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The Treatment of Six Sigma in Introductory Operations Management Textbooks: Clearing Up the Confusion

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ABSTRACT

This paper critically examines the treatment of the statistical basis for Six Sigma and process capability in popular operations management textbooks. It discusses areas of confusion and suggest ways of treating the topic that make sense to instructors as well as students. Even though Six Sigma was introduced almost 30 years ago, misconceptions persist. In the textbooks we have found no consistency of approach or understanding of the statistical underpinnings (3.4 defects per million opportunities) of Six Sigma. Sometimes statements are made that are factually incorrect and cause frustration for students and instructors. Similar difficulties are encountered in discussions of the related concept of process capability. The paper suggests changes that will help resolve these issues and bring much-needed clarity to discussions of these important ideas. Students will find the material much more accessible and instructors will find it much easier to convey the concepts underlying this important topic.

Keywords: Six Sigma; Process Capability; Tolerance Specifications; Total Quality Management

1. INTRODUCTION

Six Sigma is an important and popular approach to achieving very high levels of quality. Since its development at Motorola in 1980s, Six Sigma (Harry, 1998) has revolutionized the theory and practice of quality management across all types of organizations worldwide.

Six Sigma programs aim for *very* high levels of good output – *no more than 3.4 defective units out for every one million units* produced (Hoerl, 1998). However, more important than any numerical target is the organizational approach it embodies to systematically identifying, quantifying, and solving quality problems. This organizational approach (Evans and Lindsay, 2014) relies on trained problem-solvers (Greenbelts, Blackbelts, Master Blackbelts, etc.) using a clearly defined process (Define, Measure, Analyze, Improve, and Control) to shepherd a quality improvement project from initiation to completion. Organizational backing at the highest levels is key to successful implementation and institutionalization of a Six Sigma program (Banuelas & Antony, 2002).

Implementations of Six Sigma are too numerous to list in detail – the reader is directed to a website like *isixsigma.com* which is a comprehensive resource on Six Sigma. Implementations cover every type of organization in the manufacturing, service, and government sectors (Antony, Kumar, & Rae (2007); Wessel & Burcher (2004); Raisinghani, Ette, Pierce, Cannon, & Daripaly (2005), Antony, Krishan, Cullen, & Kumar (2012); Cudney, Elrod, & Stanley (2014)). Recent *unusual* adoptions illustrate the breadth of possible applications: Six Sigma tools to improve the US Army behavioral health surveillance process (Watkins, Kemeter, Spiess, Corrigan, Kateley, Wills, Mancha, Nichols, & Bell, 2013), Six Sigma optimization of 'mystery shopping' (Shakir, 2014), and Six Sigma methodology in the control of internal auditing quality in Jordan, (Al-Rawi, Noor, Al-Nuami, 2012).

The appeal of Six Sigma has spawned derivatives like Lean Six Sigma (LSS) (George, 2002; Zhang, Irfan, Khattak, Zhu, & Hassan, 2012) which combines the Six Sigma approach with waste reduction, and Design for Six Sigma (DFSS) (Cudney & Furterer, 2012; Gardener & Wiggs, 2013) which seeks to broaden the scope of the Six Sigma approach and make its goals more achievable.

While not all adoptions have been successful, Six Sigma has undoubtedly changed the way organizations view quality. The idea that quality can be continuously improved by following a well-structured measurement-based approach is now firmly rooted in the organizational mindset.

2. PURPOSE OF THIS PAPER

Given the importance and relevance of Six Sigma to a vast range of productive processes and enterprises, business school curricula have devoted a considerable amount of attention to it. Numerous pedagogical approaches have been tried (Zuckweiler, 2011; Conger & Miller, 2013; and Ellis, Goldsby, Baily, & Oh, 2014) to convey the essence of Six Sigma. Stevenson & Mergen (2006) identify three realistic ways that business schools have attempted this: (i) integrating Six Sigma throughout the curriculum, or (ii) teaching it in dedicated courses (on quality management, lean management, process management, etc.), or (iii) including it as a topic in a course on operations management or strategy and policy. The last alternative is the simplest from an implementation perspective; most introductory operations management courses already teach quality management which provides a natural home for Six Sigma.

Practitioners, researchers, and other experts have identified three distinct aspects to Six Sigma –

(i) a measurement and statistics driven approach to achieving very high levels of excellence typified by "6σ quality" – 3.4 million defects per million opportunities (dpmo);
(ii) a structured approach to problem solving typified by the **D**efine, **M**easure, **A**nalyze, **I**mprove, and **C**ontrol (DMAIC) paradigm; and
(iii) an organizational structure characterized by trained black belts, green belts, etc., who drive the program at the operational level.

Most introductory textbooks on operations management used in business schools provide sufficiently detailed coverage of all three aspects. The related concept of process capability is generally discussed in a chapter on statistical process control.

The concern of this paper is with the textbook treatment of the first aspect – the statistical underpinnings of the Six Sigma goal of 3.4 defects per million opportunities. Both authors have taught operations management for several years from a variety of textbooks. In these textbooks there is no consistency of approach or understanding of the statistical underpinnings. Key concepts are unexplained or glossed over; statements are made that are factually incorrect and cause much confusion for students. Earlier papers (Tadikamalla, 1994; Mitra, 2004) have clearly elucidated the statistical foundations of Six Sigma. Yet many operations textbooks continue to provide a less-than-satisfactory discussion of the topic. The concept of process capability which is strongly linked to that of Six Sigma similarly suffers from lack of clarity and consistency. The result is that students do not understand the Six Sigma goal and why it was chosen, they fail to understand the concept of process capability and the appropriate measure to use, and finally have trouble deciding if a process is Six Sigma capable. This impacts instructors too. They tend to skip confusing material, look for work-arounds, or simply repeat assertions that are incorrect.

The purpose of this paper is to review the treatment of the statistical aspects of Six Sigma and process capability in popular textbooks and discuss areas of confusion and suggest ways of treating these topics that make sense to instructors as well as students. Thus this paper is aimed at instructors of operations management who want to provide a robust coverage of Six Sigma as well as the authors and would-be authors of introductory operations management textbooks.

The next section provides a quick introduction to the statistical underpinnings of the Six Sigma goal of 3.4 dpmo and to process capability. Section 4 reviews ten popular operations management textbooks and points out areas of weakness. Section 5 closes the paper with recommendations for how the discussion of this important topic might be structured.

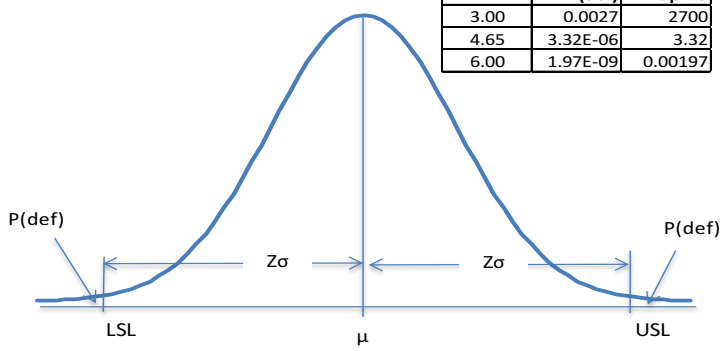
3a. Statistical Underpinnings of Six Sigma

Consider a part that has to have some dimension be between a lower specification limit (LSL) and an upper specification limit (USL). The difference USL-LSL is the specification range. Usually USL = $\mu+a$ and LSL = $\mu-a$, where a is the allowed tolerance.

The term 6σ is meant to convey the idea that if the standard deviation σ of the process is small enough that $a = 6\sigma$ (or USL-LSL = 12σ), the process will produce no more than 3.4 dpmo. This leads students to believe that the specification limits should be 6 standard deviations above and below the process mean to achieve 3.4 dpmo. However, the probability of observations from a normal distribution with mean μ and standard deviation σ being outside μ±6σ is 0.000000001973. So if the specification limits are set at 6σ on either side of the mean, we should expect fewer than 2 defects in one *billion* units. This is a *much* higher standard and is at odds with the 3.4 dpmo number. In fact, as illustrated in Figure-1 below, in order to achieve the 3.4 dpmo standard, the specification limits would have to be about ±4.65σ from the mean.

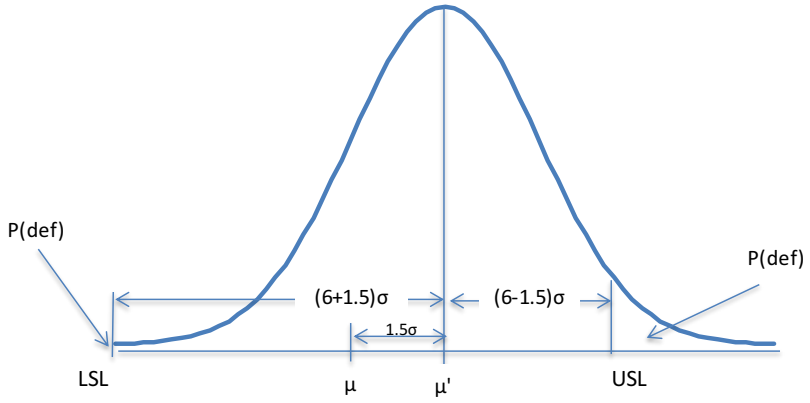
Figure 1. Dpmo Z Standard Deviations from the Mean

Z	2*P(def)	dpmo
3.00	0.0027	2700
4.65	3.32E-06	3.32
6.00	1.97E-09	0.00197



To reconcile the 3.4 dpmo number with 6σ one has to understand the concept of mean-shift that Six Sigma introduces into its calculations. Six Sigma assumes that, as a practical matter, the process mean does not remain centered on its target value in the middle of the specification range, but shifts either downward or upward during production. This can happen for any number of reasons (tool wear, worker fatigue, incorrect settings, machines drifting off settings, etc.) and makes it closer to one or the other specification limit. This shift results in a higher probability of the part's dimension exceeding this limit. Six Sigma assumes that this shift can be as much as 1.5σ in one or the other direction. Figure-2 illustrates the case where the process mean (denoted here by μ') shifts 1.5σ above the center of the specification range μ. Assume that the specification limits were set at μ±6σ. Because of the mean-shift, the USL is only 4.5σ from the process mean μ', whereas the LSL is 7.5σ from μ'.

Figure 2. The Effect of Mean Shift



The probability of the outcome being defective is now P(Z<-7.5)+ P(Z>4.5). The total area in the tails is 0.0000034 and translates to 3.4 defects per million opportunities. Similar calculations can be done if the mean shifts downward by 1.5σ. Six sigma methodology assumes, as a worst case, that the mean can shift by 1.5 in either direction.

3b. Process Capability

Process capability looks at the issue of whether a process is capable of producing output to the specifications specified by the customer or user. Two measures are frequently discussed – C_p (*process capability ratio*) and C_{pk} (*process capability index*).

C_p is the ratio of the specification range to the natural spread of the process (assumed to be 6σ if the output is normally distributed):

$$C_p = \frac{USL-LSL}{6\sigma} \tag{1}$$

The above definition of C_p assumes that the process is centered at the middle of the specification range – (USL+LSL)/2. When this is not true, C_p overstates the capability of the process and is misleading. In this case C_{pk} is the appropriate measure to use:

$$C_{pk} = min\left\{\frac{USL-\mu'}{3\sigma}, \frac{\mu'-LSL}{3\sigma}\right\} \tag{2}$$

where μ' is the *actual* process mean.

Clearly $C_{pk} \leq C_p$. If the process mean shifts by m standard deviations, then it can be easily shown that $C_{pk} = C_p - m/3$. Thus a process with C_p=2 whose mean has shifted by 1.5 standard deviations will have a C_{pk}=1.5.

It is straightforward to relate process capability to the probability of defective units. A general expression for the probability of a defective is:

$$P(Defect) = P(Z > 3C_{pk}) + P\left(Z < -3C_{pk}\left(\frac{k+2s}{k-2s}\right)\right) \tag{3}$$

were s is the mean-shift, k is the specification range (USL-LSL) and $0 \leq s < k/2$. When $s=0$, $C_{pk}=C_p$ and $P(Defect) = P(Z > 3C_p) + P(Z < -3C_p)$. As s approaches $k/2$, the second term in (3) above approaches zero and the first term dominates.

3c. Numerical Example

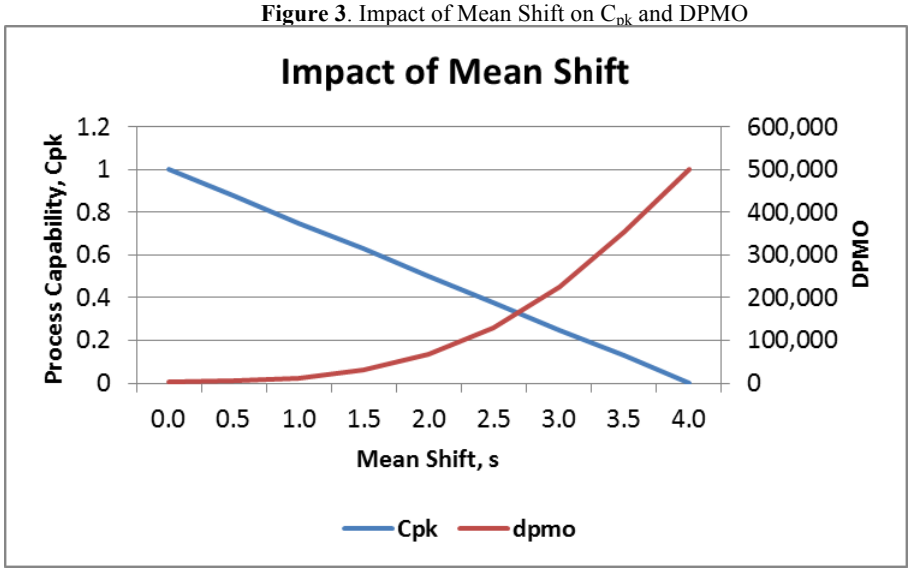
Suppose a manufacturing process is designed to produce a part whose specifications are 16±4 mm. Assuming that the process output is normally distributed with a mean of 16 mm.

(i) If the process is designed to be at least minimally capable *(C_p=1),* the standard deviation of the process should be 8/6 = 1.33 mm. This will result in an expected defect rate of 2700 dpmo.

(ii) If the process must meet Six Sigma standards of 3.4 dpmo, then USL and LSL must each be 4.65 standard deviations from the process mean. In other words C_p must be 1.55. The standard deviation of the process must be 0.86 mm.

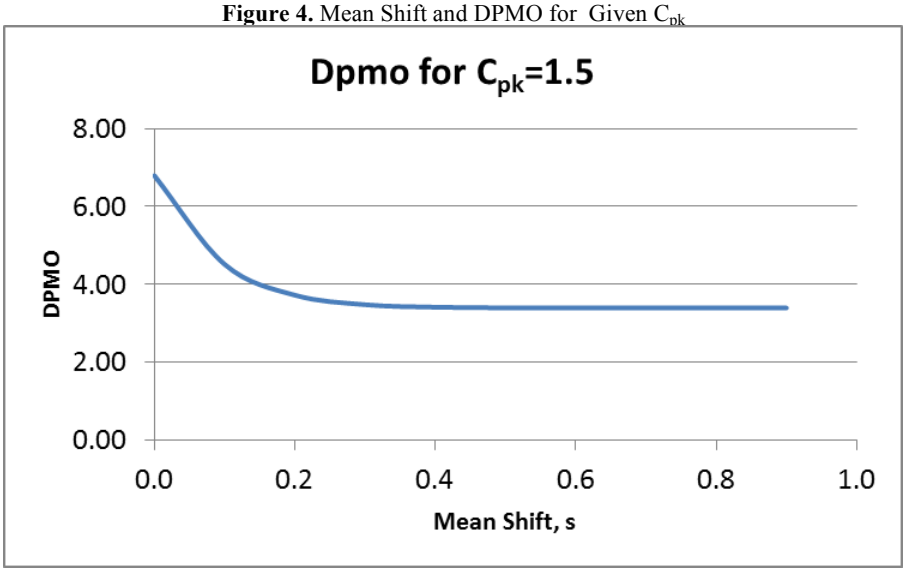
(iii) If the process mean shifts away from the center of the specfication range, C_p will overstate the process capability; the correct measure to use is C_{pk}. If the shift is *s*, then $C_{pk} = C_p - s/3\sigma$. With σ =1.33 mm and for various values of *s*, the values of C_{pk} are given in the Figure-3 below:

Figure 3. Impact of Mean Shift on C_{pk} and DPMO



(iv) The same values of C_p and C_{pk} do not imply the same probability of defectives. Thus C_p=*1.5* will always imply 6.8 dpmo, whereas what C_{pk}=*1.5* implies depends on the mean shift, as Figure-4 below (derived from (3) shows:

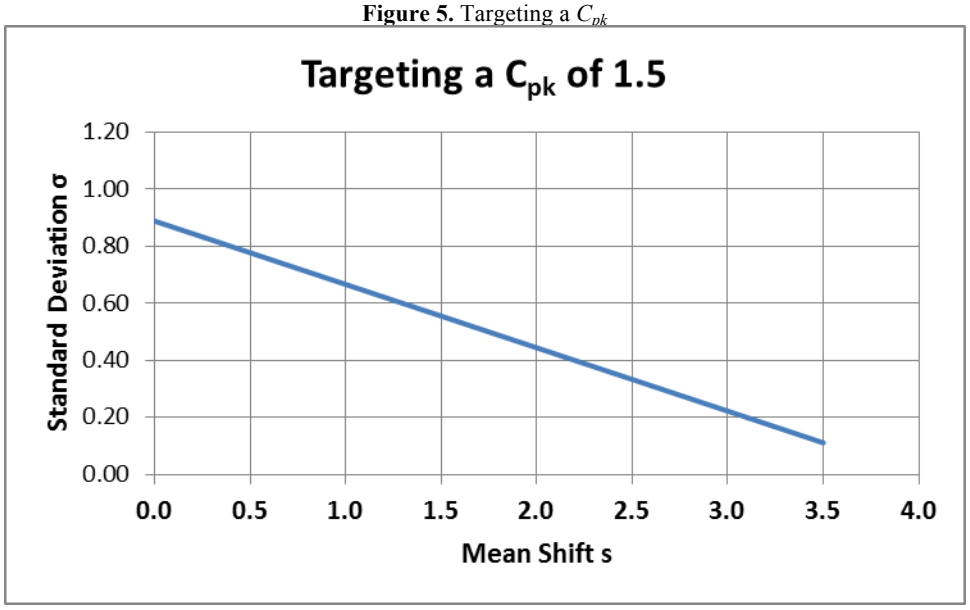
Figure 4. Mean Shift and DPMO for Given C_{pk}



Thus it could be misleading to simply look at a C_{pk} value and decide whether or not the process is Six Sigma compliant – i.e., operates at a level of 3.4 dpmo. The mean shift must also be considered.

(iv) If the process is not operating with a desired capability level C_{pk} the process managers have to either reduce the mean-shift, the process standard deviation, or both. Thus, for example, if C_{pk} is currently 1.10 (with σ= 1.06 mm and s=0.5 mm) and needs to be 1.5, it can get there in a number of possible ways as shown by the graph in Figure-5 below. It should be clear that the process standard deviation has to be reduced to a level of at least 0.86 mm if nothing can be done about the mean shift.

Figure 5. Targeting a C_{pk}



4. METHODOLOGY OF TEXTBOOK REVIEW

For the purposes of this paper the latest electronic editions of 10 current popular textbooks of operations management were reviewed in detail, focusing on their discussion of (i) the statistical aspects of Six Sigma and (ii) process capability. These textbooks are used in required operations management courses at both the undergraduate and graduate levels in business schools and are quite typical of how this material is covered. They have been around for many editions and are available in a variety of formats.

Often the two topics are discussed in different chapters. Six Sigma tends to be discussed in chapters dealing with quality management either in the context of total quality management (TQM) or as a stand-alone topic. Process capability is usually discussed along with control charts and acceptance sampling in chapters titled "Statistical Quality Control" or "Statistical Process Control."

The results of this review are summarized in Appendix-1. Key issues are discussed in the next section.

5. REVIEW FINDINGS

All textbooks do an adequate-to-good job of discussing Six Sigma as an organizational approach to quality improvement. All of them discuss the DMAIC approach and 7 of the 10 books talk about the role of black-belts and green-belts in driving the quality improvement process in organizations. Several have case studies on the DMAIC process. The differences that exist among textbooks in dealing with these two aspects of Six Sigma simply reflect the authors' priorities and understanding of what must be discussed within the constraints of a book chapter.

However, when it comes to the statistical underpinnings of Six Sigma goal of 3.4 dpmo there is a great deal of variability in treatment. This variability carries over to the discussion of process capability.

Of the 10 textbooks surveyed, all mention the 3.4 dpmo number.

- Three (MS, RT, and SRG) offer a detailed explanation of the 3.4 dpmo target and its assumption of the mean shift of 1.5σ. One – BH, briefly mentions the mean shift in this connection. The remaining six offer no explanation for the 3.4 number, except to say that it comes from the normal distribution. The suggestion is that it is somehow related to the area in the tails corresponding to 6σ.
- Several textbooks use a picture of a normal distribution to motivate the 6σ concept. Here too there is confusion. For example two textbooks - HR, p.213; RS, p.221 - provide pictures of normal distributions showing a tail area for μ±3σ as 0.0027 (or 2700 out of 1 million) which is correct, along with a tail area for μ±6σ as 0.0000034 (or 3.4 out of 1 million) which is *not* correct.

All ten textbooks discuss process capability. All of them with the exception of JC discuss both C_p and C_{pk}, generally in that order; JC discusses only C_{pk}. Six of the ten make a connection with Six Sigma. While the mathematics of C_p and C_{pk} are dealt with in a straightforward manner, it is the interpretations of C_p and C_{pk} in the context of Six Sigma that are inconsistent and sometimes incorrect. The basic problem is the conflation of C_p and C_{pk} and the assumption that a value of 2.0 for either will comply with Six Sigma requirements. This is reflected in statements like:

> *"Because C_p < 2, the process is still not capable of providing Six Sigma quality."* (BH, p.118).
> *"Firms striving for Six Sigma performance will use 2.00 as a critical value."* (KRM, p.179).
> *"Achieving Six Sigma quality with no more than 3.4 dpm provides a C_p index 12σ/6σ = 2.0 (assuming the process can shift by as much as 1.5 standard deviations)."* (MS, p.155).
> *"…goal of achieving a process variability so small that design specifications represent six standard deviations above and below the mean. That means a process capability index equal to 2.00…"* (S, p.438).
> *"In a Six Sigma approach the goal is to achieve a process standard deviation that is 12 times smaller than the range of outputs allowed by the product's design specifications."* (SMCH, p.182).
> *"Six Sigma … equates to a C_p of 2 with only 3.4 defective parts per million."* (HR, p.250).

As the numerical example in Section 3 shows, similar values of C_p and C_pk do not have similar implications for process capability and for Six Sigma. The other confusion is that a value of 2.0 (of C_p or C_{pk}) makes a process Six Sigma compliant. Again, the numerical example shows that this is not true either.

Students' confusion with these topics reflects the confusion of the textbooks:

- Inability to explain the 3.4 dpmo figure or translate it to a conceptual understanding of mean shifts and their impact
- When to use C_p or C_{pk}
- What is or is not Six Sigma compliant based on a C_p or C_{pk} number
- Difficulty calculating probability of defectives with and without mean shifts

None of these textbooks discusses the issue of how to improve process capability. Given that the basic measure of capability, C_p, only focuses on process variability, the implication seems to be that process improvement efforts should focus on reducing process standard deviation. For a given situation it is not possible to say *a priori* whether it is easier to reduce the standard deviation or the mean shift (Tadikamalla, 1994). It may not be possible to change one without also impacting the other. Further, both the process mean and process standard deviation are likely to be functions of multiple process settings and unlikely to be amenable to quick fixes in the short run.

6. DISCUSSION AND RECOMMENDATIONS

As the findings of Section 5 show there is considerable confusion in the way the statistical underpinnings of Six Sigma are treated in current textbooks of operations management. This confusion carries over to the discussion of process capability.

What can instructors do to clarify their presentation of this important topic? The following suggestions might help:

- The 3.4 dpmo number is too entrenched in the Six Sigma literature and mention of it cannot be avoided. Instructors should present the 3.4 dpmo number in the right context as explained in this paper. Depending on the statistical competence of their students they can get into the details and clarify the origins of that number. A cleaner approach might be to simply discuss it as a goal that Motorola used in its implementation based on its processes and manufacturing parameters. As Tadikamalla (1994) and Mitra (2004) point out, there is little empirical or theoretical justification for any particular mean-shift assumption. Organizations should pick quality targets that are right and realistic for them; there is no single number that is the gold-standard. Maleyeff and Krayenvenger (2004) show how effective quality improvement projects can be developed with goals that are appropriate for a particular environment.
- Instructors should skip the discussion of C_p altogether. It carries little conceptual or practical value and represents one more formula that students have to learn. Processes will almost always be off-center in which case C_{pk} is the appropriate measure to use. This will simplify the treatment of process capability considerably and avoid the C_p-C_{pk} confusion.
- Instructors should refrain from referring to $C_p=2$ as the Six Sigma benchmark capability even with the appropriate clarification about the mean shift. When the process is not centered the appropriate process capability measure to use is C_{pk}. As a rough guide a C_{pk} value greater than 1.5 would imply dpmo values that are in the Six Sigma neighborhood.
- If C_p has to be discussed instructors should be careful about making equivalences between similar values of C_p and C_{pk}. Similar values do not imply similar probabilities of defective output.
- Instructors should similarly be careful when trying to relate process capability to Six Sigma. If the process is not centered, the most straightforward way of determining whether or not the process is Six Sigma compliant is to actually calculate the probabilities of defective output.

These recommendations should bring much-needed clarity to coverage of the statistical aspects of Six Sigma and process capability. Students will find the material much more accessible and instructors will find it much easier to convey the concepts underlying these important ideas.

AUTHOR BIOGRAPHIES

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TEXTBOOKS REVIEWED

Heizer, J. and Render, B. (2014), *Operations Management: Sustainability and Supply Chain Management,* 11th Edition, Prentice Hall. (HR)

Jacobs, R.F. and Chase, R.B. (2014), *Operations and Supply Chain Management*, 14th Edition, McGraw-Hill Higher Education. JC

Krajewski, L., Ritzman, L., and Malhotra, M. (2013), *Operations Management: Processes and Supply Chain,* 10th Edition, Prentice Hall. (KRM)

Meredith, J.R. and Shafer, S.M. (2013), *Operations Management for MBAs*, 5th Edition, John Wiley and Sons. (MS)

Reid, D.R. and Sanders, N.R. (2013), *Operations Management*, 5th Edition, John Wiley and Sons. (RS)

Bozarth, C. and Handfield, R. (2016), *Introduction to Operations and Supply Chain Management*, 4th Edition, Prentice Hall. (BH)

Russell, R. and Taylor, B.W. (2011), *Operations Management: Creating Value Along the Supply Chain,* 7th Edition, John Wiley and Sons. (RT)

Schroeder, R., Rungtusanatham, M.J., Goldstein, S. (2013), *Operations Management in the Supply Chain: Decisions and Cases,* 6th Edition, McGraw-Hill Higher Education. (SRG)

Stevenson, W. (2012), *Operations Management*, 11th Edition, McGraw-Hill Higher Education. (S)

Swink, M., Melnyk, S., Bixby Cooper, M. and Hartley, J. (2014), *Managing Operations Across the Supply Chain*, 2nd Edition, McGraw-Hill Higher Education. (SMCH)

REFERENCES

Al-Rawi, S., Noor, A. A. N., & Al-Nuami, M. (2012). Using Six Sigma Methodology in Controlling Internal Auditing Quality (A Field Study on Award Winning Quality and Excellence Private Hospitals in Amman Governorate. *Jordan Journal of Business Administration*, 8(4).

Antony, J., Krishan, N., Cullen, D., & Kumar, M. (2012). Lean Six Sigma for higher education institutions (HEIs) Challenges, barriers, success factors, tools/techniques. *International Journal of Productivity and Performance Management*, 61(8), 940-948.

Antony, J., Kumar, M., & Rae Cho, B. (2007). Six sigma in service organisations: Benefits, challenges and difficulties, common myths, empirical observations and success factors. *International journal of quality & reliability management*, 24(3), 294-311.

Banuelas Coronado, R., & Antony, J. (2002). Critical success factors for the successful implementation of six sigma projects in organisations. *The TQM magazine*, 14(2), 92-99.

Conger, Sue and Miller, Richard, " Problem-Based Learning for a Lean Six Sigma Course" (2013). All Sprouts Content. Paper 523. http://aisel.aisnet.org/sprouts_all/523

Cudney, E. A., Elrod, C. C., & Stanley, S. M. (2014). A systematic literature review of Six Sigma practices in education. *International Journal of Six Sigma and Competitive Advantage*, 8(3-4), 163-175.

Cudney, E. A., & Furterer, S. L. (Eds.). (2012). *Design for six sigma in product and service development: Applications and case studies*. CRC Press.

Ellis, S. C., Goldsby, T. J., Bailey, A. M., & Oh, J. Y. (2014). Teaching Lean Six Sigma within A Supply Chain Context: The Airplane Supply Chain Simulation. *Decision Sciences Journal of Innovative Education,* 12(4), 287-319.

Evans, J., & Lindsay, W. (2014). *An introduction to Six Sigma and process improvement*. Cengage Learning.

Gardner, M., & Wiggs, G. (2013, June). Design for Six Sigma: The First 15 Years. In *ASME Turbo Expo 2013: Turbine Technical Conference and Exposition* (pp. V07AT28A006-V07AT28A006). American Society of Mechanical Engineers.

George M.L. (2002) Lean Six Sigma: *Combining Six Sigma Quality with Lean Production Speed.* McGraw-Hill, Blacklick, OH.

Harry, M.J. (1998) Six Sigma: a breakthrough strategy for profitability, *Quality Progress*, 31(5); pp 60-64.

Hoerl, R.W. (1998) Six Sigma and the future of the quality profession, *Quality Progress*, 31(6), pp: 35-42.

Mitra, A. (2004) Six Sigma Education: A Critical Role for Academia. *The TQM Magazine*, 16(4), pp: 293-302.

Raisinghani, M. S., Ette, H., Pierce, R., Cannon, G., & Daripaly, P. (2005). Six Sigma: concepts, tools, and applications. *Industrial management & Data systems*, 105(4), 491-505.

Shakir, T. (2014). Six Sigma Optimization of Mystery Shopping: A Hypothetical Case Study on the Nigerian Banking Industry. https://secure.asq.org/perl/msg.pl?prvurl= http://rube.asq.org/2014/09/six-sigma-mystery-shopping-nigerian-banking.pdf

Stevenson, W.J. & Mergen, E.A. (2006) Teaching Six Sigma Concepts in a Business School Curriculum. *Total Quality Management*, Vol. 17, No. 6, 751-756.

Tadikamalla, P.R. (1994), "The Confusion over Six-Sigma Quality," *Quality Progress*, November 1994, pp 83-85.

Watkins, E. Y., Kemeter, D. M., Spiess, A., Corrigan, E., Kateley, K., Wills, J. V., Mancha, B.E., Nichols, J., & Bell, A. M. (2013). Performance excellence: using Lean Six Sigma tools to improve the US Army behavioral health surveillance process, boost team morale, and maximize value to customers and stakeholders. *US Army Medical Department Journal*, 91-95. Chicago.

Wessel, G., & Burcher, P. (2004). Six Sigma for small and medium-sized enterprises. *The TQM Magazine*, 16(4), 264-272.

Zhang, Q., Irfan, M., Khattak, M. A. O., Zhu, X., & Hassan, M. (2012). Lean Six Sigma: a literature review. *Interdisciplinary Journal of Contemporary research in business*, 3(10), 599-605.

Zuckweiler, Kathryn M. "Teaching six sigma to undergrads: A simplified real project approach." *Decision Sciences Journal of Innovative Education* 9, no. 1 (2011): 137-142.

APPENDIX 1. Results of Textbook Review

Authors	Acronym	Six Sigma: As An Organizational Approach (Belts, DMAIC)	Discussion of Six Sigma and Normal Dist?	Mention 3.4 dpm?	Explanation of 3.4 dpm?
Cecil Bozarth & Robert Handfield	BH	Yes	No	Yes	Yes
Robert F. Jacobs & Richard B. Chase	JC	Yes	No	Yes	No
Lee Krajewski, Larry Ritzman, & Manoj Malhotra	KRM	Yes	No	Yes, in footnote	No
Jack R. Meredith, Scott M. Shafer	MS	Yes. No discussion of belts	Yes	Yes	Yes, complete.
Roberta Russell & Bernard W. Taylor	RT	Yes	Yes	Yes	Yes, complete.
Dan R. Reid & Nada R. Sanders	RS	Yes	Yes	Yes	No
William Stevenson	S	Yes	No	Yes	No
Morgan Swink, Steven Melnyk, M Bixby Cooper, & Janet Hartley	SMCH	Yes	No	Yes	No
Jay Heizer & Barry Render	HR	Yes. No discussion of belts	Yes. Figure 6.4 is incorrect.	Yes	No.
Roger Schroeder, Johnny Rungtusanatham, Susan Goldstein	SRG	Yes. No discussion of belts	No	Yes	Yes, complete.

(continued)

Authors	Discussion of Mean Shift?	Process Capability Ratio, Cp	Process Capability Index Cpk	Link Cp and Cpk with Six Sigma?
Cecil Bozarth & Robert Handfield	Brief explanation	Yes, discussed first.	Yes	Yes
Robert F. Jacobs & Richard B. Chase	Brief explanation	No	Yes	Yes
Lee Krajewski, Larry Ritzman, & Manoj Malhotra	Brief mention in footnote.	Yes, as a test to see if variability is culprit	Yes, discussed first.	Yes
Jack R. Meredith, Scott M. Shafer	Yes, full discussion.	Yes, discussed first.	Yes, briefly	Yes
Roberta Russell & Bernard W. Taylor	Yes	Yes, discussed first.	Yes	No
Dan R. Reid & Nada R. Sanders	No mention.	Yes	Yes	No
William Stevenson	No mention.	Yes	Yes	Yes - slight
Morgan Swink, Steven Melnyk, M Bixby Cooper, & Janet Hartley	No, but assumes it in Table 6-5	Yes	Yes, but use a non-standard form.	Yes, briefly.
Jay Heizer & Barry Render	No mention.	Yes. FN-6, for Cp of 2.0 is not correct.	Yes	Yes, Cp=2 means 3.4 dpmo. Incorrect.
Roger Schroeder, Johnny Rungtusanatham, Susan Goldstein	Yes	Yes	Yes, briefly	No

NOTES