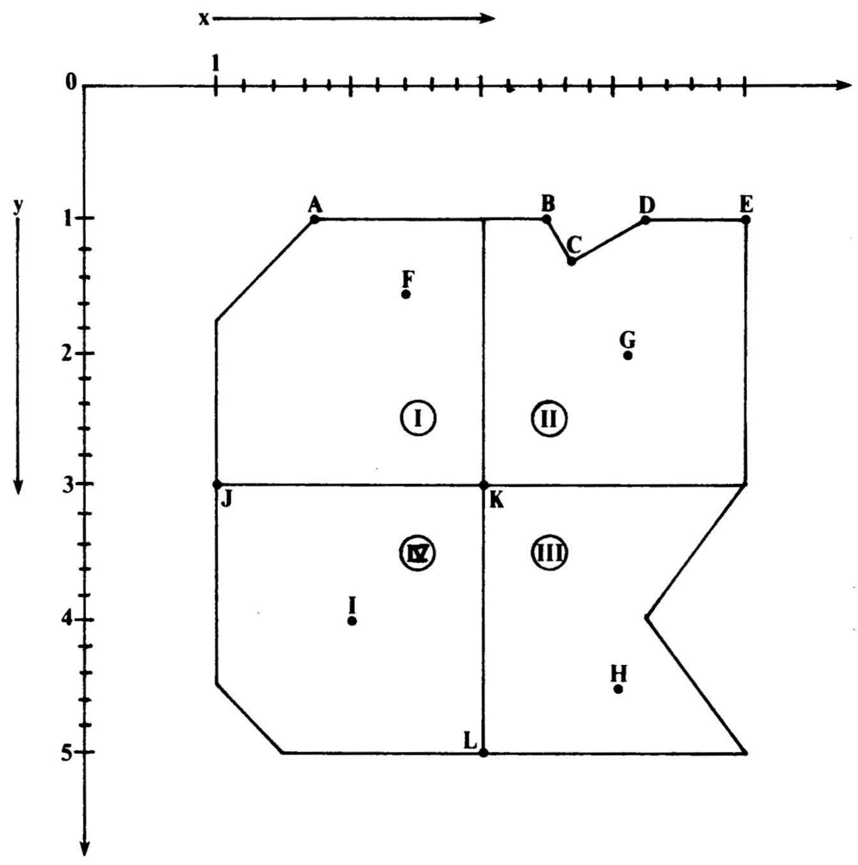
### The Proximal Map

In a proximal map, regions are defined by the value of the data points. Boundaries are constructed along the line where the values change, as illustrated in figure 5-5. The proximal map is constructed using an input deck that is similar to the deck for a contour map. The only difference is that in a proximal map the user must specify three special electives in the F-MAP package. The card deck for a proximal map is shown in figure 5-4.

### The Conformant Map

A conformant map is used to represent political boundaries or other areas where representation of data as a continuous surface is inappropriate. A value is given to each zone enclosed by a boundary. The conformant map uses three packages: A-CONFORMOLINES to delineate the data zones; E-VALUES to allocate a weight on values for each data zone; and F-MAP to specify the form of the map in terms of electives. The C-OTOLEGENDS is optional. The package structure of a conformant map is shown in figure

FIGURE 5-1: AN EXAMPLE MAP




| DATA POINTS | VALUES | DATA ZONES | VALUES |
|---|---|---|---|
| F | 1509 | I | 1509 |
| G | 2347 | II | 2347 |
| H | 1302 | III | 1302 |
| I | 2764 | IV | 2764 |

In this example, "data points" are in one-to-one correspondence with "data zones". Such correspondence is not necessary.

TABLE 5-1: SYMAP SUBROUTINES

| SUBROUTINES | CONTENTS | WHAT THE USER MUST SPECIFY |
|---|---|---|
| A-OUTLINE | Coordinates of all map edge points | An outline of the source map (for contour or proximal maps) |
| A-CONFORMOLINES | Coordinates of vertices on the zonal outlines | The positions of the data zones (for conformant maps) |
| B-DATA POINTS | Coordinates of points which are to be weighted | The positions of points to be weighted |
| C-OTOLEGENDS | Coordinates of map legends | The content of information legends appearing on the face of the map or within the rectangular map border (optional) |
| D-BARRIERS | Coordinates of any "obstacles" in the source map | The characteristics of any barrier to interpolation between data points (e.g., a river, border line, an expressway, etc.) |
| E-VALUES | Data values | The values that weight each data point (for contour and proximal maps) or data zone (for conformant maps) |
| F-MAP | Special instructions to describe map size, shape, and appearance | Any elective map specifications |

Source: Adapted from Elliot E. Dudnik, *SYMAP User's Reference Manual* (Chicago: Department of Architecture, University of Illinois at Chicago Circle, 1971).

FIGURE 5-2: PACKAGE FOR CONTOUR MAPS

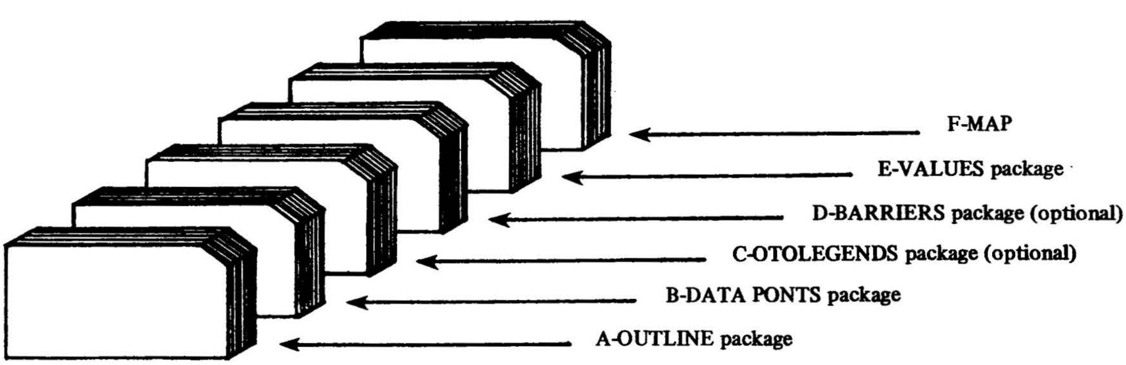


FIGURE 5-3: AN EXAMPLE CONTOUR MAP
DERIVED FROM FIGURE 5-1

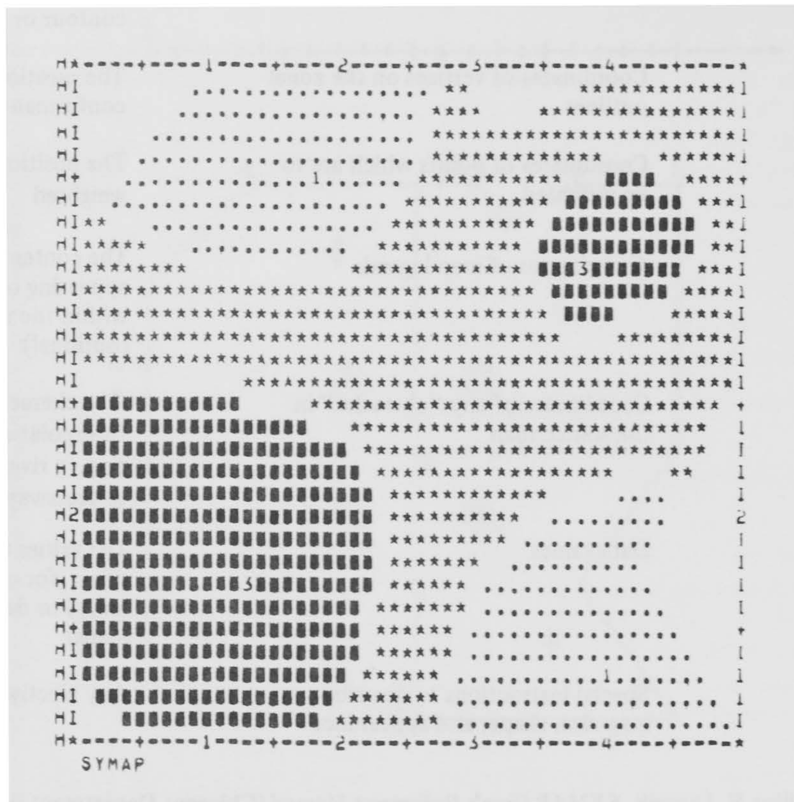



FIGURE 5-4: PACKAGE FOR PROXIMAL MAPS

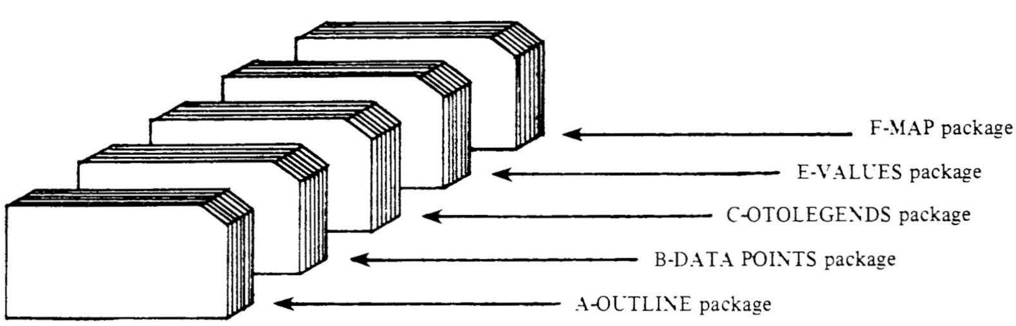


FIGURE 5-5:AN EXAMPLE PROXIMAL MAP
DERIVED FROM FIGURE 5-1

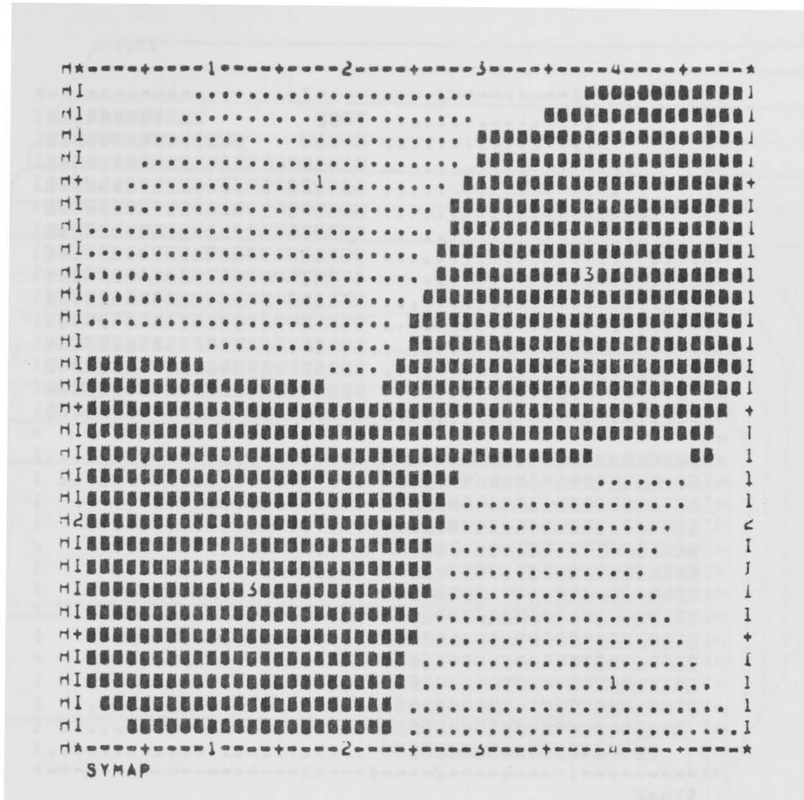



FIGURE 5-6: PACKAGE FOR CONFORMANT MAPS

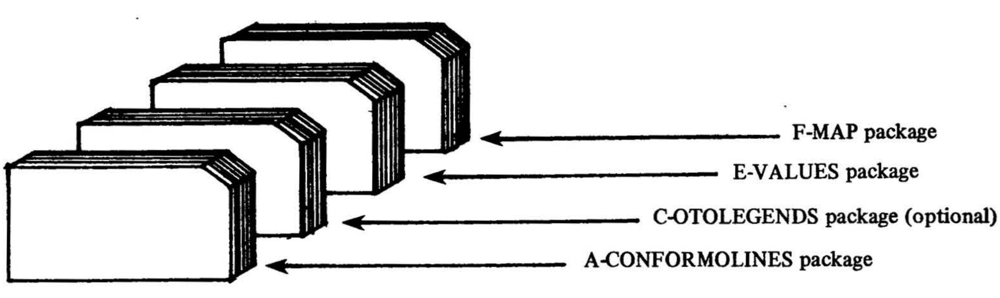


FIGURE 5-7: AN EXAMPLE CONFORMANT MAP
DERIVED FROM FIGURE 5-1

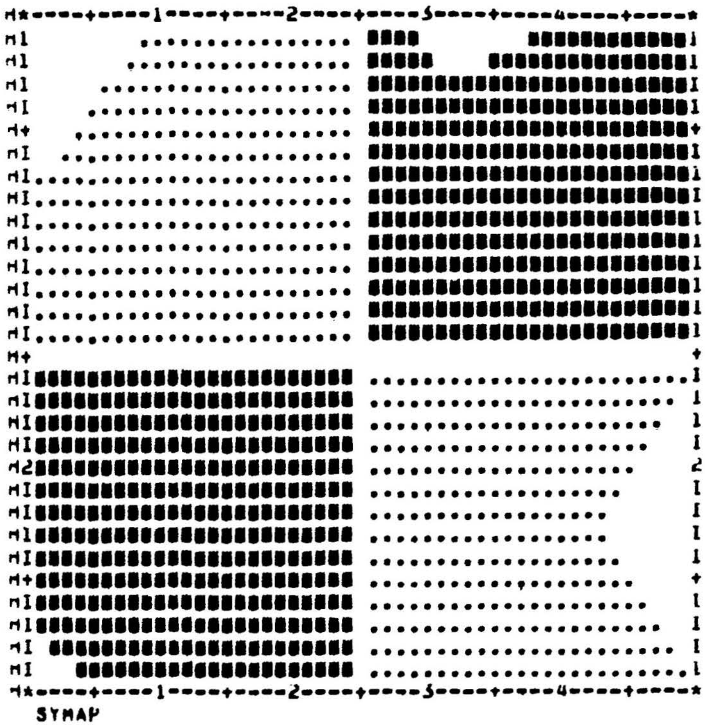



FIGURE 5-8: CONTROL CARDS FOR SUBMITTING
ANY SYMAP JOB ON THE UT COMPUTER

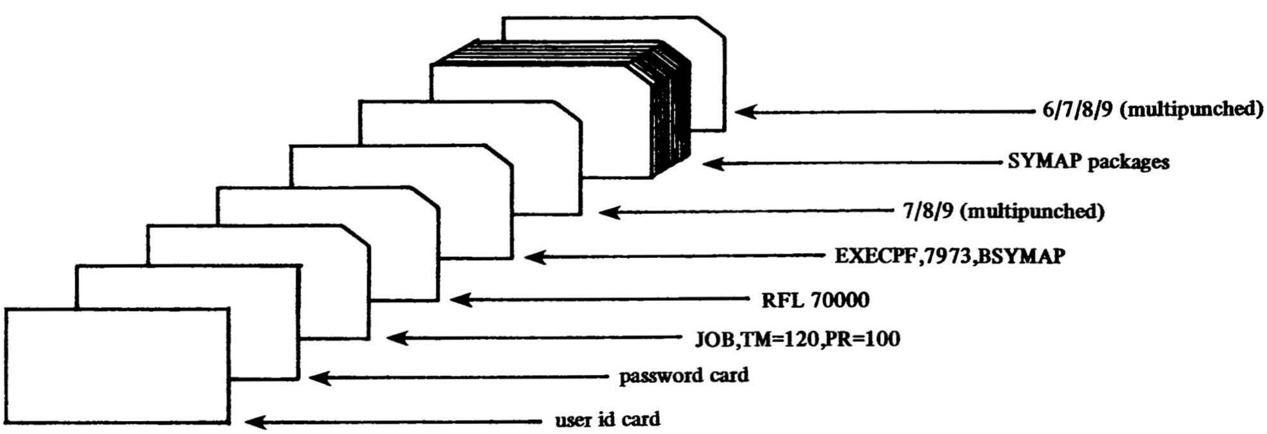
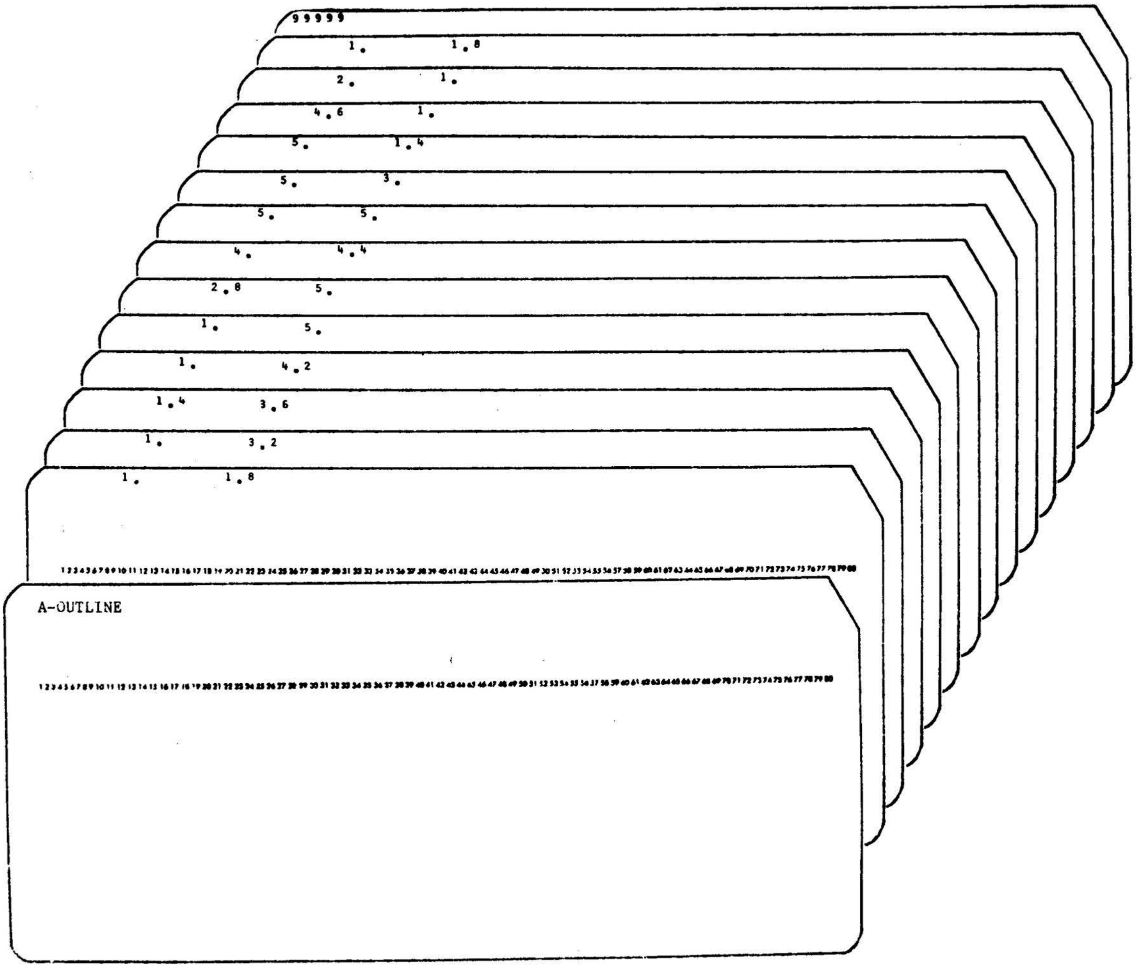


FIGURE 5-9: CARD STRUCTURE OF A-OUTLINE PACKAGE




5-6. The conformant map of figure 5-7 delineates regions in a way identical to the source map, figure 5-1.

## A GUIDE TO SYMAP KEYPUNCHING

Each package uses data punched on cards according to a particular format. Figure 5-8 is an illustration of the structure of a "general" SYMAP control card deck. The following subsections describe and list the cards for most commonly used subroutines: A-OUTLINES, A-CONFORMOLINES, B-DATA POINTS, E-VALUES, and F-MAP. Additional information on these and other subroutines is available in reference (3).

## A-OUTLINE

This package describes the outline of the source map for a contour or proximal map. The deck consists of an initial card with A-OUTLINE in columns 1-9, a final card with 99999 punched in columns 1-5, and a set of cards listing points. The cards inserted between the first and the last cards contain the coordinate locations of points that outline the study area (those points at which the outline changes its direction). Each point appears on a separate card, starting with the most "northwest" vertex. Proceeding clockwise, all outline points are punched, including a repeat of the initial point. If there are two or more points of equal y-axis value, punch first the one furthest to the left (the one with the lower x-axis value). The vertical coordinate should appear as a decimal number in columns 11-20. The horizontal coordinate should appear as a decimal number in columns 21-30. A complete A-OUTLINE data deck for the example problem is shown in figure 5-9.

### B-DATA POINTS

This package, used with contour and proximal maps, specifies the location of data points to which values will be associated. The deck consists of a title card, an ending card, and a set of cards listing point coordinates. On the first card of this package, punch B-DATA POINTS in columns 1-13. On the last card, punch the number 99999 in columns 1-5.

The coordinate locations of all appropriate data points appear on a separate card between the first and the last cards. There is a limit of 1000 data points for one map. Punch the vertical coordinate as a decimal number in columns 11-20. Punch the horizontal coordinate as a decimal number in columns 21-30. Figure 5-10 is an example B-DATA POINTS deck for the source map.

### A-CONFORMOLINES

The A-CONFORMOLINES package describes the zonal outline of each data zone for conformant maps. A complete deck consists of a title card (A-CONFORMOLINES in columns 1-15), an ending card (99999 in columns 1-5), and sets of cards indicating zonal outlines (see figure 5-11).

Specifications for each of the zonal outlines are inserted between the first and the last cards. Care must be taken to associate each data zone with its corresponding data value. On the first card for each conformant outline, punch the reference number of the associated data zone as an integer in columns 1-5. In column 10, punch either the letter A, L, or P to indicate whether the zonal outline is to be represented as an area, a line, or a point, respectively. In the sample problem each zone represents an area; hence an "A" is punched in column ten of the first card of each zone outline (see figure 5-11). Then punch the coordinate location of each point in the outline, beginning with the upper left-hand corner (the "northwest") and proceed clockwise. The location of the first vertex should be repeated to close the outline. Repeat this procedure for each data zone.

FIGURE 5-10: CARD STRUCTURE OF B-DATA POINTS PACKAGE

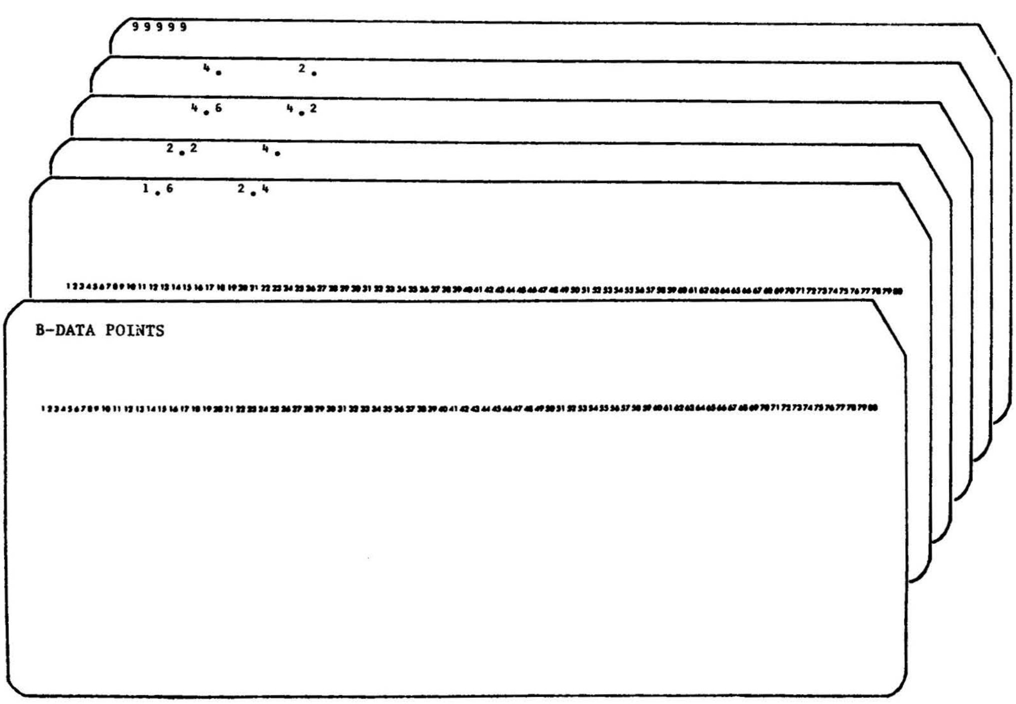
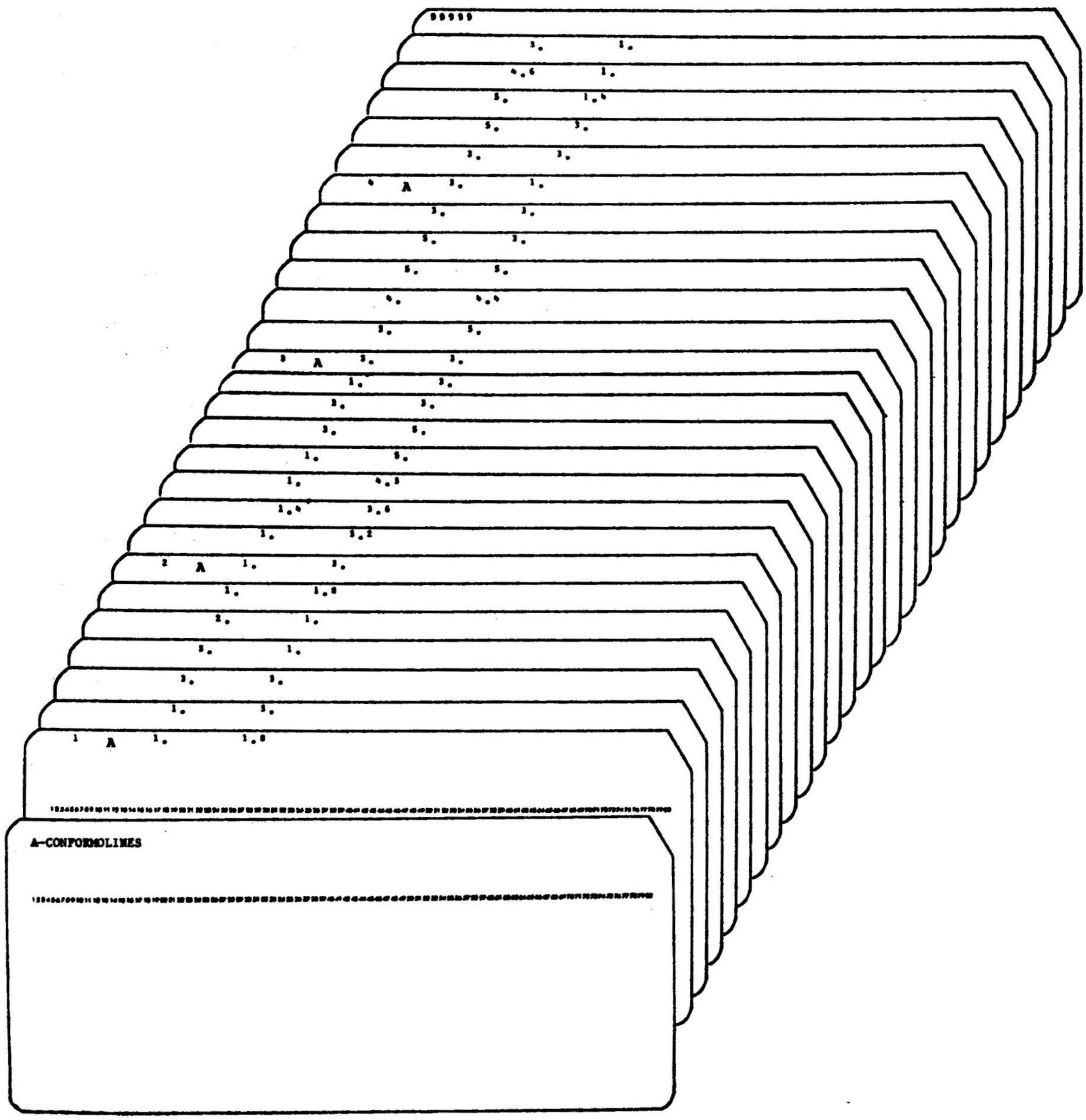


FIGURE 5-11: CARD STRUCTURE OF A-CONFORMOLINES PACKAGE



## E-VALUES

The E-VALUES relate data (values or weights) to points (contour and proximal maps) or to data zones (conformant maps). The deck includes one title card (E-VALUES in column 1-8), one ending card (99999 in columns 1-5), and a collection of cards listing values or weights.

One card is included for each of the data points (in the B-DATA POINTS package) or the zonal outlines (in the A-CONFORMOLINES package), proceeding strictly according to the order of the data points or zones. Each value is punched on a separate card. If value is negative, punch a minus sign before it. Punch each value as a decimal number in columns 11-20 (see figure 5-12).

## F-MAP

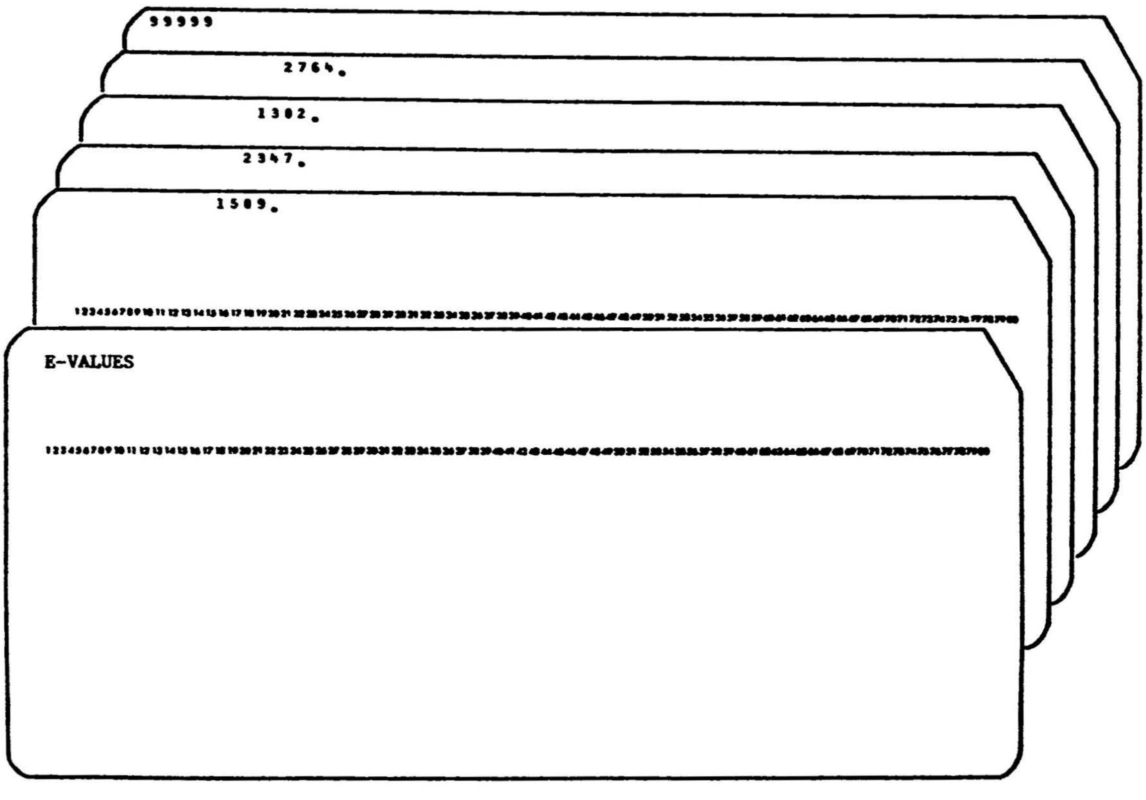
The F-MAP package specifies characteristics such as map size, symbolism, and structure of the contour, proximal or conformant maps. On the first card of this package, punch F-MAP in columns 1-5. On the last card, punch the number 99999 in columns 1-5.*

On the second, third, and fourth cards, punch any title that should appear below the map. Although three cards must appear in the deck, one or more of these cards may be left blank. Words or characters can appear within columns 1-72 of these title cards.

On other cards, to be inserted between the fourth and the last cards, punch any electives that may be desired. Table 5-2 gives the format of commonly used F-MAP electives that control the final map's content, scale, size, and tone. Detailed information on these options is available in reference (4). Figures 5-13, 5-14, and 5-15 are the F-MAP packages that produced figures 5-3, 5-5, and 5-7, respectively.

*After the last card, punch the number 999999 in columns 1-6. This card enables the program to terminate normally without generating an "end of file" message. When running multiple maps at one submission, this card is required only after the last F-MAP package.

FIGURE 5-12: CARD STRUCTURE OF E-VALUES PACKAGE

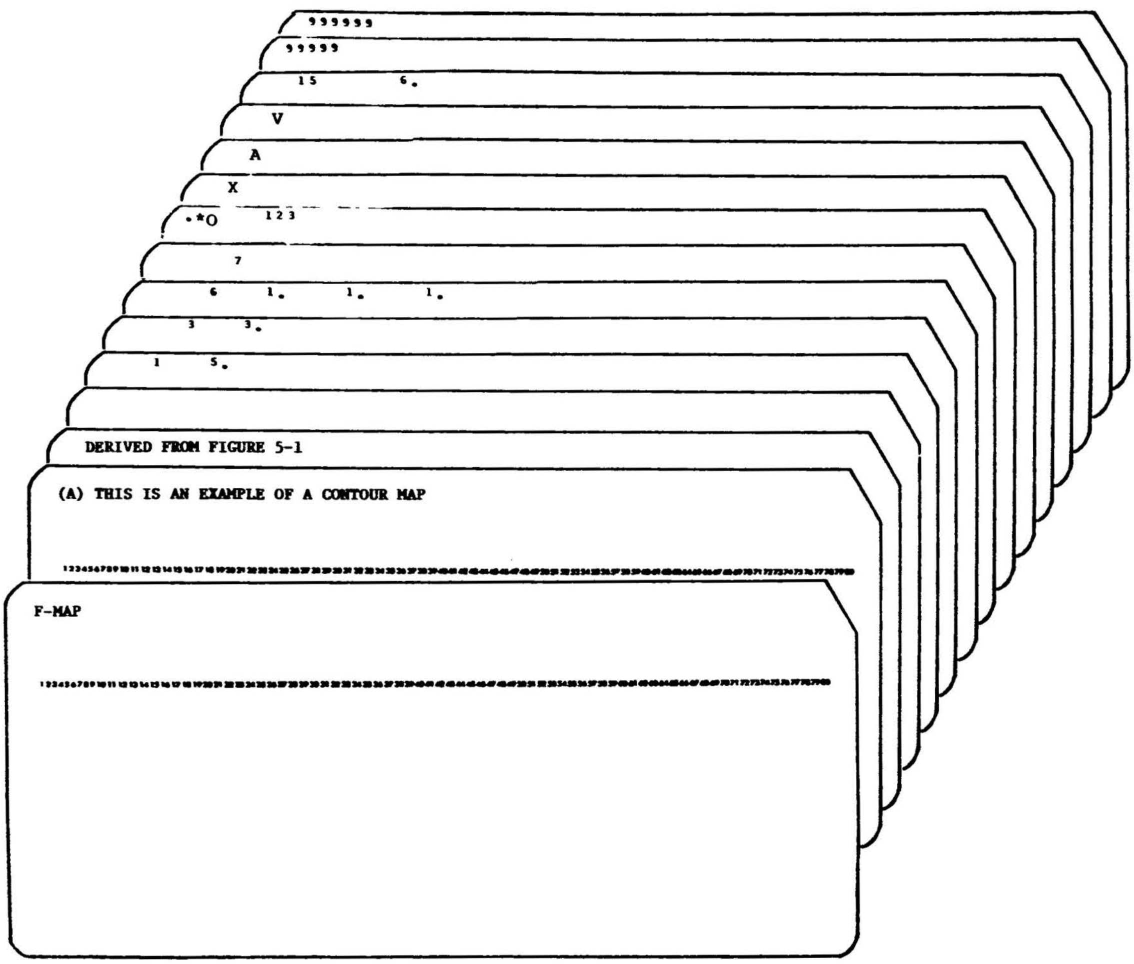


## TABLE 5-2: SYMAP ELECTIVES

| ELECTIVE NUMBER | CARD NUMBER | DEFINITION | COLUMN | VARIABLE | DEFAULT OPTIONS | COMMENTS |
|---|---|---|---|---|---|---|
| 1 | 1 | Size of output map | 5 | 1 | 13.0 inches for the larger dimension of the map, with the smaller dimension proportioned accordingly | If one or both dimensions exceed 72.0 inches, elective number 16 must be specified |
| | | | 11-20 | Vertical dimension of desired map in inches as a decimal number | | |
| | | | 21-30 | Horizontal dimension of desired map in inches as a decimal number | | |
| 3 | 1 | Number of levels into which total value range is to be divided by symbolism | 5 | 3 | 5 levels | |
| | | | 11-20 | Number of levels desired (from 2 to 10) as a decimal number | | |
| 6 | 1 | Specifies whether the intervals or levels are equal or not equal | 5 | 6 | Each level with an equal range | If intervals are to be equal, punch 1 |
| | | | 11-20<br>21-30<br>31-40<br>etc. | Up to ten intervals may be specified, each in a field of ten spaces | | |
| 7 | 1 | Symbolism | 5 | 7 | Takes standard symbolism | If there is no overprinting, cards 3, 4, and 5 will be blank |
| | 2 | | 1-10 | The symbolism character for each level (column 1 for the symbol to designate the first level, column 2 for the symbol to designate the second level, etc.) | | |
| | | | 11-20 | Respective data point symbols (column 11 for the symbol to designate data points in the first level, etc.) | | |
| | 3,4,5 | | 1-10 | Any overprint characters desired | | |
| 15 | 1 | Number of output characters per inch | 4-5 | 15 | 8 lines per inch and 10 columns per inch | By specifying 6.0 lines per inch, fewer lines of output will result, but the overall size of the map will be the same |
| | | | 11-20 | The number of lines per inch (vertically) as a decimal number | | |
| | | | 21-30 | The number of columns per inch (horizontally) as a decimal number | | |
| 31 | 1 | Specify the proximal type of map | 4-5 | 31 | | No other specification is required on these cards |
| 36 | 1 | | 4-5 | 36 | | |
| 37 | 1 | | 4-5 | 37 | | |

Source: Adapted from Elliot E. Dudnik, *SYMAP User's Reference Manual* (Chicago: Department of Architecture, University of Illinois at Chicago Circle, 1971), p. 29.

FIGURE 5-13: CARD STRUCTURE OF F-MAP PACKAGE FOR A CONTOUR MAP




## USER DIFFICULTIES

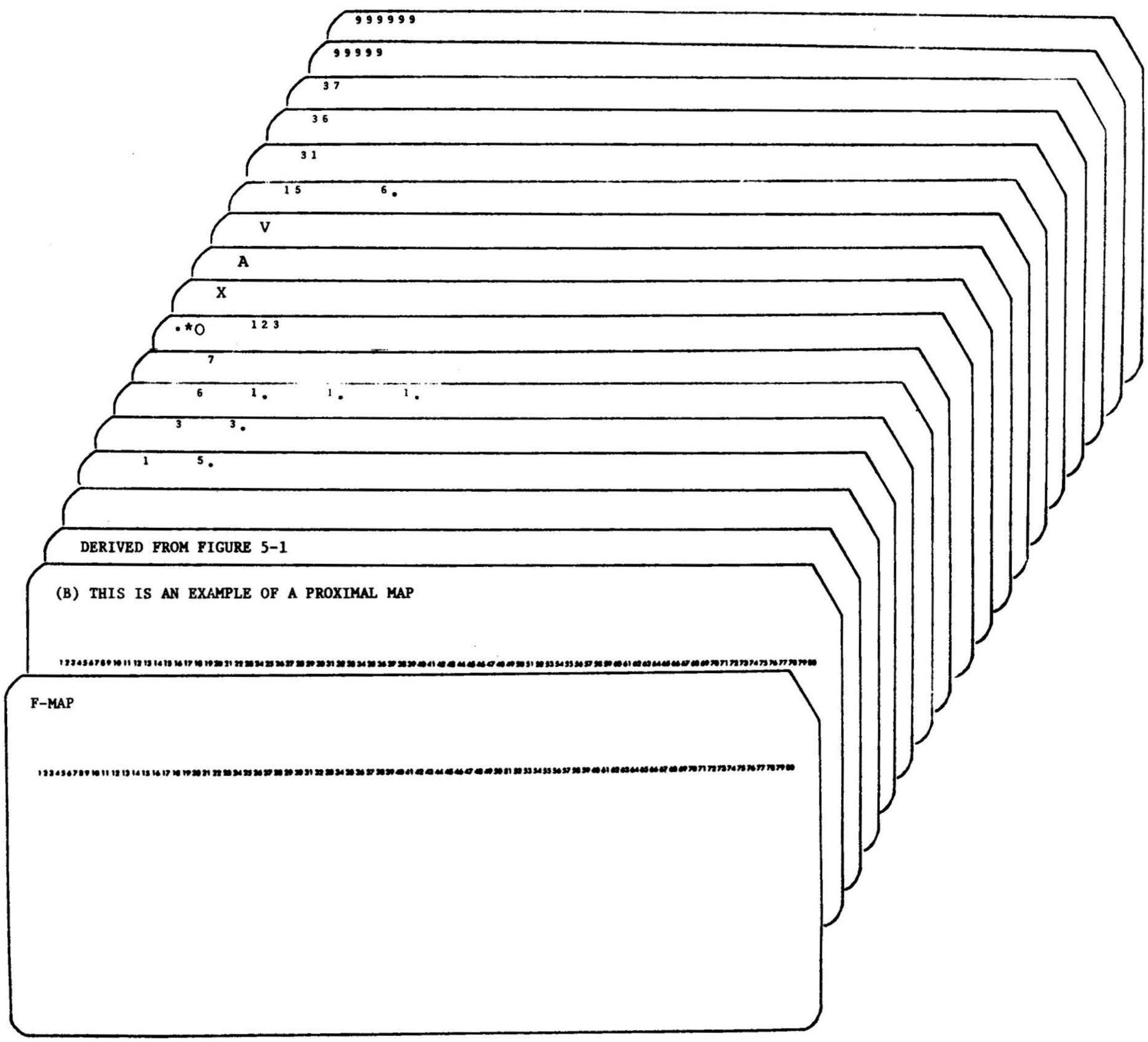
Incorrect keypunching for F-MAP package electives is a source of mapping errors and map distortions. To illustrate such incorrect maps, this section includes three user keypunching or omission errors that were observed in practice. A review of these problems will assist the SYMAP user in detecting and identifying this sort of error.

One error relates to elective seven, which permits the user to specify symbols for printing the map. To use this elective, five cards must be punched correctly. Figure 5-16 illustrates an incorrect map produced by an incorrect second card. This map has poorly defined regions and does not include the four data point numbers.

A second map error can be caused by incorrectly specifying elective fifteen, the number of characters per inch for map printing. The default option is 8 lines per inch and 10 columns per inch. If the map is to appear with more (or fewer) characters per inch, elective fifteen must be used to generate the proper proportions. Figure 5-17 is a conformant map produced by SYMAP in which elective fifteen was not specified. The dimensions of the map in figure 5-17 does not replicate correctly the form of the map shown in figure 5-7.

A third kind of error, common in printing proximal maps, is the omission of electives 31, 36, or 37. Each elective is necessary to produce a proximal map and each requires only one separate card. For example, if elective 31 is

FIGURE 5-14: CARD STRUCTURE OF F-MAP PACKAGE FOR A PROXIMAL MAP




not specified, the sample proximal map will resemble figure 5-18 rather than 5-5. Figure 5-18 contains an unnecessary and incorrect set of values printed in the circled area.

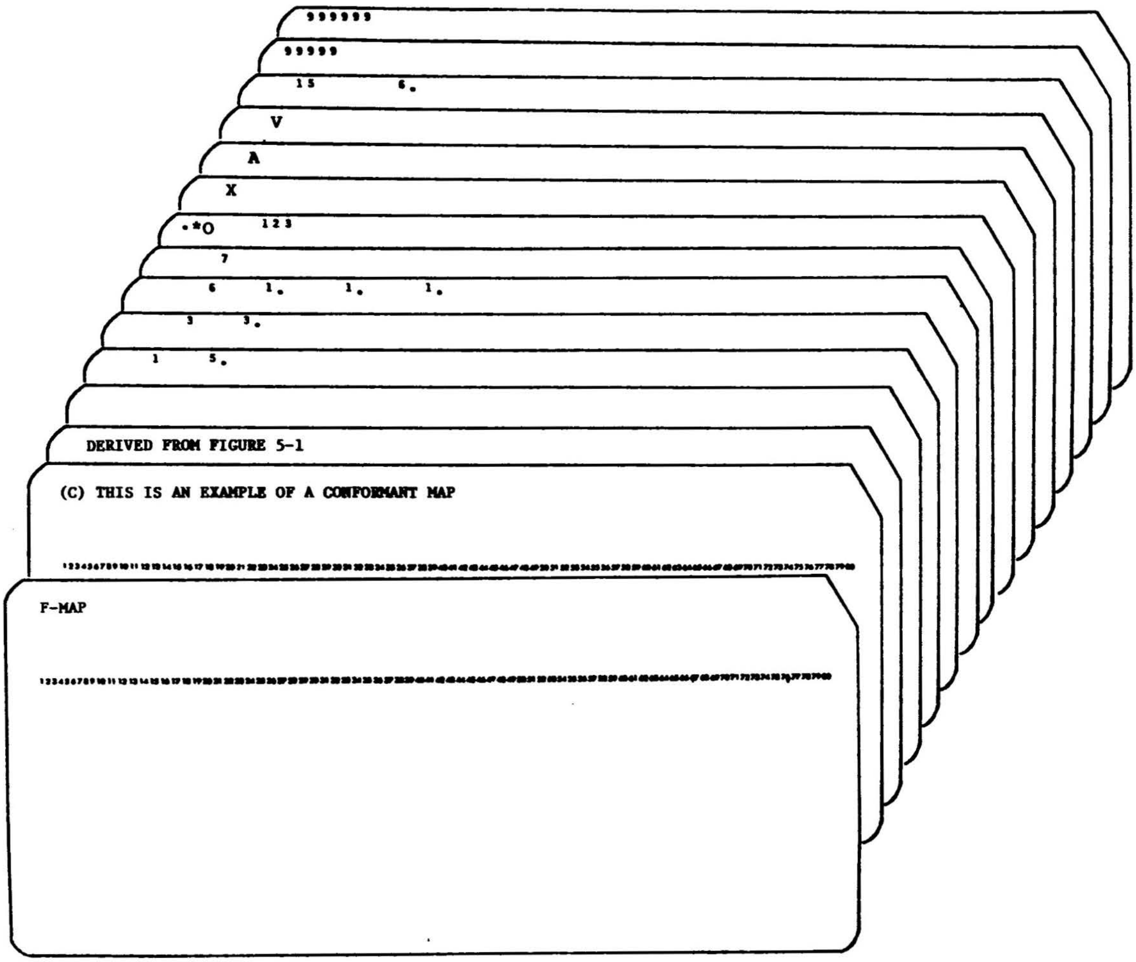
These and other keypunch errors or card omissions can lead to quite specific distortions in the output maps. A careful SYMAP user should double-check all keypunched information prior to map printing.

**COMPUTER MAPS OF AUSTIN**

Project members constructed maps of Austin by using the 358 transportation serial zones as the study area. The time-consuming task of constructing an A-CONFORMOLINES package consisting of 2686 points that delineate each of the 358 serial zones in Austin was done by hand, without the help of a digitizer. Then an available (although incomplete) listing of the total number of EMS calls recorded from each serial zone over a five-month period was used in the E-VALUES package. In addition, the F-MAP package was structured using electives numbers 1,3,6,7,8, and 15, and standard symbolism. Figure 5-19 shows a conformant map of Austin with the distribution of calls.

For the contour and proximal maps of the city, additional information was obtained from the source map. The perimeter points of the study area were located to construct the A-OUTLINE package. The midpoints of each of the 358 serial zones were selected as the B-DATA POINTS. The values related to each data point were the call fre-

FIGURE 5-15: CARD STRUCTURE OF F-MAP PACKAGE
FOR A CONFORMANT MAP




quency distribution used in the conformant map; thus, the E-VALUES package remained unchanged. Finally, the F-MAP package of the conformant map was used again to produce the contour and proximal maps. Figures 5-20 and 5-21 are respectively a contour and a proximal map of the city of Austin. Due to some errors in either the computer software or the data set, the contour and proximal maps are incorrect.*

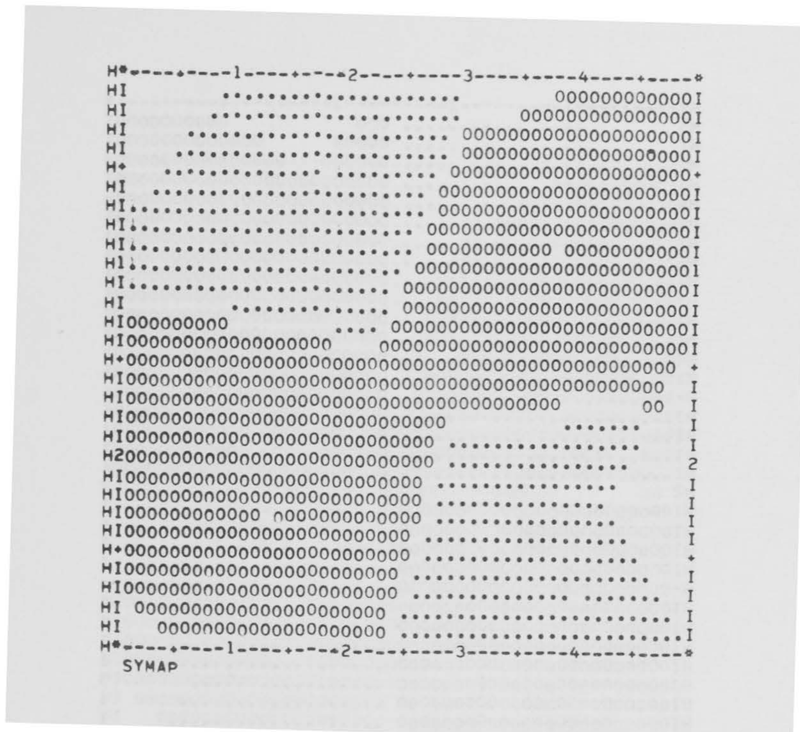
The costs of SYMAP mapping vary with the complexity of the map and the size (number of output panels) generated by the printer. Nine different single panel maps of the 385 serial zones of Austin were generated by project members. The average time cost per SYMAP map was 21.894 seconds on The University of Texas at Austin CDC 6400/6600 computer system.

*Given the limits on time for preparing this chapter, there was no opportunity to discover the source of this error.

## THE USE OF COMPUTER MAPPING IN EMS PLANNING

Computer mapping is a technique for depicting geographic, economic, social, and demographic information. The display of data in computer maps can enhance an analyst's ability to visualize implications of data. One particular use of computer graphics in emergency medical service planning is to arrange information relevant to ve-

FIGURE 5-16: AN ILLUSTRATION OF SYMBOL PUNCH ERROR




hicle sites and service areas.

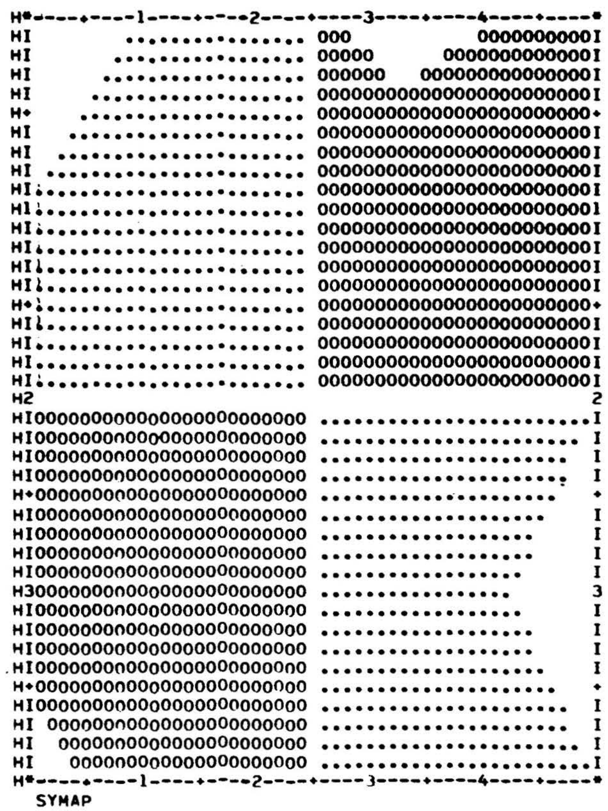
The purpose of this section is to discuss the use of computer mapping as an aid in visualizing the geographical implications of future EMS vehicle service areas. The SYMAP program allows a user to illustrate geographic, demographic, economic, or EMS service data in high quality maps that are inexpensive to generate. Furthermore, the computer mapping programs do not ordinarily require prior knowledge of computer programming on the part of the user.

The SYMAP software package can plot one set of information in any of three forms–conformant, contour, or proximal maps. Each of these maps illustrates the data in a different perspective.

The SYMAP user can store geographical boundaries of zones or points within (or outside) these zones. Once this information is on tape or disk, a SYMAP user can edit or manipulate the data in a number of ways. For example, an analyst could map one set of values (such as total serial zone population) in several ways by varying the number of intervals or each interval's upper and lower limits. Each map provides a different perspective on the distribution of population throughout areas of the city. A series of these maps could be overlaid to produce composite maps.

Conformant maps are likely to be the most valuable of map forms. A conformant map is used to represent real boundaries, when data representation as a continuous surface is inappropriate. Each zone is enclosed by a boundary and given a data value. For example, a conformant map could be used to illustrate the boundaries of the relevant EMS planning areas. In the city of Austin, these areas are transportation serial zones. One value is assigned to each zone; any economic or demographic data, such as per capita

FIGURE 5-17: AN INCORRECT CONFORMANT MAP

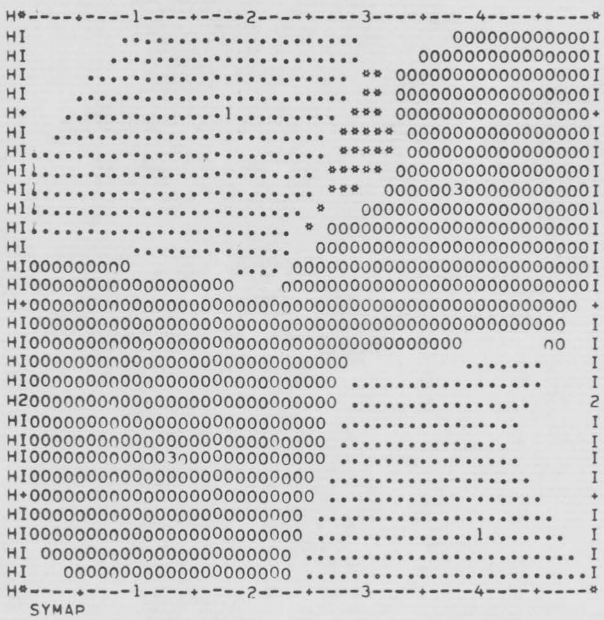



income, can be related to these areas through SYMAP. A "barrier" option allows a user to depict how a highway or a river can divide areas of the city from one another.

Each computer-generated map distorts information by associating one value with discrete areas of the city. A conformant map uses a single value to represent a variable in a large area. This assumption is not accurate if the variable being graphed is distributed continuously. If per capita annual income were to be graphed, a zone with both high- and low-income persons would be represented as a zone with a medium level of income. Thus, a single value for the average income in a zone could distort the economic situation of people in that zone.

The contour map consists of closed curves known as contour lines which connect all points having the same numerical value. A contour map could help EMS planners

FIGURE 5-18: AN INCORRECT PROXIMAL MAP




appreciate the "density" of various demographic indicators, such as "total population" or "persons over 62 years of age." The contour lines will delimit the areas where the population density is higher or lower than specified intervals. The contour map shows the value of a variable without relation to political boundaries or specific points in a zone. Contour maps are most appropriate for representing variables that are continuous. In such maps, it is also possible to illustrate barriers.

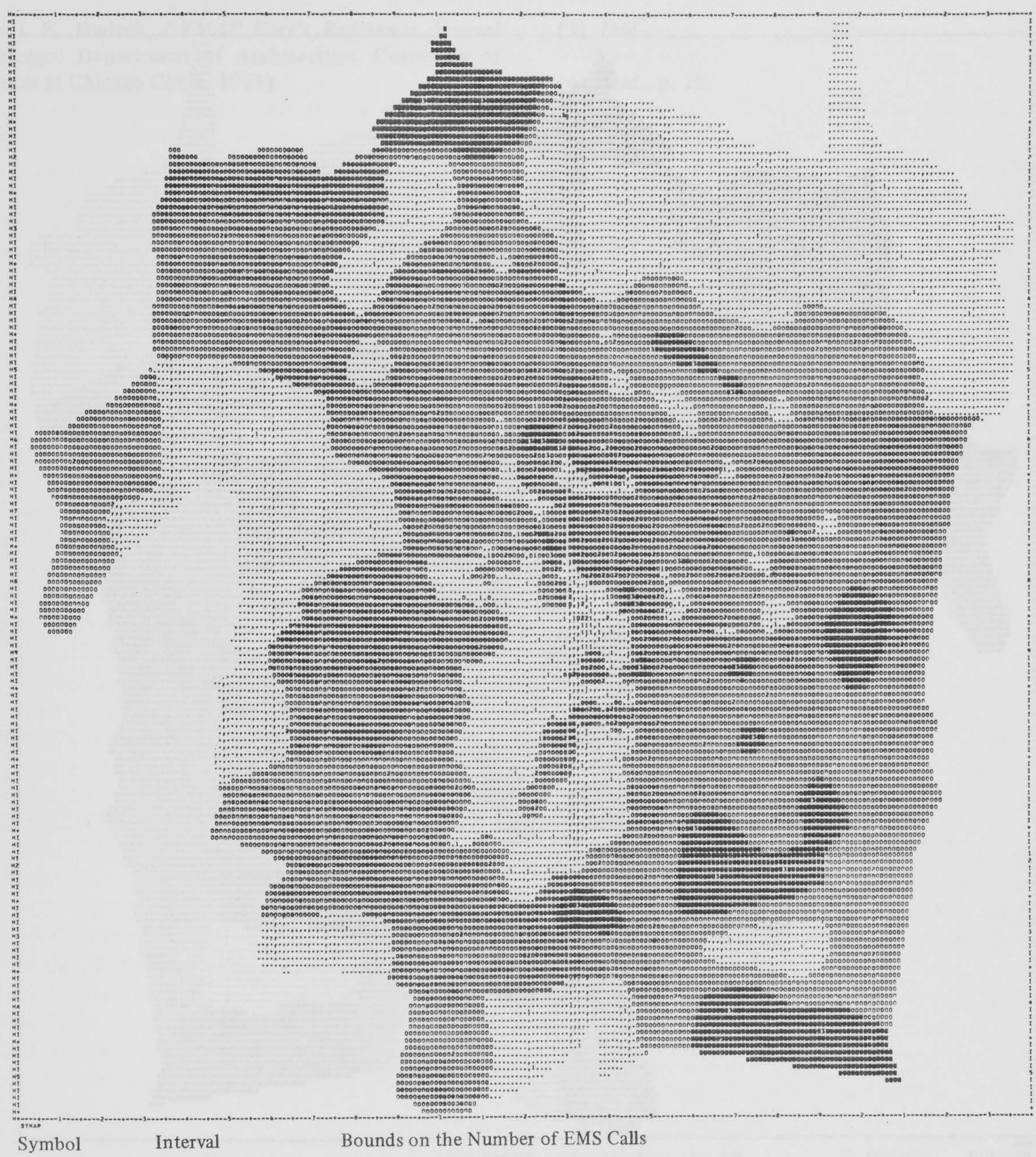
The data points themselves define a proximal map; zone boundaries are created by the computer, equidistant from adjacent points to which data values have been assigned. A proximal map can be used to depict the primary service area covered by a particular EMS vehicle base or the limits of the area covered by the vehicle station, given some defined response time. By varying the response time, several different maps can be generated. This could allow an analyst to compare the patterns of overlapping coverage by vehicles in the city of Austin.

## FIGURE 5-19: A CONFORMANT MAP OF THE CITY OF AUSTIN*

| Symbol | Bounds on the Number of EMS Calls: Lower Bound | Upper Bound |
|---|---|---|
| | 0 | 5 |
| | 5 | 30 |
| | 30 | 221 |

*The serial zones are weighted by a hypothetical frequency distribution of calls for emergency medical service. The conformant map does not illustrate the mid-point of serial zones.

FIGURE 5-20: A CONTOUR MAP OF THE CITY OF AUSTIN*



| Symbol | Interval Level | Bounds on the Number of EMS Calls: Lower Bound | Bounds on the Number of EMS Calls: Upper Bound |
|---|---|---|---|
| | 1 | 0 | 5 |
| | 2 | 5 | 30 |
| | 3 | 30 | 221 |

*The serial zones are weighted by a hypothetical frequency distribution of calls for emergency medical service. An interval number appears in the mid-point of each of the 358 serial zones.

FIGURE 5-21: A PROXIMAL MAP OF THE CITY OF AUSTIN*

| Symbol | Interval Level | Bounds on the Number of EMS Calls: Lower Bound | Upper Bound |
|---|---|---|---|
| | 1 | 0 | 5 |
| | 2 | 5 | 30 |
| | 3 | 30 | 221 |

*The serial zones are weighted by a hypothetical frequency distribution of calls for emergency medical service. An interval number appears in the mid-point of each of the 358 serial zones.

# References

(1) Elliot E. Dudnik, *SYMAP User's Reference Manual* (Chicago: Department of Architecture, University of Illinois at Chicago Circle, 1971).

(2) *Ibid.*

(3) *Ibid.*

(4) *Ibid.*, p. 29.

# Chapter Six
# The Use of SYMVU and CALFORM in Mapping Analyses

SYMVU and CALFORM are two computer programs that instruct a pen plotter to draw maps. SYMVU takes information directly from SYMAP programs and converts it into three-dimensional versions of SYMAP maps. CALFORM produces pen-drawn two-dimensional conformant maps using different input information than that used in SYMAP; consequently, the program requires the preparation of a new deck of computer cards. Each of these map programs can be used to aggregate and display information related to EMS service in the city of Austin.

## SYMVU

SYMVU is the name of a program capable of using SYMAP data cards and a pen plotter to produce three-dimensional oblique view maps (1). The basic input to a SYMVU program is a SYMAP program that is stored on tape. To obtain a SYMVU plot, the user runs first a SYMAP program with the proper changes and then a separate SYMVU deck. This SYMVU program accesses the SYMAP data on tape and plots a three-dimensional equivalent of the SYMAP map.

For example, figure 6-1 shows a SYMVU map that corresponds to the example SYMAP map in figure 5-1. To obtain such a corresponding SYMVU map, the user would modify the original SYMAP deck (see figure 6-2) by substituting two cards ("PUBLIC,SYMAP,INPUT" and "SAVEPF,B645, TAPE8") for two cards in the original SYMAP deck (RFL 70000" and "EXECPF,7973,BSYMAP"). The user would also add an elective card at the back of the F-MAP package just before the "99999" card ("21" punched in columns 4 and 5). This revised SYMAP program will produce a two-dimensional map on the line printer and store the results on tape. If another SYMAP program is run with this control deck, the old tape will be erased and the new two-dimensional map will be stored on the tape.

To run a SYMVU program, the user needs to access the SYMAP results stored on the tape and plot a three-dimensional version of the map. The SYMVU deck shown in figure 6-3 includes eight cards–three control cards (see figure 6-4), a 7/8/9 multipunch card, a title card, two elective cards, and a 6/7/8/9 multipunch card. The alphanumeric symbols punched in columns 1 through 72 on the title card will be printed as a heading for the map.

Figure 6-3 also illustrates the two elective cards that specify program electives controlling how the map will look. These different electives, which are described in the SYMVU reference manual, can be specified by the user or by default values (2). Table 6-1 explains some of the major electives.

Several SYMVU maps can be produced in sequence with data on tape. Figure 6-5 lists the cards for a computer deck that would generate maps at several viewer angles. To plot several maps in one computer run, a user needs to punch multiple program decks (including control cards, title, and elective cards), separated by a 7/8/9 card. Two control cards (a "REWIND TAPE8" and "SYMVU" card) must be included in the control deck for each map to be plotted. For example, if a user wanted to plot four maps in one run, the control deck would consist of the standard control cards and three pairs of the REWIND TAPE8 and SYMVU cards. Each map must also have a separate title and elective card. The deck in figure 6-6, for example, can generate map views from 45, 60, and 25 degrees. The three maps from this one SYMVU run are shown in figure 6-6.

### Example Maps of Austin

Figure 6-7 is a three-dimensional representation of the geographical distribution of Black, Mexican-American, and total residents in Austin. Each map is a three-dimensional "picture" of the data value levels for the 358 individual serial zones. Each map was first stored on tape by SYMAP and then plotted by a SYMVU program.

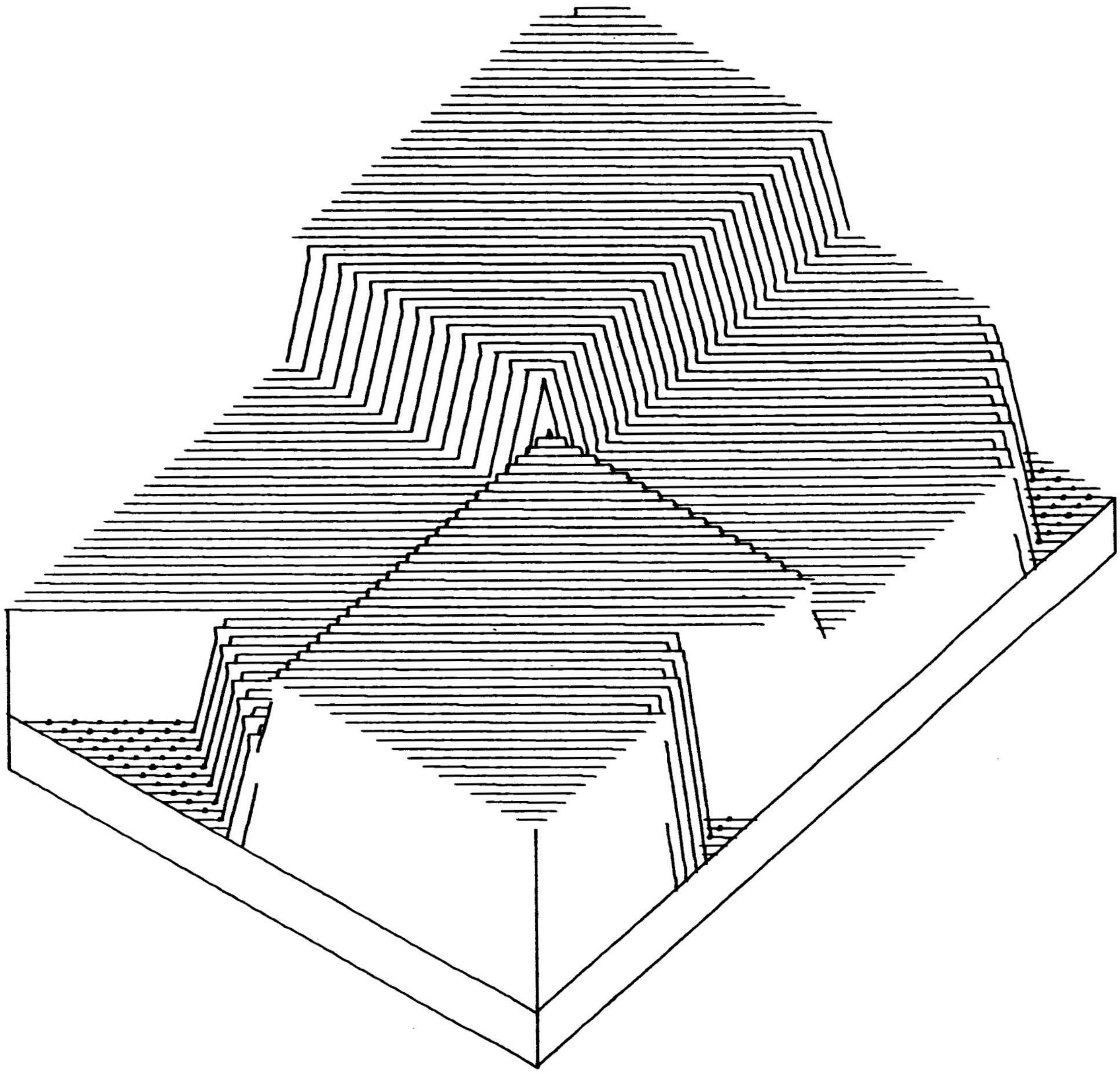
Figure 6-8 illustrates two conformant maps of call history shown at different azimuths and altitudes. Note how rotation of the azimuth from 12 to 15 degrees clarifies the height of the peak of call frequency in the Central Business District.

The maps produced by SYMVU in three dimensions offer the user the ability to represent visually the value differences in data zones. SYMVU can show gradual changes in data values; an individual viewing the map can immediately sight peaks and valleys of data values without reference to a key. This three-dimensional feature allows the user to portray information in a form that is not limited by the number of intervals.

## CALFORM

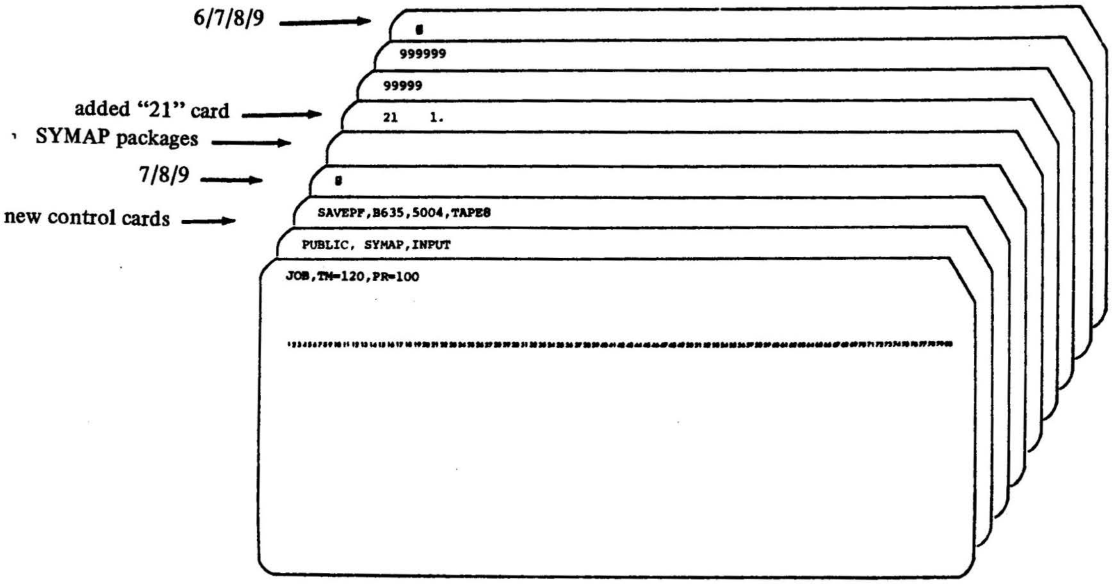
CALFORM is the name of a computer program that produces conformant maps on a pen plotter. To prepare a conformant map, the user must define point locations, values for each point, and map options (3).

FIGURE 6-1: A SYMVU VERSION OF THE EXAMPLE MAP



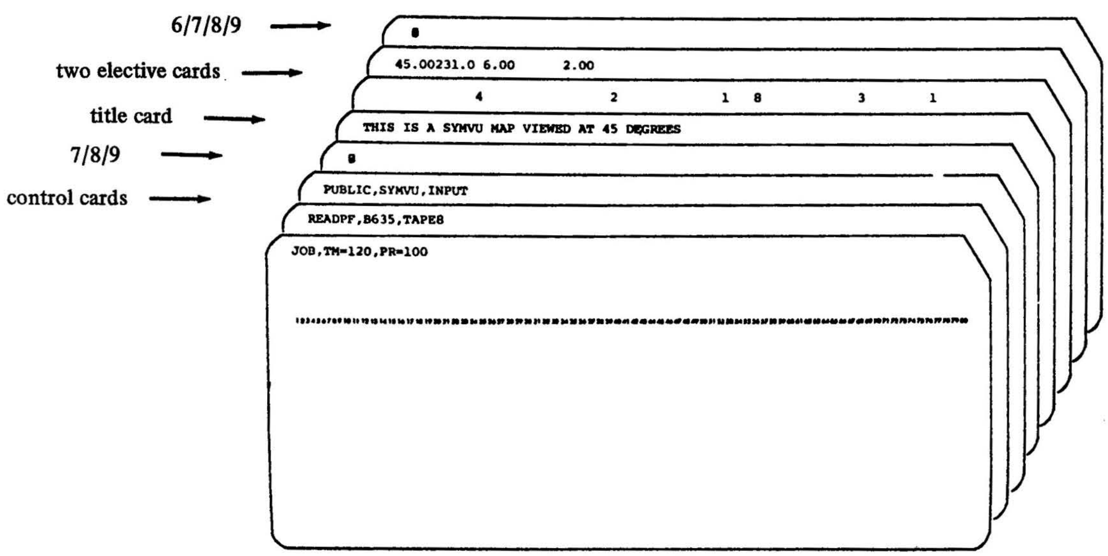
This is a SYMVU map viewed at 45 degrees

## FIGURE 6-2: REVISED SYMAP DECK




This deck stores SYMAP data for SYMVU runs.

## FIGURE 6-3: SYMVU DECK




This deck produced figure 6-1

FIGURE 6-4: CONTROL CARDS FOR SYMVU

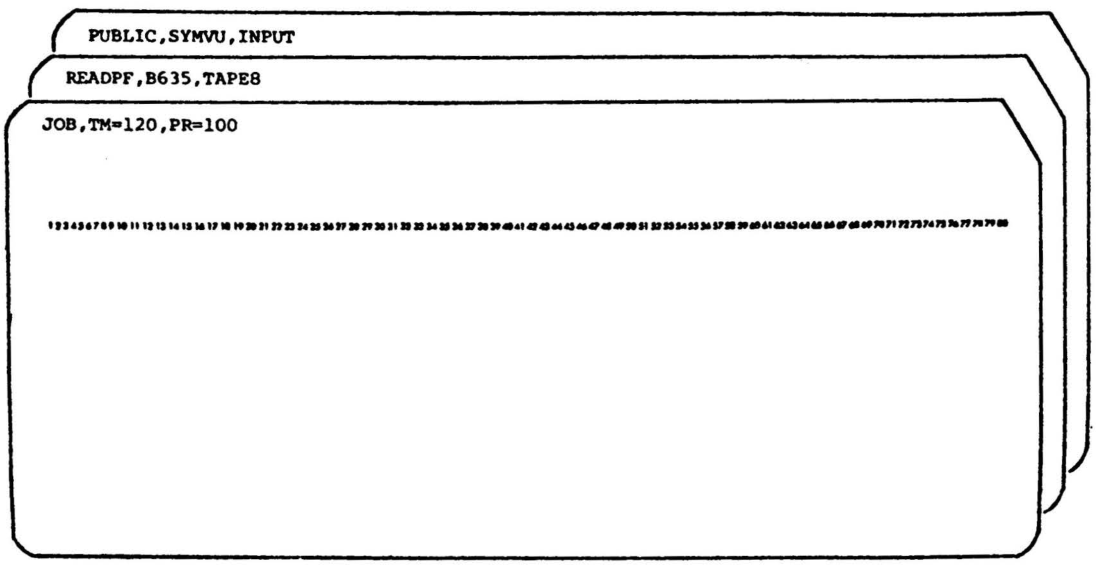
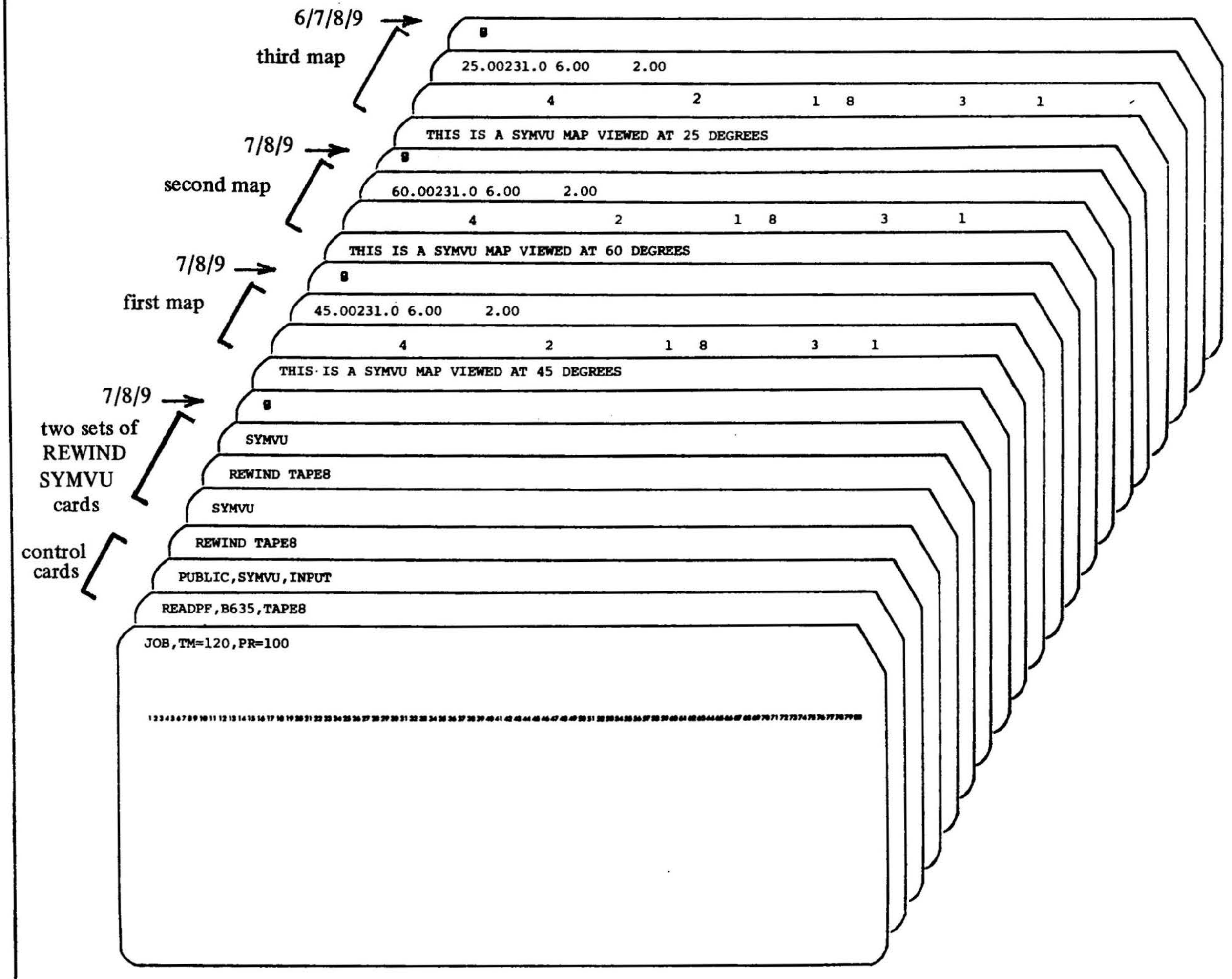
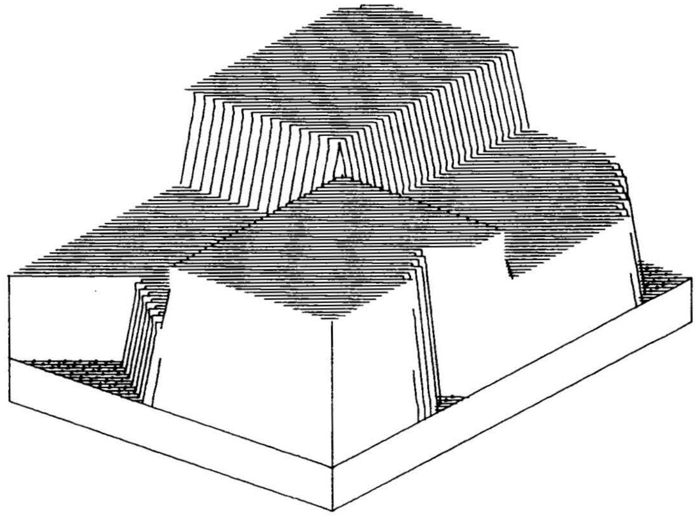


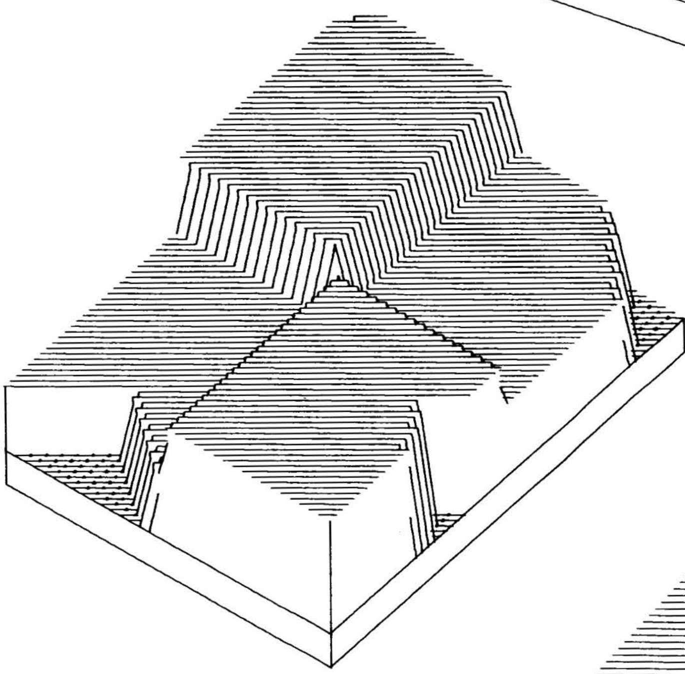
FIGURE 6-5: SYMVU DECK FOR MULTIPLE RUNS



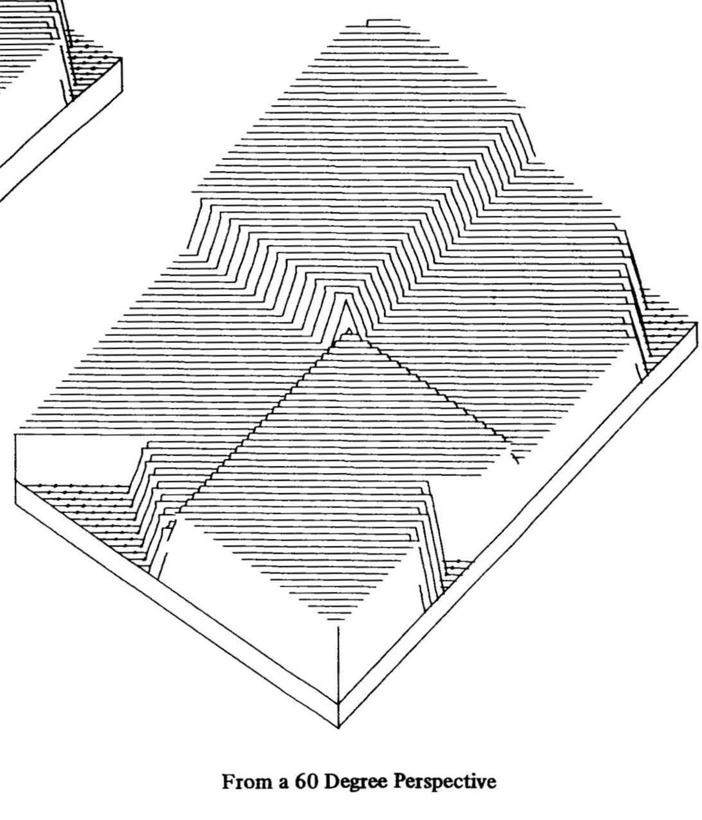
## FIGURE 6-6: THREE VIEWS OF THE EXAMPLE MAP



From a 25 Degree Perspective



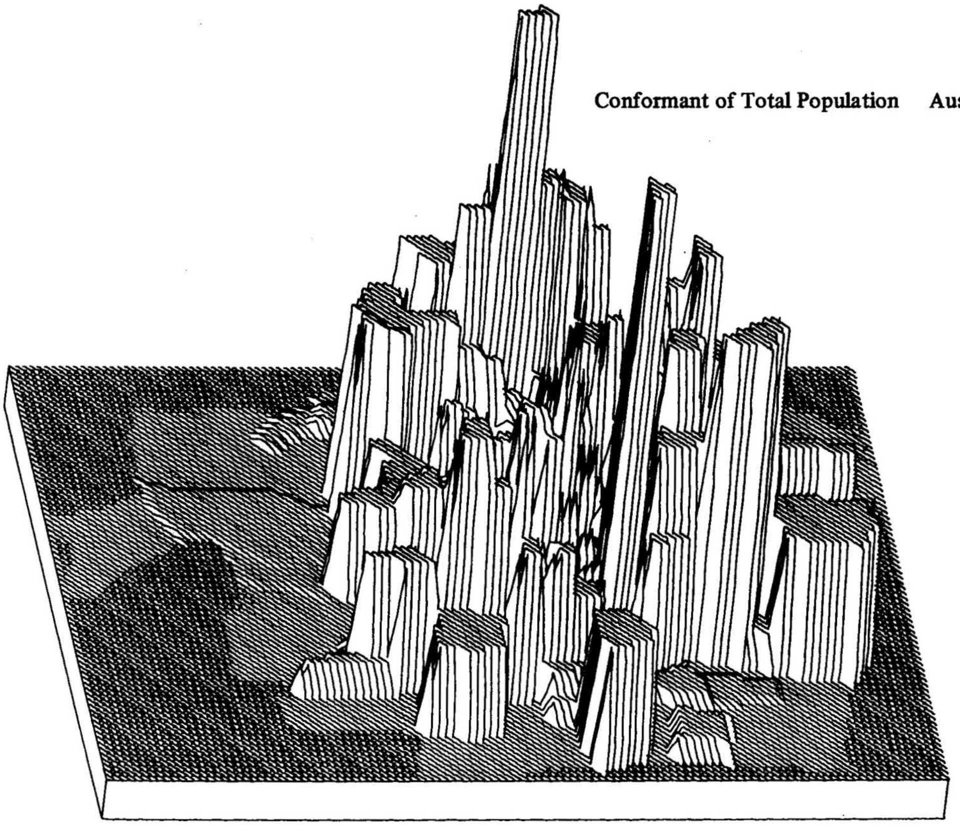
From a 45 Degree Perspective



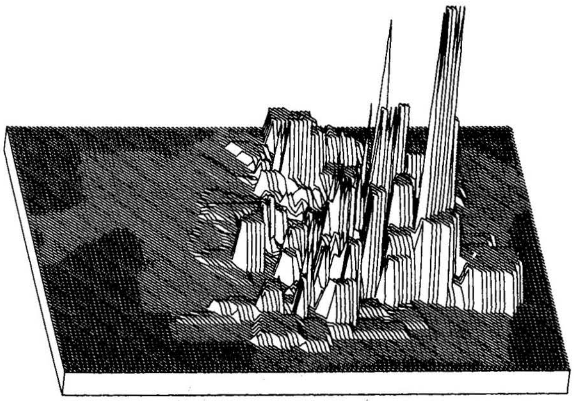
From a 60 Degree Perspective

These views are reduced from the original plots.

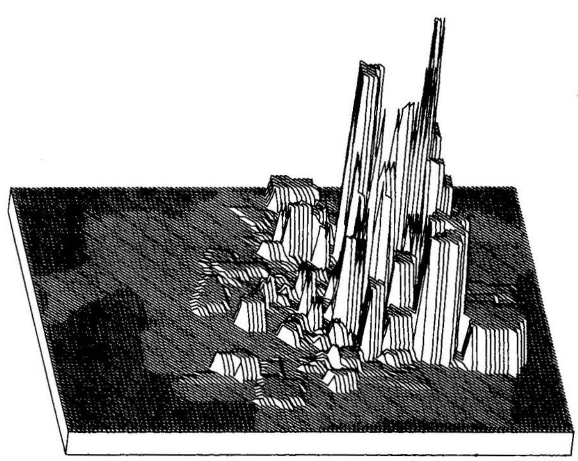
FIGURE 6-7: THREE SYMVU MAPS OF AUSTIN POPULATION



Conformant of Total Population Austin

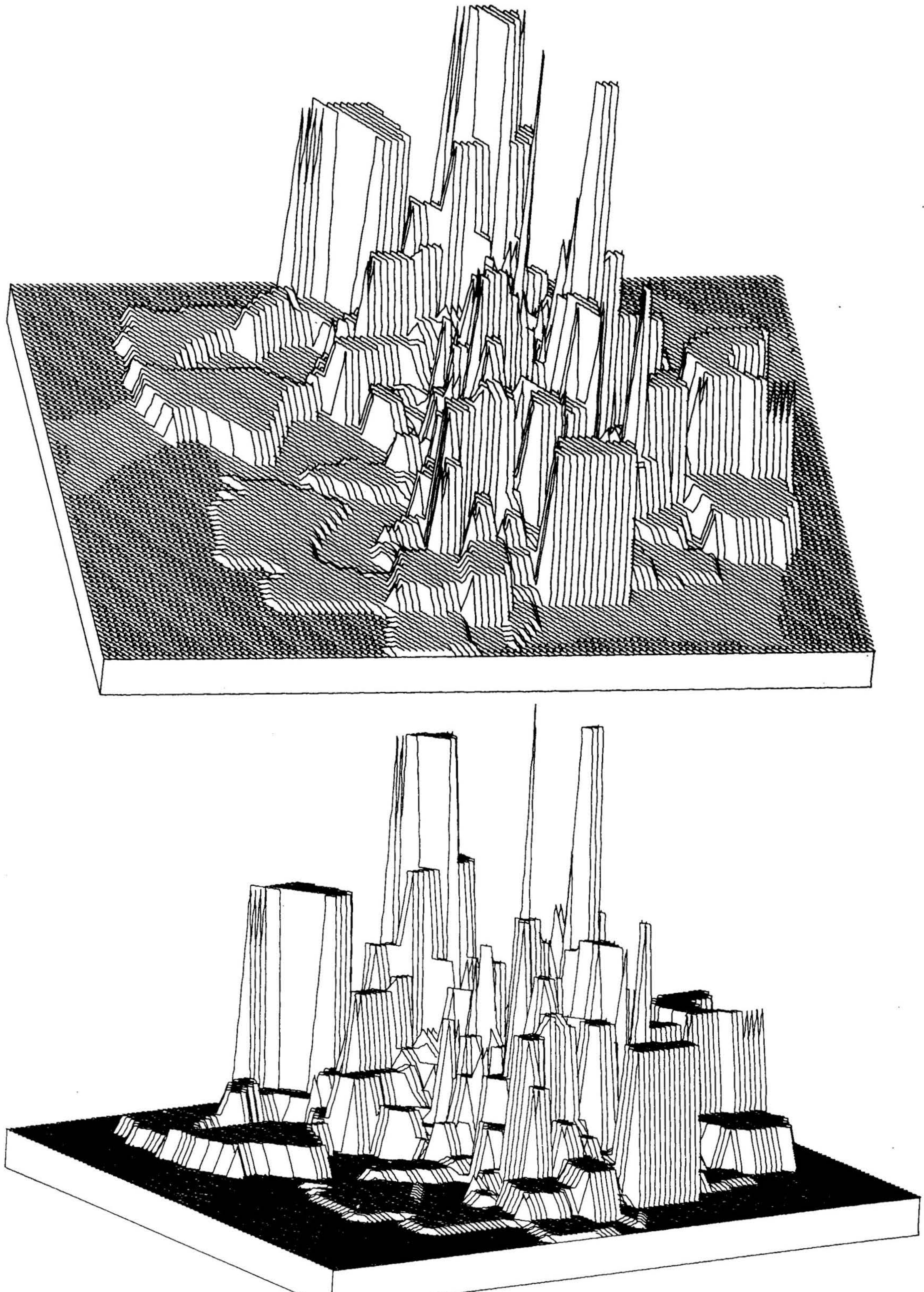


Conformant of Spanish Population Austin



Conformant of Black Population Austin

FIGURE 6-8: TWO CONFORMANT SYMVU MAPS OF EMS CALLS IN AUSTIN*



*The serial zones are weighted by a hypothetical frequency distribution of EMS calls.

FIGURE 6-9: A CALFORM VERSION OF THE EXAMPLE MAP

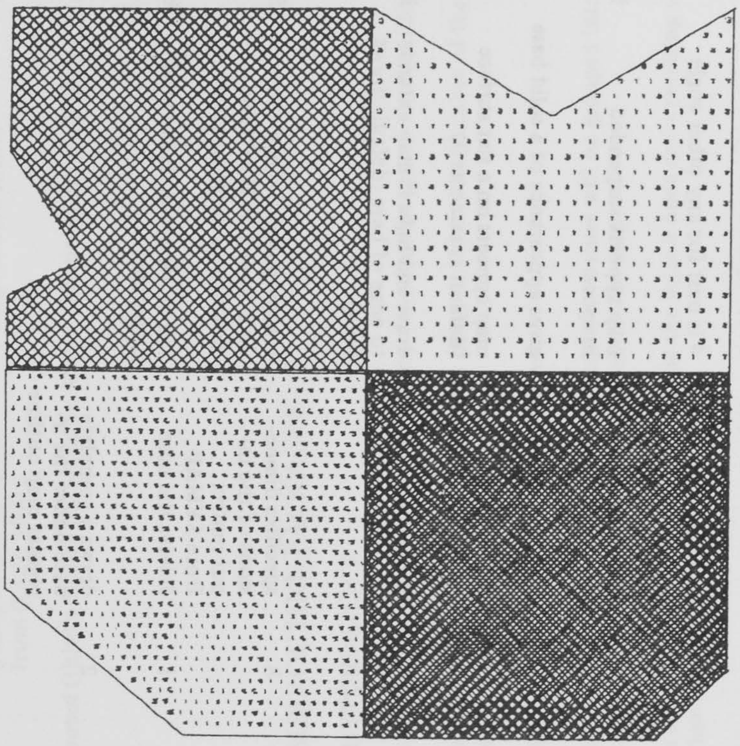


Figure 6-9 is the conformant map drawn on the pen plotter by CALFORM using the subroutine packages described below and derived from the example map of the SYMAP chapter. This CALFORM map can be compared with figure 5-1, the conformant map drawn by SYMAP.

The structure of the CALFORM deck is illustrated in figure 6-10. The deck consists of control cards followed by subroutine packages resembling the SYMAP packages. The control cards for the CALFORM deck are identical to the SYMAP deck, except for the substitution of one card ("PUBLIC,CALFORM,INPUT" for "PUBLIC,SYMAP,INPUT"). The control cards are illustrated in figure 6-11.

The remainder of the CALFORM deck consists of subroutine packages, whose general purposes are described in table 6-2 (4). The following subsections describe these packages in more detail, making reference to figure 5-1, the example map in the SYMAP chapter.

**POINTS Package**

The POINTS package defines coordinates of map reference points. To prepare the POINTS package, the user should follow the instructions of the SYMAP chapter for labeling map coordinate points. Both CALFORM and SYMAP use the same process for identifying points on the map by (y,x)-coordinates, although the format of the POINTS package is different from the A-CONFORMOLINES package of SYMAP.

For CALFORM, the user needs to assign a unique number to each set of (y,x)-coordinates so that each point can be referenced in the POLYGONS package. For example, the point (1.8,1.) in figure 5-1 would be assigned the number 1 in the CALFORM POINTS package. The point (3.,1.) would be designated as 2, the point (3.2,1.) as 3, and so on. All points used to draw the data zone outlines should be numbered in sequence. Any point contained on the outlines of several zones should be assigned only a unique number.

The CALFORM program must be told where to begin writing all titles and headings; consequently, the user may want to create some extra points an inch or two below or beside the map surface as a site for CALFORM to start writing.

The upper limit on the number of total points is four thousand. In any CALFORM run the user has the option of requesting the line printer to list all individual cards of the POINTS package.

## TABLE 6-1: SYMVU OPTIONS

| CARD # | COLUMN (S) | MUST BE USED? | FORMAT | USE | OPTIONS: VALUES | FUNCTION | COMMENTS | NAME |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | yes | integer, right-justified | specifies how direction lines on map are to be drawn | 1 | lines are drawn along columns | 1 is best for viewing azimuth angles between 60 and 120 or 240 and 300, required for 90 or 270 | Linetype |
| | | | | | 2 | lines are drawn along rows | 2 is best for azimuth angles between 330 and 30 or 150 and 210, required for 0 or 180 | |
| | | | | | 4 | lines are drawn along diagonals | 4 is best for any other angle | |
| 1 | 32 | no | integer, right-justified | draws shading on the area outside the map area | 1 | prints nothing | map appears suspended in space | Nozero |
| | | | | | 2 | prints crosshatch | gives appearance of a solid base | |
| | | | | | 0 | prints lines | map appears on a flat surface (default is same as 0) | |
| 1 | 44 | no | integer, right-justified | draws lines connecting map surface to base where edge of map is not already touching the base | 1 | deletes end lines | draw end lines if map extends to edge of base (default draws lines) | Endlin |
| 1 | 45-48 | yes | integer, right-justified | specifies number of vertical lines per inch | 8 | specifies dimensions of the input matrix from SYMAP | always punch 8 when using data from a SYMAP tape, default will cause an error | Symap |
| 1 | 60 | no | integer, right-justified | draws a base on which the map surface rests | 1 | deletes the base | the block option is the most attractive | Base |
| | | | | | 2 | draws a complete base under the irregular map outline | | |
| | | | | | 3 | draws a block ½ inch tall for the map surface to rest on | | |
| 1 | 65-68 | yes | integer, right-justified | specifies where input is coming | 1 | when using data from a SYMAP tape | default will cause an error | Fdata |
| 2 | 1-5 | no | decimal point | specifies elevation of the viewing position above the horizontal plane (altitude) | punch in angle from 0.0 to 360.0 | | default is altitude of 0.00 | Altitude |

(TABLE 6-1, continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | 6-10 | no | decimal point | specifies horizontal angle of viewing (azimuth) | punch in azimuth from 0.00 to 360.0 | default is azimuth of 0.0 | Azimuth |
| 2 | 11-15 | no | decimal point | specifies width of plot | punch width in inches from 0.00 to 10.0 | width—height must not exceed 11 inches, default is 6.00 inches | Width |
| 2 | 16-25 | no | decimal point | specifies height of plot | punch height in inches from 0.1 to 10.0 | default is 3.00 inches | Height |

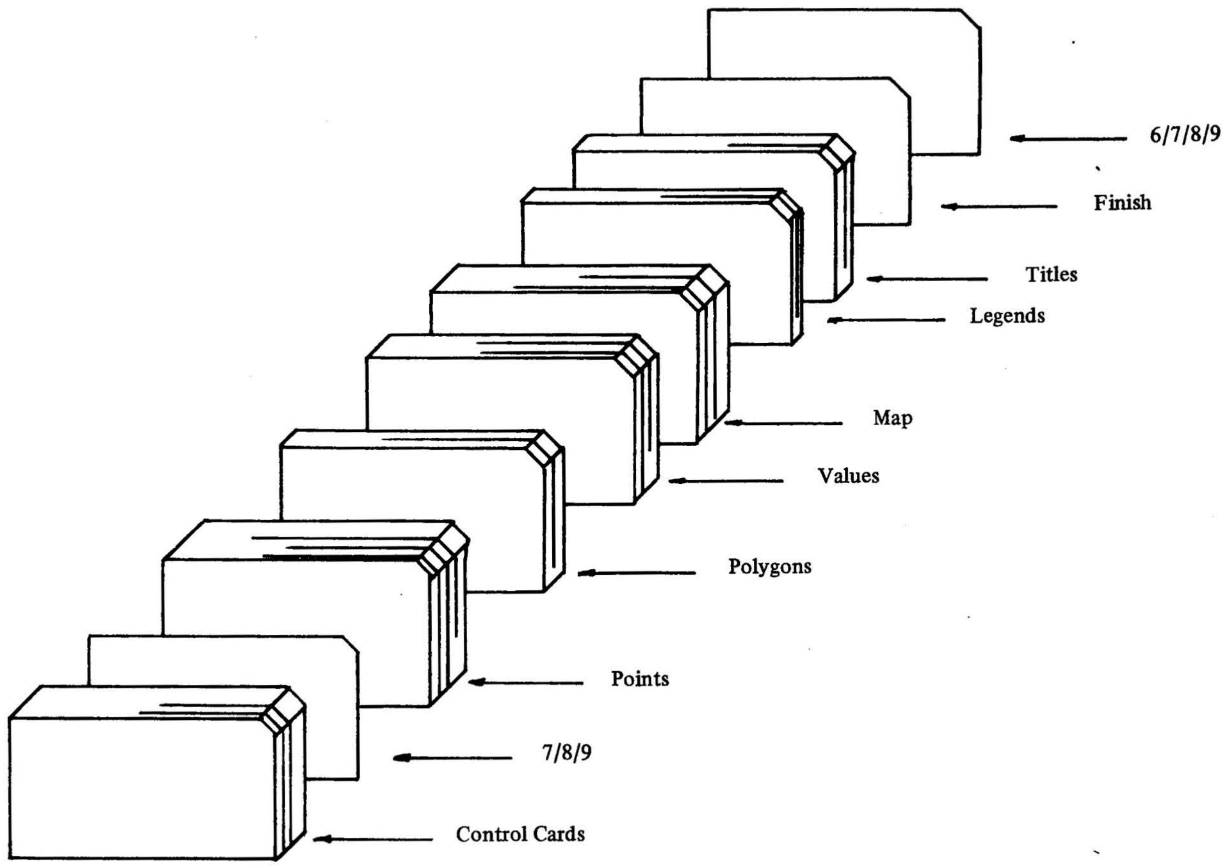
Source: Laboratory for Computer Graphics and Spatial Analysis, *SYMVU Manual* (third edition) (Cambridge, Mass.: Graduate School of Design, Harvard University, 1977).

## TABLE 6-2: CALFORM SUBROUTINE PACKAGES

| NAME | PURPOSE | USER RESPONSIBILITY |
|---|---|---|
| POINTS | Defines coordinates of map reference points | User identifies points by their (x,y)-coordinates and assigns them an identifier number |
| POLYGONS | Defines boundaries of data zones, using the vertices defined in the POINTS package | User describes the outline of the data zones using the identifier number of the corresponding points; user names each zone |
| VALUES | Assigns data values to data zones | User assigns a value to each named data zone |
| MAP | Specifies type of map to be drawn and the various symbolism characteristics | User specifies the ranges of intervals that data zone values will be grouped into, and decides how the different groups will be shaded on the map |
| LEGENDS (optional) | Describes permanent character legends which are to appear on the current map, and if desired on subsequent maps | User can label all maps in a series by defining the legend once and exercising the repeat option thereafter |
| TITLES (optional) | Describes temporary character legends which appear only on the current map | User can also put a distinct label on each map in a series by defining a title for each map |
| LINES (optional) | Describes line segments which are to appear on the current, or subsequent, maps | User can draw physical features across data zones such as highways, rivers, landmarks, etc. |
| FINISH | Closes plotting unit and terminates the program run | User puts card at the end of the program telling computer that mapping is finished |

Source: Laboratory for Computer Graphics and Spatial Analysis, *CALFORM Manual* (version 1.1) (Cambridge, Mass: Graduate School of Design, Harvard University, 1972), p. 1.

FIGURE 6-10: CALFORM DECK STRUCTURE




The user may specify the map scale (the number of inches per unit of the map). If no specification is made, CALFORM will interpret (y,x)-coordinates in inches and produce a map using one inch per unit. For example, figure 6-9 is a CALFORM map that represents figure 5-1. The original map had units of ½ inch. Because the program that produced figure 6-9 did not specify map unit size, one inch units were used; thus the CALFORM map is twice the size of the original.

To create a POINTS package, punch "POINTS" in columns 1 through 6 of the first card. Put an "X" in column 15 if the line print list of the POINTS package is desired in the output. If x-coordinates are in units other than inches, the number of inches per map unit can be punched as a decimal number in columns 21 through 30. Do the same for y-coordinates in columns 31 through 40. If columns 21 through 40 are left blank, the program will use a default value of one inch per unit for the coordinates.

The next cards in the POINTS package are the locations of each point. On each point location card, punch the sequence number (1,2, . . . ,n) as an integer, right-justified in columns 1 through 5. The x- and y-coordinates should appear as decimal numbers in columns 11 through 20 and in columns 21 through 30, respectively. There is only one card for each point. The last card of the POINTS package has "END" in columns 8 through 10. Figure 6-12 shows the first two cards of the POINTS package used to produce 6-9.

**POLYGONS Package**

The POLYGONS package defines the outline of data zones by reference to the unique vertex numbers of the POINTS package. Each data zone (collection of points) must be identified with a distinct four-character alphanumeric name. Following the name, the user lists in sequence the numbers from the POINTS package that outline the polygon data zone. Start at any vertex on the outline of a data zone and go clockwise until the beginning vertex is repeated.

In the example map, the upper left data zone was named NOR1 and its vertices (starting at point A and going clockwise) were numbered 1 through 5. The upper right data

FIGURE 6-11: CONTROL CARDS FOR CALFORM DECK

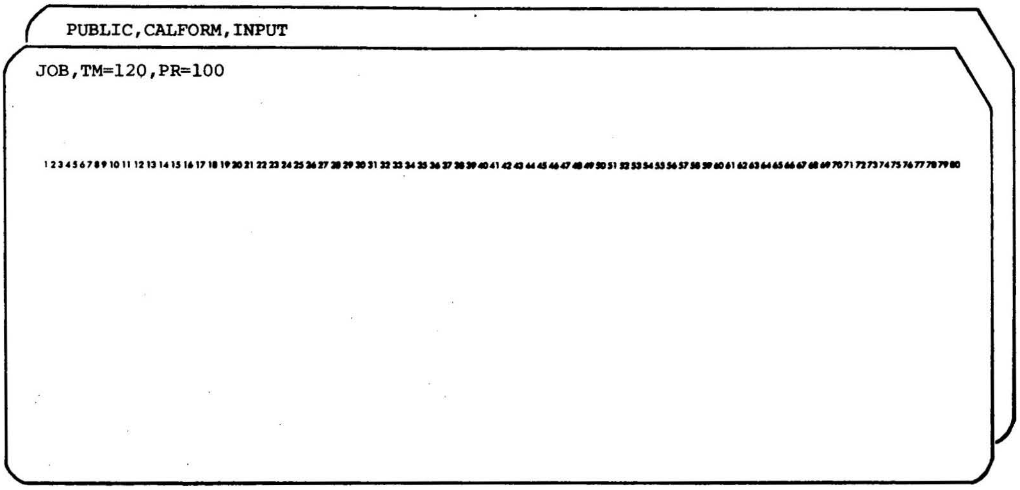
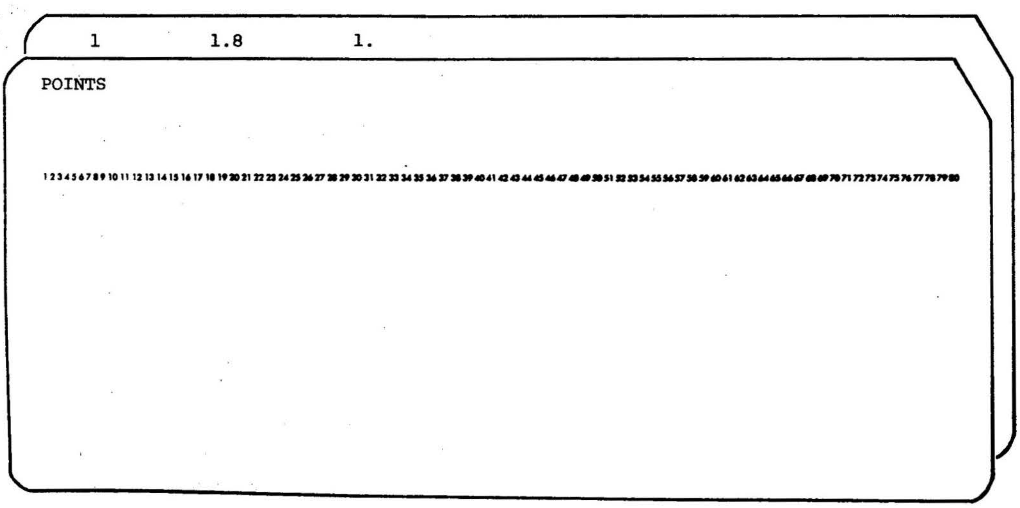



FIGURE 6-12: FIRST TWO CARDS OF THE POINTS PACKAGE



zone was named NOR2; its vertices were numbered 6 through 10 and begin at point B. The two vertices shared by NOR1 and NOR2 are only given one number and are used by each zone in describing their respective outlines. So NOR1 is described by the set of points [1, 2, 3, 4, 5, and 1]. NOR2 is described by the set [2, 6, 7, 8, 9, 10, 3, and 2]. To prepare a card indicating the outline of a data zone, punch the alphanumeric four-character name for the zone in columns 1 through 4. The sequential point numbers in the polygon are punched in columns 11 through 15, the second in columns 16 through 20, etc. If the listing of points does not fit on one card, prepare as many cards as are necessary in a similar fashion. Punch (a) the polygon's identifier name in columns 1 through 4 on the second card, (b) a sequence identifier in column 5 (optional), and (c) the remainder of the points (in 5-column fields) in columns 11 through 80. Figure 6-13 illustrates the first two cards of the POLYGONS package used to produce figure 6-9.

The list of points is concluded by punching "9999" right-justified in a five-column field. If the last point is punched in columns 76 through 80, then a continuation card must be punched for the 9999. Omission of the 9999 code will generate a major program error. Punch "END" in columns 8 through 10 on the last POLYGONS package card.

### VALUES Package

The VALUES package assigns a data value to each zone described in the POLYGONS package. There must be one VALUES card for each zone, and VALUES cards must appear in the same order as the cards of the POLYGONS package. If no VALUES package exists, the CALFORM program will draw only data zone outlines without map zone shading.

In the example SYMAP, zone NOR1 should be assigned the value of 1509 and NOR2 should be assigned the value of 2347. The other two zones, names SOU1 and SOU2, can be assigned values of 2674 and 1302, respectively.

A VALUES package used in the CALFORM example is shown in figure 6-14. The first card of the VALUES package cards has "VALUES" punched in columns 1 through 6. An "X" in column 15 will suppress the listing of the package on the line printout. The next cards assign values to each data zone. On each card the four-character name of the data zone is punched in columns 1 through 4. The corresponding data value should be punched as a decimal number in columns 11 through 20. The last card of the values card has "END" punched in columns 8 through 10.

### MAP Package

The MAP package tells the program how to draw the map. The user specifies intervals for data values and shading symbolism for intervals. The user can specify the intervals into which the data can be grouped and shading patterns for each interval. One card is punched for each interval, including an identifier number and an upper and a lower bound of the value interval.*

The CALFORM program does provide standard shadings—one for each interval up to a limit of ten intervals. The fewer the number of intervals, the more distinct the shading patterns. The user has the option of printing a shading key.

Both standard shading and user-specified intervals were employed to generate figure 6-9. Four intervals were defined as 1, 2, 3, and 4 with lower and upper bounds of 1000 to 1499, 1500 to 1999, 2000 to 2499, and 2500 to 2999.

To punch the MAP package, punch "MAP" in columns 1 through 3 of the first card. An "X" in column 15 suppresses the outlining of the data zones with a thin line. The number of desired intervals is punched as an integer number right-justified in columns 9 and 10. If no number is punched, the CALFORM default is five intervals. An "S" in column 8 will specify standard shading. The letters "USER" in columns 17 through 20 denote user specified intervals.

A set of cards to define the intervals follow the first card. Each interval should be identified by an integer punched right-justified in columns 4 and 5. The lower and upper bounds of the interval range are punched as decimal numbers in columns 11 through 20, and 21 through 30, respectively.

If "KEY" is punched in columns 8 through 10 on the final map package card, a "box" describing a shading key will be drawn. The number of significant decimal places for the interval values should be punched as a decimal number in columns 51 through 60; otherwise, decimal places will be truncated. For suppression of the key, punch "NOKEY" in columns 6 through 10. The first two MAP package cards used in the CALFORM example are shown in figure 6-15.

### LEGENDS Package and TITLES Package

A LEGENDS package places headings or titles on CALFORM maps. Headings can be written directly beside the map or directly on it. The user specifies the point to be used as the lower left-hand corner of the legend. Legends can be up to forty characters long. CALFORM automatically makes the characters 0.2 inches tall and writes them parallel to the horizontal axis of the plot, unless otherwise instructed by the user. Character legends defined for use in one map may be used on subsequent maps by invoking a "repeat" option on the legends card. This repeat is used when more than one map is being plotted on one run and the same legend appears on all the maps. Legends are drawn by the plotter over what is already on the paper, be it blank space

*Detailed instructions on interval types not used in this chapter are found in reference (5).

FIGURE 6-13: FIRST TWO CARDS OF THE POLYGONS PACKAGE

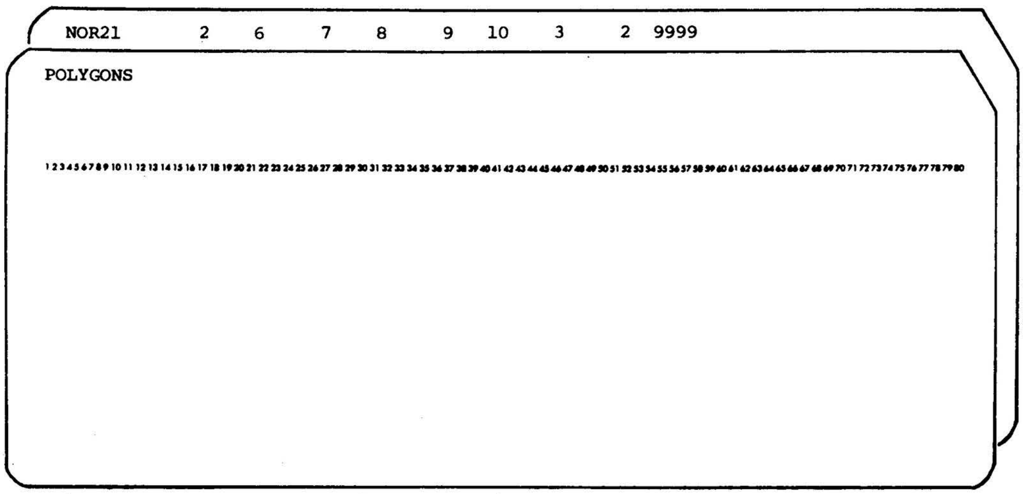



FIGURE 6-14: VALUES PACKAGE

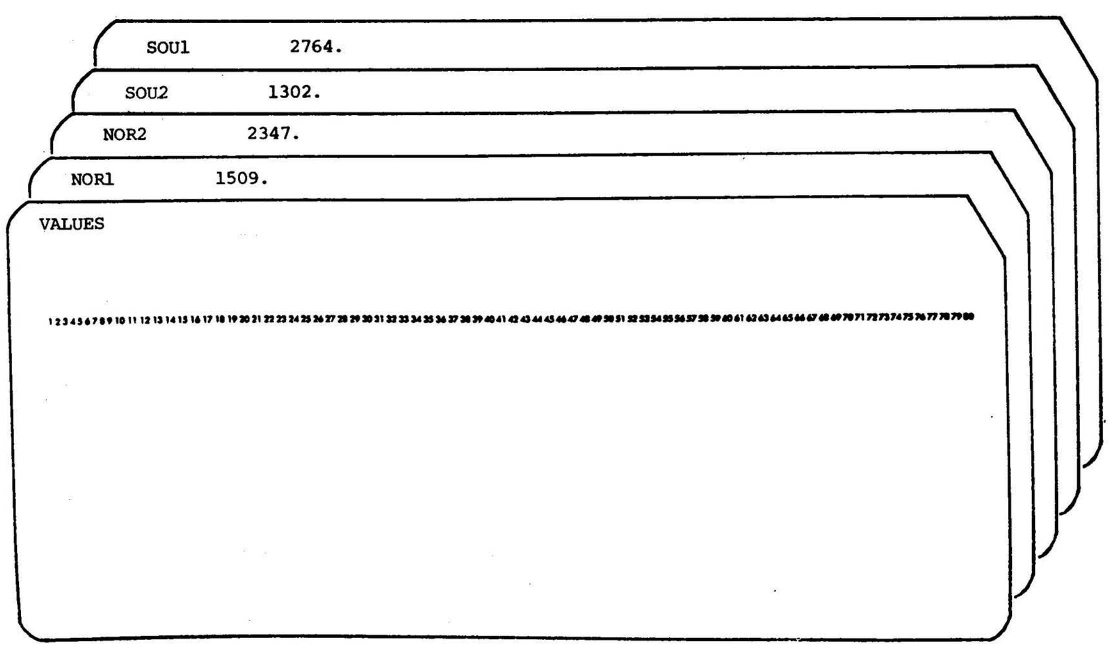


FIGURE 6-15: FIRST TWO MAP PACKAGE CARDS

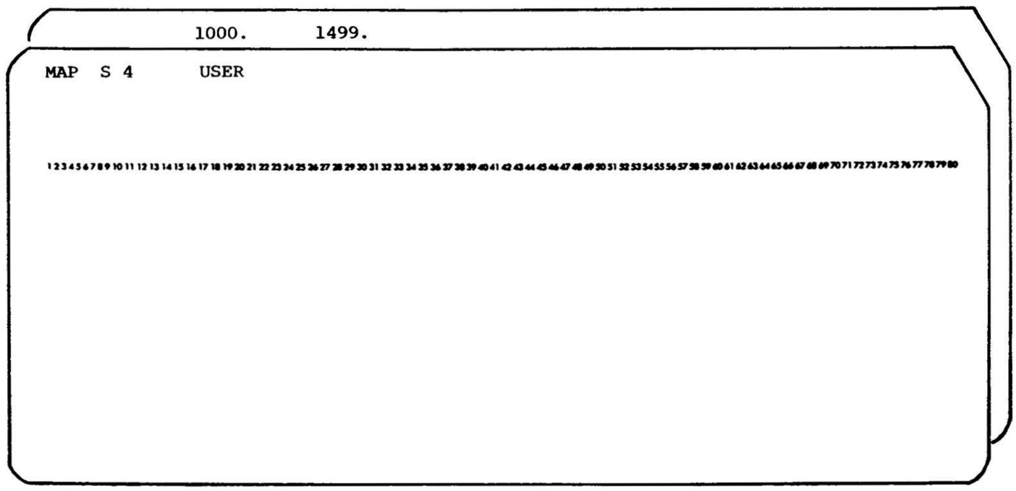
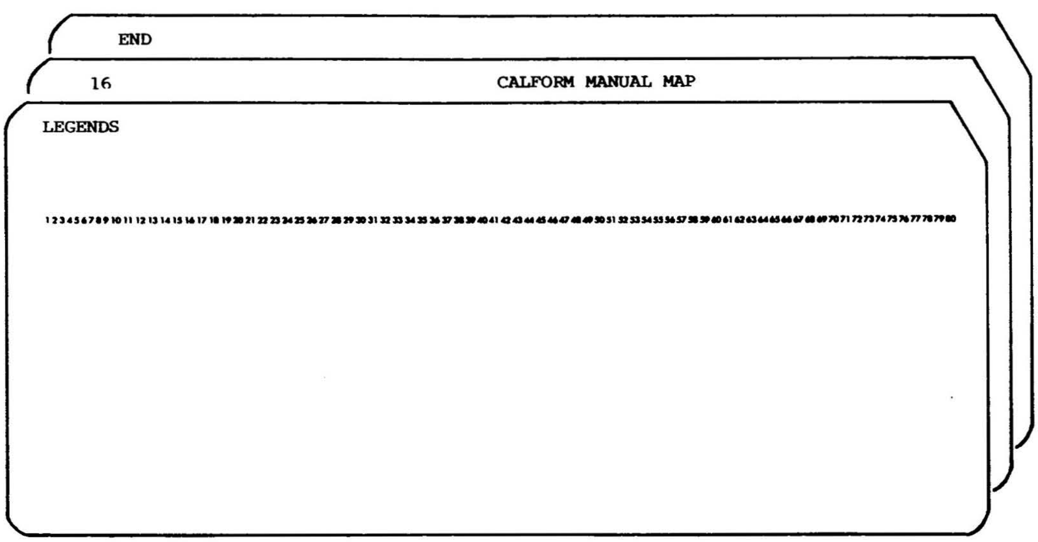



FIGURE 6-16: LEGENDS PACKAGE



or map. If the starting point happens to be a point on a map, then the legend will appear on the map surface.

For example, a LEGENDS package was used in the program that drew figure 6-9.* An extra point was defined beyond the map surface in the POINTS package [point (2.,6.)] and numbered as point 16. A LEGENDS card told the plotter to write "CALFORM MANUAL MAP" starting at point 16.

The word "LEGENDS" should be punched on the first LEGENDS card in columns 1 through 7. If a previously defined legend is to be repeated, then punch "11" in columns 9 and 10. To suppress a listing of the LEGENDS package, punch "X" in column 15. On a second card, columns 1 through 5 are used to specify the sequence number of the point to be used as the lower left-hand corner of the legend. The legend is punched in columns 41 through 80. The desired character height in vertical map units is punched as a decimal number in columns 11 through 20. The default value is 0.2 inches high. A decimal number in columns 21 through 30 specifies the degrees the legend is to be inclined from the x-axis. The default value is 0.0 degrees. If no repeat option is punched in the first card, the user must define the legends to be drawn on each map. The word "END" is punched in columns 8 through 10 of the last card. Figure 6-16 illustrates the LEGENDS cards used to generate figure 6-9.

The TITLES package is similar to the LEGENDS package, except that "TITLES" is punched on the first card and there is no repeat option. Titles defined in such a package will only appear on one map. If several different titles are desired for several maps, then the user would include a TITLES package for each map.

*The legend does not, however, appear on figure 6-9.

### FINISH Package

The FINISH package consists of one card and must be the last card in any CALFORM run. The word "FINISH" should appear in columns 1 through 6.

### USE OF SYMVU AND CALFORM MAPS OF AUSTIN

It is not necessary to be a computer programmer to use SYMVU and CALFORM. Once a map coordinate grid is prepared, it is easy to create the other data packages.

The cost of producing a SYMVU map depends upon the complexity of the map and its size. Nine different single panel (9" by 3" or 9" by 6") maps of the 358 Austin serial zones were generated by project members. The average time per SYMVU map was 63.671 seconds on the University of Texas at Austin CDC 6400/6600 computer system. A portion of the cost is related to the running of the SYMAP program and storing the results on tape. The average time cost related to the drawing of the SYMVU maps was 41.777 seconds.

Due to limited time and a lack of proper equipment, the EMS Policy Research Project did not produce CALFORM maps using city of Austin data. To produce these maps, it would have been necessary to use equipment to "digitize" map coordinate points into the proper format, and project members were unable to obtain a digitizer.

# References

(1) Laboratory for Computer Graphics and Spatial Analysis, *SYMVU Manual* (third edition) (Cambridge, Mass.: Graduate School of Design, Harvard University, 1977).

(2) *Ibid.*

(3) Laboratory for Computer Graphics and Spatial Analysis, *CALFORM Manual* (version 1.1) (Cambridge, Mass.: Graduate School of Design, Harvard University, 1972).

(4) *Ibid.*, p. 1.

(5) *Ibid.*

# Appendices

Appendix A is a list of the bibliographic materials collected by the Emergency Medical Services Policy Research Project members during 1978-79. This list includes books, articles, and reports on location analysis, location analysis related to health or emergency services, emergency medical services, and computer mapping. The list is not intended to be a definitive bibliography, but only a collection of some useful references.

Appendix B is a listing of the output from the CALL/CZSR computer program run. The pages reproduce output from the census track analysis described in chapter four.

# Appendix A

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# Appendix B

## AN ILLUSTRATION OF CALL/CZSR OUTPUT

This appendix reproduces pages from CALL/CZSR program output from the "census track" analysis presented in chapter four.

# EXAMPLE CALL/CZSR PROGRAM OUTPUT

```
                         A S S I G N M E N T   O F   A M B U L A N C E   L O C A T I O N S            PAGE  1


LAMDA = 35.00 LIMIT=  999  CARE =  15.00 TRSFR  =  20.00
 NAMB =     5 NHOSP =     1 NDIST =    34 NFRAC =     30 TRANS =   .63

HOSPITAL       LOC IN DIST #

BRACKENRIDGE         7

 AMB  TYPE      LOC  IN  DIST
  1    1              1
  2    1              9
  3    1             14
  4    1             23
  5    1             31

  KEY

  1    2    2    3    3    3    4    4    5    6
  6    6    6    7    8    8    8    8    8    8
  8    8    8    8    8    9    9    9    9    9
 10   10   10   11   13   13   13   14   14   14
 15   16   17   17   17   19   19   20   22   23
 24   25   27   28   28   29   29   29   29   29
 29   31   31   32

 NEVAL =   28   SP =     4.725   KK =  0    KOUNT =   1

 CURRENT AMBULANCES LOCATIONS     2    8    31   30   31

 NEVAL =   58   SP =     4.230   KK =  1    KOUNT =   2

 CURRENT AMBULANCES LOCATIONS     3    8    31   30   31

 NEVAL =   87   SP =     3.906   KK =  4    KOUNT =   3

 CURRENT AMBULANCES LOCATIONS     3    8    31   29   31

 NEVAL =  118   SP =     3.906   KK =  4    KOUNT =   4

 CURRENT AMBULANCES LOCATIONS     3    8    31   29   31
```

```
                         A S S I G N M E N T   O F   A M B U L A N C E   L O C A T I O N S            PAGE  2


                                         S Y S T E M   P A R A M E T E R S


                          MEAN ON SCENE CARE TIME (MIN)                       15.00

                          MEAN TRANSFER TIME AT HOS7ITAL (MIN)                20.00

                          PROBABILITY OF TRANSPORT                              .63

                          MEAN NUMBER OF INCIDENTS PER DAY                    35.00

                          NUMBER OF AMBULANCES                                    5

                          NUMBER OF HOSPITALS                                     1

                          NUMBER OF DISTRICTS                                    34

                          NUMBER OF SEARCH POINTS EVALUATED                     119
```

A S S I G N M E N T   O F   A M B U L A N C E   L O C A T I O N S   PAGE 3

H O S P I T A L

| HOSPITAL | LOCATED IN DIST | CASES PER DAY | PERCENT OF CASES |
|---|---|---|---|
| BRACKENRIDGE | 7 | 22.050 | 100.00 |

A S S I G N M E N T   O F   A M B U L A N C E   L O C A T I O N S   PAGE 4

A M B U L A N C E S

| | INITIAL LOCATION | | | | | FINAL LOCATION | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| AMBULANCE | IN DIST | MEAN RESPONSE | CALLS PER DAY | PERCENT OF CALLS | PERCENT UTILIZED | IN DIST | MEAN RESPONSE | CALLS PER DAY | PERCENT OF CALLS | PERCENT UTILIZED |
| 1 | 1 | 12.95 | 4.37 | 12.48 | 16.20 | 3 | 13.45 | 5.55 | 15.87 | 20.79 |
| 2 | 9 | 13.47 | 7.58 | 21.65 | 28.38 | 8 | 12.03 | 6.39 | 18.25 | 23.28 |
| 3 | 14 | 14.34 | 4.76 | 13.61 | 18.12 | 31 | 12.17 | 10.37 | 29.64 | 37.91 |
| 4 | 23 | 8.68 | 7.05 | 20.13 | 24.05 | 29 | 8.04 | 5.86 | 16.76 | 19.75 |
| 5 | 31 | 10.49 | 11.25 | 32.13 | 39.79 | 31 | 12.17 | 6.82 | 19.49 | 24.93 |

A S S I G N M E N T   O F   A M B U L A N C E   L O C A T I O N S   PAGE 5

S Y S T E M   P E R F O R M A N C E

| NUMBER OF BUSY AMBULANCES | INITIAL LOCATION PROBABILITY | INITIAL LOCATION MEAN RESPONSE (MIN) | FINAL LOCATION PROBABILITY | FINAL LOCATION MEAN RESPONSE (MIN) |
|---|---|---|---|---|
| 0 | .3184 | 4.317 | .3389 | 3.228 |
| 1 | .3644 | 5.878 | .3667 | 3.887 |
| 2 | .2085 | 8.000 | .1984 | 4.465 |
| 3 | .0796 | 11.665 | .0715 | 5.765 |
| 4 | .0228 | 17.355 | .0194 | 6.985 |
| 5 | .0064 | 20.409 | .0051 | 20.409 |

| STATISTIC | INITIAL | FINAL |
|---|---|---|
| MEAN RESPONSE (MIN) | 6.638 | 3.906 |
| MEAN TIME TO HOSPITAL (MIN) | 62.047 | 59.465 |
| MEAN RETRIEVAL TIME (MIN) | 20.409 | 20.409 |
| MEAN SERVICE TIME (MIN) | 47.091 | 44.514 |
| MEAN NUMBER IN SYSTEM | 1.145 | 1.082 |

ASSIGNMENT OF AMBULANCE LOCATIONS PAGE 6

DISTRIBUTION OF RESPONSE

| CLASS INTERVAL | INTIAL PROBABILITY | INTIAL CUMULATIVE PROBABILITY | FINAL PROBABILITY | FINAL CUMULATIVE PROBABILITY |
|---|---|---|---|---|
| 0 - 1 | .1482 | .1482 | .2560 | .2560 |
| 1 - 2 | 0.0000 | .1482 | 0.0000 | .2560 |
| 2 - 3 | .0262 | .1744 | .0803 | .3363 |
| 3 - 4 | .0312 | .2056 | .1729 | .5091 |
| 4 - 5 | .1463 | .3519 | .0957 | .6049 |
| 5 - 6 | .1341 | .4860 | .1172 | .7221 |
| 6 - 7 | .0570 | .5430 | .1024 | .8244 |
| 7 - 8 | .1124 | .6554 | .0302 | .8546 |
| 8 - 9 | .0489 | .7043 | .0228 | .8774 |
| 9 - 10 | .0706 | .7748 | .0363 | .9137 |
| 10 - 11 | .0152 | .7900 | .0281 | .9418 |
| 11 - 12 | .0715 | .8616 | .0176 | .9594 |
| 12 - 13 | .0283 | .8899 | .0064 | .9658 |
| 13 - 14 | .0489 | .9388 | .0132 | .9790 |
| 14 - 15 | .0063 | .9451 | .0025 | .9814 |
| 15 - 16 | .0044 | .9495 | .0068 | .9883 |
| 16 - 17 | .0111 | .9606 | .0059 | .9942 |
| 17 - 18 | .0040 | .9646 | .0002 | .9944 |
| 18 - 19 | .0033 | .9679 | 0.0000 | .9944 |
| 19 - 20 | .0093 | .9772 | 0.0000 | .9944 |
| 20 - 21 | .0007 | .9779 | 0.0000 | .9944 |
| 21 - 22 | .0050 | .9829 | 0.0000 | .9944 |
| 22 - 23 | .0015 | .9844 | .0004 | .9947 |
| 23 - 24 | .0021 | .9865 | .0001 | .9948 |
| 24 - 25 | .0006 | .9871 | 0.0000 | .9948 |
| 25 - 26 | .0007 | .9879 | 0.0000 | .9948 |
| 26 - 27 | .0017 | .9896 | 0.0000 | .9948 |
| 27 - 28 | .0006 | .9902 | 0.0000 | .9948 |
| 28 - 29 | .0014 | .9916 | .0001 | .9949 |
| 29 - 30 | .0020 | .9936 | 0.0000 | .9949 |
| MAXIMUM REWPONSE TIME | 43.0000 | | 28.0000 | |

ASSIGNMENT OF AMBULANCE LOCATIONS PAGE 7

FIRST-IN AMBULANCE ARRAY

| DIST. NO. | AMBULANCE NUMBER (FIRST-IN LEFT TO RIGHT) | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 3 | 5 | 4 | 2 |
| 2 | 1 | 3 | 5 | 4 | 2 |
| 3 | 1 | 2 | 3 | 5 | 4 |
| 4 | 1 | 2 | 3 | 5 | 4 |
| 5 | 1 | 3 | 5 | 2 | 4 |
| 6 | 1 | 3 | 5 | 2 | 4 |
| 7 | 3 | 5 | 1 | 2 | 4 |
| 8 | 2 | 4 | 3 | 5 | 1 |
| 9 | 2 | 3 | 5 | 4 | 1 |
| 10 | 3 | 5 | 2 | 4 | 1 |
| 11 | 3 | 5 | 2 | 1 | 4 |
| 12 | 3 | 5 | 1 | 2 | 4 |
| 13 | 3 | 5 | 4 | 1 | 2 |
| 14 | 3 | 5 | 4 | 1 | 2 |
| 15 | 3 | 5 | 4 | 2 | 1 |
| 16 | 1 | 3 | 5 | 4 | 2 |
| 17 | 1 | 3 | 5 | 4 | 2 |
| 18 | 1 | 3 | 5 | 4 | 2 |
| 19 | 1 | 3 | 5 | 4 | 2 |
| 20 | 1 | 3 | 5 | 4 | 2 |
| 21 | 1 | 3 | 5 | 4 | 2 |
| 22 | 3 | 5 | 4 | 1 | 2 |
| 23 | 1 | 3 | 5 | 4 | 2 |
| 24 | 4 | 1 | 3 | 5 | 2 |
| 25 | 1 | 3 | 5 | 4 | 2 |
| 26 | 3 | 5 | 1 | 4 | 2 |
| 27 | 3 | 5 | 4 | 1 | 2 |
| 28 | 1 | 4 | 3 | 5 | 2 |
| 29 | 4 | 2 | 3 | 5 | 1 |
| 30 | 4 | 1 | 3 | 5 | 2 |
| 31 | 3 | 5 | 2 | 4 | 1 |
| 32 | 5 | 3 | 4 | 2 | 1 |
| 33 | 3 | 5 | 4 | 1 | 2 |
| 34 | 3 | 5 | 4 | 1 | 2 |

ASSIGNMENT OF AMBULANCE LOCATIONS PAGE 8

RESPONSE TIME BY DISTRICT

| DIST. NO. | MINIMUM RESPONSE (MIN) | MEAN RESPONSE (MIN) |
|---|---|---|
| 1 | 8.00 | 10.44 |
| 2 | 3.00 | 6.03 |
| 3 | 0.00 | 4.68 |
| 4 | 2.00 | 3.64 |
| 5 | 3.00 | 5.20 |
| 6 | 5.00 | 5.88 |
| 7 | 5.00 | 5.32 |
| 8 | 0.00 | 2.67 |
| 9 | 3.00 | 3.22 |
| 10 | 2.00 | 3.20 |
| 11 | 4.00 | 4.68 |
| 12 | 6.00 | 6.68 |
| 13 | 5.00 | 6.89 |
| 14 | 3.00 | 5.48 |
| 15 | 2.00 | 4.16 |
| 16 | 8.00 | 10.54 |
| 17 | 6.00 | 9.08 |
| 18 | 4.00 | 7.50 |
| 19 | 6.00 | 8.32 |
| 20 | 8.00 | 8.31 |
| 21 | 15.00 | 16.38 |
| 22 | 9.00 | 12.16 |
| 23 | 10.00 | 12.20 |
| 24 | 13.00 | 13.78 |
| 25 | 9.00 | 11.46 |
| 26 | 11.00 | 11.75 |
| 27 | 6.00 | 9.11 |
| 28 | 4.00 | 6.18 |
| 29 | 0.00 | 4.31 |
| 30 | 7.00 | 8.98 |
| 31 | 0.00 | 2.67 |
| 32 | 3.00 | 4.32 |
| 33 | 9.00 | 10.21 |
| 34 | 7.00 | 10.14 |

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