My Blood Pressure is What???
Control Charts and Blood Pressure

Doctor's offices are really predictable. When you go, you know you will usually have to wait awhile. And when you finally get in, a nurse will take your blood pressure, your temperature, and your weight - funny how the doctor's scales always seem to be on the heavy-side.

I was at the doctor's office in January of this year. A new doctor for me. The nurse took my blood pressure. It was 141/88. She said that was a little high and asked if I normally had blood pressure this high. In the past, I have usually been in the 120/70 range. But I am getting older. When I saw the doctor, she said that I needed to check my blood pressure at home for a while to see if it stays that high. And if so, come back to see her.

So, I needed to take measurements over time. What a great practical application and opportunity to use statistical process control. What is the variation in my blood pressure? Is it consistent and predictable? Has it increased? Are there special causes present? Great everyday application for using control charts. So, this month we will take a look at how you can use control charts to monitor blood pressure readings – using my blood pressure readings over a two month period.

In this issue:

Blood Pressure Overview

Since I have always had a "good" blood pressure, I really didn't know when blood pressure became too high. So, I did some investigating on the web. Internet can't be wrong.

This is from www.webmd.org. Blood pressure readings are made up of two numbers: the top number is called the systolic blood pressure and the bottom number is the diastolic blood pressure. They, of course, measure different things. As your heart beats and contracts, it pushes blood through your arteries. This action creates pressure on the arteries. This is what the top number is measuring. A normal systolic blood pressure is below 120. The bottom number is a measure of the pressure in the arteries between heart beats – when the heart rests. A normal diastolic blood pressure is less than 80. Blood pressure is measured millimeters of mercury (mm Hg).

My 141/88 does appear high. Yet, according to www.heart.org:

> "A single high reading does not necessarily mean that you have high blood pressure. However, if readings stay at 140/90 mm Hg or above (systolic 140 or above OR diastolic 90 or above) over time, your doctor will likely want you to begin a treatment program."

A single point in time means essentially nothing. You have to be able to compare it to past history. Is a high reading "normal" – you need treatment - or is it just due to a special cause? Only good way to find out if my blood pressure stays above 140 and 90 is to chart the data over time. Perfect application of a control chart, don't you think?

The Mayo Clinic website divides blood pressure readings into four categories as shown in the table below.

Table 1: Blood Pressure Categories

Top Number (Systolic)	Bottom number (Diastolic)	Your Category
Below 120	and Below 80	Normal blood pressure
Between 120-139	or Between 80-89	Prehypertension
Between 140-159	or Between 90-99	Stage 1 hypertension
160 or higher	or 100 or higher	Stage 2 hypertension

The website says if you are in the normal or prehypertension category, you should "maintain or adopt a healthy life style." I guess that means exercise, weight control and the proper diet. If you are in Stage 1 hypertension, you should maintain or adopt a healthy life style and, if your blood pressure is not down within a month, you should contact your doctor about taking medications to help reduce your blood pressure. If you are in Stage 2 hypertension, you need to go see your doctor about getting on medication – and, of course, maintain or adopt a healthily life style.

Measuring Blood Pressure

More from the WebMD website. When you go to the doctor's office, your blood pressure is measured using a blood pressure cuff (doctors call it a sphygmomanometer). It consists of a small pressure gauge that is attached to an inflatable cuff. A nurse wraps the cuff around your upper arm. The cuff is then inflated to a pressure higher than your systolic blood pressure. The nurse uses a stethoscope to listen to the blood moving through your artery. As the cuff around your arm deflates, the first sound the nurse hears is a whooshing noise. The pressure where this happens is the top number – the systolic pressure. The pressure when that noise goes away is the bottom number – the diastolic blood pressure.

You can also purchase blood measure measuring devices for use at home. I purchased one a few years ago, from HEB grocery store, called "In Control". Got to love that name when you think about control charts. Anyway, this is the device I used to measure my blood pressure over the past couple of months.

How Repeatable is Measuring Blood Pressure?

How repeatable is this "in Control" blood pressure measuring device? Of course, this is something we always should be concerned about. How repeatable is our measurement system? To take a quick look at this, I simply took my blood pressure five times in a row. The results are shown in Table 2. (Note: you probably need to do this more than five times to get a better estimate, but my arm got tired of getting squeezed by that cuff).

Table 2: Blood Pressure Measurement Repeatability

Trial	Top Number (Systolic)	Bottom Number (Diastolic)
1	129	79
2	133	75
3	129	85
4	128	80
5	129	83
Average	129.6	80.4
Est. Sigma	2.2	4.9

The top number seems pretty predicable. The average for the five systolic readings was 129.6. The average moving range between consecutive samples was 2.5. As shown in our December 2014 newsletter on evaluating the measurement process, we can use this average moving to estimate the measurement system variability. The equation below gives the estimate of the measurement variance.

$$\sigma_e^2 = \left(\frac{\overline{mR}}{1.128}\right)^2 = \left(\frac{2.5}{1.128}\right)^2 = (2.2)^2 = 4.8$$

So, the variance for the systolic blood pressure measurement is 4.8.

Now, look at bottom number for the diastolic blood pressure. A little surprised at the variation in the bottom number? The average was 80.4. The average moving range was 5.5 –more than twice the average moving range of the top number. The variance for the bottom number is:

$$\sigma_e^2 = \left(\frac{\overline{mR}}{1.128}\right)^2 = \left(\frac{5.5}{1.128}\right)^2 = (4.9)^2 = 24.0$$

We will use these variances to determine the % of variance due to the measurement system below (as described in that December 2014 newsletter).

The Results

I took my blood pressure readings at random times over a two month period. According to information from those websites, you should take you blood pressure reading at the same time each day and when you are relaxed. I didn't take it at the same time, just whenever I thought about it. And not every day. But I made sure that I was relaxed - hadn't just exercised - or just drank coffee – they say caffeine causes your blood pressure to increase.

The "in Control" device had a memory that stores the results. It turns out that there four readings I took back in 2014. These four readings provided me the baseline data. The results are shown in table 3.

Table 3: Blood Pressure Readings

Date	Top Number (Systolic)	Bottom Number (Diastolic)		Date	Top Number (Systolic)	Bottom Number (Diastolic)
4/25/2014	127	66		2/25/2015	144	88
9/3/2014	126	69		2/26/2015	136	95
9/3/2014	130	77		2/27/2015	157	100
10/5/2014	125	65		3/6/2015	137	80
2/15/2015	142	89		3/8/2015	152	76
2/16/2015	125	89		3/9/2015	145	98
2/16/2015	131	79		3/16/2015	133	79
2/18/2015	141	77		3/19/2015	131	79
2/19/2015	134	76		3/20/2015	129	77
2/19/2015	122	92		3/24/2015	142	82
2/23/2015	148	89		3/30/2015	136	86
2/24/2015	130	92				

The next step is to construct a control chart of the results. Since these are individual readings, we will use the individuals (X-mR) control chart. For information on how to construct and interpret this chart, please see our newsletter on individuals control charts.

We will start with the top number – the systolic blood pressure. Figure 1 is the X control chart for the data. The individual readings are plotted on the X control chart. The average is calculated and added to the chart. Then the upper and lower control limits are added. The control limits are split so the first four samples represent my baseline data from 2014. Not much data, but all I have for that time frame. How often does that happen in real life? You just have to go with the data you have.

Remember what the control limits do. They separate common causes of variation – the normal variation in your process – from special causes – things that are not supposed to be there. Common causes of variation is consistent and predictable. As long as the data are within the control limits and there are no patterns, the process is said to be in statistical control. It is consistent and predictable.

Figure 1 is in statistical control. There are no points beyond the control limits or any patterns. My systolic blood pressure seems to be in control. The control limits would indicate that the systolic blood pressure can vary anywhere from 106 to 170. That covers the four categories in Table 1. The category I fall into depends pretty much simply on random variation – at least it appears that way. The average systolic blood pressure is 137 – up 10 from the baseline data. That would put me in the prehypertension category – "on average."

Figure 2 plots the moving range between consecutive points. For example, the first moving range is the range between the first two blood pressure readings: $|127 - 126| = 1$. The moving range chart is in statistical control as well. This means that the short-term variation - the range between consecutive blood pressure readings - is consistent. On average, the systolic blood pressure reading will vary by 12 each day. Some days it can be 39 above or below the previous reading.

Just like before, we can estimate the standard deviation from the average moving range on the chart. The average moving range is 12. So, the estimated standard deviation is found by dividing this average moving range by 1.128 (as we did before). The estimated standard deviation is 10.6 for the variation in my blood pressure over time.

We can compare this value to the measurement system variance calculated above (4.8 for the systolic measurement system). The % of variance due to the measurement system is the ratio of that variance to the variance from my blood pressure "process" – which is $(10.6)^2 = 112.4$

% of variance due to the systolic blood pressure measurement = 4.8/112.4 = 4.2%

The measurement system for the systolic blood pressure seems quite good.

The diastolic blood pressure results are shown in Figures 3 (X chart) and 4 (moving range chart). Again, the blood pressure results are in statistical control. Again, some variation in the results. The X control chart indicates that my diastolic blood pressure can range from 67 to 104 – over the range of all four categories once again. The average is about 85 – which puts me in the prehypertension category. So, that seems to go with the systolic result. But the average is quite a bit above the four measurements in the baseline period which average 69.

The estimated standard deviation from the moving range chart for the diastolic blood pressure is 6.3. So, the variance for my blood pressure process is 36.69. We can now compare that to the measurement system variance.

% of variance due to the diastolic blood pressure measurement = 24/36.69 = 60%

Figure 1: Systolic Blood Pressure Results

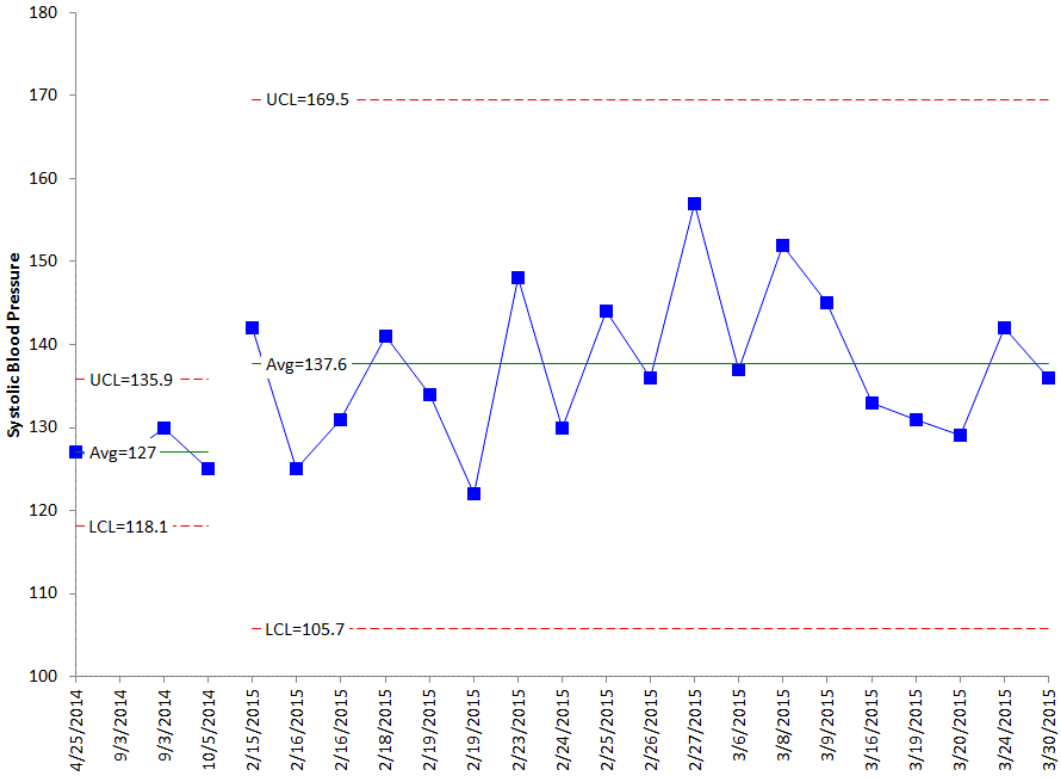


Figure 2: Systolic Blood Pressure Moving Range Results

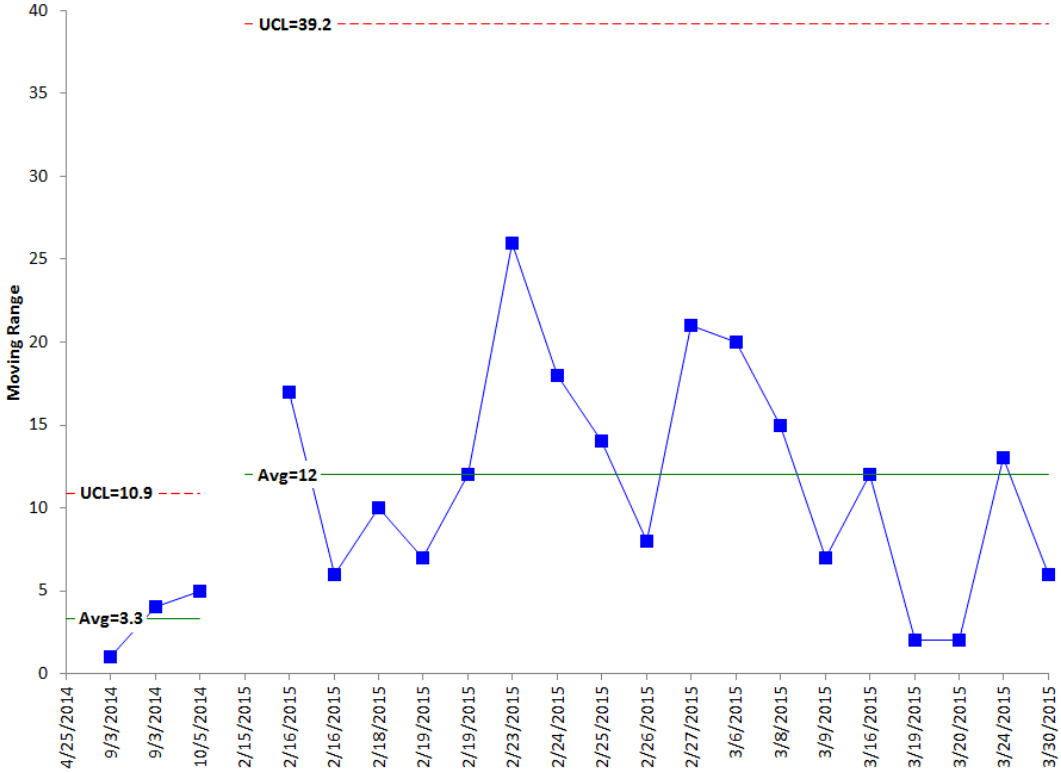


Figure 3: Diastolic Blood Pressure Results

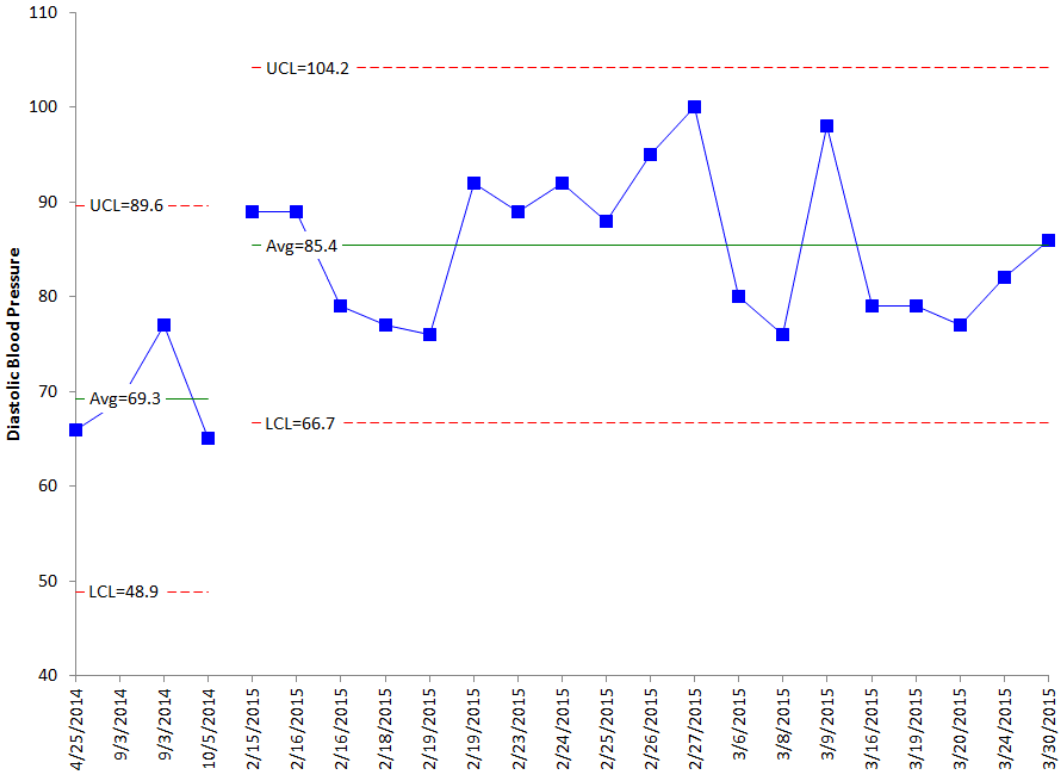
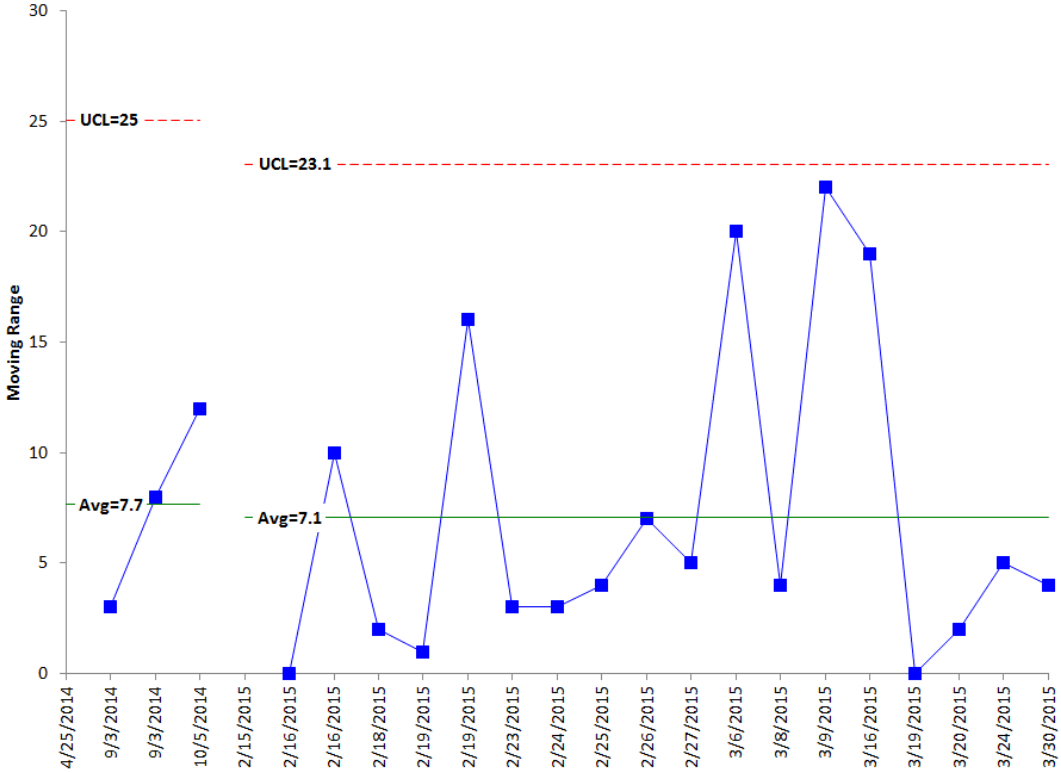


Figure 4: Diastolic Blood Pressure Moving Range Results



The diastolic blood pressure measurement system contributes a lot to the variation – much more than the 4% due to the systolic result. I don't know if this is typical – or just the case that I only measured my blood pressure five times in a row. But it seems to be a big difference from the result for the systolic measurement system variance.

Conclusions

Obviously, this was not a detailed scientific study of the variation in my blood pressure. There were many variables that were not controlled. Nor do I have any medical training. I was just doing what my doctor told me to do – measure my blood pressure over time. Still, the results were my blood pressure measurements. But I have no idea if the results here are typical. Here is what I conclude at this point:

- My systolic blood pressure has increased from what it was in the past based on the four baseline samples and the fact that I always remember that blood pressure being around 120; the "new" average for my systolic blood pressure is 137.
- My diastolic blood pressure has also increased from what it was in the past based on the four baseline readings and the fact I always remember that blood pressure being around 70; the "new" average for my diastolic blood pressure is 85.
- My blood pressure varies a lot more than I thought it would, but that variation appears to be consistent and predictable (in control)
- Based on these readings, my blood pressure falls in the prehypertension category listed by the Mayo clinic.
- The systolic blood pressure measurement seems to be much more repeatable than the diastolic blood pressure measurement.

Next steps? I will take these charts into my doctor the next time I go. It will be interesting to hear what she says. But one thing I definitely have is baseline data on my blood pressure. And this chart will easily tell me the impact of any medication or diet I may be on in the future. Pretty powerful.

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Thanks so much for reading our publication. We hope you find it informative and useful. Happy charting and may the data always support your position.

Sincerely,

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