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Chapter 4

Numerical summaries for data

4.1 Introduction

So far we have only considered graphical methods for presenting data. These are always useful starting points. For many purposes, though, we might also require numerical methods for summarising data.

4.2 Mathematical notation

Before we can talk more about numerical techniques we first need to define some basic notation. This is to allow us to generalise all situations with a simple shorthand.

Very often in statistics we replace actual numbers with letters in order to be able to write general formulae. We generally use a single letter to represent sample data and use subscripts to distinguish individual observations in the sample. Amongst the most common letters to use is x , although y and z are frequently used as well. For example, suppose we ask a random sample of three people how many mobile phone calls they made yesterday. We might get data 1, 5, 7. If we take another sample we will most likely get different data, say 2, 0, 3. Using algebra we can represent the general case as x_1, x_2, x_3 :

1st sample	1	5	7
2nd sample	2	0	3
typical sample	x_1	x_2	x_3

This can be generalised further by referring to the data as a whole as x and the i th observation in the sample as x_i . Hence, in the first sample above, the second observation is $x_2 = 5$ whilst in the second sample it is $x_2 = 0$. The letters i and j are most commonly used as the index numbers for the subscripts.

The total number of observations in a sample is usually referred to by the letter n . Hence in our simple example above $n = 3$.

The next important piece of notation to introduce is the symbol \sum . This is the upper case of the Greek letter *sigma*. It is used to represent the phrase “sum the values”. This symbol is used as follows:

$$\sum_{i=1}^n x_i = x_1 + x_2 + \cdots + x_n.$$

This notation is used to represent the sum of all the values in our data (from the first $i = 1$ to the last $i = n$), and is often abbreviated to $\sum x$ when we sum over all the data in our sample.

Two other mathematical basics need to be reintroduced. First, the use of powers is important in many statistical formulae. We all know that, for example, the square of three means raising 3 to the power 2, i.e. $3^2 = 3 \times 3 = 9$. This can be generalised to x^k , which means multiplying x by itself k times.

The other important idea is the use of brackets. Brackets are used to impose an ordering on the way operations are carried out. The operation inside the bracket is carried out before the one outside. Consider the following three cases:

$$\begin{aligned} 3 + 4^2 &= 19 \\ 3^2 + 4^2 &= 25 \\ (3 + 4)^2 &= 49. \end{aligned}$$

In the first case, we simply square 4 and then add this to 3. In the second case, we square both numbers and then add them together, while in the third case, because of the brackets, we add the numbers together and then square the result. Each one of these seemingly similar formulae gives a very different result. If we consider the last two formulae in general terms we could represent the second as $\sum x^2$, that is, we raise all the x s to the power 2 and then add them together. The third equation can be represented as $(\sum x)^2$, that is, all the x s are summed together and then this sum raised to the power 2. This is an important distinction which we will use later.

4.3 Measures of Location

These are also referred to as measures of centrality or averages. In general terms, they tell us the value of a “typical” observation. There are three measures which are commonly used: the *mean*, the *median* and the *mode*. We will consider these in turn.

4.3.1 The Arithmetic Mean

The arithmetic mean is perhaps the most commonly used measure of location. We often refer to it as the average or just the mean. The arithmetic mean is calculated by simply adding all our data together and dividing by the number of data we have. So if our data were 10, 12, and 14, then our mean would be

$$\frac{10 + 12 + 14}{3} = \frac{36}{3} = 12.$$

We denote the mean of our sample, or sample mean, using the notation \bar{x} . In general, the mean is calculated using the formula

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

or equivalently as

$$\bar{x} = \frac{\sum x}{n}.$$

For small data sets this is easy to calculate by hand, though this is simplified by using the statistics (**SD**) mode on a university approved calculator.

Sometimes we might not have the raw data but data are available in the form of a table. It is still possible to calculate the mean from such data. Let us first consider the case where we have some ungrouped discrete data. Previously we have seen the data

Date	Cars Sold	Date	Cars Sold
01/07/04	9	08/07/04	10
02/07/04	8	09/07/04	5
03/07/04	6	10/07/04	8
04/07/04	7	11/07/04	4
05/07/04	7	12/07/04	6
06/07/04	10	13/07/04	8
07/07/04	11	14/07/04	9

The mean number of cars sold per day is

$$\bar{x} = \frac{9 + 8 + \dots + 8 + 9}{14} = 7.71.$$

These data can be presented as the frequency table

Cars Sold ($x_{(j)}$)	Frequency (f_j)
4	1
5	1
6	2
7	2
8	3
9	2
10	2
11	1
Total (n)	14

The sample mean can be calculated from these data as

$$\bar{x} = \frac{4 \times 1 + 5 \times 1 + 6 \times 2 + \dots + 11 \times 1}{14} = 7.71.$$

We can express this calculation of the sample mean from discrete tabulated data as

$$\bar{x} = \frac{1}{n} \sum_{j=1}^k x_{(j)} f_j.$$

Here the different values of X which occur in the data are $x_{(1)}, x_{(2)}, \dots, x_{(k)}$. In the example $x_{(1)} = 4, x_{(2)} = 5, \dots, x_{(k)} = 11$ and $k = 8$.

If we only have grouped frequency data, it is still possible to *approximate* the value of the sample mean. Consider the following (ordered) data:

8.4 8.7 9.0 9.0 9.2 9.3 9.3 9.5 9.6 9.6
9.6 9.7 9.7 9.9 10.3 10.4 10.5 10.7 10.8 11.4

The sample mean of these data is 9.73. Grouping these data into a frequency table gives

Class Interval	Mid-point (m_j)	Frequency (f_j)
$8.0 \leq x < 8.5$	8.25	1
$8.5 \leq x < 9.0$	8.75	1
$9.0 \leq x < 9.5$	9.25	5
$9.5 \leq x < 10.0$	9.75	7
$10.0 \leq x < 10.5$	10.25	2
$10.5 \leq x < 11.0$	10.75	3
$11.0 \leq x < 11.5$	11.25	1
Total (n)		20

When the raw data are not available, we don't know where each observation lies in each interval. The best we can do is to assume that all the values in each interval lie at the central value of the interval, that is, at its mid-point. Therefore, the (approximate) sample mean is calculated using the frequencies (f_j) and the mid-points (m_j) as

$$\bar{x} = \frac{1}{n} \sum_{j=1}^k f_j m_j.$$

For the grouped data above, we obtain

$$\bar{x} = \frac{1}{20} (1 \times 8.25 + 1 \times 8.75 + \dots + 3 \times 10.75 + 1 \times 11.25) = 9.775.$$

This value is fairly close to the correct sample mean and is a reasonable approximation given the partial information we have in the table.

For large samples with narrow intervals, this approximate value will be very close to the correct sample mean (calculated using the raw data).

4.3.2 The Median

The median is occasionally used instead of the mean, particularly when the data have an asymmetric profile (as indicated by a histogram). The median is the middle value of the observations when they are listed in ascending order. It is straightforward to determine the median for small data sets, particularly via a stem and leaf plot. For larger data sets, the calculation is more easily done using MINITAB.

The median is that value that has half the observations above it and half below. If the sample size (n) is an odd number, the median is

$$\text{median} = \left(\frac{n+1}{2}\right)^{\text{th}} \text{ largest observation.}$$

For example, if our data were 2,3,3,5,6,7,9 then the sample size ($n = 7$) is an odd number and therefore the median is the

$$\frac{7+1}{2} = 4^{\text{th}} \text{ largest observation,}$$

that is, the median is the fourth largest (or smallest) ranked observation: for these data median = 5.

If the sample size (n) is an even number the process is slightly more complicated:

$$\text{median} = \text{average of the } \left(\frac{n}{2}\right)^{\text{th}} \text{ and the } \left(\frac{n}{2} + 1\right)^{\text{th}} \text{ largest observations.}$$

For example, if our data were 2,3,3,5,6,7,9,10 then the sample size ($n = 8$) and is an even number and therefore

$$\begin{aligned} \text{median} &= \text{average of the } \left(\frac{8}{2}\right)^{\text{th}} \text{ and the } \left(\frac{8}{2} + 1\right)^{\text{th}} \text{ largest observations} \\ &= \frac{5+6}{2} \\ &= 5.5. \end{aligned}$$

It is possible to estimate the median value from an ogive as it is half way through the ordered data and hence is at the 50% level of the cumulative frequency. The accuracy of this estimate will depend on the accuracy of the ogive drawn.

4.3.3 The Mode

This is the final measure of location we will look at. It is the value of the random variable in the sample which occurs with the highest frequency. It is usually found by inspection. For discrete data this is easy. The mode is simply the most common value. So, on a bar chart, it would be the category with the highest bar. For example, consider the following data, 2,2,2,3,3,4,5. Quite obviously the mode is 2 as it occurs most often. We often talk about modes in terms of categorical data. Recalling the newspaper example, the mode was The Sun, as it was the most popular paper.

It is possible to refer to modal classes with grouped data. This is simply the class with the greatest frequency of observations. For example, the modal class of

Class	Frequency
$10 \leq x < 20$	10
$20 \leq x < 30$	15
$30 \leq x < 40$	30

is obviously $30 \leq x < 40$. It is not possible to put a single value on the mode with such continuous data. However, the modal class might tell you much about the data. Modal classes are also obvious from histograms, being the highest peaked bar. Of course, if we change the class boundaries, the position of the modal class may change.

4.4 Measures of Spread

A measure of location is insufficient in itself to summarise data as it only describes the value of a typical outcome and not how much variation there is in the data. For example, the two datasets 6,22,38 and 21,22,23 both have the same mean (22) and the same median (22). However the first set of data ranges considerably from this value while the second stays very close. They are quite clearly very different data sets. The mean or the median does not fully represent the data. There are three basic measures of spread which we will consider, the *range*, the *inter-quartile range* and the *sample variance*.

4.4.1 The Range

This is the simplest measure of spread. It is simply the difference between the largest and smallest observations. In our simple example above the range for the first set of numbers is $38 - 6 = 32$ and for the second set it is $23 - 21 = 2$. These clearly describe very different data sets. The first set has a much wider range than the second.

There are two problems with the range as a measure of spread. When calculating the range you are looking at the two most extreme points in the data, and hence the value of the range can be unduly influenced by one particularly large or small value, known as an *outlier*. The second problem is that the range is only really suitable for comparing (roughly) equally sized samples as it is more likely that large samples contain the extreme values of a population.

4.4.2 The Inter-Quartile Range

The inter-quartile range describes the range of the middle half of the data and so is less prone to the influence of the extreme values.

To calculate the inter-quartile range (IQR) we simply divide the the ordered data into four quarters. The three values that split the data into these quarters are called the *quartiles*. The first quartile (*lower quartile*, $Q1$) has 25% of the data below it; the second quartile (*median*, $Q2$) has 50% of the data below it; and the third quartile (*upper quartile*, $Q3$) has 75% of the data below it. We already know how to find the median and the other quartiles are calculated as follows:

$$Q1 = \frac{(n + 1)}{4} \text{th smallest observation}$$
$$Q3 = \frac{3(n + 1)}{4} \text{th smallest observation.}$$

Just as with the median, these quartiles might not correspond to actual observations. For example, in a dataset with $n = 20$ values, the lower quartile is the $5\frac{1}{4}$ th largest observation, that is, a quarter of the way between the 5th and 6th largest observations. This calculation is essentially the same process we used when calculating the median. Consider again the data

8.4 8.7 9.0 9.0 9.2 9.3 9.3 9.5 9.6 9.6
9.6 9.7 9.7 9.9 10.3 10.4 10.5 10.7 10.8 11.4

Here the 5th and 6th smallest observations are 9.2 and 9.3 respectively. Therefore, the lower quartile is $Q1 = 9.225$. Similarly the upper quartile is the $15\frac{3}{4}$ smallest observation, that is, three quarters of the way between 10.3 and 10.4; so $Q3 = 10.375$.

The inter-quartile range is simply the difference between the upper and lower quartiles, that is

$$IQR = Q3 - Q1$$

which for these data is $IQR = 10.375 - 9.225 = 1.15$.

The interquartile range can also be *estimated* from the ogives in a similar manner to the median. Simply draw the ogive and then read off the values for 75% and 25% and calculate the difference between them. This is especially useful if you only have grouped data. Again the accuracy depends on the quality of your graph.

The inter-quartile range is useful as it allows us to start to make comparisons between the ranges of two data sets, without the problems caused by outliers or uneven sample sizes.

4.4.3 The Sample Variance and Standard Deviation

The *sample variance* is the standard measure of spread used in statistics. It is usually denoted by s^2 and is simply the “average” of the squared distances of the observations from the sample mean. Strickly speaking, the sample variance measures deviation about a value calculated from the data (the sample mean) and so we use an $n - 1$ divisor rather than n . That is, we use the formula

$$s^2 = \frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots + (x_n - \bar{x})^2}{n - 1}.$$

We can rewrite this using more condensed mathematical notation as simplified to

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

or equivalently as

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

Note that the notation x_i^2 represents the squared value of the observation x_i . That is, $x_i^2 = (x_i)^2$.

The *sample standard deviation* s is the positive square root of the sample variance. This quantity is often used in preference to the sample variance as it has the same units as the original data and so is perhaps easier to understand.

If this appears complicated, don't worry as most basic calculators will give the sample standard deviation when in **SD** mode. Note that the correct standard deviation is given by the s or σ_{n-1} button on the calculator and **not** the σ or σ_n buttons.

A different calculation is needed when the data are given in the form of a grouped frequency table with frequencies (f_i) in intervals with mid-points (m_i). First the sample mean \bar{x} is approximated

(as described earlier) and then the sample variance is approximated as

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

Consider again the data

8.4 8.7 9.0 9.0 9.2 9.3 9.3 9.5 9.6 9.6
9.6 9.7 9.7 9.9 10.3 10.4 10.5 10.7 10.8 11.4

We have already calculated the sample mean as $\bar{x} = 9.73$. Now

$$\begin{aligned} \sum x^2 &= 8.4^2 + 8.7^2 + \dots + 11.4^2 = 1904.38 \\ n(\bar{x})^2 &= 1893.458 \end{aligned}$$

and so the sample variance is

$$s^2 = \frac{1}{19}(1904.38 - 1893.458) = 0.57484$$

and the sample standard deviation is

$$s = \sqrt{s^2} = \sqrt{0.57484} = 0.75818.$$

To ensure you understand the formulae and notation it would be a good idea for you to work through the following example:

x_i	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$	x_i^2
1			
1			
2			
3			
5			
6			
6			
6			
7			
8			
Totals			

$$n =$$

$$\sum x =$$

$$\bar{x} = \frac{\sum x}{n} =$$

$$\sum (x - \bar{x})^2 =$$

$$s^2 = \frac{1}{n-1} \sum (x - \bar{x})^2 =$$

$$\sum x^2 =$$

$$s^2 = \frac{1}{n-1} \left\{ \sum x^2 - n(\bar{x})^2 \right\} =$$

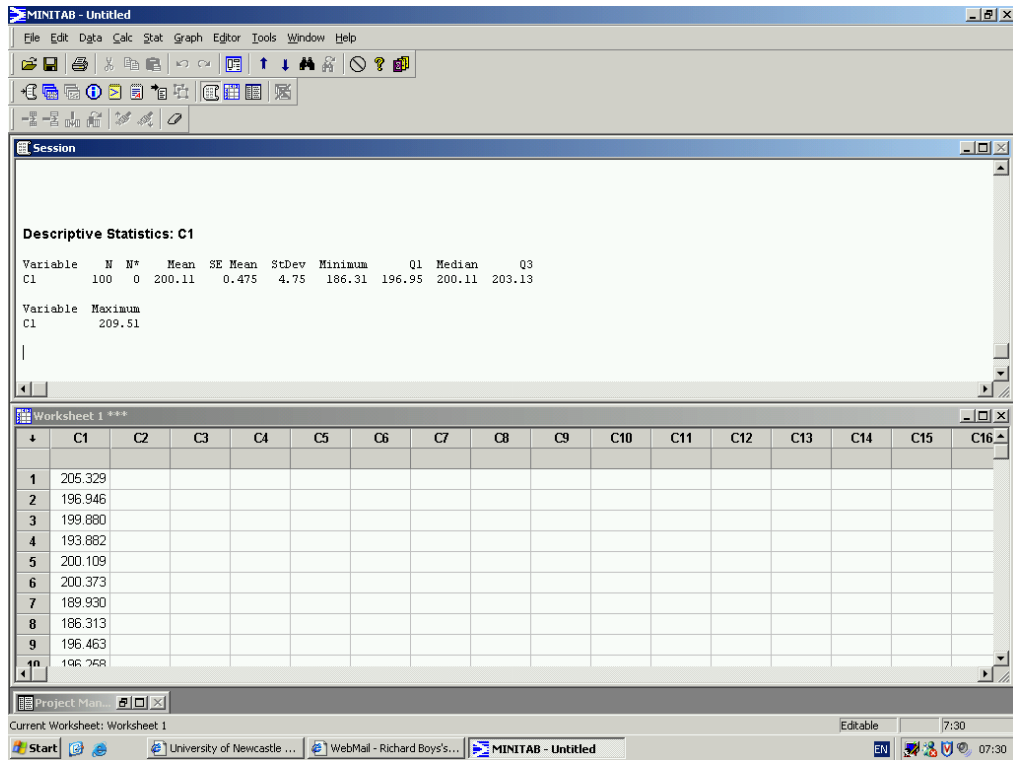
$$s = \sqrt{s^2} =$$

4.5 Summary statistics in MINITAB

MINITAB can be used to calculate many of the basic numerical summary statistics described so far. These summaries for data in a selected column can be obtained using the commands

Stats > Basic Statistics > Display Descriptive Statistics

The results are output in the session window as follows:



4.6 Box and Whisker Plots

Box and whisker plots are another graphical method for displaying data and are particularly useful in highlighting differences between groups, for example, different spending patterns between males and females or comparing pricing within designated market segments. These plots use some of the key summary statistics we have looked at earlier, the quartiles and also the maximum and minimum observations.

The plot is constructed as follows. After laying out an x -axis for the full range of the data, a rectangle is drawn with ends at the the upper and lower quartiles. The rectangle is split into two at the median. This is the “box”. Finally, lines are drawn from the box to the minimum and maximum values – these are the “whiskers”. A box and whisker plot for data with summary statistics

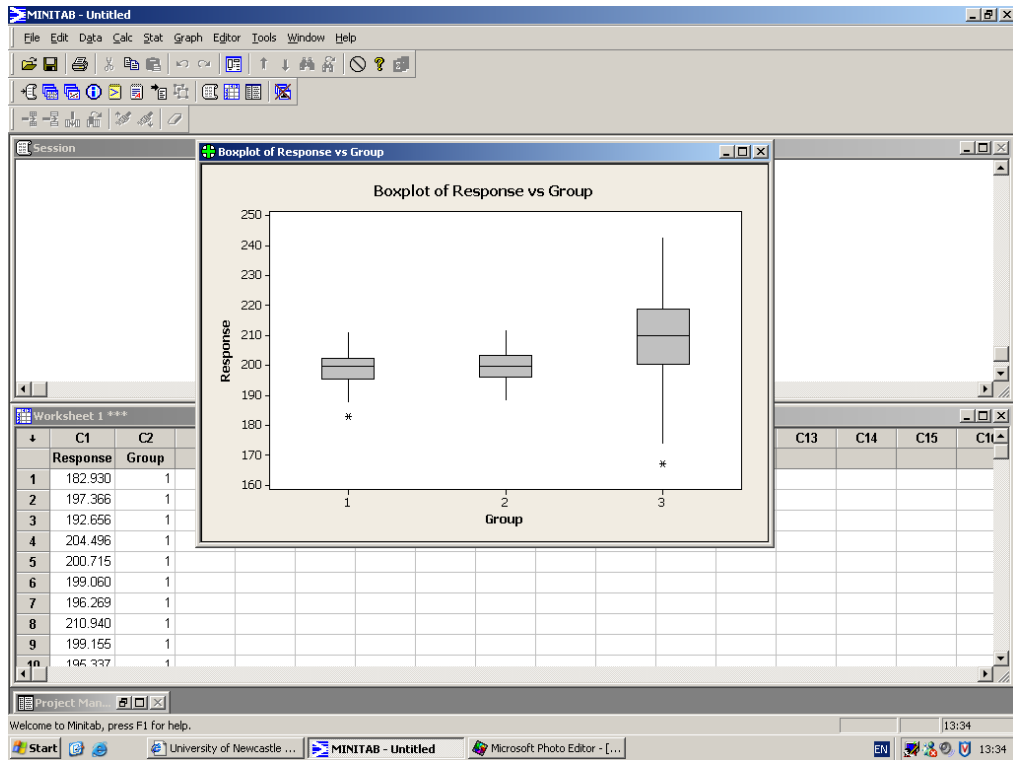
Minimum	$min = 10$
Lower quartile	$Q1 = 40$
Median	$Q2 = 43$
Upper quartile	$Q3 = 45$
Maximum	$max = 50$

would look like

MINITAB will produce box and whisker plots using the following commands.

1. Enter the data into the worksheet, say column C1
2. Graph > Boxplot... and select the Simple graph format
3. Next enter the column containing the data under Graph variables:
4. Add a title using Labels...
5. Click on **OK**.

If the data have subgroups, such as results from three different surveys, then box and whisker plots of the sample data can be plotted by group by first entering the group variable into the worksheet, say as column C2, and then selecting the With Groups graph format. The group variable is then entered into the subsequent dialogue box under Categorical variables for grouping. Displaying group structure is one of the main uses of box and whisker plots. For example



clearly shows that although there is overlap between the three sets of data, the first and second datasets contain roughly similar responses and that these are quite different from those in the third set. Note that the asterisks (*) at the ends of the whiskers is the way MINITAB highlights outlying values.

4.7 Exercises 4

Recall the data from Exercise 2 on the weight (in *kg*) of 50 sacks of potatoes leaving a farm shop.

10.4	10.0	9.3	11.3	9.6
11.2	10.5	8.5	10.4	8.2
9.3	9.6	10.3	10.0	11.5
11.3	10.8	8.9	10.0	9.5
10.0	11.3	11.0	9.7	10.6
9.9	10.2	10.6	10.2	8.1
8.7	9.4	10.9	10.0	9.9
9.2	11.6	9.6	9.5	10.4
10.6	8.8	10.1	10.3	9.7
10.7	10.6	12.8	10.6	10.2

1. Calculate the mean of the data.
2. Put the data in a grouped frequency table.
3. Estimate the sample mean from the grouped frequency table.
4. Calculate the median of the data.
5. Find the modal class.
6. Calculate the range of the data.
7. Calculate the inter-quartile range.
8. Calculate the sample standard deviation.
9. Draw a box and whisker plot for these data and comment on it.