DETERMINING THE TRAVEL CHARACTERISTICS OF EMERGENCY SERVICE VEHICLES

PREPARED FOR THE OFFICE OF POLICY DEVELOPMENT AND RESEARCH, DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

JACK HAUSNER

R-1687-HUD
APRIL 1975
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ADDENDUM TO R-1687-HUD

"Determining The Travel Characteristics of Emergency Service Vehicles" by Jack Hausner

On page 14, the format of the data card for each response should be:

<table>
<thead>
<tr>
<th>Column(s)</th>
<th>Information</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Blank</td>
<td>3X</td>
</tr>
<tr>
<td>4-7</td>
<td>Odometer reading before the response</td>
<td>F4.1</td>
</tr>
<tr>
<td>8-11</td>
<td>Odometer reading after the response</td>
<td>F4.1</td>
</tr>
<tr>
<td>12-13</td>
<td>Travel time: minutes</td>
<td>I2</td>
</tr>
<tr>
<td>14-15</td>
<td>Travel time: seconds (0-60)</td>
<td>I2</td>
</tr>
<tr>
<td>16-19</td>
<td>Alarm box number (may be left blank unless Part 2 output is desired)</td>
<td>I4</td>
</tr>
<tr>
<td>20-23</td>
<td>Time response was made (using a 24-hour clock; e.g., 6:51 P.M. is punched as 1851, etc.)</td>
<td>I4</td>
</tr>
<tr>
<td>24</td>
<td>Weather condition (may be left blank)</td>
<td>A1</td>
</tr>
<tr>
<td>25</td>
<td>Traffic condition (may be left blank)</td>
<td>A1</td>
</tr>
<tr>
<td>26</td>
<td>Due (may be left blank unless separate analyses are requested for first- and second-due responses)</td>
<td>I1</td>
</tr>
<tr>
<td>27</td>
<td>Blank</td>
<td>1X</td>
</tr>
<tr>
<td>28</td>
<td>&quot;Usual route followed&quot; indicator (may be left blank).</td>
<td>A1</td>
</tr>
</tbody>
</table>
This Report describes the mechanics of a data-gathering experiment and a computer program that can be used to help analyze the experimental results. The experiment is designed to gather data to determine the relationship of travel time and travel speed to travel distance and time of day for emergency service vehicles responding to calls for service within a municipality. The resulting empirical travel characteristics are important input parameters for many mathematical models that can be used to study the deployment problems of municipal emergency service systems.

The program described in this Report has already been used to analyze the data collected in travel time experiments in several cities, including: New York City; Trenton, New Jersey; Jersey City, New Jersey; Yonkers, New York; and Wilmington, Delaware.*

The program was initially developed under a contract with the Fire Department of New York, which had as its major purpose the improvement of deployment of the Department's fire-fighting equipment. Modification of the program to generalize it for use in other cities, and to extend its capabilities, was supported by a contract with the Office of Policy Development and Research of the United States Department of Housing and Urban Development (HUD). Among the objectives of the HUD contract are the development, field testing, and documentation of methods to improve allocation procedures in municipal emergency service agencies throughout the United States. This Report is part of a series of HUD-funded reports that describe several different methods for analyzing the deployment of emergency service vehicles and document their application in a number of cities.

* An analysis of the results of the New York City experiment is given in Measuring the Travel Characteristics of New York City's Fire Companies, by Peter Kolesar and Warren Walker (R-1449-NYC, The New York City-Rand Institute, April 1974).
SUMMARY

Travel time, defined as the time from the dispatch of an emergency unit until its arrival at the scene of an incident, is an important measure of the performance of an emergency service. However, most municipalities know very little about how quickly their emergency units respond and how travel times and travel speeds vary with response distance, time of day, and region of the city.

This Report discusses a procedure for determining the travel characteristics of emergency service vehicles. It involves (1) conducting an experiment to collect data on a large number of responses and (2) analyzing the resulting data using a computer program that has been given the name "Travel Time Analysis Program." Instructions and data collection forms are provided for conducting the experiment, and the computer program is described, including the input data and output reports.

The program summarizes the experimental data, and estimates the relationship between travel time and travel distance by fitting several curves to the data. The effects of the time of day and weather and traffic conditions on travel speed are also examined.

The latter part of this Report serves as a user's manual for the Travel Time Analysis Program, and includes a program listing, a description of the input data, a detailed explanation of the output, and a sample printout.
ACKNOWLEDGMENTS

The author is indebted to Peter Kolesar and Warren Walker for their many ideas that are embodied in this Report, to Peter Dormont for refining the program, and to Ruth Macy for her editing of the manuscript.
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I. INTRODUCTION

Information on the travel characteristics of emergency vehicles, such as fire engines, police cars, and ambulances, plays a vital role in the analysis and evaluation of the performance of these emergency services. One of the most important indicators of the performance of any emergency service system is response time, the time interval between the receipt of a call for service and the arrival of an emergency unit at the scene of the incident. Since response time can have a significant impact on the loss of life and property at an emergency, it is used as a principal measure of effectiveness in many models developed for analyzing the deployment of emergency vehicles. Surprisingly, in many municipalities very little is known about how quickly their emergency units respond and how response times and travel velocities vary with distance, time of day, and region of the city.

Response time can be divided into three components—dispatch time, turnout time, and travel time. Dispatch time is the time elapsed between the receipt of a call for service and the dispatch of the service unit. Turnout time, which is a factor only if the emergency unit is not immediately ready to respond when dispatched, is the time elapsed between the dispatch of a unit to a call for service and the departure of the emergency unit for the scene. This component is relatively constant, since departure preparations generally consume the same amount of time regardless of the type of call. The third component of response time is travel time, or the time it takes for the emergency unit to arrive at the incident after it begins its response.

In this Report we discuss a computer program that helps to determine the travel parameters that can be used to estimate travel times in a region. With the use of various regression methods, several curves are fitted to experimental data to find the relationship between travel time and travel distance in the region. The computer program that computes the regression parameters also performs additional calculations using the experimental data. This Report serves as a user's manual for the computer program, which has been given the name "Travel Time Analysis Program." It describes the input data and how it is collected and explains the program's output reports. Several techniques for estimating travel distance are also reviewed.

*Throughout this Report, travel "velocity" is synonymous to travel "speed."
Once the travel parameters for a region have been determined, it is easy to estimate the time required for an emergency unit to travel a given distance within that region. The travel time estimates can then be used to evaluate the effectiveness of alternate deployment policies, to compare the performance of the emergency service agency over several regions of a city, or to provide planners and administrators with an idea of the quality of emergency service being provided to the citizens of their municipality. Dispatch time and turnout time, which are generally constant throughout a municipality and for different deployment policies, can be estimated independently. These estimates can then be added to the travel time to produce an estimate of the response time.

**ESTIMATING TRAVEL DISTANCE**

Travel distance is much easier to estimate than is travel time. As a result, many emergency service standards (for example, those developed for fire departments by the Insurance Services Office) are based on distance (D). There are many simple methods that can be used to estimate D for a specific response. For example, the distance can be measured on a map by following the actual route of response. An easy method to estimate distances by computer involves superimposing a rectangular grid on a map of the city and storing this grid in the computer. Then, any point in the city, such as a street intersection, firehouse, or fire alarm box, can be identified by a pair of grid coordinates \((x, y)\). The distance between two points specified by \((x_1, y_1)\) and \((x_2, y_2)\) can then be estimated using a function of these coordinates. For example:

1. the Euclidean distance (the straight line distance between the two points) is given by \(D_E = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}\);
2. the right angle distance (the distance calculated as if all streets in the city intersected at right angles) is given by \(D_R = |x_2 - x_1| + |y_2 - y_1|\).

Another distance measure used in the analysis of deployment policies is the average response distance to emergencies occurring in a large region. Kolesar and Blum [7] show that the average response distance is directly proportional to the square root of the area of the region and inversely proportional to the average number of available service units.

*Figures in square brackets identify references listed at the end of this document.*
in the region. This model is termed the "square root law" because of its mathematical form.

Specifically, for any given region $i$, let

$$A_i = \text{physical area of region};$$
$$N_i = \text{number of fire stations with units of given type (engines or ladders) in region};$$
$$\lambda_i = \text{average hourly alarm rate in region during period of interest};$$ and
$$ES_i = \text{expected total operational time for all units of given type at average incident in region (in hours)}.\star$$

According to the square root law, the expected distance traveled by the closest available unit of the given type to an alarm in the region can be approximated by

$$ED_i = k_i \sqrt{\frac{A_i}{N_i - \lambda_i ES_i}},$$

where $k_i$ is a constant of proportionality which depends on the street configuration and location of firehouses in the region. The product $\lambda_i ES_i$ represents the expected number of units busy at alarms in the region, and, therefore, $N_i - \lambda_i ES_i$ represents the expected number of units available to respond to alarms.

**FOUR FUNCTIONS FOR ESTIMATING TRAVEL TIME FROM TRAVEL DISTANCE**

The above discussion is concerned with techniques for estimating travel distance. The factor that determines loss of life and property at an emergency incident, however, is the time elapsed until an emergency unit reaches the scene. Thus, we are interested in estimating the time, $T$, required for an emergency vehicle to travel a given distance, $D$, where $D$ may be known or may be estimated by using one of the above techniques.

In 1971, an experiment was conducted by the Fire Department of New York in which data were collected on over 1700 responses made by fire-fighting apparatus to actual alarms. Details of the experiment and its analysis can be found in [8]. Analysis of these data and data from similar experiments conducted in other cities revealed that there were four useful functions that, 

\*By "operational time" we mean the time consumed by all the various activities of all units related to "servicing" the incident, including response time, search, extinguishment, overhaul, etc.
in different situations, provided good ways of approximating the expected travel time for an emergency unit to travel a given distance. In regions in which response distances are generally short and units are unable to attain cruising velocities, travel times were found to increase with the square root of the distance traveled. That is,

\[ T = c \sqrt{D}, \quad (1) \]

where \( T \) is the expected time required to travel a distance, \( D \). In regions where average response distances are long enough to allow responding units to reach cruising velocities, travel times (beyond a threshold) were found to increase linearly with response distance. That is,

\[ T = a + bD. \quad (2) \]

By pooling data from all regions of a city, a third function, which is continuous and piecewise square root-linear, was found to provide a good approximation for estimating the travel time for a given response distance anywhere in the city. This function,

\[
\begin{align*}
T &= c \sqrt{D} \quad &D < d \text{ miles}, \\
T &= a + bD \quad &D \geq d \text{ miles},
\end{align*}
\]

(3)

is actually a combination of curves (1) and (2) in which the parameters \( a, b, \) and \( c \) are chosen so that the curves are tangent at \( D = d \) miles. This function is part of a model developed at the Institute that is used to compare the attractiveness of alternative fixed sites for emergency service units by providing information on several performance measures, the most important of which is travel time [1].

Another function that we have found useful for approximating the relationship between response distance and travel time is

\[ T = aD^b. \quad (4) \]

This function is used to relate travel time to average response distance in the Institute's parametric allocation model [9], which is used to generate and/or evaluate alternative allocations of emergency service units within a city.
DETERMINING PARAMETER VALUES FOR EACH OF THE FUNCTIONS

The general relationships (1) - (4) have been found to provide good estimates of travel times for emergency service vehicles in a wide range of cities. The actual relationships for any municipality can be found by determining the appropriate values of the parameters a, b, c, d, α, and β, which depend on the geography and street configuration of the region and on the travel characteristics of the emergency vehicles. Interestingly, the results of the experiments carried out in a number of cities indicate that approximately the same values of the parameters apply in all of them. This suggests that a city may not have to carry out an experiment of its own to be able to obtain reasonably good estimates of travel times from travel distances. For the results of some of these experiments, see [3, 4, 5, 8]. Some geographical results from travel time experiments carried out in several cities are presented in Appendix F.

This Report describes procedures that have been developed at The New York City-Rand Institute for empirically determining the parameters relating travel time to response distance in the four models described above, and for determining the goodness of each of the fits. First, data are collected on responses made by the emergency service vehicles. The data on each response, which can be collected either by direct observation or by using estimation procedures, include the response distance, the travel time, an identification of the location responded to, the time of day, and information on traffic and weather conditions. In the second step, the Travel Time Analysis Program processes the raw data, finds the least squares fits for each of the four functions, and summarizes the results. Included in the program's output are a listing of the data, tabular and graphical summaries, and statistical analyses.

Simple processing of the raw data provides useful information on some performance characteristics of the service being studied. In addition to providing general information on travel times, travel velocities, and travel distances, the program also analyzes the effect of the time of day and weather and traffic conditions on travel time.

The least squares fits for each of the four relationships are obtained as follows. For curves (1) and (2), a, b, and c are determined by least squares regression. For curve (3), which combines the square root and linear
relationship, the best fit is found by using an iterative method that
varies the point of tangency of curves (1) and (2). The point chosen is
the one that produces square root and linear curves on either side that
minimize the sum of the squared deviations between the empirical observa-
tions and the fitted curves.

In order to obtain estimates of $\alpha$ and $\beta$ in (4), we first apply a loga-
rithmic transformation to obtain

$$\ln T = a + b \ln D$$

and fit this relationship by least squares regression. Then the estimates of
$\hat{\alpha}$ and $\hat{\beta}$ are: $\hat{\alpha} = e^a$ and $\hat{\beta} = b$. A mathematical description of all of these
regressions is given in Appendix B.

The collection and preparation of the input data for the Travel Time
Analysis Program is described in Section II; the program's output is
described in Section III; and Section IV is a user's guide for running the
program.
II. COLLECTING AND CODING THE RESPONSE DATA

This section describes the mechanics of an experiment designed for collecting data on responses made by emergency service units. The data are designed to be analyzed using the Travel Time Analysis Program, which is described in Section III, to determine the travel characteristics of the emergency service vehicles. It should be noted that there are other ways to collect the data required by the program. See [5] for an alternative approach.

In order to obtain a statistically reliable picture of both citywide and regional travel characteristics, the emergency units selected to participate in the experiment should satisfy the following three important criteria:

1. **Location**—The primary response districts of the selected units should represent a topographical cross-section of the city. In addition, enough units should be included to cover all types of response patterns in the city.

2. **Response Frequency**—The duration of the experiment should allow for the collection of at least 100 observations for each participating emergency unit. Therefore, if the experiment is not to last too long, the units chosen should be reasonably busy, but not so busy that the experiment would be too much of a burden.

3. **Odometer Availability**—This is the most easily overlooked of the three requirements. Each vehicle involved in the experiment must have a working odometer capable of measuring travel distances to the nearest tenth of a mile. Care must be taken in checking that these odometers operate independently of all other systems on the emergency vehicle. For example, the odometers on some fire engines continue to rotate while the pumps are in operation, although the vehicle itself is no longer in motion.

Each unit participating in the travel time experiment is supplied with a stopwatch, a detailed set of coding instructions, and several copies of a form on which to record data on all responses made by that unit during the course of the experiment. The information recorded for each
response consists of the odometer reading before departure, the odometer reading after arrival at the incident, the stopwatch reading indicating the duration of the run, the location of the incident, the time of occurrence, a description of weather and traffic conditions, and an indication of whether the unit was expected to be the first to arrive at the scene (this does not apply for services where only one unit is normally dispatched).

In designing the experiment, we recognized the fact that responding to an emergency is the highest priority task of any emergency service unit. The data collection form was therefore designed to ensure minimal interference with service delivery. All required information can be entered prior to dispatch to the incident and after completion of all duties at the scene.

A sample coding form appears in Appendix A.2 and instructions for filling out the form appear in Appendix A.1. These forms have been used successfully in several cities for recording responses made by fire-fighting units. However, the format is general enough so that the forms can be used for other emergency services.

After the forms are completed, the information is keypunched and the cards are used as input to the Travel Time Analysis Program.
III. DESCRIPTION OF THE TRAVEL TIME ANALYSIS PROGRAM

The Travel Time Analysis Program, written in FORTRAN, is divided into six parts, corresponding to the six types of output reports. Since some of the reports can be quite long and not all of the reports will be of interest to every user, the program allows the printing of certain output sections to be suppressed. In this section, each part of the output is described in detail. For a sample of the output from the program, see Appendix E. The figures cited in the descriptions below may be found in Appendix E. A complete listing of the program appears in Appendix D.

PART 1. LISTING OF THE EXPERIMENTAL DATA (Fig. 2)

This part of the program produces an ordered list, ranked by travel time, of the travel data collected by a given unit or group of units for each response. The following information is provided for each response:

- Travel time—in minutes
- Distance traveled—in miles
- Average velocity—in miles per hour
  (velocity = distance x 60/travel time)
- Time of day—in 24-hour military time (e.g., 3:15 p.m. is 1515)
- Numerical identification of location to which response was made
  (e.g., census block, street alarm box number, etc.)
- Indication of whether responding unit had first- or second-
due responsibility
- Sequence number of observation in input deck. This information
  is useful in locating the original data card for correction or
  removal
- Weather and traffic conditions.

PART 2. ANALYSIS OF REPLICATES TO A LOCATION (Fig. 3)

This part of the output lists all locations to which more than one response was made by the same unit. This information is useful in judging the overall reliability of the data collection by providing an estimate of the variance of the distance ($s^2$). If the data were collected conscientiously, this $s^2$ should represent only the "pure error," since for responses
to the same location only random variation should account for the differences in the travel distance. (This output is of interest only if the responding unit always starts from the same place.) For all replicate locations, the output of this section contains:

- Identification of location to which multiple responses were made
- Average travel distance of replicated responses
- Sum of squared deviations of replicate distances from average travel distance to location
- Standard deviation of average travel distance
- Number of replicates to location.

The mean square error is calculated over all the replicated observations. The mean square error is then an estimate of the variance, \( \sigma^2 \). (For a description of the calculations made in this part, see Appendix C.)

PART 3. ASSORTED STATISTICS (Fig. 4)

These statistics, involving travel time (T), travel distance (D), and average velocity (V), are useful in performing further statistical analyses with the response data. Each statistic is computed separately for first-due responses, second-due responses, and all responses. The statistics are the sums of the following variables: T, D, V, TxD, VxD, V^2, T^2, D^2, \( \sqrt{D} \), \( T\sqrt{D} \), \( V\sqrt{D} \), log V, log T, log D, log D x log V, log D x log T, (log T)^2, (log D)^2, and (log V)^2.

PART 4. CURVE FITTING (Figs. 5 through 8)

Regressions

For each of three categories of observations (first-due, second-due, and all) three curves are fitted by ordinary least squares regression. They are:

- Model 1: \( T = c\sqrt{D} \)
- Model 2: \( T = a + bD \)
- Model 4: \( \ln T = a + b \ln D \),

where T is the travel time, D is the travel distance, and a, b, and c are the coefficients to be estimated. Details of the calculations involved in these regressions are given in Appendix B.1.
The regression output includes:

- For each coefficient, the estimated value of the coefficient, variance, standard error, and t-ratio
- For each curve, the sum of squares of differences between observed and predicted values of T over all observations used to fit the curve
- Table of fitted values of T at selected distances, D.

**Fitting a Piecewise Square Root-Linear Response Time Function**

A fourth curve, a spline function that is continuous and piecewise square root-linear, is fit only for all the data taken together. This curve is of the form

\[
\begin{align*}
T &= c \sqrt{D} & D < d. \\
T &= a + bD & D \geq d,
\end{align*}
\]

where the best values of a, b, c, and d are determined, using an optimal search routine, to minimize the sum of squares of the differences between the observed and predicted values of T. For further information on the calculations made in this part, see Appendix B.2.

**PART 5. DATA SUMMARIES (Fig. 9)**

In this part the data are aggregated and summarized by travel distance and by time of day for each of the three categories (first-due, second-due, and all). For every interval of one-tenth mile, the total number of observations in that interval, the average velocity, and the average travel time are calculated. The relationship of travel velocity to time of day is studied by computing average velocities for each of the 12 two-hour time intervals of the day. In addition, "rush hour" travel velocities are compared to nonrush hour travel velocities. Rush hours are defined by the program to be 8 a.m. to 9 a.m. and 4:30 p.m. to 5:30 p.m.

**PART 6. GRAPHICAL OUTPUT (Figs. 10 through 12)**

In this part, three graphs are presented for each of the three categories of observations (first-due, second-due, and all).

**Graph 1:** A plot of observed travel times vs. travel distances, showing all experimental observations and, at each value of the travel distance (in
increments of .1 mile), the average of the observed travel time. An asterisk (*) indicates an observed point. The letter "A" indicates the average time at each value of travel distance.

**Graph 2:** This plot is similar to Graph 1, but instead of average travel times, the fitted values of the travel times computed in Part 4 are included with the experimental observations on the graph at each increment of .1 mile. The numeral "1" indicates a fitted value from Model 1, while the numerals "2," "3," and "4" indicate fitted values of Model 2, Model 3, and Model 4, respectively.

**Graph 3:** A plot of travel velocity vs. time of day. An asterisk (*) indicates an observed point. A string of four "A"s indicates the average travel velocity in each two-hour interval.
IV. INSTRUCTIONS TO THE USER

This section serves as a user's guide to the Travel Time Analysis Program and consists primarily of instructions for setting up the data deck necessary for running the program. Also covered is a method for choosing which of the four functions best fits the data. For a more detailed discussion of how to use the program output, see [8].

RUNNING THE PROGRAM

The Travel Time Analysis Program, written in FORTRAN IV, requires approximately 150,000 bytes of core storage when run in the batch mode on an IBM System 360 or 370 computer. The data deck necessary for running the program consists of two control cards followed by the experimental data. The data on each card begin in column 1.

Control Cards

Card 1: Contains a six-element vector detailing which parts of the program output (described in Section III) are desired. Each element of the vector corresponds to one part of the program output. The value of an element is 1 if that part of the output is to be exhibited, or 0 if the corresponding output part is to be omitted. This vector is entered in the first six columns of Card 1.

For example: If the vector entered is 100110, then only parts 1, 4, and 5 will be printed out. If the vector entered is 111111, all output will be printed.

Card 2: Contains two single-digit numbers, labeled internally "LBR" and "IREG." LBR is a 0–1 variable indicating whether separate analyses should be done for first- and second-due responses. A value of 1 means that the breakdown will be made, while a value of 0 indicates that no such breakdown is required. (Although second-due responses may be of interest in the fire service, they may be meaningless in other emergency services.) IREG, which can have integer values ranging from 1 to 4, indicates which of the four fields of the header card associated with each emergency service vehicle is to be used to group the data for the run. For example, if IREG is 3, all sets of data having the same characters in the third field of their header cards will be summarized together in one set of output reports. Therefore, data can be aggregated by service area, command, individual unit, etc.
Data Set

For each emergency service vehicle whose travel time data are being processed, the following cards are necessary:

- Header card
- Data cards (one for each response)
- Blank card.

The items listed above constitute one set of data. More than one set of data may be included in each run.

The header card can utilize up to four fields, each consisting of four columns, as descriptors of the data. For example, a header card for data collected by Engine Company 1, located in Region 2, and a member of Battalion 3 and Division 4, would read:

DV4 BT3 RG1 E1.

Sample Data Deck

Control Card 1: 111111
Control Card 2: 14
First set of data: DV1 BT1 RG1 E1
- Data cards for Engine 1
- Blank card
Second set of data: DV1 BT1 RG2 E2
- Data cards for Engine 2
- Blank card
Third set of data: DV1 BT1 RG2 E3
- Data cards for Engine 3
- Blank card

Control Card 1 indicates that all six output sections are to be exhibited. Control Card 2 indicates that the first- and second-due breakdown should be made (LBR = 1) and that field number 4 of the header card should be used to group the data (IREG = 4). This means that output for Engine 1, Engine 2, and Engine 3 will be exhibited separately. If the value of IREG is 3, then output for Engine 1 would be displayed separately and output for Engine 2 and Engine 3 would be combined since they comprise Region 2. If IREG is 1, then output for Engine 1, Engine 2, and Engine 3 would be combined since they are all in Division 1.
CHOOSING THE BEST FIT

After the program has been run, the user must examine the output to decide which of the four functions offers the best fit to the experimental data and, therefore, best describes the relationship between travel time and travel distance.

Using Figs. 5 through 8 of the sample output presented in Appendix E, we can plot each of the four functions on one graph. The plots are shown in Fig. 1. The graph also displays the average travel time for all observations in each .1-mile interval. Examining the graph, we see that the four functions are very similar to each other, and fit the data surprisingly well, especially for distances under a mile. An examination of the experimental data displayed on the graph does not reveal which function offers the best fit.

To determine the goodness of each fit we use the sum of the squared deviations of the observations from the fit for each function, listed as SSQD in the output. In this case the SSQDs are:

<table>
<thead>
<tr>
<th>Function</th>
<th>Sum of Squared Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $T = \frac{2.27}{D}$</td>
<td>91.93</td>
</tr>
<tr>
<td>2. $T = .51 + 1.74D$</td>
<td>80.08</td>
</tr>
<tr>
<td>3. $T = \begin{cases} \frac{1.93}{D} &amp; D &lt; .32 \text{ mile} \ .55 + 1.71D &amp; D \geq .32 \text{ mile} \end{cases}$</td>
<td>79.78</td>
</tr>
<tr>
<td>4. $T = 2.21D^{.73}$</td>
<td>81.37</td>
</tr>
</tbody>
</table>

Function 3, the spline function, fits the experimental data best, followed closely by Functions 2 and 4. For making deployment policy decisions, any of the three could be used to characterize the relationship between travel time and travel distance. The differences between the estimates would be small, and not at all meaningful for policy decisions. However, since for distances greater than one mile, Function 1 might underestimate the travel time, care should be exercised in its use.

In Appendix F we present graphs showing fits of some of these functions to experimental data collected in New York City (Fig. 13); Trenton, New Jersey (Fig. 14); Yonkers, New York (Fig. 15); and Denver, Colorado (Fig. 16). The Denver graph shows again how similar the fits of the various functional forms are, particularly in the range of distances that are of most interest (under one mile).
Figure 1. Four functions for relating travel time to travel distance.

Model 1:
\[ T = 2.27 \sqrt{D} \]

Model 2:
\[ T = 0.51 + 1.74D \]

Model 3:
\[ T = \begin{cases} 
1.93\sqrt{D} & D < 0.32 \\
0.55 + 1.71D & D \geq 0.32 
\end{cases} \]

Model 4:
\[ T = 2.21 D^{0.73} \]

\( n \) ~ The Average of \( n \) Observations
Appendix A

INSTRUCTIONS AND FORMS FOR A
FIRE DEPARTMENT'S TRAVEL TIME EXPERIMENT
Appendix A.1

SAMPLE INSTRUCTIONS FOR A FIRE DEPARTMENT'S TRAVEL TIME EXPERIMENT

The purpose of this experiment is to obtain accurate information about actual response times and response distances. The information gathered will be useful to the Department in selecting the location of new firehouses. Please follow the instructions carefully. It is essential that the information provided be accurate. Should some information be inadvertently forgotten, lost, or erroneously recorded, simply record the time out and box number and neatly draw a line through the rest of the information.

The following instructions indicate how each entry is to be made. The headings of the appropriate data columns are capitalized and underlined. All data columns are to be filled in (use zeros if necessary to fill in all columns, as indicated in the sample entries at the top of the data sheet).

1. Enter **Mileage Before** each run when the apparatus returns to quarters from a previous run or assignment. Enter the last four digits on the odometer (including the tenths of a mile).

2. Upon returning to quarters from a previous run, reset the stopwatch to zero. Start the stopwatch as the apparatus begins motion. On arrival at the scene, stop the stopwatch. Be sure that you do not reset it to zero.

3. When taking up (after the incident, but before the apparatus begins the return trip to quarters), record the last four digits on the odometer as the **Mileage After**.

4. Record the **Duration of Run** as the reading on the stopwatch in minutes and seconds (to the nearest second).

5. After returning to quarters record the information for the columns labeled **Box Number**, **Time Out**, **Weather Condition**, **Traffic Condition**, **Due**, and **Usual Route Followed** in the following manner:

   a. Verify **Box Number** with Fire Control; this should be recorded for all alarms, including telephone alarms.

   b. Verify **Time Out** (the time at which the alarm was received) with Fire Control; this should be recorded to the nearest minute and should include the AM and PM designation.

   c. **Weather Condition** is to be recorded as D for dry conditions; and W for wet (meaning either precipitation falling or wet streets).
(d) Traffic Condition records your judgment of traffic conditions, with L for light traffic or empty streets, M for moderate, and H for heavy (reserve the use of H for those situations in which traffic conditions clearly impeded the apparatus or caused it to take an alternate and less direct route).

(e) Due is an indication of whether the apparatus is responding as first-due engine, second-due engine, first-due ladder, etc. Use the code 1E, 2E, 2L, etc., appropriately.

Please note that the first two lines of the report form are filled in with information for sample runs. A reminder: All columns must be filled in, so that a time out of 6:51 AM is entered as 0651AM; a Mileage After of 0230 is so entered; a duration of 2 minutes and 6 seconds is recorded as 0206, etc.
### Appendix A.2

**SAMPLE DATA FORM FOR TRAVEL TIME EXPERIMENT**

<table>
<thead>
<tr>
<th>COMPANY: _______________</th>
<th>Odometer before Responding</th>
<th>Odometer before Returning</th>
<th>Duration of Run Min. Sec.</th>
<th>Alarm Box Number</th>
<th>Time Out Hr. Min.</th>
<th>AM/PM</th>
<th>Weather Condition</th>
<th>Traffic Condition</th>
<th>Due</th>
<th>Usual Route Followed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codes:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather Condition</td>
<td>D=Dry</td>
<td>W=Wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Condition</td>
<td>L=Light</td>
<td>M=Moderate</td>
<td>H=Heavy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual Route Followed</td>
<td>U=Usual</td>
<td>D=Detour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Due</td>
<td>1E=First Engine</td>
<td>2L=Second Ladder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example: 12341252031202210651A M W L 1E U
Appendix B

MATHEMATICAL DETAILS OF FITTING
THE FOUR TRAVEL TIME FUNCTIONS
Appendix B.1

MATHEMATICAL DETAILS OF LEAST SQUARES REGRESSIONS FOR MODELS 1, 2, AND 4

Model 1: \( T = c \sqrt{D} \),

where \( T \) = travel time
\( D \) = travel distance
\( c \) = parameter to be estimated.
Let \( n \) = the number of observations.
Then, in order to obtain the best (least squares) estimate of \( c \), call it \( \hat{c} \), we compute:

\[
S = \text{the sum of the squared deviations from the true line}
\]
\[
= \sum_{i=1}^{n} \left( T_i - c \sqrt{D_i} \right)^2.
\]

We wish to choose \( c \) in order to minimize \( S \). We therefore differentiate \( S \) with respect to \( c \) and set it equal to 0:

\[
\frac{\partial}{\partial c} \left( \sum_{i=1}^{n} \left( T_i - c \sqrt{D_i} \right)^2 \right) = 0 = 2 \sum_{i=1}^{n} \frac{T_i - c \sqrt{D_i}}{\sqrt{D_i}}.
\]

Therefore,

\[
\hat{c} = \frac{\sum_{i=1}^{n} (T_i \sqrt{D_i})}{\sum_{i=1}^{n} D_i}.
\]

Our estimate of the variance of \( c \) is

\[
\sigma_c^2 = \frac{S}{(n-1) \sum_{i=1}^{n} D_i}.
\]

The standard error of \( c \) is estimated by \( \delta_c \).
The t-ratio is \( \frac{\hat{c}}{\delta_c} \).

*For more details, see [6].
Model 2: \( T = a + bD \),

where \( T = \) travel time  
\( D = \) travel distance  
\( a, b = \) parameters to be estimated.

As above, we wish to minimize

\[
S = \sum_{i=1}^{n} (T_i - a - bD_i)^2.
\]

In order to get an estimate of \( a \), call it \( \hat{a} \), and \( b \), call it \( \hat{b} \), we take partial derivatives of \( S \) with respect to \( a \) and \( b \):

\[
\frac{\partial S}{\partial a} = 2 \sum_{i=1}^{n} (T_i - a - bD_i) \\
\frac{\partial S}{\partial b} = -2 \sum_{i=1}^{n} (T_i - a - bD_i)D_i.
\]

Setting these two equations equal to zero and solving the two equations for the two unknowns, we get

\[
\hat{b} = \frac{\sum_{i=1}^{n} [(T_i - \bar{T})(D_i - \bar{D})]}{\sum_{i=1}^{n} (D_i - \bar{D})^2}
\]

and \( \hat{a} = \bar{T} - \hat{b}\bar{D} \),

where \( \bar{T} = \frac{\sum_{i=1}^{n} T_i}{n} \),

and \( \bar{D} = \frac{\sum_{i=1}^{n} D_i}{n} \).

We estimate the variance of \( a \) by:

\[
\sigma^2_a = \frac{S}{n-2} \left( \frac{\sum_{i=1}^{n} D_i^2}{n \sum_{i=1}^{n} (D_i - \bar{D})^2} \right)
\]
and the variance of \( b \) by:

\[
\sigma_b^2 = \frac{S}{n-2} \left[ \frac{1}{\sum_{i=1}^{n} (D_i - \bar{D})^2} \right].
\]

The corresponding standard errors are given by \( \hat{\sigma}_a \) and \( \hat{\sigma}_b \).
The \( t \)-ratios are \( \frac{\hat{a}}{\hat{\sigma}_a} \) and \( \frac{\hat{b}}{\hat{\sigma}_b} \).

**Model 4:** \( T = \alpha D^\beta \)

where \( T = \) travel time
\( D = \) travel distance
\( \alpha, \beta = \) parameters to be estimated.

Using a logarithmic transformation, we get

\[
\ln T = \ln \alpha + \beta \ln D,
\]

and, if we define
\( T' = \ln T, \)
\( a = \ln \alpha, \)
\( b = \beta, \)
\( D' = \ln D, \)

we can rewrite the above equation as
\( T' = a + b D' \)

and proceed as in Model 2, obtaining least squares estimates \( \hat{a} \) and \( \hat{b} \). To get estimates of \( \alpha \) and \( \beta \), called \( \hat{\alpha} \) and \( \hat{\beta} \), respectively, we set

\( \hat{\beta} = \hat{b} \), and

\( \hat{\alpha} = e^{\hat{a}}. \)
Appendix B.2

FITTING THE PIECEWISE TRAVEL TIME FUNCTION FOR MODEL 3

The problem of fitting a continuous piecewise square root-linear travel time curve to the experimental data can be expressed mathematically as follows:

Given N sets of observations \((T_i, D_i, M_i), i = 1, 2, \ldots, N\), where \(T_i\) denotes the average travel time (in minutes) of the \(M_i\) responses having a response distance of \(D_i\) (in miles), find values of the parameters \(a, b, c,\) and \(d\) to

\[
\text{minimize} \quad \sum_{i=1}^{N} M_i (T_i - f(D_i))^2
\]

subject to:

\[
f(D) = \begin{cases} 
  c\sqrt{D}, & \text{if } D \leq d, \\
  a + bD, & \text{if } D > d,
\end{cases}
\]

and \(a + bd = c\sqrt{d}\)

\(b = c/(2\sqrt{d})\).

The first two constraints specify the form of the piecewise function to be fitted, and the second two specify that the two pieces of the curve are to be tangent at the break point, \(d\) (they must meet and have the same slope at \(d\)). After eliminating \(a\) and \(c\) by solving for them in terms of \(b\) and \(d\), the problem can be written as:

Find \(b\) and \(d\) to minimize

\[
q(b, d) = \sum_{i=1}^{N} M_i (T_i - 2b\sqrt{D_i})^2 + \sum_{i=N_d+1}^{N} M_i (T_i - bd - bD_i)^2,
\]

where, assuming that the sets of observations are ordered by increasing value of \(D_i\), \(N_d\) is the largest value of \(i\) such that \(D_i \leq d\). If a value of \(d\) (and, hence, of \(N_d\)) is fixed, \(b^*(d)\), the optimal value of \(b\) for that value of \(d\),

*For more details, see [8].
can be determined by differentiating (1) with respect to \( b \) and equating the derivative to zero. The result is

\[
b^*(d) = \frac{\sum_{i=1}^{N_d} M_i T_i \sqrt{D_i} + \sum_{i=N_d+1}^{N} M_i T_i (d + D_i)}{4d \sum_{i=1}^{N_d} M_i D_i + \sum_{i=N_d+1}^{N} M_i (d + D_i)^2}.
\]

Then, by varying \( d \), an optimal pair of values \( b^* \) and \( d^* \) can be determined.
Appendix C

ANALYSIS OF REPLICATES TO A BOX
We can use replicate observations (i.e., two or more responses to the same location) to obtain a reliable estimate of \( \sigma^2 \), the overall variance of the distances recorded in the experiment (call the estimate \( S^2 \)). Suppose \( D_{k1}, D_{k2}, \ldots, D_{kn_k} \) are \( n_k \) replicate response distances observed at location \( k \). The contribution to the pure error sum of squares from the observations at location \( k \) is:

\[
z_k = \frac{n_k}{\sum_{i=1}^{n_k} D_{ki}^2} - \frac{n_k D_k^2}{\sum_{i=1}^{n_k} D_{ki}^2},
\]

where

\[
\bar{D}_k = \frac{D_{k1} + D_{k2} + \ldots + D_{kn_k}}{n_k}
\]

with \( n_k - 1 \) degrees of freedom.

Looking at all \( m \) boxes with multiple observations, we get:

Total sum of squares (pure error) = \( \sum_{i=1}^{m} z_i \) with \( (\sum_{i=1}^{m} n_i) - m \) degrees of freedom.

Therefore, the estimate of mean square for pure error is

\[
S^2 = \frac{\sum_{i=1}^{m} z_i}{(\sum_{i=1}^{m} n_i) - m}
\]

For more details, see [2].
Appendix D

PROGRAM LISTING
COMMON /MAIN/, NO(3), SSDG(RO), VP1M(RO), PR(3), SSDQ1(3),
  SDZ(4), AZV(4), VTUP(RO), SSD0(RO), VST(AO), Q(OA), T,
  SE(3), SEB(3), SEC(3), PRA(1), PR(3), THC(3), VARC(3), X2(3),
  VARA(3), VARB(3), DUBAR(3), DIBAR(3), S1(3), S2(3), K21(3), VTZSSQ(4),
  EDI2(3), EQU(3), EDUSOD(3), EVSDG(3), FLV(3), ELU(3), ELI(3),
  ELV1(3), ELV2(3), ELI2(3), R2(3), FRP(3), PR(3),
  DUBAR(3), DIBAR(3), D2PR(3), S2PR(3),

COMMON /INTL/, FIRST<FCO(0), ALL<ZEH, UNF, TWU, THKEF, FOUR, FIVE, STK,
  EIG, BLANK, SUB, PLUS, CONC, DEC, STAR, BAVGE, AVGF


COMMON /RSVP2/<B(3), C(3), AL(3), BET(3), A(3), AVDX(RO),
  XBR(3), APR(3),
  1 AVL(3), DSTMX

COMMON /RSVP4/<ASPL, BSPL, CSPL, DSP

DIMENSION IB(18000), YQ(2000), XYZ(1521), XXY(306), REG(4)

REAL NO, NR

INTEGER TMOU, DOUR, DUPL, NXYI(18)

INTEGER TMOU2, IP2(1000), ISO(1000), IDU(1000), TD(1000), OUTPUT(4)


LOGICAL IZERONE, TXG, THREE, FOUR, FIVE, SIX, EIG, BLANK, SUB, PLUS, CONC

LOGICAL IC, STAR, BAVGE, AVGF

LOGICAL IOK, ODR, TRAF, USUAL

EQUIVALENCE (XYZ(1), NO(1)), (XXY(1), B(1)), (NXYI(1), DUBAR(1))

C******************************************************
C***** PART 0  INITIALIZATION ****************************
C******************************************************

READ(5,1100)OUTPUT(i), I=1,6
READ(5,1100)IBR,IREG
1100 FORMAT(6(I1)
1 IBEG=0
2 ASPL=0
3 BSPL=0
4 CSPL=0
5 DSP=0
6 IF(IBR.EQ.0) IBER=3
C******************************************************
C***** END OF PART 0 ***********************************
C******************************************************
C******************************************************
C***** PART 1  PREPARE AND EXHIBIT INPUT DATA *********
C******************************************************

19 READ(5,15,END=13) RFG(1), RFG(2), RFG(3), RFG(4)
25 FORMAT(4(A4)
26 IF(IBEG.EQ.0) GO TO 1
27 IF(UNNEQ(REG,IREG)) GO TO 13
28 GO TO 20
29 MX=0
30 J=0
31 DO 2 I=1,1521
32 XYZ(I)=0
33 DO 6 I=1,106
34 WXY(I)=0
35 DO 7 I=1,18
36 NXY(I)=0
37 UNEQ(REG)
38 IBEG=0
39 DISTX=0
40 READ(5,10,END=65) BEFMI, AFMTI, DOUR, DUPL, IMUX, TMOUT, DRAM,
  CTRAF, IDUE, USUAL
FORMAT(3X,2F4.1,1Z12,2I4,2A1,11X,A1)
IF ((1EQ.0) AND ((TMOUT.EQ.0)) GO TO 19
TEMP=AFMTM-BEF#1
IF (TEMP.EQ.0.09) GO TO 20
ICAT=1
IF ((TMOUT.GT.0500) AND ((TMOUT.LE.0800)) OR ((TMOUT.GT.0900) AND
((TMOUT.LE.1600)) OR ((TMOUT.LE.1730)))) ICAT=2
IF ((TMOUT.GT.0800) AND ((TMOUT.LE.0900)) ICAT=3
IF ((TMOUT.GT.1630) AND ((TMOUT.LE.1730)) ICAT=4
J=J+1
IF (BFMTM.GT.AFNDT AFMTM.BEF#1)
IF ((IDUE.EQ.0) OR ((IDUE.GT.2)) IDUE=3
IF (LDUR.EQ.3) IDUE=3
IDU(J)=IDUE
K=IDU(J)
N=K
DUN=DURM
DUS=DURS
WEAT(J)=DRY
TRAC(J)=TRAF
ROUTE(J)=USUAL
IRA(J)=IOBX
ISO(J)=J
TRAVMI(J)=AFMTM-BEFT
YOJ(J)=SORT(TRAVMI(J))
TD(J)=TMOUT
TIM(J)=60.*DUN+DUS/3600.
VEL(J)=TRAVMI(J)/TIM(J)
IF (TRAVMI(J).GT.DISTMN) DISTMN=TRAVMI(J)
TIM=MJ(J)+E0.
X=ALOG(*TRAVMI(J))
Y=ALOG(VEL(J))
Z=ALOG(TIM(J))
DT=TRAVMI(J).T10.05
DIST=DT
IF (DIST.GT.MX) MX=DIST
IF (DIST.EQ.0) DIST=1
DN=1081 ID=1,2
IF ((K.EQ.3) AND ((1.EQ.1)) GO TO 1081
IF (I.EQ.2) N=3
VTZ(1.7ICAT,N)=VTZ(1.CAT,N)+VEL(J)
VTZ5Q(I.7CAT,N)=VTZ5Q(1.7CAT,N)+VEL(J)*VEL(J)
NOTZ(I.7CAT,N)=NOTZ(I.7CAT,N)+1
EDU(N)=EDU(N)+TIN
EDI(N)=EDI(N)+TRAVMI(J)
EV(N)=EV(N)+VFL(J)
EDU(N)=EDU(N)+TIN+TRAVMI(J)
EDV(N)=EDV(N)+VEL(J)+TRAVMI(J)
EV2(N)=EV2(N)+VEL(J)*VEL(J)
EDI2(N)=EDI2(N)+TIN+TIN
ED12(N)=ED12(N)+TRAVMI(J)*TRAVMI(J)
ESD(N)=ESD(N)+YQJ
EDUSQ(N)=EDUSQ(N)+TIN+YQJ
EV5Q(N)=EV5Q(N)+VEL(J)*YQJ
ELV(N)=ELV(N)+Y
ELD(N)=ELD(N)+Z
ELDV(N)=ELDV(N)+X
ELY(N)=ELDV(N)+X+Y
ELOLD(N)=ELOLD(N)+X+Z
ELOD2(N)=ELOD2(N)+Z+7
ELD2(N)=ELD2(N)+X+X
ELV2(N)=ELV2(N)+Y
NO(N)=NO(N)+1
VDIST(1.DIST,N)=VDIST(1.DIST,N)+VEL(J)
VDUR(1.DIST,N)=VDUR(1.DIST,N)+TIM(J)
0(1.DIST,N)=0(1.DIST,N)+1
SSDQ(MXK,N)=SSDQ(MXK,N)+VEL(J)*VEL(J)
SSDQ(DIST,N)=SSDQ(DIST,N)+TIM(J)*TIM(J)
JL=(10J-1)/200+1
IF ((JL.EQ.1) OR ((JL.GT.13))) GO TO 1081
VTM(JL,N)=VTM(JL,N)+VEL(J)
P(JL,N)=P(JL,N)+1
SSQ(JL,N)=SSQ(JL,N)+VFL(J)*VFL(J)
CONTINUE
NCOUNT=J
GOTO 70
C
DO 52 I=2,JCOUNT

DO 53 [I=1,JCOUNT

IF(TIM(I-1) LE TIM(I)) GO TO 53

VTMP=VEL(I-1)

VEL(I-1)=VEL(I)

VEL(I)=VTMP

DTMP=TRAVM(I)

TRAVM(I-1)=TRAVM(I)

TRAVM(I)=DTMP

ITEM=TO(I-1)

TD(I-1)=TD(I)

TD(I)=ITEM

IB(I-1)=IB(I)

IB(I)=IB(I)

ISTEMP=ISG(I)

ISG(I-1)=ISG(I)

ISG(I)=ISTEMP

TIMEPT=TIME(I)

TIME(I-1)=TIME(I)

TIME(I)=TIMEPT

YQTEMP = YQD(I)

YD(I-1)=YQD(I)

YQD(I)=YQTEMP

IPTMP=IDU(I)

IDU(I-1)=IDU(I)

IDU(I)=IPTMP

WEATMP=WEATH(I)

WEATH(I-1)=WEATH(I)

WEATH(I)=WEATMP

TFTEMP=TRAFC(I)

TRAFC(I-1)=TFTEMP

TFTEMP=TRAFC(I)

RTMP=ROUTE(I)

ROUTE(I-1)=ROUTE(I)

ROUTE(I)=RTMP

53 CONTINUE

52 CONTINUE

IF (OUTPUT(I) EQ 0) GO TO 1000

33 FORMAT (I1,13X,*REGION: *,A4)

WRITE (6,33) N

WRITE (6,41) JCOUNT

41 FORMAT (I1,*NUMBER OF OBSERVATIONS = *,I5/,)

WRITE (6,34)

34 FORMAT (1H0,13X,*DURATION*,2X,*DISTANCE*,5X,*VELOCITY*,5X,*TIME*,
15X,*BOX = (DUE)*,5X,*SFQ*,2X,*WEATHER*,2X,*TRAFFIC*,2X,*ROUTE*/
21X,*MINS*,5X,*MILE*,8X,*MPH*/)

DO 73 J=1,JCOUNT

TIM=TIM(N) # 0

OX=BLANK

IF (ID(N) EQ 1) OX=ONE

IF (ID(N) EQ 2) OX=Two

35 FORMAT (1H , 13X,F5.2,5X,F5.2,8X,F6.2,7X,14,4X,14,3X,*,
14,3X,5X,14,5X,A1,8X,A1,7X,A1)

WRITE (6,35) TIM, TRAVM, VEL, TO(N), ID(N), OX, ISG(V), WEATH(N),
1TRAFC(N), ROUTE(N)

73 CONTINUE
```c
C******************************************
C******************************************
C********** PART 2 **********
C********** RANK DATA BY BOX AND DISPLAY **********

C
170 IF(OUTPUT(2).EQ.0) GO TO 2000
171 DO 61 I=1,JCOUNT
172 61 IP0INT(I)=I
173 DO 62 I=2,JCOUNT
174 DO 63 I=1,JCOUNT
175 IF(IB(I-1)+LE,IB(I)) GO TO 03
176 I=TEMP=IB(I-1)
177 IB(I-1)=IB(I)
178 IB(I)=TEMP
179 IPOINT(I)=I
180 IPOINT(I)=IPOINT(I)
181 IPOINT(I)=IPOINT(I)
182 63 CONTINUE
183 62 CONTINUE
184 WRITE(6,452)UN
185 452 FORMAT(1H1,5X,'REPLICATES TO A BOX',5X,T125,'AA//')
186 WRITE(6,56)
187 56 FORMAT(1H0,5X,'BOX NO.',5X,'AVG. DIST.',9X,'$SSQ$,8X,'STD. DEV.
1 X,X,'OBSERVATIONS/')
188 SSQ=0.
189 NB=0
190 NC=0
191 I=1
192 200 N=IP0INT(I)
193 NR=0.
194 SUMO=0.
195 100 SUMO=SUMO+TRAVM(1POINT(I))
196 SUMSQ=SUMSQ+TRAVM(1POINT(I))*TRAVM(1POINT(I))
197 NR=NR+1.
198 IF(I.EQ.JCOUNT) AND (NR.EQ.1.) GO TO 400
199 IF(I.EQ.JCOUNT) GO TO 300
200 I=I+1
201 IF(NR.EQ.1.) GO TO 100
202 IF(NR.EQ.1.) GO TO 200
203 300 $SSQ$=SUMO$SUMQ$/NR
204 $SISQ$=SUMO$SUMQ$/$SISQ$
205 IF($SISQ$LT+.00001) $SISQ$=0.
206 DBAR=SUMO/NR
207 DVE=SORT($SISQ$/($NR-1$))
208 $SSQ$=$SSQ$+$SISQ$
209 NC=NC+I
210 NB=NB+1
211 WRITE(6,54) N,DBAR,$SISQ$,DVE,NR
212 IF(I.EQ.JCOUNT) GO TO 400
213 GO TO 200
214 400 $SSQ$=$SSQ$/(NC-ND)
215 WRITE(6,55) NC,NB,$SSQ$
216 54 FORMAT(1H0,5X,'TOTAL RUNS = ',15,10X,'NO. OF DISTINCT BOXES = ',
1 X,'MEAN SQUARE ERROR =',F10.5)
217 55 FORMAT(1H0,' END OF PART 2')
```
C*********************************************************************** PART 1
C***********************************************************************/
C
C IF(OUTPUT(3),EQ.0) GO TO 3000
220  WRITE(6,441) UN
222  WRITE (6,215)
223  215  FORMAT(H0.40X,'ASSORTED STATISTICS',/,'A4X','(TIME, DISTANCE, VELOCITY),/ '//', //', 'T29,' 'FIRST DVF BOXES SECOND DVF BOXES')
224  2  ALL BOXES///)
225  WRITE(6,216) EDU(1),I=1,3
226  WRITE(6,217) EDU(1),I=1,3
227  WRITE(6,218) EV(1),I=1,3
228  WRITE(6,219) EV(1),I=1,3
229  WRITE(6,220) EDU(1),I=1,3
230  WRITE(6,221) EDU(1),I=1,3
231  WRITE(6,222) EDU(1),I=1,3
232  WRITE(6,223) EDU(1),I=1,3
233  WRITE(6,224) EDU(1),I=1,3
234  WRITE(6,225) EDU(1),I=1,3
235  WRITE(6,226) EDU(1),I=1,3
236  WRITE(6,227) EDU(1),I=1,3
237  WRITE(6,228) EDU(1),I=1,3
238  WRITE(6,229) EDU(1),I=1,3
239  WRITE(6,230) EDU(1),I=1,3
240  WRITE(6,231) EDU(1),I=1,3
241  WRITE(6,232) EDU(1),I=1,3
242  WRITE(6,233) EDU(1),I=1,3
243  WRITE(6,234) EDU(1),I=1,3
244  216  FORMAT(H0.5X,'SUM OF T**S',J=30,3(F10.4,10X))
245  217  FORMAT(H0.5X,'SUM OF V**S',J=30,3(F10.4,10X))
246  218  FORMAT(H0.5X,'SUM OF D**S',J=30,3(F10.4,10X))
247  219  FORMAT(H0.5X,'SUM OF T**D',J=30,3(F10.4,10X))
248  220  FORMAT(H0.5X,'SUM OF V**D',J=30,3(F10.4,10X))
249  221  FORMAT(H0.5X,'SUM OF T**V',J=30,3(F10.4,10X))
250  222  FORMAT(H0.5X,'SUM OF D**V',J=30,3(F10.4,10X))
251  223  FORMAT(H0.5X,'SUM OF V**T',J=30,3(F10.4,10X))
252  224  FORMAT(H0.5X,'SUM OF D**T',J=30,3(F10.4,10X))
253  225  FORMAT(H0.5X,'SUM OF T**Q',J=30,3(F10.4,10X))
254  226  FORMAT(H0.5X,'SUM OF V**Q',J=30,3(F10.4,10X))
255  227  FORMAT(H0.5X,'SUM OF D**Q',J=30,3(F10.4,10X))
256  228  FORMAT(H0.5X,'SUM OF T**T',J=30,3(F10.4,10X))
257  229  FORMAT(H0.5X,'SUM OF V**V',J=30,3(F10.4,10X))
258  230  FORMAT(H0.5X,'SUM OF D**D',J=30,3(F10.4,10X))
259  231  FORMAT(H0.5X,'SUM OF T**T',J=30,3(F10.4,10X))
260  232  FORMAT(H0.5X,'SUM OF V**T',J=30,3(F10.4,10X))
261  233  FORMAT(H0.5X,'SUM OF D**T',J=30,3(F10.4,10X))
262  234  FORMAT(H0.5X,'SUM OF T**V',J=30,3(F10.4,10X))
263  235  FORMAT(H0.5X,'SUM OF OBSERVATIONS',J=30,3(F10.4,10X))
264  3000 CONTINUE
C***********************************************************************
C

DO 401 LK=LB+1,3
   C(LK)=EU0DQ(LK)/EDI(LK)
   DUBAR(LK)=EU0(LK)/ND(LK)
   DIBAR(LK)=EDI(LK)/ND(LK)
   DULBAR(LK)=FD0D(LK)/ND(LK)
   DILBAR(LK)=ELD1(LK)/ND(LK)
271 401 CONTINUE

DO 402 K1=1,JCOUNT
   TIM=TIM(K)@60.
   N=N+1
   X=ALOG(TRAWM1(K))
   Y=ALOG(TT1(K))
   DO 406 I=1,2
   IF((I.EQ.2).AND.(N.EQ.3)) GO TO 406
   S(N)=S(N)+(TIM-C(N)+Y0(K))@2
   R(N)=R(N)+(TRAWM(K)-DIBAR(N)+TIM-DUBAR(N))
   DPN(D)=20(N)+(TRAWM(K)-DIBAR(N))@2
   BPR(N)=BPR(N)+(X-DILBAR(N)+(Y-DULBAR(N))
   DPN(D)=D0PR(N)+(X-DILBAR(N))@2
283   406 CONTINUE

DO 407 LK=LB+1,3
   B(LK)=B(LK)/O2(LK)
   VARC(LK)=S(LK)/((ND(LK)-1)*EDI(LK))
   SEC(LK)=SQR(VARC(LK))
   TRC(LK)=C(LK)/SEC(LK)
   A(LK)=DUBAR(LK)-R(LK)*DIBAR(LK)
   BPR(LK)=BPR(LK)/D0PR(LK)
   APR(LK)=DULBAR(LK)-BPR(LK)*DILBAR(LK)
   APR(LK)=EXP(APR(LK))
299 407 CONTINUE

CALL SPLINE(NX,UN)
   SPLSS=0.
   DO 410 K1=1,JCOUNT
   TIM=TIM(K)@60.
   N=N+1
   DO 411 I=1,2
   IF((I.EQ.2).AND.(N.EQ.3)) GO TO 411
   S(N)=S(N)+(TT1)-N(N)*TRAWM(K))@2
   S0PR(N)=S0PR(N)+(TT1-(APR(N)*TRAWM(K)+BPR(N))@2
297   411 CONTINUE

TST=ASPLN+B0SPLN*TRAWM(K)
   IF(TRAWM(K)+NX+D0SPLN) TST=CSPLN+5QRT(TRAWM(K))
309   SPLSS=SPLSS+TST-TT1)@2
310   410 CONTINUE

   DO 412 LK=LB+1,3
   X2(LK)=ND(LK)-2.
   X1(LK)=ND(LK)-1.
   O1=94(LK)**2*EDIZ(LK)
   IF(X2(LK)+LE.-0.) GO TO 4110
   VARA(LK)=S2(LK)+FD2P(LK)+(X2(LK)-ND(LK)*O2(LK))
   VARB(LK)=S2(LK)+(X2(LK)+FD2P(LK))
   SEAL(LK)= SQRT(VAR(A(LK)))
   SEB(LK)= SQRT(VAR(B(LK)))
   TRA(LK)=A(LK)/SEAL(LK)
   TRB(LK)=B(LK)/SEB(LK)
321   GO TO 4140
324 4110 VARA(LK)=.0.
325   VARB(LK)=.0.
326   SEAL(LK)=.0.
327   SEB(LK)=.0.
328   TRA(LK)=.0.
329   TRB(LK)=.0.
330 4140 CONTINUE

   RS01=0.
   RS02=0.
332   DO 420 LL=1,MX
   IF(0(LLL)) LLE. 0.) GO TO 4200
   VOU(LL,LK)=VOU(LL,LK)+60.
335   S(DDD(LK))=S(DDD(LK))@3630.
337   TRAV=VOU(LL,LK)/O2(LK)
338   RSQ1=RSQ1+001(LK)+SQR(FLAT(LL))@2
339   RSQ2=RSQ2+001(LK)+SQR(FLAT(LL))@2
340 4200 CONTINUE

V1=EU0DZ(LK)-FD0D(LK))@2/ND(LK)
   RZ1(LK)=1.-RSQ1/V1
   RZ2(LK)=1.-RSQ2/V1
CONTINUE
IF (OUTPUT(4), EQ, 0) GO TO 4000
WRITE(6,404)
481 FORMAT(I1), ' MODEL 1 T=V/SQRT(D)
WRITE(6,403) UN
403 FORMAT(10H4,10H1,11X, ' FIRST DUE', 'T34', 'SECOND DUE', 'T59', '1', 'ALL')
WRITE(6,700)
709 FORMAT(H10,'COEFF',5X,3F15.4, 'VALUE ', 'VARIANCE', 4X)
WRITE(6,404) (C(IP), VAR(IP), IP=1, J)
404 FORMAT(I2, 'C', 8X, 3(F7.2, 2X, F7.2), 5X)
WRITE(6,710)
710 FORMAT(H10,'11X',3, 'STD. EERR', 'T-RAT', '10', 'X5'))
WRITE(6,704) (9999(IP), 9999(IP), IP=1, J)
704 FORMAT(H10, '11X', 3, (F7.2, 2X, F7.2), 5X)
WRITE(6,408) (51(IP), 51(IP), IP=1, J)
408 FORMAT(H10,'55D',7X,3(F7.2, 2X, F7.2), 14X)
WRITE(6,405) (XI(IP), IF(IP), IP=1, J)
405 FORMAT(H10, '10D', 'IF', 'F', 3X, 3(F5.1, 16X))
WRITE(6,521) (R21(IP), IP=1, J)
521 FORMAT(H10, '2', 'R21', '15X')
5231 FORMAT(H10, 'R21', '15X')
WRITE(6,409)
409 FORMAT(H10,'/4', '10M', 2X, 'D', '25X', 'T=V/SQRT(D) - FITTED')
WRITE(6,89)
89 FORMAT(I1)
WRITE(6,483)
483 FORMAT(H10,'MODEL 2', 'T=A+B*D')
WRITE(6,402) UN
WRITE(6,709)
405 FORMAT(H10,'4', 'A', '8X', 3(F7.2, 2X, F7.2), 5X)
WRITE(6,710)
710 FORMAT(H10,'4', 'A', '8X', 3(F7.2, 2X, F7.2), 5X)
WRITE(6,408) (51(IP), 51(IP), IP=1, J)
408 FORMAT(H10,'55D',7X,3(F7.2, 2X, F7.2), 14X)
WRITE(6,405) (XI(IP), IF(IP), IP=1, J)
405 FORMAT(H10, '10D', 'IF', 'F', 3X, 3(F5.1, 16X))
WRITE(6,521) (R21(IP), IP=1, J)
521 FORMAT(H10, '2', 'R21', '15X')
5231 FORMAT(H10, 'R21', '15X')
WRITE(6,409)
409 FORMAT(H10,'/4', '10M', 2X, 'D', '25X', 'T=A+B*D - FITTED')
WRITE(6,89)
89 FORMAT(I1)
WRITE(6,483)
483 FORMAT(H10,'MODEL 2', 'T=A+B*D')
WRITE(6,402) UN
WRITE(6,709)
405 FORMAT(H10,'4', 'A', '8X', 3(F7.2, 2X, F7.2), 5X)
WRITE(6,710)
710 FORMAT(H10,'4', 'A', '8X', 3(F7.2, 2X, F7.2), 5X)
WRITE(6,408) (51(IP), 51(IP), IP=1, J)
408 FORMAT(H10,'55D',7X,3(F7.2, 2X, F7.2), 14X)
WRITE(6,405) (XI(IP), IF(IP), IP=1, J)
405 FORMAT(H10, '10D', 'IF', 'F', 3X, 3(F5.1, 16X))
WRITE(6,521) (R21(IP), IP=1, J)
521 FORMAT(H10, '2', 'R21', '15X')
5231 FORMAT(H10, 'R21', '15X')
WRITE(6,409)
409 FORMAT(H10,'/4', '10M', 2X, 'D', '25X', 'T=A+B*D - FITTED')
WRITE(6,89)
89 FORMAT(I1)
WRITE(6,483)
C
C********************************************************************
C SUMMARY STATISTICS
C********************************************************************

424 IF (OUTPUT(5).EQ.0).AND.((OUTPUT(6).EQ.0)) GO TO 1
424 DO 374 LBX=LRX,3
425 IF (OUTPUT(5).EQ.0) GO TO 5000
426 GO TO (371,372,373),LBX
427 371 TYPBX=FIRST
428 GO TO 374
429 372 TYPBX=SECOND
430 GO TO 374
431 373 TYPBX=ALL
432 WRITE(6,377) TYPBX,UN
433 377 FORMAT(I1,5X,A4,' BOXES',I1,15X,'A4)
434 GO TO 378
435 374 WRITE(6,375) TYPBX,UN
436 375 FORMAT(I1,5X,A4,' DUE BOXES',I1,15X,'A4)
437 IF (10*3X,'DISTANCE',3X,'NO.',3X,'AVERAGE',3X,'STANDARD',3X,'AVERAGE',3X,'STANDARD'/15X,'PAIR',2X,'VELOCITY',2X,'DEVIA')
438 378 WRITE(6,3)
439 5000 CONTINUE
440 DO 76 LL=1,MX
441 TEMP1=0(LL,LBX)
442 IF (TEMP1.LE.0) GO TO 76
443 X=FLOAT(LL)/10.
444 AVD=VDIST(LL,LBX)/TEMP1
445 AVDU=VDIR(LL,LBX)/TEMP1
446 AVDX(LL,LBX)=AVDU/60.
447 SDV=0.
448 SGD=0.
449 IF (TEMP1.LT.2.) GO TO 67
450 SDV=SQRT((SQD(LL,LBX)-TEMP1*AVD*AVD)/(TEMP1-1.))
451 SGD=SQRT((SQDU(LL,LBX)-TEMP1*AVDU*AVDU)/(TEMP1-1.))
452 67 WRITE(6,77)X,TEMP1,AVD,SDV,AVDU,SGD
453 77 FORMAT(I1,6X,F4.2,4X,F4.2,4X,F6.2,4X)
454 76 CONTINUE
455 IF (OUTPUT(5).EQ.0) GO TO 5001
456 WRITE(6,5)
457 5 FORMAT(I1,///)
458 IA=001
459 WRITE(6,4)
460 4 FORMAT(I10,3X,'TIME OF DAY',3X,'AVERAGE',4X,'STANDARD',3X,'PAIR',3X,'VELOCITY',3X,'AVERAGE',3X,'STANDARD'/15X,'PAIR',3X,'VELOCITY',3X,'AVERAGE','','STANDARD'/)
461 5001 CONTINUE
462 DO 78 LI=1,12
463 TEMP1=P(LI,LBX)
464 78 I2=IA+199
465 IF (TEMP1.EQ.0) GO TO 48
456  AVT=VT*(LI+LIX)/TEMPI
457  AVL*(LI+LIX)=AVT
458  IF(OUTPUT(SXLEQ,0)) GO TO 78
459  SQT=0.
460  IF(TEMPI+LT+2.) GO TO 68
461  SQT=SQR((L+SQT*(LI+LIX)-TEMPI*AVT/AVT*(TEMPI-1.))
462  GO TO 68
463  A
464  AVT=0.
465  SQT=0.
466  WRITE(6,79) IA,IZ,AVT,SQT,TEMPI
467  79 FORMAT(1H4I4X,14,14I4X,F6.2,5X,F6.2,6X,F4.0)
468  IA=IA+200
469  78 CONTINUE
470  IF(OUTPUT(SXLEQ,0)) GO TO 5002
471  DO 1 100=1,4
472  IF(NTZ(10Q+LIX)+EQ,0) GO TO 8
473  AVTZ(10Q+LIX)=AVTZ(10Q+LIX)/NOTZ(10Q+LIX)
474  IF(NTZ(10Q+LIX)+LT+2) GO TO 8
475  SQTZ(10Q+LIX)=SQR((AVTZ(10Q+LIX)-NOTZ(10Q+LIX)*AVTZ(10Q+LIX)
476  1 **2)/(NOTZ(10Q+LIX)-1).
477  8 CONTINUE
478  451 FORMAT(1H11,T125,A4,///)
479  WRITE(6,9)
480  9 FORMAT(1H1,///)
481  WRITE(6,4)
482  4 WRITE(6,14) AVTZ(1,LIX),SQTZ(1,LIX),NOTZ(1,LIX)
483  14 FORMAT(1H4X,2X,8 PM TO 5 AM* T19,F6.2,5X,F6.2,5X,14)
484  WRITE(6,16) AVTZ(2,LIX),SQTZ(2,LIX),NOTZ(2,LIX)
485  16 FORMAT(1H4X,2X,5 AM TO 8 PM* T19,F6.2,5X,F6.2,5X,14.1
486  1. NO R/SH MRS.)
487  WRITE(6,11) AVTZ(3,LIX),SQTZ(3,LIX),NOTZ(3,LIX)
488  11 FORMAT(1H4X,2X,9 AM TO 9 AM* T19,F6.2,5X,F6.2,5X,14)
489  WRITE(6,12) AVTZ(4,LIX),SQTZ(4,LIX),NOTZ(4,LIX)
490  12 FORMAT(1H4X,2X,**30 PM** T19,F6.2,5X,F6.2,5X,14///
491  S(LIX)=EV(LIX)/NO(LIX)
492  5(LIX)=DIABAR(LIX)
493  5(TC(LIX))=DUMBAR(LIX)
494  501 DELIBX=SQR((EV(LIX)**2)/NO(LIX))/NO(LIX)-1)
495  DOILB=(ED(LIBX)**2)/NO(LIBX))/NO(LIBX)-1))
496  503 SQU(T(FOUX,LIBX)**2)/NO(LIBX))/NO(LIBX)-1))
497  504 WRITE(6,86)
498  505 WRITE(6,87)S(LIBX),DI(LIBX),DS(LIBX),D(LIBX),TC(LIBX),TDF(LIBX)
499  506 WRITE(6,88)NO(LIBX)
500  507  86 FORMAT(1H11,*,SUMMARY STATISTICS*,*,T25,*,AVERAGE*,*,T35,*,STD. DEVIA
501  508  87 FORMT(H100,4X,*VELOCITY*,T25,F10.4,T35,F10.4,*,*,DISTANCE*,
502  88 FORMT(H100,4X,*NUMBER OF OBSERVATIONS = *,F5.0)
510  502 CONTINUE
GRAPHICAL OUTPUT

C
N=20.*D(ISMX)
1F(FLOAT(N) .LT. 20.*D(ISMX)) N=N+1
CALL GRPH(1,LBX,TPBX,N)
CALL GRPH(3,LBX,TPBX,N)
CALL GRPH(2,LBX,TPBX,48)
376 CONTINUE
C
GO TO 1
STOP
FND

C

SUBROUTINE GRPH(KLX,LBX,TPBX,N)
COMMON /INT/ FIRST,SECONDO,ALL,ZER,ONE,TWO,THREE,FOUR,FIVE,SIX,
EIGH,BLANK,PLUS,CONC,DEC,STAR,BAVE,AVGE
REAL FIRST/1-ST/,SECONDO/2-HD/,ALL/ALL/
LOGICAL/ZER,ONE,TWO,THREE,FOUR,FIVE,SIX/,EIGH,BLANK,PLUS,CONC,STAR
END

SUBROUTINE GRPH(KLX,LBX,TPBX,N)
COMMON /INT/ FIRST,SECONDO,ALL,ZER,ONE,TWO,THREE,FOUR,FIVE,SIX,
EIGH,BLANK,PLUS,CONC,DEC,STAR,BAVE,AVGE
COMMON /RSVP2/ U(1),C(3),AL(3),BETA(3),A(3),AVDX(0,3),
X SPTR(3),APR(3),
1 AVSX(15,3),DISTMX
COMMON /RSVP3/ G
DIMENSION XL(13)
LOGICAL? G(130,130)
LOGICAL? ZER,ONE,TWO,THREE,FOUR,FIVE,SIX,EIGH,BLANK,PLUS,CONC,
IDFC,STAR,BAVE,AVGE
WRITE(6,89)
89 FORMAT(111)
GO TO (31,32,31)XLX
31 WRITE(6,131) UN,TPBX
131 FORMAT(1H1,1X,MILES,10X,**OBSERVED POINT,5X,'A=AVGARE',5X,
1 T125,AA)
GO TO 200
32 WRITE(6,132) UN,TPBX
132 FORMAT(1H1,1X,TIME OF DAY,10X,**OBSERVED POINT,5X,'A=AVGARE',
1 T125,AA/T125,AA)
200 N=N+1
DO 101 K=1,N
DO 101 L=1,130
101 G(K,L)=BLANK
CALL PLOT(KLX,LBX)
IF(KLX.EQ.0) CALL ADD1(LBX)
IF(KLX.EQ.2) CALL ADD2(LBX)
IF(KLX.EQ.3) CALL ADD3(LBX)
DO 103 LY=1,130
103 GLX(LY)=SUB
DO 104 LX=16,130+10
104 GLX(LY)=PLUS
DO 105 LX=1,N
105 GLX(6)=CONC
IF(KLX.EQ.2) GO TO 301
LX=11
NP=10
INIT=0
DO 106 LX=1,N,10
106 INIT=INIT+1
GLX(1)=DEC
ICM=INIT/2 - INIT/2
IF(ICM.EQ.0) GLX(4)= FIVE
IF(ICM.EQ.0) GLX(4)= ZERO
IF(INIT.LE.11) GLX(2)= FIVF
IF(INIT.LE.9) GLX(2)= FIVF
IF(INIT.LE.7) GLX(2)= IHRF
IF(INIT.LE.5) GLX(2)= TWD
IF(INIT.LE.3) GLX(2)= ONE
IF(INIT.LE.1) GLX(2)= ZER
106 G(LX)=PLUS
107 GO TO 302
301 NP=8
302 LI=10
303 INIT=0
304 G(2,1)=ZER
305 G(2,2)=ZER
306 G(2,3)=ZER
307 G(2,4)=ZER
308 DC 306 LX=L7, W, NP
309 INIT=INIT+1
310 G(LX,4)=ZFR
311 G(LX,3)=ZER
312 IF(INIT.EQ.5) G(LX,1)=T#0
313 IF(INIT.EQ.5) G(LX,2)=ZER
314 IF(INIT.LE.4) G(LX,1)=ONE
315 IF(INIT.LE.2) G(LX,1)=TFR
316 IF(INIT.EQ.4) G(LX,2)=S1X
317 IF(INIT.EQ.3) G(LX,2)=TWO
318 IF(INIT.EQ.2) G(LX,2)=FIG
319 IF(INIT.EQ.1) G(LX,2)=FOUR
320 G(LX,6)=PLUS
321 XL(1)=0
322 IF(KLM.EQ.2) GO TO 172
323 WRITE(6,112)
324 112 FORMAT(1H ,T40.1, DURATION = MIN, /)
325 DO 108 JL=2,13
326 XL(JL)=XL(JL-1) + 1.
327 GO TO 300
328 108 XL(JL)=XL(JL-1) + 5.
329 WRITE(6,111)XL(IP), IP=1, 13)
330 111 FORMAT(1H ,T40.1, VELOCITY = X, P, H, /)
331 DO 100 JL=2,13
332 WRITE(6,113)
333 100 XL(JL)=XL(JL-1) + 5.
334 WRITE(6,111)XL(IP), IP=1, 13)
335 111 FORMAT(1H ,T40.1, VELOCITY = X, P, H, /)
336 DO 107 INX=1, M
337 107 WRITE(6,109)(G(INX,J), J=1, 130)
338 109 RETURN
339 END
340
341 SUBROUTINE PLOT(XL, LNX)
342 COMMON /INTL/, FIRST, ECOND, ALL, ZER, ONE, TWO, THREE, FOUR, FIVE, SIX,
343 EIG, BLK, SUB, PLUS, CONC, DEFC, TM, BAVG, AVG
344 COMMON /RSVP1/, VEL(2000), TIM(2000), TRAVM(2000), DUR, JD, D, UN, JCOUNT, INX
345 COMMON /RSVP2/ L
347 LOGICAL#1 G(130, 130)
348 LOGICAL*1 TERNONE, TOW, THREE, FOUR, FIVE, SIX, EIG, BLK, SJH, PLUS, CONC,
349 DEFC, TM, BAVG, AVG
350 DO 102 I=1, JCOUNT
351 IF(LRM.EQ.3) GO TO 116
352 IF(IDU(I).NE.LBX) GO TO 102
353 116 IF(KLM.EQ.2) GO TO 115
354 IF(IX.GT.10.05*TRAVM(I)+1) 1 Y=(2000.0*(TIM(I)+.0007))/20 + 6
355 1 Y=MIND(IY, 130)
356 GO TO 114
357 115 IY=(IX*(TD(I)+20))/100 + 2
358 IY=(20.0*(VEL(I)+25))/10 + 6
359 IF(IX.GT.130) IY=130
360 IF(IY.GT.130) IY=130
361 114 G(IY, IY)=STARE
362 102 CONTINUE
363 RETURN
364 END
SUBROUTINE AND1(LBX)
COMMON /INTL/ FIRST, SCOND, ALL, ZER, ONE, TWO, THREE, FOUR, FIVE, SIX,
      EIG, BLANK, SUB, PLUS, CONC, DEC, STAR, BAVE, AVGE
COMMON /RSVP2/ B(3), C(3), AL(3), BETA(3), A(3), AVDX(80, 3),
      X BPR(3), APR(3),
      1 AV(15, 3), DSTMX
COMMON /RSVP3/ G
LOGICAL*1 G(130, 130)
LOGICAL*1 ZER, ONE, TWO, THREE, FOUR, FIVE, SIX, EIG, BLANK, SUB, PLUS, CONC,
      IDEC, STAR, BAVE, AVGE
DO 171 I=1, MX
IF (AVDX(I) .LE. 0.0) GO TO 171
171 CONTINUE
RETURN
END

SUBROUTINE ADD2(LBX)
COMMON /INTL/ FIRST, SCOND, ALL, ZER, ONE, TWO, THREE, FOUR, FIVE, SIX,
      EIG, BLANK, SUB, PLUS, CONC, DEC, STAR, BAVE, AVGE
COMMON /RSVP2/ B(1), C(3), AL(3), BETA(3), A(3), AVDX(80, 3),
      X BPR(3), APR(3),
      1 AV(15, 3), DSTMX
COMMON /RSVP3/ G
LOGICAL*1 G(130, 130)
LOGICAL*1 ZER, ONE, TWO, THREE, FOUR, FIVE, SIX, EIG, BLANK, SUB, PLUS, CONC,
      IDEC, STAR, BAVE, AVGE
KC=2
DO 204 I=1, 2
ICY=(204*AV(1, LBX)+25)/10+6
KC=KC+4
KD=KC+3
DD 206 J=KC, KD
G(I, JY)=AVGE
206 CONTINUE
204 CONTINUE
RETURN
END

SUBROUTINE ADD3(LBX)
COMMON /INTL/ FIRST, SCOND, ALL, ZER, ONE, TWO, THREE, FOUR, FIVE, SIX,
      EIG, BLANK, SUB, PLUS, CONC, DEC, STAR, BAVE, AVGE
COMMON /RSVP2/ B(1), C(3), AL(3), BETA(3), A(3), AVDX(80, 3),
      X BPR(3), APR(3),
      1 AV(15, 3), DSTMX
COMMON /RSVP3/ G
COMMON /RSVP4/ ASPLIN, BSPLIN, CSPLIN, DASPLIN
LOGICAL*1 G(130, 130)
LOGICAL*1 ZER, ONE, TWO, THREE, FOUR, FIVE, SIX, EIG, BLANK, SUB, PLUS, CONC,
      IDEC, STAR, BAVE, AVGE
XY=0.
N=DSTMX*10.
DO 202 I=1, NT
XY=XY+1
202 CONTINUE
IX=(20, NXY)+1
Y=SOR(TY) .LT. C(LBX)/60.*
1F (Y .LT. 0.0) OR (Y .GE. 2.0) GO TO 205
IY=12300.*Y/20+6
EI=BLANK, SUB, PLUS, CONC,
205 Y=XY*3(LBX)*A(LBX)
204 Y=Y/60.*
1F (Y .LT. 0.0) OR (Y .GE. 2.0) GO TO 205
ERROR: Document content not legible.
$S1=0$

746 DO 300 J=1,NG

747 $S1=S1*N(J)*((T(J)-A*S0(J)))^2$

748 NPART=NPART*N(J)

749 300 CONTINUE

750 $S2=0$

751 DO 400 J=M,N

752 $S2=S2+N(J)*((T(J)-A^2-R0(J)))^2$

753 400 CONTINUE

754 Q1=$S1+S2$

755 IF(Q1.GE.QMIN) GO TO 195

756 QMIN=Q1

757 NMIN=NPART

758 AMIN=B

759 GMIN=G

760 199 CHK=Q1-QMIN

761 IF(CHK.GT.0.1) GO TO 201

762 IF(QMIN.EQ.NSUM) GO TO 201

763 200 CONTINUE

764 201 CONTINUE

765 C=2.*MIN+SQRT(GMIN)

766 AX=C*SQRT(GMIN) - BMIN*GMIN

767 ASPLIN=AX

768 BSPLIN=AMIN

769 CSPLIN=C

770 DSPLIN=GMIN

771 RETURN

772 END

773 SUBROUTINE SPLIN2(U,M,RHSS)

774 COMMON/RSPV4/,ASPLIN,BSPLIN,CSPLIN,DSPLIN

775 AX=ASPLIN

776 BMIN=BSPLIN

777 C=CSPLIN

778 GMIN=DSPLIN

779 VCR=60.*BMIN

780 ACC=240.*C**2

781 DC=GMIN/VCR

782 WRITE(6,93) AX,BMIN,C,GMIN

783 WRITE(6,93) AX,BMIN,C,GMIN

784 91 FORMAT(I14) MODEL 3 SQUARE ROUT - LINEAR (SPLINE) FIT ',T,23, .

785 1A4(')

786 WRITE(6,92)

787 92 FORMAT(I10,'COMPANY',2X,'CRUISING',2X,'ACCELERATION',2X, .

788 'CRUISING',/12, .

789 'VELOCITY',T22,'(M,P,H,PE0,T3H,DISATCE',T12,'(M,P,H)',T23,

790 'MIN)',T36,'(NILE)',/17)

791 WRITE(6,64) U,M,RHSS

792 64 FORMAT(I10,2X,4X,5X,F5.2,7X,F7.2,9X,F5.2)

793 WRITE(6,93) AX,BMIN,C,GMIN

794 93 FORMAT(I10,'PARAMETER: A = ',F6.3,' B = ',F6.3,' C = ',F6.3,

795 ' D = ',F5.2,

796 WRITE(6,94) SPLSSQ

797 94 FORMAT(*SUM OF SQUARE DEVIATIONS = ',F10.2)

798 WRITE(6,95)

799 95 FORMAT(*,I10,2X,*D',4X,'R - FITTED/

800 XY=0.

801 DO 610 I=1,30

802 XY=XY+/1

803 SPT=AX + RMIN*XY

804 IF(XY .LE. GMIN) SPT=C*SQRT(XY)

805 WRITE(6,611) XY,SPT

806 611 FORMAT(F3.1,4X,F7.2)

807 610 CONTINUE

808 RETURN

809 END
Appendix E

SAMPLE PROGRAM OUTPUT
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Figure 2. Listing of the experimental data.
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Fig. 2 (continued)

| 2.48 | 1.10 | 26.57 | 2258 | 5172 (1) | 113 (1) | L | U |
| 2.50 | 1.00 | 24.00 | 1339 | 2224 (1) | 37 (1) | L | U |
| 2.50 | 1.50 | 36.00 | 1444 | 2212 (1) | 97 (1) | U | U |
| 2.53 | 1.40 | 33.16 | 2006 | 1841 (1) | 57 (1) | L | U |
| 2.53 | 1.00 | 24.63 | 2272 | 5621 (7) | 62 (7) | L | U |
| 2.55 | 1.50 | 35.29 | 1852 | 1735 (1) | 175 (1) | L | U |
| 2.55 | 0.20 | 29.50 | 1911 | 6225 (1) | 163 (1) | L | U |
| 2.57 | 1.40 | 32.75 | 1633 | 8416 (2) | 18 (2) | L | U |
| 2.58 | 0.40 | 9.29 | 1113 | 8217 (1) | 51 (1) | L | U |
| 2.58 | 0.70 | 10.26 | 2021 | 8435 (1) | 187 (1) | L | U |
| 2.62 | 1.30 | 29.60 | 2149 | 8421 (1) | 106 (1) | L | U |
| 2.65 | 1.30 | 20.43 | 25 | 1533 (2) | 111 (2) | L | U |
| 2.67 | 0.50 | 11.25 | 2312 | 7337 (1) | 112 (1) | L | U |
| 2.67 | 0.90 | 20.25 | 1262 | 2222 (2) | 67 (2) | L | U |
| 2.67 | 0.80 | 18.00 | 1559 | 5276 (2) | 49 (2) | L | U |
| 2.70 | 1.60 | 13.33 | 1305 | 4351 (1) | 146 (1) | L | U |
| 2.72 | 1.30 | 28.71 | 1218 | 4351 (1) | 145 (1) | L | A |
| 2.72 | 0.90 | 19.08 | 2204 | 3272 (1) | 82 (1) | L | U |
| 2.73 | 1.90 | 41.71 | 954 | 6305 (1) | 170 (1) | L | U |
| 2.75 | 0.50 | 10.91 | 1723 | 5277 (2) | 7 (2) | L | U |
| 2.75 | 1.10 | 29.00 | 2305 | 8413 (2) | 300 (2) | L | U |
| 2.77 | 1.20 | 17.14 | 1459 | 3324 (1) | 293 (1) | L | U |
| 2.80 | 0.80 | 14.40 | 1635 | 6321 (2) | 179 (2) | L | U |
| 2.92 | 0.40 | 24.00 | 1347 | 9251 (1) | 70 (1) | L | U |
| 3.00 | 1.30 | 27.86 | 1215 | 4351 (2) | 219 (2) | L | U |
| 3.02 | 0.70 | 13.92 | 1930 | 4226 (2) | 104 (2) | L | U |
| 3.03 | 1.70 | 33.63 | 2021 | 5514 (1) | 136 (1) | L | U |
| 3.10 | 1.40 | 27.70 | 1347 | 5221 (2) | 64 (2) | L | U |
| 3.17 | 0.60 | 11.37 | 1352 | 8225 (1) | 195 (1) | L | U |
| 3.20 | 1.20 | 24.17 | 1710 | 8217 (1) | 136 (1) | L | U |
| 3.25 | 1.00 | 35.08 | 2232 | 4114 (1) | 45 (1) | L | U |
| 3.30 | 1.20 | 21.93 | 1233 | 5224 (1) | 92 (1) | L | U |
| 3.33 | 1.50 | 27.09 | 2352 | 3233 (1) | 90 (1) | L | U |
| 3.44 | 1.00 | 17.91 | 2030 | 6441 (2) | 59 (2) | L | U |
| 3.50 | 1.60 | 27.43 | 1430 | 2223 (2) | 155 (2) | L | U |
| 3.61 | 0.90 | 15.28 | 1522 | 6123 (2) | 59 (2) | L | U |
| 3.67 | 1.00 | 25.23 | 1859 | 2663 (1) | 49 (1) | L | U |
| 3.67 | 1.70 | 28.47 | 905 | 2631 (1) | 56 (1) | L | U |
| 3.70 | 1.30 | 21.57 | 2118 | 7421 (2) | 65 (2) | L | U |
| 3.73 | 1.60 | 26.42 | 1022 | 4515 (1) | 132 (1) | L | U |
| 3.87 | 1.50 | 24.66 | 201 | 6337 (1) | 173 (1) | L | U |
| 3.87 | 2.10 | 34.36 | 2330 | 2343 (2) | 27 (2) | L | U |
| 3.90 | 1.90 | 31.09 | 1620 | 3225 (2) | 168 (2) | L | U |
| 3.96 | 1.00 | 16.29 | 59 | 5113 (2) | 90 (2) | L | U |
| 4.00 | 1.20 | 19.48 | 2357 | 2347 (2) | 157 (2) | L | U |
| 4.00 | 1.20 | 19.20 | 1373 | 1412 (2) | 156 (2) | L | U |
| 4.05 | 1.40 | 21.82 | 1727 | 2434 (2) | 14 (2) | L | U |
| 4.05 | 2.00 | 29.63 | 1340 | 2434 (2) | 150 (2) | L | U |
| 4.10 | 0.90 | 13.22 | 638 | 6533 (2) | 100 (2) | L | U |
| 4.08 | 2.00 | 29.39 | 12325 | 12325 (1) | 65 (1) | L | U |
| 4.10 | 1.20 | 25.41 | 1459 | 3324 (1) | 160 (1) | L | U |
| 4.10 | 1.50 | 20.93 | 2031 | 2513 (1) | 270 (1) | L | U |
| 4.13 | 2.30 | 31.13 | 1834 | 2415 (2) | 43 (2) | L | U |
| 4.20 | 1.40 | 17.50 | 2202 | 3272 (2) | 44 (2) | L | U |
| 4.20 | 1.70 | 20.60 | 1959 | 8521 (1) | 54 (1) | L | U |
REPLICATES TO A BOX

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TOTAL RUNS = 164  NO. OF DISTINCT BOXES = 54

MEAN SQUARE ERROR = 0.11852

Figure 3. Analysis of replicates to a location.
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Figure 4. Assorted statistics.
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SSGD: 52.41, D. OF F.: 173, RSS: 0.99

### Model 1: T*C*SQRT(D) - FITTED

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Figure 5. The fit for Model 1.
MODEL 2 \( T = A + B \cdot D \)

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\( SSQD \) 43.52  26.20  80.06

\( D \) of \( F \) 172  53  243

\( R^2 \) 0.96  0.87  0.98

\( D \)  

\( T = A + B \cdot D \) - FITTED

| 0.1 | 0.63 | 1.05 |
| 0.2 | 0.80 | 1.21 |
| 0.3 | 0.98 | 1.37 |
| 0.4 | 1.15 | 1.53 |
| 0.5 | 1.32 | 1.68 |
| 0.6 | 1.49 | 1.84 |
| 0.7 | 1.66 | 2.00 |
| 0.8 | 1.83 | 2.16 |
| 0.9 | 2.00 | 2.31 |
| 1.0 | 2.17 | 2.47 |
| 1.1 | 2.35 | 2.63 |
| 1.2 | 2.52 | 2.79 |
| 1.3 | 2.69 | 2.94 |
| 1.4 | 2.86 | 3.10 |
| 1.5 | 3.03 | 3.26 |
| 1.6 | 3.20 | 3.43 |
| 1.7 | 3.37 | 3.57 |
| 1.8 | 3.54 | 3.73 |
| 1.9 | 3.71 | 3.89 |
| 2.0 | 3.89 | 4.05 |
| 2.1 | 4.06 | 4.20 |
| 2.2 | 4.23 | 4.36 |
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| 2.4 | 4.57 | 4.68 |
| 2.5 | 4.74 | 4.83 |
| 2.6 | 4.91 | 4.99 |
| 2.7 | 5.08 | 5.15 |
| 2.8 | 5.25 | 5.31 |
| 2.9 | 5.43 | 5.46 |
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**Figure 6.** The fit for Model 2.
Figure 7. The fit for Model 3.
### Figure 8. The fit for Model 4.

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### TIME OF DAY

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### SUMMARY STATISTICS

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*Figure 9. Data summaries.*
Figure 10. Graph of travel time vs. response distance, showing all experimental observations.
Figure 11. Graph of travel time vs. response distance, showing fitted curves for all four models.
Figure 12. Graph of travel velocity vs. time of day, showing all experimental observations.
Appendix F

TRAVEL TIME VS. RESPONSE DISTANCE
GRAPHS FOR SEVERAL CITIES
Figure 13. Graph of travel time vs. response distance for New York City.
Figure 14. Graph of travel time vs. response distance for Trenton, New Jersey.
Figure 15. Graph of travel time vs. response distance for Yonkers, New York.
Figure 16. Graph of travel time vs. response distance for Denver, Colorado.
REFERENCES


