NTIA Report 95-319 (6)

Performance Evaluation of Data Communication Services: NTIA Implementation of American National Standard X3.141 Volume 6. Data Display

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August 1995

PREFACE

Certain commercial products are identified in this document as examples of typical hardware which might be used to display graphical information. In no case does such reference imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the system is necessarily the best available for the purpose.

CONTENTS

FIGURES

TABLES

PERFORMANCE EVALUATION OF DATA COMMUNICATION SERVICES: NTIA IMPLEMENTATION OF AMERICAN NATIONAL STANDARD X3.141

VOLUME 6: DATA DISPLAY

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The six volumes of this report are:

Volume 1. Overview
Volume 2. Experiment Design
Volume 3. Data Extraction
Volume 4. Data Reduction
Volume 5. Data Analysis
Volume 6. Data Display

This volume shows how to use software that draws graphs of the ANS X3.102 primary delay performance parameters. The four types of two-dimensional graphs are histograms, box plots (i.e., abbreviated histograms), chronological plots, and regression lines. Histograms and box plots can represent data from either a single test or pooled data from multiple tests; only one histogram can be drawn on a page, but several box plots can be drawn on one page. Chronological plots represent data from a single test; several plots can be drawn on a page. Regression plots fit lines to points, each of which is a trial or the estimate of the mean of a test. Because the values occur at different quantifiable levels, regression lines usually represent data from multiple tests; several regression plots can be drawn on a page.

All system commands and routines are UNIX[tm] commands and shell scripts. The routines are intended to be used on the HP7475A vector plotter but can be used on other plotters if some routines are altered. Data for these routines usually come from the output of data reduction (Volume 4).

Box plots, chronological plots, and regression plots use the general-purpose plotting packages called **vp** and **vpz**, which could be used for other graphs.

Key words: box plots; chronological plots; data communication systems; histograms; HP7475A vector plotter; linear regression plots; primary delay performance parameters.

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1. INTRODUCTION

1.1 Performance Parameters and Available Plots

Table 1b is a list of the 24 ANS X3.102 performance parameters categorized as delay, rate, and failure probability parameters:

- Delay. The four primary delay parameters (i.e., Access Time, Block Transfer Time, Source Disengagement Time, and Destination Disengagement Time) can be analyzed by any of the four types of plots.[2]

- Rate. The primary rate parameter, User Information Bit Transfer Rate, can be analyzed by all but chronological plots. However, since there is only one value per test for this parameter, multiple tests would be required.[3]

- Failure Probability. The failure probability parameters can't be analyzed by this software.

The data display software provides four types of two-dimensional plots: histograms, box plots, chronological plots, and regression plots.

A histogram is an estimate of the population density function. It consists of vertical bars that approximate the continuous density function of a delay parameter. It can represent either data from a single test or pooled data from multiple tests. One histogram is drawn on each page.

A box plot is an abbreviated histogram (Box et al., 1978).[4] It can represent either data from a single test or pooled data from multiple tests. It is

- a vertical line segment extending from the minimum value, through the median, to the maximum value, and

- a narrow rectangle along the segment containing the middle 50% of the density. See Section 3.

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[2]Ancillary parameters can be drawn only if the shell script **mkvp** is altered.

[3]Generally, data display software can accept any number of trials per test provided it is greater than one. Since User Information Bit Transfer Rate and User Fraction of Input/Output Time have only one trial per test, files of these parameters are not created by shell scripts. The user must create a file of these data using a procedure similar to that discussed in Section 5.1.

[4]The box plot is named because of its shape.

a. Organization by primary communication function and performance criterion

PRIMARY COMMUNICATION FUNCTIONS				PERFORMANCE CRITERIA		
				SPEED	ACCURACY	DEPENDABILITY
	ACCESS			• ACCESS TIME • *USER FRACTION OF ACCESS TIME*	• INCORRECT ACCESS PROBABILITY	• ACCESS DENIAL PROBABILITY • ACCESS OUTAGE PROBABILITY
	USER INFORMATION TRANSFER	BIT TRANSFER		—	• BIT ERROR PROBABILITY • BIT MISDELIVERY PROBABILITY • EXTRA BIT PROBABILITY	• BIT LOSS PROBABILITY
		BLOCK TRANSFER		• BLOCK TRANSFER TIME • *USER FRACTION OF BLOCK TRANSFER TIME*	• BLOCK ERROR PROBABILITY • BLOCK MISDELIVERY PROBABILITY • EXTRA BLOCK PROBABILITY	• BLOCK LOSS PROBABILITY
		TRANSFER SAMPLE TRANSFER	TRANSFER AVAIL-ABLILTY	—	• TRANSFER DENIAL PROBABILITY	
			THROUGHPUT	• USER INFORMATION BIT TRANSFER RATE • *USER FRACTION OF INPUT/OUTPUT TIME*	—	—
	DISENGAGEMENT	SOURCE DISENGAGEMENT		• SOURCE DISENGAGEMENT TIME • *USER FRACTION OF SOURCE DISENGAGEMENT TIME*	• SOURCE DISENGAGEMENT DENIAL PROBABILITY	
		DESTINATION DISENGAGEMENT		• DESTINATION DISENGAGEMENT TIME • *USER FRACTION OF DESTINATION DISENGAGEMENT TIME*	• DESTINATION DISENGAGEMENT DENIAL PROBABILITY	

b. Organization by primary communication function and random variable

PRIMARY COMMUNICATION FUNCTIONS				RANDOM VARIABLES		
				DELAY	RATE	FAILURE
	ACCESS			• ACCESS TIME	• *USER FRACTION OF ACCESS TIME*	• INCORRECT ACCESS • ACCESS OUTAGE • ACCESS DENIAL
	USER INFORMATION TRANSFER	BIT TRANSFER		—	—	• BIT ERROR • BIT MISDELIVERY • EXTRA BIT • BIT LOSS
		BLOCK TRANSFER		• BLOCK TRANSFER TIME	• *USER FRACTION OF BLOCK TRANSFER TIME*	• BLOCK ERROR • BLOCK MISDELIVERY • EXTRA BLOCK • BLOCK LOSS
		TRANSFER SAMPLE TRANSFER	TRANSFER AVAIL-ABLILTY	—	—	• TRANSFER DENIAL
			THROUGHPUT	—	• USER INFORMATION BIT TRANSFER RATE • *USER FRACTION OF INPUT/OUTPUT TIME*	—
	DISENGAGEMENT	SOURCE DISENGAGEMENT		• SOURCE DISENGAGEMENT TIME	• *USER FRACTION OF SOURCE DISENGAGEMENT TIME*	• SOURCE DISENGAGEMENT DENIAL
		DESTINATION DISENGAGEMENT		• DESTINATION DISENGAGEMENT TIME	• *USER FRACTION OF DESTINATION DISENGAGEMENT TIME*	• DESTINATION DISENGAGEMENT DENIAL

Table 1. ANS X3.102 Performance Parameters

Because the box plot reduces the histogram, essentially to a vertical line segment, several "histograms" can be drawn side-by-side on a page for convenient comparison.

Chronological plots simply show the sequence of trial values of a test so that the effect of time can be seen – including dependence. Hence, the nature of chronological plots precludes using pooled data from multiple tests. Several chronological plots can be drawn on one page.

A regression plot consists of

- points representing either trial values or the estimates of means of tests conducted at different quantifiable levels of a variable condition and
- a line "fitted" to these points.

The line minimizes the sum of the squares of the differences between these points and corresponding points of the line. The slope of a regression line indicates the degree of dependence of the performance parameter upon the variable condition (at least for the levels represented). For example, a regression line would show the effect of the variable condition, Block Length, upon Block Transfer Time. Values are drawn at quantifiable levels of a variable condition. Generally, NTIA experiment design considers values obtained at different levels to constitute different tests. Hence, regression lines generally require multiple tests. An exception can occur with the variable condition, Time of Day: the trials in a sample can be considered to be replications within a given level (in which case multiple tests are required) or they can be considered to be single observations at different levels of Time of Day (in which case a single test is sufficient). In the latter case, a regression line is fitted to the data of a chronological plot. Several regression lines can be drawn on a regression plot.

Table 2 is a matrix that summarizes the available plots of primary delay parameters for single or multiple tests, and for single or multiple plots per page.

Table 2. Available Plots for Primary Delay Parameters

		PLOTS/PAGE	
		Single Plot	Multiple Plots
HISTOGRAMS	Single Tests	√	-
	Multiple Tests	√	-
BOX PLOTS	Single Tests	√	√
	Multiple Tests	√	√
CHRONOLOGICAL PLOTS	Single Tests	√	√
	Multiple Tests	-	-
REGRESSION PLOTS	Single Tests	√	√
	Multiple Tests	√	√

Section 2 shows how to draw histograms. Sections 3, 4, and 5 discuss the initial procedures for box plots, chronological plots, and regression plots, respectively. Section 6 discusses subsequent procedures that are common to these three types of plots. The Appendix is a software manual that is modelled after the UNIX[tm] software manual.

1.2 Data Files

The shell scripts **do**, **dopre**, and **doqik** generate the plot files for a single test (in **/usr/data/6d**).[5] These files are listed in Table 3 where nnnn represents the four digit test number. The name extensions are

- **chr** for chronological data,
- **his** for histograms,
- **leg** for legends,
- **mnu** for menus, and
- **tem** for templates.

[5]The names of all files, shell scripts, programs, and commands in this report are in bold type.

Table 3. Files Produced by **do** or **dopre** for Plots of Delay Parameters for Single Tests[6]

	FILES			
DELAY PARAMETERS	HISTOGRAMS	BOX PLOTS	CHRN. PLOTS	REGR. PLOTS
Access Time	**nnnndac.his** **nnnndac.tem** -	**nnnndac.chr** **nnnndac.leg** **nnnndac.men**	**nnnndac.chr** **nnnndac.leg** **nnnndac.men**	**nnnndac.chr** **nnnndac.leg** **nnnndac.men**
Block Transfer Time	**nnnndb2.his** **nnnndb2.tem** -	**nnnndb2.chr** **nnnndb2.leg** **nnnndb2.men**	**nnnndb2.chr** **nnnndb2.leg** **nnnndb2.men**	**nnnndb2.chr** **nnnndb2.leg** **nnnndb2.men**
Source Disengagement Time	**nnnndd1.his** **nnnndd1.tem** -	**nnnndd1.chr** **nnnndd1.leg** **nnnndd1.men**	**nnnndd1.chr** **nnnndd1.leg** **nnnndd1.men**	**nnnndd1.chr** **nnnndd1.leg** **nnnndd1.men**
Destination Disengagement Time	**nnnndd2.his** **nnnndd2.tem** -	**nnnndd2.chr** **nnnndd2.leg** **nnnndd2.men**	**nnnndd2.chr** **nnnndd2.leg** **nnnndd2.men**	**nnnndd2.chr** **nnnndd2.leg** **nnnndd2.men**

Data display software can be employed to provide a "quick look" (hence, **doqik**) at Access Time, Block Transfer Time, and Source Disengagement Time for a single test immediately after they are converted to ASCII text files. However, because the data have not been reduced, they will be somewhat inaccurate. Since the data display procedures are not implemented quickly, the benefit from plotting these premature files is uncertain.

Trace programs convert the output of data reduction programs into a form suitable for drawing by the data display programs. The shell script **do** invokes these programs. The data suitable for plotting, from either the conversion or reduction programs, will be a file consisting of two columns of unsorted data. The data must be sorted for the histogram, box, or regression programs, but they must be left in their original (chronological) order for the chronological plot.

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[6]Throughout this volume, **ddata.zzz** or **ddatai.zzz** (where i = 1, 2, ... ,N) will represent any of these file names. File names produced by **doqik** are identical to those in this table except the **d** that follows the fourth **n** is replaced by **q**. Further manual processing is required for those files with the **chr** extension in the case of box and regression plots.

If a histogram or box plot is to be made of the data pooled from multiple tests (say, N tests), the unsorted data from the tests must first be concatenated into a file before following the procedure outlined in the appropriate section.[7]

For example, to concatenate N **.chr** files, type

```
cat ddata1.chr .... ddataN.chr | awk '{print $2}' | sort -n > sorted.dat.
```

This leaves the N **ddatai.chr** files untouched but creates a new file called **sorted.dat**. Then, **sorted.dat** may be edited to remove all negative entries (which were entered to indicate trials that resulted in a failure).

To make **sorted.dat** for the N **.chr** files without having to edit to remove negative numbers later, type

```
cat ddata1.chr ... ddataN.chr | awk '$2 >=0 {print $2}' | sort -n > sorted.dat.
```

This command merges the N files, extracts the non-negative data, sorts it, and then writes the sorted data into the file **sorted.dat**. Again, the original files are untouched.

The software described here is designed to be as general as possible, so that the user can generate plots from any file of numerical data. The programs are also modular, so drawing a single graph requires several calls to separate programs. When it is desirable to draw the same type of graph for many different sets of data, it is tedious to enter all the graphic commands as demonstrated in this volume. Instead, the user should create a command file (using **sh** or **csh** – as described in the UNIX[tm] manual) which calls the programs in an appropriate order. Such command files are not provided by NTIA since they would differ significantly between applications.

[7]Regression plots require paired data. Since this concatenation uses only the second column of the paired data, the above procedure should not be used for regression plots.

1.3 Using Plotters

NTIA software is designed to use an HP7475A vector plotter, but it can use other plotters after appropriate modification.

The plotting software has probably been loaded from diskette 6, and the programs compiled (Section 7.2 of Volume 1). If it was not loaded or if it has been changed, in **~net/src/d6**, type

make all.

After compilation, type,

make move.

This command moves the plot commands to **~net/bin**.

1.3.1 Using the HP7475A Vector Plotter

An HP7475A vector plotter must be attached to a serial port of the computer and configured to run at 4,800 baud. To use a different baud, the routine **initplot()** in **~net/src/d6/lib** must be changed, and the data display programs must be recompiled.

The plotting subroutines assume that the plotter device is called **/dev/plot**. The plotter must be linked to this symbolic name. For example, if your plotter is connected to **tty01**, type

ln /dev/tty01 /dev/plot.

You must have write permission in the **/dev** directory to do this; if you do not, your system administrator must execute the link command when logged in as **root**. If you are not using the name **/dev/plot**, you can change the default name used by this software by editing the file **~net/src/d6/lib/plot.h** and changing the constant **P_PLOTTER** to another name. If this is changed, all the plotting programs must be recompiled as above.

1.3.2 Using Other Plotters

If you have another plotter, you must either modify the plotting programs **~net/src/d6/lib/*.c**, or substitute your equivalent subroutines for NTIA's within **hpgraph.c**, **vp.c**, **vpz.c**, **vpaxes.c**, and **vplegend.c**. All of these programs are in **~net/src/d6**.

2. DRAW HISTOGRAMS

A histogram is an estimate of a population density. It is created from outcomes in a sample obtained from a population. The outcomes are ordered, the abscissa is partitioned judiciously, and the percent of outcomes within each segment of the partitioned abscissa is determined. The histogram is created by drawing these percentages at the midpoint of each segment.[8]

The program **histogrm** takes as input a list of sorted numbers from a file (**sorted.dat**) and creates a histogram file containing a list of points describing histogram bars (**ddata.his**). The program **hpgraph** reads the data from a histogram file (**ddata.his**) and a template file (**ddata.tem**) and plots the results on **/dev/plot**. Figure 1 contains a sample histogram of Source Disengagement Time from a public data network.

Figure 2 is a structured design diagram showing the operator procedures required to draw a histogram of either a single test or a histogram of pooled data from multiple tests. For single tests processed by NTIA software, the first four procedures are accomplished by the shell script **do** (or **dopre**): It sorts the data, creates a plottable **.his** file (with an appropriate bar width), and creates the template file. If **do** or **dopre** has created the **.his** file for a desired test, skip to Section 2.4. Otherwise, proceed through the following three sections.

2.1 Sort the Data and Create a Plottable File

Executing the **histogrm** program on the sorted data file will create the histogram file. As previously mentioned, this file can be plotted by the graphics program **hpgraph**. The **histogrm** program recognizes the end of sorted data files as the first negative number, which must be appended.

---

[8]The shape of the histogram can suggest the population, then a chi-squared goodness of fit test can determine if there is a significant difference between the sample (histogram) and the suggested population (density).

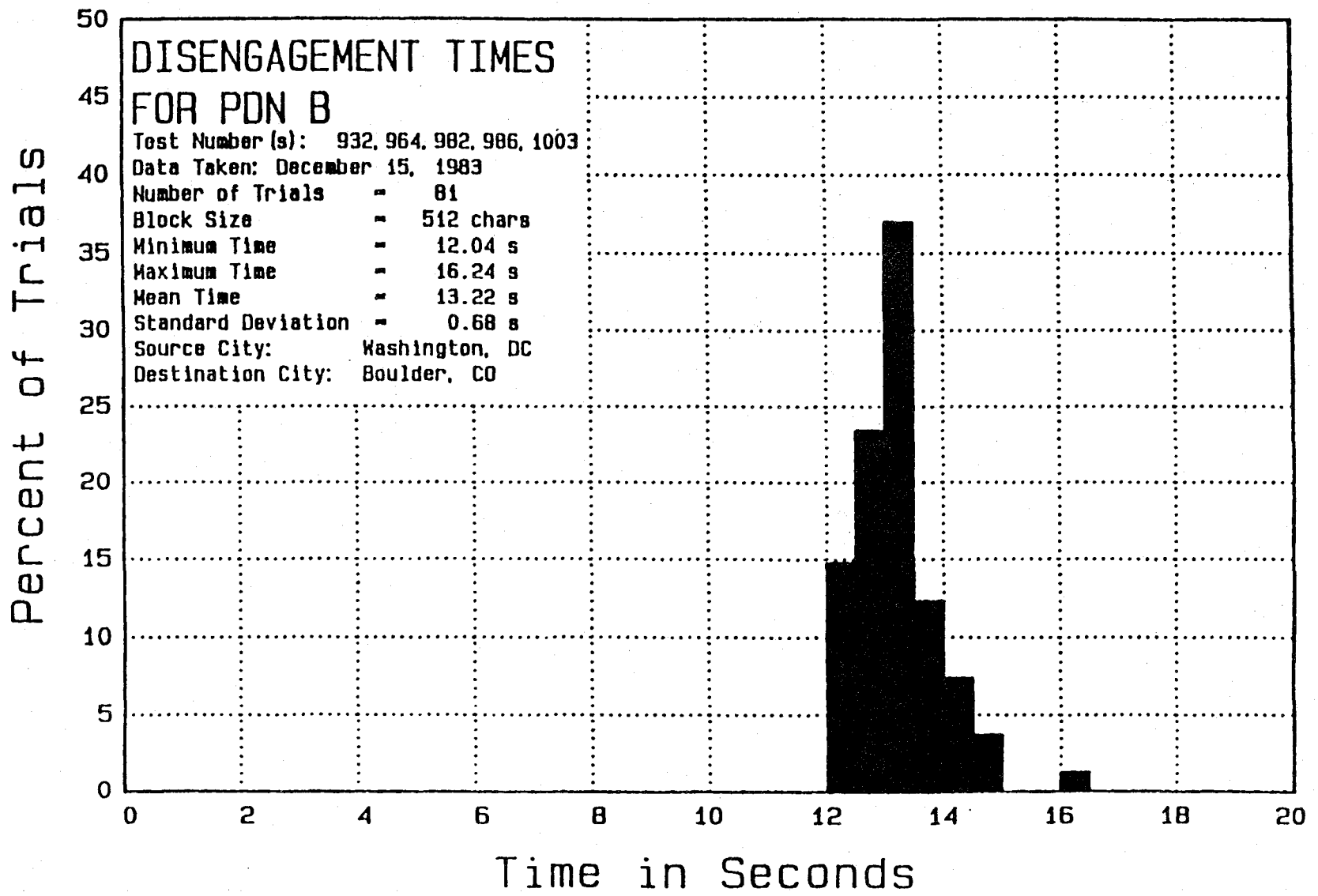

Figure 1. Example of histogram of Source Disengagement Time.

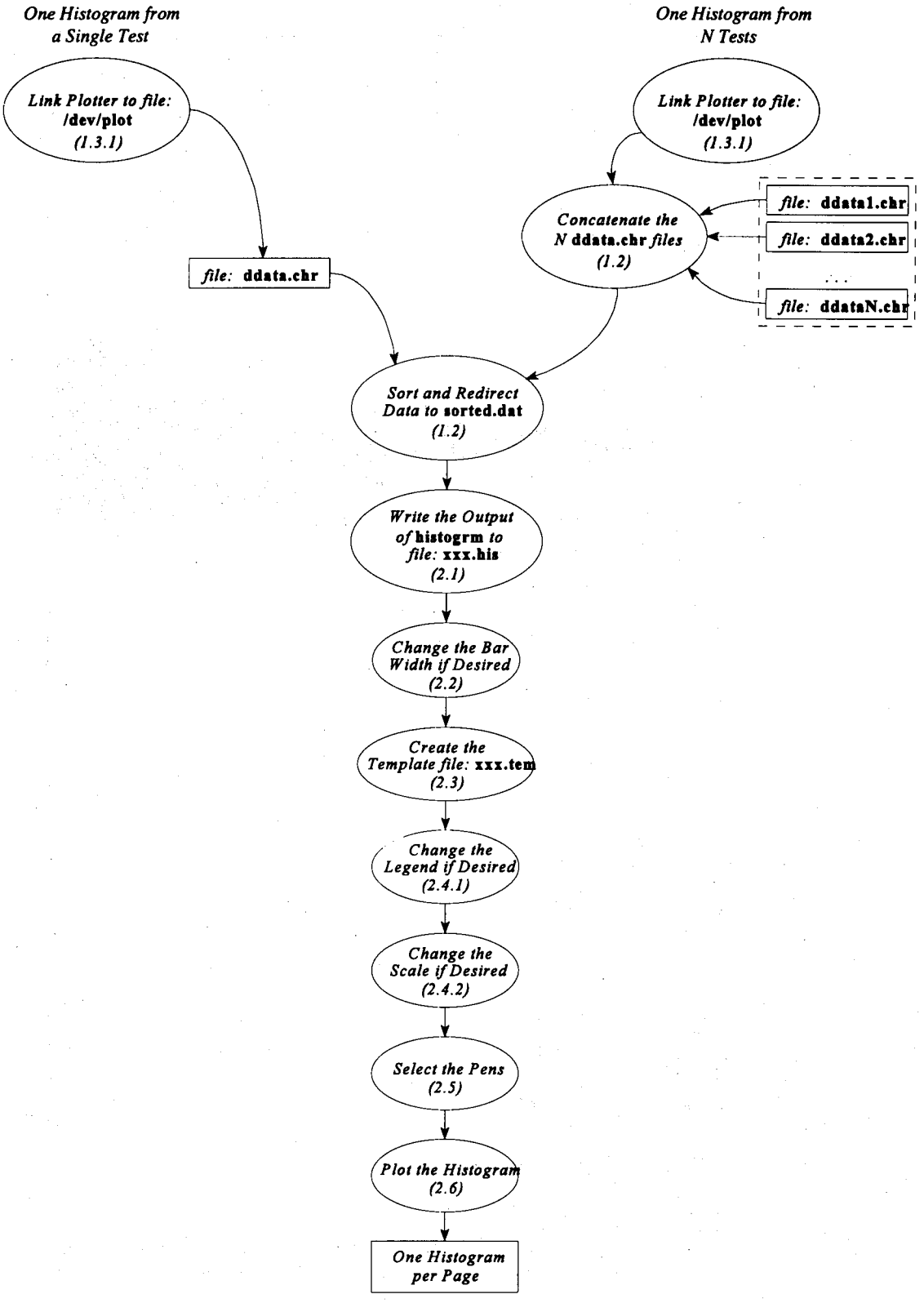

Figure 2. Structured design diagram of the procedures to draw a histogram.

To do this to **sorted.dat**, type,

echo "-1.0" >> sorted.dat.

As with **sort**, the output of **histogrm** goes to the standard output by default. Therefore, type,

histogrm sorted.dat > xxx.his

where **xxx** is a unique identifier for the histogram.

The **sorted.dat** file is created as described in Section 1.2.

2.2 Change the Bar Width

If, after plotting the data, it is decided that the value for the number of bars (i.e., 40) is inappropriate, the default value can be overridden with an optional argument on the command line.

To obtain 20 bars, for example, type,

histogrm sorted.dat 20 > xxx.his

2.3 Create the Template File

A template file is a file which contains the data for the legend and the name of the histogram data file that is to be plotted. A template file must be created for the histogram. Figure 3 shows the format required for the template file and an example of one. It can be prepared either by shell script (in the case of single tests processed by NTIA software) or manually (as required for pooled data, for example).

2.3.1 Histograms of Single Tests Processed by NTIA Software

For histograms of single tests processed by NTIA software, the shell scripts **do**, **dopre**, or **doqik** prepare the template files listed in Table 3 (i.e., nnnndac.tem, nnnndb2.tem, nnnndd1.tem and nnnndd2.tem).

```
ddata.tem:
----------
BLOCK TRANSFER
Network V
Time in Seconds
Percent of Trials
1111 1113
May 11, 1989
xfr 64
Boulder, CO
Boulder, CO
ddata.his

format:
-------
Title, line 1
Title, line 2
x-axis title
y-axis title
test number(s)
date of test
type of test (xfr or ovh) followed by size of blocks transferred
source site (site of test terminal)
destination site (site of test host)
name of histogram file
```

Figure 3. Sample template file.

2.3.2 Histograms of Other Data

For histograms of other data, the template file must be created from an editor. It must be named **xxx.tem** where **xxx** is some unique identifier for the histogram. The seventh line must contain either **ovh** (for access-disengagement tests) or **xfr** (for user information tests) and the size, in bytes, of the blocks transferred. Moreover, the last line of the template file must contain the name of the file containing the data, (e.g., **ddata.his**).[9]

2.4 The Functions of hpgraph

hpgraph has several important functions. It plots the legend, allows the scale to be changed, determines the spacing of the grid lines, numbers them, and labels the axes.

2.4.1 Plot The Legend

The program **hpgraph** uses the following lines of information from the template file: two titles, label for x-axis, label for y-axis, test number(s), date, type of test (and Block Size for user information transfer tests), Source Site, and Destination Site. **hpgraph** uses information from the histogram data file to place the legend in a corner of the graph that does not contain plotted data. The user may edit the template file to change the legend information.

2.4.2 Change the Scale

hpgraph determines the maximum x and y values on the graph. These can be overridden by adding a line at the bottom of the template file. This line will contain the desired maximum values of x and y (separated by a blank).

To do this, (using your x and y values) type

echo "x y" >> xxx.tem.

The values **x** and **y** will be read as floating point numbers, so end them with a decimal point if they are integers (e.g. 32., not 32).

[9]It will be the next to last line if the scale is changed as described in Section 2.4.2.

2.4.3 Other Functions

hpgraph also

- determines the spacing of grid lines, numbers them, and
- places the two axis labels from the template file next to the axes.

2.5 Select the Pens

Different pens are used to draw the border, the axes, the legend, the grid lines, and the histogram bars. Therefore the colors of the graph can be changed by using different combinations of pens in the plotter. Table 4 lists the function, color, and width of each pen as **hpgraph** believes it to be. The color of any part of the graph can be changed by switching pens in the plotter's pen wheel.

Before executing **hpgraph**, make sure the pens are loaded into the plotter correctly.

Table 4. Pen Usage in **hpgraph**

PEN #	FUNCTION	COLOR/WIDTH
1	Plot Border Label Axes Outline Bars	Black/7mm
2	Plot Legend	Black/3mm
3	Color Bars	Red/7mm
4	-	-
5	Plot Grid	Blue/3mm
6	-	-

2.6 Draw the Histogram

Histograms can be drawn either from single tests processed by NTIA software or from other data.

2.6.1 Histograms of Single Tests Processed by NTIA Software

To draw a histogram from data prepared by the shell script **do** or **dopre**, type

hpgraph ddata.

If the plot is to be made on a transparency, the program should be called with the **[t]** option. Type

hpgraph ddata t.

This option indicates to **hpgraph** that the plot is to be made slowly so the ink doesn't get smeared on the transparency.

2.6.2 Histograms of Other Data

To draw a histogram from data prepared manually, type

hpgraph xxx.

where the template file is named **xxx.tem**.

If the plot is to be made on a transparency, the program should be called with the [t] option. Type

hpgraph xxx t.

This option indicates to **hpgraph** that the plot is to be made slowly so the ink doesn't get smeared on the transparency.

3. DRAW BOX PLOTS

A box plot is a consolidated histogram. The outcomes of a sample are ordered. Then the following five values are determined: the minimum, the 25th percentile, the 50th percentile (i.e. the median), the 75th percentile, and the maximum. All five values are indicated by a tic mark on a line segment; further, the tic marks at the 25th and 75th percentiles form the ends of a slender rectangle (i.e., "box"). This rectangle emphasizes the middle 50% of the outcomes.

Since a box plot is much narrower than a histogram, several box plots, say M of them, can be drawn side-by-side for comparison. The data for each plot can come from a single test or the pooled data from N tests. Figure 4 shows several box plots on a single page. Figure 5 is a structured design diagram showing the procedure to draw box plots.

3.1 Sort the Data

The box plot programs operate on a sorted data file. For multiple tests, this file is created by the procedure described in Section 1.2. For single tests, the shell script **do** produces an unsorted **.chr** file.

To create the sorted data file (having no negative numbers), type

```
awk '$2 >= 0 {print $2}' ddata.chr | sort -n > sorted.dat.
```

The conditional **$2 >= 0** may be omitted if negative data are to be included in **sorted.dat**.

3.2 Determine the Five Values of Each Box Plot

The program **quartile** produces the five values (minimum, median, maximum, and upper and lower 25th percentiles) from **sorted.dat**.

Type

```
quartile sorted.dat > quart.
```

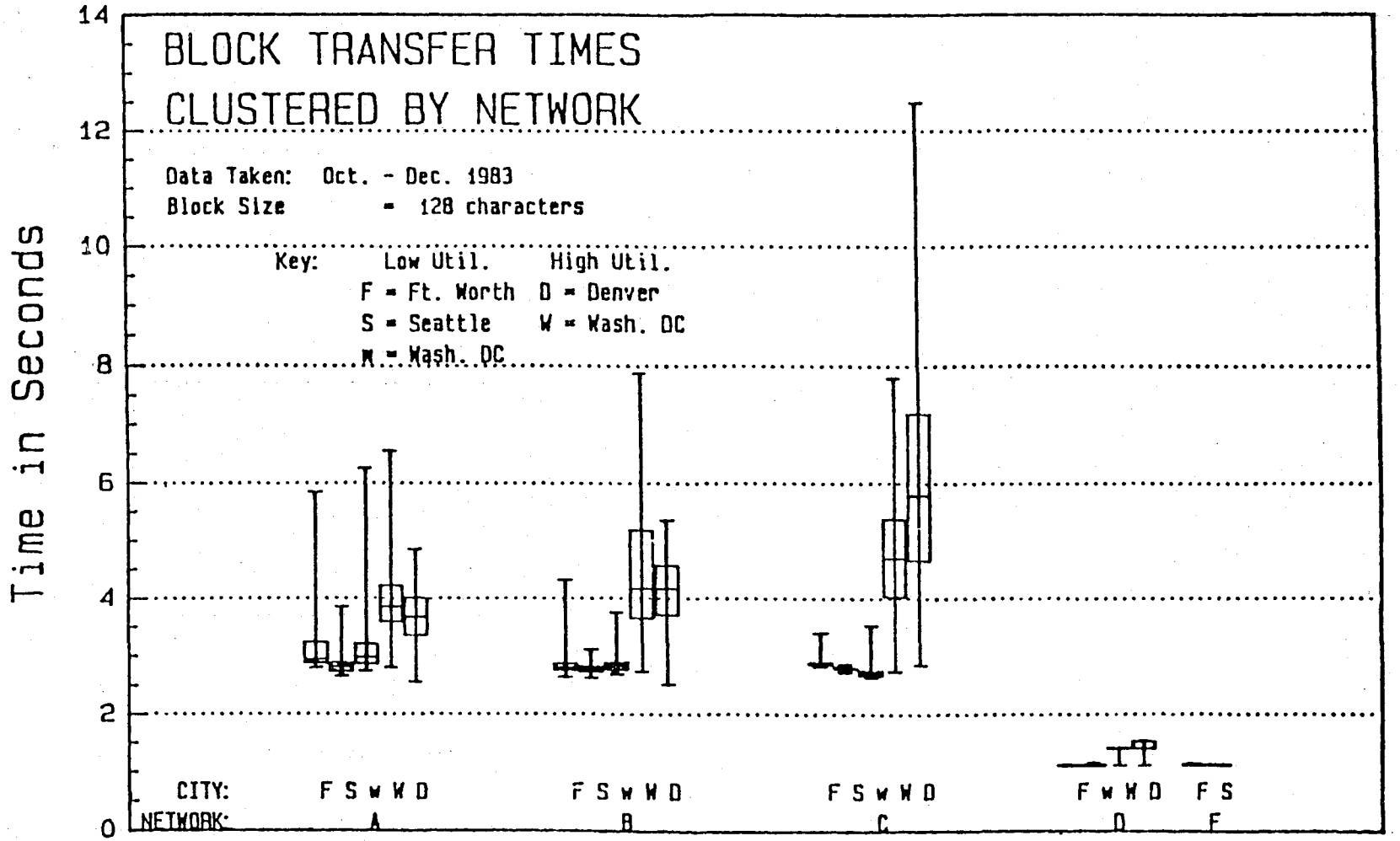

Figure 4. Example of box plots of Block Transfer Times.

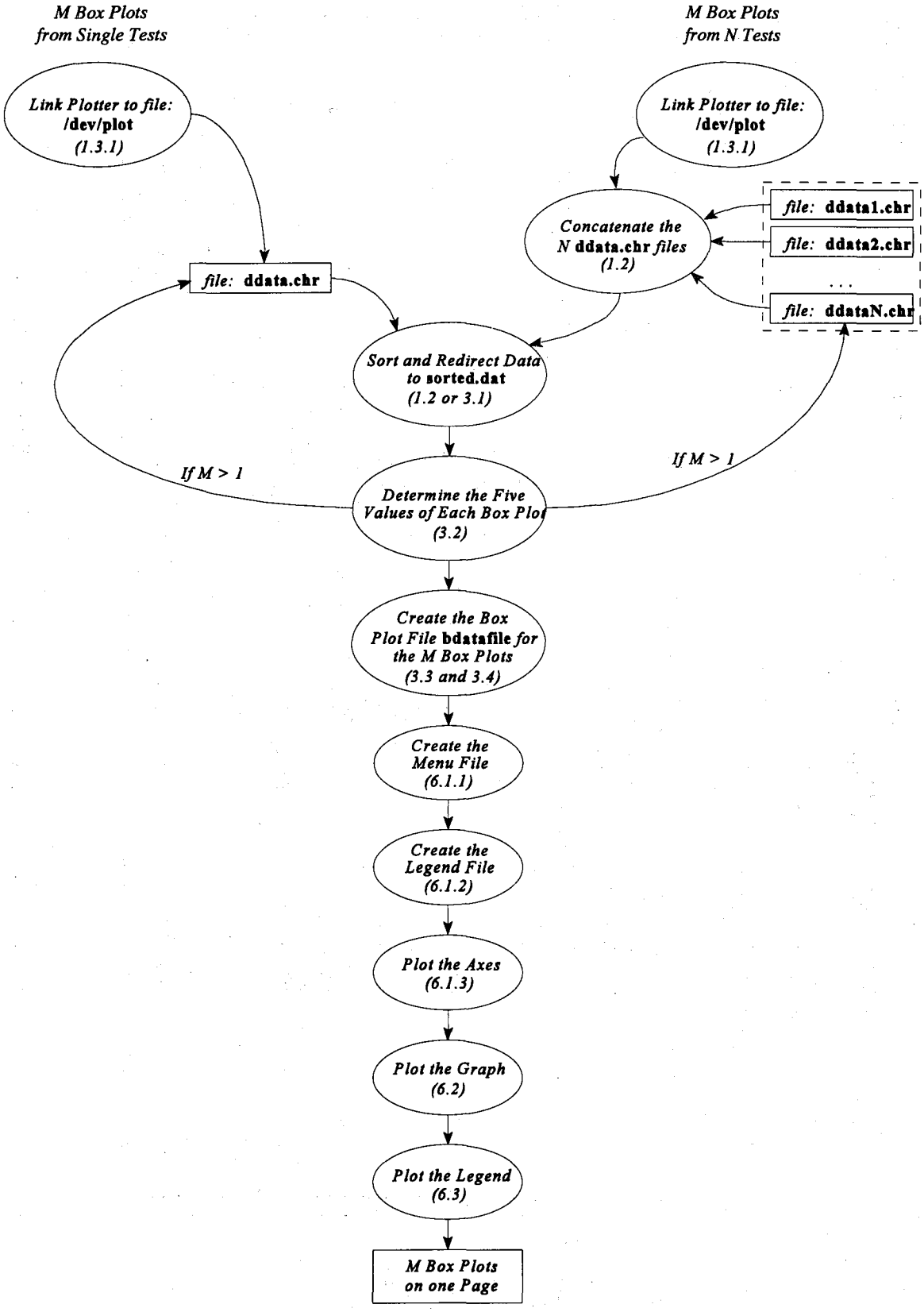

Figure 5. Structured design diagram of the procedures to draw box plots.

Figure 6a shows sample output from **quartile**.

```
39.24          41.05          41.91          42.83          49.29
```

a. Sample output of **quartile** (**quart**)

```
1.70        39.24
1.66        39.24
1.75        39.24
1.70        39.24
1.70        41.91
1.61        41.91
1.79        41.91
1.70        41.91
1.70        49.29
1.66        49.29
1.75        49.29
1.70        49.29
1.70        42.83
1.61        42.83
1.61        41.05
1.79        41.05
1.79        42.83
1.70        42.83
```

b. Sample output of **box** (**bdatafile**).

Figure 6. Sample output of **quartile** and **box**.

3.3 Create the Box Plot File

The output of **quartile** is input to program **box**.

Type

```
box quart > bdatafile.
```

The file **bdatafile** consists of a series of data points describing the box plot, with the plot's relative center being 1 on the x-axis.[10]

[10]The plot's absolute position on the page depends upon how the x- and y-axes are defined in the menu file (See Section 6.1.1).

If the graph is to be placed elsewhere on the x-axis, include a second argument to **box** that is the desired x-axis location. For example, type

```
box quart 2.2 > bdatafile.
```

to center the plot around the line x = 2.2.

Figure 6b shows sample output from **box**. The file **bdatafile** can be plotted by the program **vpz**. Unless multiple box plots are to be drawn, go to Section 6.

3.4 Prepare Data from Multiple Box Plots

If a number of box plots, say M, are to be drawn on the same page, then the coordinates of each must be concatenated and separated by a pair of coordinates with a negative value of Y; this negative value causes the plotting routine **vpz** to lift the pen between box plots.

The data are now ready for plotting. The file **bdatafile** is the data file to be plotted by **vpz** in Section 6.

Type

```
cat bdatafile1 > bdatafile
echo "0.0 -1.0" >> bdatafile
cat bdatafile2 >> bdatafile
echo "0.0 -1.0" >> bdatafile
                .  .  .
cat bdatafileM >> bdatafile.
```

If the M plots contain negative data, **vpz** must be called for each **bdatafile**. In this case, do not concatenate the separate box plot files.

4. DRAW CHRONOLOGICAL PLOTS

A chronological plot is a plot of the outcomes from a sample in the order they occurred. This plot is useful to spot trends as a function of time. It also shows dependence that may exist among trials; dependence can seriously affect the precision of an estimate, decreasing it if the autocorrelation is positive. (See either Volume 2 or Volume 5.) Figure 7 shows chronological plots of tests of Block Transfer Time. Figure 8 is the operator procedure diagram required to generate a chronological plot.

Since a chronological plot consists of data in the order they were collected, do not sort this data. If data were obtained from NTIA software and a single chronological plot is desired, skip to Section 6 and use the files listed in Table 3.

4.1 Prepare Data for a Single Chronological Plot

To prepare a single column of data in a file for plotting, cardinal numbers are inserted in a column on the left.[11] This can be accomplished with the **awk** command. The following writes the output of **awk** into a file. The file **cdatafile** is the data file to be plotted by **vpz**.[12]

Type

```
awk '{ print NR, "  " , $1 }' datafile > cdatafile.
```

Go to Section 6 since a single plot is desired.

4.2 Prepare Data for Multiple Chronological Plots

If several, say M, chronological plots are to be drawn on one page, the M files must be processed as in Section 4.1. For example, files containing single data columns must have cardinal numbers inserted in a column to the left. This can be accomplished with multiple invocations of the **awk** command used in Section 4.1.

---

[11]This assumes that the independent variable is the trial number.

[12]Negative numbers that denote failures are retained for chronological plots.

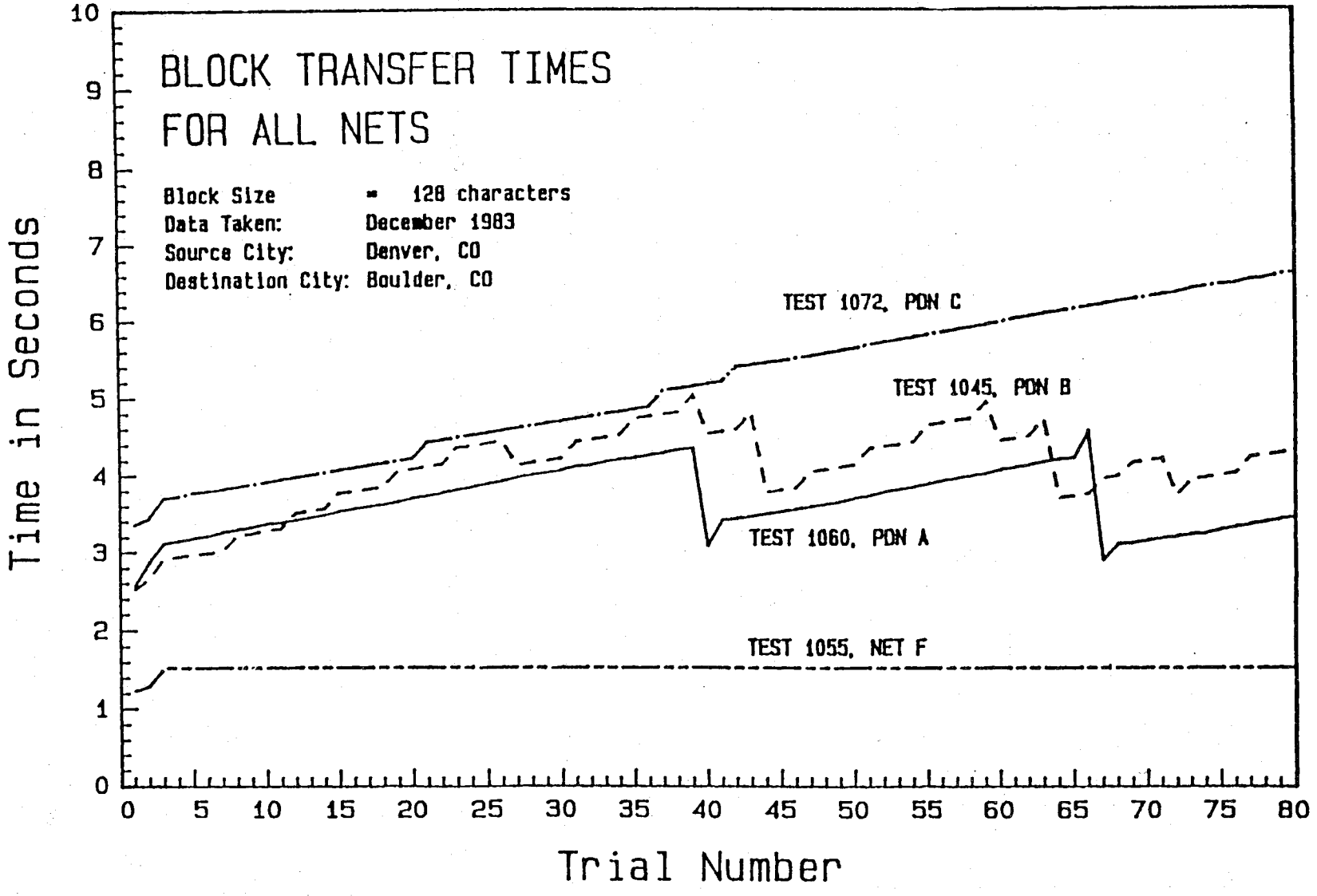

Figure 7. Example of chronological plots of Block Transfer Times.

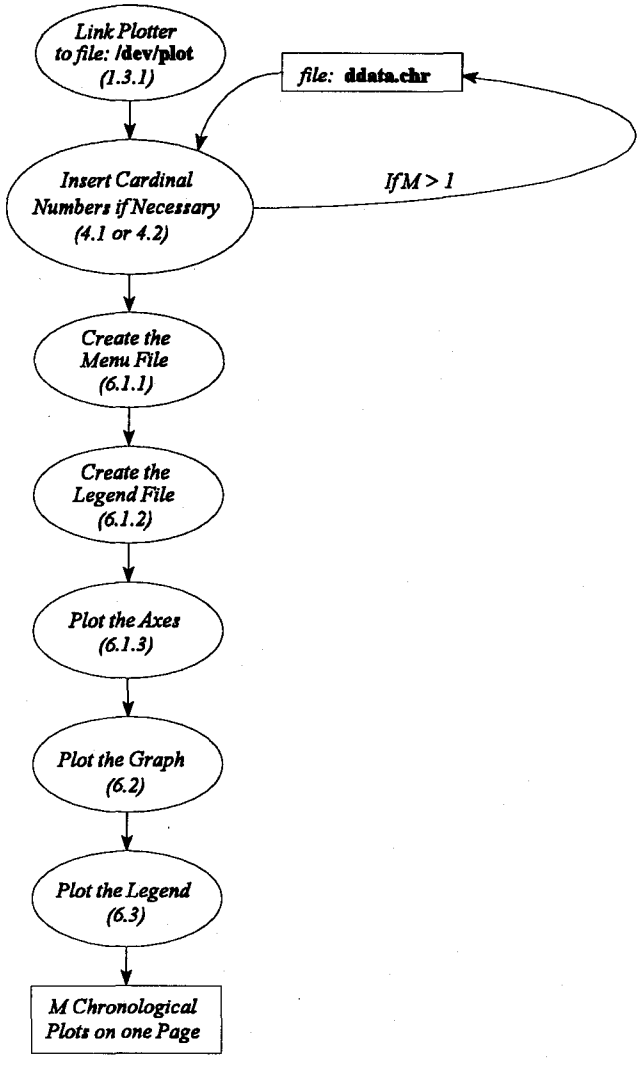

Figure 8. Structured design diagram of the procedures to draw chronological plots.

Type

```
awk '{ print NR, " " , $1 }' datafile1 > cdatafile1
awk '{ print NR, " " , $1 }' datafile2 > cdatafile2
                              ...
awk '{ print NR, " " , $1 }' datafileM > cdatafileM.
```

Each of the resulting M files may be used separately with **vpz** to draw each of the chronological curves on the same graph with different colors.

If a single color of ink is to be used, the resulting files can be concatenated and separated by coordinates with negative y values to signal the plotting device to lift the pen (**vpz** only).

This is done by typing

```
cat cdatafile1 > cdatafile
echo "0.0 -1.0" >> cdatafile
cat cdatafile2 >> cdatafile
echo "0.0 -1.0" >> cdatafile
                  ...
cat cdatafileM >> cdatafile.
```

The **.chr** files obtained from NTIA software can be concatenated using the same procedure, but substituting the **.chr** names for the **cdatafile** names. The file **cdatafile** now contains the data for the M plots, and a single invocation of **vpz** (or **vp**) is required. Section 6 explains further steps.

5. DRAW REGRESSION PLOTS

Regression is the process of estimating the dependent variable from the independent variable in a sample. One of the main purposes of regression is curve fitting. In general, a regression curve could fit performance parameter values obtained for each quantitative level of one or more variable conditions.[13] However, NTIA software fits a straight line to performance parameter values, and the values are considered to have been obtained when the quantitative levels of a single variable condition were changing. The straight line is "fitted" to the data using the method of least squares. Least squares selects the line that renders a minimum, the sum of the squares of the vertical distances between each outcome and the corresponding point on the line.

A regression plot consists of both the data and the regression line drawn in the x-y plane. Figure 9 shows three regression plots of Block Transfer Time as it varies with levels of the variable condition, Block Size. Figure 10 is a structured design diagram showing the procedures required for regression plots.

5.1 Draw a Single Regression Plot

The first data file needed is, say, **ddata.chr**. It is a two column listing of the data points to be plotted (x in the left column and y in the right). If the data from trials form a single column in a file, cardinal numbers must be added in a column to the left, exactly as described in Section 4.1.

To pool data from N tests, type

cat ddata1.chr ... ddataN.chr > ddata.

[13]Quantitative levels are required, otherwise the levels cannot be ordered on the abscissa.

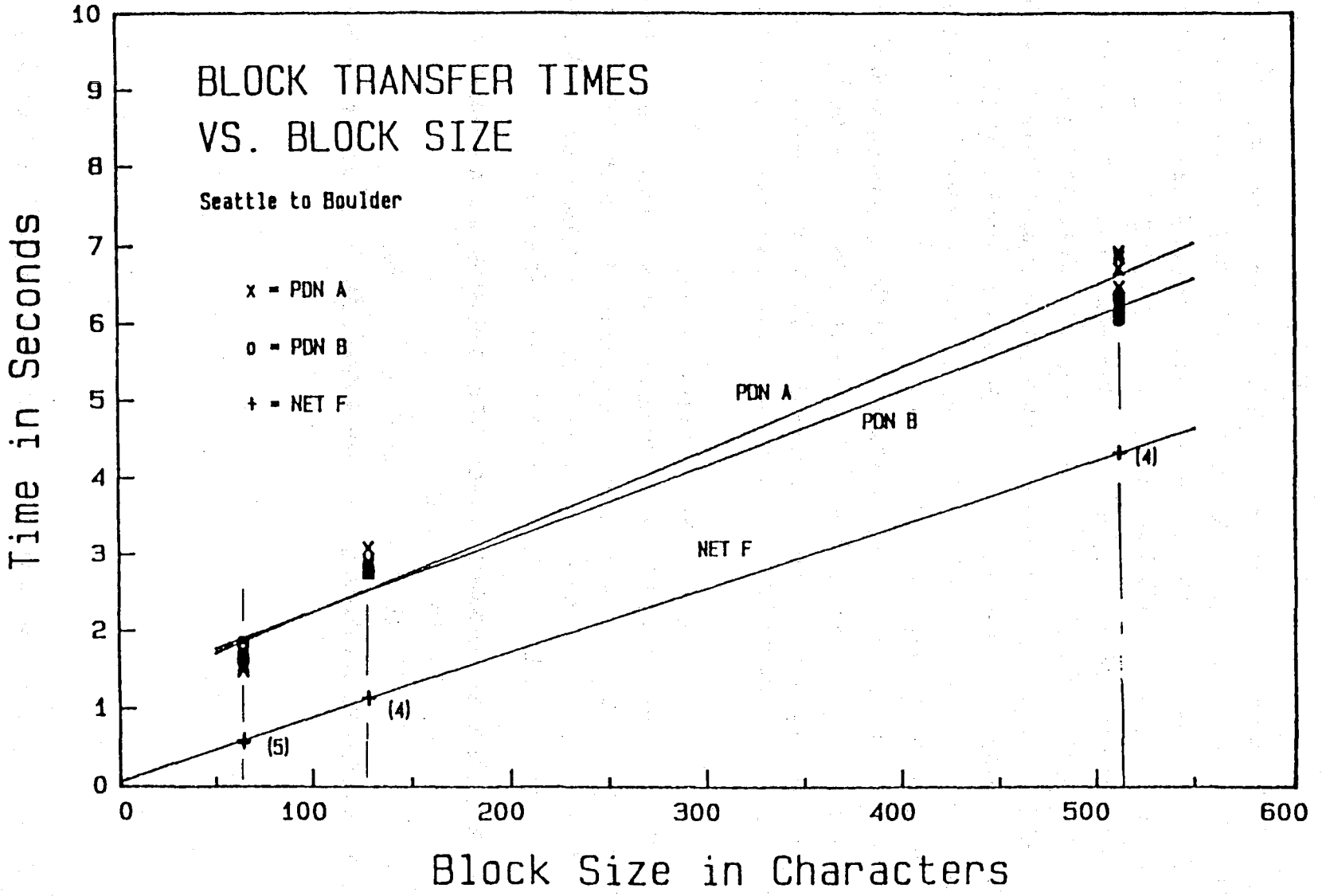

Figure 9. Example of regression plots of Block Transfer Time.

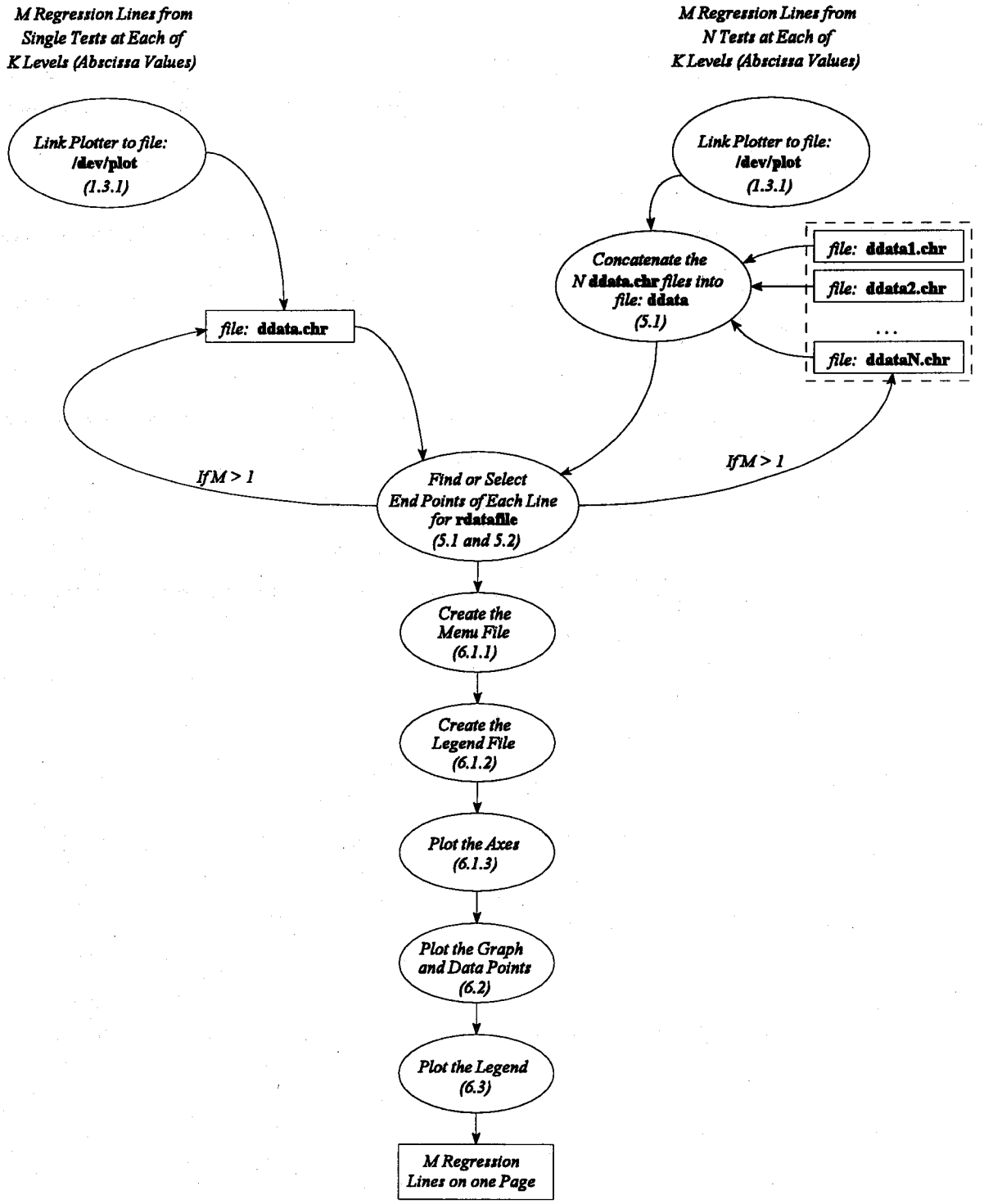

Figure 10. Structured design diagram of the procedures to draw regression plots.

The file **ddata** is used by the program **regres** which computes the endpoints of the regression line.[14]

Type

regres ddata slpint > rdatafile.

The program **regres** either computes the minimum and maximum x values or uses alternate endpoints.

The alternate endpoints can be specified by typing

regres ddata slpint low_endpoint high_endpoint > rdatafile

where **low_endpoint** and **high_endpoint** are integers.

The file **rdatafile** is the data file to be plotted by **vpz**. Go to Section 6 if a single regression line is desired.

5.2 Draw Multiple Regression Plots

Multiple invocations of **vpz** may also be used to draw several regression lines on one page; different colors of ink can then be used (as mentioned in Section 4.2).

If there are several, say M, regression lines on one graph, the output of of M calls to **regres** (see Section 5.1) can be concatenated and separated by coordinates with negative y values to signal the plotting device to lift the pen.

[14] **regres** also calculates the y-intercept and slope of the regression line. It writes these values to a file specified as the second argument to **regres** (i.e., **slpint**).

This is done by typing

```
cat rdatafile1 > rdatafile
echo "0.0 -1.0" >> rdatafile
cat rdatafile2 >> rdatafile
echo "0.0 -1.0" >> rdatafile
        .   .   .
cat rdatafileM >> rdatafile.
```

The file rdatafile contains the regression line data to be plotted by **vpz** in Section 6. With the **-tN** option, **vpz** can also be used to plot the data points in **ddata**, so that the data and the fit can be displayed together. See Section 6.2.1.

6. CREATE BOX, CHRONOLOGICAL, AND REGRESSION PLOTS ON THE HP7475A

Creating a box, chronological, or regression plot on the HP7475A plotter requires three files: a menu file, a data file, and a legend file.

The procedure for creating the data files for these three kinds of plots is described in Sections 3 through 5 of this volume. This section shows how to set up the menu and legend files and use the graphical display programs **vpz**, **vp**, **vpaxes**, and **vplegend**. Figure 11 is a sample session for creating box, chronological, and regression plots, respectively.

6.1 Prepare the Axes

6.1.1 Create the Menu File

One of the files used by the plotting programs is a menu file, an example of which is shown in Figure 12. For the chronological plot of a single test, the shell script **do** creates the menu file with **.mnu** extension. The left hand column in the menu file contains the menu file data. The right hand column can contain comments describing each line; the plotting programs ignore the right hand column, but it must contain text. The following are elements of the menu file:

- **xmin** and **xmax** are the left-most and right-most abscissa values on the graph, and **ymin** and **ymax** are the minimum and maximum ordinate values on the graph.
- **xnumbers** and **ynumbers** indicate the division increments of the axes. A value of zero causes no numbering.
- **xtics** and **ytics** indicate how often tics are to be placed along the axes. A value of zero causes no tics.
- **xgrid** should be set to 1 if vertical grid lines are to be drawn or 0 if no vertical grid lines are to be drawn.
- **ygrid** has the same function as **xgrid** but for horizontal grid lines.
- **xtitle** and **ytitle** are strings of text to be printed next to the x-axis and y-axis.

The title strings must not have embedded spaces; if a space is desired, insert **\s** between the characters to be separated (as in Figure 12). A **\N** at the beginning of **xtitle** or **ytitle**, where **N** is a one digit positive integer, will increase the character size in that line by a factor of N.

```
*********************************************************************
* Sample session to create one centered box plot, assuming NTIA     *
* software has already created a .chr file called 1234db2.chr.      *
*********************************************************************
% awk '$2 >= 0 {print $2}' 1234db2.chr | sort -n > sorted.dat
% quartile sorted.dat > quart
% box quart 1.0 > bdatafile
% cat > 1234db2.mnu              (do makes this file automatically
0           xmin:          for chronological plots if data
2           xmax:          comes from a single test processed
0           xnumbers:      by NTIA software)
0           xtics:
0           xgrid:
\2Test\s\s1234           xlabel:
0           ymin:
10          ymax:
2           ynumbers:
1           ytics:
0           ygrid:
\2Time\sin\sSeconds      ylabel:
^D(EOF)
% cat > 1234box.leg             (do makes this file automatically
\2Box Plot Legend          if data comes from a single test
Any Text Will Be Plotted        processed by NTIA software)
^D(EOF)
% vpaxes 1234db2.mnu
% vpz bdatafile 1 1234db2.mnu
% movit 1250 6500         (position pen in upper left corner)
% vplegend 1234box.leg

*********************************************************************
* Further commands required for chronological plot, assuming the    *
* menu file is modified appropriately.                              *
*********************************************************************
% cat > 1234chr.leg             (do makes this file automatically
\2Chron Plot Legend             if data comes from a single test
Any Text Will Be Plotted        processed by NTIA software)
^D(EOF)
% vpaxes 1234db2.mnu
% vpz 1234db2.chr 1 1234db2.mnu
% movit 1250 6500         (position pen in upper left corner)
% vplegend 1234chr.leg

*********************************************************************
* Further commands required for regression plot to fit a line to    *
  * chron. data, assuming the menu file is modified appropriately.  *
*********************************************************************
% cat > 1234reg.leg             (do makes this file automatically
\2Regression Plot Legend        if data comes from a single test
Any Text Will Be Plotted        processed by NTIA software)
^D(EOF)
% regres 1234db2.chr slpint > rdatafile
% vpaxes 1234db2.mnu
% vpz rdatafile 1 1234db2.mnu
% movit 1250 6500         (position pen in upper left corner)
% vplegend 1234reg.leg
```

Figure 11. Sample session creating box, chronological, and regression plots.

Create the menu file if needed; it can have any name.

```
1                   xmin:
80                  xmax:
10                  xnumbers:
5                   xtics:
0                   xgrid:
\2Trial\sNumber          xlabel:
0                   ymin:
10                  ymax:
2                   ynumbers:
1                   ytics:
0                   ygrid:
\2Time\sin\sSeconds      ylabel:
```

Figure 12. Sample menu file for the plotting programs.

6.1.2 Create the Legend File

The legend file should contain the lines as they are to appear in the legend(s). For a single test, the shell script **do** creates the legend file with **.leg** extension. The character size in any line preceded by **\N** (where N is a one-digit positive integer) will be larger by a factor of N. If parts of the graph are to be labeled separately, there should be a separate legend file for each label.

Create a legend file if needed; it can have any name.

6.1.3 Plot the Axes

Make sure the paper and pens are loaded into the plotter. To plot the axes of the graph, type

vpaxes menufile.

This could take a few minutes if the menu specifies that a grid is to be drawn.

6.2 Draw the Graph

If none of the data in the data file has a negative value, use the program **vpz** to draw the graph. This will plot the data relative to the axes already plotted. The order in which **vpz** and **vpaxes** are called does not matter as long as the paper is not disturbed. **vpz** can be called several times, if necessary, to put several different graphs from different data files on the same axes. The same menu file should be used each time so the scaling will be the same.

If the data contain some negative values, either **vp** or **vpz** may be used:

- Plot Negative y Values. When **vp** is used, the negative y value is plotted normally.

- Don't Plot Negative y Values. When **vpz** is used, the pen is lifted at negative y values so that those values are not plotted.

vp is called the same way **vpz** is called. The general usage for **vpz** (or **vp**) is

vpz [-tlinetype] datafile [pen# [menufile [t]]]

The default pen is number one, a black 7mm (see Table 4). The default menu file is file **menu** in the current working directory.

6.2.1 Select the Line Types

It may be desirable to draw different parts of the graph with different line types or in different colors. In this case, the different parts of the graph should be kept in separate files and drawn with separate calls to **vpz**.

vpz can use different line types (solid, dashed, etc.) with the **-tN** option on the command line.

Type

vpz -tN datafile pen# menufile

where **N** is one of the following:

- A small positive integer corresponding to a specific line type. For example, a dotted line results from the number 1, and a dashed line results from the number 2. Other line types are built into the plotter. (See plotter documentation.)
- Some ASCII character that will be plotted at each data point; the characters will not be connected.

6.2.2 Select the Medium

As in **hpgraph**, if you want to plot on a transparency instead of paper, call **vpz** or **vp** and enter the character **t** at the end of the line. This will cause the plotter to pause between parts of the graph to let the ink dry.

This is done by typing,

vpz datafile pen# menufile t

6.3 Draw the Legend

After the graph is drawn, use the arrow keys on the plotter or the program **movit** to position the pen in the upper left corner of the area in which you want the legend to appear. **movit** uses a Cartesian coordinate system whose origin is in the lower left portion of the paper. Of course, the pen can be repositioned for each legend.

To use **movit**, type

movit x-position y-position

where **x-position** is an integer between 0 and approximately 10,500, and **y-position** is an integer between 0 and approximately 7,000. Then print the legend by typing,

vplegend legendfile.

7. ACKNOWLEDGEMENTS

The authors would like to thank Lorna L. Kent for drawing many of the structured design diagrams.

8. REFERENCES

Box, G.E.P., W.G. Hunter, and J.S. Hunter (1978), *Statistics for Experimenters* (John Wiley & Sons, Inc., New York)

APPENDIX: DATA DISPLAY SOFTWARE MANUAL

This appendix is a software manual that describes each of the programs used for data display. The format is modelled after the UNIX^{tm} software manual.

NAME:

box – Create data for a box plot from a file containing the maximum, minimum, median, and upper and lower quartiles of the data.

SYNOPSIS:

box <y-value filename> [x-position]

DESCRIPTION:

This program takes five y-value numbers from an input file (e.g., the output file of **quartile(1)**) and makes a box plot in an x-axis position as specified by the x-position argument. This is a plottable set of data which may be used by vector graphic devices. The program is designed to work in conjunction with the block program output. The default x-position is 1. Output is sent to **stdout**.

FAMILY:

data display

FILES:

filename – Contains maximum, minimum, median, and quartiles of data set.

SEE ALSO:

quartile

DIAGNOSTICS:

Produces error message and aborts if unable to open y-value filename.

AUTHORS:

John Waber and Dave Wortendyke, 1985 at NTIA.

NAME:

hpgraph - Make a histogram on an HP vector plotter.

SYNOPSIS:

hpgraph <template name> **[t]**

DESCRIPTION:

hpgraph takes as its argument a template name which is the name of a template file without the extension. The template name allows the program to open the template file which contains the name of the data file that is used. **hpgraph** plots histograms on an HP 7475A vector plotter. The **t** option slows the plotter's operation to allow transparencies to be made. The plotter must be connected to a port that is turned off and has hardware handshaking. There must be a link between **/dev/plot** and the tty that the plotter is connected to.

FAMILY:

data display

FILES:

filename.tem - template file.

DIAGNOSTICS:

Produces error messages and aborts if unable to open the template file, the data file, or **/dev/plot**. Warns user to allow ink to dry when transparency option is used.

SEE ALSO:

histogrm(1) Graph data.

AUTHOR:

Scott Seebass, 1984 at NTIA.

NAME:

histogrm - Create data for **hpgraph** histogram from a file of sorted data.

SYNOPSIS:

histogrm filename [bars [width]]

DESCRIPTION:

histogrm generates points representing a histogram and writes them to **stdout**. **hpgraph** can display **histogrm** output on the hp7475A vector plotter. The input data file must be a list of sorted numbers ending with a negative number. The width argument overrides the default bar width computed by the program. The bars argument will override the default number of bars, which is 40.

FAMILY:

data display

FILES:

filename – file of sorted values.

SEE ALSO:

hpgraph(1)

DIAGNOSTICS:

Prints error message if more than 4,000 values are present in the input file.

AUTHOR:

Chris Bogart, 1985 at NTIA.

NAME:

movit - Command HP vector plotter to move pen to specified x-position and y-position.

SYNOPSIS:

movit x-position y-position

DESCRIPTION:

movit allows exact and consistent positioning of the plotter pen for the placement of legends and labels. The arguments x-position and y-position should be integers, sized to place the pen appropriately within the approximately 10500 x 7000 area. The coordinate (0, 0) is in the lower left corner of the page.

FAMILY:

data display

SEE ALSO:

vplegend(1)

AUTHOR:

Darin Schwartz, 1986 at NTIA

NAME:

quartile - Compute the minimum, median, maximum, and upper and lower quartiles for a file of sorted data.

SYNOPSIS:

quartile <sorted data file name>

DESCRIPTION:

This program will take an ordered set of numbers and compute five y-value numbers from them: the minimum, lower 25% quartile, the median, the upper 25% quartile, and the maximum, in that order. It is slightly inaccurate for small numbers of samples, but all right for 50+ unless data are greatly spread, since no interpolation is done on the data. The file is read twice so a large array is not needed. Hence, there is no limit to how much data can be in the file. Output is sent to stdout.

FAMILY:

data display

FILES:

filename - file containing sorted positive data.

SEE ALSO:

box(1)

DIAGNOSTICS:

Prints error message and aborts if unable to open input file.

AUTHOR:

Dave Wortendyke, 1985 at NTIA.

NAME:

regres - Perform a least square linear fit on a set of data.

SYNOPSIS:

regres datafile outputfile [xmin [xmax]]

DESCRIPTION:

regres reads a data file with paired values. There are two outputs from this program. The slope and intercept of the linear least square fit curve is written to an output file, and the coordinates with minimum and maximum x-axis values are printed to **stdout**. The method of least squares is utilized to find the y-axis values.

FAMILY:

data display

FILES:

datafile - file of paired data.
outputfile - file to receive slope and intercept.

DIAGNOSTICS:

Prints error message and aborts if unable to open the input file or the output file.

AUTHOR:

Cathy Edgar, 1987 at NTIA.

NAME:

vp - Plot a graph from a data file to an HP7475A vector plotter.

SYNOPSIS:

vp [-tlinetype] datafile [pen# [menufile [t]]]

DESCRIPTION:

vp plots a graph whose points are listed in **datafile**. The coordinate system is described in the menu file, the name of which can be specified. The default is **menu**. The pen number argument tells which pen to use, and if **t** is specified then the plot is done more slowly (for transparencies). If the **-t** option is a number between one and six, the graph will be plotted with one of six kinds of dotted lines. If the linetype is zero, no lines will be drawn, but the points will be plotted unconnected. If the argument is a non-numeric character, that character will be plotted at each point of the graph, and no lines will be drawn. The menu file must have the following format:

```
x-min                   comment 1
x-max                   comment 2
x-numbering             comment 3
x-tics                  comment 4
x-grid                  comment 5
x-label                 comment 6
y-min                   comment 7
y-max                   comment 8
y-numbering             comment 9
y-tics                  comment 10
y-grid                  comment 11
y-label                 comment 12
```

The values given (floating point) must be separated by white space from a comment given later in the line as shown. The program will ignore the comment. Example:

```
1                              x-min
20                             x-max
2                              x-numbering
1                              x-tics
1                              x-grid (use 0 for false/no)
\2Trial\sNumber                x-label (Note: \# specifies font size
                                        [default=1])
20                             y-min
30                             y-max
1                              y-numbering
1                              y-grid
\2Times\sin\sSeconds           y-label (Note: as above \s means
                               space)
```

FAMILY:

data display

FILES:

datafile - file contains graph data.
menu or name specified in command line.

SEE ALSO:

vplegend(1), **vpaxes(1)**, **vpz(1)**

DIAGNOSTICS:

Warns user to allow ink to dry when transparency option is used. Prints error and aborts if unable to open the data file or menu file.

AUTHOR:

Chris Bogart, 1985 at NTIA.

NAME:

vpaxes - Plot the axes for a graph on an HP 7475A vector plotter.

SYNOPSIS:

vpaxes menufile [t]

DESCRIPTION:

vpaxes reads the file **menufile** specified in the command line, and draws the axes per instructions there. See **vp(1)** for the format of the menu file. If x-numbering or y-numbering is given as 0, the graph will not be numbered along that axis. Similarly, if x-ticks or y-ticks are 0, the ticks will be omitted on that axis.

FILES:

menufile - file defining structure of axes.

FAMILY:

data display

SEE ALSO:

vplegend(1), vp(1), vpz(1)

DIAGNOSTICS:

Prints error and aborts if unable to open **menufile**.

AUTHOR:

Darin Schwartz, 1985 at NTIA.

NAME:

vplegend - Draw a graph legend on the HP7475A vector plotter.

SYNOPSIS:

vplegend legendfile

DESCRIPTION:

vplegend lets the user position the pen (either manually or with **movit(1)**), then type **ok**, and push the RETURN key. Then, it sends out the file to the plotter to be plotted verbatim with one exception. Any line in the data file that starts with \ followed by a one-digit number will be printed that number of times larger.

FAMILY:

data display

FILES:

legendfile – file containing text of legend.

SEE ALSO:

movit(1), **vp(1)**, **vpaxes(1)**, **vpz(1)**

BUGS:

It would be better, if instead of pushing the RETURN key, the user could just press the ENTER key on the plotter.

DIAGNOSTICS:

Prints error and aborts if unable to open **legendfile**.

AUTHOR:

Chris Bogart, 1985 at NTIA.

NAME:

vpz - Plot a graph, which may have gaps in it, from a data file to an HP7475A vector plotter.

SYNOPSIS:

vpz [-tlinetype] datafile [pen# [menufile [t]]]

DESCRIPTION:

vpz plots a graph whose points are listed in **datafile**. The coordinate system is described in the menu file, which can be specified. The default is **menu**. Any negative numbers in the data file will cause the program to not connect the previous and following points on a graph, so that missing points may be indicated by negative values, or separate graphs on the same page can be plotted from the same data file, with a negative value between the two sets of points. The **pen#** argument tells which pen to use, and if **t** is specified then the plot is done more slowly for transparencies. If the **-t** option is a number between one and six, the graph will be plotted with one of six kinds of dotted lines. If the argument is zero, no lines will be drawn, but the points will be plotted unconnected. If the argument is a nonnumeric character, that character will be plotted at each point of the graph, and no lines will be drawn. See **vp(1)** for a description of the menu file used by **vpz**.

FAMILY:

data display

FILES:

datafile – file containing graph data.
menu or **menufile** specified in command line – file defining structure of axes.

SEE ALSO:

vplegend(1), **vpaxes(1)**, **vp(1)**

DIAGNOSTICS:

Warns the user to allow ink to dry when transparency option is used. Prints error and aborts if unable to open **datafile** or **menufile**.

AUTHOR:

Chris Bogart, 1985 at NTIA.

FORM **NTIA-29**
(4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

	1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.
	95-319 (6)		

4. TITLE AND SUBTITLE
Performance Evaluation of Data Communication Services: NTIA Implementation of American National Standard X3.141, Volume 6. Data Display

5. Publication Date
August 1995

6. Performing Organization Code
NTIA/ITS.N3

7. AUTHOR(S) C.A. Bogart, D.R. Schwartz, M.J. Miles, R.S. Reichert, and D.R. Wortendyke

9. Project/Task/Work Unit No.

8. PERFORMING ORGANIZATION NAME AND ADDRESS
National Telecommunications and Information Admin.
Institute for Telecommunication Sciences
325 Broadway
Boulder, CO 80303

10. Contract/Grant No.

11. Sponsoring Organization Name and Address
National Telecommunications and Information Admin.
Herbert C. Hoover Building
14th and Constitution Avenue, NW
Washington, DC 20230

12. Type of Report and Period Covered

13.

14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This volume shows how to use software that draws graphs of the ANS X3.102 primary delay performance parameters. The four types of two-dimensional graphs are histograms, box plots (i.e., abbreviated histograms), chronological plots, and regression lines. Histograms and box plots can represent data from either a single test or pooled data from multiple tests; only one histogram can be drawn on a page, but several box plots can be drawn on one page. Chronological plots represent data from a single test; several plots can be drawn on a page. Regression plots fit lines to points, each of which is a trial or the estimate of the mean of a test. Because the values occur at different quantifiable levels, regression lines usually represent data from multiple tests; several regression plots can be drawn on a page.

All system commands and routines are UNIX commands and shell scripts. The routines are intended to be used on the HP7475A vector plotter but can be used on other plotters if some routines are altered. Data for these routines usually come from the output of data reduction (Volume 4).

Box plots, chronological plots, and regression plots use the general-purpose plotting packages called vp and vpz, which could be used for other graphs.

Key words: box plots; chronological plots; data communication systems; histograms; HP7475A vector plotter; linear regression plots; primary delay performance parameters

17. AVAILABILITY STATEMENT	18. Security Class. *(This report)*	20. Number of pages
☒ UNLIMITED.	Unclassified	57
☐ FOR OFFICIAL DISTRIBUTION.	19. Security Class. *(This page)*	21. Price:
	Unclassified	

*U.S. GOVERNMENT PRINTING OFFICE: 1995-676-490/25108