PART IV

SIX SIGMA CASE STUDIES

CHAPTER 16 PAPER ORGANIZERS INTERNATIONAL

CHAPTER 17 A PAPER HELICOPTER EXPERIMENT
CASE STUDY

CHAPTER 16

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

CHAPTER OUTLINE

- 16.1 Background of the Case Study
- 16.2 Define Phase
- 16.3 Measure Phase
- 16.4 Analyze Phase
- 16.5 Improve Phase
- 16.6 Control Phase

LEARNING OBJECTIVES

After reading this chapter, you will be able to:

- Conduct a Six Sigma DMAIC project
- Use the tools and methods of the Define, Measure, Analyze, Improve, and Control Phases

16.1 BACKGROUND OF THE CASE STUDY

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 punchers, folders, three-ring binders, and a full range of related products to serve its customers' paper-handling needs. The employees, or internal customers, of Paper Organizers International use Metallic Securing Devices (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 process for purchasing MSDs to eliminate complaints from employees in the Paper Shuffling Department.

Origin of the MSD Six Sigma Project

POI's mission statement is "Put the **R**ight Information in the Right **P**lace," **RIP** it! To accomplish this mission, POI has established a cascading set of business objectives and business indicators, which ultimately result in potential Six Sigma projects, see Table 16.1 on page 491.

The monthly production costs in the PSD are shown on the Individual and Moving Range chart in Figure 16.1 (see the next to last row in the fourth column in Table 16.1).

Figure 16.1 on page 492 indicates that production costs are stable (no special causes such as points beyond a control limit or too many sequences up and down, etc.) in the PSD with an average monthly cost of \$1,096,880.00 and a standard deviation of \$99,000 ($\overline{R}/d_2 = $111,672/1.128$). Additionally, production costs are approximately normally distributed (see Figure 16.2 on page 492). Team members discovered that PSD management considers monthly production costs to be very high, given the volume of work being processed by the department.

The four potential Six Sigma projects shown in the rightmost column of Table 16.1 are prioritized for attention in Table 16.2. Table 16.2 on page 493 is a Cause-and-Effect-type matrix (see Section 4.1) that weights the importance of each potential Six Sigma project to each of POI's business objectives.

The cell values are assigned by top management and are defined as follows: 0 = no relationship, 1 = weak relationship, 3 = moderate relationship, and 9 = strong relationship. The Finance Department developed the importance weights for each business objective to maximize the impact of Six Sigma projects on the bottom line of the organization. Consequently, the most critical project with respect to the business objectives is the MSD quality project; see 4.95 in the last row of Table 16.2. The champion and process owner of the MSD process prepared an initial project charter and presented it to the members of the MSD quality project team.

^{*}The idea for a Six Sigma case study focusing on Metallic Securing Device (paper clips) was adapted from an exercise developed by Oriel Inc. (Madison, WI) for Johnson & Johnson.

 TABLE 16.1 POI's Business Objectives and Indicators with Potential Six Sigma Projects

President		Director of P	Director of Paper Shuffling Department (PSD)			
Business objectives	Business indicators	Area objectives	Area indicators	Potential Six Sigma projects		
Increase the number of orders	Number of orders/ month (c-chart)	Increase the number of orders in PSD	Number of orders in PSD/month (c-chart)	New customer promotions project		
Increase the number of POI services (filing, organizing, etc.) utilized by each customer	Average/and standard deviation of number of services utilized per customer/quarter $(\overline{X} \text{ and } S\text{-charts})$	Increase the number of ser- vices utilized by each customer in PSD	Average and standard deviation of number of services utilized per PSD customer/quarter (\overline{X}) and S-charts)	Existing customer promotions project		
Minimize production costs	Production costs/ month (I and MR charts)	Minimize pro- duction costs in PSD	Production costs in PSD/month (Figure 16.1; I and MR charts)	MSD quality project		
Eliminate employee complaints	Number of employee complaints/month (c-chart)	Eliminate em- ployee com- plaints from PSD	Number of employee complaints from PSD/month (c-chart)	Employee morale project		

16.2 DEFINE PHASE

The Define phase has three components: business case with a project objective, SIPOC analysis, and Voice of the Customer (VoC) analysis.

Prepare a Business Case with a Project Objective

Preparing a business case requires team members to answer the following eight partially redundant questions. Some of the answers can be obtained from the draft project objective completed by the champion and process owner. The redundancy in the questions helps team members distill the critical elements of the business case.

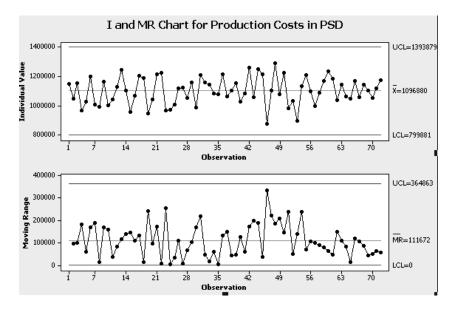


FIGURE 16.1 Minitab Individual and Moving Range Chart of Monthly Production Costs in the PSD

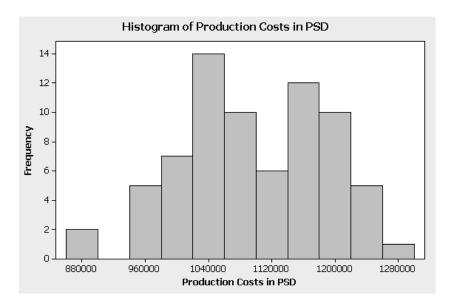


FIGURE 16.2 Minitab Histogram of Monthly Production Costs in the PSD

 TABLE 16.2
 Prioritization of Potential Six Sigma Projects

Potential Six				otential Six Sigma p	Sigma projects		
Business objectives			New customer promotions project	Existing customer promotions project	MSD quality project	Employee morale project	
Increase the number of orders	W	.35	3	3	0	0	
Increase the number of POI services utilized by each customer	i g h	.10	1	3	0	0	
Minimize pro- duction costs	t s	.40	0	0	9	3	
Eliminate employee complaints		.15	0	0	9	9	
Weighted average of potential Six Sigma projects			1.15	1.35	4.95*	2.55	

 $^{*4.95 = (0.35 \}times 0) + (0.10 \times 0) + (0.40 \times 9) + (0.15 \times 9)$

Question: What is the name of the process?

Answer: MSD Purchasing Process. The first step in the supply chain for the MSD process is the process for purchasing MSDs. Hence, the first operation to be investigated by MSD quality project team members is the process for purchasing MSDs. Team members may study other factors that affect the quality of MSDs, such as the method of use or shelf-life at a later time.

Question: What is the aim of the process?

Answer: The aim of the purchasing process as it relates to this project is to purchase MSDs that improve the productivity and morale of the employees in the PSD and decrease production costs.

Question: What is the business case (economic rationale) for the project? This is answered by addressing the following subquestions:

Question: Why do the MSD project at all?

Answer: According to a judgment sample of three employees and two managers from the PSD, team members determined that MSDs that cannot withstand four or more bends are unacceptable because they are unlikely to remain intact throughout the paper shuffling processes and will not hold papers tightly. This is called durability. Defective MSDs

create costs for POI; for example: (a) papers from different clients may get mixed together if not properly bound, requiring additional processing time, (b) employees may have to use multiple MSDs for one project, creating additional material costs, and (c) employees get frustrated and do not perform their jobs efficiently and productively, consequently increasing labor costs. Additionally, team members discovered that a large proportion of the boxes containing MSDs arrive to the PSD with five or more broken MSDs. This is called *functionality*. This creates additional processing costs for POI; for example, (a) increased unit costs and (b) frustrated and nonproductive employees and managers. Team members used the same judgment sample as above and determined that approximately 60% of individual MSDs do not meet durability criteria, and 60% of MSD boxes do not meet functionality criteria (see the survey questionnaire in Table 16.3 and the data matrix in Table 16.4).

TABLE 16.3 Survey Questionnaire

,
Survey
Name: 1. Please estimate the percentage of MSDs that cannot withstand four or more bends 2. Please estimate the percentage of MSD boxes that contain greater than five broken MSDs

TABLE 16.4 Survey Data

Survey Number	Response Q1	Response Q2
]	55%	70%
2	50%	55%
3	60%	65%
4	65%	60%
5	70%	50%
Average	60%	60%

Question: Why do the MSD project now?

Answer: Because the PSD is experiencing very high monthly production costs (see Figures 16.1 and 16.2) and because internal customers, including managers and hourly employees, are submitting an increased number of complaints: 14 in the first quarter, 18 in the second quarter, and 32 in the third quarter, as recorded in the Purchasing Department's complaint log for the fiscal year 2003. There are 100 hourly workers in the PSD.

Question: What business objectives are supported by the MSD quality project?

Answer: The MSD project is most strongly related to the "minimize production costs" and "eliminate employee complaints" business objectives (see Table 16.2).

Question: What are the consequences of not doing the project?

Answer: The consequences of not doing the project are decreased profit margins due to higher production costs and increased employee complaints due to frustration with materials.

Question: What projects have higher or equal priority?

Answer: At this time, the MSD quality project has the highest priority (4.95) (see the bottom row of Table 16.2).

Question: What is the problem statement? What is the pain?

Answer: Low-quality MSDs create additional production costs and employee frustration.

Question: What is the goal (desired state) for this project?

Answer: The Champion and Process Owner of the MSD process initially determined that a 100-fold improvement in MSD quality (durability and functionality) should be the goal for the Six Sigma project. They derived the concept of a 100-fold improvement from Motorola's 1986 stated improvement rate of tenfold every 2 years, or a 100-fold every 4 years during the kickoff of the Six Sigma effort. Because 100-fold improvement means the defects per million opportunities (DPMO) would decrease from 600,000 to 6,000, and a DPMO of 6,210 represents a Four Sigma process, team members decided to use Four Sigma as the goal for the MSD project.

Question: What is the project scope? This is answered by answering the following subquestions:

Question: What are the process boundaries?

Answer: The starting point for the project is when the Purchasing Department receives purchase orders from the PSD. The stopping point for the project is when the PSD places MSDs into inventory.

Question: What, if anything, is out of bounds?

Answer: The project team cannot change the way employees handle or use MSDs.

Question: What resources are available for the project?

Answer: The budget for the MSD project is \$30,000.00. This includes estimated hourly salaries of project participants. Team members Brian Mercurio and Jeremy Pressman are the only project participants who will incur additional job responsibilities as a result of the project. Budget estimates show "opportunity cost" and "hard costs" (see Table 16.5). The estimated hard costs (\$10,500) and expected opportunity costs (\$15,540) are less than the budget of \$30,000.

Question: Who can approve expenditures?

Answer: Only the Process Owner, Dana Rasis, can approve expenditures.

TABLE 16.5 Estimated Labor Costs for the Project

Name	Position	Estimated salary/ hour	Expected number of hours per week	Expected opportunity costs for 21 weeks	Expected hard costs for 21 weeks (direct labor costs)
Adam Johnson	Champion	\$100	2	\$4,200	
Dana Rasis	Process Owner	\$50	2	\$2,100	
Bettina Arguelles	Green Belt	\$50	5	\$5,250	
Brian Mercurio	Team member	\$25	10	\$0	\$5,250
Jeremy Pressman	Team member	\$25	10	\$0	\$5,250
Lindsey Barton	Finance rep.	\$45	2	\$1,890	
Mary Montano	IT rep.	\$50	2	\$2,100	
Total				\$15,540	\$10,500

Question: How much can the team spend beyond \$30,000.00 without seeking additional authority?

Answer: Nothing.

Question: What are the obstacles and constraints of the project?

Answer: The team must work within a \$30,000 budget and a 21-week time constraint.

Question: What time commitment is expected of team members?

Answer: Team members are expected to be present at weekly Friday morning meetings from 8:00 a.m. until 9:00 a.m. Team members are also expected to provide progress of project tasks at each meeting. Completion of project tasks will require additional hours of work per week.

Question: What will happen to each team member's regular job while working on the project?

Answer: If any, overtime hours will be compensated for team members and support staff. The estimated rate for overtime labor is 1.5 times normal labor. Overtime labor is not included in the budget in Table 16.5.

Question: Is there a Gantt chart for the project? *Answer: A Gantt chart is shown in Table 16.6.* **Question:** What are the benefits of the project?

Answer: The soft benefits of the project include eliminating complaints from the PSD and increasing employee morale. The hard (financial) benefits of the project are minimizing labor costs and material costs. The hard cost benefits are estimated on page 498.

The labor costs of the current and proposed systems are presented in Table 16.7.

TABLE 16.6 Gantt Chart for the MSD Project

Steps Resp.	Resp.												Week	¥								
		-	7	က	4	2	9	_	œ	6	10	Ξ	12	13	14	15	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	17	28	19	20	21
Define Measure Analyze Improve Control	8 B B B B B B B B B B B B B B B B B B B	\times	\times	× × ×	×	××	\times \times	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

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TABLE 16.7 Labor Costs

100 employees in the Paper Shuffling Department (PSD)

- × 40 hours/week/paper shuffling employee
- \times 10% of time devoted to clipping
- @ 400 hours/week devoted to clipping in PSD
- × \$25/hour/paper-shuffling employee
- \$10,000/week devoted to clipping
- x 50 weeks/year
- \$500,000/year devoted to clipping
- × 0.60 defective clips (judgment sample estimate of durability of the current system) Broken clips are not selected for use on jobs. This makes 0.6 a conservative estimate of the percentage of defective clips in the current system.*

\$300,000/year on defective clipping for current system

× 0.0062 defective clips (durability of the proposed system) **

\$3,100/year on defective clipping for proposed system

Hence, a lower bound on the estimated annual savings on labor costs from improving the MSD purchasing process is \$296,900 (\$300,000 – \$3,100). The PSD incurs a 10% annual employee turnover. To capitalize on savings in labor costs, the department will now hire 4 new employees instead of 10 new employees, for a savings of 6 full-time employees (\$296,900/\$25 = 11,876 hours; 11,876/40 hours per week/50 weeks per year = 5.938 = ~6 employees saved). Alternatively, the PSD may now serve more customers with its current employee base.

The material costs of the current system are shown in Table 16.8.

Hence, the annual savings on material costs from improving MSD purchasing process is \$44,820 (\$75,000 – \$30,180). This yields a lower bound on the estimated annual total hard benefit savings of \$341,720.00.

Question: What are the roles and responsibilities of team members?

Answer: The roles and responsibilities of team members are shown in Table 16.9.

Do A SIPOC Analysis

The second part of the define phase requires that team members perform a SIPOC analysis. A SIPOC analysis is a simple tool for identifying the suppliers and their inputs into a process, the high-level steps of a process, the outputs of the process, and the customer segments interested in the outputs. A SIPOC analysis of POI's Purchasing Department is shown in Figure 16.3 on page 500.

^{*}This conservative estimate does not include problems arising from defective clips not detected until after they have been used and have caused failure on the job.

^{**}Again, broken clips are not selected for use on jobs.

TABLE 16.8 Material Costs

100 employees in the Paper Shuffling Department

- × 60 projects/week/paper-shuffling employee
- × 50 weeks/year
- @ 300,000 projects/year requiring 3,000,000 MSDs (10 clips per project on average)
- \times 0.60 defective clips (judgment sample estimate of current system).
- 7,500,000* clips must be used to complete 300,000 projects
- $\times 0.01/clip$

@ \$75,000/year on clips in current system

- × 0.0062 defective clips (proposed system)
- 3,018,000 ** clips must be used to complete 300,000 projects
- $\times .01/clip$

@ \$30,180/year on clips in proposed system

- *1/(1-0.6) = 2.5 clips needed to get a good clip. So $3,000,000 \times 2.5 = 7,500,000$.
- **1/(1 0.0062) = 1.006 clips needed to get a good clip. So $3,000,000 \times 1.006 = 3,018,000$.

 TABLE 16.9
 Roles and Responsibilities

Project Name: MSD Purchasing Process

Role	Responsibility	Stakeh	older	Supervisor's signature
		Signature	Date	
Champion	Adam Johnson	AJ	9/1/2003	
Process Owner	Dana Rasis	DR	9/1/2003	
Green Belt	Bettina Arguelles	ВА	9/2/2003	
Team member 1	Bryan Mercurio	ВМ	9/3/2003	
Team member 2	Jeremy Pressmen	JP	9/3/2003	
Finance rep	Lindsey Barton	LB	9/4/2003	
IT rep	Michelle Montano	MM	9/4/2003	

Conduct a "Voice of the Customer" Analysis

The third part of the define phase involves team members collecting and analyzing VoC data. VoC data is verbal or written information collected from a sample of users in a selected market segment. The questionnaire used to collect data from users of MSDs in the PSD is shown in Table 16.10 on page 501.

Team members analyze the "Voice of the Customer" (VoC) data by market segment (see column 1 of Table 16.11 on page 502). Next, they use all the raw VoC data points (see column 2 of

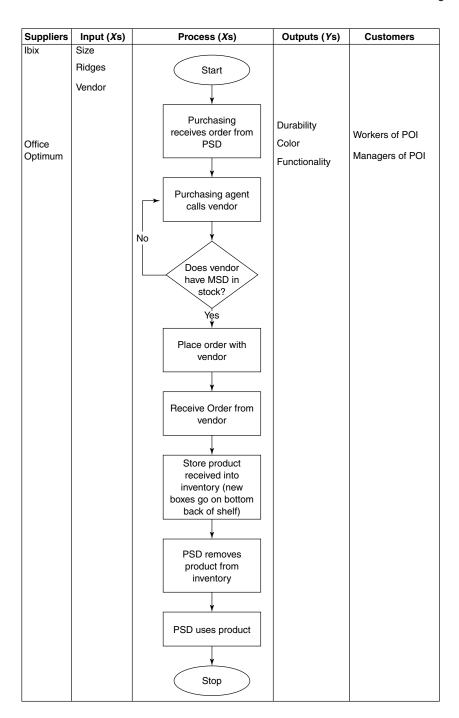


FIGURE 16.3 SIPOC Analysis

TABLE 16.10 Voice of the Customer Questionnaire

Questions*

What emotions come to mind when you think about MSDs?
What needs and wants come to mind when you think about MSDs?
What complaints or problems would you like to mention about MSDs?

Table 16.11) to create affinity diagram themes [see References 3 and 5 and Chapter 15], called *focus points* (see boldface numbers linking columns 2 and 3 in column 3 in Table 16.11). Next, team members identify the engineering issue underlying each focus point, called *cognitive issues* (see column 4 in Table 16.11). Then team members convert each cognitive issue into one or more quantitative engineering variable, called *critical-to-quality* (CTQ) variables (see column 5 in Table 16.11). Finally, team members develop technical specifications for each CTQ (see column 6 of Table 16.11).

A Kano questionnaire (see Table 16.12 on page 504) is a tool used by team members to classify a set of CTQs (see column 1 in Table 16.12) into an appropriate Kano quality category (see columns 2 and 3 in Table 16.12) from a large sample of regular users of a product, service, or process (see Chapter 4). There are six common Kano categories:

- 1. One-way (O)—User satisfaction is proportional to the performance of the feature; the lower the performance, the lower the user satisfaction; the higher the performance, the higher the user satisfaction.
- 2. Must-be (M)—User satisfaction is not proportional to the performance of the feature; the lower the performance, the lower the user satisfaction, but high performance creates feelings of indifference to the feature.
- 3. Attractive (A)—Again, user satisfaction is not proportional to the performance of the feature; low levels of performance create feelings of indifference to the feature, but high levels of performance create feelings of delight to the feature.
- 4. Indifferent (I)—User does not care about the feature.
- 5. Questionable (Q)—User response does not make sense (e.g., delighted if feature is present and delighted if feature is absent).
- Reverse (R)—User offers responses opposite the responses expected by individuals conducting the Kano survey (e.g., "do not like it" if feature is present and "delighted" if feature is absent).

Additionally, team members use a Kano questionnaire to classify CTQs into their appropriate Kano cost category (see column 4 in Table 16.12). There are three common Kano cost categories:

1. Approximately, 80% of users are willing to pay at least a 10% cost increase for a new feature or a new product or service, above current offerings of products or services.

^{*}These questions do not consider the opinions, feelings, and attitudes of the upstream, downstream, and external customers of the PSD.

TABLE 16.11 Analysis Table for Voice of the Customer Data

_	2	က	4	'n	9
Selected market segment	Raw VoC data	Affinity diagram theme (focus point)	Driving issue (cognitive	CTO	Tech specs
Paper organizing managers		Variation in durability 1	Durability	Ability to withstand bendina	> 4 bends without breaking
	"My employees are frustrated about the MSDs. They complain that they break too fast." 1 & 2	Variation in color 2	Color	Number of different MSD colors	= 1 color of MSDs
	"My employees are complaining that the MSDs are not holding up during the organizing process." 1	Variation in functionality 3	Functionality	Number of broken MSDs in a box	≤ 5 broken MSDs in a box
	"The employees are also complaining that the color of the MSDs change from one day to the next. It seems to be confusing them." 2				
	"My employees are very unhappy with the purple and blue MSDs. They would prefer only one color of MSDs be used consistently." 2				
	"My employees say that more than five MSDs per box arrive broken." 3				
	"I've heard from numerous employees that the MSDs coming straight from inventory are already broken." 3				

Hourly employees

"The MSDs are falling apart before we are ready to file the papers into binders. An MSD should be able to take at least four bends." 1

"The MSDs aren't helping us to do our work efficiently." **1 & 2**

"I would prefer if we used only one color of MSDs." 2

"I don't understand why we use different colors of MSDs." \mathbf{Z}

"The MSDs just break when trying to bend them over the paper stacks. They should take at least four bends." 1

"It is very frustrating when you open a brand new

box of MSDs and find that more than five of the

clips are already broken." **3** "It is very time-consuming to sift out the broken MSDs from a brand new box coming straight from

inventory." 3

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- 2. Approximately, 60% of users are willing pay at least a 10% cost increase for a new feature or a new product or service, above current offerings of products or services.
- 3. Approximately, 10% of users are willing to pay a 10% cost increase for a new feature or a new product or service, above current offerings of products or services.

TABLE 16.12 Kano Questionnaire for MSDs

CTQs	How would you feel if the following CTQ were present in the product?	How would you feel if the CTQ were not present in the product?	What percentage of cost increase, over current costs, would you be willing to pay for this CTQ?
Ability to withstand ≥ 4 bends	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	0% [] 10% [] 20% [] 30% [] 40% or more []
= One color of MSDs	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	0% [] 10% [] 20% [] 30% [] 40% or more []
≤ 5 Broken MSDs in a box	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	Delighted [] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	0% [] 10% [] 20% [] 30% [] 40% or more []

The questionnaire in Table 16.12 was given to the 100 paper shufflers in the PSD. Table 16.13 is used to classify the survey responses from each of the 100 paper shufflers for each of the CTQs into their Kano categories.

TABLE 16.13 Classification Table for Responses to a Kano Questionnaire

	Not p	oresent quest	tion response	(see column	3 in Table 1	5.12)
Present Question Response		Delighted	Expect it and like it	No feeling	Live with it	Do not like it
(see column 2 in	Delighted	Q	Α	Α	Α	0
Table 16.12)	Expect it and like it	R		1		Μ
	No feeling	R		I		Μ
	Live with it	R		1	1	Μ
	Do not like it	R	R	R	R	Q

For example, if one of the paper shufflers answered the Kano survey about durability as is shown in Table 16.14, the CTQ would be classified as "attractive" for that paper shuffler (see Table 16.13 for classification table).

TABLE 16.14 One Paper Shuffler's Kano Questionnaire for MSDs

CTQs	How would you feel if the following CTQ were present in the product?	How would you feel if the CTQ were not present in the product?
Durability: Ability to withstand ≥ 4 bends	Delighted [X] Expect it and like it [] No feeling [] Live with it [] Do not like it [] Other []	Delighted [] Expect it and like it [] No feeling [X] Live with it [] Do not like it [] Other []

The responses for the 100 paper shufflers are tabulated in Table 16.15.

Durability is a must-be quality characteristic, and its presence is required to achieve employee indifference. Its absence creates employee dissatisfaction. The PSD is not willing to pay more for durable MSDs. Functionality is a one-way quality characteristic. Its absence is related to employee dissatisfaction, and its presence is related to employee satisfaction. The PSD is not willing to pay more for functional MSDs. Color is an indifferent quality characteristic. PSD employees do not care about it and are not willing to pay more for MSDs that are uniform in color.

The final step of a VoC analysis is to define each CTQ (see Table 16.16). Returning to the first part of the Define phase, team members can now define the project's objectives.

 TABLE 16.15
 Tabulated Responses to Kano Questionnaire

CTQs	Kano quality category	Kano cost category
Durability: Ability to withstand four or more bends	M = 80 O = 20 M = 35	0% = 100
Color: Only 1 color per box	O = 15 I = 50	0% = 100
Functionality: Less than or equal to five broken MSDs in a box	M = 10 O = 90	0% = 100

TABLE 16.16 Definition of CTQs

сто	Definition of unit	Definition of opportunity for defect	Definition of defect	Kano Category
Durability: Ability to withstand bending	MSD	MSD	Break < 4 bends	Must-be: Fundamental to the delivery of the most basic level of customer satisfaction.
Color: Number of different MSD colors	1 box of MSDs	MSD	MSD colors in one box > 1	Indifferent: Far less critical than durability to paper shufflers.
Functionality: Number of broken MSDs in a box	1 box of MSDs	MSD	Broken MSDs in one box > 5	One-way: Improving the number of functional MSDs in a box will improve employee satisfaction in a linear fashion.

Project Objective 1: Decrease (direction) the percentage of MSDs that cannot withstand four or more bends without breaking (measure) bought by the Purchasing Department (process) to 0.62% (goal) by January 1, 2004 (deadline). Go for Four Sigma!

Project Objective 2: Decrease (direction) the percentage of boxes of MSDs with more than five broken clips (measure) bought by the Purchasing Department (process) to 0.62% (goal) by January 1, 2004 (deadline). Go for Four Sigma!

A correlation exists between the project objectives. A broken MSD cannot withstand four or more bends because it is already broken. Improving the percentage of functional MSDs per box will increase the percentage of MSDs that can withstand four or more bends.

16.3 MEASURE PHASE

The Measure phase has three steps. They are: operationally define each CTQ, perform a gage R&R study on each CTQ, and develop a baseline for each CTQ.

Operationally Define Each CTQ

Team members operationally define durability and functionality by establishing criteria for durability and functionality, developing a test for each set of criteria, and formulating a decision rule for each criteria. The operational definitions for durability and functionality are shown below.

Operational Definition for CTQ1: Durability. Criteria for a selected MSD can be seen in Figure 16.4.

1. Bend Zero: Closed clip	
2. Bend One: Open clip	
3. Bend Two: Closed clip	
4 Rend Three: reneat hend One	

- 5. Bend Four: repeat bend Two
- 6. Bend ?: repeat until break
- 7. Count number of successful bends. Do not count the bend the break occurs on.

FIGURE 16.4 Criteria for Number of Bends of an MSD

Test for a selected MSD:

- 1. Select the top front box of MSDs on the shelf in the inventory room.
- 2. Close your eyes, then open the box of MSDs, then haphazardly select one intact MSD. No switching is allowed.
- 3. Utilize the criteria for the selected MSD.
- 4. Count the number of bends until breaking.

Decision for a selected MSD:

- 1. If the number of bends is ≥ 4 , then MSD is conforming.
- 2. If the number of bends is < 4, then MSD is defective.

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Operational Definition for CTQ2: Functionality. *Criteria* for a box of MSDs: Count the number of "broken" clips. A clip is "broken" if it is in two pieces, regardless of the relative sizes of the pieces. It is a fact that clips can be broken only into two pieces. *Test* for a box of MSDs:

- 1. Select the top front box of MSDs on the shelf in the inventory room.
- 2. Count the number of "broken" clips.

Decision for a box of MSDs:

- 1. If the number of MSDs that are broken ≤ 5 , then the box of MSDs is conforming.
- 2. If the number of MSDs that are broken > 5, then the box of MSDs is defective.

The same box of MSDs is used for both operational definitions.

Perform a Gage R&R Study on Each CTQ

Team members conduct an attribute Gage R&R (repeatability and reproducibility) study on the measurement system of each CTQ to determine whether it is adequate for the needs of the project. Gage R&R is only part of a measurement system analysis. Linearity, stability, and calibration are also components of a measurement system analysis that can be conducted. These components were not studied as part of this Six Sigma project. The measurement of durability requires a destructive test.

Therefore, a simple Gage R&R study was not done for durability at this time. In the near future, an operational definition of the testing process for durability will be established, and testing will be audited to assure consistency. The measurement system for functionality is studied using the following sampling plan.

- 1. A shelf in the storage area contains boxes of MSDs purchased throughout the week. There are different types of MSD boxes in the storage area (different vendors, sizes, etc.).
- The Gage R&R study required two inspectors to sample the same 10 boxes of MSDs twice.
- 3. The top 10 boxes on the front of the shelf were selected for the Gage R&R study.
- 4. The study is repeated as is deemed necessary by PSD management.

Two PSD managers have the responsibility of inspecting the MSDs for functionality; they are called *Inspector 1* (Tom) and *Inspector 2* (Jerry). Both Tom and Jerry counted the number of defective MSDs, twice, in random order. The functionality data is shown in Table 16.17 but not in random order.

TABLE 16.17 Gage R&R Data for Functionality

Box	Inspector	Count	Fuctionality	Вох	Inspector	Count	Fuctionality
1	1	1	10	6	1	1	9
1	1	2	10	6	1	2	9
1	2	1	10	6	2	1	9
1	2	2	10	6	2	2	9
2	1	1	9	7	1	1	6
2	1	2	9	7	1	2	6
2	2	1	9	7	2	1	6
2	2	2	9	7	2	2	6
3	1	1	5	8	1	1	6
3	1	2	5	8	1	2	6
3	2	1	5	8	2	1	6
3	2	2	5	8	2	2	6
4	1	1	4	9	1	1	9
4	1	2	4	9	1	2	9
4	2	1	4	9	2	1	9
4	2	2	4	9	2	2	9
5	1	1	5	10	1	1	11
5	1	2	5	10	1	2	11
5	2	1	5	10	2	1	11
5	2	2	5	10	2	2	11

GAGER&R-FUNCTIONALITY 2

A Gage run chart shows that there is no variation within inspectors or between inspectors, as seen in Figure 16.5. All the variation is between the 10 boxes of MSDs. Therefore, the measurement system is acceptable to measure functionality. The same is true for durability.

Develop a Baseline for Each CTQ

Team members conduct a study (as part of routine business) to determine the baseline capability for each CTQ. At the beginning of each hour, one box of MSDs is selected from the storage area. The procedure for selecting a box of MSDs is simply to select the top-frontmost box on the shelf. The selection process was not altered during a sampling period of two 8-hour shifts. Baseline capability data is shown in Table 16.18.

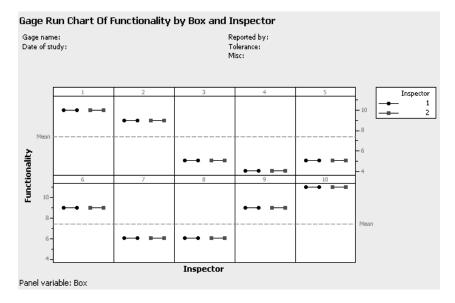


FIGURE 16.5 Minitab Gage Run Chart for Functionality

TABLE 16.18 Baseline Capability Data

Hour	Durability	Functionality	Hour	Durability	Functionality
Shift 1—Hour 1	5	12	Shift 2—Hour 1	12	6
Shift 1 — Hour 2	7	4	Shift 2—Hour 2	9	6
Shift 1 — Hour 3	3	8	Shift 2—Hour 3	3	9
Shift 1 — Hour 4	2	6	Shift 2—Hour 4	1	5
Shift 1 — Hour 5	9	1	Shift 2—Hour 5	1	4
Shift 1 — Hour 6	2	5	Shift 2—Hour 6	1	5
Shift 1 — Hour 7	1	11	Shift 2—Hour 7	1	9
Shift 1 — Hour 8	1	9	Shift 2—Hour 8	4	10
Yield	6/16 = 0.373	6/16 = 0.37	5		



The yields for durability and functionality are both 0.375, as determined by the number of tests out of 16 trials shown in Table 16.18 that met their respective CTQ's (i.e., at least four bends for durability, no more than five broken MSDs per box for functionality). This indicates very poor

levels of durability and functionality for the MSDs received into the PSD and supports the initial yield estimates of 40.0%, or 60% defective MSDs (see Table 16.4).

An individuals and moving range (I-MR) chart for the durability baseline data indicates that the variability of durability is not stable over time (see the bottom panel of Figure 16.6). An investigation of the range between the eight and ninth MSDs did not reveal any obvious special cause of variation that could be used to improve the durability of MSDs.

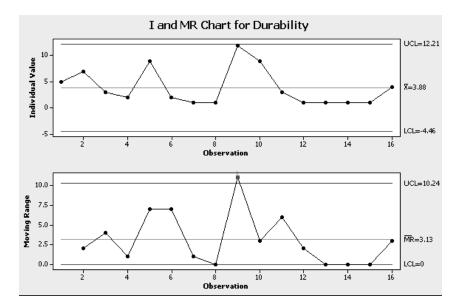


FIGURE 16.6 Minitab Individual and Moving Range Chart for Baseline Durability Data

The I-MR chart assumes approximate normality of the CTQ (durability). The durability data is not normally distributed, as shown in Figure 16.7.

Hence, use of the durability I-MR chart is not advised at this time. However, the distribution of durability may approximate a Poisson distribution. Consequently, team members constructed a *c*-chart** for the "count of bends" before each MSD breaks, which is displayed in Figure 16.8.

Figure 16.8 indicated a possible special cause Shift 2—Hour 1 when 12 bends were observed for the durability test. Further investigation and notes related to the test did not reveal any obvious differences between the MSD tested and the others, although during the first hour, the tester indicated that he may have bent the MSD slower than usual during the test, which may have caused less stress and consequently more bends.

^{**}If the durability were measured using a continuous measurement system allowing for a fractional number of bends before breaking, then a log or similar transformation of the distribution may be appropriate before using an I-MR charting procedure.

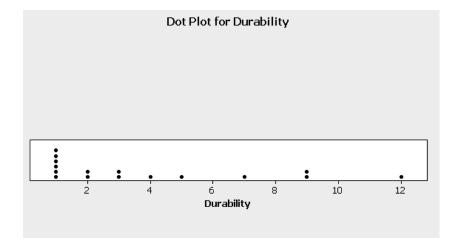


FIGURE 16.7 Minitab Dot Plot of Baseline Durability Data

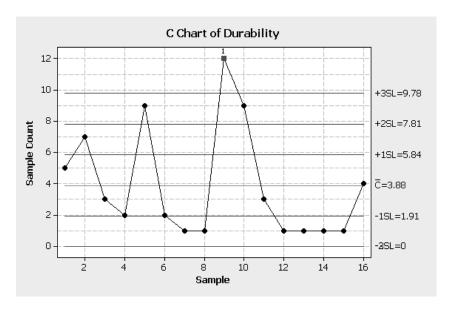


FIGURE 16.8 Minitab c-Chart for Durability

A c-chart for functionality shown in Figure 16.9 indicates that it is stable over time.

The functionality data (see Figure 16.10) appears to be approximately Poisson distributed. Hence, use of the functionality c-chart is acceptable at this time. Finally, team members estimate the current process performance for each CTQ in Table 16.19.

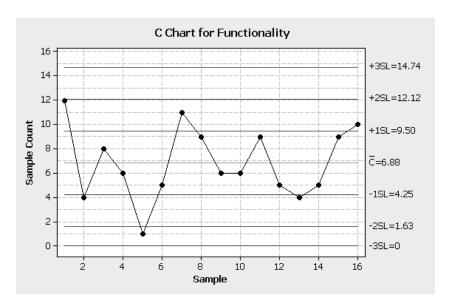


FIGURE 16.9 Minitab c-Chart for Functionality Baseline Data

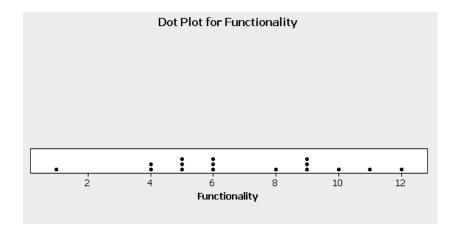


FIGURE 16.10 Minitab Dot Plot for Functionality Baseline Data

 TABLE 16.19
 Current Process Performance for CTQs

CTQs	Yio	eld	DPMO		
	Current	Current Desired		Desired	
Durability Functionality	37.50% 37.50%		625,000 625,000		

Notice the desired 100-fold improvement shown in the DPMO columns (Current = 625,000 and Desired = 6,210). This is consistent with the goals stated in the Define phase of the DMAIC model.

16.4 ANALYZE PHASE

The Analyze phase has five steps:

- 1. Develop a more detailed process map (that is, more detailed than the process map developed in the SIPOC analysis of the Define phase).
- 2. Construct operational definitions for each input or process variable (called Xs).
- 3. Perform a Gage R&R study on each *X* (test the adequacy of the measurement system).
- 4. Develop a baseline for each *X*.
- 5. Develop hypotheses between the *X*s and *Y*s.

The Ys are the output measures used to determine whether the CTQs are met.

Team members prepare a detailed process map identifying and linking the *X*s and *Y*s, as shown in Figure 16.11.

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 shown below.

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

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 (number of papers is 10 or more)	Small stack of paper (number of 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 the cycle time in days by subtracting the order date from the date on the bill of lading.

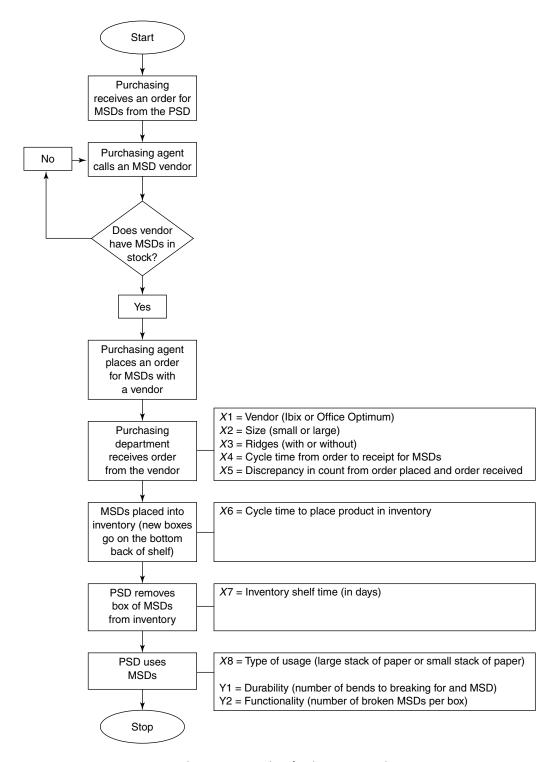


FIGURE 16.11 Process Map Linking CTQs and Xs for the MSD Purchasing Process

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 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.

X₅ Discrepancy in count from order placed and order In boxes of MSDs by order received

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 the 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 the 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.

Team members conduct Gage R&R studies for the *X*s. Recall that the purpose of a Gage 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, Gage R&R studies were not conducted by team members.

Team members gather baseline data on durability (Y_1) functionality (Y_2) , and the relevant Xs using the following sampling plan. For a 2-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, which can be seen Table 16.20.

TABLE 16.20 Baseline Data

Sample	Day	Hour	X ₁	X ₂	X ₃	X ₇	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
							(cor	ntinued)

For each sampled box, team members determined the durability (Y_1) and functionality (Y_2) measurements. Furthermore, information concerning the vendor (X_1) , size of the MSD (X_2) , whether the MSD has ridges (X_3) , and inventory shelf-life is recorded (X_7) .

 TABLE 16.20 Baseline Data (continued)

Sample	Day	Hour	X ₁	X ₂	X ₃	X ₇	Dur	Fun
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]	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
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]	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
							(cor	ntinued)

TABLE 16.20 Baseline Data (continued) (continued)

Sample	Day	Hour	X 1	X ₂	X ₃	X ₇	Dur	Fun
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

DATAMINING

 X_1 = vendor (0 = Office Optimum and 1 = Ibix)

The 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_7) can be addressed in subsequent Six Sigma 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), as shown in Table 16.21. 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 slightly 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 (see Table 16.21).

Team members develop hypotheses [Y = f(X)] about the relationships between the Xs and the Ys to identify the Xs that are critical to improving the center, spread, and shape of the Ys with 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 operating a process. In this case, the baseline data in Table 16.20 is the passive data set that will be subject

 $X_2 = \text{size } (0 = \text{small and } 1 = \text{large})$

 X_3 = ridges (0 = without and 1 = with)

 X_7 = inventory shelf-time, in days

TABLE 16.21 Basic Statistics on Baseline Data

Variable		Proportion	Mean	Standard deviation
Y ₁ : Durability	Four or more bends/clip	0.4625	5.213	3.703
Y ₂ : Functionality	Five or fewer broken/box	0.4250	7.025	3.438
X ₁ : Vendor	0 = Office Optimum 1 = Ibix	0.5625 0.4375		
X ₂ : Size	O = Small 1 = Large	0.4250 0.5750		
X ₃ : Ridges	0 = Without ridges 1 = With ridges	0.5000 0.5000		
X_7 : Inventory shelf-time	Shelf-time in days		6.5000	2.5160

to data mining procedures. Dot plots or box plots of durability (Y_1) and functionality (Y_2) stratified by X_1, X_2, X_3 , and X_7 can be used to generate some hypotheses about main effects (i.e., the individual effects of each X on Y_1 and Y_2). Interaction plots can be used to generate hypotheses about interaction effects (i.e., those effects on Y_1 or Y_2 for which the influence of one X variable depends on the level or value of another X variable) if all combinations of levels of X variables

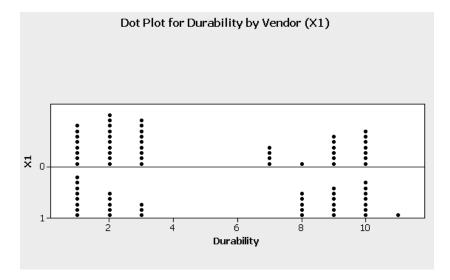


FIGURE 16.12 Minitab Dot Plot for Durability by X_1 (i.e., Vendor)

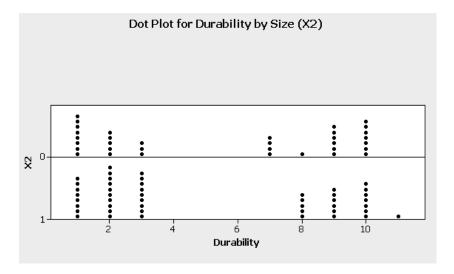


FIGURE 16.13 Minitab Dot Plot for Durability by X_2 (i.e., Size)

are studied. If not all combinations of levels of X variables are studied, then interaction effects are often not discovered.

Team members constructed dot plots from the baseline data in Table 16.20 to check whether any of the Xs (i.e., main effects) impact durability (Y_1) and functionality (Y_2). The dot plots for durability are shown in Figures 16.12–16.15. The dot plots for functionality are shown in Figures 16.16–16.19.

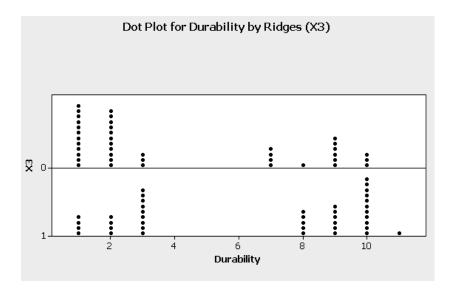


FIGURE 16.14 Minitab Dot Plot for Durability by X_3 (i.e., Ridges)

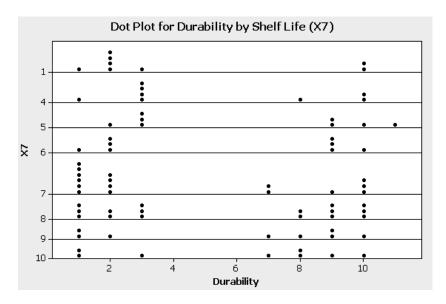


FIGURE 16.15 Minitab Dot Plot for Durability by $X_{\mathcal{T}}$ (i.e., Shelf-life)

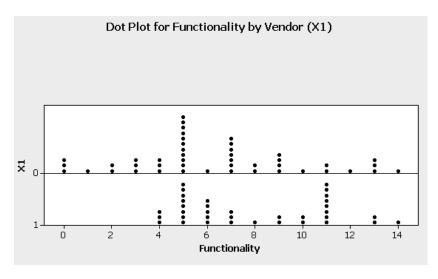


FIGURE 16.16 Minitab Dot Plot for Functionality by X_1 (i.e., Vendor)

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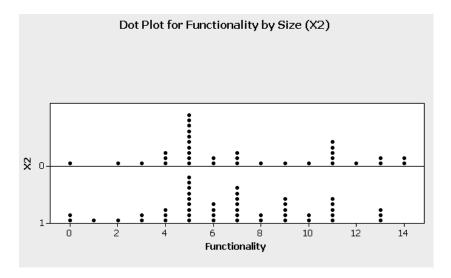


FIGURE 16.17 Minitab Dot Plot for Functionality by X_2 (i.e., Size)

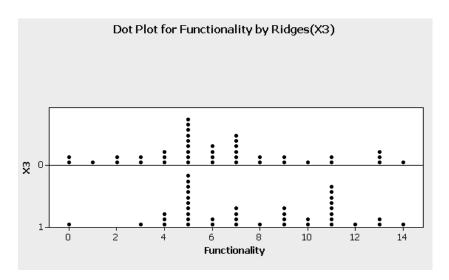


FIGURE 16.18 Minitab Dot Plot for Functionality by X_3 (i.e., Ridges)

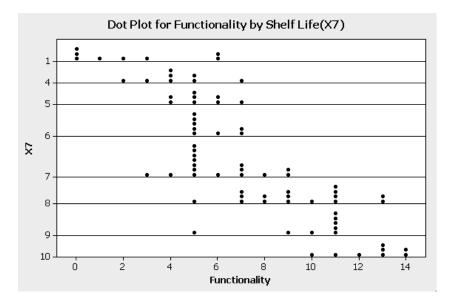


FIGURE 16.19 Minitab Dot Plot for Functionality by X_7 (i.e., Shelf-life)

The dot plots for durability (Y_1) indicate: (1) the values of durability tend to be low or high, with a significant gap between 4 and 6 for X_1 , X_2 , X_3 , and X_7 , and (2) the variation in durability is about the same for all levels of X_1 , X_2 , X_3 , and X_7 . The dot plots for functionality (Y_2) indicate: (1) the values of functionality tend to be lower when $X_1 = 0$ than when $X_1 = 1$, (2) the variation in functionality is about the same for all levels of X_2 and X_3 , and (3) the values of functionality tend to be lower for low values of X_7 .

Discussion of the Analysis of Durability. Because there are no clear differences in variation (i.e., spread) of durability for each of the levels of X_1 , X_2 , X_3 , and X_7 , the team wondered whether there might be differences in the average (i.e., center) for each level of the individual X_3 . Team members constructed a main effects plot for durability to study differences in averages (see Figure 16.20).

Figure 16.20 indicates that for the ranges of shelf-life observed, there is no clear pattern for the relationship of shelf-life (X_7) to the average durability. On the other hand, it appears that ridges (i.e., $X_3 = 1$) have a positive relationship to the average durability. At first glance, it would seem that better results for average durability are seen when the vendor Ibix is chosen using small MSDs (i.e., $X_1 = 1$ and $X_2 = 0$), whereas using large MSDs from Office Optimum (i.e., $X_1 = 0$ and $X_2 = 1$) yields worse results.

While discussing the dot plots and main effects plot, it is dangerous to make any conclusions without knowing whether 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 interaction plot for X_1 , X_2 , and X_3 . X_7 was not included in the interaction plot because the main effects plot indicated

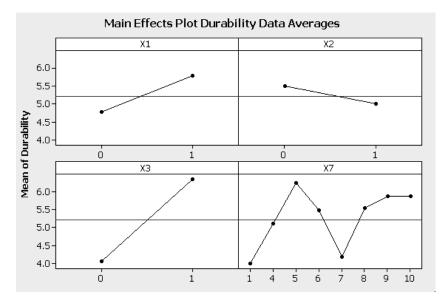


FIGURE 16.20 Minitab Main Effects Plot for Durability by X_1 , X_2 , X_3 , and X_7 .

no clear pattern or relationship with durability (Y_1) . All combinations of levels of the X variables must be present to draw an interaction 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 phase). Fortunately, although not all combinations were observed equally often, they were all present. Figure 16.21 is the interaction plot for durability.

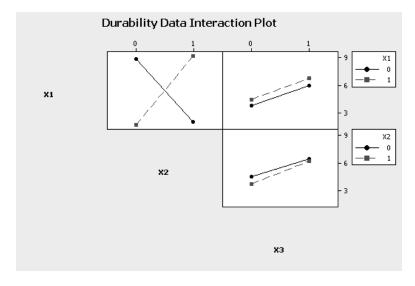


FIGURE 16.21 Minitab Interaction Effects Plot for Durability by X_1 , X_2 , and X_3

Surprise! The interaction plot indicates that there is a possible interaction between X_1 (i.e., vendor) and X_2 (i.e., size). How is this known? When there is no interaction, the lines should be parallel to each other, indicating that 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 X_1 and X_2 not only are not parallel, but they cross. The average durability is the highest when either large Ibix MSDs (i.e., $X_1 = 1$ and $X_2 = 1$) or small Office Optimum MSDs (i.e., $X_1 = 0$ and $X_2 = 0$) 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 occurs when small MSDs from Ibix are used, but the interactions plot suggests this combination yields a bad average durability. To study all of this further, the team decides that during the Improve phase, they will run a full factorial design to examine the relationship of X_1 , X_2 , and X_3 on durability (Y_1) because the main effects plot indicates potential patterns. Again, there does not appear to be a relationship between durability (Y_1) and X_2 .

Discussion of the Analysis of Functionality. Figures 16.22 and 16.23 show the main effects and interaction effects plots for functionality (Y_2) .

The main effects plot indicates that higher values of shelf-life (X_7) yield higher values for functionality (Y_2) . The team surmised that the longer a box of MSDs sets in inventory (i.e., higher

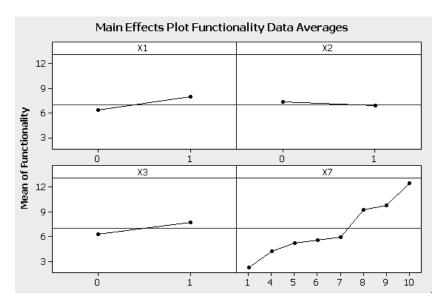


FIGURE 16.22 Minitab Main Effects Plot for Functionality by X_1 , X_2 , X_3 , and X_7 .

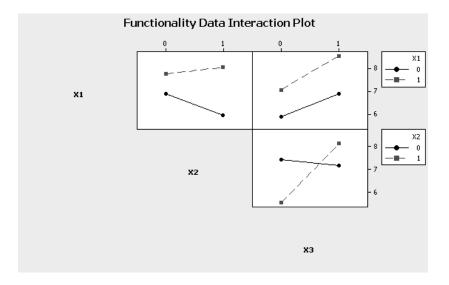


FIGURE 16.23 Minitab Interaction Effects Plot for Functionality by X_1 , X_2 , and X_3

values of shelf-life), the higher will be 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 the establishment of better inventory handling procedures will solve the problem.

The interaction effect plot indicates a potential interaction between the X_2 (i.e., size) and X_3 (i.e., ridges). Better results for functionality (i.e., low values) were observed for large MSDs without ridges (i.e., $X_2 = 1$ and $X_3 = 0$). Why this may be the case needs to be studied further. Also, there may be an interaction between X_1 (i.e., vendor) and X_2 (i.e., size), but it appears that better results are observed whenever Office Optimum is used (i.e., $X_1 = 0$). In other words, the average count of broken MSDs is lower (i.e., functionality average is lower) whenever Office Optimum is the vendor.

Analyze Phase Summary. The Analyze phase resulted in the following hypotheses:

Hypothesis 1: Durability = $f(X_1 = \text{Vendor}, X_2 = \text{Size}, X_3 = \text{Ridges})$ with a strong interaction effect between X_1 and X_2 .

Hypothesis 2: Functionality = $f(X_1 = \text{vendor}, X_2 = \text{size}, X_3 = \text{ridges}, X_7 = \text{shelf-life})$, the primary driver being X_7 with some main effect due to X_1 and an interaction effect between X_2 and X_3 .

 X_7 is the main driver of the distribution of functionality (Y_2) and is under the control of the employees of POI. Hence, team members restructured Hypothesis 2 as follows: Functionality = $f(X_1 = \text{vendor}, X_2 = \text{size}, X_3 = \text{ridges})$ for each fixed level of X_7 (shelf-life).

16.5 IMPROVE PHASE

The Improve phase involves designing experiments to understand the relationship between the Ys and the vital few Xs and major noise variables (see Chapter 13); 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 tests of the action plans.

Team members conducted an experimental design to determine the effect of X_1 (vendor), X_2 (size), and X_3 (ridges), and their interactions, on the Y_8 , with $X_7 = 0$ (no shelf-life—MSDs are tested immediately upon arrival to POI before they are placed in inventory). A 2^3 full factorial design with two replications (16 trials) was performed for durability and functionality. The factor conditions for vendor (X_1) are Office Optimum (-1) or Ibix (1); the factor conditions for size (X_2) are small (-1) or large (1), and the factors conditions for ridges (X_3) are without ridges (-1) or with ridges (1). The experiment was set up in two blocks to increase experimental reliability, with the first eight runs conducted in the morning and the second eight 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 is collected) from confusing the results. Additional information can be gathered because 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 two replications in run order, the first eight runs constituting the first replicate) is shown in Table 16.22.

TABLE 16.22 Durability and Functionality Data

Std order	Run order	Vendor	Size	Ridges	Durability	Functionality
2	1	lbix	Small	Without	1	8
4	2	lbix	Large	Without	9	9
3	3	Office Optimum	Large	Without	1	8
8	4	lbix	Large	With	11	8
5	5	Office Optimum	Small	With	10	0
6	6	lbix	Small	With	4	2
7	7	Office Optimum	Large	With	4	3
1	8	Office Optimum	Small	Without	10	2
16	9	lbix	Large	With	9	3
10	10	lbix	Small	Without	3	0
12	11	lbix	Large	Without	9	0
14	12	lbix	Small	With	3	7
13	13	Office Optimum	Small	With	9	6
11	14	Office Optimum	Large	Without	2	4
9	15	Office Optimum	Small	Without	8	1
15	16	Office Optimum	Large	With	2	4



Pareto charts showing which of the vital few Xs and the interactions between them have a statistically significant effect on durability (Y_1) and functionality (Y_2) at the 10% level of significance can be seen in Figures 6.24 and 6.25, respectively.

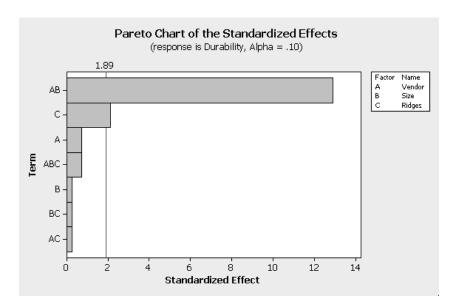


FIGURE 16.24 Minitab Pareto Chart of Effects for Durability

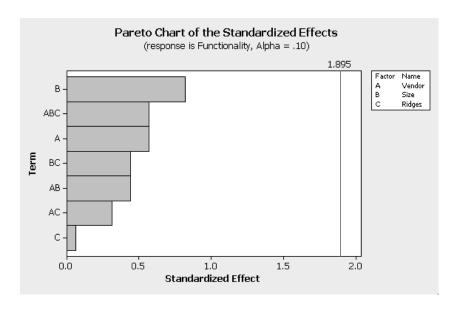


FIGURE 16.25 Minitab Pareto Chart of Effects for Functionality

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 size and the main effect due to ridges. There are no significant effects due to vendor, size, or ridges present for functionality. This indicates that because the effect of shelf-life was held constant in this designed experiment, although 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. Because 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.

Because interaction effects should be interpreted prior to studying main effects, the team decided to construct an interaction effect plot for vendor and size. Figure 16.26 is the interaction effect plot for vendor and size, relative to durability.

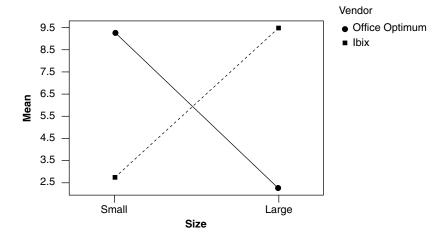


FIGURE 16.26 Minitab Interaction Effect Plot for Vendor and Size, Relative to Durability

The interaction effect plot between size and vendor shown in Figure 16.26 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 of MSD, differences in supplier processes for each size of MSD, or other supplier-dependent reasons. Team members can ask each vendor why its 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 (Y_1).

The only significant main effect not involved within a significant interaction effect is X_3 , ridges. The main effect for ridges on durability is shown in Figure 16.27.

This plot 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, because ridges is a main effect

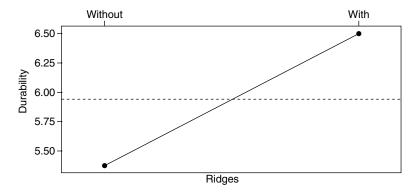


FIGURE 16.27 Minitab Main Effect Plot for Ridges, Relative to Durability

independent of any interaction effects, 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 16.22 are used, the average durability for Office Optimum's small MSDs with ridges is (10 + 9) / 2 = 9.5, and 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, 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 flow-chart for the Purchasing Department incorporating the findings of the Six Sigma project is shown in Figure 16.28.

The team members conducted a pilot test of the revised best practice (see the flowchart in Figure 16.28). Data for durability from the pilot test is shown in Table 16.23.

Table 16.23 on page 533 indicates that the rolled throughput yield (RTY) for durability is 100%. Functionality was also tested (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. This resulted in an RTY of 75%, which 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 16.29 on page 534 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 16.23 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 (Figures 16.30 on page 534 and 16.31 on page 535, respectively).

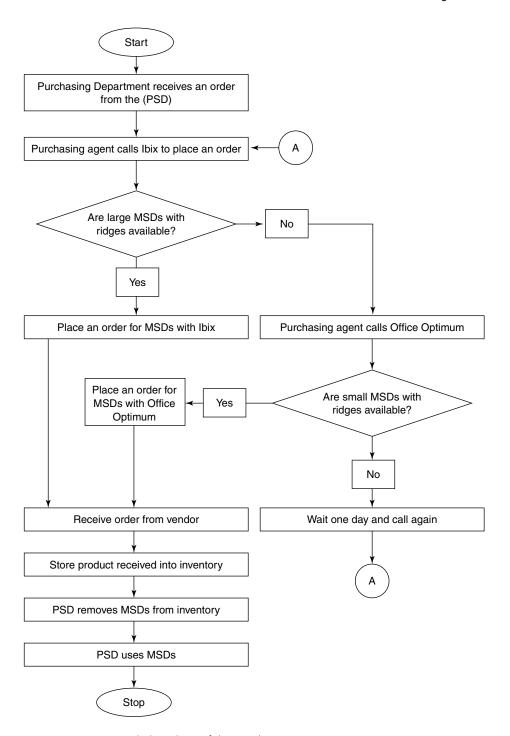


FIGURE 16.28 Revised Flowchart of the Purchasing Department

TABLE 16.23 Data from the Pilot Test

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

WEB PILOT

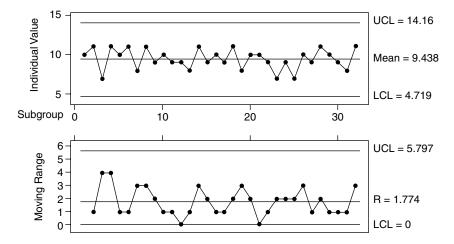


FIGURE 16.29 Minitab Individual Value and Moving Range Chart for Durability

Figures 16.29, 16.30, and 16.31 show that durability (Y_1) 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 not shown here), respectively. The mean and standard deviation for large MSDs from Ibix are 10.25 and 0.83, respectively. Because the CTQ for durability requires the number of bends to be four or more, 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, it is extremely unlikely that the MSDs will fail the CTQ for durability (Y_1) .

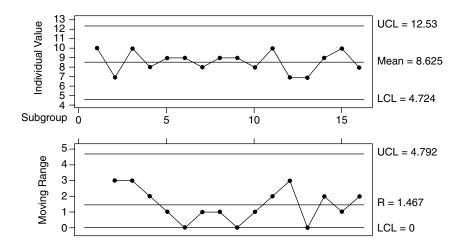


FIGURE 16.30 Minitab Individual Value and Moving Range Chart for Durability of Small MSDs from Office Optimum

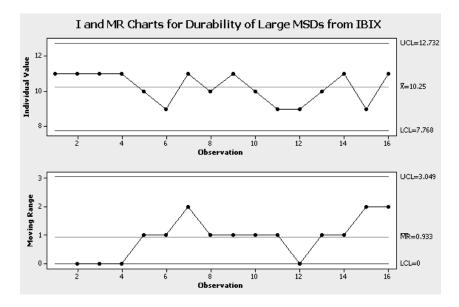


FIGURE 16.31 Minitab Individual Value and Moving Range Chart for Durability of Large MSDs from Ibix

16.6 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; turning the process over to the process owner; and disbanding the team and celebrating their success.

Team members identified and prioritized two problems while mistake proofing the process improvements discovered in the improve phase. They are: (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.

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 Figure 16.28 on page 532 and (2) Office Optimum and Ibix are out of MSDs with ridges. Team members assigned risk ratings to both risk elements, as shown in Table 16.24.

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

TABLE 16.24 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.

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 6-month trial period in which they check incoming purchase orders for requests for MSDs without ridges. If the trial period reveals no requests for MSDs without ridges, the POI Purchasing Department will revise Figure 16.28 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 for 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 decreased costs from producing only MSDs with ridges because of the lower amortized costs of having only one production line.

Team members prepare ISO 9000 documentation for the revisions to the training manual for the purchasing process from Figure 16.28.

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 whether the boxes of MSDs being purchased are either small Office Optimum MSDs with ridges or large Ibix MSDs with ridges. The percentage of 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 Figure 16.28. The *p*-chart will be the basis for continuously turning the Plan-Do-Study-Act (PDSA) cycle for the revised purchasing process.

Team members check the business indicator from the PSD and determine that production costs in the PSD decreased, probably due to the MSD Six Sigma project (see Figure 16.32). The MSD project took effect in month 73 of Figure 16.32.

Conclusion

This chapter presented a Six Sigma 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 for continuing turns of the PDSA cycle, and celebrate the project's success with team members.

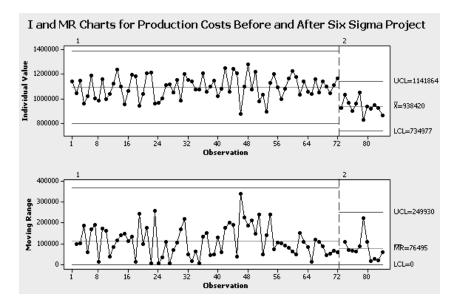


FIGURE 16.32 Individuals and Moving Range Chart Obtained from Minitab of Production Costs in the PSD Before and After the MSD Six Sigma Project

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