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Paper Organizers International: A Fictitious Six Sigma Green Belt Case Study. II

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ABSTRACT

The purpose of this paper is to present the second part of a detailed, step-by-step case study of a simple Six Sigma Green Belt project. In the last edition of Quality Engineering, the first part of a Six Sigma Green Belt case study was presented. That paper showed the Define and Measure phases of the DMAIC method. This paper presents the rest of the case study, or the Analyze, Improve, and Control phases of the DMAIC method.

Key Words: *Six Sigma; Case study; Green Belt; DMAIC; Analyze; Improve; Control*

PURPOSE

The purpose of this paper is to present the final part of a fictitious application of the DMAIC model[1] to be used as an educational aid by those individuals interested in learning the structure of a simple "Six Sigma" project, called a Green Belt project. The first paper presented the Define and Measures phases. This paper presents the Analyze, Improve, and Control phases.

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REVIEW OF THE COMPANY

Paper Organizers International (POI) offers a full range of filing, organizing, and paper shuffling services. To accomplish these tasks, POI purchases Metallic Securing Devices* (MSDs), staplers, hole punches, folders, three-ring binders, and a full range of related products to serve its customers in paper handling needs. The employees, or internal customers, of POI use MSDs to organize piles of paper pending placement into folders or binders.

The Purchasing Department of POI has noticed an increase in complaints from employees in the Paper Shuffling Department (PSD) about MSDs breaking and failing to keep papers together. This creates opportunities for client papers to be mixed together. The Purchasing Department would like to improve the purchasing process to eliminate complaints from employees in the PSD.

DEFINE PHASE

The Define phase involves understanding the relationships between Suppliers–Inputs–Process–Outputs–Customers (SIPOC), gathering and analyzing Voice of the Customer data, and preparing a project charter. Recall, the two-part project objective for the MSD project is:

Project Objective 1: Decrease (direction) the percentage of MSDs that cannot withstand 4 or more bends without breaking (measure) bought by the Purchasing Department (process) from 62.50 to 00.62% (goal) by January 1, 2001 (deadline). Go for 4-sigma!

Project Objective 2: Decrease (direction) the percentage of boxes of MSDs with more than 5 broken clips (measure) bought by the Purchasing Department (process) from 62.50 to 00.62% (goal) by January 1, 2001 (deadline). Go for 4-sigma!

MEASURE PHASE

The measure phase has three steps; they are: operationally define the CTQs (critical to quality characteristics), perform a gauge Reliability and Reproducibility (R&R) study on each CTQ, and develop a baseline for each CTQ. First, durability and functionality were operationally defined to the satisfaction of all relevant stakeholders of the MSD project. Second, an Attribute Gauge R&R study of functionality showed that its measurement system is sufficient for the needs of this project. An attribute Gauge R&R study was not performed on durability due to the destructive nature of the test. Even so, an operational definition of the testing process will be established and testing will be audited to assure consistency in the near future. Finally, a baseline capability study of durability revealed that it is not stable with a predictable distribution of output. A similar study of functionality indicated that it is stable with a predictable distribution of output. However, neither CTQ is operating at an acceptable level (DPMO = 625,000 or approximately 1.2 process sigma) of quality.

This article begins where "Paper Organizers International: A Fictitious Green Belt Case Study—Part 1,[1]" left off, with the Analyze phase of the DMAIC method.

ANALYZE PHASE

The Analyze phase has five steps: develop a more detailed process map (i.e., more detailed than the process map developed in the SIPOC analysis of the Define phase), construct operational definitions for each input or process variable (called *X*s), perform a gauge R&R study on each *X* (test the adequacy of the measurement system), develop a baseline for each *X*, and develop hypotheses between the *X*s and *Y*s. The *Y*s are the output measures used to determine if the CTQs are met. First, team members prepare a detailed process map identifying and linking the *X*s and *Y*s (Fig. 1).

Note: Some Six Sigma project teams identify the *X*s in the Measure phase of the DMAIC model. This is done when the *X*s have been defined and monitored prior to the start of the Six Sigma project through an organizational metrics tracking system (for example, dashboards or balanced scorecards). If the *X*s and CTQs were not defined and monitored prior to the start of the project, then the *X*s are monitored and analyzed in the Analyze phase, as is the situation in this case study.

Second, team members develop an operational definition for each *X* variable identified on the process map. The operational definitions for *X*1, *X*2, *X*3, and *X*8 relate to individual MSDs and are as follows.

Criteria: Each *X* conforms to either one or the other of the options.

*The idea for a Six Sigma case study focusing on MSD was adapted from Cordis Corporation's (A Division of Johnson & Johnson) Six Sigma training manuals that were developed by Oriel Inc. (Madison, WI). Metallic Securing Devices (MSDs) are paper clips.

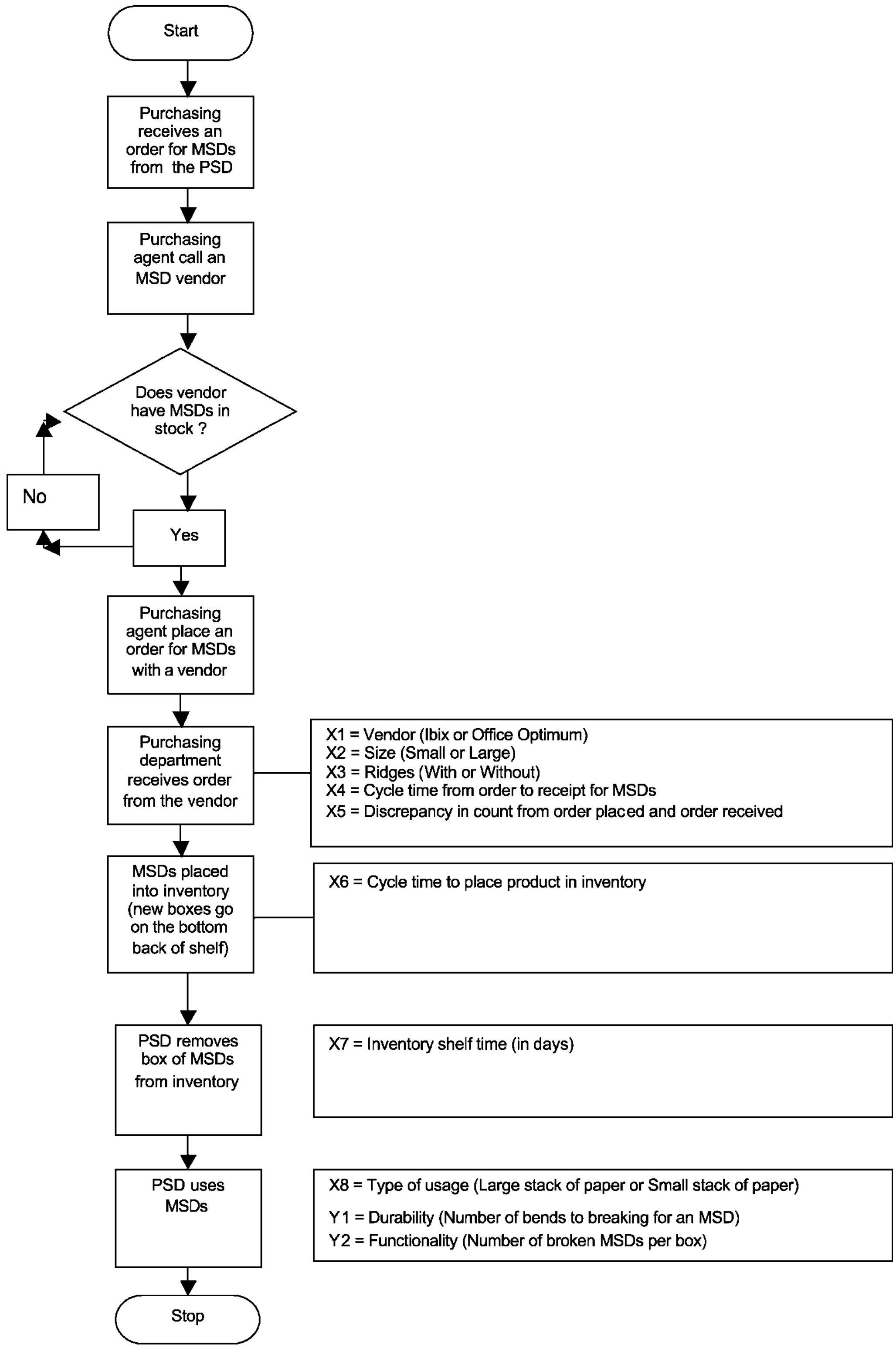

Figure 1. Process map linking CTQs and *X*s for the MSD purchasing process.

*X*1	Vendor	Ibix	Office Optimum
*X*2	Size	Small (stock size)	Large (stock size)
*X*3	Ridges	With ridges	Without ridges
*X*8	Type of usage	Large stack of paper (# papers is 10 or more)	Small stack of paper (# papers is 9 or less)

Test: Select MSD. *Decision*: Determine *X*1, *X*2, *X*3, and *X*8 options for the selected MSD.

The operational definitions for the procedures used to measure *X*4, *X*5, *X*6, and *X*7 are shown below.

Criteria: Compute cycle time in days by subtracting the order date from the date on the bill of lading.

*X*4	Cycle time from order to receipt for MSDs	In days

Test: Select a box of MSDs upon receipt of shipment from vendor. Compute the cycle time. *Decision*: Determine *X*4 for the selected box of MSDs.

Criteria: Count the number of boxes of MSD received for a given order. Subtract the number of boxes ordered from the number of boxes received for the order under study.

*X*5	Discrepancy in count from order placed and order received	In boxes of MSDs by order

Test: Select a particular purchase order for MSDs. *Decision*: Compute the value of *X*5 in number of boxes for the selected purchase order.

Criteria: Compute cycle time in days to place a shipment of MSDs in inventory by subtracting the date the shipment was received from the date the order was placed in inventory.

*X*6	Cycle time to place product in inventory	In days

Test: Select a particular purchase order. *Decision*: Compute the value of *X*6 in days for the selected purchase order.

Criteria: Compute inventory shelf time in days for a box of MSDs by subtracting the date the box was placed in inventory from the date the box was removed from inventory.

*X*7	Inventory shelf time	In days

Test: Select a box of MSDs. *Decision*: Compute the value of *X*7 in days for the selected box of MSDs.

Third, team members conduct Gauge R&R studies for the *X*s. Recall, that the purpose of a Gauge R&R study is to determine the adequacy of the measurement system for an *X*. In this case, the measurement systems for all of the *X*s are known to be reliable and reproducible; hence, Gauge R&R studies were not conducted by team members.

Fourth, team members collect baseline data for each of the *X*s. Team members gathered baseline data on durability (*Y*1) and functionality (*Y*2), and relevant *X*s using the following sampling plan. For a two-week period, the first box of MSDs brought to the PSD each hour was selected as a sample; this yielded a sample of 80 boxes of MSDs (Table 1). For each sampled box, team members determined the durability (*Y*1) and functionality (*Y*2) measurement. Furthermore, they collected information concrning the vendor (*X*1), size of the MSD (*X*2), whether or not the MSD has ridges (*X*3), and inventory shelf life will be recorded (*X*7). Please note that Purchasing Department will separately study cycle time from order to receipt of order (*X*4), discrepancy between ordered and received box counts (*X*5), and cycle time from receipt of order to placement in inventory (*X*6). These last factors may influence such concerns as choice of vendor, ordering procedures, and inventory control, but they do not impact durability and functionality. Furthermore, the MSDs are not tested after they are used so the type of usage (*X*8) is not studied here. As was indicated in the Define phase, certain variables (e.g., *X*4, *X*5, *X*6, and *X*8) can be addressed in subsequent Green Belt projects.

The baseline data revealed that the yield for durability is 0.4625 (37/80) and the yield for functionality is 0.425 (34/80) (Table 2). As before, this indicates very poor levels for the CTQs in the PSD. For comparison purposes, the judgment sample carried out by the team during the Define phase showed that the yield was approximately 40% (i.e., the team assumed the failure rate was approximately 60%) for both durability and functionality. The slight increased yields in this study can be due to natural variation in the process. The baseline data also showed that 56.25% of all MSDs are from Office Optimum (*X*1), 42.50% of MSDs are small (*X*2), 50.00% of all MSDs are "without ridges" (*X*3), and the average shelf time for boxes of MSDs (*X*7) is 6.5 days, with a standard deviation of 2.5 days (Table 2).

Fifth, team members develop hypotheses [$Y = f(X)$] about the relationships between the *X*s and the *Y*s to identify the *X*s that are critical to improving the center, spread, and shape of the *Y*s in respect to customer specifications. This is accomplished through data mining. Data mining is a method used to analyze passive data; that is, data that is collected as a consequence of

Table 1

Base Line Data

Sample	Day	Hour	$X1$	$X2$	$X3$	$X7$	Dur	Fun
1	Mon	1	1	0	0	7	2	5
2	Mon	2	0	1	0	7	2	9
3	Mon	3	0	0	1	7	10	7
4	Mon	4	0	1	0	7	1	4
5	Mon	5	0	0	0	7	7	3
6	Mon	6	0	1	1	7	2	5
7	Mon	7	0	1	1	7	1	9
8	Mon	8	0	0	0	7	7	5
9	Tue	1	0	1	0	8	2	8
10	Tue	2	0	1	0	8	1	7
11	Tue	3	0	1	0	8	1	13
12	Tue	4	1	1	1	8	9	5
13	Tue	5	1	1	0	8	9	9
14	Tue	6	1	1	1	8	10	11
15	Tue	7	1	1	1	8	10	11
16	Tue	8	0	0	1	8	8	9
17	Wed	1	1	1	1	9	8	11
18	Wed	2	1	0	0	9	1	11
19	Wed	3	1	1	1	9	10	11
20	Wed	4	0	0	0	9	7	11
21	Wed	5	1	1	1	9	9	9
22	Wed	6	0	0	1	9	9	5
23	Wed	7	1	0	1	9	2	11
24	Wed	8	1	0	0	9	1	10
25	Thu	1	1	0	1	10	1	14
26	Thu	2	0	1	1	10	1	10
27	Thu	3	1	1	1	10	8	13
28	Thu	4	0	0	1	10	10	12
29	Thu	5	0	0	0	10	7	14
30	Thu	6	0	1	1	10	3	13
31	Thu	7	0	0	0	10	9	13
32	Thu	8	1	1	1	10	8	11
33	Fri	1	0	1	0	1	2	0
34	Fri	2	0	1	0	1	2	1
35	Fri	3	0	1	0	1	1	6
36	Fri	4	0	1	0	1	3	3
37	Fri	5	0	1	0	1	2	2
38	Fri	6	1	1	0	1	10	6
39	Fri	7	0	0	1	1	10	0
40	Fri	8	0	1	0	1	2	0
41	Mon	1	0	1	1	4	3	4
42	Mon	2	0	1	0	4	3	7
43	Mon	3	0	1	1	4	3	3
44	Mon	4	0	0	0	4	10	2
45	Mon	5	1	1	0	4	8	5
46	Mon	6	0	1	1	4	3	4
47	Mon	7	1	0	0	4	1	4
48	Mon	8	0	0	1	4	10	5
49	Tue	1	1	1	1	5	11	6
50	Tue	2	1	0	1	5	3	4

Table 1

Continued

Sample	Day	Hour	$X1$	$X2$	$X3$	$X7$	Dur	Fun
51	Tue	3	1	1	0	5	10	6
52	Tue	4	1	0	1	5	3	5
53	Tue	5	1	0	0	5	2	4
54	Tue	6	0	0	0	5	9	5
55	Tue	7	0	0	1	5	9	5
56	Tue	8	0	1	0	5	3	7
57	Wed	1	0	0	1	6	9	5
58	Wed	2	1	1	0	6	9	7
59	Wed	3	0	0	0	6	9	5
60	Wed	4	1	0	0	6	2	6
61	Wed	5	1	0	1	6	2	5
62	Wed	6	1	1	1	6	10	5
63	Wed	7	0	1	0	6	1	7
64	Wed	8	0	1	0	6	2	5
65	Thu	1	0	0	1	7	10	7
66	Thu	2	1	1	0	7	9	5
67	Thu	3	1	0	0	7	1	7
68	Thu	4	0	1	0	7	2	5
69	Thu	5	1	0	1	7	1	6
70	Thu	6	0	1	0	7	1	5
71	Thu	7	1	0	0	7	1	8
72	Thu	8	1	1	1	7	10	5
73	Fri	1	0	1	1	8	3	7
74	Fri	2	1	1	1	8	9	7
75	Fri	3	1	0	0	8	1	13
76	Fri	4	0	1	1	8	2	8
77	Fri	5	0	1	1	8	3	9
78	Fri	6	1	1	1	8	8	10
79	Fri	7	1	0	1	8	3	11
80	Fri	8	0	0	1	8	10	11

$X1$ = Vendor (0 = Office Optimum and 1 = Ibix); $X2$ = Size (0 = Small and 1 = Large); $X3$ = Ridges (0 = Without and 1 = With); $X7$ = Inventory shelf time, in days.

running a process. In this case, the baseline data in Table 1 is the passive data set that will be subject to data mining procedures. Dot plots or box plots of durability ($Y1$) and functionality ($Y2$) stratified by $X1$, $X2$, $X3$, and $X7$ can be used to generate some hypotheses about main effects (i.e., the individual effects of each X on $Y1$ and $Y2$). Interaction plots can be used to generate hypotheses about interaction effects (i.e., those effects on $Y1$ or $Y2$ for which the influence of one X variable depend on the level or value of another X variable) if all combinations of levels of X variables are studied. If all combinations of levels of X variables are not studied, then often interaction effects are not discovered. Frequently, screening designs are utilized to uncover interaction effects.

Table 2

Basic Statistics on Baseline Data

Variable		Proportion	Mean	Standard Deviation
$Y1$: Durability	4 or more bends/clip	0.4625	5.213	3.703
$Y2$: Functionality	5 or fewer broken/box	0.4250	7.025	3.438
$X1$: Vendor	0 = Office Optimum	0.5625		
	1 = Ibix	0.4375		
$X2$: Size	0 = Small	0.4250		
	1 = Large	0.5750		
$X3$: Ridges	0 = Without Ridges	0.5000		
	1 = With Ridges	0.5000		
$X7$: Inventory shelf time	Shelf time in days		6.5000	2.5160

Team members constructed dot plots from the baseline data in Table 1 to check if any of the Xs (i.e., main effects) impact durability ($Y1$) and functionality ($Y2$). The dot plots for durability are shown in Figs. 2–5. The dot plots for functionality are shown in Figs. 6–9.

The dot plots for durability ($Y1$) indicate: (1) the values of durability tend to be low or high with a significant gap between 4 and 6 for $X1$, $X2$, $X3$, and $X7$, and (2) the variation in durability is about the same for all levels of $X1$, $X2$, $X3$, and $X7$. The dot plots for functionality ($Y2$) indicate: (1) the values of functionality tend to be lower when $X1 = 0$ than when $X1 = 1$, (2) the variation in functionality is about the same for all levels of $X2$ and $X3$, and (3) the values of functionality tend to be lower for low values of $X7$.

Discussion of the Analysis of Durability

Since there are no clear differences in variation (i.e., spread) of durability for each of the levels of $X1$, $X2$, $X3$, and $X7$, the team wondered if there might be differences in the average (i.e., center) for each level of the individual Xs. Team members constructed a main effects plot for durability to study differences in averages (Fig. 10).

Figure 10 indicates that for the range of shelf lives observed there is no clear pattern for the relationship of shelf life ($X7$) to the average Durability. On the other hand, it appears that ridges (i.e., $X3 = 1$) has a positive relationship to the average Durability. At first glance it would seem that the better results for the average Durability are seen when the vendor Ibix is chosen using small MSDs (i.e., $X1 = 1$ and $X2 = 0$), while using large MSDs from Office Optimum (i.e., $X1 = 0$ and $X2 = 1$) yield worse results.

While discussing the dot plots and main effects plot, it was suggested that it is dangerous to make any conclusions without knowing if there are interaction effects. An interaction effect is present when the amount of change introduced by changing one of the Xs depends on the value of another X. In that case, it is misleading to choose the best value of the Xs individually without first considering the interactions between the Xs. Consequently, team members did an interactions plot for $X1$, $X2$, and $X3$. $X7$ was not included in the interactions plot because the main effects plot indicated no clear pattern or relationship with durability ($Y1$). All combinations of levels of the X variables must be present to draw an interactions plot. This is often not the case with passive data (i.e., no plan was put in place to insure all combinations were observed in the data gathering

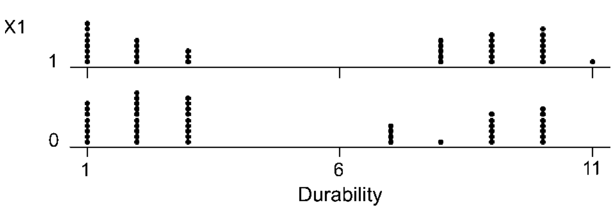

Figure 2. Dot plot for durability by $X1$ (i.e., vendor).

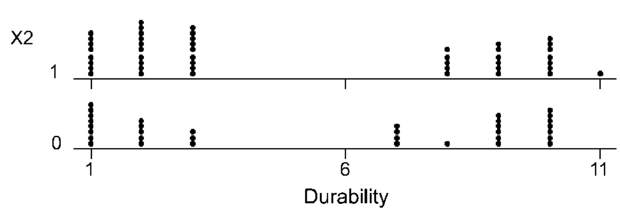

Figure 3. Dot plot for durability by $X2$ (i.e., size).

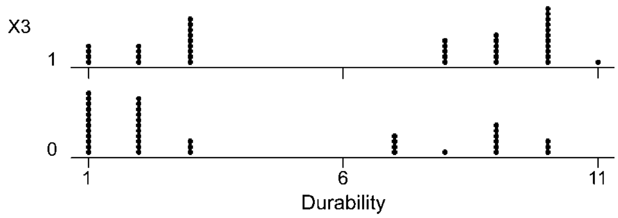

Figure 4. Dot plot for durability by $X3$ (i.e., ridges).

phase). Fortunately, although not all combinations were observed equally often they were all present. Figure 11 is the interaction plot for Durability.

Surprise! The interaction plot indicates that there is a possible interaction between $X1$ (i.e., vendor) and $X2$ (i.e., size). How is this known? When there is no interaction the lines should be parallel to each other indicating the amount of change in average Durability when moving from one level of each X variable to another level should be the same for all values of another X variable. This plot shows the lines on the graph of $X1$ and $X2$ not only are not parallel, but they cross. The average Durability is the highest when either large Ibix MSDs (i.e., $X1 = 1$ and $X2 = 1$) or small Office Optimum MSDs (i.e., $X1 = 0$ and $X2 = 0$) are used. This means the choice of vendor may depend on the size of MSD required. The main effects plot suggests that the best results for average Durability would occur when small MSDs from Ibix are used, but the interactions plot suggests this combination would yield a bad average Durability. In order to study all this further the team decides that during the Improve phase they will run a full factorial design to examine the relationship of $X1$, $X2$,

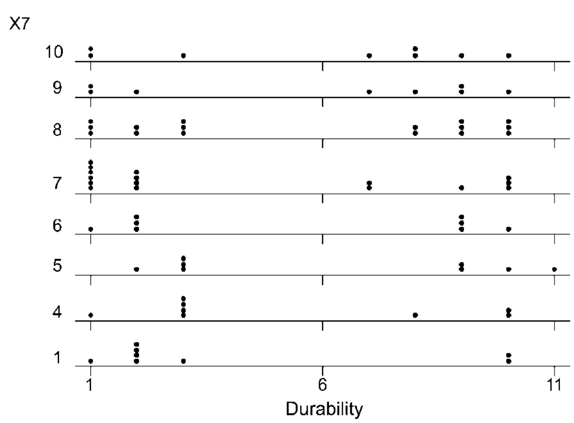

Figure 5. Dot plot for durability by $X7$ (i.e., shelf life).

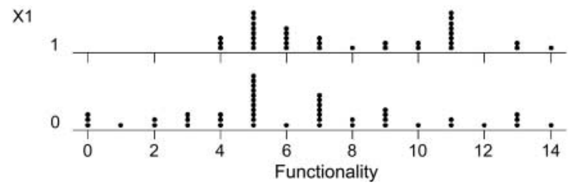

Figure 6. Dot plot for functionality by $X1$ (i.e., vendor).

and $X3$ on Durability ($Y1$) since the main effects plot indicates potential patterns. Again, there does not appear to be a relationship between Durability ($Y1$) and $X7$.

Discussion of the Analysis of Functionality

Figures 12 and 13 represent the main effects and interactions effects plots, respectively, for Functionality ($Y2$). The main effects plot indicates that higher values of shelf life ($X7$) yield higher values for Functionality ($Y2$). The team surmised that the longer a box of MSDs sits in inventory (i.e., higher values of shelf life), the higher the count of broken MSDs (i.e., functionality will be high). From a practical standpoint, the team felt comfortable with this conclusion. They decided the Purchasing Department should put a Six Sigma project in place to investigate whether the potential benefit of either a "just in time" MSD ordering process or establishing better inventory handling procedures will solve the problem.

The interaction effects plot indicate a potential interaction between the $X2$ (i.e., size) and $X3$ (i.e., ridges). The better results for functionality (i.e., low values) were observed for large MSDs without ridges (i.e., $X2 = 1$ and $X3 = 0$). Why this may be the case would need to be studied further. In addition, there may be an interaction between $X1$ (i.e., vendor) and $X2$ (i.e., size), but it appears that better results are observed whenever Office Optimum is used (i.e., $X1 = 0$). In other words, the average count of broken MSDs is lower (i.e., functionality average is lower) whenever Office Optimum is the vendor.

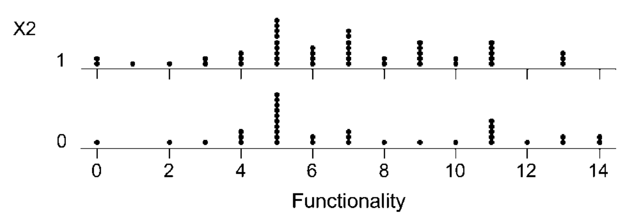

Figure 7. Dot plot for functionality by $X2$ (i.e., size).

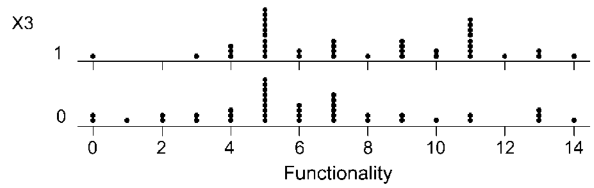

Figure 8. Dot plot for functionality by $X3$ (i.e., ridges).

Analyze Phase Summary

The Analyze Phase resulted in the following hypotheses:

Hypothesis 1: Durability $= f(X1 = \text{Vendor},\ X2 = \text{Size},\ X3 = \text{Ridges})$ with a strong interaction effect between $X1$ and $X2$.

Hypothesis 2: Functionality $= f(X1 = \text{Vendor},\ X2 = \text{Size},\ X3 = \text{Ridges},\ X7 = \text{Shelf Life})$ with the primary driver being $X7$ with some main effect due to $X1$ and an interaction effect between $X2$ and $X3$.

$X7$ is the main driver of the distribution of Functionality ($Y2$) and is under the control of the employees of POI. Hence, team members restructured Hypothesis 2 as follows:

Functionality $= f(X1 = \text{Vendor},\ X2 = \text{Size},\ X3 = \text{Ridges})$ for each fixed level of $X7$ (Shelf Life).

Improve Phase

The improve phase involves designing experiments to understand the relationship between the Ys and the vital few Xs and major noise variables, generating the actions needed to implement the levels of the vital few Xs that optimize the shape, spread, and center of the distributions of the Ys, developing action plans, and conducting pilot test of the action plans.

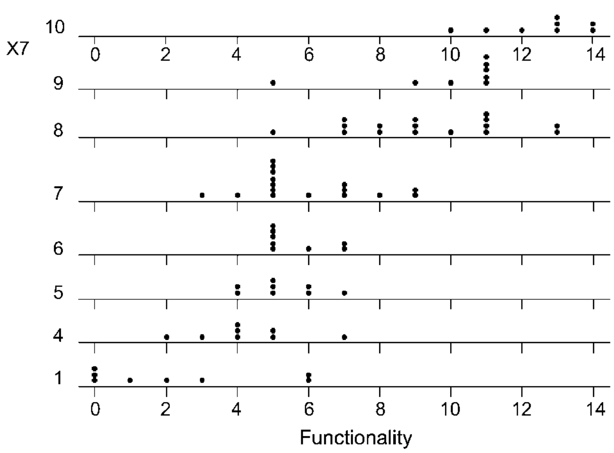

Figure 9. Dot plot for functionality by $X7$ (i.e., shelf life).

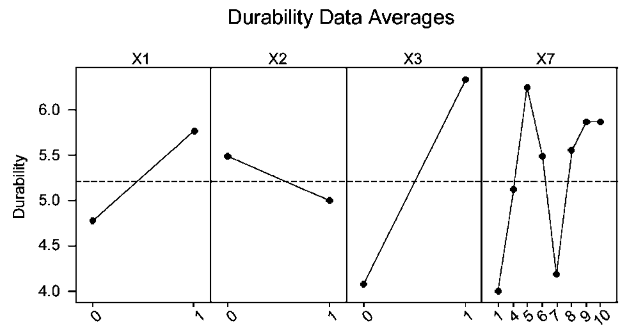

Figure 10. Main effects plot for durability by $X1$, $X2$, $X3$, and $X7$.

First, team members conducted an experimental design to determine the effect of $X1$ (Vendor), $X2$ (Size), and $X3$ (Ridges), and their interactions, on the Ys with $X7 = 0$ (no shelf life—MSDs are tested immediately upon arrival to POI before they are placed in inventory). A 2^3 full factorial design with 2 replications (16 trials) was performed for durability and functionality. The factor conditions for Vendor ($X1$) are Office Optimum (-1) or Ibix (1); the factor conditions for Size are "Small" (-1) or "Large" (1), and the factors conditions for Ridges ($X3$) are "Without Ridges" (-1) or "With Ridges" (1). The experiment was set-up in two blocks to increase experimental reliability, with the first 8 runs conducted in the morning and the second 8 runs conducted in the afternoon. The runs were randomized within each block. The purpose of the blocks and randomization is to help prevent lurking (background) variables that are related to time (e.g., time of day and order in which data are collected) from confusing the results. Additional information can be gathered since 16 trials were run, rather than the minimum of 8 trials, especially regarding potential interactions. The data from the 2^3 full factorial design, with 2 replications in run order with the first 8 runs constituting the first replicate, are shown in Table 2.

A Pareto Chart showing which of the vital few Xs, and the interactions between them, have a statistically significant effect on Durability ($Y1$) at the 10% level of significance can be seen in Fig. 14.

The major effects (i.e., those that have significance level less than 0.10, in other words over 90% confidence level) for Durability are the interaction of Vendor and

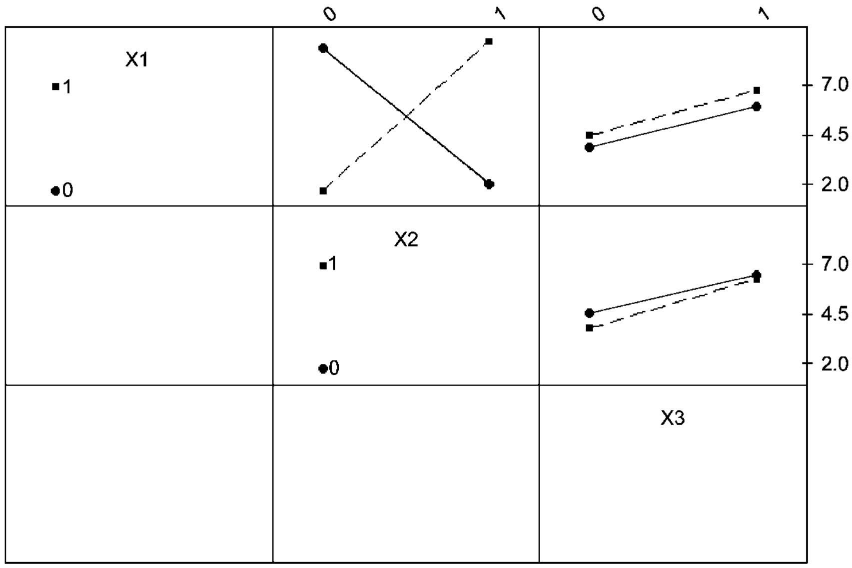

Figure 11. Interaction effects plot for durability by $X1$, $X2$, and $X3$.

Size and the main effect due to Ridges. There are no significant effects due to Vendor, Size, or Ridges present for Functionality. No Pareto diagram is shown for significance of effects. This indicates that since the effect of shelf life was held constant in this designed experiment, while it was shown to affect Functionality in the data mining analysis, the team can restrict its attention to improving Functionality by addressing shelf life first. As Durability is the only outcome influenced by Vendor, Size, or Ridges in this designed experiment, further consideration in this study will be restricted to Durability. Another project can address shelf life and its effect on Functionality.

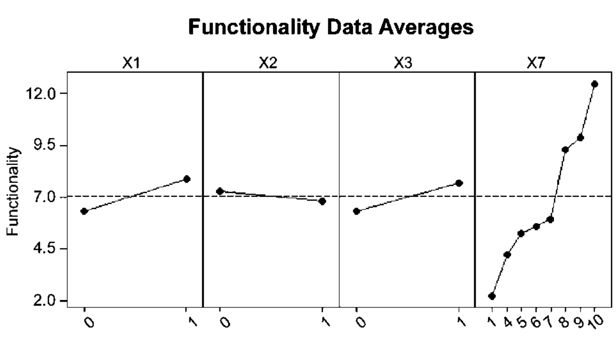

Figure 12. Main effects plot for functionality by $X1$, $X2$, $X3$, and $X7$.

Since interaction effects should be interpreted prior to studying main effects the team decided to construct an interaction effect plot for Vendor and Size. Figure 15 shows the interaction effect plot for Vendor and Size relative to Durability.

The interaction effect plot between Size and Vendor shown in Fig. 15 indicates that the best results for Durability are obtained using small MSDs supplied by Office Optimum or large MSDs supplied by Ibix. The reasons for this interaction may be due to factors such as materials used for each size MSD, differences in supplier processes for each size MSD, or other supplier-dependent reasons. Team members can ask each vendor why their sizes show significant differences in average durability, if there is a preference to use only one vendor. Otherwise, the Purchasing Department should buy small MSDs from Office Optimum or large MSDs from Ibix to optimize Durability ($Y1$).

The only significant main effect not involved within a significant interaction effect is $X3 =$ Ridges. The main effect for Ridges on Durability is shown in Fig. 16.

It indicates that the average Durability is about $6.5 - 5.4 = 1.1$ more when an MSD with Ridges is used rather than an MSD without Ridges. Therefore, since Ridges is a main effect independent of any interaction effects, then the right selection of MSDs is to use Office Optimum for small MSDs with ridges and Ibix for large MSDs with ridges. If the experimental results from Table 2 are used, then the average Durability for Office Optimum's small MSDs

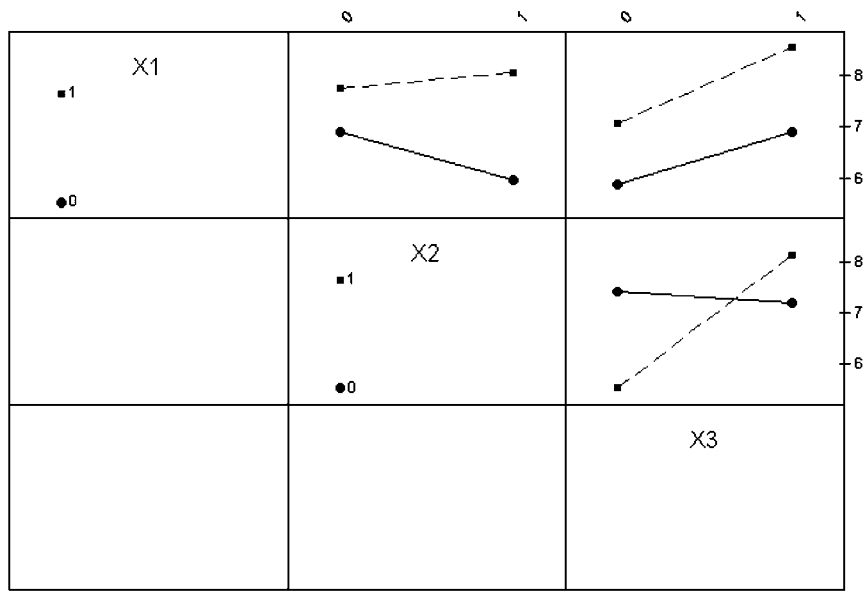

Figure 13. Interaction effects plot for functionality by $X1$, $X2$, and $X3$.

with ridges is $(10+9)/2=9.5$ while the average Durability for Ibix's large MSDs with ridges is $(11+9)/2=10.0$. Both averages are well above the required corresponding CTQ of at least 4. As long as the variation (spread) of results is small enough so that no individual Durability result is far from these averages, then the team is successful with respect to Durability. The variation in these results can be monitored using control charts after changing the purchasing process for selecting MSDs.

The team members decided to purchase all "MSDs with Ridges." In addition, the choice of Vendor and Size will be as follows: (Vendor = Office Optimum) and (Size = Small) or (Vendor = Ibix) and (Size = Large) to maximize average durability. In addition, the team decided to take on another project to reduce shelf life to less than 5 days to address Functionality. The revised flowchart for the Purchasing Department incorporating the findings of the Six Sigma project is shown in Fig. 17.

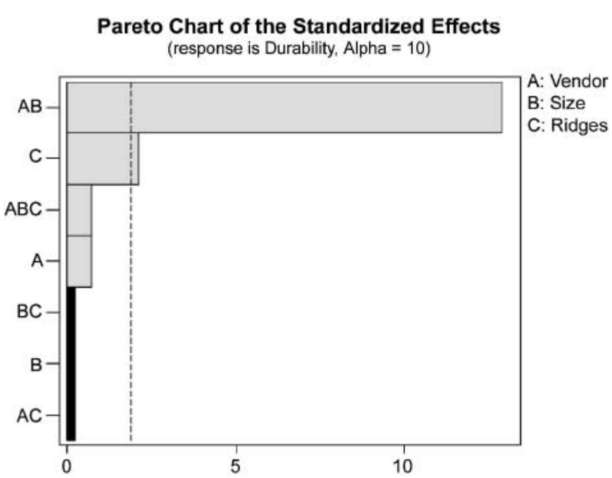

Figure 14. Pareto chart of effects for durability.

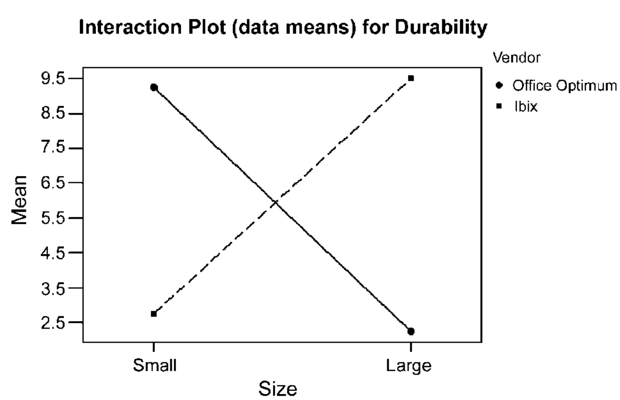

Figure 15. Interaction effect plot for vendor and size for durability.

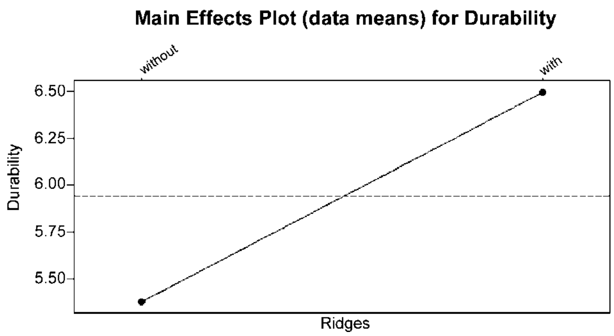

Figure 16. Main effect plot for ridges for durability.

The team members conducted a pilot test of the revised best practice (flowchart). Data for durability from the pilot test is shown in Table 3.

Table 3 indicates that the RTY (rolled throughout yield) for durability is 100%. Functionality was also tested, but not shown here, using shelf life = 0 days; that is, the MSDs were tested immediately upon arrival to POI before they were placed in inventory. It resulted in a RTY of 75% that is better than the baseline RTY. The effect on Functionality of shelf life and inventory control procedures will be investigated in subsequent projects if management decides these projects should be chartered.

Figure 18 shows that durability is in control with a higher mean number of bends for all MSDs in the pilot test. The test pilot data shown in Table 3 includes results for both small MSDs from Office Optimum and large MSDs from Ibix. Subsequently, team members realized that, with all things being equal, large MSDs from Ibix should have a higher average durability than small MSDs from Office Optimum. Consequently, team members constructed two control charts, one for small MSDs from Office Optimum and another for large MSDs from Ibix (Figs. 19 and 20), respectively.

Figures 18–20 show that Durability ($Y1$) is in control, but it is dangerous to compute any process capability statistics due to the small sample sizes. However, estimates for the mean and standard deviation of Small MSDs from Office Optimum are 8.625 and 1.05 (calculated from the data but the calculation is not shown here), respectively. The mean and standard deviation for Large MSDs from Ibix are 10.25 and 0.83, respectively. Since the CTQ for durability requires the number of bends to be 4 or more, then this requirement is 4.4 standard deviations below the mean for Small MSDs from Office Optimum and 7.5 standard deviations below the mean for Large MSDs from Ibix. Team members all agreed that as long as the process for both Small MSDs from Office Optimum with ridges and Large MSDs from Ibix with ridges remain in control, then it is extremely unlikely that the MSDs will fail the CTQ for Durability ($Y1$).

Control Phase

The control phase involves mistake proofing the improvements and/or innovations discovered in the Six Sigma project, establishing a risk management plan to minimize the risk of failure of product, service, or process, documenting the improvement and or innovation in ISO 9000 documentation, and preparing a control plan for the process owners who will inherit the improved or innovated product, service, or process.

First, team members identified and prioritized two problems while mistake proofing the process improvements discovered in the improve phase; they were: (1) purchasing agents do not specify with ridges on a purchase order, and (2) purchasing agents do not consider that the choice of vendor depends on the size of the MSDs being requested on the purchase order. Team members created solutions that make both errors impossible; they are: (1) the purchase-order entry system does not process an order unless "with ridges" is specified on the purchase order, and (2) the purchase-order entry system does not process an order unless Office Optimum is the selected vendor for small MSDs and Ibix is the selected vendor for large MSDs.

Second, team members use risk management to identify two risk elements, they are: (1) "failing to train new purchasing agents" in the revised purchasing process shown in Fig. 17, and (2) Office Optimum and Ibix are out of MSDs with ridges. Team members assigned risk ratings to both risk elements (Table 4).

Both risk elements must be dealt with in risk abatement plans. The risk abatement plan for failing to train new purchasing agents is to document the revised purchasing process in training manuals. The risk abatement plan for "vendor out of MSDs with ridges" is for POI to request that both Office Optimum and Ibix manufacture only MSDs with ridges due to their superior durability. This is a reasonable and acceptable suggestion to POI, Office Optimum, and Ibix because the cost structures for manufacturing MSDs with and without ridges are equal, and neither Office Optimum nor Ibix has other customers requesting MSDs without ridges. Office Optimum and Ibix agree to produce only MSDs with ridges after a six-month trial period in which they check incoming purchase orders for requests for MSDs without ridges. If the trial period reveals no requests for

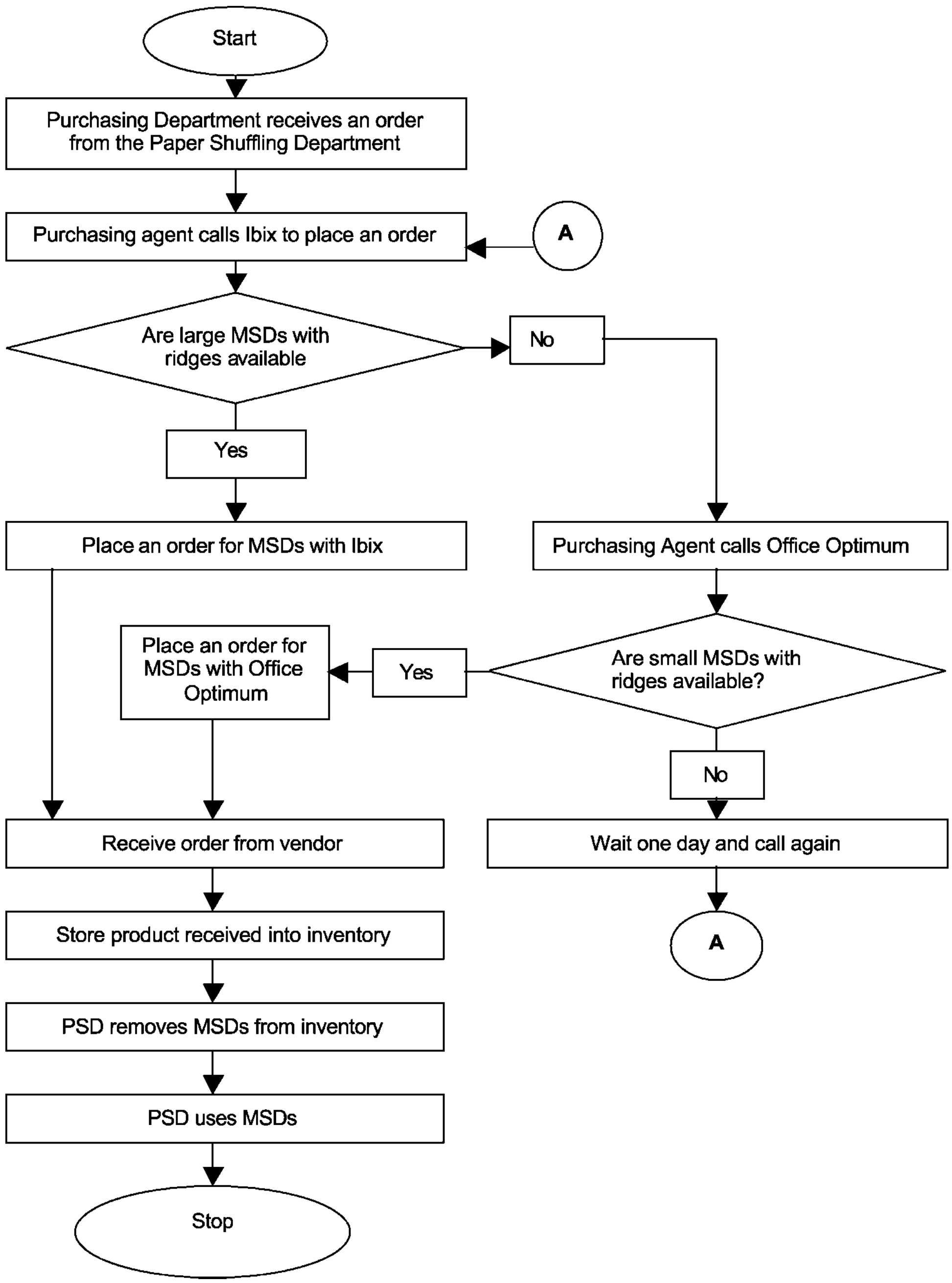

Figure 17. Revised flowchart of the purchasing department.

MSDs without ridges, then the POI Purchasing Department will revise Fig. 17 and the appropriate ISO 9000 documentation to reflect the possibility of purchasing only MSDs with ridges. Additionally, Office Optimum and Ibix thanked POI for pointing out to them that average durability is higher for MSDs with ridges than MSDs without ridges. Both vendors claim that they are going to experiment with possible different ridge patterns to increase durability and decrease costs. Both vendors stated that they anticipate decrease costs from only producing MSDs with ridges because of the lower amortized costs of having only one production line.

Table 3

Data from the Pilot Test

Hour	Vendor	Size	Ridges	Durability
Shift 1—Hour 1	Office Optimum	Small	With	10
	Ibix	Large	With	11
Shift 1—Hour 2	Office Optimum	Small	With	7
	Ibix	Large	With	11
Shift 1—Hour 3	Office Optimum	Small	With	10
	Ibix	Large	With	11
Shift 1—Hour 4	Office Optimum	Small	With	8
	Ibix	Large	With	11
Shift 1—Hour 5	Office Optimum	Small	With	9
	Ibix	Large	With	10
Shift 1—Hour 6	Office Optimum	Small	With	9
	Ibix	Large	With	9
Shift 1—Hour 7	Office Optimum	Small	With	8
	Ibix	Large	With	11
Shift 1—Hour 8	Office Optimum	Small	With	9
	Ibix	Large	With	10
Shift 2—Hour 1	Office Optimum	Small	With	9
	Ibix	Large	With	11
Shift 2—Hour 2	Office Optimum	Small	With	8
	Ibix	Large	With	10
Shift 2—Hour 3	Office Optimum	Small	With	10
	Ibix	Large	With	9
Shift 2—Hour 4	Office Optimum	Small	With	7
	Ibix	Large	With	9
Shift 2—Hour 5	Office Optimum	Small	With	7
	Ibix	Large	With	10
Shift 2—Hour 6	Office Optimum	Small	With	9
	Ibix	Large	With	11
Shift 2—Hour 7	Office Optimum	Small	With	10
	Ibix	Large	With	9
Shift 2—Hour 8	Office Optimum	Small	With	8
	Ibix	Large	With	11
RTY				$32/32 = 1$

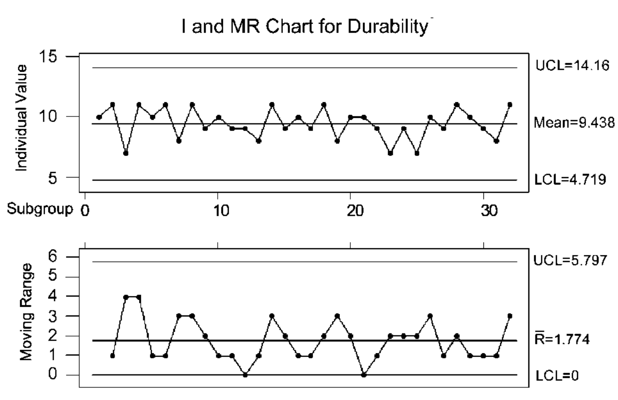

Figure 18. Control chart for durability.

Third, team members prepare ISO 9000 documentation for the revisions to the training manual for the purchasing process from Fig. 17.

Fourth, team members develop a control plan for the PSD that requires a monthly sampling of the boxes of MSDs in inventory. The purpose of the sampling plan is to check if the boxes of MSDs being purchased are either small Office Optimum MSDs with ridges or large Ibix MSDs with ridges. The percentage nonconforming boxes of MSDs will be plotted on a p-chart. PSD management will use the p-chart to highlight violations of the new and improved purchasing process shown in Fig. 17. The p-chart will be the basis for continuously tuning

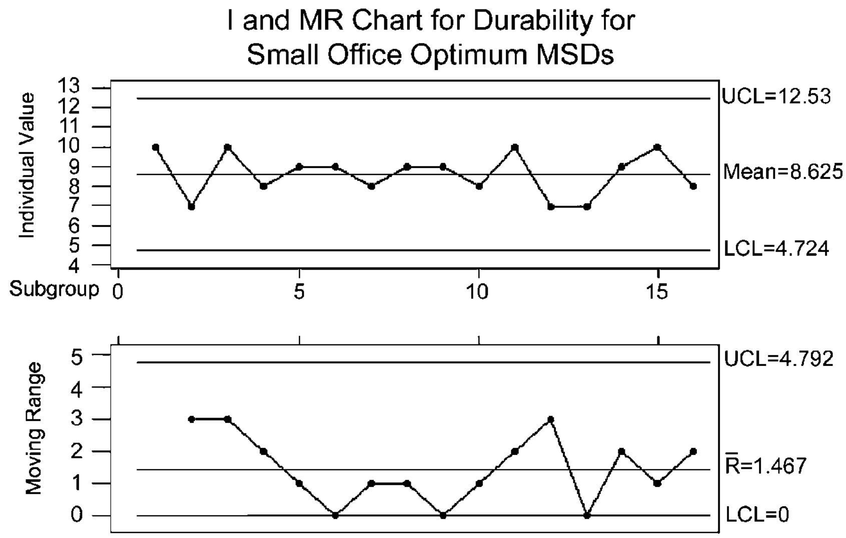

Figure 19. Control chart for durability for small MSDs from office optimum.

the PDSA (plan-do-study Act) cycle for the purchasing process.

Finally, team members checked the business indicator from the PSD dashboard (see Figs. 1 and 2 in Ref. [1]) and determined that production costs in the PSD decreased, probably due to the MSD Six Sigma project (Fig. 21). The MSD project took effect in month 73 of Fig. 21.

CONCLUSION

This paper presented the Analyze, Improve, and Control phases of a Six Sigma Green Belt case study. It is time for the Champion and Black Belt to disband the project team, turn the improved process over to the Purchasing Department, and celebrate the project's

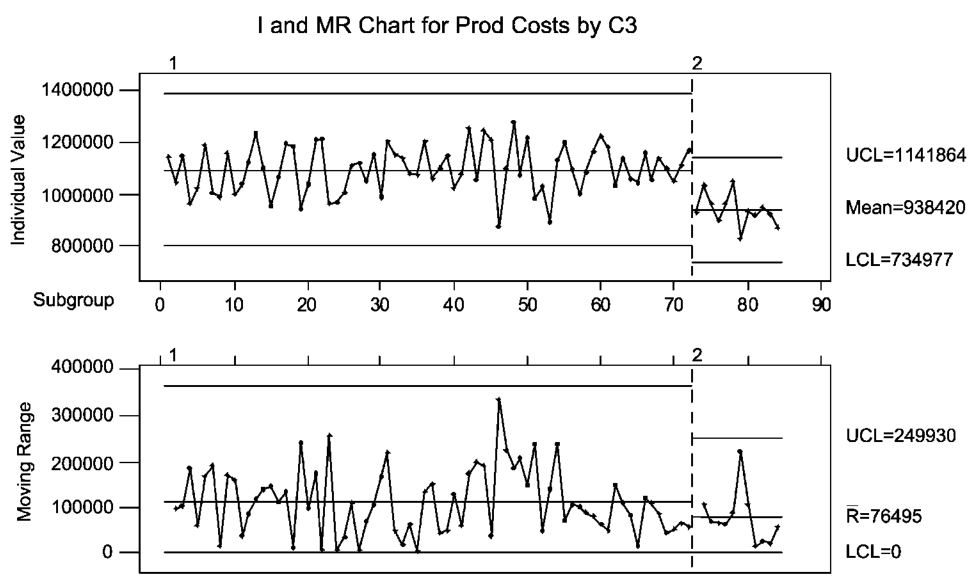

Figure 20. Control chart for Durability for Large MSDs from Ibix.

Table 4

Risk Elements for Purchasing Process

Risk Elements	Risk Category	Likelihood of Occurrence	Impact of Occurrence	Risk Element Score	
Failing to train new purchasing agents	Performance	5	5	25	High
Vendor out of MSDs with ridges	Materials	2	5	10	Medium

Scale: 1–5 with 5 being the highest.

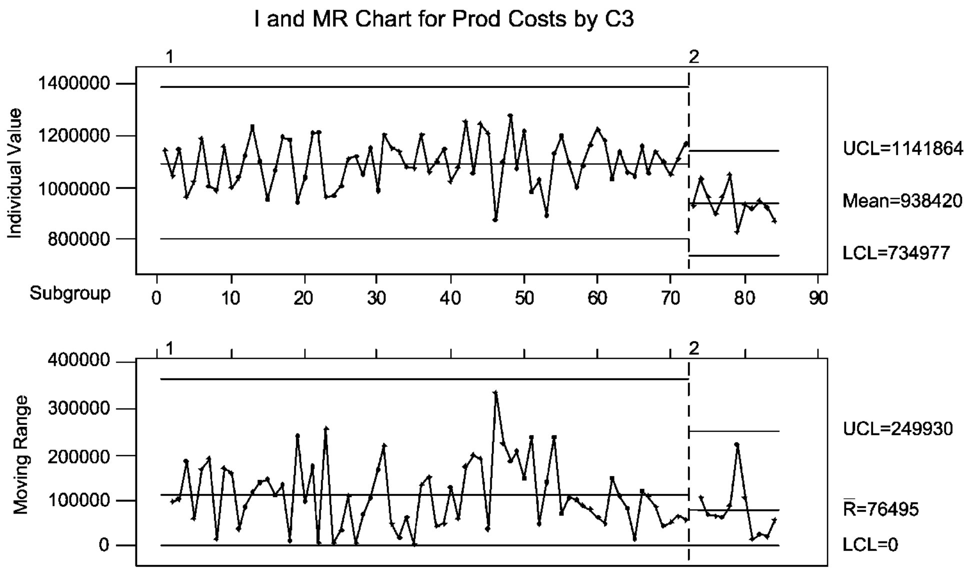

Figure 21. Individuals and moving range chart of production costs in the PSD before and after the MSD Six Sigma project.

success with team members. The authors hope that readers find this case study a profitable learning experience.

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Dr. Popovich earned his Ph.D. in Statistics (1983), his Masters degree (1979), and his B.S. in Mathematics (1977) at the University of Florida. He has taught at the University of Florida, University of Central Florida, Florida Atlantic University, Nova Southeastern University, and has guest lectured at several other universities.

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