

CHAPTER TWO

Descriptive Statistics

2.1 Introduction

The description of a data set includes, among, other things:

- Presentation of the data by tables and graphs.
- Examination of the overall shape of the graphed data for important features, including symmetry or departures from it.
- Scanning the graphed data for any unusual observation that seems to stick far out from the major mass of the data.
- Computation of numerical measures for a typical or representative value of the center of the data.
- Measuring the amount of spread or variation present in the data.

2.2 The Population and the Sample

Population: A population is a complete collection of all observations of interest (scores, people measurements, and so on). The collection is complete in the sense that it includes all subjects to be studied.

Sample: A sample is a collection of observations representing only a portion of the population.

Simple Random Sample: A simple random sample (SRS) of measurements from a population is the one selected in such a manner that every sample of size n from the population has equal chance (probability) of being selected, and every member of the population has equal chance of being included in the sample.

Drawing Simple Random Samples using a Table of Random Numbers

An easy way to select a SRS is to use a random number table, which is a table of digits 0,1,...,9, each digit having equal chance of being selected at each draw. To use this table in drawing a random sample of size n from a population of size N , we do the following:

1. Label the units in the population from 0 to $N - 1$.
2. Find r , the number of digits in $N - 1$. For example; if $N = 100$, then $r = 2$.
3. Read r digits at a time across the columns or rows of a random number table.
4. If the number in (3) corresponds to a number in (1), the corresponding unit of the population is included in the sample, otherwise the number is discarded and the next one is read.
5. Continue until n units have been selected.

If the same unit in the population is selected more than once in the above process of selection, then the resulting sample is called a SRS with replacement; otherwise it is called a SRS without replacement. The observations in the sample are the enumeration or readings of the units selected.

Example 2.1 (cf. Devore, J. L. and Peck, R., 1997, 56). To draw a SRS, consider the data below as our population. In a study of wrap breakage during the weaving of fabric, one hundred pieces of yarn were tested. The number of cycles of strain to breakage was recorded for each yarn and the resulting data are given in the following table.

86	175	157	282	38	211	497	246	393	198
146	176	220	224	337	180	182	185	396	264
251	76	42	149	66	93	423	188	203	105
653	264	321	180	151	315	185	568	829	203
98	15	180	325	341	353	229	55	239	124
249	364	198	250	40	571	400	55	236	137
400	195	38	196	40	124	338	61	286	135
292	262	20	90	135	279	290	244	194	350
131	88	61	229	597	81	398	20	277	193
169	264	121	166	246	186	71	284	143	188

Here we have a population of size $N = 100$. To draw a simple random of size $n=10$ without replacement, we proceed as follows:

1. Label the units in the population from 00 to 99.
2. Find r , the number of digits in N . For example, if $N=100$, then $r = 2$.
3. Read 2 digits at a time across the columns or rows of a random number table (See Appendix A1).

Suppose we read the first two digits of the first two columns of the above random number table to get the following numbers

85 71 76 83 51 18 76 69 61 26 36

4. Since the random digit 85 corresponds to a unit in (1), we select unit 85 of the population in the sample. If any random digit in (3) exceeds 99, the random digit is discarded and the next one is read. After selecting 6 random numbers of two digits, we find a random number 76 which is discarded for SRS without replacement as it appeared before.

Continue until $n = 10$ units have been selected. Thus we have the sample units:

85 71 76 83 51 18 69 61 26 36

so that the sample observations are:

81 262 290 229 368 396 135 195 234 185

A SRS with replacement in the above example would be:

81 262 290 229 368 396 290 135 195 234.

Drawing Simple Random Samples Using Statistica

To select a SRS without replacement of size $n=10$ from a population of size $N=100$ from example 2.1 using Statistica, we do the following:

1. Label the units in the population from 0 to 99
2. Create a new data sheet (to get a sheet of 10 cases, the size of the sample)
3. Double-click the variable name (Say Var1)
4. In Long name (label or formula with function), write “ = Rnd(100)”
5. In Display format, choose number and in Decimal place input 0 / OK/ Yes, you will get 10 random numbers of two digits.
6. Each of the 10 random numbers selected in the previous step corresponds to a value in the population. They constitute the observations in the sample.

2.3 Graphical Description of Data

Stem-and-Leaf Plot

One useful way to summarize data is to arrange each observation in the data into two categories “stems and leaves”. First of all we represent all the observations by the same number of digits possibly by putting 0’s at the beginning or at the end of an observation as needed. If there are r digits in an observation, the first x ($1 \leq x \leq r$) of them constitute stems and last $(r-x)$ digits called leaves are put against stems. If there are many observations in a stem (in a row), they may be represented by two rows by defining a rule for every stem.

Example 2.2 (cf. Vining, 1998) In a galvanized coating process for large pipes, standards call for an average coating weight of 200 lbs per pipe. These data are the coating weights for a random sample of 30 pipes.

216	202	208	208	212	202	193	208	206	206
206	213	204	204	204	218	204	198	207	218
204	212	212	205	203	196	216	200	215	202

Step 1: Divide each observation in the sample into a stem and a leaf. For 3-digit observations there would be two choices:

- stem = first digit, leaf = last two digits
- stem = first two digits, leaf = third digit.

The choice of stem and leaf that makes the stem-and-leaf plot compact is preferred. The first choice would make only two stems with too many leaves in a stem while the second choice would make 3 stems with a reasonable number of leaves in each stem. So the second choice is preferred.

Step 2: List the stems in order in a column.

Step 3: Proceed through the data set, placing the leaf for each observation in the appropriate stem or row.

Leaves are sometimes ordered and the corresponding display is called Ordered Stem-and-leaf Display.

Stem-and-Leaf Display for the Coating Weight Data

Stem	Leaf	Frequency
19	3 6 8	3
20	0 2 2 2 3 4 4 4 4 5 8 8 8 6 6 6 7	18
21	2 2 2 3 5 6 6 8 8	9
Total		30

Example 2.3: A sample of $n = 25$ Job CPU Times (in seconds) is selected from 1000 CPU times (See Mendenhall and Sincich, 1995, 25).

1.17 1.61 1.16 1.38 3.53 1.23 3.76 1.94 0.96
 4.75 0.15 2.41 0.71 0.02 1.59 0.19 0.82 0.47
 2.16 2.01 0.92 0.75 2.59 3.07 1.40

Construct a Stem and Leaf Plot of the data.

Step 1: Divide each observation, in the sample into two parts, the stem and the leaf. For 3-digit observations, there would be two choices:

- stem = first digit, leaf = last two digits
- stem = first two digits, leaf = third digit

For the CPU data, the first choice would be better.

Step 2: List the stems in order in a column.

Step 3: Proceed through the data set, placing the leaf for each observation in the appropriate stem or row.

The first entry corresponds to 0.02, the second to 0.15 and so on. It is not a bad idea to put decimal in the place it occurs in the sample though it is not popular.

Ordered Stem-and-Leaf Display for the CPU Data

Stem	Leaf	Frequency
0	02 15 19 47 71 75 82 92 96	9
1	16 17 23 38 40 59 61 94	8
2	01 16 41 59	4
3	07 53 76	3
4	75	1
Total		25

Stem-and-Leaf Plot Using Statistica (ANOVA/MANOVA Module)

To construct stem-and-leaf plot by Statistica, first create a data sheet then enter the entire data in one column. To obtain Stem-and-leaf diagram for the galvanized coating weight data in Example 2.2, enter the data in one column (say Var1), follow the steps to construct a stem-and-leaf plot for the data:

1. Statistics / Basic Statistics / Tables (you will get Figure 2.1)
2. Descriptive Statistics / OK
3. Variables (select Var1) / OK

4. In Descriptive Statistic Spreadsheet, click Normality (you will get Figure 2.2)
5. Stem & leaf plot (you will get Figure 2.3).

Note: Sometimes all the digits under stem and leaf will be zeros which can be avoided by checking Compressed in Figure 2.2.

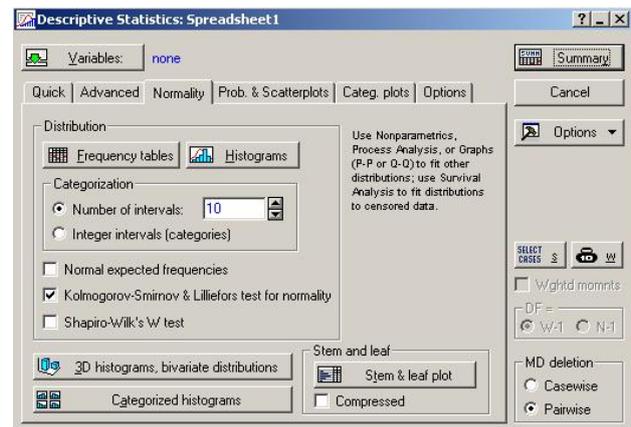
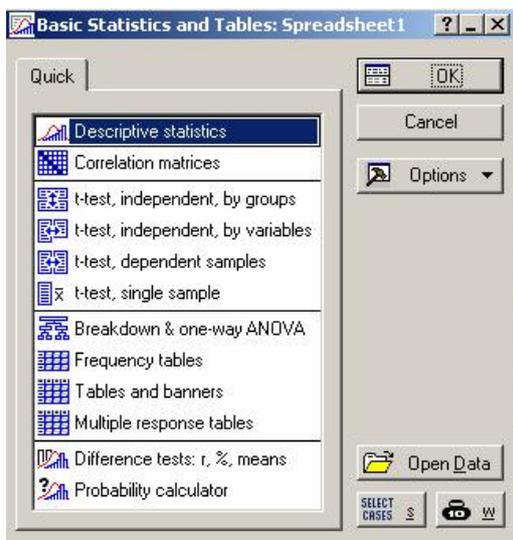


Figure 2.2 Descriptive Statistics

Figure 2.1 Basic Statistics and Tables

stem°leaf (leaf unit=10.00000, e.g., 6°5 = 65.00000)	Class n	Percentiles
19° 3	1	
19° 68	2	
20° 0222344444	10	25%
20° 56667888	8	median
21° 2223	4	75%
21° 56688	5	
22°	0	
min = 193.0000 max = 218.0000 Total N: 30		

Figure 2.3 Stem and leaf Plot

These steps result in the stem and leaf plot as shown in Figure 2.3. For example, the second row contains 196 and 198. Note that the seventh row contains no value. This should not be mistaken for 220.

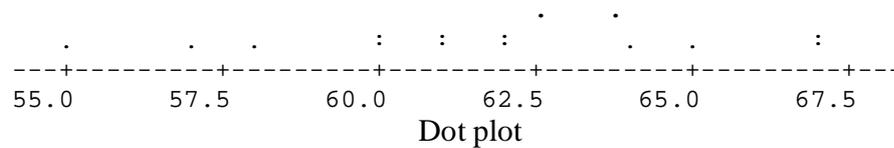
Dot plot

A dot plot is constructed by first drawing a horizontal scale that spans the range of the data. The observations are located on the horizontal scale by placing a dot over the appropriate value. If the observations repeat, then dots are placed on top of each other, forming a pile against that particular observation.

Example 2.4: The following data represents the yields of 15 one-acre plots.

67 61 62 65 61 60 55 61 62 57 64 60 58 62 67

Construct a dot plot for the above data.

**2.4 Frequency Tables**

When summarizing a large set of data it is often useful to classify the data into classes or categories and to determine the number of individuals belonging to each class, called the class frequency. A tabular arrangement of data by classes together with the corresponding frequencies is called a frequency distribution or simply a frequency table. Consider the following definitions:

Class Width: The difference between the upper and lower class limits of a given class.

Frequency: The number of observations in a class.

Relative Frequency: The ratio of the frequency of a class to the total number of observations in the data set.

Cumulative Frequency: The total frequency of all values less than the upper class limit.

Relative Cumulative Frequency: The cumulative frequency divided by the total frequency.

Example 2.5: Consider the data in Example 2.2. The steps needed to prepare a frequency distribution for the data set are described below:

Step 1: Range = Largest observation – Smallest observation
 $= 218 - 193 = 25$.

Step 2: Divide the range between into classes of (preferably) equal width. A rule of thumb for the number of classes is \sqrt{n} .

$$\text{Class width} \approx \frac{\text{Range}}{\text{Number of classes}}$$

Since we have a sample of size 30, the number of classes in the histogram should be around $\sqrt{30} \approx 5.48$. In this case, the class width would be approximately $25/5.48 = 4.56 \approx 5$. The smallest observation is 193. The first class boundary may well start at 193 or little below it, say at 190 (just to avoid the smallest observation, in general,

falling on the class boundary). Thus the first class is given by (190, 195]. The second class is given by (195, 200]. Complete the class boundaries for all classes. In Statistica, the lower boundary of the first class is called the starting point while the class width is called the step size.

Step 3: For each class, count the number of observations that fall in that class. This number is called the class frequency.

Step 4: The relative frequency of a class is calculated by f/n where f is the frequency of the class and n is the number of observations in the data set.

Cumulative Relative Frequency of a class, denoted by F , is the total of the relative frequencies up to that class. To avoid rounding in every class, one may accumulate the frequencies up to a class and then divide by n . The resulting quantity Relative Cumulative Frequency (F/n) is just the same as Cumulative Relative Frequency and is desirable in a frequency table. For the data in Example 2.2, we have the following frequency distribution:

Class	Count	f	F	Relative f	Relative F
(190, 195]	/	1	1	0.033 ...	0.033
(195, 200]	//	2	3	0.066 ...	0.100
(200, 205]	//// //	10	13	0.333 ...	0.433
(205, 210]	//// //	8	21	0.266 ...	0.700
(210, 215]	////	4	25	0.133 ...	0.833
(215, 220]	////	5	30	0.166 ...	1.000
		30		1.00	

To construct a frequency distribution using Statistica, first create a data sheet and enter the data in one column and follow the steps:

1. Statistics/Basic Statistics/Tables
2. Descriptive Statistics/OK
3. Variables/Select variables(Say Var1) / OK
4. In Quick, click Frequency tables. These Steps give the frequency table in Fig 2.4.

The screenshot shows a window titled 'Workbook39* - Frequency table: Var1 (Spreadsheet1)'. The main area displays a frequency table with the following data:

Category	Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All
190.0000 < x <= 195.0000	1	1	3.33333	3.3333	3.33333	3.3333
195.0000 < x <= 200.0000	3	4	10.00000	13.3333	10.00000	13.3333
200.0000 < x <= 205.0000	10	14	33.33333	46.6667	33.33333	46.6667
205.0000 < x <= 210.0000	7	21	23.33333	70.0000	23.33333	70.0000
210.0000 < x <= 215.0000	5	26	16.66667	86.6667	16.66667	86.6667
215.0000 < x <= 220.0000	4	30	13.33333	100.0000	13.33333	100.0000
Missing	0	30	0.00000		0.00000	100.0000

Statistical tests shown at the top: K-S d = .12096, p > .20; Lilliefors p > .20.

Figure 2.4 Frequency Table

2.5 Graphs of Frequency Distributions

Frequency Histogram

A frequency histogram is a bar diagram where a bar against a class represents frequency of the class.

To construct a frequency histogram for the data in example 2.2 using Statistica, follow the same steps as in example 2.4 with the same data.

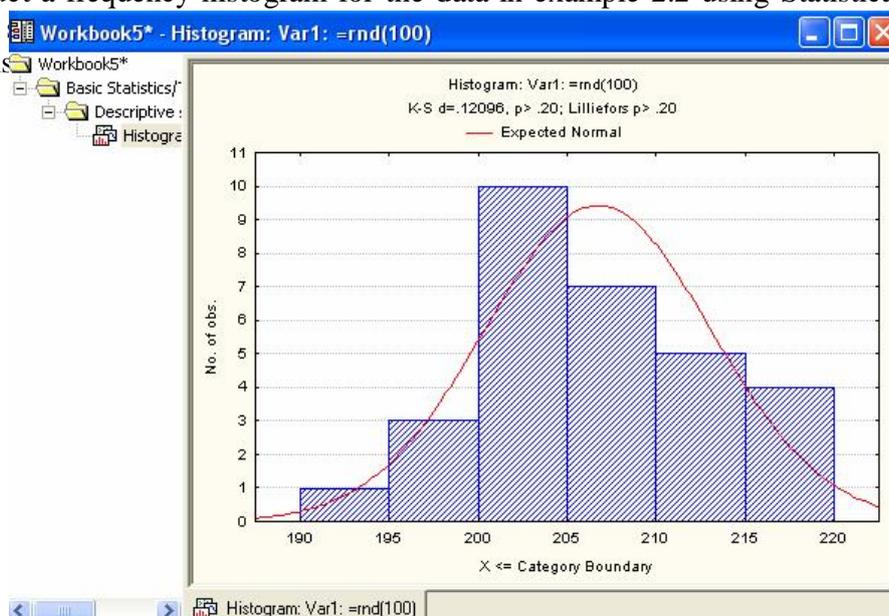


Figure 2.5 Histogram

Frequency Tables under the Basic Statistics and Tables Module

If you go to *Statistics/Basic statistics/Tables/Frequency tables* then press **OK**, it will open *The Frequency Tables Menu*. One advantage of this menu is that it allows flexibility in the construction of frequency distributions and frequency histograms. One can change the step size and the starting point of the range of a variable in preparing a frequency distribution or plotting a histogram. To construct a frequency histogram for our data above with a step size of 10 and starting point of 185, follow the steps:

1. Statistics/ Basic Statistics/Tables
2. Frequency tables/OK
3. Variables (select variable)/OK
4. In Frequency table spreadsheet, click Advanced (you will get Figure 2.6)
5. Check step size (enter 10)
6. Uncheck at minimum
7. Enter 185 for starting at
8. Histogram (see Figure 2.7).

Alternatively, if we wish to construct the frequency histogram starting from the minimum value, we will eliminate steps (6 and 7) above. For a frequency distribution, we follow the same steps and replace Step 8 with Summary: Frequency Tables.

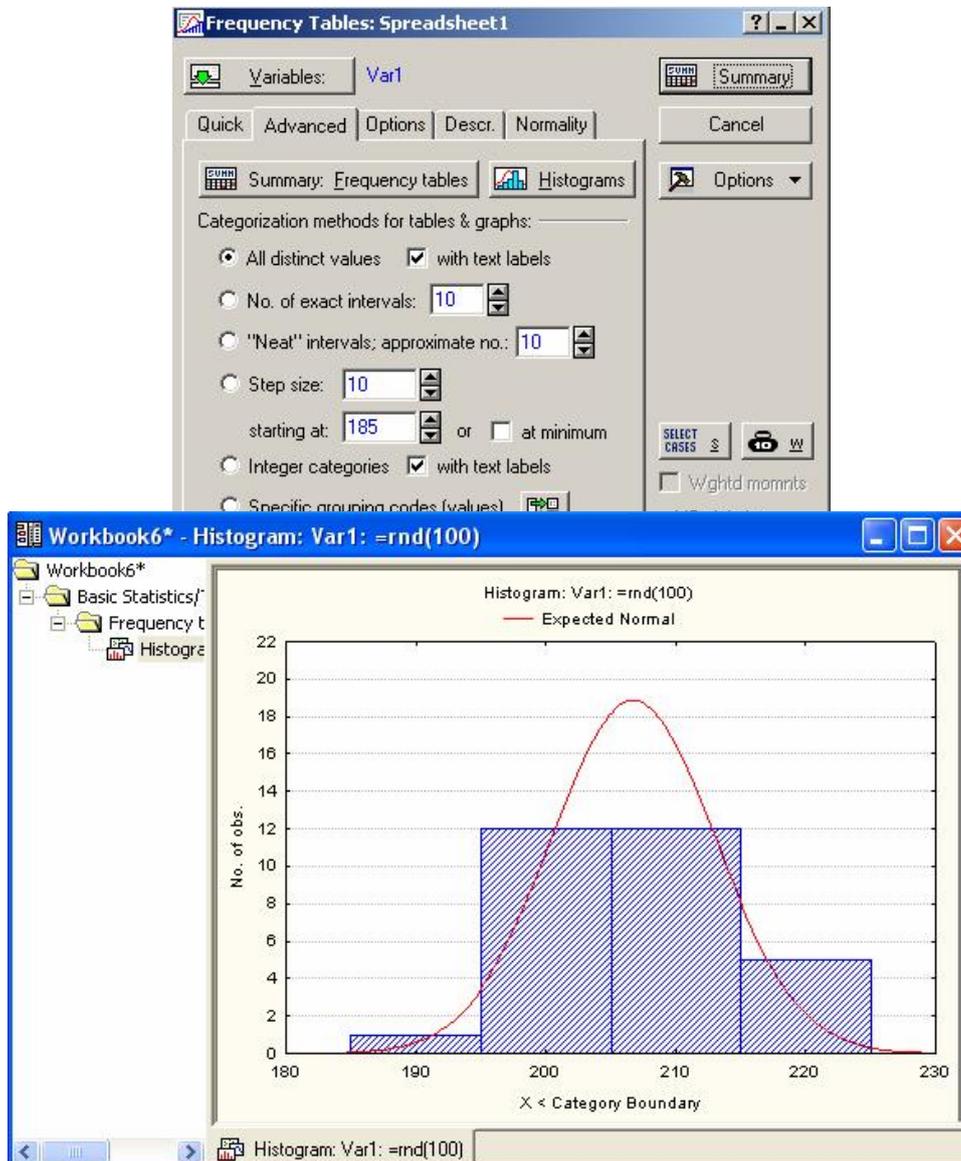


Figure 2.7 Histogram

Frequency Plots

The data of Example 2.2 have been summarized by a frequency distribution in Figure 2.4. We may use Figure 2.4, frequency distribution to find the midpoint, then enter the midpoint of each interval in one column in the datasheet, another column to enter the count (frequency) of each interval (relative frequencies, cumulative relative frequencies can also be entered in two other columns).

Use frequency or relative frequency or cumulative relative frequency as vertical axis as needed by the graph.

(a) Frequency Plot: If frequencies of classes are plotted against the mid values of respective classes, the resulting scatter graph is called a Frequency Plot. To use Statistica, follow the steps:

1. Graphs/ 2D graphs/Scatterplots
2. Variables (choose variables, count for y and midpoint for x) / OK

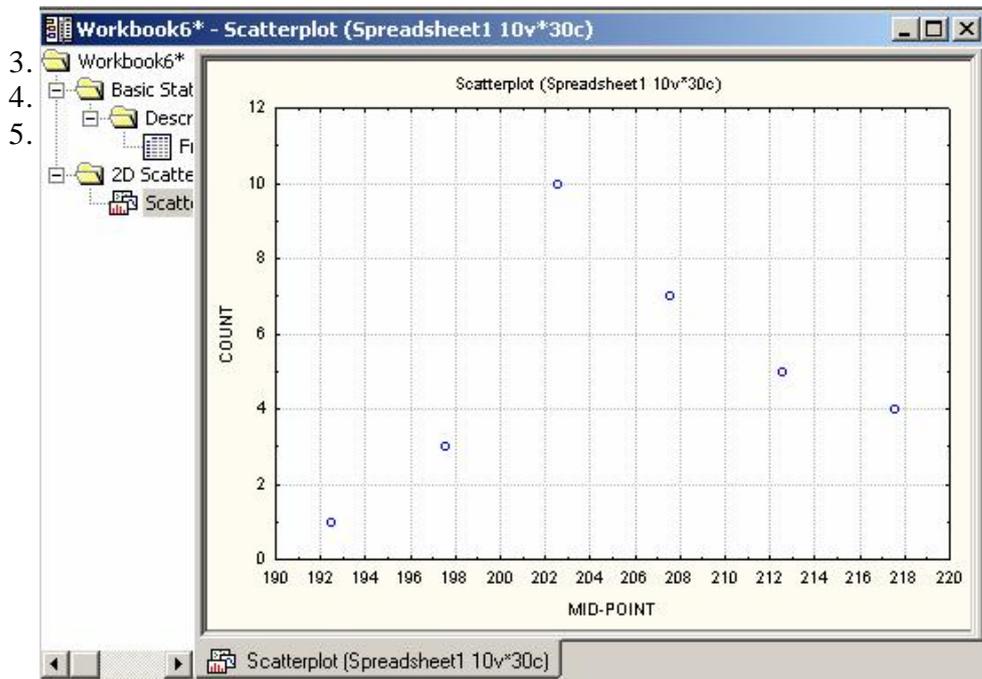


Figure 2.8 Frequency Plots

(b) Frequency Curve: If the dots of the frequency plot are joined by a smooth curve the resulting curve is called a frequency curve.

(c) Frequency Polygon: If the dots in a frequency plot are joined by lines, the resulting graph is called a Frequency Polygon. The polygon is sometimes extended to the midpoints of extreme adjacent classes (in both sides) with no frequencies.

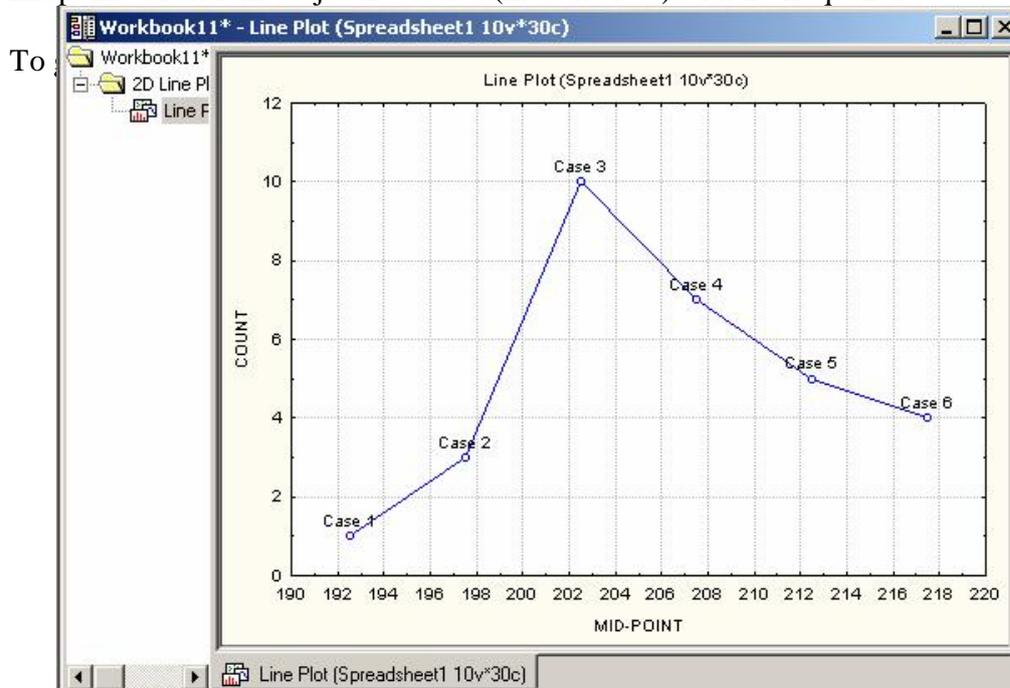


Figure 2.9 Frequency Polygon

(d) Relative Frequency Plot: If relative frequencies of classes are plotted against the mid values of respective classes, the resulting scatter graph is called a Relative Frequency Plot.

(e) Relative Frequency Curve: If the dots of the Relative Frequency Plot are joined by a smooth curve, the resulting curve is called a Cumulative Relative Frequency Curve. It is ideally done for large sample size and smaller class widths of class intervals.

(f) Relative Frequency Polygon: If midpoints of the dots in a frequency plot are joined by lines, the resulting graph is called a frequency polygon. The polygon is extended to the midpoints of extreme adjacent classes (in both sides) with no relative frequencies.

(g) Cumulative Relative Frequency Histogram: cumulative relative frequency is the same as relative cumulative frequency. Area of a bar should represent the cumulative relative frequency. Thus the height of a bar is the ratio of cumulative relative frequency and class width. If every class has the same width, then the height of a bar of a class is proportional to the cumulative relative frequency of that class.

(h) Cumulative Relative Frequency Plot: If cumulative relative frequencies (divided by the class width in case of unequal class widths) of classes are plotted against the upper limits of the respective classes, the resulting scatter graph is called a Cumulative Relative Frequency Plot.

2.6 The Bar Chart and the Pie Chart

Both bar and pie charts are used to represent discrete and qualitative data.

Bar Chart

A bar chart gives the frequency (or relative frequency) corresponding to each category, with the height or length of the bar proportional to the category frequency (or relative frequency). To make a bar chart, the classes are marked along the horizontal axis and a vertical bar of height equal to the class frequency is drawn over the respective classes.

Example 2.6: Consider the following example of different brands of disks:

Sony	Imation	Verbatim	Imation	Verbatim	Sony	Verbatim	Sony
Verbatim	Verbatim	Sony	Verbatim	Verbatim	Verbatim	Sony	Verbatim
Sony	Verbatim	Sony	Verbatim	Sony	Verbatim	Verbatim	Verbatim
Verbatim	Verbatim	Verbatim	Sony	Verbatim	Verbatim	Verbatim	Verbatim
Verbatim	Verbatim	Verbatim	Verbatim	Verbatim	Verbatim	Sony	Imation
Sony	Verbatim	Imation	Verbatim	Sony	Sony	Verbatim	Verbatim
Verbatim	Verbatim	Verbatim	Sony	Verbatim	Verbatim	Sony	Sony
Verbatim	Sony	Verbatim	Verbatim	Verbatim	Verbatim	Verbatim	Verbatim
Sony	Verbatim	Sony	Verbatim	Verbatim	Sony	Verbatim	Verbatim
Verbatim	Verbatim	Verbatim	Sony	Imation	Verbatim	Verbatim	Imation
Imation	Verbatim	Verbatim	Verbatim	Verbatim	Verbatim	Sony	Verbatim
Verbatim	Verbatim	Sony	Verbatim	Verbatim	Sony	Verbatim	Sony
Verbatim	Imation	Verbatim	Sony	Verbatim	Verbatim	Verbatim	Verbatim
Sony	Verbatim	Sony	Verbatim	Verbatim	Sony	Imation	Imation

Verbatim	Verbatim	Verbatim	Sony	Verbatim	Verbatim	Verbatim	Verbatim
Verbatim	Verbatim	Verbatim	Verbatim	Sony	Verbatim	Sony	Sony
Sony	Verbatim	Verbatim	Verbatim	Verbatim	Imation	Verbatim	Verbatim
Verbatim	Imation	Verbatim	Verbatim	Verbatim	Verbatim	Verbatim	Sony

To draw a Bar Chart using Statistica, we first construct a frequency distribution by following the steps:

1. Add number of cases up to 144 “size of the sample”
2. Input the sample “name of disks” in one column
3. Statistics / Basic Statistics and Tables
4. Frequency Table / OK
5. In Frequency Tables spreadsheet, choose Advanced
6. Click Variables, select variable (Say VAR1) / OK
7. In Categorization methods for tables & graphs select Specific grouping code (Values), then click the icon to the right of it
8. Press ALL / OK
9. Press Summary Frequency Tables, to get the frequency table below.

Floppy Disk	Frequency	Relative Frequency
Imation	12	0.083
Sony	36	0.250
Verbatim	96	0.667
Total	144	1.000

To graph the bar chart, put the above frequency in Var5 and the names in Var4, and then do the following (*make sure that there are not more than three cases*):

1. Graphs/ 2D Graphs / Bar/Column Plots
2. Click Variables (select the Variable Var 5)/OK
3. In Quick, choose (regular “under graph type”)
4. Click Options 1

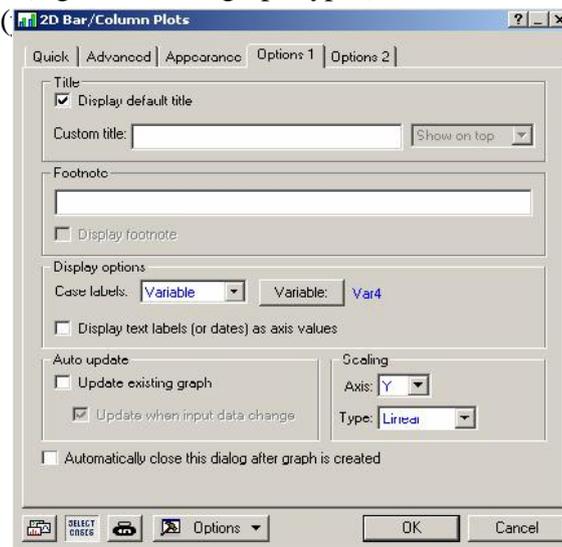


Figure 2.10 2d Bar/Column Plots

5. Under Display options, in Case label choose variable
6. Click variable (select Var4)/OK
7. OK

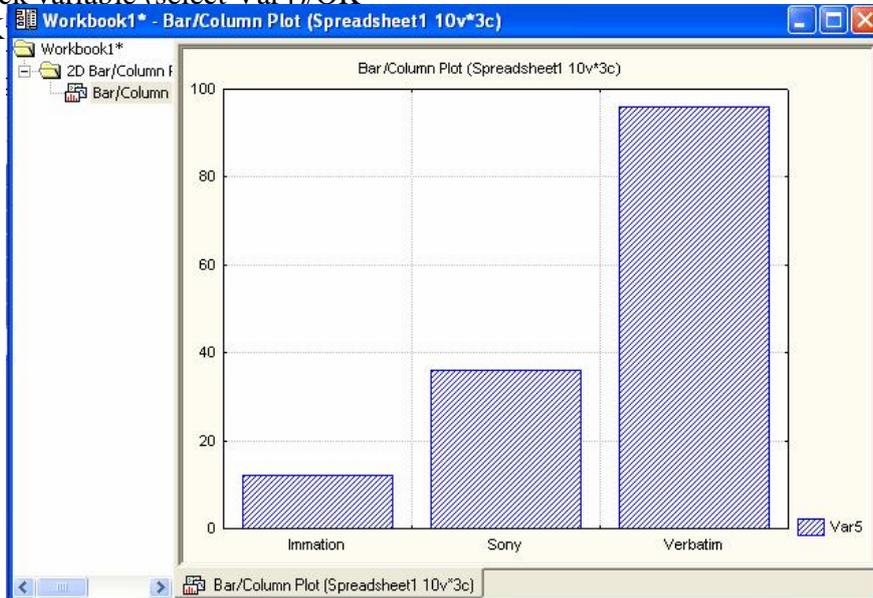


Figure 2.11 Bar/Column Plots

Pie chart

A Pie chart is made by representing the relative frequency of a category by an angle of a circle determined by:

$$\text{Angle of a category} = \text{Relative frequency of the category} \times 360$$

Example 2.7: For a table, a pie chart can be drawn using

1. Graphs/ 2D
2. To get Fig

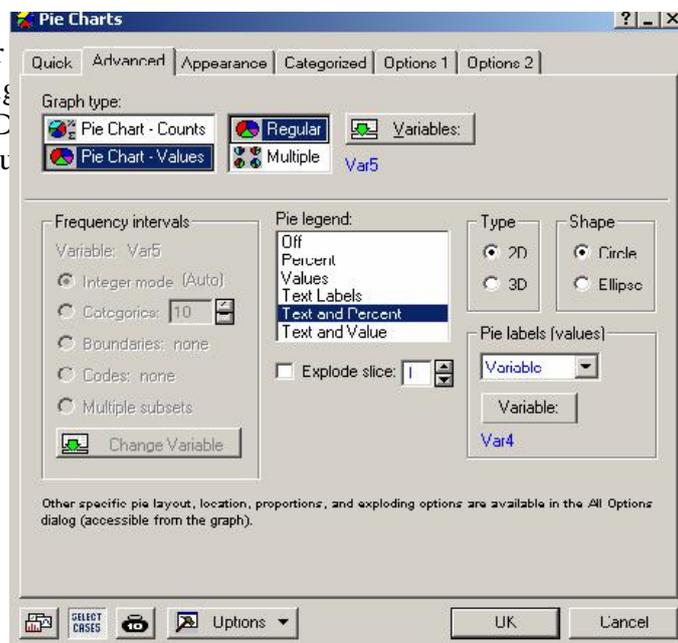


Figure 2.12 Pie Charts Pane

3. Variables “select the variable Say Var5” /OK
4. Under Graph Type choose Pie chart-Values / Regular
5. Hit Pie Chart “Pie Chart (S...)”
- 6.
- 7.

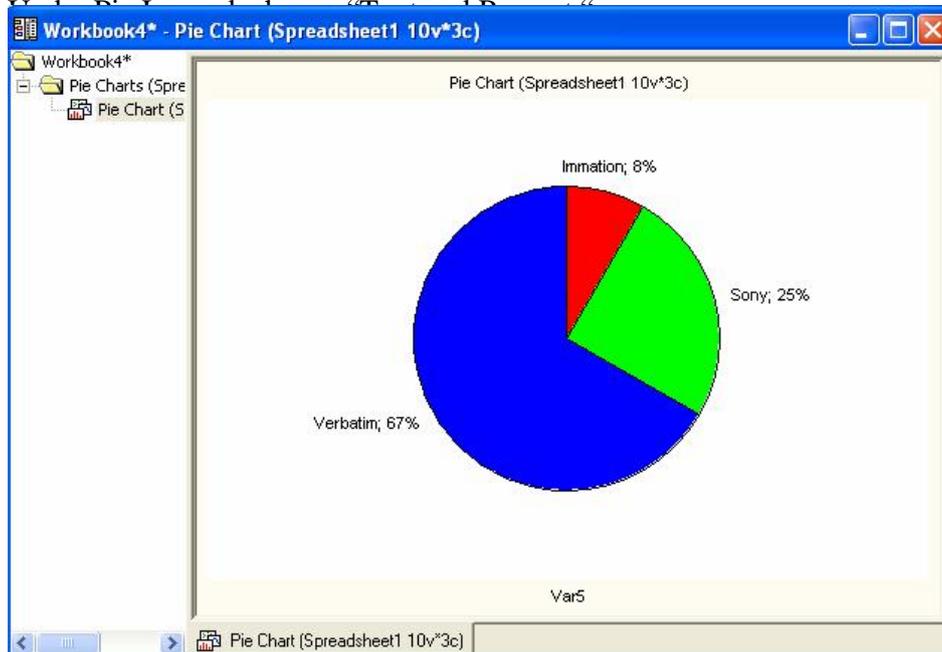


Figure 2.13 Pie Chart

2.7 Numerical Measures

Sometimes we are interested in a number which is representative or typical of the data set. The mean and the median are such numbers. Similarly, we define the range of the data which gives some idea about the variation or dispersion of observations in the data. The most important measure for dispersion is the sample standard deviation.

Measures of Location

Population Mean: The population mean is denoted by μ , and for a finite population is defined by

$$\mu = \frac{1}{N} \sum_{i=1}^N x_i \quad \text{where the } x_i \text{'s are the population values}$$

Sample Mean: The mean \bar{x} of a sample is the average of the observations x_1, x_2, \dots, x_n in the sample. It is given by:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

Example 2.8 Consider a sample of bottle bursting strength data of a set of 5 soft drink bottles

251 255 254 253 252

The sample mean is given by $\bar{x} = (251+255+\dots+252)/5 = 253$.

Sample Median: The median of a sample of n observations x_1, x_2, \dots, x_n is the middle observation when the observations are arranged in ascending or descending order if the number of observations is odd. If the number of observations is even, it is the average of the middle two observations. In other words, for any sample of size n , the median \bar{x} is given by

$$\bar{x} = \begin{cases} \left(\frac{n+1}{2}\right)\text{th observation} & \text{if } n \text{ is odd} \\ \frac{1}{2} \left(\left(\frac{n}{2}\right)\text{th} + \text{the next observation} \right) & \text{if } n \text{ is even} \end{cases}$$

For the bottle bursting strength data, the median is 253. There are 2 observations below it and 2 above it.

Example 2.9 Marks obtained by 6 students in STAT 319 are given by

81 82 98 83 80 85.

The ordered sample observations are 80 81 82 83 85 98, so that the median is $\bar{x} = (82+83)/2 = 82.5$.

Mode: The mode of a sample is the observation occurring the maximum number of times i.e. the observations with the largest frequency.

Example 2.10 The following samples provide prices, in Saudi Riyals (SR), of a computer monitor.

(a) 1200, 1000, 1500, 1200, 1000, 1200

(b) 1300, 1200, 1000

What is the modal price?

Solution: (a) The modal price is SR1200.

(b) There is no modal price.

Example 2.11 The following table shows the hourly wages in SR earned by the employees of a small company and the number of employees who earn each wage.

Wages/hour	6	8	10	13
Number of employees	3	5	4	4

The modal wage per hour is 8 SR.

Measures of Variability

Population Variance: The variance of a population is denoted by

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2 \quad , \text{ when } N \text{ is finite}$$

Sample Variance: For a sample of size n , the variance, denoted by s^2 , is the Total Sum of Squares (TSS) of observations around their mean divided by $n-1$. That is

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 .$$

Note that TSS can also be written as

$$TSS = \sum_{i=1}^n x_i^2 - \frac{1}{n} \left(\sum_{i=1}^n x_i \right)^2 = \sum_{i=1}^n x_i^2 - n\bar{x}^2 .$$

Standard Deviation: The standard deviation is the positive square root of the variance and is given by

$$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} \quad (\text{for the population})$$

$$s = \sqrt{s^2} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} = \sqrt{\frac{1}{n-1} \left(\sum_{i=1}^n x_i^2 - n\bar{x}^2 \right)} \quad (\text{for the sample})$$

For example, the standard deviation for the data in Example 2.8 is given by

$$s = \sqrt{\frac{1}{4} [320055 - 5(253)^2]} = \sqrt{\frac{1}{4} [320055 - 320045]} = \sqrt{\frac{10}{4}} \approx 1.58114 .$$

Percentiles

The α^{th} percentile P_α is the value that exceeds $\alpha\%$ of the data, and is obtained by the following steps:

Step 1: Determine $R_\alpha = \alpha (n+1)/100$, $\alpha = 1, 2, \dots, 99$.

Step 2: Separate i (the largest integer not exceeding R_α) and the decimal part (d) of R_α and write $R_\alpha = i + d$.

Step 3: Order the observations in an ascending manner.

Step 4: The α^{th} percentile is then given by

$$P_\alpha = x_{(i)} + d (x_{(i+1)} - x_{(i)}) = (1-d)x_{(i)} + d x_{(i+1)}, \quad \alpha = 1, 2, \dots, 99 ,$$

where $x_{(i)}$ is the i^{th} observation after ordering the observations ascendingly.

The 25th percentile is called the 1st quartile and is denoted by Q_1 .

The 50th percentile is called the 2nd quartile and is denoted by Q_2 .

The 75th percentile is called the 3rd quartile and is denoted by Q_3 .

Example 2.12 (cf. Vinning, 1998, 1993). An independent consumer group tested radial tires from a major brand to determine expected tread life. The data (in thousands of miles) are given below:

50	54	52	47	56	51	51
48	56	53	43	56	58	42

Find the 1st, 2nd and 3rd quartiles .

The ordered sample observations are given by

42	43	47	48	50	51	51
52	53	54	56	56	56	58

The ranks of the quartiles are:

$$R_{25} = (25) \frac{n+1}{100} = \frac{14+1}{4} = 3.75, \quad (i=3 \quad \text{and} \quad d=0.75)$$

$$R_{50} = (50) \frac{n+1}{100} = \frac{14+1}{2} = 7.5, \quad (i=7 \quad \text{and} \quad d=0.5)$$

$$R_{75} = (75) \frac{n+1}{100} = \frac{3(14+1)}{4} = 11.25, \quad (i=11 \quad \text{and} \quad d=0.25)$$

so that the quartiles are given by:

$$Q_1 = 3.75^{\text{th}} \text{ obs} = (1-0.75) (3^{\text{rd}} \text{ obs}) + 0.75 (4^{\text{th}} \text{ obs}) = 0.25(47) + 0.75(48) = 47.75$$

$$Q_2 = 7.5^{\text{th}} \text{ obs} = (1-0.50) (7^{\text{th}} \text{ obs}) + 0.50 (8^{\text{th}} \text{ obs}) = 0.50(51) + 0.50(52) = 51.50$$

$$Q_3 = 11.25^{\text{th}} \text{ obs} = (1-0.25) (11^{\text{th}} \text{ obs}) + 0.25 (12^{\text{th}} \text{ obs}) = 0.75(56) + 0.25(56) = 56.$$

The Empirical Rule (ER)

If the relative frequency of the data is approximately mound shaped (i.e. bell shaped), then

1. Approximately 68% of the measurements will lie within 1 standard deviation of their mean, i.e. within the interval $[\mu - \sigma, \mu + \sigma]$ for a population, $[\bar{x} - s, \bar{x} + s]$ for a sample.
2. Approximately 95% of the measurements will lie within 2 standard deviations of their mean, i.e. within the interval $[\mu - 2\sigma, \mu + 2\sigma]$ for a population, $[\bar{x} - 2s, \bar{x} + 2s]$ for a sample.
3. Almost all the measurements (i.e. 100%) will lie within 3 standard deviations of their mean, i.e. within the interval $[\mu - 3\sigma, \mu + 3\sigma]$ for a population, $[\bar{x} - 3s, \bar{x} + 3s]$ for a sample.

A population/sample satisfying the above three properties is said to satisfy the empirical rule, though in many cases, it may not guarantee a bell shaped distribution.

Example 2.13 The observations in Example 2.3 are reproduced in ascending order:

0.02 0.15 0.19 0.47 0.71 0.75 0.82 0.92 0.96 1.16
 1.17 1.23 1.38 1.40 1.59 1.61 1.94 2.01 2.16 2.41
 2.59 3.07 3.53 3.76 4.75

For the data, we have $\bar{x} = 1.63$, $s = 1.19$

1. The interval $[\bar{x} - s, \bar{x} + s] = [0.437, 2.823]$ contains 18 observations which leads to the proportion $\frac{18}{25} = 72\%$ which is not close to 68% as expected by the Empirical Rule. Since the rule is violated, we say ER is not satisfied by the sample.
2. The interval $[\bar{x} - 2s, \bar{x} + 2s] = [-0.755, 4.015]$ contains 24 observations which leads to the proportion $\frac{24}{25} = 96\%$ which is not far from 95% as expected by the Empirical Rule.
3. The interval $[\bar{x} - 3s, \bar{x} + 3s] = [-1.948, 5.208]$ contains all 25 observations which lead to the proportion $\frac{25}{25} = 100\%$ which is exactly the same as expected by the Empirical Rule.

If all the three rules are approximately satisfied by the sample, we say that the rule is satisfied. Thus, for this data set the empirical rule is not satisfied.

Coefficient of Variation

The sample coefficient of variation relates variability in the sample to the mean. It is defined by

$$CV = s / \bar{x}.$$

Example 2.14 Suppose that calibration inspection time based on a sample of 100 observations has a mean of 14.342 and standard deviation 1.72 (Lapin, 1997, p22). The coefficient of variation of the sample given by

$$\frac{1.72}{14.342} = 0.12$$

It indicates that the sample standard deviation is only 12% as large as the mean. Since our sample yields a $CV = 0.12$, therefore we conclude that the sample does not have much variation relative to the mean.

Coefficient of Skewness

A measure of skewness indicates the direction of the relative frequency distribution, either skewed to lower values or higher values. The sample coefficient of skewness is given by

$$CS = \frac{\bar{x} - \bar{y}_6}{s/3}$$

A negative value of CS implies that the relative frequency distribution is negatively skewed (left tailed distribution) while a positive value of CS implies that the relative frequency distribution is positively skewed (right tailed distribution).

For the CPU data in Example 2.13 the coefficient of skewness is given by:

$$CS = \frac{1.63 - 1.38}{1.1928/3} = 0.629$$

which indicates that the sample is positively skewed, i.e. the relative frequency histogram has a long right tail.

Proportion

The population proportion is defined as $p = \frac{X}{N}$, where X is the number of observations in the population possessing a particular characteristic, and N is the population size. The sample proportion is given by $\hat{p} = x/n$ where n is the sample size, x is the number of observations possessing that particular characteristic in the sample.

In a statistics course 30 students sat for final exam, 6 got A , 3 failed and the rest got other grades B, C, D . Then the proportion of students who got A is $6/30 = 0.20$, and the proportion of failing students is $3/30 = 0.10$.

2.8 Descriptive Statistics Using Statistica

To do the descriptive statistics of the data given in Example 2.2, enter the data in one column, **make sure that there are no more than 30 cases**. Follow the steps below:

1. Statistics / Basic Statistic / Tables
2. Select Descriptive Statistics: Spreadsheet
3. Click Add

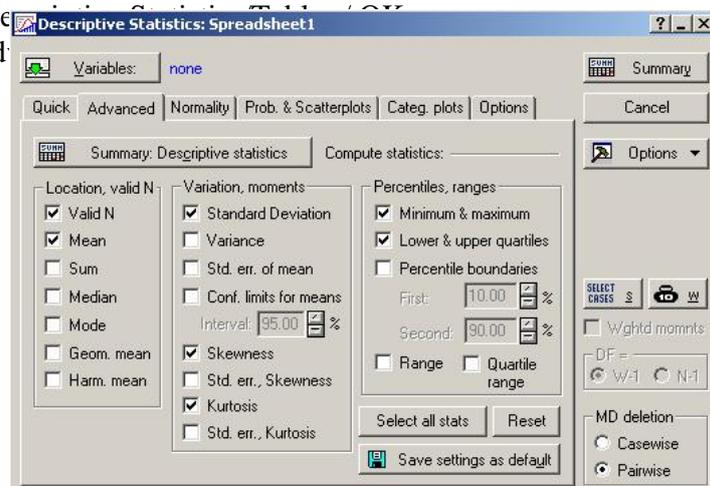
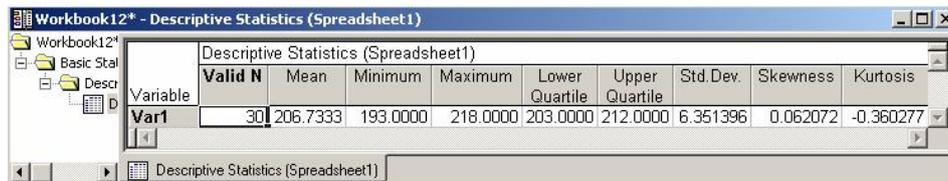


Figure 2.14 Descriptive Statistics Spreadsheet

4. Variables/ select variable(Say Var1)
5. Select desired statistics
6. Click Summary

If Valid N, Mean, Maximum and Minimum, Std. Dev., Lower and Upper Quartiles, Skewness and Kurtosis were selected for one sample in step (5), then we would have the Spreadsheet given by Figure 2.15.



Variable	Valid N	Mean	Minimum	Maximum	Lower Quartile	Upper Quartile	Std.Dev.	Skewness	Kurtosis
Var1	30	206.7333	193.0000	218.0000	203.0000	212.0000	6.351396	0.062072	-0.360277

Figure 2.15 Computed Descriptive Statistics

2.9 The Box Plot

A box aligned with the first and the third quartiles as edges, median at the appropriate place in the scale is called a box plot. It is extended to both directions up to the smallest and the largest values. These extensions may be called arms. This technique displays the structure of the data set by using the quartiles and the extreme values of a sample.

The following intervals, called inner fences and outer fences, are used to detect outliers.

$$\text{Inner fences: } [Q_1 - 1.5(IQR), Q_3 + 1.5(IQR)] = [LIF, UIF]$$

$$\text{Outer fences: } [Q_1 - 3.0(IQR), Q_3 + 3.0(IQR)] = [LOF, UOF]$$

where $IQR = Q_3 - Q_1$ is the interquartile range and LIF, UIF are *Lower and Upper Inner Fence* and LOF, UOF are *Lower and Upper Outer Fence*.

Observations that fall within the inner fence and outer fence are deemed to be suspected outliers and those falling outside the outer fence are highly suspect outliers (Sincich, 1992).

Example 2.14 Construct the Box plot with the CPU data in Example 2.3.

Solution: The quartiles are given by

$$Q_1 = 6.5 \text{ th obs} = 0.5(0.75) + 0.5(.82) = 0.785,$$

$$Q_2 = \frac{13}{2} = 6.5 \text{ th observations} = 1.38,$$

$$Q_3 = 19.5 \text{ th obs} = 0.5(2.16) + 0.5(2.41) = 2.285,$$

$$IQR = Q_3 - Q_1 = 2.285 - 0.785 = 1.5$$

The Inner Fences are given by $Q_1 \pm 1.5(IQR) = 0.785 \pm 1.5(1.5)$ i.e. $[-1.465, 3.035]$ while the Outer Fences are given by $Q_3 \pm 3(IQR) = 0.785 \pm 3(1.5)$ i.e. $[-3.715, 5.285]$. Clearly the observation 4.75 in the CPU data is a suspect outlier by the inner Fence Method.

Since the second quartile (Q_2) is closer to the first quartile (Q_1) than it is to the third quartile (Q_3) i.e. $Q_2 - Q_1 < Q_3 - Q_2$, the distribution is positively skewed.

With the data in one column in the Basic Statistics Module in Statistica, one can construct a box plot by following the steps:

1. Statistics/Basic Statistics/Tables
2. Descriptive Statistics/OK
3. Variables/Select variable (Var3) /OK
4. From the choices appeared in the *Descriptive Statistics spreadsheet (Quick, Advanced,..., Options)*, Click Options (there are four types of Box-Whisker plots available in the package)
5. Choose Median /Quart/Range (in Options for Box-Whisker plots)
6. Click Quick
7. Box & Whisker plot for all variables.

These steps will give two graphs, one of them as standard containing Mean/SD/1.96*SD, and the other containing Median/Quart/Range as in Figure 2.16.

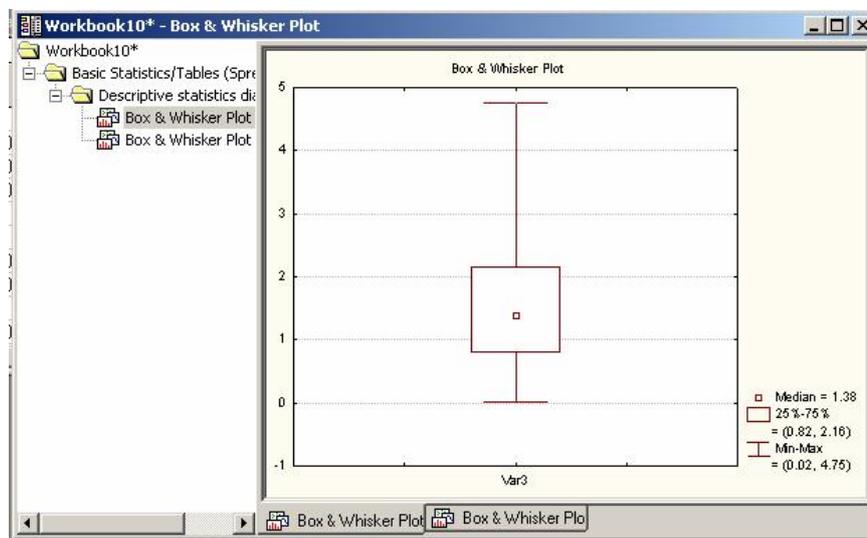


Figure 2.16 Box-Whisker Plot

2.10 Approximate Mean and Variance of Grouped Data

The CPU data in Example 2.3 has been used to make the following frequency distribution.

Class	Class Interval	Midvalue	f	Relative f	F	Relative F
1	[0, 1)	0.5	9	0.36	9	0.36
2	[1, 2)	1.5	8	0.32	17	0.68
3	[2, 3)	2.5	4	0.16	21	0.84
4	[3, 4)	3.5	3	0.12	24	0.96
5	[4, 5)	4.5	1	0.04	25	1.00

The above table is 'equivalent' to CPU data with mid-values as given below:

0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5
 2.5 2.5 2.5 2.5
 3.5 3.5 3.5
 4.5

The sample mean of the above sample can now be calculated by the usual formula

$$\bar{x} = \left(\frac{0.5 + 0.5 + \dots + 4.5}{25} \right) = 1.66.$$

Note the discrepancy between the sample mean (1.63) calculated from the ungrouped data in Example 2.3 and the sample mean (1.66) calculated from the grouped data. The expression for the mean can also be written by the distinct numbers as

$$\bar{x} = \frac{1}{25} [0.5(9) + 1.5(8) + 2.5(4) + 3.5(3) + 4.5(1)] = \frac{1}{n} \sum_{i=1}^k x_i f_i$$

where k is the number of classes in the Frequency Table.

The sample variance can be calculated as follows:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^k (x_i - \bar{x})^2 f_i = \frac{1}{n-1} \left(\sum_{i=1}^k x_i^2 f_i - \frac{\left(\sum_{i=1}^k x_i f_i \right)^2}{n} \right)$$

Thus, for the data consisting of the above mid-values we have $s^2 = 1.39$.

Exercises

- 2.1 Refer to Example 2. 1, do the following:
- (a) Select a SRS of size 12 using a random number table.
 - (b) Select a SRS of size 20 using Statistica.
 - (c) Construct a frequency distribution using the class intervals [30,70],[70,140) and so on.
 - (d) Draw the histogram corresponding to the frequency distribution in part (a). How would you describe the shape of this histogram?
 - (e) Draw a stem and leaf plot for the above data.
 - (f) Draw a box plot and comment on the symmetry and shape of the data.

- 2.2 (cf. Devore, J. L. and Peck, R., 1997, 72). The paper “The Pedaling Technique of Elite Endurance Cyclists” (Int. J. of Sport Biomechanics (1991, pp. 29-53) reported the accompanying data on single-leg power at a high workload.

244 191 160 187 180 176 174 205 211 183 211 180 194 200

- (a) Find the mean, median, standard deviation, variance, lower and upper quartiles, range inter quartile range, coefficient of variation, co-efficient of skewness for the above data.
 - (b) Do the data satisfy the empirical rule?
- 2.3 (cf. Montgomery, D. C., et. al 2001, 25-26). The following data are direct solar intensity measurements (watts/m-sq) on different days at a location in southern Spain:

562 869 708 775 775 704 809 856 655 806 878 909
918 558 768 870 918 940 946 661 820 898 935 952
957 693 835 905 939 955 960 498 653 730 753.

- (a) Calculate the following summary statistics for this sample Mean, median, standard deviation, variance, co-efficient of variation, co-efficient of skewness, range, lower and upper quartiles, inter-quartile range.
 - (b) Construct the box plot.
- 2.4 (Montgomery, D. C., et. al, 2001, 25-26). The following data are the compressive strengths in pounds per square inch (psi) of 80 specimens of a new aluminum-lithium alloy undergoing evaluation as a possible material for aircraft structural elements.

105 221 183 186 121 181 180 143 97 154 153 174 120 168 167 141
245 228 174 199 181 158 176 110 163 131 154 115 160 208 158 133
207 180 190 193 194 133 156 123 134 178 76 167 184 135 229 146
218 157 101 171 165 172 158 169 199 151 142 163 145 171 148 158
160 175 149 87 160 237 150 135 196 201 200 176 150 170 118 149

- (a) Construct a frequency distribution and a frequency histogram starting from 70 and the step size 20.
- (b) Construct a stem and leaf plot.
- 2.5 Refer to Exercise 2.1 draw a random sample of size 20 using the random number table at the end of your manual.
- (a) With replacement
- (b) Without replacement.

- 2.6 (cf. Johnson, R. A., 2001, 53). The following measurements of the diameters (in feet) of Indian mounds in southern Wisconsin were gathered by examining reports in the Wisconsin Archeologist.

22 24 24 30 22 20 28 30 24 34 36 15 37

- (a) Find the upper and lower quartiles and 90th percentile for the above data.
- (b) Find the range and the inter quartile range of this data.
- (c) Calculate the mean, median & standard deviation.
- (d) Find the proportion of the observations that are in the intervals $\bar{x} \pm s$, $\bar{x} \pm 2s$, and $\bar{x} \pm 3s$.
- (e) Compare the results in part (d) with the empirical guidelines.
- (f) Display the data in the form of a box plot.
- 2.7 (Johnson, R. A., 2000, 22). Consider the following humidity readings rounded to the nearest percent:

29 44 12 53 21 34 39 25 48 23
17 24 27 32 34 15 42 21 28 37

- (a) Construct a frequency distribution and histogram starting from 10 and with a width (step size) of the intervals 10.
- (b) Construct a stem and leaf plot of the above data.
- 2.8 (Devore, J. L. and Farnum, N. R., 1999, 16). Corrosion reinforcing steel is a serious problem in concrete structures located in environments affected by severe weather conditions. For this reason researchers have been investigating the use of reinforcing bars made of composite material. One study was carried out to develop guidelines for bonding glass-fiber-reinforced plastic rebars to concrete. Consider the following 48 observations on measured bond strength:

11.5 12.1 9.9 9.3 7.8 6.2 6.6 7.0 13.4 17.1 9.3 5.6
5.7 5.4 5.2 5.1 4.9 10.7 15.2 8.5 4.2 4.0 3.9 3.8
3.6 3.4 20.6 25.5 13.8 12.6 13.1 8.9 8.2 10.7 14.2 7.6
5.2 5.5 5.1 5.0 5.2 4.8 4.1 3.8 3.7 3.6 3.6 3.6

- (a) Construct a stem-and-leaf display for these data.
- (b) Construct a frequency distribution and histogram, starting from 2 and with a step size 2.

- 2.9 (cf. Montgomery, D. C., et. al, 2001, 25). In Applied Life Data Analysis (Wiley, 1982), Wayne Nelson presents the break-down time of an insulating fluid between electrodes at 34 kV. The times in minutes, are as follows:

0.19 0.78 0.96 1.31 2.78 3.16 4.15 4.67 4.85 5.81
6.50 7.35 8.01 8.27 12.06 13.75 32.52 33.91 36.71 72.89

- (a) Calculate the sample average and the sample standard deviation.
(b) Calculate the coefficient of variation and coefficient of skewness.

- 2.10 (cf. Montgomery, D. C., et. al, 2001, 25). An article in the *Journal of Structural Engineering* (1989, p115) describes an experiment to test the yield strength of circular tubes with caps welded to the ends. The first yields (in kN) are

96 102 102 102 104 104 108 126 126 128 128 140 156 160 160 164 170

Calculate the sample median, upper and lower quartile and construct a box plot.

- 2.11 (cf. Montgomery, D. C., et. al, 2001, 25). The data on visual accommodation (a function of eye movement) when recognizing a speckle pattern on a high resolution CRT screen is as follows:

36.45 67.90 38.77 42.18 26.72 50.77 39.30 49.71 67.90
38.77 42.18 26.72 50.77 39.30 67.90 38.77 42.18 26.72
50.77 39.30 67.90 38.77 42.18 26.72 50.77 39.30 29.12

- (a) Calculate the sample mean, median, mode, variance and the sample standard deviation.
(b) Calculate the coefficient of variation and coefficient of skewness and interpret these values.
(c) Prepare a stem-and-leaf plot of the above data and comment on the shape of the data.
(d) Construct a frequency histogram, and compare it with stem-and-leaf plot.
(e) Draw a cumulative relative frequency curve and determine the 40th percentile, the 70th percentile. Explain these quantities.
- 2.12 (cf. Montgomery, D. C., et. al, 2001, 30). The following data are the numbers of cycles to failure of aluminum test coupons subjected to repeated alternating stress at 21,000 psi, 18 cycles per second:

1115 1567 1223 1782 1055 1310 1883 375 1522 1764
1540 1203 2265 1792 1330 1502 1270 1910 1000 1608
1258 1015 1018 1820 1535 1315 845 1452 1940 1781
1085 1674 1890 1120 1750 798 1016 2100 910 1501
1020 1102 1594 1730 1238 865 1605 2023 1102 990
2130 706 1315 1578 1468 1421 2215 1269 758 1512
1109 785 1260 1416 1750 1481 885 1888 1560 1642

- (a) Construct a stem-and-leaf display for these data.

- (b) Construct a frequency distribution and histogram, starting from 750 and with a step size 200.
- (c) Is the empirical rule satisfied?
- 2.13 (cf. Montgomery, D. C., et. al, 2001, 2001, 42). The pH of a solution is measured eight times by one operator using the same instrument. She obtains the following data:

7.05 7.20 7.18 7.19 7.20 7.15 7.20 7.18 7.19 7.20 7.21 7.16
 7.15 7.20 7.08 7.19 7.25 7.21 7.16 7.15 7.20 7.18 7.19 7.20
 7.21 7.16 7.21 7.16 7.15 7.26 7.18 7.19 7.20 7.21 7.16 7.19.

Calculate the following summary statistics: Mean, Median, Range, IQR, Standard Deviation and Variance.

- 2.14 (cf. Montgomery, D. C., et. al, 2001, 42). A sample of 30 resistors yielded the following resistances (ohms):

38 47 45 41 35 35 34 45 44 47 45 41 35 35 36
 34 45 34 45 44 47 45 41 35 47 45 41 35 43 43

Compute summary statistics for this data.

- 2.15 (cf. Montgomery, D. C., et. al, 2001, 37). An article in the Transactions of the Institution of Chemical Engineers (1956, 34, 280-293) reported data from an experiment investigating the effect of several process variable on the vapor phase oxidation of naphthalene. A sample of percentage mole conversion of naphthalene to maleic anhydride follows:

4.2 4.7 5.0 3.8 3.6 3.0 5.1 3.1 3.8 4.8
 4.0 5.2 4.3 2.8 2.0 2.8 3.3 4.8 5.0.

- (a) Calculate the sample mean, variance, standard deviation, range, coefficient of variation and skewness.
- (b) Calculate the sample median, lower and upper quartiles, inter-quartile-range.
- (c) Construct a box plot of the data.
- 2.16 (cf. Montgomery, D. C., et. al, 2001, 37). The following data are the temperatures of effluent at discharge from a sewage treatment facility on consecutive days:

43 47 51 48 52 50 46 49 45 52 46 51
 44 49 46 51 49 45 44 50 48 50 49 50

- (a) Calculate the sample mean, variance, standard deviation, range, coefficient of variation and skewness.
- (b) Calculate the sample median, lower and upper quartiles, inter-quartile-range.
- (c) Construct a box plot of the data.
- (d) Find the 5th and 95th percentiles of the temperature.
- (e) Construct a dot plot for the temperature data.

- 2.17 (Devore, J. L. and Farnum, N. R., 1999, 4-5). The tragedy that befell the space shuttle Challenger and its astronauts in 1986 led to a number of studies to investigate the reasons for mission failure. Attention quickly focused on the behavior of the rocket engine's O-rings. Here is data consisting of observations on O-ring Temperature ($^{\circ}\text{F}$) for each test firing or actual launch of the shuttle rocket engine (Presidential Commission on the Space Shuttle Challenger Accident, 1986, 1, pp.129-131).

84 49 61 40 83 67 45 66 70 69 80 58 68 60 67 72 73 70
57 63 70 78 52 67 53 67 75 61 70 81 76 79 75 76 58 31

- (a) Prepare a dot plot of the sample.
(b) Construct a stem-and-leaf display for these data.
(c) Construct a frequency distribution and histogram, starting from 25 and with a step size 10.
- 2.18 (Devore, J. L. and Farnum, N. R., 1999, 18). In the manufacture of printed circuit boards, finished boards are subjected to a final inspection before they are shipped to customers. Here is data on the type of defect for each board rejected at final inspection during a particular time period:

Type of defect	Frequency
Low copper plating	112
Poor electrolyses coverage	35
Lamination problems	10
Plating separation	8
Etching problems	5
Miscellaneous	12

Make a bar chart and a pie chart of the above data.

- 2.19 (Devore, J. L., 2000, 18). Power companies need information about customer usage to obtain accurate forecast of demands. Investigators from Wisconsin Power and Light determined energy consumption (BTUs) during a particular period for a sample of 90 gas-heated homes. An adjusted consumption value was calculated as follows:

Class	1-3	3-5	5-7	7-9	9-11	11-13	13-15	15-17	17-19
Frequency	1	1	11	21	25	17	9	4	1

- (a) Find mean, median, standard deviation, variance, lower and upper quartiles, range inter quartile range, co-efficient of variation, co-efficient of skewness for the above data.
(b) Does the Empirical Rule satisfy the above data?
(c) Construct a frequency histogram of the above data.