Title of manuscript:

"How Big Should Be My Dot? Using Spreadsheet Simulation to Evaluate Subgroup Size Strategies"

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Abstract:

Some of our students approach quantitative methods courses with a blend of fear and loathing. They may fail to grasp the connection between particular principles and their application to actual process analysis and improvement. To provide enhanced relevance for the topic of run chart subgroup size determination, we used spreadsheet simulation to create a visual tool that illustrates the relationship between subgroup size, underlying process variation and anticipated levels of improvement.

1.0 Introduction

Regrettably, some of our students are not particularly enamored with quantitative methods courses. Despite an instructor's best intentions and careful preparation, a student's approach to our material may range from being a passive bystander to outright fear and loathing.

For over the past decade, however, the use of spreadsheets has been touted as a pedagogical tool to bolster the appeal of our courses and to capitalize on the extensive spreadsheet skills students are developing in other courses (Powell, 1997; Grossman, 2002; Grossman, 2006). Indeed, a host of textbooks have appeared that focus on the application of spreadsheet model-building skills in operations analysis and decision-making (Albright, Winston and Zappe, 2008; Weida, Richardson and Vazsonyi, 2001).

Against this backdrop, we developed a spreadsheet tool to analyze important statistical concepts in run charts. The run chart tool can be used in process studies to illustrate trends in data over time and to provide evidence of statistically significant change. A run chart "dot" represents actual process performance (for example, average waiting time in a healthcare facility). An important issue is the number of observations - also known as "subgroup size"- that decision-makers should use for each dot. A larger subgroup size may provide greater confidence in the process analysis, but could come at the expense of considerable data collection time and effort. Although our students can be taught these concepts through algebraic manipulation of the sample size expression, we felt they would be better served by a tool that could simulate run chart behavior and visually display the impact of particular subgroup size strategies.

We have used this tool – with some success - for introductory quantitative methods/ operations management courses and for executive education (specifically for the needs of health care professionals attending clinical practice redesign courses). Our spreadsheet approach could also be worthwhile for those instructors teaching Lean/ Six Sigma concepts (George, 2002), since measurement and analysis play a critical role in the Six Sigma philosophy.

The remainder of our paper proceeds as follows. In section 2, we discuss the specifics of run charts and how they provide evidence of statistically significant change. We also cover the manner in which we built our spreadsheet simulation model. Then, we provide some simulation model screenshots for the case of a normally distributed random variable. We offer some concluding remarks and directions for further study in the concluding section.

2.0 Method

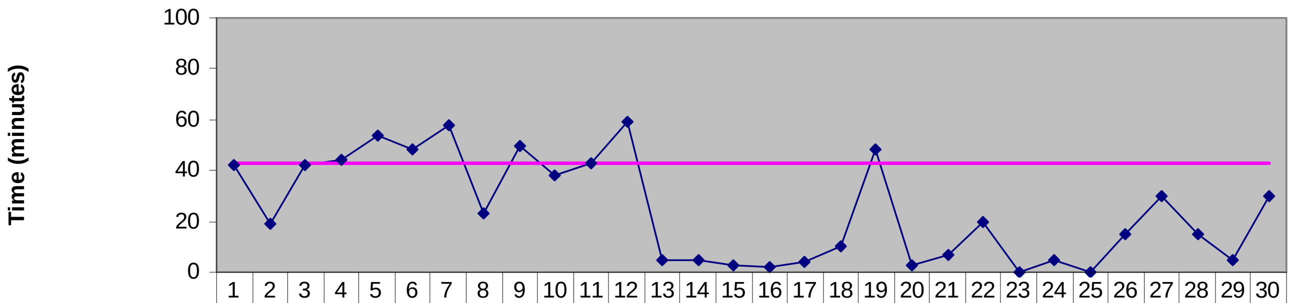
A run chart is a line graph of data plotted over time. It enables one to visualize the flow of data and is an especially important tool in documenting process analysis and improvement activities. Although it can detect evidence of statistically significant change, it cannot distinguish between special and common cause variation as is the case with control charts (Murray, 2006).

When the basic features of run charts are presented in our quantitative methods or executive education courses, a vital question concerns the number of observations to include in each run chart dot. In other words, should a decision-maker create a chart in which dots represent individual occurrences, or should the dots correspond to an average of a particular number of data points? In our experience, class participants can recite the benefits and drawbacks of larger subgroup sizes, but seem unable to grasp the impact of underlying process variation on subgroup size decisions. It is for this purpose that we created our spreadsheet simulation tool.

We wish to point out here that for an academic audience, the development of a spreadsheet tool with associated simulation capabilities may seem like a trivial exercise. Besides, subgroup size principles could be demonstrated with sample size equations. However, it has been our experience in actual classroom settings that students' interest in the material is heightened. The ability to "play" with a spreadsheet and observe the impact of making parameter changes creates an active participant role for our students in these courses.

We shall now discuss some fundamental features of run charts. When developing such a chart, the typical practice is to calculate a median based on the first ten dots. As depicted in Figure 1, this median is then extended as a straight line through the run chart. Ultimately, this median helps to clarify process improvement.

Figure 1
A basic run chart



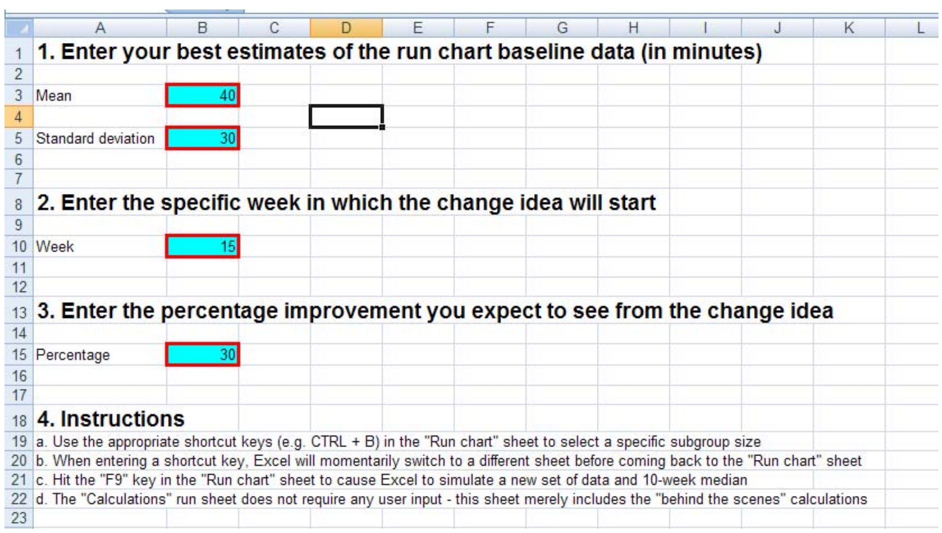
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Wait times	42	19	42	44	54	48	58	23	50	38	43	59	5	5	3	2	4	10	48	3	7	20	0	5	0	15	30	15	5	30
Median	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43

The determination of whether or not a run chart displays evidence of statistically significant change is made by evaluating at least three “rules”. If any one of these rules is met, then we can conclude that a statistically significant change has occurred. The first rule is denoted by a shift in the run chart; this is defined by six or more consecutive points either all above or all below the median. The second rule explores the trend in a run chart, and is given by five or more points all going up or all going down. Finally, the “runs” rule calculates the number of times the run chart crosses the median. By comparing this value to an upper and lower limit (based on the number of plotted points in our run chart), we can detect whether there are “too few” or “too many” runs. Having too few or too many runs would signal that “something has gone on” and that there is evidence of a statistically significant change.

To create a more participatory learning environment for understanding subgroup size issues, we created a run chart in Excel that plotted points for 30 weeks worth of data. We specifically incorporated four different probability distributions for the underlying parameter of interest (normal, poisson, lognormal and binomial). For the purposes of this paper, we will concentrate on the normal distribution case.

Figure 2 shows a screenshot from our spreadsheet model. In this particular sheet, students are asked to input particular values for the mean and standard deviation of a random variable. They also enter the specific week at which a particular change idea will occur, as well as the anticipated improvement (in terms of a decrease in the process mean) that this change idea will generate. In the example provided in Figure 2, the change idea occurred in week 15, halfway throughout the 30-week run chart period, and resulted in a 30% reduction in the process mean. Color and borders are used to highlight the input that class participants need to provide.

Figure 2
Spreadsheet screenshot



Using the mean and standard deviation chosen by the student, the spreadsheet simulation model draws a value from that distribution. For each of the 30 weeks in our run chart, we simulate 30 individual observations (we chose 30 individual observations since this represents our largest subgroup size). Since some students may select a particularly large value of the standard deviation relative to the mean – and thus obtain negative values for the variable of interest – our model replaces such negative values with 0. Following typical practice, the median is calculated on the data from the first 10 weeks of the run chart.

We set up Excel macros to model specific subgroup sizes (1, 5, 10, 15, 20, 25 and 30) and made these subgroup sizes accessible through various shortcut keys. By selecting a different shortcut key, students can represent different subgroup size strategies. Of course, students can simulate repeated draws with the same subgroup sizes by hitting “F9”. We have found this feature to be especially motivating for obtaining and retaining participant interest.

3.0 Results

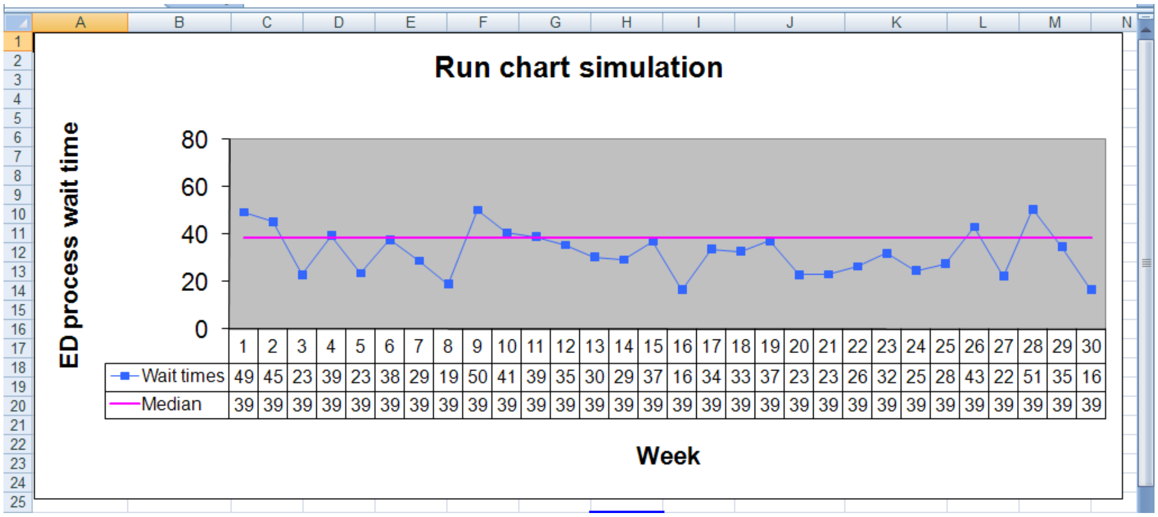
Besides capturing some student interest, our other objective was to create a tool that could demonstrate the practical implications of data collection. Based on particular values for the underlying process variation, the projected levels of improvement and selected subgroup sizes, when could a decision-maker be confident that they have collected “enough” data? (As described previously, these issues could be addressed through a statistical calculation, but the value of visibility provided by a spreadsheet model could promote enhanced student understanding).

One could recognize that they have gathered enough data – in other words, that their dot includes a sufficient number of data points – when increasing subgroup sizes yield similar run chart behaviors. If a decision-maker obtained very similar run charts for subgroup sizes of, say, 10 and 20 data points, then they could be confident that collecting 20 data points in each dot is probably unnecessary. It provides similar conclusions as that obtained with the smaller subgroup size. If the goal is to obtain the "best bang for your buck", then using the smaller subgroup size may be warranted. On the other hand, if a smaller group size displays a relatively large amount of variability in a run chart (thereby making it more difficult to ascertain via the run chart rules that a statistically significant change has occurred), then a larger subgroup size would be preferred.

In the following Excel screenshots, we provide the results for different subgroup sizes in the case of a random variable with a mean of 40 and a standard deviation of 10. The anticipated change (30% reduction in process mean) was allowed to occur in week 15. We arbitrarily selected the title "Emergency Department (ED) process wait time" for these run charts.

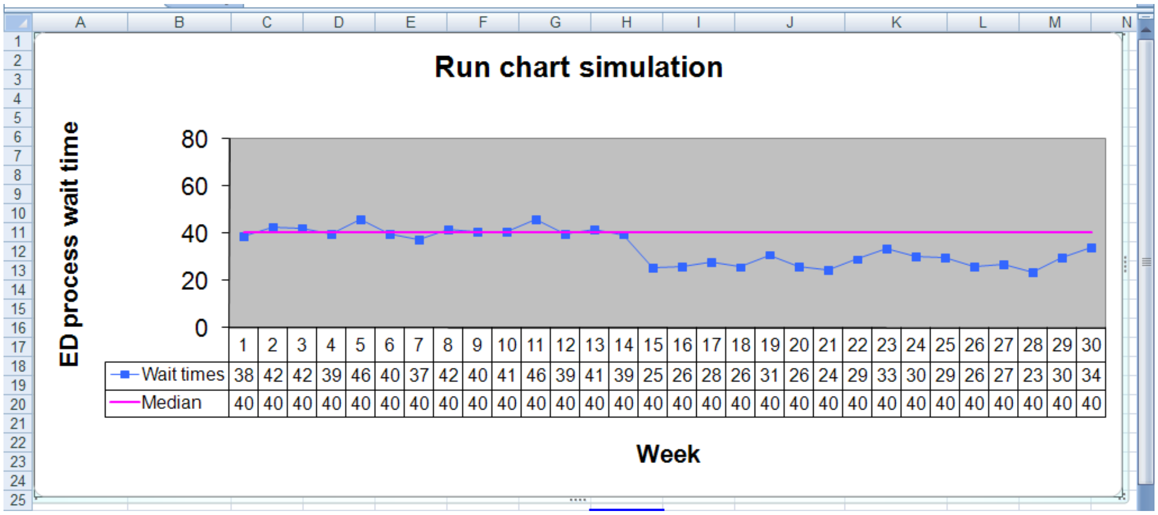
Figure 3 shows the results for a subgroup size of 1. In this example, there is considerable variability both before and after week 15 (the week in which the change occurred). Although one could use the shift rule to detect statistically significant change (since there is a string of at least 6 consecutive points after week 15 that are below the median), the variability of data points in the latter stages of the run chart may be troubling. Opting for a subgroup size of 1 may not provide the precision one needs when using run charts to analyze process improvement. (As an aside, we remind the reader that the example cited in Figure 3 is but one replication of a simulation model. Obviously, one would need to perform multiple replications in order to draw statistically valid conclusions).

Figure 3
Subgroup size of 1



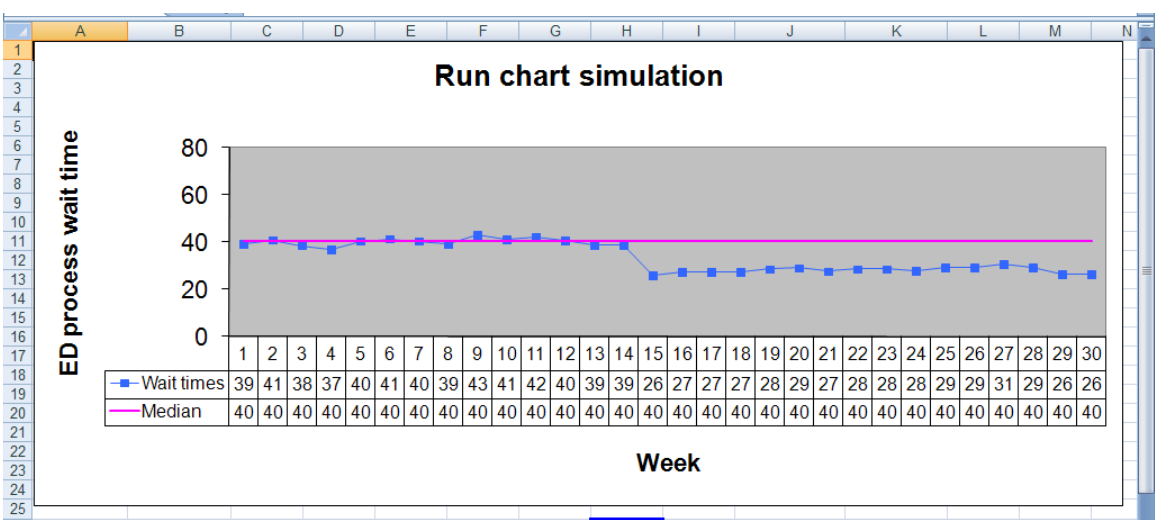
Continuing with the same mean and standard deviation values as those used in Figure 3, we next ran a run chart simulation model with a subgroup size of 10. The results are reported in Figure 4. It is fairly obvious that the 30% reduction in the process mean occurring in week 15 has resulted in a shift in the run chart. Each point on the run chart from week 15 and onwards is below the median, thus indicating evidence of a statistically significant change in our process. Moreover, our subgroup size of 10 provides a fairly consistent set of points in the second half of the run chart. Selecting this particular subgroup size may be advantageous.

Figure 4
Subgroup size of 10



In Figure 5, we illustrate the use of a subgroup size of 30 (again with the same mean and standard deviation values as those used in the previous screenshots). In this example, the reduced variability is even more pronounced. Nonetheless, the shift in the run chart is still apparent. Since the use of a subgroup size of 10 or 30 may lead one to draw similar conclusions, opting for the larger subgroup size may be unnecessary.

Figure 5
Subgroup size of 30



4.0 Conclusions

We have presented the development of a spreadsheet simulation model to illustrate the impact of underlying process variation, anticipated levels of improvement and particular subgroup sizes on run chart behavior. The spreadsheet model exposes students to the use of statistical methodologies in process analysis and improvement, but does so by allowing them to be active participants in the topic. Instead of becoming inactive bystanders, this simulation tool permits students to play with different parameter settings and instantly observe the results.

Running the model requires no advanced spreadsheet skills. Indeed, students simply need to enter particular values, select an appropriate subgroup size (through a shortcut key) and hit "F9" to obtain additional simulation replications. Instructors teaching more advanced spreadsheet model-building courses could make the creation of this simulation tool one of their course assignments. As currently developed, this spreadsheet model requires no VBA programming; indeed, the most complex parts of the model-building from a student's perspective may be the MAX(NORMINV(RAND(),*mean*,*standard_deviation)*,0) function to draw non-negative values from the normal distribution, and the creation of macros to select respective subgroup sizes.

Although our undergraduate and executive education students appear to enjoy using this spreadsheet tool, we need to be able to capture whether this tool results in greater comprehension of statistical principles. If the appeal solely becomes entertainment – without the ability to enhance student learning – then we are not likely achieving our most important objectives. A possible approach to test this tool would be to administer a test or assignment on subgroup size concepts to two groups of our students, one of which played with the simulation model while the other one had typical lecture coverage. One may also be able to test this with a single group of students by conducting a subgroup size test before and after presentation of the simulation model.

From an academic perspective, a possible future research direction could involve a more sophisticated analysis with this spreadsheet tool. We could design an experiment in which several replications are run for a group of scenarios. The scenarios would correspond to different levels of subgroup size, process variation, and anticipated improvement. Such an experiment could identify which of the three run chart rules (shift, trend, runs) provides evidence of statistically significant change for various parameter settings. This could help inform the practice of data collection, since it could show the likelihood of documenting evidence of significant change for different subgroup sizes.

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