Process control gone awry? The curious case of Centrella® toothpicks

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ABSTRACT

Quality control is an integral part of manufacturing and operations management. The level of quality output must align to the business objectives, so as not to incur more cost to the business nor result in the loss of customer satisfaction. Statistical process control (SPC) is a common method of monitoring the manufacturing process to determine if it is producing within the quality control goals, using a statistics-based methodology. This case provides a business example, with actual observed data from a toothpick manufacturing process, for students to learn about SPC. The case questions are designed to lead students through exploratory analysis of the data, followed by detailed analysis of SPC, and finally, management decisions based on the results obtained. Students will learn more about statistics, SPC, operations management, along with business implications for finance, customer satisfaction and business ethics.

Keywords: Statistical Process Control, SPC, x-bar chart, R-chart, c-chart, p-chart

INTRODUCTION

Quality control is an integral part of manufacturing. Definitions of what constitutes a quality product can be user-based, manufacturing-based, or product-based (Heizer & Render, 2012, p. 157). A tangible benefit of better quality is better company reputation. The cost of attaining the desired quality level (ISO 9000[1] for instance) can vary significantly depending on the type of product or service in question, and so can the positive (adverse) reputational effect of producing (not producing) a quality product. It is conceivable that manufacturing processes weigh the benefits versus the costs when determining the "optimal" level of investment in quality control. To production and quality control managers, quality means conforming to standards and "making it right the first time" (Heizer & Render, 2012, p. 157).

A common tool used in quality management is Statistical Process Control (SPC). SPC is the "use of modern statistical methods for quality control and improvement." (Montgomery, 2009, p. v). Standards are monitored by taking measurements as the process is underway, and corrective actions are taken if required as the product or service is being produced. SPC involves applying statistical techniques to data collected from random samples obtained at different points of time and at different stages of the manufacturing process, to assess whether they are within acceptable limits. The manufacturing process is allowed to continue if the results are positive. If measurements fall outside acceptable limits, the process is stopped, and assignable causes identified and removed. Inspection also plays a crucial role in the process.

Some amount of natural variation (in length, size, or weight for example) can be expected in any production process. Control charts help distinguish between natural variations and special (assignable) causes of variation. The different types of control charts used in SPC to measure quality include the following:

1. x-bar charts: used to determine whether process average (or central tendency) is within control,
2. R-charts: used to determine whether process variation (or dispersion) is within control,
3. p-charts: used to measure the proportion of defectives per sample of output, and
4. c-charts: used to count the number of defects per unit of output.

X-bar and R-charts are used in complementarity to track changes in the mean and the variation of the process distribution, respectively. Similarly, the p-chart and c-charts provide information on the quality of the product in terms of the proportion and count of defectives, respectively.

This case study uses data from 15 samples, each of which contains information on the total number of toothpicks and the number of defectives in 10 boxes of "250 round toothpicks" of the Centrella® brand. The samples were purchased at different points of time from an Ultra Foods store. Since they were being sold to the customer, they would have passed the quality control check at the toothpick manufacturing facility. The data provides an opportunity to perform an ex-post analysis of the manufacturing and filling processes.

THE COMPANY AND THE PRODUCT

Central Wholesale Grocers was founded in 1917 as a retailers' cooperative based in Joliet, IL. According to the company profile on Hoovers.com, the wholesale food distributor was

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[1] ISO 9000 derives its name from the International Standards Organization (ISO). It is a set of quality standards based on seven quality management principles. (ASQ, 2018)

owned by about 225 members, supplied 40,000 food items and general merchandise to over 400 independent grocery stores, and served five Midwest states of Illinois, Indiana, Iowa, Michigan, and Wisconsin. The company distributed both national brands as well as products carrying its own Centrella® brand (such as milk, butter, and toothpicks); the latter were marketed exclusively to member stores. The cooperative also operated about 30 stores including Ultra Foods, Strack & Van Til, Town & Country, and Key Market. (http://www.hoovers.com/company-information/cs/company-profile.central_grocers_inc.4ef4391b08b97fa9.html)

In May 2017, Central Grocers Inc. filed for chapter 11 bankruptcy protection after Coca-Cola Co., General Mills Inc., Post Consumer Brands and Mars Financial Services filed an involuntary chapter 7 petition for a combined outstanding debt of $1.8 million (Rizzo and Gleason, 2017). Over the next few months, underperforming Ultra Foods stores were closed, 19 Strack stores were sold to a "stalking horse bidder," and about 550 employees at the Joliet warehouse were laid off (Trotter and Marotti, 2017).

Centrella® toothpicks were packaged in at least two different sizes: boxes of 250 and 750, and were sold at Ultra Foods stores. The company was in bankruptcy proceedings at the time this case study was prepared; consequently, specific information about where the toothpicks were manufactured, could not be gathered. It is recommended that students watch Discovery Channel's "How It's Made: Toothpicks" episode (https://youtu.be/rP_7FIpPFEQ) to get a general understanding of the toothpick manufacturing process, which will be helpful for the analysis they will perform for this case.

THE DATA, AND TWO IMPORTANT NOTES

The original data for this case were collected from samples of boxes of "250 round toothpicks," purchased at various points of time from Ultra Foods for an inferential statistics experiment similar to that described in Roy (2018). The original samples varied in size from 12 to 28. For this SPC case study, samples of size 10 were randomly selected from each of the original samples. Data from 15 samples of 10 boxes each are provided as a Data table (Appendix). Each sample has two pieces of information from each box: (i) the total number of toothpicks (this includes both non-defective and defective), and (ii) the number of defective toothpicks. As students will discover, the total number of toothpicks as well as the number of defectives, varies significantly from one box to another within a sample, as well as between samples collected at different points of time. This provides a case for further exploration of statistical process control (SPC) at the toothpick manufacturing facility.

In accordance with the SPC process, it is conceivable that during the "toothpick making" part of the manufacturing process, a certain number of toothpicks would have been sampled for testing at different times and possibly at different stages of the process. (The "How It's Made: Toothpicks" episode suggests visual inspection for defectives after toothpicks have gone through the sifter and the polisher, for instance.) 'A toothpick' would therefore have been the unit of observation for the "making" process. 'A box of toothpicks,' on the other hand, would have been the unit of observation for the "filling" process.

Since the SPC for this case study is being conducted ex-post, after the product has been packaged and has reached the consumer, the process can only be replicated using 'a box of toothpicks' as the unit of observation for both the "making" and "filling" stages. This is an important detail that the student should take note of.

Users of this case should also note that the samples collected for this data set could have come from different batches and possibly even different manufacturing facilities. Batch numbers were not recorded when the samples were collected. Further, as mentioned earlier, specific information about manufacturing facilities could not be gathered. The analysis should therefore be viewed as an illustration of SPC only, not a definitive analysis of SPC at the Centrella® toothpick manufacturing facilities.

CASE STUDY OF STATISTICAL PROCESS CONTROL

As mentioned, two pieces of information were recorded for each unit (box): (i) the total number of toothpicks (non-defective plus defective), and (ii) the number of defective toothpicks. From a manufacturing process perspective, there are two processes involved that would contribute to this type of data. The first is the process that makes the toothpicks (i.e., the making process). Did this process yield good toothpicks or defective ones? The second is the process that places the already-made toothpicks in the box (i.e., the filling process). Did this process place the proper number of toothpicks (250, if that is what the manufacturer's goal was) in the box?

What, reasonably, is the manufacturer's goal? This is presented as the first case question. Students are expected to provide supporting explanation for their answer. The "How It's Made: Toothpicks" episode mentions calibrating the filling machine for the desired count. While toothpicks are not an expensive product (and the manufacturer may not mind if boxes are sometimes over-filled), a manufacturer pursuing a pure profit motive would not aim to consistently overfill (unless compensating for poor product quality). Business ethics and customer satisfaction, on the other hand, requires that boxes not be consistently under-filled either.

For the second case question, students will conduct preliminary analysis of the data to get a feel for the amount of variation in the making and filling processes. They are expected to calculate descriptive statistics (mean, range, and standard deviation) for each sample to get a sense of how controlled the production processes were at the toothpick manufacturing facility. They may also conduct exploratory analysis using box plots.

The subsequent case questions ask students to utilize SPC to assess whether processes at the Centrella® toothpick manufacturing facility were in control or out of control. Students are expected to create an x-bar chart to analyze whether the correct number of toothpicks was being filled per box. They will also check for the extent of variation in the filling process by creating an R-chart.

An important attribute of boxes of toothpicks from the customer perspective is the number of good versus defective toothpicks in the box. As consumers, students will want to analyze the quality of the product and the consistency of the toothpick making process. For this, they will create a c-chart (number of defectives per unit of output, which is a box) and/or a p-chart (proportion of defectives in a sample).

Finally, they will role play as quality control managers to draw lessons from their SPC analysis.

CASE QUESTIONS[2]

The deliverable for this case study is a written report. Students are expected to conduct an analysis of the data to detect underlying problems, if any, in quality control at the Centrella® toothpick manufacturing facility. Specifically, they must address the following questions:

Question 1: The "How It's Made: Toothpicks" episode mentions calibrating the filling machine for the desired number of toothpicks to be placed in each box. This is a crucial component of the quality control process. What, reasonably, do you think the manufacturer would calibrate the machine to? Explain your answer.

Question 2: Conduct a preliminary analysis of the data to analyze how different the samples were. Include in your analysis a discussion of the variation you find in sample means and standard deviations. If you have completed a statistics course, pick 3 or 4 samples at random and conduct exploratory analysis of the distributions by drawing box plots. Summarize whether the data and the box plots indicate any cause for concern.

Question 3: Was the toothpick making process in control, or did it produce an unreasonably high number of defectives? To comment on the quality of toothpicks, you will need to conduct an analysis of the number of defective toothpicks in a box using a c-chart, and/or the proportion of defective toothpicks in the sample using a p-chart. Do the data indicate any cause for concern? If so, what could these be attributable to?

Question 4: Was the filling process in control? Part of this analysis requires creating an x-bar chart. Conduct the required analysis and discuss any cause(s) of concern, if any, that you detect. What could these be attributable to?

Question 5: Was the filling process in control? The second part of this analysis requires creating an R-chart. Conduct the required analysis. Do you see any cause(s) of concern? What could these be attributable to?

Question 6: Summarize all your results. If you were a quality control manager at the Centrella® toothpick manufacturing facility, what lesson(s) would you draw from your analysis?

Teaching Suggestion 1: This case is designed for an undergraduate student audience who possess educational background in statistics. It is appropriate for an operations management or introductory quality course. The case may also be used for graduate students. For the graduate audience, more complex business issues and implications can be explored, along with more advanced SPC calculations, such as the S-chart as a replacement for the R-chart. On Question 3 above, the p-chart may be reserved only for graduate-level student audiences, as the nature of this data requires a more complex calculation for the p-chart (the sample size [the number of toothpicks in each of the 10-box samples] is variable, so the basic p-chart approach for constant sample size is not applicable) (Montgomery, 2009, p. 301-303).

[2] Teaching notes containing all calculations are available from either of the authors upon request.

Teaching Suggestion 2: In addition to illustrating SPC with this case study, the instructor may wish to facilitate an "active learning" exercise with real toothpicks. For a minimal cost, one box of 250 round toothpicks can be purchased and distributed to each student. The student can count the total number of toothpicks in their box, and then perform an "inspection" process to determine the number of defective toothpicks in the box. Utilizing the data collected across all students, this would be a class "sample." Although the brand will not be the same, the exercise will be effective in illustrating the SPC data collection process, variation in the two data points (total count and number of defective toothpicks in each box), and the need for consistent rules in the inspection process.

APPENDIX: DATA

Data for analysis is provided below. Two columns are associated with each of 15 samples. The first column is the total number of toothpicks in each of 10 boxes, and the second the number of defectives in each of these boxes.

Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
Total	Defective	Total	Defective	Total	Defective	Total	Defective	Total	Defective
261	4	260	5	242	0	256	1	246	0
243	0	263	2	245	1	257	0	249	1
258	1	261	3	247	0	254	1	248	2
243	1	259	1	247	2	247	0	253	4
254	2	251	2	249	1	253	1	247	0
257	6	248	4	250	0	251	0	254	1
255	2	245	5	250	0	264	7	242	0
242	4	246	0	252	2	245	8	246	2
245	0	254	2	260	8	252	2	248	0
248	1	242	4	262	4	249	4	241	2

Sample 6		Sample 7		Sample 8		Sample 9		Sample 10	
Total	Defective	Total	Defective	Total	Defective	Total	Defective	Total	Defective
245	0	260	0	255	1	257	0	257	0
245	0	260	0	255	0	256	0	248	1
246	1	256	0	241	6	253	0	258	1
245	0	248	1	241	1	250	2	260	5
250	2	255	1	253	8	249	0	254	3
251	1	255	0	253	7	252	0	254	0
246	0	255	0	255	0	257	3	250	3
242	2	259	0	246	6	266	0	257	0
246	0	261	0	256	5	242	3	250	0
245	0	260	0	254	6	244	2	250	0

Sample 11		Sample 12		Sample 13		Sample 14		Sample 15	
Total	Defective	Total	Defective	Total	Defective	Total	Defective	Total	Defective
248	1	245	4	246	3	248	0	252	1
257	0	247	0	246	5	247	7	250	2
258	0	252	5	246	5	249	2	248	2
250	3	240	1	247	1	248	5	256	0
256	0	249	3	249	6	249	0	243	2
236	4	250	5	251	7	247	1	245	2
254	2	247	2	250	2	249	0	254	3
240	0	248	6	249	1	243	3	242	4
263	0	253	6	237	1	246	0	247	4
249	0	249	8	247	1	249	1	254	6

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