

Learn Six Sigma

A Lean Six Sigma Yellow Belt Training Guide

Featuring Examples Using SigmaXL v.8



Lean Sigma CorporationTM

Michael Parker

LEARN SIX SIGMA

USING SIGMAXL v.8

A LEAN SIX SIGMA YELLOW BELT TRAINING GUIDE
FEATURING EXAMPLES FROM SIGMAXL v.8

Lean Sigma Corporation

Michael Parker

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0.0 Introduction

This book has been written to explain the topics of Lean Six Sigma and provide step by step instructions on how perform key statistical analysis techniques using SigmaXL. The content of this book has been updated to include instructions using SigmaXL version 8.

This book will provide the reader with all the necessary knowledge and techniques to become an effective Lean Six Sigma practitioner. For those who have already achieved certification this book is an excellent reference manual as well as companion for all who pass on the virtues of Lean Six Sigma.



Another valuable component to this publication is the use of numerous step by step analysis instructions for the reader to learn exactly how to perform and interpret statistical analysis techniques using SigmaXL. Anywhere throughout this book where you see the image of a chart on a clipboard followed by the words “Data file:” will be a place where the reader will need the necessary data file to accurately follow the exercise. This data file can be downloaded at <https://www.leansigmacorporation.com/support-files/sample-data.xlsx>.

1.0 DEFINE PHASE

1.1 SIX SIGMA OVERVIEW

1.1.1 WHAT IS SIX SIGMA?

In statistics, *sigma* (σ) refers to standard deviation, which is a measure of variation. You will come to learn that variation is the enemy of any quality process; it makes it much more difficult to meet a customer's expectation for a product or service. We need to understand, manage, and minimize process variation.

Six Sigma is an aspiration or goal of process performance. A Six Sigma goal is for a process average to operate approximately 6σ away from the customer's high and low specification limits. A process whose average is about 6σ away from the customer's high and low specification limits has abundant room to "float" before approaching the customer's specification limits.

Most people think of Six Sigma as a disciplined, data-driven approach to eliminating defects and solving business problems. If you break down the term, Six Sigma, the two words describe a measure of quality that strives for near perfection.

A Six Sigma process only yields 3.4 defects for every 1 million opportunities! In other words, 99.9997% of the products are defect-free, but some processes require more quality and some require less.

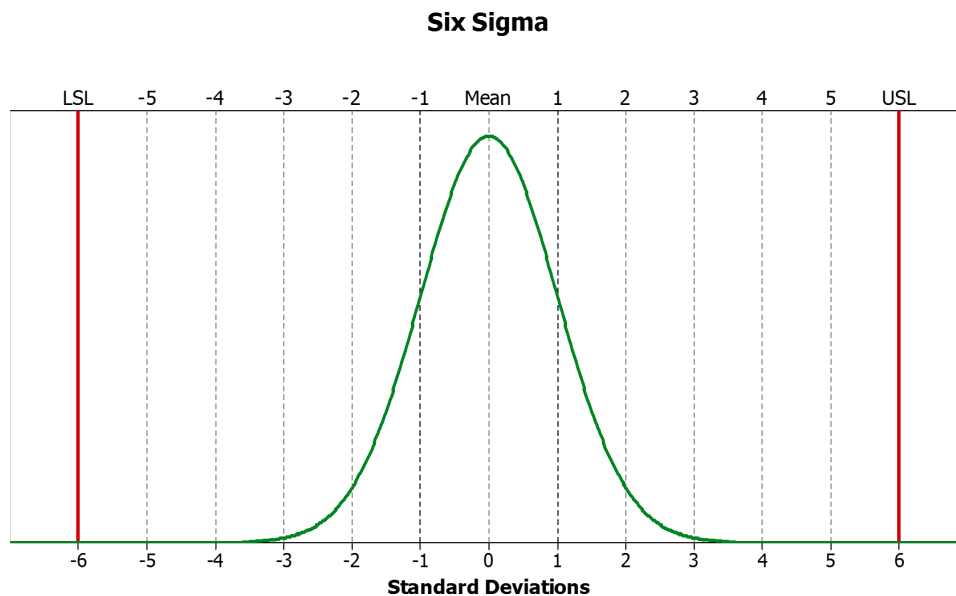


Fig. 1.1 Six Sigma Process with mean 6 standard deviations away from either specification limit.

The more variation that can be reduced in the process (by narrowing the distribution), the more easily the customer's expectations can be met.

It is important to note that a Six Sigma level of quality does not come without cost, so one must consider what level of quality is needed or acceptable and how much can be spent on resources to remove the variation.

What is Six Sigma: Sigma Level

Sigma level measures how many sigma there are between your process average and the nearest customer specification. Let us assume that your customer's upper and lower specifications limits (USL and LSL) were narrower than the width of your process spread. The USL and LSL below stay about one standard deviation away from the process average. Therefore, this process operates at *one sigma*.

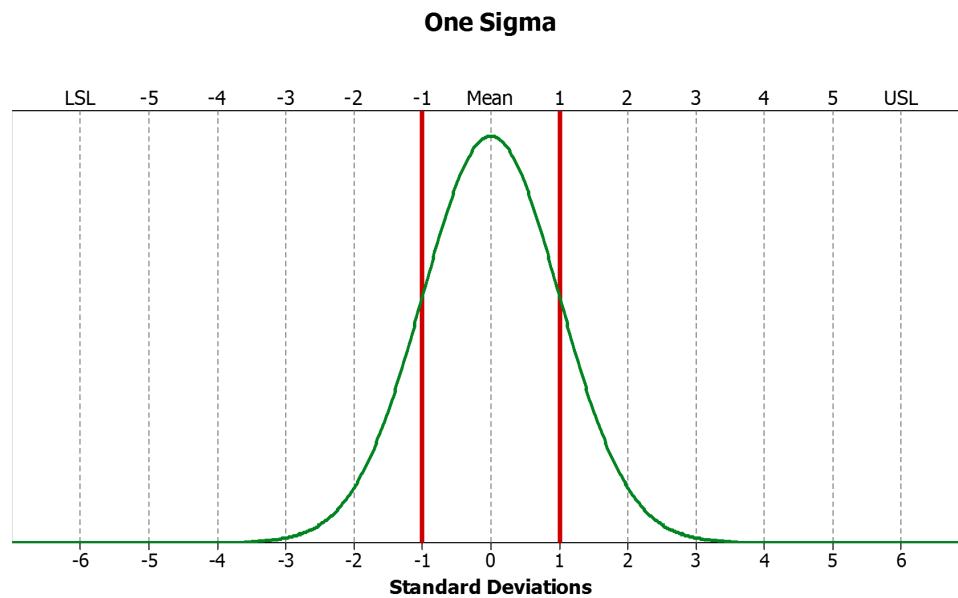


Fig. 1.2 Process operating at 1 sigma with mean one standard deviation away from closest spec limit.

In Fig. 1.1, the LSL and USL were at six standard deviations from the mean. Would that process be more or less forgiving than the one shown in Fig. 1.2?

Answer: *This process is much less forgiving. It is a one sigma process because the USL and LSL are only one standard deviation from the mean. The area under the blue curve to the left of the LSL and to the right of the USL represents process defects.*

A process operating at one sigma has a defect rate of approximately 70%. This means that the process will generate defect-free products only 30% of the time, so for every three units that are good, seven are defective. Obviously, a one sigma process is not desirable anywhere because its implications are high customer claims, high process waste, lost reputation, and many others.

What about processes with more than one sigma level? A higher sigma level means a lower defect rate. Let us look at the defect rates of processes at different sigma levels.

Table 1.1 shows each sigma level's corresponding defect rate and DPMO (defects per million opportunities). The higher the sigma level, the lower the defective rate and DPMO. The table shows how dramatically the quality can improve when moving from a one sigma process, to two-sigma, to three, and so on. Next, we will look at how this concept applies to some everyday processes.

Sigma Level	Defect Rate	DPMO
1	69.76%	697612
2	30.87%	308770
3	6.68%	66810
4	0.62%	6209
5	0.023%	232
6	0.00034%	3.4

Table 1.1 Sigma level, Defect Rate and DPMO

Let us look at processes operating at three-sigma, which has a defect rate of approximately 7%. What would happen if processes operated at three-sigma? According to <http://www.qualityamerica.com>:

- Virtually no modern computer would function.
- 10,800,000 health care claims would be mishandled each year.
- 18,900 US savings bonds would be lost every month.
- 54,000 checks would be lost each night by a single large bank.
- 4,050 invoices would be sent out incorrectly each month by a modest-sized telecommunications company.
- 540,000 erroneous call details would be recorded each day from a regional telecommunications company.
- 270 million erroneous credit card transactions would be recorded each year in the United States.

Just imagine what a three-sigma process would look like in the tech industry, in health care, in banking. Can you apply this concept to a process that you relate to? What if processes operated with 1% defect rate? There would be:

- 20,000 lost articles of mail per hr. (Implementing Six Sigma – Forest W. Breyfogle III).
- Unsafe drinking water almost 15 minutes per day.
- 5,000 incorrect surgical operations per week.
- Short or long landings at most major airports each day.
- 200,000 wrong drug prescriptions each year.
- No electricity for almost seven hours per month.

Even at a 1% defect rate, some processes would be unacceptable to you and many others. Would you drink the water in a community where the local water treatment facility operates at a 1% defect rate? Would you go to a surgeon with a 1% defect rate?

So, what is Six Sigma? Sigma is the measure of quality, and Six is the *goal*.

What is Six Sigma: The Methodology

Six Sigma itself is the *goal*, not the method. To achieve Six Sigma, you need to improve your process performance by:

- Minimizing the process variation so that your process has enough room to fluctuate within customer's spec limits.
- Shifting your process average so that it is centered between your customer's spec limits.

Accomplishing these two process improvements, along with stabilization and control (the ability to maintain the process improvements or level of quality over time), you can achieve Six Sigma. This way, the process becomes more capable of meeting the specification limits that are set by the customer.

The methodology prescribed to achieve Six Sigma is called DMAIC. DMAIC is a systematic and rigorous methodology that can be applied to *any* process in order to achieve Six Sigma. It consists of five phases of a project:

1. **Define**
2. **Measure**
3. **Analyze**
4. **Improve**
5. **Control**

You will be heavily exposed to many concepts, tools, and examples of the DMAIC methodology through this training. The goal of this training is to teach you how to apply DMAIC and leverage the many concepts and tools within it. At the completion of the curriculum, you will become capable of applying the DMAIC methodology to improve the performance of *any* process.

1.1.2 SIX SIGMA HISTORY

The Six Sigma terminology was originally adopted by Bill Smith at Motorola in the late 1980s as a quality management methodology. As the "Father of Six Sigma," Bill forged the path for Six Sigma through Motorola's CEO Bob Galvin who strongly supported Bill's passion and efforts.

Bill Smith originally approached Bob Galvin with what he referred to as the "theory of latent defect." The core principle of the theory is that *variation* in manufacturing processes is the main driver for *defects*, and eliminating variation will help eliminate defects. In turn, it will eliminate the wastes associated with defects, saving money and increasing customer satisfaction. The threshold agreed to by Motorola was 3.4 defects per million opportunities. Does it sound familiar?

Starting from the late 1980s, Motorola extensively applied Six Sigma as a process management discipline throughout the company, leveraging Motorola University. In 1988, Motorola was

recognized with the prestigious Malcolm Baldrige National Quality Award for its achievements in quality improvement.

Six Sigma has been widely adopted by companies as an efficient way of improving the business performance since General Electric implemented the methodology under the leadership of Jack Welch in the 1990s. As GE connected Six Sigma results to its executive compensation and published the financial benefits of Six Sigma implementation in their annual report, Six Sigma became a highly sought-after discipline of quality. Companies across many industries followed suit. In some cases GE taught companies how to deploy the methodology, and in many cases experts from GE and other pioneer companies were heavily recruited to companies that were new to methodology.

Most Six Sigma programs cover the aspects, tools, and topics of Lean or Lean Manufacturing. The two, work hand in hand, benefitting each other. Six Sigma focuses on minimizing process variability, shifting the process average, and delivering within customer's specification limits. Lean focuses on eliminating waste and increasing efficiency.

While the term Lean was coined in the 1990s, the methodology is mainly based on the concepts of the Toyota Production System, which was developed by Taiichi Ohno, Shigeo Shingo, and Eiji Toyoda at Toyota between 1948 and 1975.

Lean and its popularity began to form and gain significant traction in the mid-1960s with the Toyota initiative TPS or Toyota Production System, originally known as the "just-in-time production system." The concepts and methodology of Lean, however, were fundamentally applied much earlier by both Ford and Boeing in the early 1900s.

The DMAIC methodology is essentially an ordered collection of concepts and tools that were not unique to Six Sigma. The concepts and tools are leveraged in a way that leads down a problem-solving path.

Despite the criticism and immaturity of Six Sigma in many aspects, its history continues to be written with every company and organization striving to improve its business performance. The track record for many of these companies after implementing Six Sigma, speaks for itself.

1.1.3 SIX SIGMA APPROACH

Six Sigma Approach: $Y = f(x)$

The Six Sigma approach to problem solving uses a transfer function. A *transfer function* is a mathematical expression of the relationship between the inputs and outputs of a system. The relational transfer function that is used by all Six Sigma practitioners is:

$$Y = f(x)$$

The symbol Y refers to the measure or output of a process. Y is usually your primary metric, the measure of process performance that you are trying to improve. The expression $f(x)$ means

function of x , where x 's are factors or inputs that affect the Y . Combined, the $Y = f(x)$ statement reads "Y is a function of x ," in simple terms, "My process performance is dependent on certain x 's."

The objective in a Six Sigma project is to identify the critical x 's that have the most influence on the output (Y) and adjust them so that the Y improves. It is important to keep in mind this concept throughout the DMAIC process. The system (or process) outputs (Y 's) are a function of the inputs (x).

Example

Let us look at a simple example of a pizza delivery company that desires to meet customer expectations of on-time delivery.

Measure = on-time pizza deliveries

Y = percent of on-time deliveries

$f(x)$ would be the x 's or factors that heavily influence timely deliveries

x_1 : might be traffic

x_2 : might be the number of deliveries per driver dispatch

x_3 : might be the accuracy of directions provided to the driver

x_4 : might be the reliability of the delivery vehicle

The statement $Y = f(x)$ in this example will refer to the proven x 's determined through the steps of a Six Sigma project. Most would agree that an important requirement of pizza delivery is to be fast or on-time. In this example, let us consider factors that might cause variation in Y (percent of on-time deliveries). In the DMAIC process, the goal is to determine which inputs (x 's) are the main drivers for the variation in Y .

With this approach, all potential x 's are evaluated throughout the DMAIC methodology. The x 's should be narrowed down until the vital few x 's that significantly influence on-time pizza deliveries are identified.

This approach to problem solving will take you through the process of determining all potential x 's that *might* influence on-time deliveries and then determining through measurements and analysis which x 's *do* influence on-time deliveries. Those significant x 's become the ones used in the $Y = f(x)$ equation.

The $Y = f(x)$ equation is a very powerful concept and requires the ability to measure your output and quantify your inputs. Measuring process inputs and outputs is crucial to effectively determining the significant influences to any process.

1.1.4 SIX SIGMA METHODOLOGY

Six Sigma is a data-driven methodology for solving problems, improving, and optimizing business problems. Six Sigma follows a methodology that is conceptually rooted in the

principles of a five-phase project. Each phase has a specific purpose and specific tools and techniques that aid in achieving the phase objectives.

The five phases of DMAIC are:

1. **Define**
2. **Measure**
3. **Analyze**
4. **Improve**
5. **Control**

The goals of the five phases are:

1. **DEFINE**—To define what the project is setting out to do and scope the effort
2. **MEASURE**—To establish a baseline for the process, ensure the measurement system is reliable, and identify all possible root causes for a problem
3. **ANALYZE**—To narrow down all possible root causes to the critical few that are the primary drivers of the problem
4. **IMPROVE**—To develop the improvements for the process
5. **CONTROL**—To implement the fix and a control plan to ensure the improvements are sustained over time

In terms of the transfer function, the five phases mean:

1. **DEFINE**—Understand the project Y's and how to measure them
2. **MEASURE**—Prioritize potential x's and measure x's and Y's
3. **ANALYZE** —Test x-Y relationships and verify/quantify important x's
4. **IMPROVE**—Implement solutions to improve Y's and address important x's
5. **CONTROL**—Monitor important x's and the Y's over time

Six Sigma Methodology: Define Phase

The goal of the *Define* phase is to establish a solid foundation and business case for a Six Sigma project. Define is arguably the most important aspect of any Six Sigma project. It sets the foundation for the project and, if it is not done well and properly thought, it is very easy for a project to go off-track.

All successful projects start with a current state challenge or problem that can be articulated in a quantifiable manner—without a baseline and a goal, it is very difficult to keep boundaries around the project. But it is not enough to just know the problem, you must quantify it and also determine the goal. Without knowing how much improvement is needed or desired, it can be very difficult to control the scope of the project.

Once problems and goals are identified and quantified, the rest of the Define phase will be about valuation, team, scope, project planning, timeline, stakeholders, Voice of the Customer, and Voice of the Business.

Define Phase Tools and Deliverables

1. *Project charter*, which establishes the:

- Business Case
- Problem Statement
- Project Objective
- Project Scope
- Project Timeline
- Project Team

The project charter is essentially a contract formed between a project team, the champion, and the stakeholders. It defines what the project is going to do, why they are going to do it, when it will be done, and by whom. It includes the business case, problem statement, project objective, scope, timeline, and team.

2. *Stakeholder Assessment*

Stakeholder assessment involves the following:

- High-Level Pareto Chart Analysis
- High-Level Process Map
- Voice of the Customer/ Voice of the Business and Critical to Quality Requirements Identified and Defined
- Financial Assessment

A stakeholder assessment is done to understand where there are gaps in stakeholder support and develop strategies to overcome them. High-level Pareto chart and process maps, along with Voice of the Customer, Voice of the Business, and Critical to Quality Requirements also help to develop the scope and put some guardrails around the process.

Six Sigma Methodology: Measure Phase

The goal of the *Measure* phase is to gather baseline information about the process (process performance, inputs, measurements, customer expectations etc.). This phase is necessary to determine if the measurement systems are reliable, if the process is stable, and how capable the process is of meeting the customer's specifications.

Throughout the Measure phase you will seek to achieve a few important objectives:

- Gather All Possible x's
- Assess Measurement System and Data Collection Requirements
- Validate Assumptions
- Validate Improvement Goals
- Determine Cost of Poor Quality
- Refine Process Understanding

- Determine Process Stability
- Determine Process Capability

Measure Phase Tools and Deliverables

The tools and deliverables for this phase are:

- Process Maps, SIPOC, Value Stream Maps—To visualize a process
- Failure Modes and Effects Analysis—To identify possible process failure modes and prioritize them
- Cause-and-Effect Diagram—To brainstorm possible root causes for defects
- XY Matrix—To prioritize possible root causes for defects
- Six Sigma Statistics
- Basic Statistics and Descriptive Statistics—To understand more about your process data
- Measurement Systems Analysis—To establish repeatability, reproducibility, linearity, accuracy, and stability
- Variable and/or Attribute Gage R&R
- Gage Linearity and Accuracy or Stability
- Basic Control Charts—To assess process stability
- Process Capability and Sigma Levels—To assess and quantify a process' ability to meet customer specification limits
- Data Collection Plan—To ensure that when data is collected, it is done properly

Six Sigma Methodology: Analyze Phase

The *Analyze* phase is all about establishing verified drivers. In the DMAIC methodology, the Analyze phase uses statistics and higher-order analytics to discover relationships between process performance and process inputs. In other words, this phase is where the potential root causes are narrowed down to the *critical* root causes.

Statistical tools are used to determine whether there are relationships between process performance and the potential root causes. Where the strong relationships are discovered, these become the foundation for the solution to improve the process.

Ultimately, the Analyze phase establishes a reliable hypothesis for improvement solutions. During the Analyze phase, one needs to:

- Establish the Transfer Function $Y = f(x)$
- Validate the List of Critical x's and Impacts
- Create a Beta Improvement Plan (e.g., pilot plan)

Analyze Phase Tools and Deliverables

The Analyze phase is about proving and validating critical x's using the appropriate and necessary analysis techniques. The tools that help to formulate a hypothesis about how much improvement can be expected in the Y, given a change in the x include:

- Hypothesis Testing (e.g., t-tests, Chi-Square)
- Parametric and Non-Parametric
- Regression (Simple Linear Regression, Multiple Linear Regression)—To establish quantitative and predictive relationships between the x's and Y's

The Analyze phase is also about establishing a set of solution hypotheses to be tested and further validated in the Improve phase.

Six Sigma Methodology: Improve Phase

The goal of the *Improve* phase is make the improvement. Improve is about designing, testing, and implementing your solution. To this point, you have defined the problem and objective of the project, brainstormed possible x's, analyzed and verified critical x's. Now it's time to make it real! During the Improve phase, the following are necessary:

- Statistically Proven Results from Active Study/Pilot
- Improvement/Implementation Plan
- Updated Stakeholder Assessment
- Revised Business Case with Return on Investment
- Risk Assessment/Updated Failure Modes and Effects Analysis
- New Process Capability and Sigma

Methodologies for the Improve phase include:

- Experiments and planned studies
- Pilots or tests designed to validate relationships and determine how much change in an input is needed to induce the desired result in the output
- Implementation plan to stimulate thoughts and planning for any necessary communications, training, and preparations to implement the process improvement

Improve Phase Tools and Deliverables

The tools and deliverables of this phase are:

- Any appropriate tool from previous phases
 - An updated stakeholder assessment to ensure the right support exists to make the process change
 - An updated business case to justify the change
 - An updated Failure Modes and Effects Analysis to ensure the solution is robust and proper control points are identified
 - A revisited process capability and sigma level to quantify how well the improved process will perform against customer specifications
- Design of Experiment: Full Factorial and Fractional Factorial
- Pilot or Planned Study using Hypothesis Testing and Valid Measurement Systems
- Implementation Plan

Six Sigma Methodology: Control Phase

The last of the five core phases of the DMAIC methodology is the *Control* phase. The purpose of this phase is to establish the mechanisms to ensure the process sustains improved performance and, if it does not, to establish a reaction/mitigation plan to activate by a process owner. The Control phase is a common failure point for projects. Improvements are made, but gains will only be temporary if the proper controls are not in place.

Control Phase Tools and Deliverables

The tools and deliverables of this phase are:

- Statistical Process Control (SPC/Control Charts): IMR, Xbar-S, Xbar-R, P, NP, U, C etc.—For monitoring process inputs and outputs for stability and quickly identifying when the process goes “out of control”
 - Control Plan Documents
 - Control Plan—To ensure control points are identified and accountability for monitoring them is taken
 - Training Plan—To ensure employees are properly trained to perform process changes
 - Communication Plan—To alert any stakeholders of a change
 - Audit Checklist
- Lean Control Methods—To mistake-proof a process
 - Poka-Yoke
 - 5-S—To organize the workplace and make it more visual
 - Kanban

1.1.5 ROLES AND RESPONSIBILITIES

The various roles in a Six Sigma program are commonly referred to as “Belts.” In addition to Belts, there are also other key roles with specific responsibilities.

It is important to know the many roles in Six Sigma to understand where responsibilities lie to execute a project. Let us explore the different roles and their corresponding responsibilities in a Six Sigma program. Each of the four Six Sigma belts represents a different level of expertise in the field of Six Sigma:

- Six Sigma Master Black Belt
- Six Sigma Black Belt
- Six Sigma Green Belt
- Six Sigma Yellow Belt

Different Belt levels are associated with differing levels of expertise in Six Sigma, with Master Black Belt being the most highly trained expert, to Yellow Belt having very basic knowledge. In addition to Belts, there are other critical and complementary roles, very important to the success of Six Sigma initiatives:

- Champions
- Sponsors
- Stakeholders
- Subject Matter Experts

Roles and Responsibilities: Master Black Belt

The *Master Black Belt* (MBB) is the most experienced, educated, and capable Six Sigma expert, often thought of as a trusted advisor to high-level leaders.

A typical MBB has managed dozens of Black Belt level projects. An MBB can simultaneously lead multiple Six Sigma Belt projects, ensuring the proper and consistent application of Six Sigma across departments, while mentoring and certifying Black Belt and Green Belt candidates.

An MBB typically works with high-level operations directors, senior executives, and business managers to help with assessing and planning business strategies and tactics. This is why the MBB needs to have a strong ability to communicate with and influence leaders at all levels of an organization.

An MBB commonly advises management team on the cost of poor quality of an operation and consults on methods to improve business performance.

While an MBB is typically technically savvy with all of the concepts and tools, it is critical that he or she have the skills to communicate in a practical manner with those that are not well-versed in Six Sigma.

Typical Responsibilities of an MBB

An MBB:

- Identifies and defines the portfolio of projects required to support a business strategy
- Establishes scope, goals, timelines, and milestones
- Assigns and marshals resources
- Trains and mentors Green Belts and Black Belts
- Facilitates tollgates or checkpoints for Belt candidates
- Reports-out/updates stakeholders and executives
- Establishes organization's Six Sigma strategy/roadmap
- Leads the implementation of Six Sigma

Roles and Responsibilities: Black Belt

The *Black Belt* (BB) is the most active and valuable experienced Six Sigma professional among all Six Sigma Belts. The Black Belt is the key to success among all the other Belts.

A typical BB has:

- Led multiple projects
- Trained and mentored various Green Belts candidates
- Understood how to define a problem and drive effective solution

The BB incorporates many skills that are critical to successfully and quickly implementing a process improvement initiative through the DMAIC methodology. The BB is well rounded in terms of project management, statistical analysis, financial analysis, meeting facilitation, prioritization, and a range of other value-added capabilities, which makes a BB highly valuable asset in the business world.

BBs commonly serve as the dedicated resource continuing their line management role while simultaneously achieving a BB certification.

Typical Responsibilities of a BB

A BB has the following responsibilities:

- Project Management
 - Defines projects, scope, teams etc.
 - Marshals resources
 - Establishes goals, timelines, and milestones
 - Provides reports and/or updates to stakeholders and executives
- Task Management
 - Establishes the team's Lean Sigma roadmap
 - Plans and implements the use of Lean Sigma tools
 - Facilitates project meetings
 - Does project management of the team's work
 - Manages progress toward objectives
- Team Management
 - Chooses or recommend team members
 - Defines ground rules for the project team
 - Coaches, mentors, and directs project team
 - Coaches other Six Sigma Belts
 - Manages the team's organizational interfaces

Roles and Responsibilities: Green Belt

The *Green Belt* (GB) is considered as a less intense version of Six Sigma professional compared to the Black Belt (BB). A GB is exposed to all the comprehensive aspects of Six Sigma with less focus on the statistical theories and some other advanced analytical methodologies such as Design of Experiment. When it comes to project management, a GB has almost the same responsibilities as a BB. In general, the GB works on less complicated and challenging business problems than a BB.

While a Black Belt's sole business responsibility could be the implementation of projects, Green Belts often implement projects in addition to other job responsibilities. Therefore, the

Green Belt typically works on less complicated business problems. A Green Belt takes direction and coaching from the Black Belt.

Typical Responsibilities of a Green Belt

A GB has the following responsibilities:

- Project Management
 - Defines the project, scope, team etc.
 - Marshals resources
 - Sets goals, timelines, and milestones
 - Reports-out/updates stakeholders and executives
- Task Management
 - Establishes the team's Lean Sigma Roadmap
 - Plans and implements the use of Lean Sigma tools
 - Facilitates project meetings
 - Does Project Management of the team's work
 - Manages progress toward objectives
- Team Management
 - Chooses or recommends team members
 - Defines ground rules for the project team
 - Coaches, mentors, and directs project team
 - Coaches other Six Sigma Belts
 - Manages the team's organizational interfaces

As you can see, the roles and responsibilities are identical to those of a Black Belt. The key differences are the level of complexity and the dedication that a Black Belt has toward Six Sigma projects. Again, a Green Belt typically does projects in addition to his or her normal line job responsibilities.

Roles and Responsibilities: Yellow Belt

The *Yellow Belt* (YB) understands the basic objectives and methods of a Six Sigma project. YB has an elementary understanding about what other Six Sigma Belts (GB, BB, and MBB) are doing to help them succeed.

In a Six Sigma project, YB usually serves as a subject matter expert regarding some aspects of the process or project. Supervisors, managers, directors, and sometimes executives are usually trained at the YB level. This level of training is important to have in an environment where Six Sigma projects are prevalent, such as when managing Belts.

Typical Responsibilities of a Yellow Belt

A Yellow Belt:

- Helps define process scope and parameters
- Contributes to team selection process

- Assists in information and data collection
- Participates in experiential analysis sessions (Failure Modes and Effects Analysis, Process Mapping, Cause and Effect etc.)
- Assists in assessing and developing solutions
- Delivers solution implementations

Roles and Responsibilities: Champions and Sponsors

Champions and sponsors are those individuals (directors, executives, managers etc.) chartering, funding, or driving the Six Sigma projects that BBs and GBs are conducting. Champions and Sponsors' roles are to set direction for projects and ensure that the path is clear for the Belts to succeed: obtain resources and funding, overcome stakeholder issues, and knock down other barriers to progress.

Champions and sponsors need to have a basic understanding of the concepts, tools, and techniques involved in the DMAIC methodology so that they can provide proper support and direction. Champions and sponsors play critical roles in the successful deployment of Six Sigma. Strong endorsement of Six Sigma from the leadership team is critical for success.

Typical Responsibilities of a Champion or Sponsor

A Champion or Sponsor typically:

- Maintains a strategic oversight
- Establishes strategy and direction for a portfolio of projects
- Clearly defines success
- Provides resolution for issues such as resources or politics
- Establishes routine tollgates or project reviews
- Clears the path for solution implementation
- Assists in project team formation

From a project standpoint, it is important for the Champions and Sponsors to be highly engaged in the work. It is their role to provide oversight and guidance to define success for the project or projects. They resolve issues when necessary, such as resource needs, stakeholder conflicts, or political issues. They create the routines for tollgate reviews to ensure there are regular checkpoints with the project team.

Roles and Responsibilities: Stakeholders

Stakeholders are usually the recipients or beneficiaries of the success of a Six Sigma project. Generally speaking, a stakeholder is anyone who has interest in a project; stakeholders are usually the beneficiaries of the process improvement. A stakeholder can be a person, a group, or an organization that is affected by the project.

Stakeholders are individuals owning the process, function, or production/service line that a Six Sigma Belt focuses on improving the performance of.

BBs and GBs need to keep strong working relationships with stakeholders because without their support, it would be extremely difficult to make the Six Sigma project a success. A lack of stakeholder support can cause a project to fail, either through active or passive resistance, so it is very important to be aware of how stakeholders feel about the work being done so the team can proactively manage their perceptions and level of support.

Roles and Responsibilities: Subject Matter Experts

Subject Matter Experts (SMEs) are commonly known as the experts of the process or subject matter. They play critical roles to the success of a project. Six Sigma Belts should proactively look to key SMEs to round out their working project team. Based on SMEs' extensive knowledge about the process, they have the experience to identify which solutions can work and which cannot work.

SMEs who simply do not speak up can hurt the chances of the process' success. SMEs' input is critical to ensure the team is leveraging accurate information when it comes to the process or evaluating data and information.

SMEs are also the same people who prefer to keep the status quo. Six Sigma Belts may find many of them unwilling to help implement the changes. When selecting SMEs, it is important to choose people who are vocal, but who also bring ideas. SMEs that are closed-minded to change may be vocal, but can be a barrier to making the necessary improvements.

SUMMARY

Throughout this module, we have reviewed the various common roles and corresponding responsibilities in any Six Sigma program:

- Six Sigma Master Black Belt
- Six Sigma Black Belt
- Six Sigma Green Belt
- Six Sigma Yellow Belt
- Champion and Sponsors
- Stakeholders
- Subject Matter Experts

These Six Sigma belts and other roles are designed to deliver value to the business effectively and successfully. For a Six Sigma program to be effective, it is important to assign these roles to individuals who are well equipped to carry out the responsibilities.

1.2 SIX SIGMA FUNDAMENTALS

1.2.1 DEFINING A PROCESS

What is a Process Map?

A *process map* is a graphical representation of a process flow. It is necessary to document a process because process maps:

- Visually show how the business process is accomplished in a step by step manner.
- Describe how information or materials sequentially flow from one entity to the next.
- Illustrate who is responsible for steps and actions.
- Depict the input and output of each individual process step.

In the Measure phase, the project team should map the current state of the process. Teams should be sure not to fall into the trap of mapping an ideal state or what they think the process should look like.

Process Map Basic Symbols

Figure 1.3 below depicts a basic process map that was created with the four most commonly used process mapping symbols. The four symbols are:

- Oval – Used for start and end points
- Square or Rectangle – Used for process steps
- Diamond – Used for decision points
- Arrow – Used to represent flow direction

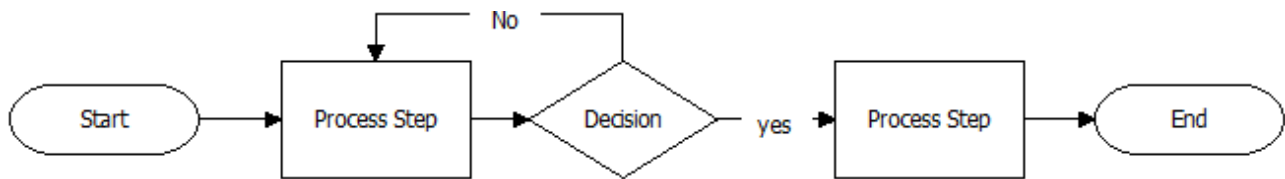


Fig. 1.3 Basic Process Mapping Symbols

Additional Process Mapping Symbols

Below are additional process mapping symbols that may be used to provide further information and detail when developing a process map. Although these symbols are not as common as those shown in figure 1.3, they are universally understood to represent process information as described:



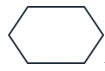
Alternative Process Step: Meaning “there is a different way of performing the step”



Predefined Process: Used to hold the place of a pre-existing process



Manual Process Step: As opposed to an “automated” step



Preparation: Indicates a preparation operation



Delay: Indicates a waiting period



Data (I/O): Shows the inputs and outputs of a process



Document: Indicates a process step that results in a document



Multi-Document: Indicates a process step that results in multiple documents



Stored Data: Indicates a process step that stores data



Magnetic Disk: Indicates a database



Off Page Connector: Indicates the process flow continues on another page



Merge: Indicates where multiple processes merge into one



Extract: Indicates a process splitting into multiple parallel processes

How to Plot a Process Map

Process Mapping Step 1: Define boundaries of the process you want to map.

- A process map can depict the flow of an entire process or a segment of it.
- You need to identify and define the beginning and ending points of the process before starting to plot.
- Use operational definitions.

The first step in plotting a process map is deciding where the beginning and ending points are for the process you are trying to depict. You might be trying to map a whole process that begins and ends with the customer, or you may be trying to map out a segment of it.

An *operational definition* is an exact description—in other words, it is useful in removing ambiguity and reduces the chances of getting disparate results from a process if performed by different people.

Process Mapping Step 2: Define and sort the process steps with the flow. There are a few ways to do this:

- Consult with process owners and subject matter experts or observe the process in action to understand how the process is performed.
- Record the process steps and sort them according to the order of their occurrence.

Usually, it is a good idea to do both; sometimes hearing what is supposed to happen might be different than what you observe, this often indicating a problem.

Process Mapping Step 3: Fill the step information into the appropriate process symbols and plot the diagram.

- In the team meeting of process mapping, place the sticky notes with different colors on a white board to flexibly adjust the under-construction process map.
- The flow lines are plotted directly on the white board. For the decision step, rotate the sticky note by 45°.
- When the map is completed on the white board, record the map using Excel, PowerPoint, or Visio.

Mapping out the process with sticky notes on a white board is a good practice to do as a team because the map is easy to adjust until finished. Use a dry-erase marker to draw the flow lines between the sticky notes.

Process Mapping Step 4: Identify and record the inputs/outputs and their corresponding specifications for each process step.

- The process map helps in understanding and documenting $Y=f(x)$ of a process where Y represents the outputs and x represents the inputs.
- The inputs of each process step can be controllable or non-controllable, standardized operational procedure, or noise. They are the source of variation in the process and

need to be analyzed qualitatively and quantitatively in order to identify the vital few inputs that have significant effect on the outcome of the process.

- The outputs of each process step can be products, information, services, etc. They are the little Y's within the process.

Ideally, the specifications should be recorded for each step so it is understood what the inputs and outputs should look like to ensure process efficiency and quality.

Process Mapping Step 5: Evaluate the process map and adjust it if needed.

- If the process is too complicated to be covered in one single process map, you may create additional detailed sub-process maps for further information.
- Number the process steps in the order of their occurrence for clarity.

Functional Process Map or “Swim Lane”

To illustrate the responsibility of different organizations involved in the process, use a functional process map. This type of map is also commonly referred to as a swim lane map. The value of this type of map is that it adds the dimension of accountability.

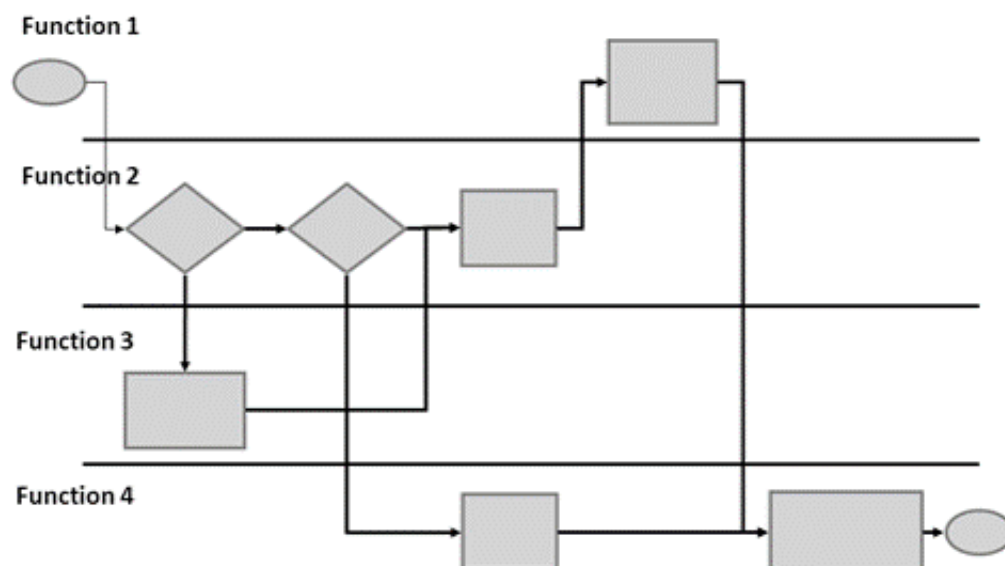


Fig. 1.4 Functional Process Map

Figure 1.4 is a functional process map or “swim lane” diagram which depicts the responsibilities for each step in the process. Swim-lane diagrams can be drawn vertically or horizontally. The swim lanes can show organizations, roles, or functions within a business.

High Level Process Map

Most high-level process maps are also referred to as *flow charts*. The key to a high-level process map is to over-simplify the process being depicted so that it can be understood in its

most generic form. As a general rule, high-level process maps should be four–six steps and no more.

Below, figure 1.5a depicts an oversimplified version of a high-level process map for cooking a 10 lb. prime rib for a dozen holiday guests. As mentioned, high level maps are basic and the challenge is summarizing a process well enough to depict it in 4 – 6 steps.

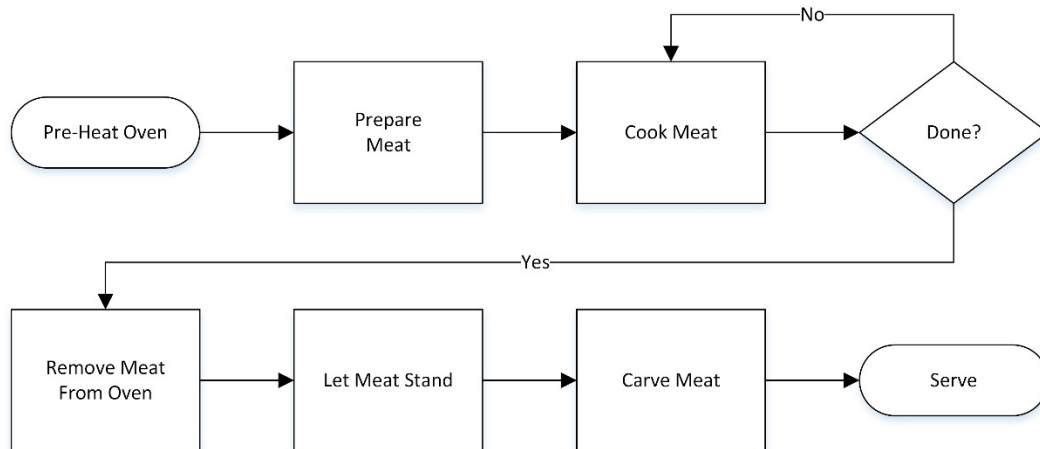


Fig. 1.5a High Level Process Map (cooking prime rib)

Detailed Process Map

Detailed process maps or multi-level maps take the high-level map much further. Detailed maps can be two, three, or more levels deeper than your high-level process map.

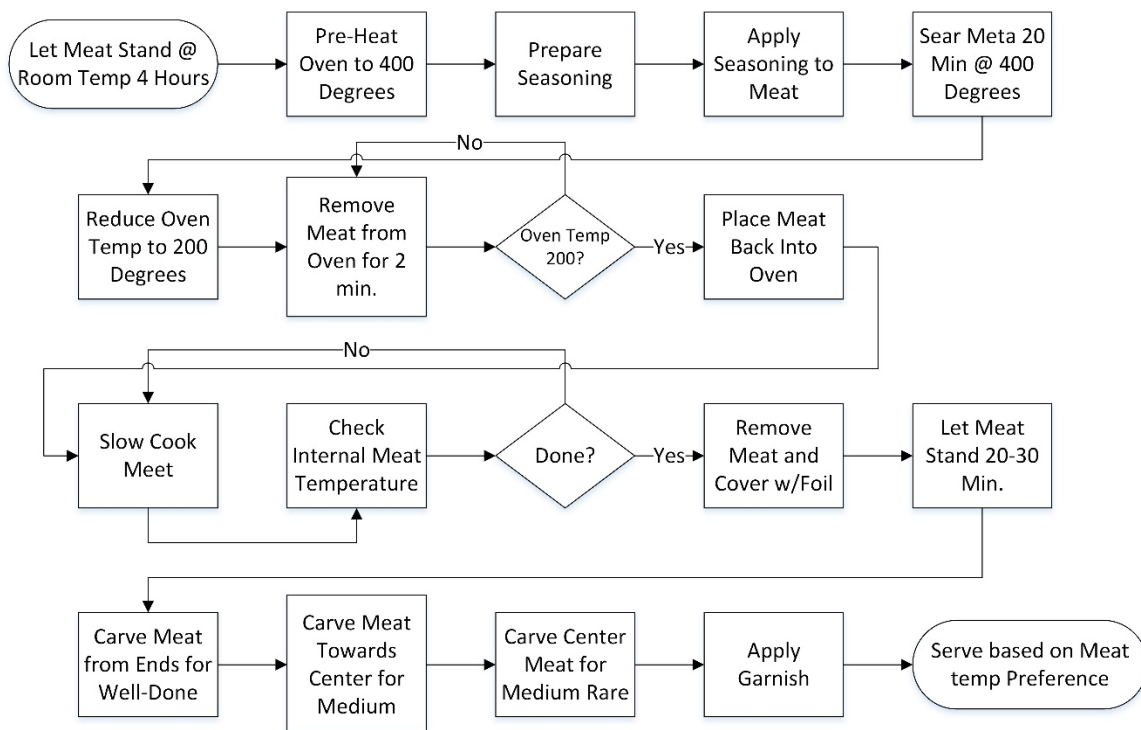


Fig. 1.5b Detailed Process Map (cooking prime rib)

Figure 1.5b is a more detailed representation of our high-level map shown in figure 1.5a. This would be considered a level 2 process map. A good guideline to use to help create the second level is that for each high-level step break it down into another two to four steps each (no more). This is usually a helpful way to index a process, so when you want to understand more about a specific part of a process later, you can find it by starting at the high level and digging down into the process steps you are interested in. Repeat this process (level 3, level 4 etc.) until reaching the desired level of detail. Some detailed maps are two or three levels deep, others can be five or six levels deep. Obviously, the deeper the levels, the more complex and the more burdensome to create and maintain. However, more detail reveals far more information.

What is SIPOC?

A SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) is a high-level visualization tool to help identify and link the different components in a process. SIPOCs summarize the inputs and outputs of a process.

SIPOCs are usually applied in the Measure phase in order to better understand the current state of the process and define the scope of the project. At the outset of a process improvement effort it is very helpful to provide an overview to people who are unfamiliar or need to become reacquainted with a process.

Key Components of a SIPOC

- **Suppliers:** The vendors who provide the raw material, services, and information. Customers can also be suppliers sometimes.
- **Input:** The raw materials, information, equipment, services, people, environment involved in the process
- **Process:** The high-level sequence of actions and decisions that results in the services or products delivered to the customers
- **Output:** The services or products delivered to the customers and any other outcomes of the process
- **Customers:** The end users or recipients of the services or products. Customers can be external or internal to an organization.

How to Plot a SIPOC Diagram

Creating a SIPOC - The first method:

1. Create a template that can contain the information of the five key components in a clear way.
2. Plot a high-level process map that covers five steps at maximum.
3. Identify the outputs of the process.

4. Identify the receipt of the process.
5. Brainstorm the inputs required to run each process step.
6. Identify the suppliers who provide the inputs.

In the first method of creating a SIPOC, begin with the process steps (five steps at most), determine the outputs, identify who the recipients of the process, then work to the left, identifying the inputs and then the suppliers for those inputs.

Creating a SIPOC - The second method:

1. Create a template that can contain the information of the five key components in a clear way.
2. Identify the receipt of the process.
3. Identify the outputs of the process.
4. Plot a high-level process map that covers five steps at maximum.
5. Brainstorm the inputs required to run each process step.
6. Identify the suppliers who provide the inputs.

In the second method, start with the customer (or the recipient of the process), work your way back by identifying the process outputs, then the high-level process map (five steps maximum), brainstorm the inputs to the process, then identify the suppliers for those inputs.

Creating a SIPOC Diagram

Step 1: Vertically List High-Level Process

If you followed the general rules for a high-level process map, then you should have no more than four to six steps for your process. List those steps in a vertical manner in the middle section labeled “Process” as depicted below.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
		Start		
		Step 1		
		Step 2		
		Step 3		
		Last Step		

Fig. 1.6 SIPOC High Level Process Map

Step 2: List Process Outputs

In step two, for each process step list any outputs that are generated from the corresponding process step. Outputs can be finished goods, documents, reports, raw materials etc.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
		Start		
		Step 1	Enter Step 1 Outputs	
		Step 2	Enter Step 2 Outputs	
		Step 3	Enter Step 3 Outputs	
		Last Step	Enter Step 4 Outputs	

Fig. 1.7 SIPOC Outputs

Step 3: List Output Customers

In step 3, list the customers that receive the outputs from each process step. Customers can be internal or external. The important thing to remember is who is the output being delivered to.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
		Start		
		Step 1	Enter Step 1 Outputs	Enter Step 1 Customers
		Step 2	Enter Step 2 Outputs	Enter Step 2 Customers
		Step 3	Enter Step 3 Outputs	Enter Step 3 Customers
		Last Step	Enter Step 4 Outputs	Enter Step 4 Customers

Fig. 1.8 SIPOC Output Customers

Step 4: List Process Inputs

For the inputs, in step 4 list any inputs that are necessary for any or all process steps. Inputs can be raw materials, information, finished goods from other processes etc.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
		Start		
	Enter Step 1 Inputs	Step 1	Enter Step 1 Outputs	Enter Step 1 Customers
	Enter Step 2 Inputs	Step 2	Enter Step 2 Outputs	Enter Step 2 Customers
	Enter Step 3 Inputs	Step 3	Enter Step 3 Outputs	Enter Step 3 Customers
	Enter Step 4 Inputs	Last Step	Enter Step 4 Outputs	Enter Step 4 Customers

Fig. 1.9 SIPOC Process Inputs

Step 5: List Suppliers of Inputs

The last step is to identify and list suppliers of the inputs. Who provides the materials or information as inputs to the process? Where do the inputs come from?

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
		Start		
Enter Step 1 Suppliers	Enter Step 1 Inputs	Step 1	Enter Step 1 Outputs	Enter Step 1 Customers
Enter Step 2 Suppliers	Enter Step 2 Inputs	Step 2	Enter Step 2 Outputs	Enter Step 2 Customers
Enter Step 3 Suppliers	Enter Step 3 Inputs	Step 3	Enter Step 3 Outputs	Enter Step 3 Customers
Enter Step 4 Suppliers	Enter Step 4 Inputs	Last Step	Enter Step 4 Outputs	Enter Step 4 Customers

Fig. 1.10 SIPOC Suppliers of Inputs

SIPOC Benefits

A SIPOC has the following benefits, SIPOCs help to:

- Visually communicate project scope
- Identify key inputs and outputs of a process
- Identify key suppliers and customers of a process
- Verify:
 - Inputs match outputs for upstream processes
 - Outputs match inputs for downstream processes.
 - This type of mapping is effective for identifying opportunities for improvement of your process.
- If you have completed your high-level process map, follow the outlined steps to create a process map of **S**uppliers, **I**ntputs, **P**rocess, **O**utputs, and **C**ustomer.

SIPOC is more powerful than a simple high-level process map because it conveys the inputs and outputs of a process, *as well as* the suppliers and customers.

What is Value Stream Mapping?

Value stream mapping is a method to visualize and analyze the path of how information and raw materials are transformed into products or services customers receive. It is used to identify, measure, and decrease the non-value-adding steps in the current process.

Non-Value-Added Activities

Non-value-adding activities are activities in a process that, from the customers' perspective, do not add any other value to the products or services customers demand. Examples of non-value-adding activities are:

- Rework—It should have been done right the first time, so a second time certainly does not add value
- Overproduction—Work that is done before it is needed, and could change, leading to rework
- Excess transportation—Moving the product around does not add value
- Excess stock—Similar to overproduction
- Waiting—Wasted time
- Unnecessary motion—Wasted energy

Not all non-value-adding activities are unnecessary. Sometimes, non-value added activities are required. For example, an inspection that is done for regulatory compliance purposes is necessary but does not add value to the product or service the customer receives.

Keys to Plotting a Value Stream Map

Plot the entire high-level process flow from when the customer places the order to when the customer receives the products or services in the end. A value stream map requires more detailed information for each step than the standard process map:

- | | |
|----------------------|--------------------------|
| • Cycle time | • Value Added Activities |
| • Available time | • Non-Value Added (NVA) |
| • Demand & Takt Time | • Preparation type |
| • Inventory | • Scrap rate |
| • Working time | • Rework rate |
| • Wait time | • Number of operators |

Basic Value Stream Map Layout

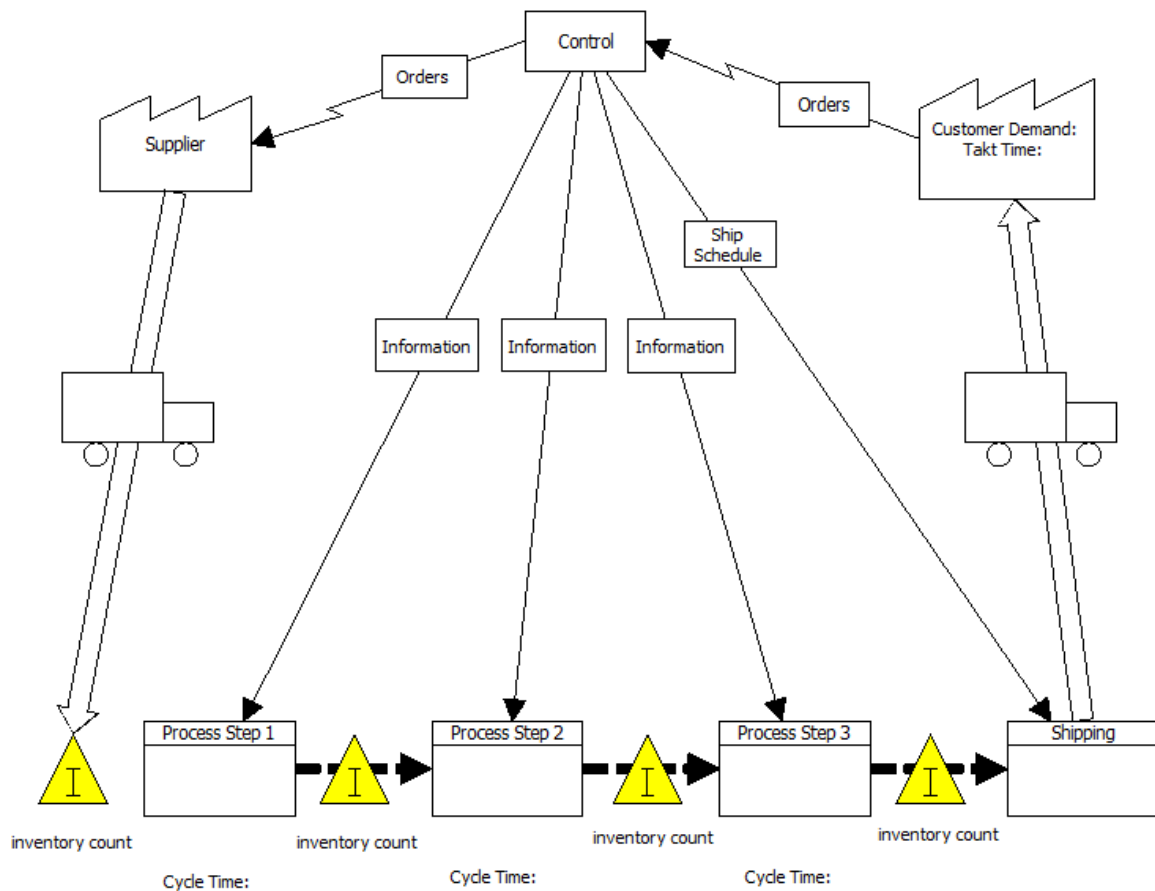


Fig. 1.11 Value Stream Map Layout

Figure 1.11 demonstrates a generic process so that you can see the simple view of the saw-tooth box in the upper right where the customer initiates orders. Orders flow to a control point and which are distributed to supplier orders and throughout the production process of four sub-processes which eventually end with the custom receiving the goods.

Value stream maps are useful to determine:

- What the current process looks like
- Where the process starts and where it ends
- How value flows through the process
- The steps which are value added in the process
- The steps which are non-value added in the process
- What the relationship is between information flow and material flow
- Average cycle time throughout the process
- Inventory levels throughout the process
- Sources of the waste
- Areas in need of the most improvement

The true value of the value stream map is not the map itself but the information gathered and assessed to create the map. This information is vital to ascertaining where inefficiencies and opportunities exist.

Additional Mapping Technique

We will now touch on an additional mapping technique that can come in very handy during a process understanding session; the thought process map.

Thought Process Mapping

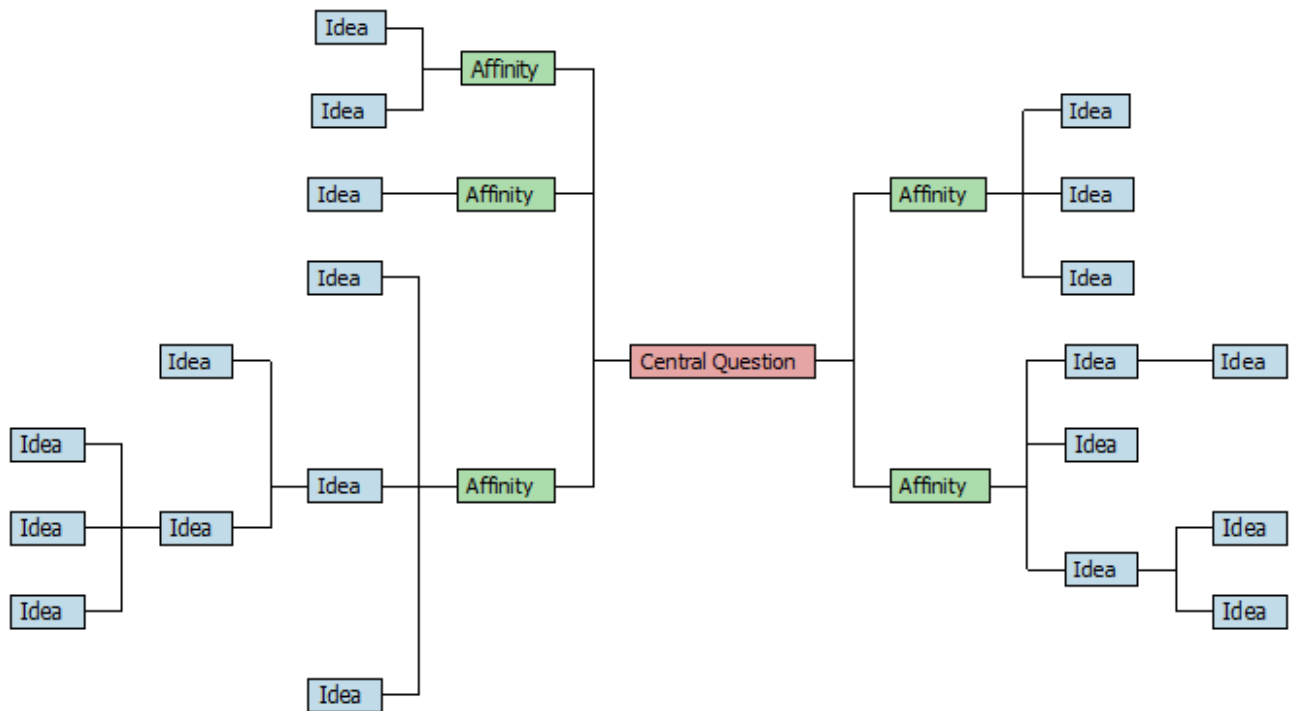


Fig. 1.12 Thought Process Map Example

A *thought process map* is a graphical tool to help brainstorm, organize, and visualize information, ideas, questions, or thoughts regarding reaching a project goal. It helps a project team to understand where they have been, where they still need to go, what questions have been answered, how were they answered, and what is yet to be answered. “Thought Maps” are a popular tool used at any phase of a project to:

- Identify knowns and unknowns
- Communicate assumptions and risks
- Discover potential problems and solutions
- Identify resources, information, and actions required to meet the goal
- Present relationship of thoughts

How to Plot a Thought Process Map

1. Define the project goal.

2. Brainstorm knowns and unknowns about the project.
3. Brainstorm questions and group the unknowns.
4. Sequence the questions below the project goal and link related questions.
5. Identify tools or methods that would be used to answer the questions.
6. Repeat steps 3 to 5 as the project continues until the goal is met.

Thought Process Map Example

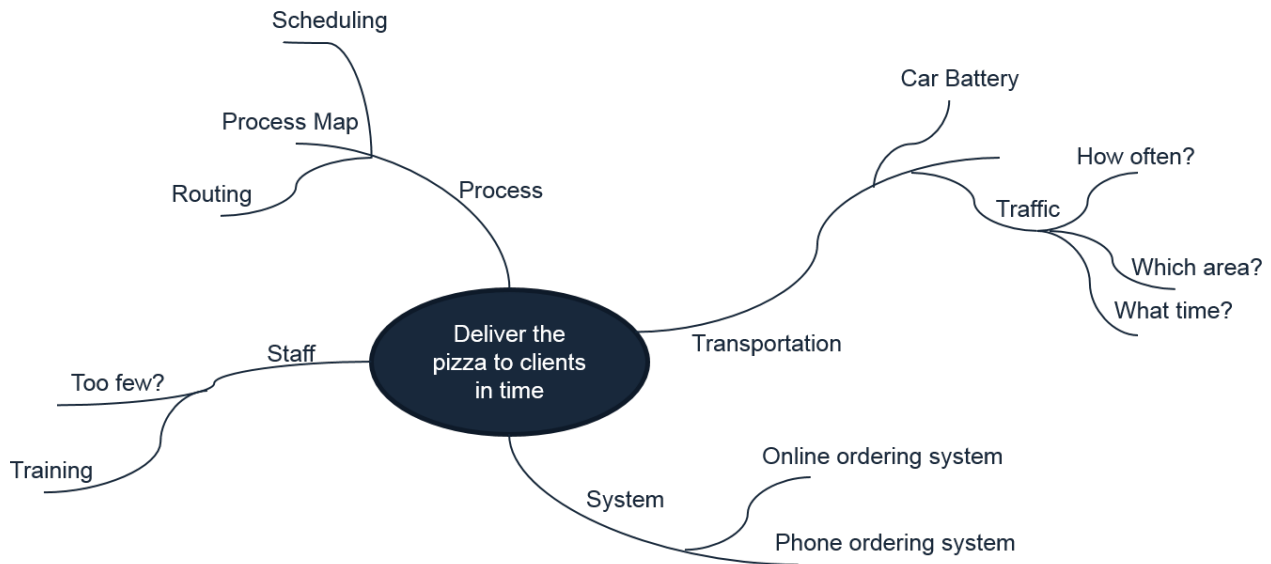


Fig. 1.13 Thought Process Map Example

This is an example of a thought process map. In this case, the main theme is on-time pizza delivery. You can see several themes and concepts explored. Thought process maps serve well to introduce questions and ideas while also being great tools to leave “trails” of where you have been so that later in a project when someone makes a suggestion that has already been evaluated you can refer to the thought map as evidence.

1.2.2 VOICE OF THE CUSTOMER AND CRITICAL TO QUALITY

Voice of the Customer

VOC stands for Voice of the Customer. Voice of the customer is a term used for a data-driven plan to discover customer wants and needs. It is *always* important to understand the VOC when designing and improving any Six Sigma process.

There are also other “voices” that need to be heard when conducting projects. The three primary forms are:

- VOC: Voice of the Customer
- VOB: Voice of the Business - What does the business require of a process?

- VOA: Voice of the Associate or Voice of the Employee - What does the employee require of a process (e.g., safety, simplicity)?

Gathering VOC

Gathering VOC should be performed methodically. The two most popular methods of collecting VOC are indirect and direct.

1. Indirect data collection for VOC involves passive information exchange, meaning the VOC was not expressly collected for the purposes of the project, but was gathered through byproducts of the process, such as:

- Warranty claims
- Customer complaints/compliments
- Service calls
- Sales reports

All the above are effective ways to understand how the customer feels about a product or service.

2. Indirect methods are less effective, sometimes dated, require heavy interpretation, and are also more difficult to confirm because the data was not collected to understand VOC specific to a business or process problem. Direct data collection methods for VOC are active and planned customer engagements, such as:

- Conducting interviews
- Conducting customer surveys
- Conducting market research
- Hosting focus groups

Direct methods are typically more effective for several reasons:

- Less need to interpret meaning
- Researchers can go a little deeper when interacting with customers and take a direction that might not have been expected or planned
- Customers are aware of their participation and will respond better upon follow-up
- Researchers can properly plan engagements (questions, sample size, information collection techniques etc.)

There are professional organizations that can perform customer data collection on behalf of a company. They commonly plan carefully by designing the questions, determining the sample size, and considering what technique is most appropriate. If there is a need to get very specific customer feedback, a survey is appropriate. However, if the need is more exploratory, interviews or focus groups are more appropriate.

Gathering VOC

- Gathering VOC requires consideration of many factors such as product or service types, customer segments, manufacturing methods or facilities etc. All this information will influence the sampling strategy because different factors might indicate different customer needs across customer segments, or perhaps the customers' feedback may differ by product type or manufacturing method.
- Consider which factors are important and build a sample size plan around them. Also, consider response rates and adjust the initial sample strategy to ensure adequate input is received.
- Once a sampling plan is in place, collect data via the direct and indirect methods discussed earlier.
- After gathering VOC, it will be necessary to translate it into something meaningful: Critical to Quality.

Critical to Quality

CTQs or *Critical to Quality* are generated from VOC feedback. Because VOC is usually vague, emotional, or simply a generalization about products or services, it is important to translate it into something that is applicable to a process: CTQs, which are the quantifiable, measurable, and meaningful translations of VOC.

To create CTQs, the VOC must be organized first into like groupings. One effective way to organize VOC is to group or bucket it using an *affinity diagram*. Affinity diagrams are ideal for large amounts of soft data resulting from brainstorming sessions or surveys.

Affinity Diagram: Building a CTQ Tree

Steps for conducting an affinity diagram exercise:

1. Clearly define the question or focus of the exercise.
("Why are associates late for work?").
2. Record all participant responses on note cards or sticky notes.
(This is the sloppy part, record everything!).
3. Lay out all note cards or post the sticky notes onto a wall.
4. Look for and identify common themes.
5. Begin moving the notes into the themes until all responses are allocated.
6. Re-evaluate and adjust.

This is an outline of building an affinity diagram (or CTQ tree); it is typically done with a group of people. The group must agree on what question they are trying to answer, or what the focus for the VOC is. It is good to do this exercise in a group because people bring different perspectives and might understand and organize VOC differently than a single person would.

Affinity Diagram: Building a CTQ Tree Step by Step

In summary, to build an affinity diagram:

- Define the question or focus.
- Record responses on note cards or sticky notes.
- Display all note cards or sticky notes on a wall if necessary.

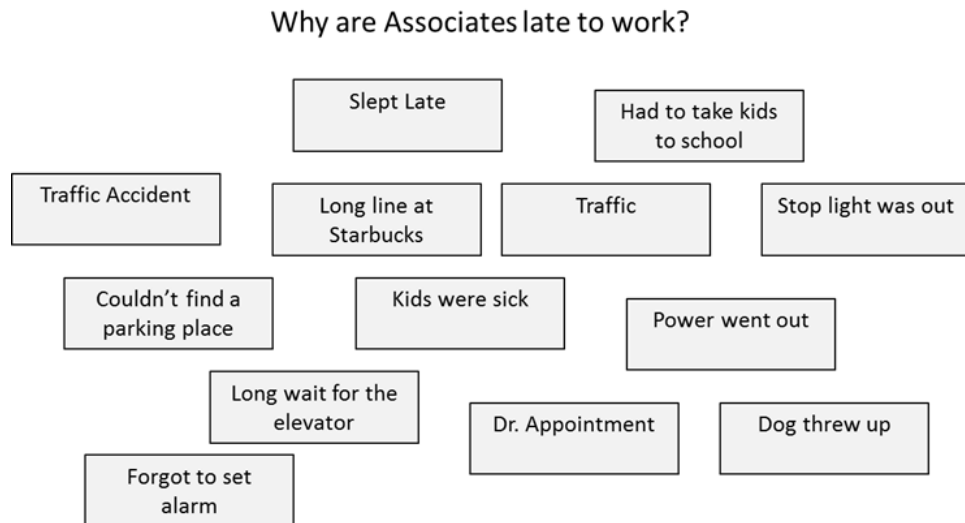


Fig. 1.14 Random reasons prior to an affinity diagram

In figure 1.14 the focus question is “Why are associates late to work?” You can see all of the responses randomly distributed across the page.

- Look for and identify common themes within the responses.

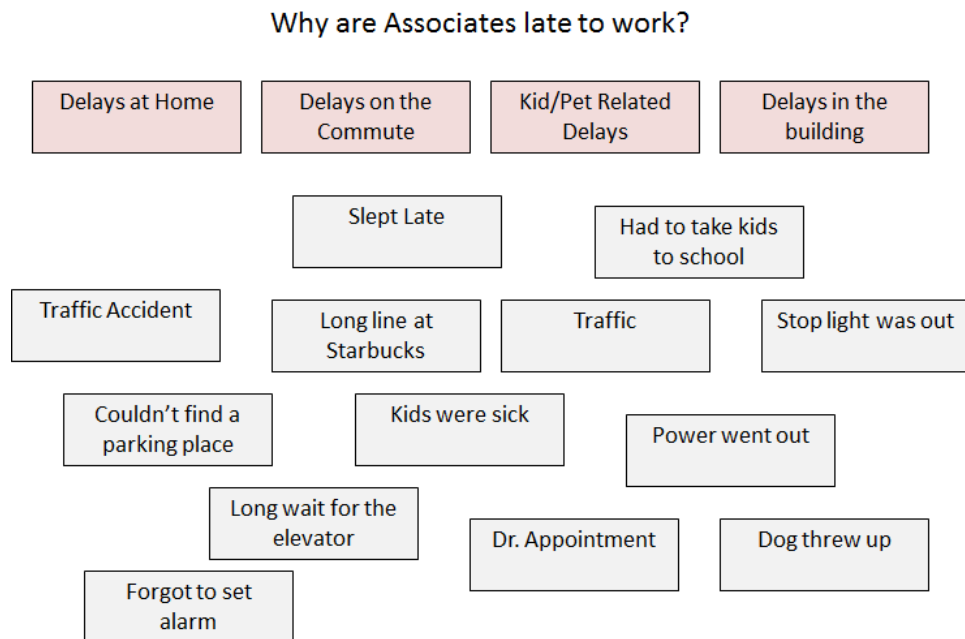


Fig. 1.15 Common themes

In figure 1.15, you can see that some common themes have emerged (delays at home, delays on the commute, kids/pet related delays, or delays in the building).

- Group note cards or sticky notes into themes until all responses are allocated.
- Re-evaluate and make final adjustments.

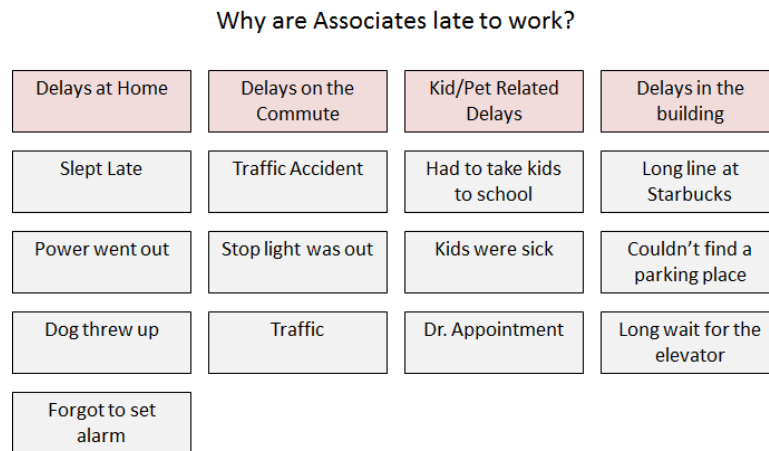


Fig. 1.16 Affinity Diagram

Finally, in figure 1.16 you can now see that the individual responses are lined up under each theme. See any that might be misplaced? How about “dog threw up?” Perhaps “delays at home” and “kid/pet-related delays” do not need to be broken down separately. These are the kinds of things to consider when evaluating and adjusting.

CTQ Tree

The next figure shows an example of a generic CTQ tree transposed from a white board to a software package (*generated with Minitab's Quality Companion 3*)

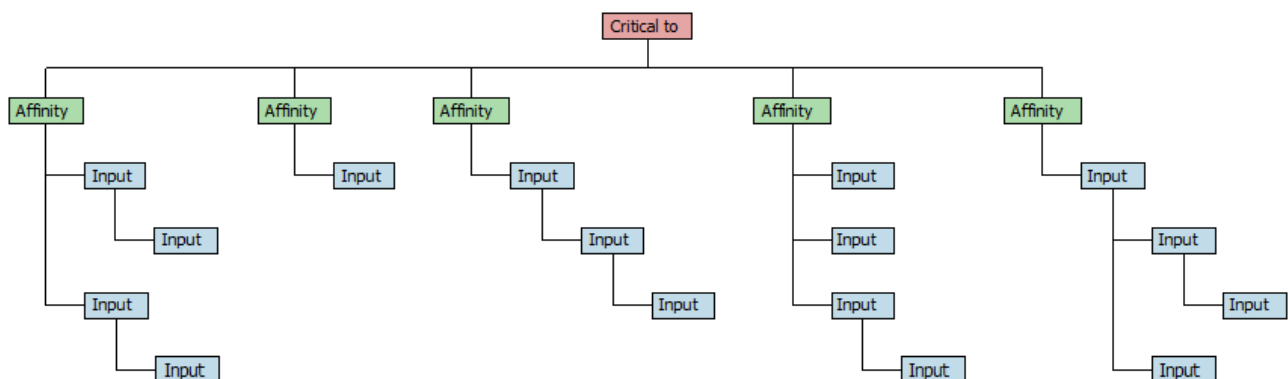


Fig. 1.17 CTQ Tree

Kano

Another VOC categorization technique is the *Kano*. The Kano model was developed by Noriaki Kano in the 1980s and it is a graphic tool that further categorizes VOC and CTQs into three distinct groups:

1. Must Haves
2. Performance Attributes
3. Delighters

The Kano helps to:

- Identify CTQs that add incremental value vs. those that are simply requirements
- Understand that having more is not necessarily better

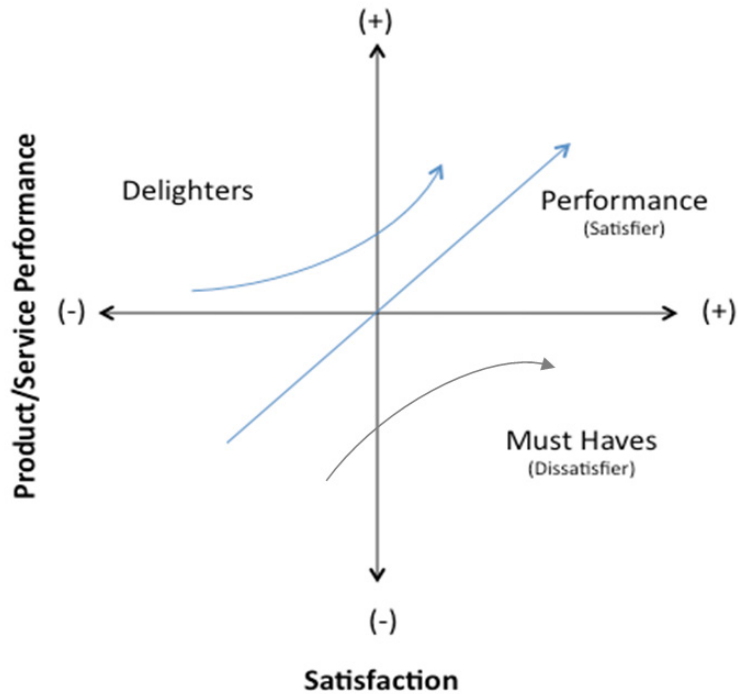


Fig. 1.18 Kano Diagram

It is important to understand what CTQs are non-negotiable (*must haves*) versus those that are nice to have. “Must have” attributes are often taken for granted when they are fulfilled, but result in dissatisfaction when they are not fulfilled. The curve for a “must have” will drop in satisfaction as you move to the left where the need is not fulfilled, but flattens out to a neutral satisfaction level as you move to the right.

A *delighter* is the opposite of the must have—if it is not fulfilled, the customer will not be dissatisfied, but as it is fulfilled, the customer’s satisfaction increases. These are things the customer did not realize they wanted or needed, until they have experienced them. Eventually, delighters will become expected, turning them into *performance attributes* or must haves.

Examples:

- How would you classify the steering wheel in a car?
- Low prices at a discount store?
- What about the touch screen on an iPhone (think back to when it came out)?

A performance attribute (or one-dimensional attribute) will increase satisfaction level as the need is fulfilled, and will decrease satisfaction when it is not fulfilled.

Validating VOC and CTQs

Once the process of collecting VOC is complete, and CTQs have been determined, the next step is to *validate* what has been developed. Confirming can be accomplished by conducting surveys through one or more of the following methods:

- Group sessions
- One-on-one meetings
- Phone interviews
- Electronic means (chat, email, social media etc.)
- Physical mail

Consider your confirming audience and try to avoid factors that may influence or bias responses such as inconvenience or overly burdensome time commitments. For example, an overly extensive customer survey might end up getting a rushed response and, therefore, may not represent the true views of an audience.

Translating CTQs to Requirements

To be able to incorporate a CTQ into the design of a process, the next step is to *translate* CTQs to specific process requirements. A *requirements tree* translates CTQs to meaningful and measurable requirements for production processes and products.

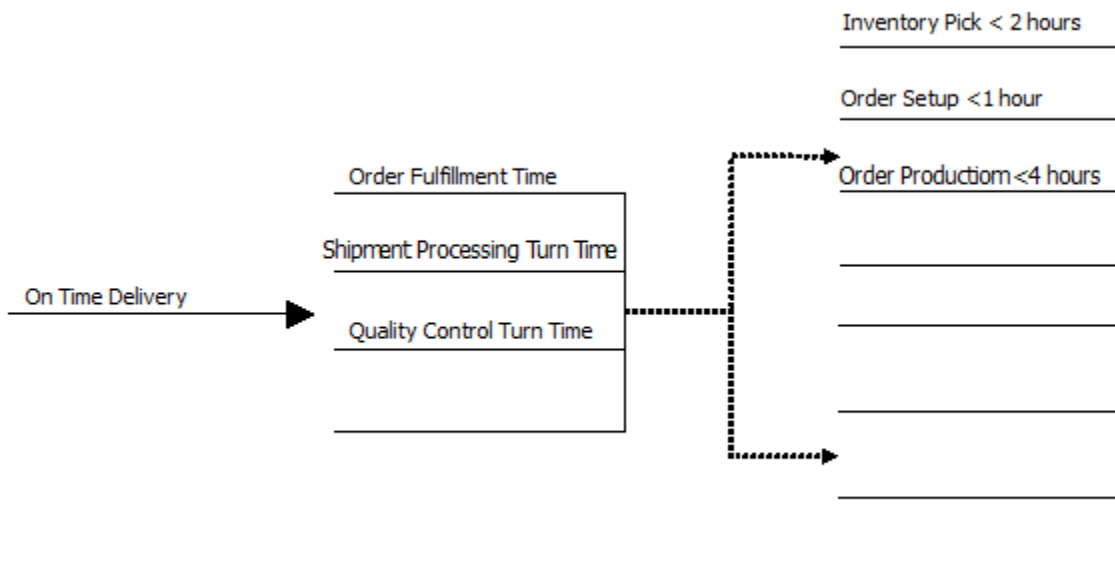


Fig. 1.19 CTQ Requirements Tree

In figure 1.19, the actual feedback from the customer (VOC) might have been something like, “Deliver my product when you say you’re going to deliver it”. This statement is then translated to something your business can measure such as “on-time delivery.”

To achieve on time delivery and ensure that you're meeting your customers' expectations, on time delivery must be translated to the very specific process requirements that your business must achieve to meet on time delivery requirements.

To do so, one must then consider what aspects of the process contribute to the time that elapses between when the customer places an order and when it is delivered. The customer's order must be fulfilled, how does that process occur and what are the necessary performance requirements? Also, the order must be inspected by quality control and processed for shipping. What are the performance requirements for those process steps?

The requirements tree help to translate a CTQ into process requirements that can be measured and attained to meet customer expectations.

1.2.3 QUALITY FUNCTION DEPLOYMENT

History of Quality Function Deployment

The QFD (Quality Function Deployment) was developed in 1972 by Shigeru Mizuno (1910–1989) and Yoji Akao (b. 1928) from the TQM practices of a Japanese company, Mitsubishi Heavy Industries Ltd. QFD aims to design products that assure customer satisfaction and value—the first time and every time.

The QFD framework can be used for translating actual customer statements and needs (the voice of the customer) into actions and designs to build and deliver a quality product. QFD is considered a valuable tool fundamental to a business' success, hence it is widely applied.

What is QFD?

- *QFD* is a construction methodology and quantification tool used to identify and measure customer's requirements and transform them into meaningful and measurable parameters. QFD uses planning matrices—it is also called "The House of Quality."
- QFD helps to prioritize actions to advance process or product to meet customer's anticipations.
- QFD is an excellent tool for contact between cross-functional groups.

Purpose of QFD

The quality function deployment has many purposes, some of the most important being:

- Market analysis to establish needs and expectations
- Examination of competitors' abilities
- Identification of key factors for success
- Translation of key factors into product and process characteristics

QFD focuses on customer requirements, prioritizes resources, and uses competitive information effectively.

Phases of QFD

There are four key phases of QFD:

- Phase I: Product Planning Including the “House of Quality” (Requirements Engineering Life Cycle)
- Phase II: Product Design (Design Life Cycles)
- Phase III: Process Planning (Implementation Life Cycle)
- Phase IV: Process Control (Testing Life Cycle)

How to build a House of Quality

The steps to building a House of Quality are:

- Determine Customer Requirements (“What’s” from VOC/CTQ)
- Technical Specifications/Design Requirements (“How’s”)
- Develop Relationship Matrix (“What’s” and “How’s”)
- Prioritize Customer Requirements
- Conduct Competitive Assessments
- Develop Interrelationship (“How’s”)
- Prioritize Design Requirements

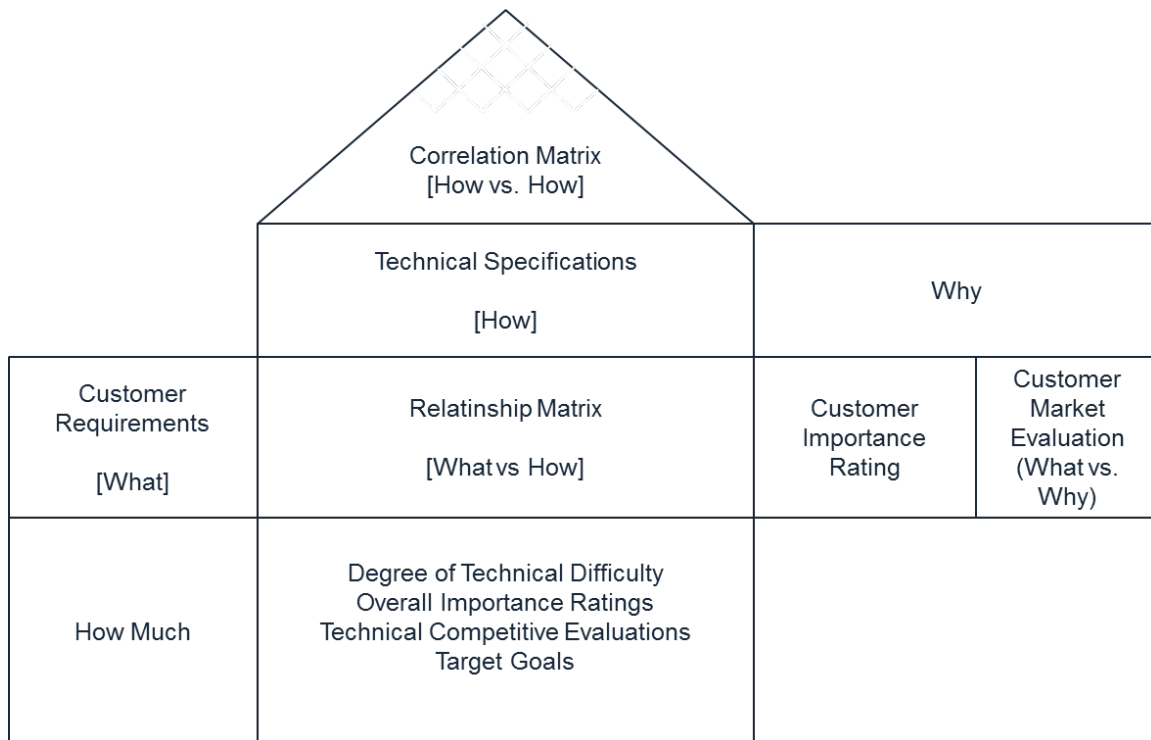


Fig. 1.20 House of Quality

This is the structure of a House of Quality. You can see that it contains the following elements, sometimes referred to as rooms:

- Customer Requirements or the “What’s” derived from VOC and CTQs
- Technical specifications or Design Requirements (the “How’s”)
- Relationship Matrix (the Roof or “What’s” and “How’s”)
- Prioritized Customer Requirements
- Competitive Assessment
- Interrelationships or Correlation Matrix (the “How’s”)
- Prioritized Design Requirements

How to Build a House of Quality Step by Step

Step 1: Determine Customer Requirements

Identify the important customer requirements. These are the “What’s” and are typically determined through the VOC/CTQ process. Use the results from your requirements tree diagram as inputs for the customer requirements in your HOQ.



Fig. 1.21 Customer Requirements

Customers drive the development of the product, not the designers. Hence, it is necessary to determine all customer requirements. Customers will provide the requirements in their own language; you will need to categorize the requirements based on importance. General customer requirements are:

- Human factors
- Physical requirements
- Reliability
- Life-cycle concerns
- Manufacturing requirement

Step 2: Technical Specifications

- Potential choices for product features
- Voice of Designers or Engineers
- Each “What” item must be refined to “How’s”

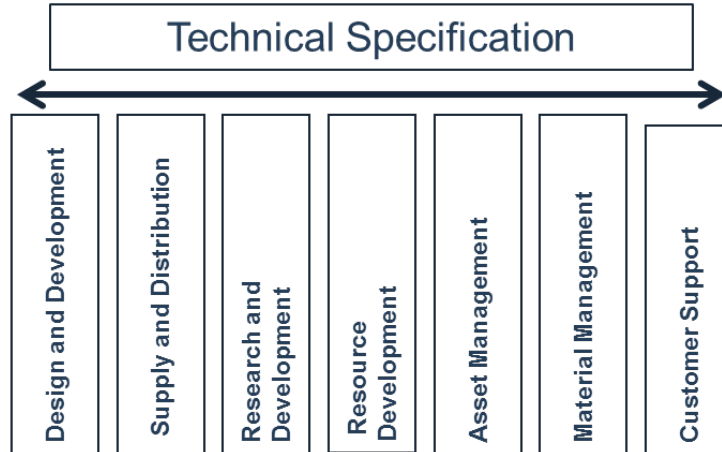


Fig. 1.22 Technical Specifications

The goal is to develop a set of technical specifications from the customer’s requirements. Designers and engineers then take the customer requirements and determine technical parameters that need to be designed into the product or process.

Step 3: Develop Relationship Matrix (“What’s” and “How’s”)

This is the center portion of the house. Each cell represents how each technical specification relates to each customer requirement.

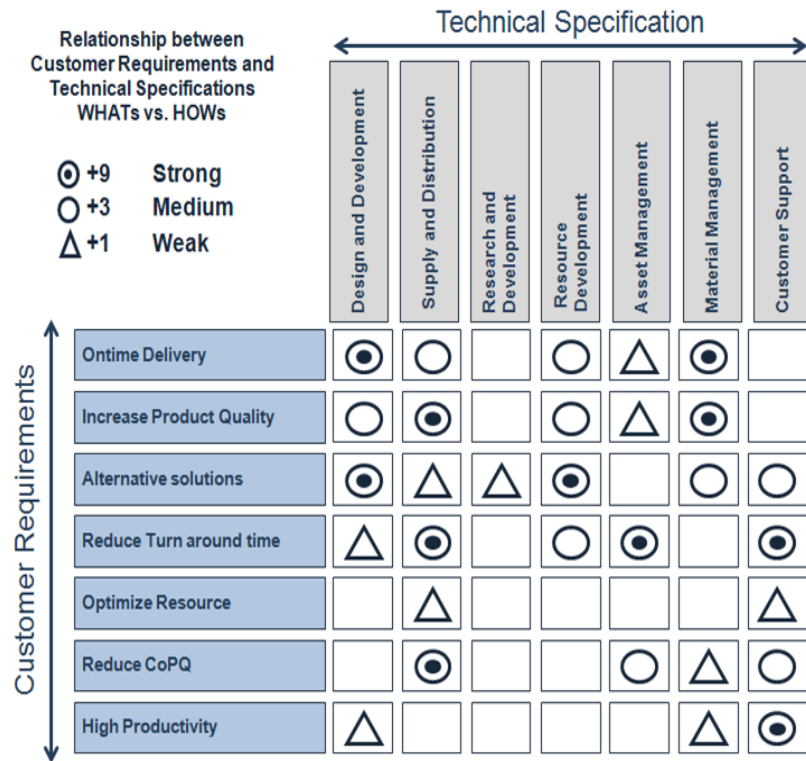


Fig. 1.23 Relationship Matrix

The relationship matrix represents the strength of the relationship between each technical specification and each customer requirement. Use symbolic notations for depicting strong, medium, and weak relationships, such as assigning weights of 1–3–9.

Step 4: Prioritize Customer Requirements

This is the right portion of the house. Each cell represents customer requirements based on relative importance to customers and perceptions of competitive performance.

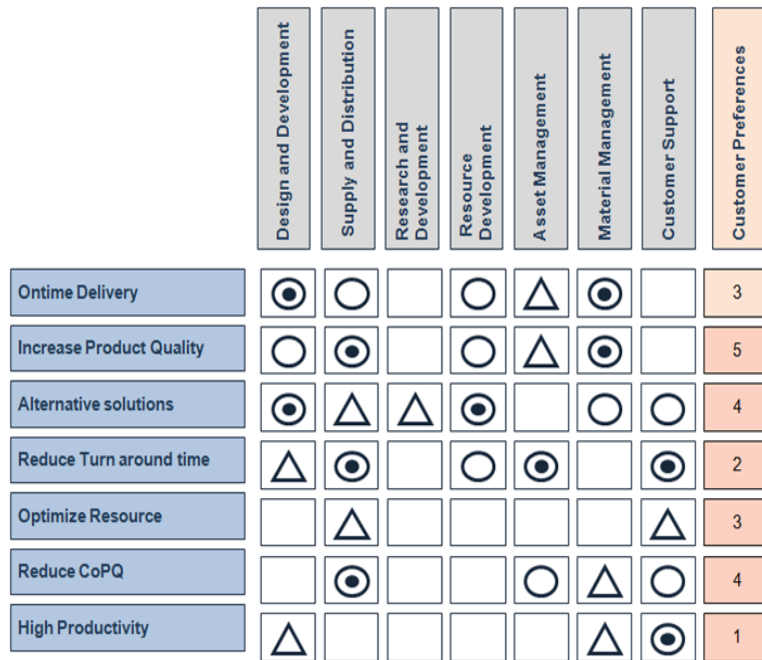


Fig. 1.24 Prioritize Customer Requirements

Prioritize the customer requirements based on importance rating, target value, scale-up factor, sales point.

Step 5: Competitive Assessments

This is the extreme right portion of the house. Comparison of the organization's product to its competitor's products.

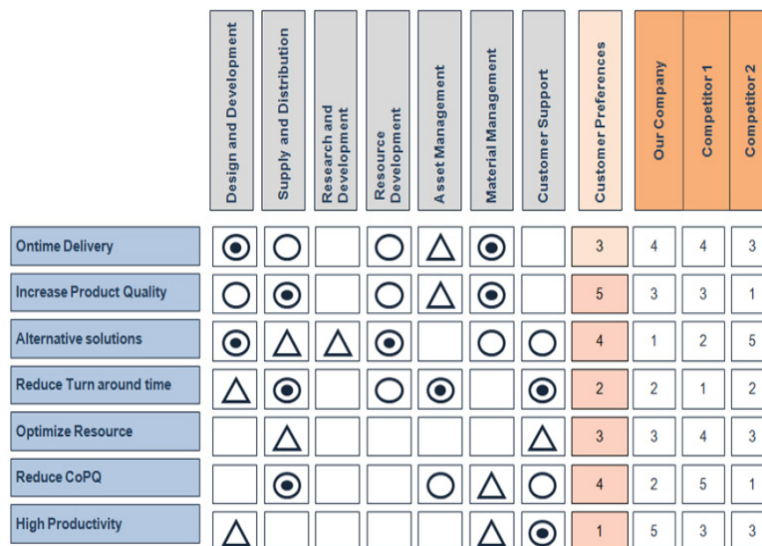


Fig. 1.25 Competitive Assessment

Use the competitive assessment as an opportunity to compare your product/process requirements and specifications with your competitors' products/process. The customer can be used to estimate 1–5 ratings on all products/processes.

Step 6: Correlation Matrix

This is the top portion of the house. It identifies the correlation between “how” items. Some have support (positive) correlations and other may have conflict or negative correlations.

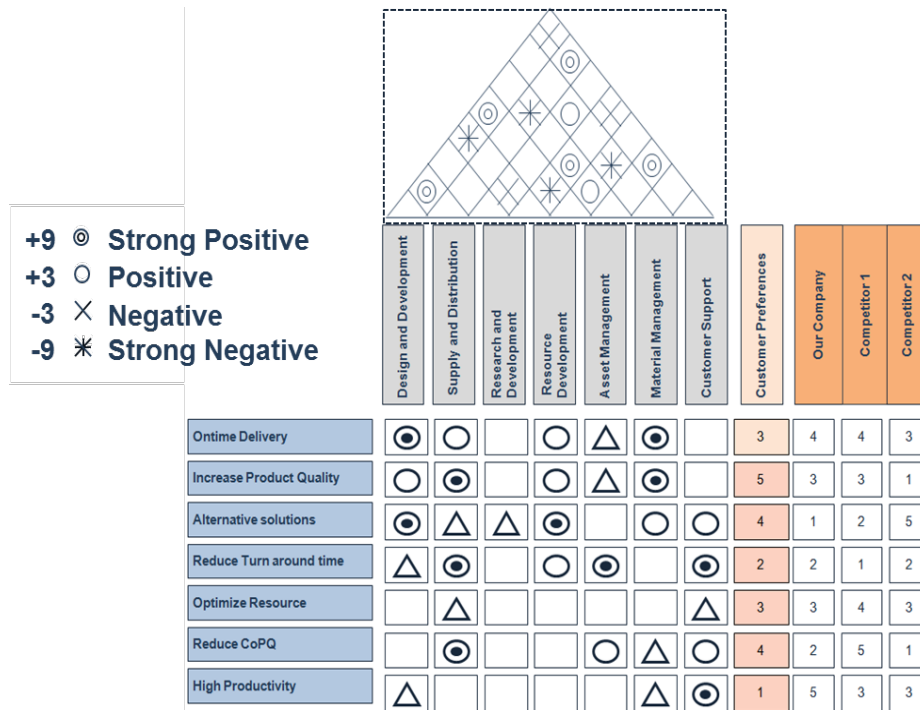


Fig. 1.26 Correlation Matrix

The purpose of the correlation matrix is to identify any inconsistency within the design or technical specifications.

Step 7: Prioritize Design Requirements

- Overall Importance Ratings—Function of relationship ratings and customer prioritization ratings
- Technical Difficulty Assessment—Like customer market competitive evaluations but conducted by the technical team

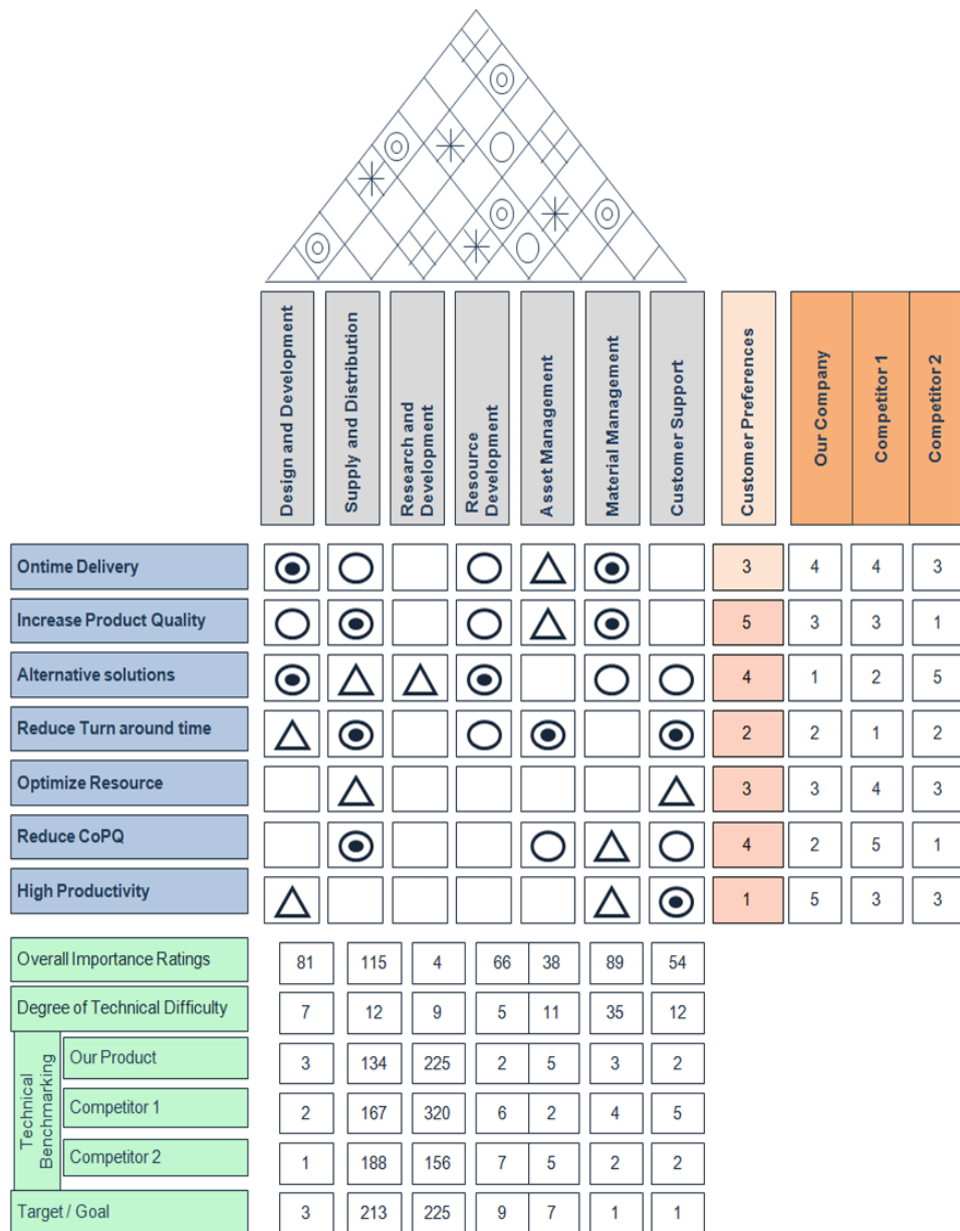


Fig. 1.27 Prioritize Design Requirements

- Overall Importance
- Technical Specification
- Competitive Evaluation
- Target Goals

Each of these prioritization categories helps to establish the feasibility and realization of each “How” item. Target Goals for example can help identify how much is good enough to satisfy the customer. Technical specifications & competitive evaluation should be performed by technical teams. Generally, 1 to 5 ratings should be used. They should be clearly stated in a measurable way.

Figure 1.28 depicts a full House of Quality with each “room” labeled. In summary, the rooms are:

1. Customer Requirements
2. Technical Specifications
3. Relationship Matrix
4. Prioritized Customer Requirements
5. Competitive Assessment
6. Correlation Matrix
7. Prioritized Design Requirements

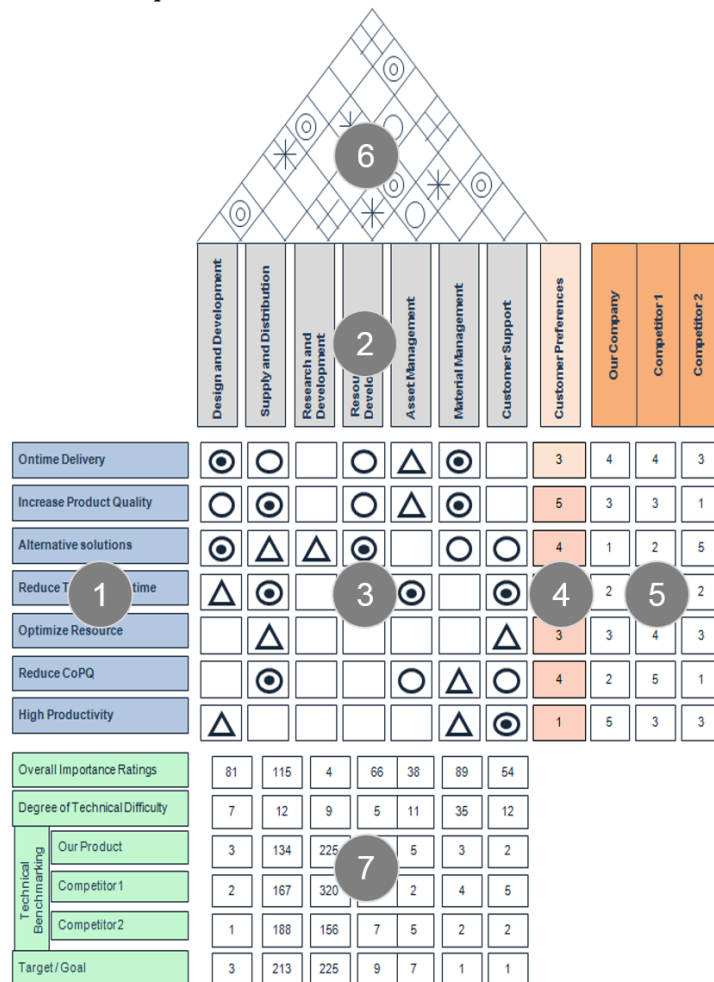


Fig. 1.28 House of Quality

Pros of QFD

- Focuses the design of the product or process on satisfying customer's needs and wants.
- Improves the contact channels between customers, advertising, research and improvement, quality and production departments, which sustains better decision making.
- Reduces the new product development project period and cost.

Cons of QFD

- The relationship matrix can be too obscure with many process inputs and/or many customer constraints.
- It can be very complicated and difficult to implement without experience.

- If throughout the process new ideas, specifications, or requirements are not discovered, you run the risk of losing team members' trust in the process.

QFD Summary

When used properly, the quality function deployment is an extremely valuable approach to product/process design. There are many benefits of QFD that can only be realized when each step of the process is completed thoroughly:

- Logical way of obtaining information and presenting it
- Smallest product development cycle
- Considerably condensed start-up costs
- Fewer engineering alterations
- Reduced chance of supervision during design process
- Collaborating environment
- Preserving everything in characters

1.2.4 COST OF POOR QUALITY

The *Cost of Poor Quality* (COPQ) is the expense incurred due to waste, inefficiencies, and defects. It is the cost absorbed when a process operates at anything less than optimal: the cost of waste, resource inefficiency, and defects (e.g., repairs, rework, service calls, scrap, warranty claims, and write-offs). COPQ can be staggering when all process inefficiencies are revealed.

Experts have estimated COPQ to be between 5% and 30% of gross sales for most companies. Consider a company that does approximately \$100 million in sales per week, and has a COPQ of 20%. That means that one day out of a five-day work week is completely devoted to producing scrap!

Understanding COPQ and where to look for it will help uncover process inefficiencies, defects, and hidden factories within your business. Consider for instance the hidden factories—Do you have procedures for rework, or workarounds? They might seem “hidden” at first, because they have come to be accepted as the normal process for doing things. There are many different types of non-value added activities that can drive waste.

Cost of Poor Quality

There are seven common forms of waste that are often referred to as the *seven deadly muda*. *Muda* is a Japanese word meaning “futility, uselessness, idleness, superfluity, waste, wastage, wastefulness.”

Technically, there are more than seven forms of waste but if you can remember these you will capture over 90% of your waste. The seven deadly muda, as defined by Taiichi Ohno (the Toyota Production System), are:

1. Defects
2. Overproduction—Producing more than what your customers are demanding
3. Over-Processing—Unnecessary time spent (e.g., relying on inspections instead of designing a process to eliminate problems)
4. Inventory—Things awaiting further processing or consumption
5. Motion—Extra, unnecessary movement of employees
6. Transportation—Unnecessary movement of goods
7. Waiting—For an upstream process to delivery, for a machine to finish processing, or for an interrupted worker to get back to work

The seven deadly muda are very important to understand. They are the best way to identify the COPQ. The presence of any muda causes many other forms of inefficiencies and hidden factories to manifest themselves. The next section we will discuss how to determine the cost of poor quality related to the seven muda.

COPQ: Costs Related to Production

Costs related to *production* are the direct costs of the presence of muda. These forms of COPQ are usually understood and easily observable. They are in fact the seven deadly muda themselves:

1. Defects—The cost of a defect itself (i.e., the lost labor and materials)
2. Overproduction—Resources spent producing more of something than what is needed, along with the material cost. This is producing “just-in-case” instead of “just-in-time” and creates excessive lead times, results in high storage costs, and makes it difficult to detect defects. Over-producing hides problems in production and takes a lot of courage to produce only what is needed (which will uncover where the issues are).
3. Over-Processing—Resources spent inspecting and fixing instead of getting right the first time
4. Inventory—Work in process on the floor is a symptom of over-processing and waiting
5. Motion—Unnecessary time spent by employees to perform the process; consider motion like bending, stretching, walking, lifting, and reaching
6. Transportation—Adds no value to the product and even increases risk of damage. This can be a hard cost to overcome if facilities are built in a way that requires transportation from one process to another.
7. Waiting—Usually because material flow is poor, production runs are too long, and distances between work centers are too long

COPQ: Costs Related to Prevention

Costs related to the *prevention* of muda are those associated with trying to reduce or eliminate any of the seven deadly muda before they occur:

- Costs for error proofing methods or devices

- Costs for process improvement and quality programs
- Costs for training and certifications, etc.

Any costs directly associated with the prevention of waste and defects should be included in the COPQ calculation.

COPQ: Costs Related to Detection

Costs related to the *detection* of muda are those associated with trying to find or observe any of the seven deadly muda after they occur. Any costs directly associated with the detection of waste and defects should be included in the COPQ calculation. Detection is not as effective as prevention, but sometimes is the only option. It can keep additional costs from being incurred, like continuing to process a defective unit. A few detection examples are:

- Costs for sampling
- Costs for quality control check points
- Costs for inspection costs
- Costs for cycle counts or inventory accuracy inspections, etc.

COPQ: Costs Related to Obligation

Costs related to *obligation* are those associated with addressing the muda that reach a customer. Any costs directly associated with customer obligations should be included in the COPQ calculation. Examples include:

- Repair costs
- Warranty costs
- Replacement costs
- Customer returns and customer service overhead, etc.

COPQ: Types of Cost

There are two types of costs to be considered when determining COPQ:

- Hard Costs—Tangible costs that can be traced to the income statement (e.g., costs of resources or materials)
- Soft Costs—Intangible costs: avoidance, opportunity costs, lost revenue, cost avoidance (the difference between what is actually spent and what *could* have been spent had no action been taken; think of this as slowing the rate of cost increases), opportunity cost (value of lost time that could have been used producing something of value)

Calculating the COPQ

1. Determine the types of waste that are present in your process.
2. Estimate the frequency of waste that occurs.
3. Estimate the cost per event, item, or time frame, whichever is appropriate.

4. Multiply the costs.

1.2.5 PARETO CHARTS AND ANALYSIS

Pareto Principle

The *Pareto principle* is commonly known as the “law of the vital few” or “80:20 rule.” It means that the majority (approximately 80%) of effects come from a few (approximately 20%) of the causes. It is a very powerful tool for scoping process improvement efforts because it tells us what the “few” causes are that drive most the effects (or in many cases defects).

This principle was first introduced in early 1900s and has been applied as a rule of thumb in various areas. Business-management consultant Joseph M. Juran suggested the principle and named it after Italian economist Vilfredo Pareto, who observed in 1906 that 80% of the land in Italy was owned by 20% of the population; he developed the principle by observing that 20% of the pea pods in his garden contained 80% of the peas. Examples of applying the Pareto principle:

- 80% of the defects of a process come from 20% of the causes
- 80% of sales come from 20% of customers

The Pareto principle helps us to focus on the vital few items that have the most significant impact. In concept, it also helps us to prioritize potential improvement efforts. Since this 80:20 rule was originally based upon the works of Wilfried Fritz Pareto (or Vilfredo Pareto), all Pareto chart and principle references should be capitalized because Pareto refers to a person (proper noun). Mr. Pareto is also credited for many works associated with the 80:20, some more loosely than others: Pareto’s Law, Pareto efficiency, Pareto distribution etc.

Pareto Charts

A Pareto chart is a chart of descending bars with an ascending cumulative line on the top. *Sum or Count:* The descending bars on a Pareto chart may be set on a scale that represents the total of all bars or relative to the biggest bucket, depending on the software you are using.

Percent to Total: A Pareto chart shows the percentage to the total for individual bars.

Cumulative Percentage: A Pareto chart also shows the cumulative percentage of each additional bar. The data points of all cumulative percentages are connected into an ascending line on the top of all bars. Not all software packages display Pareto charts the same way. Some show the percent of total for each individual bar, and others show the cumulative percentage.

Pareto Charts Case Study

Next, we will use SigmaXL to run Pareto charts on the same data set. The following table shows the count of defective products by team. Input the tabled data below into your software program and follow the instructions over the next few pages to run Pareto charts.

Count	Category
2	Team 1
12	Team 2
4	Team 3
22	Team 4
2	Team 5
2	Team 6

Table 1.2 Pareto Chart Data

Create a Pareto Chart in SigmaXL

Steps to generate a Pareto chart using SigmaXL:

1. Open the Pareto Chart spreadsheet.
2. Highlight both columns of “Count” and “Category.”
3. Click SigmaXL >Graphical Tools >Basic Pareto Chart.
4. A new window named “Basic Pareto Chart” pops up.

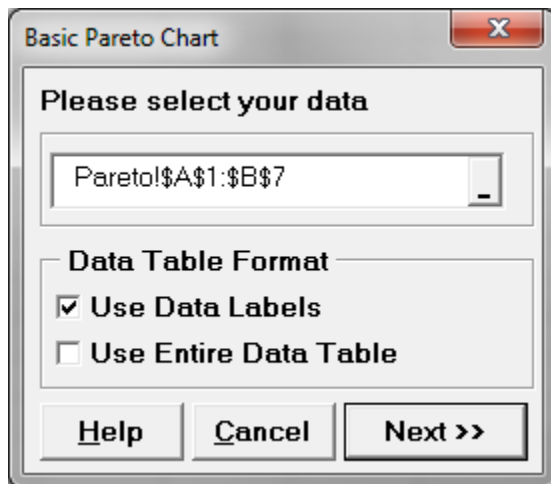


Fig. 1.29 Basic Pareto Chart dialog box

5. Click “Next>>.”
6. A new window named “Basic Pareto Chart” pops up.
7. Select “Category” as the “Pareto Category (X)” and “Count” as the “Optional Numeric Count (Y).”

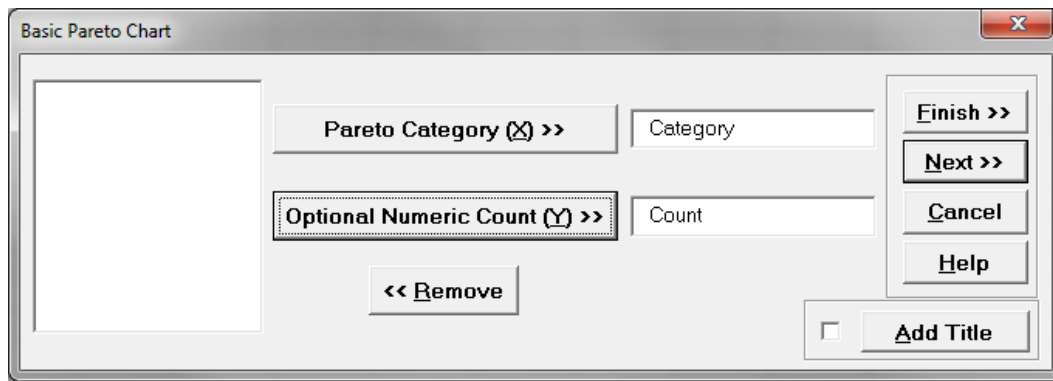


Fig. 1.30 Basic Pareto Chart dialog box with variable selection

8. Click "Finish."

The Pareto chart output is created in a newly-generated window. Figure 1.31 depicts the Pareto chart generated by SigmaXL. It represents the count of defective products by team on a descending scale. The axis on the left references the count of defects. The cumulative percentages are represented by the data points driving the line that spans across the graphic, the axis on the right is the reference for the cumulative percentage line.

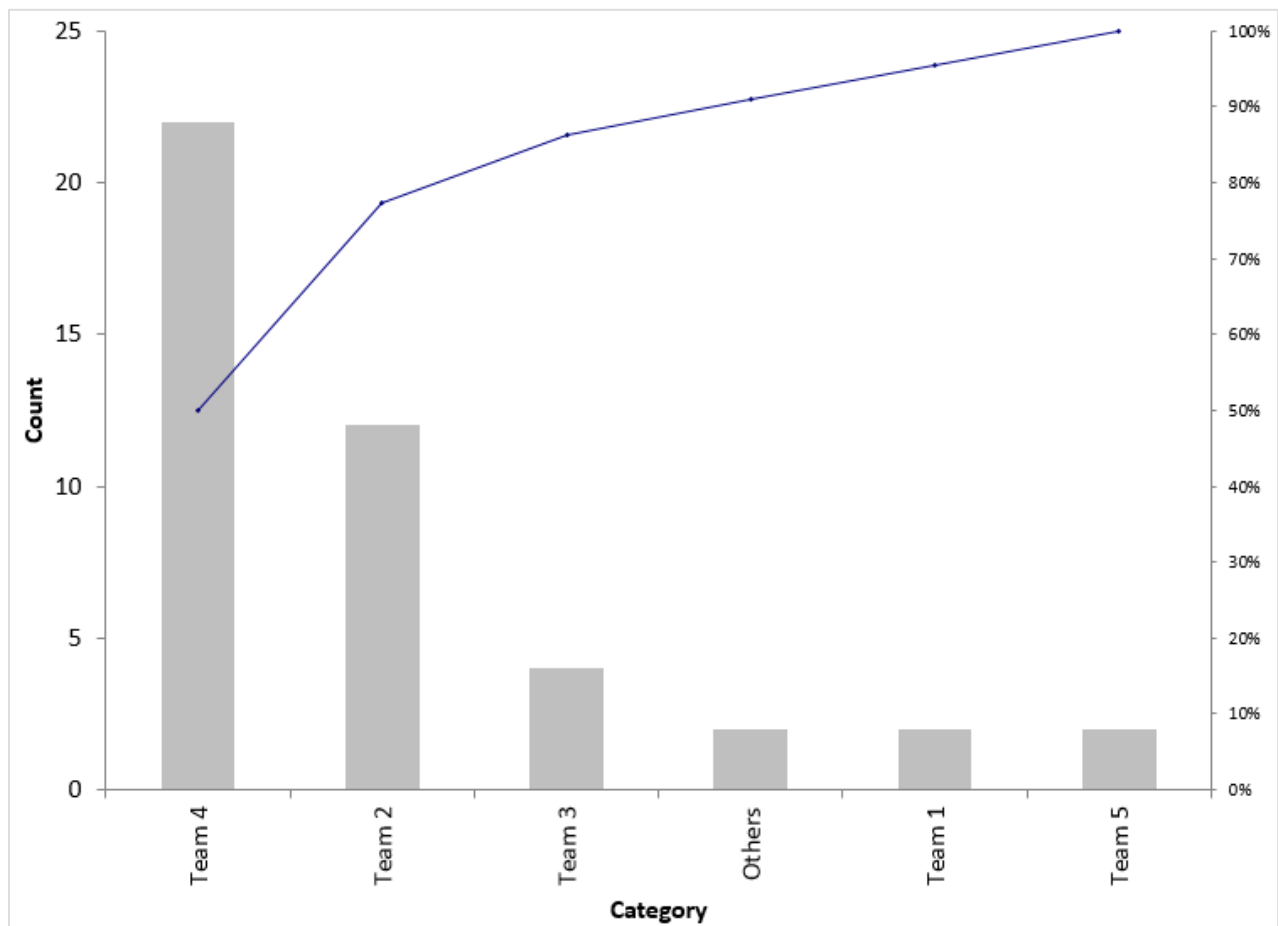


Fig. 1.31 SigmaXL Pareto Chart Output

With this data and analysis, we were looking to determine how many defective products (i.e. effects) were created by each team (i.e. causes). As you can see, SigmaXL sorted the data in decreasing order. The team with the most defective products (team 4) was placed on the left. It's also notable that the Pareto principal is present with nearly 80% of the defects being contributed by nearly 20% of the causes. Thus, the Pareto principle holds true.

Pareto Analysis

The *Pareto analysis* is used to identify root causes by using multiple Pareto charts. In Pareto analysis, we drill down into the bigger buckets of defects and identify the root causes of defects that contribute heavily to total defects. This drill-down approach often effectively solves a significant portion of the problem. Next you will see an example of three-level Pareto analysis.

- The second-level Pareto is a Pareto chart that is a subset of the tallest bar on the first Pareto. Therefore, the chart will represent categorized defects of Team 4.
- The third-level Pareto will then be a subset of the tallest bar of the second-level Pareto.

Pareto Analysis: First Level

The first-level Pareto was already demonstrated in figure 1.31. It showed the count of defective items by team. In that first level Pareto, we concluded that Team 4 accounted for 50% of the total number of defects. The next level Pareto will be a second level and will only show the defective items from Team 4 categorized in a logical manner or in a way that the data allows.

Pareto Analysis: Second Level

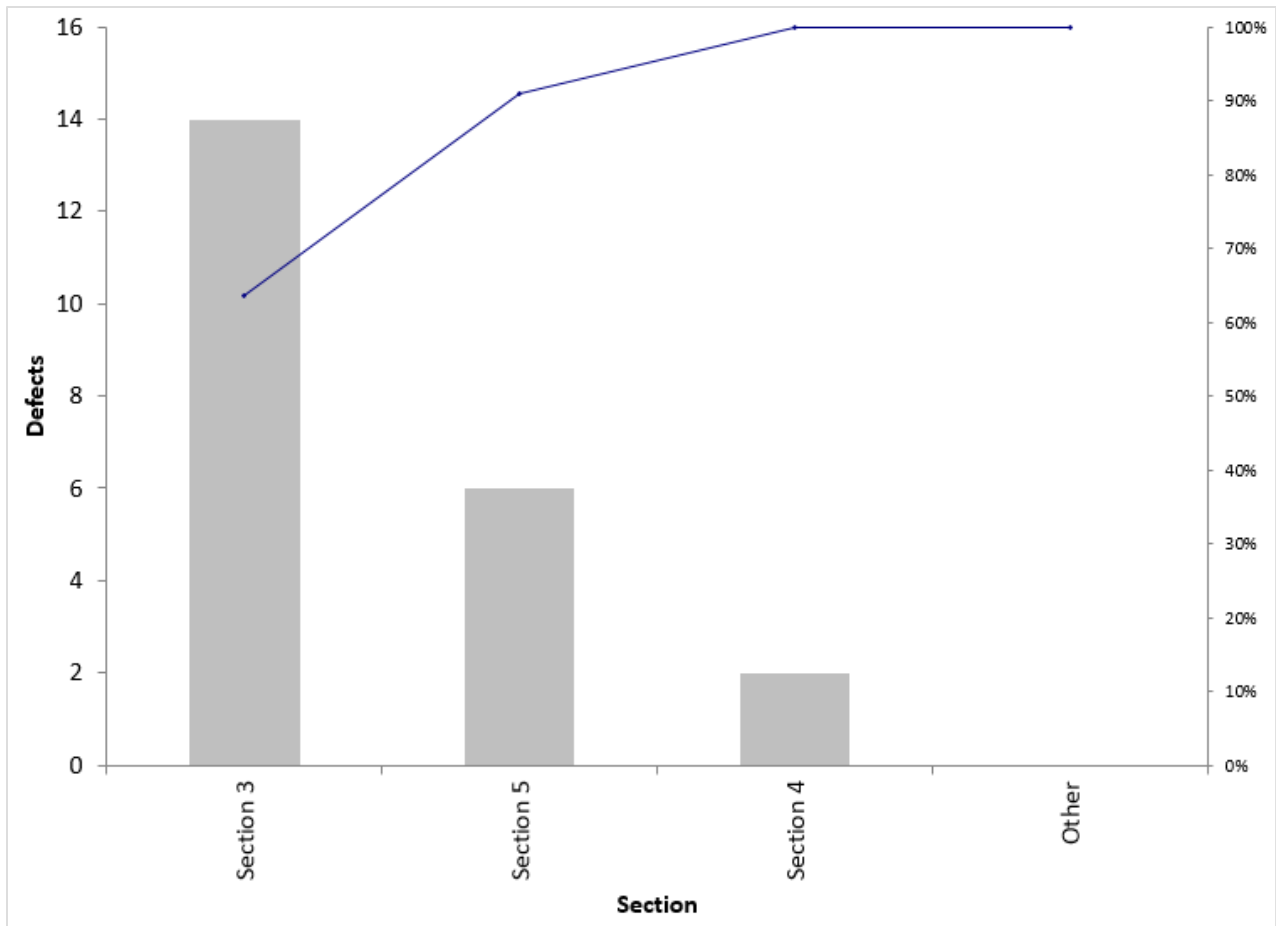


Fig. 1.32 Second Level Pareto (defects by section)

The second-level Pareto shows the count of the defective items by section for only Team 4 (22 defects). You can see that teams are broken down to sections and it appears that section 3 accounts for 63% of the total defects for team 4.

Pareto Analysis: Third Level

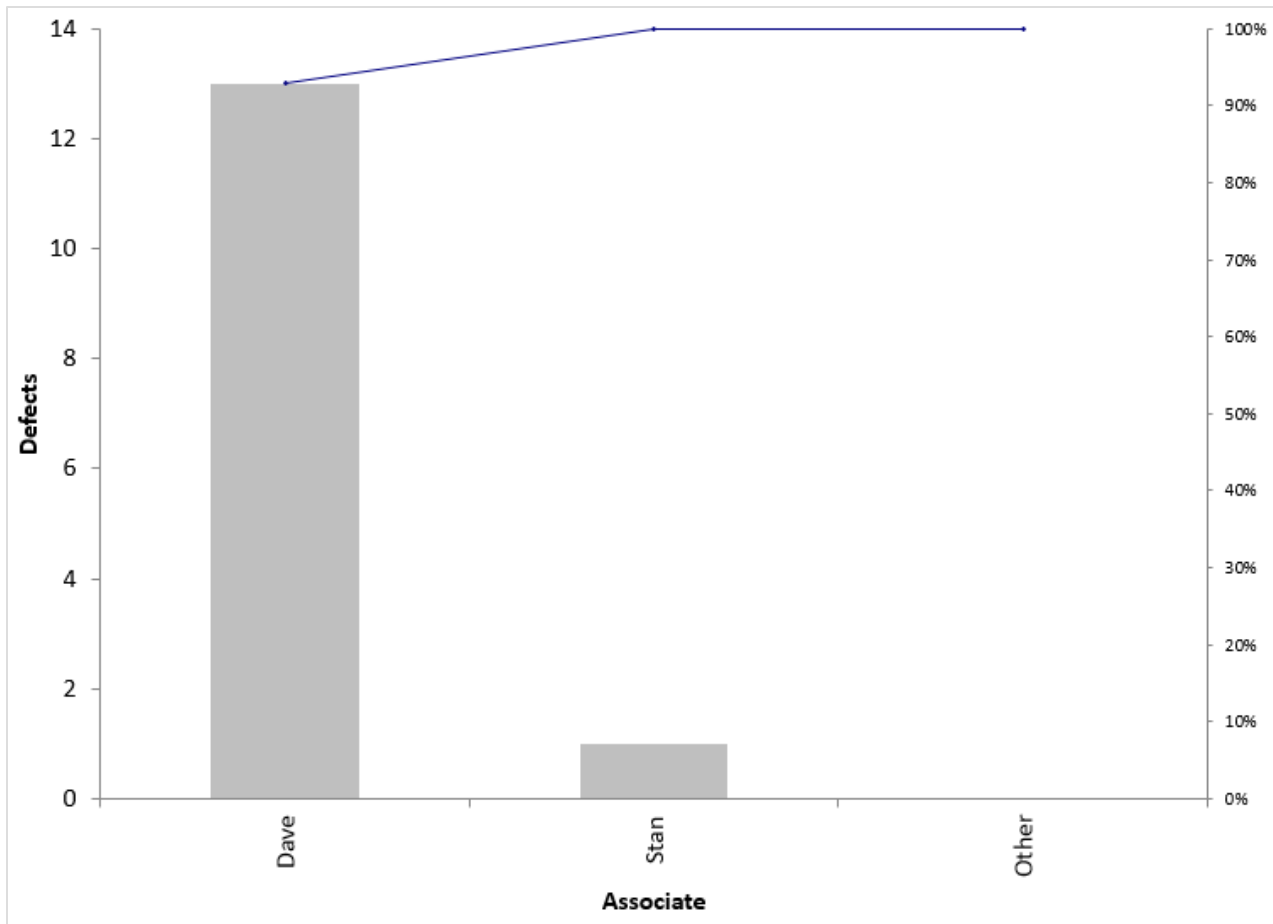


Fig. 1.33 Third Level Pareto (defects by associate)

The third-level Pareto shows the count of defective items by associate for only Section 3 of Team 4. The total defects by associate sum to the total for Section 3 and Dave accounts for 93% of Section 3's defects.

Pareto Analysis: Conclusion

Our analysis clearly shows the root of the problem being associate Dave who has 13 of the 14 defects in Section 3 of Team 4. Through this multi-level Pareto analysis, instead of focusing on all teams to reduce the number of defects, we discovered that we can focus on a single individual who is contributing 13 defects out of a total of 44 which is 30% of the total for all teams. Determining what Dave might be doing differently or wrong and solving that problem could fix about 30% of the entire defective products (13/44). This type of analysis significantly narrowed the focus necessary for reducing defective products.

1.3 SIX SIGMA PROJECTS

1.3.1 SIX SIGMA METRICS

There are many Six Sigma metrics and/or measures of performance used by Six Sigma practitioners. In addition to the ones we will cover here, several others (Sigma level, C_p , C_{pk} , P_p , P_{pk} , takt time, cycle time, utilization etc.) will be covered in other modules throughout this training. The Six Sigma metrics of interest in the *Define* phase are:

- Defects per Unit
- Defects per Million Opportunities
- Yield
- Rolled Throughput Yield

Defects per Unit

DPU, Defects per Unit, is the basis for calculating DPMO and RTY, which we will cover in the next few pages. DPU is found by dividing total defects by total units.

$$DPU = \frac{D}{U}$$

For example, if you have a process step that produces an average of 65 defects for every 598 units, then your $DPU = 65/598 = 0.109$ or 10.9%.

Defects per Million Opportunities

DPMO, Defects per Million Opportunities, is one of the few important Six Sigma metrics that you should get comfortable with if you are associated with Six Sigma. Remember 3.4 defects per million opportunities? In order to understand DPMO it is best if you first understand both the nomenclature and the nuances such as the difference between defect and defective.

Nomenclature:

- Defects = D
- Unit = U
- Opportunity to have a defect = O

To properly discuss DPMO, we must first explore the differences between “defects” and “defective.”

Defective

Defective suggests that the value or function of the entire unit or product has been compromised. Defective items will always have at least one defect. Typically, however, it takes multiple defects and/or critical defects to cause an item to be defective.

Defect

A defect is an error, mistake, flaw, fault, or some type of imperfection that reduces the value of a product or unit. A single defect may or may not render the product or unit “defective” depending on the specifications of the customer.

To summarize in simple terms, defect means that part of a unit is bad. Defective means that the whole unit is bad. Now let us turn our attention to defining “opportunities” so that we can fully understand Defects per Million Opportunities (DPMO).

Opportunities

Opportunities are the total number of possible defects. Therefore, if a unit has six possible defects, then each unit produced is equal to six defect opportunities. If we produce 100 units, then there are 600 defect opportunities (100 units × 6 opportunities/unit).

Calculating Defects per Million Opportunities

The equation is:

$$DPMO = \frac{D}{U \times O} \times 1,000,000$$

For example, let us assume there are six defect opportunities per unit and there is an average of 4 defects every 100 units.

Opportunities = 6 × 100 = 600

Defect rate = 4/600

DPMO = 4/600 × 1,000,000 = 6,667

What is the reason or significance of 1,000,000? Converting defect rates to a “per million” value becomes necessary when the performance of your process approaches Six Sigma. When this happens, the number of defects shrink to virtually nothing. In fact, if you recall from section “1.1 What is Six Sigma”, six sigma is equivalent to 3.4 defects per million opportunities. By using 1,000,000 opportunities as the barometer we have the resolution in our measurement to count defects all the way up to Six Sigma.

Rolled Throughput Yield

Rolled Throughput Yield (RTY) is a process performance measure that provides insight into the cumulative effects of an entire process. RTY measures the yield for each of several process steps and provides the probability that a unit will come through that process defect-free.

RTY allows us to expose the “hidden factory” by providing visibility into the yield of each process step. This helps us identify the poorest performing process steps and gives us clues into where to look to find the most impactful process improvement opportunities.

Calculating RTY

RTY is found by multiplying the yields of each process step. Let us take the five-step process below and calculate the RTY (the yield or percent of units that get through without a defect) using the multiplication method mentioned above.

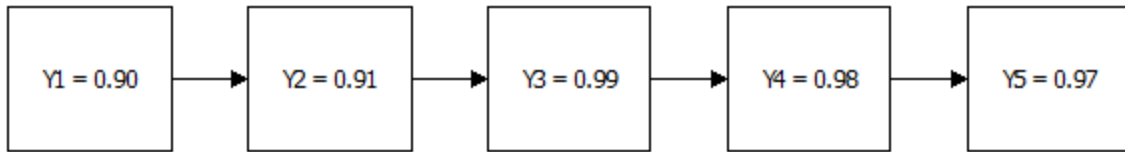


Fig. 1.34 Five Yields for a 5-step process

The RTY calculation for figure 1.34 is: $RTY = 0.90 \times 0.91 \times 0.99 \times 0.98 \times 0.97 = 0.77$

Therefore, $RTY = 77\%$. In this example, 77% of units get through all five process steps without a defect. You may have noticed that to calculate RTY we must determine the yield for each process step. Before we get into calculating yield, there are a few abbreviations that need to be declared.

- Defects = D
- Unit = U
- Defects per Unit = DPU
- Yield = Y
- $e = 2.71828$ (mathematical constant)

Calculating Yield

The *yield* of a process step is the success rate of that step or the probability that the process step produces no defects. To calculate the yield, we need to know the DPU and then we can apply it to the yield equation below.

$$Y = e^{-dpu}$$

For example, let us assume a process step has a DPU of 0.109 (65/598).

$Y = 2.718^{-0.109} = 0.8967$. Rounded, $Y = 90\%$.

In this example, the DPU (defects per unit) is 0.109 (65 defects/598 units). Plugging in the DPU, and using the mathematical constant for e (2.718), the result is 0.8967, or 90% when rounded. Below in table 1.3, is the above process yield data that we used in the earlier RTY calculation. This table allows us to see the DPU and yield of each step as well as the RTY for the whole process.

Process Step	Defects	Units	DPU	Yield	RTY
1	65	598	0.10870	0.89701	0.90
2	48	533	0.09006	0.91389	0.82
3	5	485	0.01031	0.98974	0.81
4	10	480	0.02083	0.97938	0.79
5	15	471	0.02972	0.97072	0.77

Table 1.3 DPU, Yield and RTY from figure 1.34

The rightmost column of table 1.3 shows the RTY cumulated through all the process steps. Which steps seem to be the greatest opportunities? Notice the yield in steps 1 and 2 are the lowest.

Estimating Yield

Instead of using the equation provided earlier, there is a simpler way to calculate yield using *yield estimation*: It is possible to “estimate” yield by taking the inverse of DPU or simply subtracting DPU from 1.

Yield Estimation = $1 - \text{DPU}$

Consider the DPU’s in table 1.3 and follow the 1-DPU method for estimating yield. You should have something similar to the following equations:

- Yield Estimate for process step 1: $1 - 0.10870 = 0.90$
- Yield Estimate for process step 2: $1 - 0.09006 = 0.91$
- Yield Estimate for process step 3: $1 - 0.01031 = 0.99$
- Yield Estimate for process step 4: $1 - 0.02083 = 0.98$
- Yield Estimate for process step 5: $1 - 0.02972 = 0.97$

Now, let’s calculate RTY using the Yield Estimation Method:

$$\text{RTY} = 0.90 \times 0.91 \times 0.99 \times 0.98 \times 0.97 = 0.77 = 77\%$$

The maximum DPU is 1, so to get a yield just subtract DPU from 1. As you can see, by calculating yield this way we get the same result for RTY. The previous method’s calculated result was also 77%. This may not be the most exact approach but for business professionals who make decisions based on sound analysis, the estimation method will typically suffice.

1.3.2 BUSINESS CASE AND CHARTER

Earlier we stated that DMAIC is a structured and rigorous methodology designed to be repeatedly applied to *any* process in order to achieve Six Sigma. We also stated that DMAIC was a methodology that refers to five phases of a project: Define, Measure, Analyze, Improve, and Control.

Given that the premise of the DMAIC methodology is project-based, we must take the necessary steps to define and initiate a project, hence the need for project charters. The project charter is what sets direction for a project.

Project Charter

The purpose of a *project charter* is to provide vital information about a project in a quick and easy-to-comprehend manner. It is a contract of sorts between project champions, sponsors, stakeholders, and the project team. It is a quick reference to tell the story of what, why, who,

when, etc. To set the *right* direction for a project, it is critical to define certain guardrails to ensure the project stays on track and is successful. Project charters are used to get approval and buy-in for projects and initiatives as well as declaring:

- Scope of work
- Project teams
- Decision authorities
- Project lead
- Success measures

The key elements of project charters are:

- Title
- Project Lead
- Business Case
- Problem Statement
- Project Objective
- Primary Metric
- Secondary Metrics
- Project Scope
- Project Timeline
- Project Constraints
- Project Team
- Stakeholders
- Approvers
- Constraints
- Dependencies
- Risk

Project Charter			Project Title:						
			Black Belt	Project Champion	Executive Sponsor	MBB/Mentor			
Primary Metric			Secondary Metric						
Problem Statement			Business Case						
High Level Project Timeline			Constraints & Dependencies		Project Risks		Other Diagnostics		
Phase	Start	Finish							
Define									
Measure									
Analyze									
Improve									
Control									
Approval/Steering Committee			Stakeholders & Advisors		Project Team & SME's				
Name		Organization	Name		Organization		Name		Organization

Fig. 1.35 Project Charter Template

Figure 1.35 above shows an example of a project charter with all the key elements. Because of its formatting, it's easy to share, easy to read, and is useful for quickly communicating to people who may not be familiar with the project.

Project Charter: Key Elements

Title: Projects should have a name, title, or some reference that identifies them. Branding can be an important ingredient in the success of a project so be sure your project has a reference name or title. This is how your project will be known to others, and keeping it top of mind is obviously part of ensuring its success.

Leader: All projects need a declared leader or someone who is responsible for project's **RACI** stands for **R**esponsible, **A**ccountable, **C**onsulted, and **I**nformed. RACI identifies the people that play those roles. Every project must have declared leaders indicating who is responsible and who is accountable.

Business Case: A business case is the quantifiable reason why the project is important. It is important for the business case to be quantifiable. Stakeholders have to know what success looks like. Cost of poor quality, as described earlier, is a great approach to quantifying the business case.

Business cases help shed light on problems. They explain why a business should care. A business case clearly articulates why it is necessary to do the project and what is the benefit to the customer, to employees, or to the shareholders.

A problem by itself is not enough to articulate why a project needs to be done. The business case turns the problem into the reason a business should care: What is the cost of the problem, what is the impact to customers, or what is the lost revenue opportunity? Business cases must be quantified and stated succinctly. COPQ is a key method of quantification for any business case.

Problem Statement and Objective: A properly written problem statement has an objective statement woven into it. There should be no question as to the current state or the goal.

A gap should be declared, the gap being the difference between the present state and the goal state. The project objective should be to close the gap or reduce the gap by some reasonable amount. Valuation or COPQ is the monetary value assigned to the gap.

Lastly, a well-written problem statement refers to a timeline expected to be met. A well-written problem statement includes all of the following:

- Declaration of the current state of a problem in terms of a given measure
- A goal for the measure, which establishes a gap from the current state
- An objective that states how much of the gap the project aims to close
- The monetary value of the objective (cost of poor quality)
- A timeline that the project will meet

Project Charter: Problem Statement Examples

Currently, process defect rates are 17% with a goal of 2%. This represents a gap of 15%, costing the business \$7.4 million dollars. The goal of this project is to reduce this gap by 50% before November 2010 putting process defect rates at 9.5% and saving \$3.7MM.

Process cycle time has averaged 64 minutes since Q1 2009. However, production requirements put the cycle time goals at 48 minutes. This 16-minute gap is estimated to cost the business \$296,000. The goal of this project is to reduce cycle time by 16 minutes by Q4 2010 and capture all \$296,000 cost savings. Can you identify the key elements of a problem statement?

Metrics: A measure of success is an absolute for any project.

- Metrics give clarity to the purpose of the work.
- Metrics establish how the initiative will be judged.
- Metrics establish a baseline or starting point.

For all Six Sigma projects, metrics are mandatory! How does one know if a project does what it sets out to do? It is critical that *every* project choose the right metrics to determine success. Project metrics are the center point for the work to ensure that the direction and decisions made through the course of the project are based on data. The metrics are what stakeholders will judge the success of the project on.

Primary Metric: The *primary metric* is a generic term for a Six Sigma project's most important measure of success. Choosing the primary metric should not be taken lightly. A Six Sigma expert should play a significant role in determining the primary metric to ensure it meets the characteristics of a good one. The primary metric is defined by the BB, GB, MBB, or Champion.

A primary metric is an absolute must for any project and it should not be taken lightly. Here are a few characteristics of good primary metrics. Primary metrics should be:

- Tied to the problem statement to ensure that what is being measured is a direct indication of whether the problem is being solved or not
- Measurable
- Expressed with an equation, meaning that the primary metric, Y, can be expressed as a function of the x's
- Aligned to business objectives, meaning that the primary metric should be correlated to business results
- Tracked at the proper frequency (hourly, daily, weekly, monthly etc.); in other words, they should be something that can be tracked frequently enough so that action can be taken quickly when the metric change
- Expressed pictorially over time with a run chart, time series, or control chart
- Validated with an MSA

The primary metric is the reason for your work, the success indicator, and your beacon. The primary metric is of utmost importance and should be improved, *but* not at the expense of your secondary metric. Do not trade one problem for another. Solutions need to be balanced. Be sure that you do not create an issue somewhere else when you implement a solution to improve your primary metric. That is why *secondary metrics* are important.

Secondary Metric: The *secondary metric* is the thing you do not want sacrificed on behalf of a primary improvement. A secondary metric is one that makes sure problems are not just “changing forms” or “moving around.” The secondary metric keeps us honest and ensures we are not sacrificing too much for our primary metric.

If your primary metric is a cost or speed metric, then your *secondary metric* should probably be some quality measure. For example, if you were accountable for saving energy in an office building and your primary metric was energy consumption then you *could* shut off all the lights and the HVAC system and save tons of energy . . . except that your secondary metrics are probably comfort and functionality of the work environment.

When you think about your primary metric, think about the really easy and obvious ways to improve the primary metric. Chances are that you can easily improve it by sacrificing something else. The elements of a good project charters include:

- Scope Statement—Defined by high-level process map
- Stakeholders Identified—Who is affected by the project
- Approval Authorities Identified—Who makes the final call
- Review Committees Defined—Who is on the review team
- Risks and Dependencies Highlighted—Identify risks and critical path items
- Project Team Declared—Declare team members
- Project Timeline Estimated—Set high-level timeline expectations

1.3.3 PROJECT TEAM SELECTION

Six Sigma project team selection is the cornerstone of a successful Six Sigma project. Team selection is obviously not something that is unique to a Six Sigma project. Team selection is important in any kind of project. You want to choose a group of people that complement each other, share similar goals and objectives, and are not afraid to hold each other accountable for achieving the project’s objectives.

Teams and Team Success

A *team* is a group of people who share complementary skills and experience.

- A team will be dedicated to consistent objectives.
- Winning teams share similar and coordinated goals.
- Teams often execute common methods or approaches.

- Team members hold each other accountable for achieving shared goals.

What Makes a Team Successful?

There should not be any surprises about what makes a team successful. These characteristics are all important for a team to be successful:

- | | |
|----------------|------------------------------|
| • Shared goals | • Effective communication |
| • Commitment | • Autonomy |
| • Leadership | • Diverse knowledge & skills |
| • Respect | • Adequate resources |

The keys to team success are:

- Agreed focus on the goal or the problem at hand
 - Focus on problems that have meaning to the business
 - Focus on solvable problems within the scope of influence; a successful team does not seek unattainable solutions
- Team Selection
 - Selected teammates have proper skills and knowledge
 - Adequately engaged management
 - Appropriate support and guidance from their direct leader
- Successful teams use reliable methods
 - Follow the prescribed DMAIC methodology
 - Manage data, information, and statistical evidence
- Successful teams always have “exceeds” rated players. Winning teams typically have unusually high standards
 - Have greater expectations of themselves and each other
 - Do not settle for average or even above average results

Teams should be able to agree on what the focus is. The team members all need to understand how the problem translates to something meaningful for the business. They also should be realistic about what they can and should seek to accomplish.

The people that are selected need to have “skin in the game.” Not only do they need to be knowledgeable and have the needed skills, but they (and their management) need to be motivated to seek the solution.

The team should use the facts and data to lead the way. Be disciplined to follow the DMAIC approach and be aware of when a gut feeling or emotion is driving their behavior. Of course, teams should be built from the top performers whenever possible.

Principles of Team Selection

- Select team members based on:

- Skills required to achieve the objective
- Experience (subject matter expertise)
- Availability and willingness to participate
- Team size (usually four to eight members)
- Don't go at it alone!
- Don't get too many cooks in the kitchen!
- Members' ability to navigate
- The process
- The company
- The political landscape
- Be sure to consider the inputs of others
 - Heed advice
 - Seek guidance

A team member should be selected based on the skills and subject matter expertise. For example, if you are focusing on a process improvement, find a top performing employee that performs the process on a regular basis. A team member needs to have capacity to participate on a project. Therefore, it is important to pick people with shared goals. If they have a shared goal, it is likely that they can find the time.

The team size needs to be optimal. Include enough people to generate consensus, but not too many people because they can never reach consensus, and this can paralyze a project. Be open minded, listen to others, be inclusive.

Project Team Development

All teams experience the following four stages of development. It is helpful to understand these phases so that you can anticipate what your team is going to experience. The four stages of team development process are:

1. Forming
2. Storming
3. Norming
4. Performing

Teammates seek something different at each stage:

1. In the forming stage they seek inclusion
2. In the storming stage they seek direction and guidance
3. In the norming stage they seek agreement
4. In the performing stage they seek results

Patterns of a team in the Forming stage:

- Roles and responsibilities are unclear

- Process and procedures are ignored
- Scope and parameter setting is loosely attempted
- Discussions are vague and frustrating
- There is a high dependence on leadership for guidance

In the Forming stage, people are trying to figure out where they fit in; the team is trying to figure out where the social boundaries are with each other; they are all trying to “get to know” each other.

Patterns of a team in the Storming stage:

- Attempts to skip the research and jump to solutions
- Impatience for some team members regarding lack of progress
- Arguments about decisions and actions of the team
- Team members establish their position
- Subgroups or small teams form
- Power struggles exist and resistance is present

After the delay of the forming stage, urgency can set in and they start to seek progress. Team members even seek progress by sacrificing the discipline. Patterns of a team in the Norming stage are:

- Agreement and consensus start to form
- Roles and responsibilities are accepted
- Team members’ engagement increases
- Social relationships begin to form
- The leader becomes more enabling and shares authority

In the Norming stage the team is settling into place and into roles with responsibilities. Once roles are clear, engagement increases with comfort level, and the team starts to form relationships with each other. Patterns of a team in the Performing stage are:

- Team is directionally aware and agrees on objectives
- Team is autonomous
- Disagreements are resolved within the team
- Team forms above average expectations of performance

In the Performing stage, the team is aligned and directed. The members are autonomous in that they can resolve issues within and stay on the path to progress. The team is united to exceed expectations of performance.

Well-structured and energized project teams are the essential components of any successful Six Sigma project. To have better chances of executing the project successfully, you will need to understand and effectively manage the team development process. Even with the most

perfectly defined project, a well-structured team can be the difference between success and failure.

1.3.4 PROJECT RISK MANAGEMENT

Risk

Risk is defined as a future event that *can* impact the task/project if it occurs. A broad definition of project risk is an uncertainty that can have a negative *or* positive effect on meeting project objectives. Positive risks are risks that result in good things happening—sometimes called opportunities.

What is Project Risk Management?

The main purpose of *risk management* is to foresee potential risks that may inhibit the project deliverables from being delivered on time, within budget, and at the appropriate level of quality, and then to mitigate these risks by creating, implementing, and monitoring *contingency plans*. Risk management is concerned with identifying, assessing, and monitoring project risks before they develop into issues and impact the project.

Risk analysis helps to identify and manage potential problems that could impact key business initiatives or project goals.

Three Basic Parameters of Risk Analysis

1. Risk Assessment: The process of identifying and evaluating risks, whether in absolute or relative terms
2. Risk Management: Project risk management is the effort of responding to risks throughout the life of a project and in the interest of meeting project goals and objectives
3. Risk Communication: Communication plays a vital role in the risk analysis process because it leads to a good understanding of risk assessment and management decisions

Why is Risk Analysis Necessary?

What can happen if you omit the risk analysis?

- Vulnerabilities cannot be detected
- Mitigation plans are introduced without proper justification
- Customer dissatisfaction
- Not meeting project goals
- Remake the whole system
- Huge cost and time loss

Project Risk Analysis Steps

The project risk analysis process consists of the following steps that evolve through the life cycle of a project.

1. Risk Identification: Identify risks and risk categories, group risks, and define ownership.
2. Risk Assessment: Evaluate and estimate the possible impacts and interactions of risks.
3. Response Planning: Define mitigation and reaction plans
4. Mitigation Actions: Implement action plans and integrate them into the project
5. Tracking and Reporting: Provide visibility to all risks
6. Closing: Close the identified risk

1. Risk Identification

The first action of risk management is the identification of individual events that the project may encounter during its lifecycle. The identification step comprises:

- Identify the risks
- Categorize the risks
- Match the identified risks to categories
- Define ownership for managing the risks

The process of identification, matching, and assigning ownership may involve the full project team in a brainstorming exercise or a workshop. The team should be encouraged to participate in risk identification by actively reporting risks as they arise, and to make suggestions as to the controls needed to rectify the situation.

Source of Risk:

Identification of risk sources provides a basis for systematically examining changing situations over time to uncover circumstances that impact the ability of the project to meet its objectives.

Establishing categories for risks provides a mechanism for collecting and organizing risks as well as ensuring appropriate scrutiny and management attention for those risks that can have more serious consequences on meeting project objectives.

Source of Risk	Description
Human Resources	The risks originated from human resources (e.g. resource availability, skills, training etc.)
Physical Resources	The risks originated from physical resources (e.g., hardware or software, availability of the required number at the right time etc.)
Technology	The risks originated from technology (e.g., development environment, new or complex technologies, performance requirements, tools etc.)
Suppliers	The risks are associated with a supplier (e.g., delays in supplies, capability of suppliers etc.)
Customer	The risks derived from the customer (e.g., unclear requirements, requirement volatility, change in project scope, delays in response etc.)
Security	The risks are associated with information security, security of personnel, security of assets, and security of intellectual property
Legal	The risks are associated with legal issues that may impact the project
Project Management	The risks are associated with project management processes, organizational maturity etc.

Table 1.4 Risk Identification (sources of risk)

The table above shows some examples of source of risks, from those associated with human resources to those related to project management.

Risk Parameters:

Parameters for evaluating, categorizing, and prioritizing risks include the following:

- Risk likelihood (i.e., probability of risk occurrence)
- Risk consequence (i.e., impact and severity of risk occurrence)
- Thresholds to trigger management activities

Risk parameters are used to provide common and consistent criteria for comparing the various risks to be managed and to prioritize the necessary actions required for risk mitigation planning.

2. Risk Assessment

The *risk assessment* consists of evaluating the range of possible impacts should the risk occur.

Follow these steps when assessing risks:

- Define the various impacts of each risk
- Rate each impact based on a logical severity level
- Sort and evaluate risks by severity level
- Determine if any controls already exist

- Define potential mitigation actions

We must prioritize and act on risks in order of priority. In reality, we may be able to fix simple project risks immediately, so we must also use our common sense when prioritizing. Prioritizing is good practice when we need to allocate resources and keep records of the process. The project core team must review *all* risks to ensure the full impact of risk on a project has been identified and estimated.

3. Risk Mitigation Planning

The risk owners are responsible for planning and implementing mitigation actions with support from the project team.

All team members, inclusive of partners and suppliers, may be requested to identify and develop mitigation measures for identified risks. The project core team members are responsible for identifying an appropriate action owner for each identified risk.

After mitigation actions are defined, the project core team will review the actions. The risk owner must track all mitigation actions and expected completion dates. The risk owner and the project core team members must hold all action owners accountable for the risk mitigation planning.

Documenting the process allows us to systematically address the risk that exists in the project. Once the process is documented, action plans can be formulated and responsibilities allocated for controls that need to be implemented to eliminate or reduce the risk of those hazards.

An action plan for each identified risk can include multiple actions involving the team members. In case of risk occurrence, or risk triggers, the risk owner reports to the project manager and implements the response plans.

4. Risk Mitigation Action Implementation

The *action implementation* is the responsibility of the risk owner. The action owners are responsible for the execution of the tasks or activities necessary to complete the mitigation action and eliminate or minimize the risk. The risk owner or the project manager will monitor completion dates of the mitigation action implementation.

Risk Occurrence and Contingency Plans

Whenever any risk occurs, the project team should implement *contingency plans* to ensure that project deliverables can be met. The details of each occurrence should be recorded in the risk register or other tracking tool.

The *risk register* or *risk management plan* will be maintained by the project manager and reviewed regularly. The risk register is a document that contains the results of various risk management processes. It is often displayed in a table or spreadsheet format.

5. Risk Tracking and Reporting

Risk tracking and reporting provides critical visibility to all risks. Risk owners must report on the status of their mitigation actions.

The most efficient method to track and report risk is to do it as an integral part of project team meetings through all stages in the project lifecycle. Depending on the risk severity, project managers need to report the risk status of each category of risk to senior management in the form of dashboards or through weekly status reports.

Risk Management Plan							
Company		Project/Program Name		Project Lead		Project Sponsor/Champion	
Risk ID	Risk Category	Risk Description	Risk Impact	Impact Rating	Mitigation Action	Responsible	Status

Fig. 1.36 Risk Management Plan Example

6. Risk Closure

The risk owners are responsible for recommending the risk closure to the project manager.

A risk is *closed* only when the item is not considered a risk to the project anymore. When a risk is closed, the project manager needs to update the risk status in the lessons learned document.

Risk Analysis Features

The risk analysis should be:

- Systematic
- Comprehensive
- Data driven
- Adherent to evidence
- Logically sound
- Practically acceptable
- Open to critique
- Easy to understand

Project Risk Analysis Advantages

The risk analysis:

- Aids strategic & business planning
- Meets customer requirements
- Reduces schedule delays
- Minimizes cost overruns
- Promotes effective use of resources
- Promotes continuous improvement
- Helps to achieve project goals
- Prevents surprises
- Uncovers new opportunities
- Enhances communication

What is Project Management?

Project management is the process of defining, planning, organizing, managing, leading, securing, and optimizing the resources to achieve a set of planned goals and objectives. It is the application of knowledge, skills, tools, and techniques to project activities in order to meet project requirements.

Project management involves understanding project needs, planning those needs, and properly allocating resources to achieve the desired results.

The basic steps of project management as we will cover in greater detail later are: initiating the project, planning the project, executing the project, and closing the project.

What is a Project Plan?

A *project plan* is a crucial step in project management for achieving a project's goals. A project plan is a formal approved document used to guide and execute project tasks. It provides an overall framework for managing project tasks, schedules, and costs. Project plans are coordinating tools and communication devices that help teams, contractors, customers, and organizations define the crucial aspects of a project or program. Project planning involves defining clear, distinct tasks and deliverables, and the work needed to complete each task and phase of the project.

Project Planning Stages

The stages of project planning are:

- Determine project scope and objectives: Explore opportunities, identify and prioritize needs, consider project solutions
- Plan the project: Identify input and resources requirements such as human resources, materials, software, hardware, and budgets.
- Prepare the project proposal: Based on stakeholder feedback, plan the necessary resources, timeline, budget etc.
- Implement the project: Implement the project by engaging responsible resources and parties. Ensure execution and compliance of the defined plans.
- Evaluate the project: Regularly review progress and results. Measure the project's effectiveness against *quantifiable* requirements

The five key stages of project planning are:

1. Determining project scope and objectives
2. Project planning
3. Project proposal and approval

4. Project implementation
5. Project evaluation

Planning and Scheduling Objectives

The goals of planning and scheduling are:

- To optimize the use of resources (both human and other resources)
- To increase productivity
- To achieve desired schedules and deliverables
- To establish an approach to minimize long-term maintenance costs
- To minimize the chaos and productivity losses resulting from planned production schedules, priority changes, and non-availability of resources
- To assess current needs and future challenges

Proper project planning is necessary to coordinate all resources and tasks.

Project Planning Activities

Project planning activities involve the creation of:

- Statement of work
- Work breakdown structure
- Resource estimation plan
- Project schedule
- Budget or financial plan
- Communication plan
- Risk management plan

Project Planning Activities: Statement of Work

Statement of Work (SOW) is a formal document often accompanying a contract that outlines specific expectations, limitations, resources and work guidelines intended to define the work or project.

SOWs:

- Define the scope of the project
- Establish expectations and parameters of the project
- Identify technical requirements for the project
- Provide guidance on materials to be used
- Establish timeline expectations

SOWs or statements of work are important “contracts” that outline many critical elements of a project or body of work. SOWs clarify expectations, deliverables, timelines, budgets, and responsibilities.

Project Planning Activities: Work Breakdown Structure

Work Breakdown Structure (WBS) is a decomposition of project components into small and logical bodies of work or tasks.

WBSs:

- Identify all required components of a project
- Cascades components into sub-components and tasks

WBSs are not by themselves project plans or schedules but they are a necessary step to help establish project plans and timelines. WBSs also enable logical reporting and summarizations of project progress.

Level 1	Level 2	Level 3
1.0 Bicycle	1.1 Frame	1.1.1 Set Body Frame
		1.1.2 Assemble Handlebars
		1.1.3 Install Seat & Seat Post
		1.1.4 Assemble Wheel Bearings & Axle
		1.1.5 Install Wheels
		1.1.6 Attach Brake System to Frame Set
	1.2 Wheels	1.2.1 Stage Rims
		1.2.2 Install Spokes
		1.2.3 Insert Tubes in Tires
		1.2.4 Assemble Tires on Rims
		1.2.5 Install Reflectors
	1.3 Brake System	1.3.1 Connect Brake Cables To Hand Levers
		1.3.2 Connect Brake Cables to Brake Harness
		1.3.3 Attach Brake Pads to Brake Harness
		1.3.4 Adjust/Calibrate Brake System

Fig. 1.37 Work Breakdown Structure Example

A WBS is an important parameter in project planning because projects must inevitably be divided into smaller, more manageable tasks and subtasks. These breakdowns must be aligned in a logical manner to meet customer defined target dates. The WBS is required to prepare a project schedule and/or Gantt chart as well as to identify project milestones.

Project Planning Activities: Resource Planning

Resource Estimation Plan

- Estimate Resource Requirements (Use Your WBS)
- Parts, Hardware, Software, Human Resources etc.
- Plan resources
- Establish who is responsible for what and when
- Determine quantity requirements and delivery dates etc.

Level 3	Parts Required	Quantity	Cost	Part Inventory	Responsible
1.1.1 Set Body Frame	Body Frame	1	\$9.00	4	John
1.1.2 Assemble Handlebars	Handlebars	1	\$4.00	4	John
1.1.3 Install Seat & Seat Post	Seat & Post	1 Each	\$3.00	4 Each	John
1.1.4 Assemble Wheel Bearings & Axle	Bearing & Axle	2 Each	\$1.00	8 Each	John
1.1.5 Install Wheels	Wheels	2	\$0.50	8	John
1.1.6 Attach Brake System to Frame Set					John
1.2.1 Stage Rims	Wheel Rim	2	\$0.30	12	Cathy
1.2.2 Install Spokes	Spokes	48	\$0.03	72	Cathy
1.2.3 Insert Tubes in Tires	Tubes & Tires	2 Each	\$0.33	0 Tubes 8 Tires	Cathy
1.2.4 Assemble Tires on Rims					Cathy
1.2.5 Install Reflectors	Reflectors	4	\$0.10	18	Cathy
1.3.1 Connect Brake Cables To Hand Levers	Cables & Levers	2 Each	\$0.90	12 Each	Lisa
1.3.2 Connect Brake Cables to Brake Harness	Brake Harness	2	\$0.40	8	Lisa
1.3.3 Attach Brake Pads to Brake Harness	Brake Pads	4	\$0.15	12	Lisa
1.3.4 Adjust/Calibrate Brake System					Lisa

Fig. 1.38 Resource Estimation Plan Example

The estimation of resource requirements (human, software, hardware, materials etc.) is necessary for each task and is useful for the creation of a project plan. Use your work breakdown structure to boil it down to tasks so that you can determine specific resource requirements, dependencies etc.

Project Planning Activities: Project Scheduling

Project Scheduling

- Assign beginning times to each activity in the WBS (days are used for start and durations times in example below)
- Assign duration times to each activity in the WBS
- Identify People Responsible and set completion dates
- Represent schedules as Gantt charts or network diagrams
- Identify critical dependencies between tasks

Level 2	Level 3	Task Start	Task Duration	Responsible
1.1 Frame	1.1.1 Set Body Frame	0	2	John
	1.1.2 Assemble Handlebars	2	2	John
	1.1.3 Install Seat & Seat Post	4	2	John
	1.1.4 Assemble Wheel Bearings & Axle	6	4	John
	1.1.5 Install Wheels	14	4	John
	1.1.6 Attach Brake System to Frame Set	18	3	John
1.2 Wheels	1.2.1 Stage Rims	0	1	Cathy
	1.2.2 Install Spokes	1	7	Cathy
	1.2.3 Insert Tubes in Tires	10	2	Cathy
	1.2.4 Assemble Tires on Rims	12	2	Cathy
	1.2.5 Install Reflectors	8	2	Cathy
1.3 Brake System	1.3.1 Connect Brake Cables To Hand Levers	0	8	Lisa
	1.3.2 Connect Brake Cables to Brake Harness	8	8	Lisa
	1.3.3 Attach Brake Pads to Brake Harness	16	2	Lisa
	1.3.4 Adjust/Calibrate Brake System	21	2	Lisa

Fig. 1.39 Project Scheduling Example

Scheduling is critical because without it you will miss deadlines and poorly organize dependent tasks and activities. The result of the lack of scheduling, or of poor scheduling, can be catastrophic to a project.

Project Planning Activities: Project Scheduling

Project Schedule – Gantt Chart

The advantage of a Gantt chart is its ability to display the status of each task/activity at a glance. Because it is a graphic representation, it is easy to demonstrate the schedule of tasks and timelines to all the stakeholders.

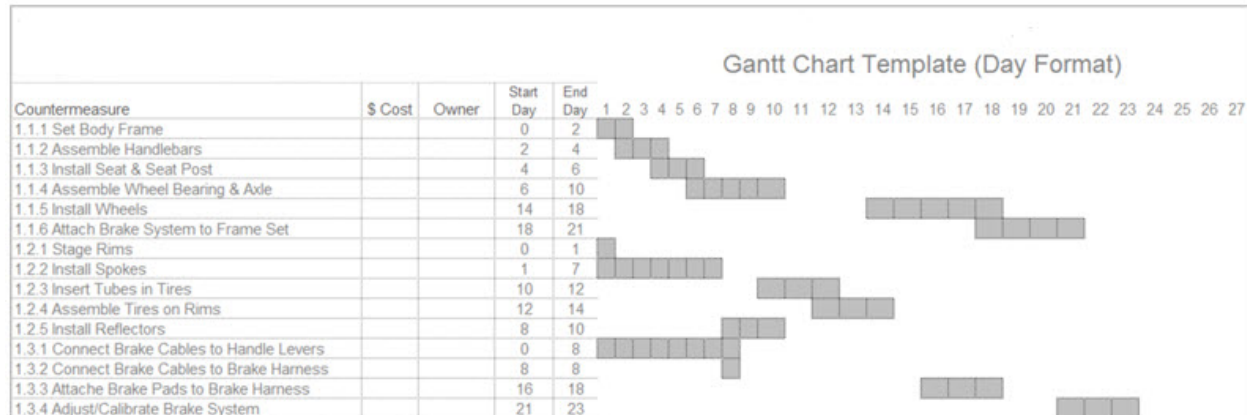


Fig. 1.40 Gantt Chart Example

A Gantt chart offers visibility to a project plan. It displays the tasks of the project plan in a simple and well-organized manner.

There are many tools available to create Gantt charts. Some of the most common and compatible for businesses are Microsoft Project, Visio, and Excel. In Microsoft Excel, there are no native Gantt chart templates so we have established a simple one to use with our bicycle example (shown in fig. 1.40). This template is available for free on our website under the "Tools" link.

Project Scheduling: Critical Path Method

Critical Path Method (CPM)

Critical path method (CPM) is a project modeling technique used to identify the set of activities that are most influential to a project's completion timeline. Critical path tasks are those that others are dependent upon.

Project timelines cannot be shortened without shortening the tasks or activities that are identified as critical path items.

Steps to Using the Critical Path Method

1. List all activities necessary to complete the project.
2. Determine the time or duration of each activity.
3. Identify the dependencies between the activities.

CPM is fundamental to project management. You must understand all required project tasks, their durations and dependencies. The critical path method can help you organize and understand how each task behaves relative to others and how the collection of all tasks fit in the grand scheme of a project.

Critical Path Method Example: Let's continue with our bicycle example referencing fig. 1.40. Note that the tasks in the WBS are already set to start based on their dependencies. For example, installing the wheels in step 1.1.5 requires the whole set of steps in 1.2 to be completed so 1.1.5 starts on day 14 when the wheels are ready.

By using your WBS, you can efficiently evaluate task durations and dependencies to find the critical tasks that will affect the final timeline of your project.

Continuing with this example; the last task, "1.3.4 Adjusting the Brake System" completes on day 23 and cannot begin until day 21 because the brake system must be attached to the bike frame before being calibrated. The reason for such a delay can be found in the earlier example. You should have noticed in the resource plan that tire tubes stock was depleted.

Let us assume the tubes take 21 days to receive from the supplier. Below is the adjustment to our Gantt chart. Notice that the project timeline is pushed out by ten days, finishing on day 33 instead of day 23.

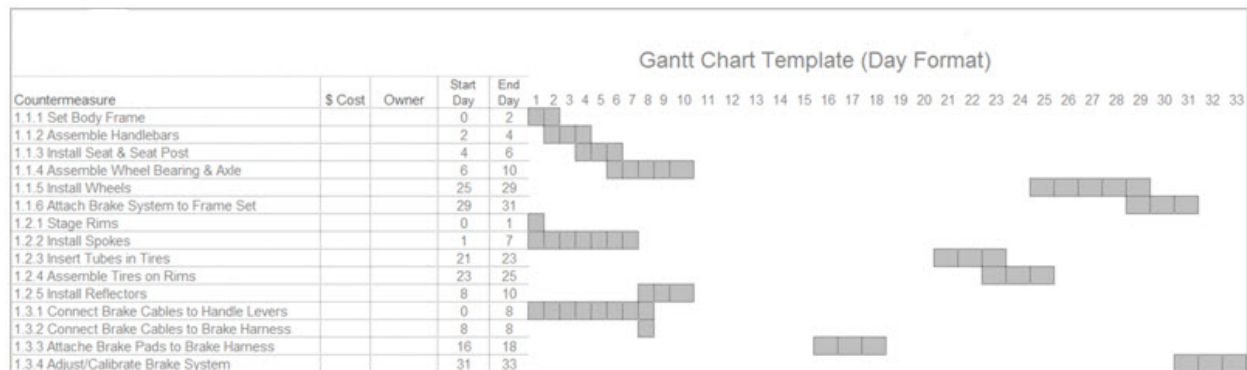


Fig. 1.41 Gantt Chart Revision (21 days for Tubes)

By coordinating the use of all project planning tools and methods covered this far (WBS, Resource Planning, Gantt Chart, CPM) you can not only depict the project tasks and timelines but you can also better manage resources as a result. The Tubes example demonstrates that there is nearly a full FTE resource wasted in waiting time. By knowing this you might be able to re-organize your projects tasks and resources to save on the cost of labor.

Project Scheduling: PERT

Program Evaluation and Review Technique (PERT)

The program evaluation and review technique (PERT) is a method of evaluation that can be applied to time or cost. PERT provides a weighted assessment of time or cost.

PERT uses three parameters for estimation:

1. Optimistic or Best Case Scenario represented by “O”
2. Pessimistic or Worst Case Scenario represented by “P”
3. Most Likely Scenario represented by “ML”

The PERT equation is:

$$E = \frac{O + 4ML + P}{6}$$

Where: E = estimate (of time or cost).

The PERT equation provides for heavier weighting of the most likely scenario but also considers the best and worst cases. In the event that a best or worst case scenario is an extreme situation, the PERT will account for it in a weighted manner.

Using the PERT formula, it is the sum of the estimates of the best case, the worst case, and four times the most likely case, all divided by six.

Let us apply the PERT formula to our estimates of receiving our needed tire tubes from the supplier and then change our schedule based on the result. Your experience with this supplier tells you that they typically overestimate the time required to deliver. Therefore, their 21 day lead time on the tubes should be considered a “worst case scenario.”

Procurement has indicated that tubes have arrived in as few as six days from this supplier. So, your best-case scenario is six days. The most likely scenario you decide will be the median of this supplier’s delivery time, which is 10 days.

Therefore:

$$E = \frac{O + 4ML + P}{6}$$

$$E = \frac{6 + 4 \times 10 + 21}{6}$$

$$E = \frac{6 + 40 + 21}{6}$$

$$E = \frac{67}{6}$$

$$E = 11$$

Using the PERT formula in this example: add the best-case scenario (6) to “four times the most likely scenario” (4*10) plus the worst case scenario (21). The result is sixty-seven. We then divide 67 by 6, which yields 11 (rounded). Eleven days is your adjusted estimate of delivery for

the tire tubes. Using 11 days in your project plan instead of 21 gives you a more confident estimate of time and removes tire tubes as the primary detracting critical path item.

Project Planning Activities: Budgeting or Financial Planning

Create a preliminary project budget that outlines the planned expenses and revenues pertaining to the project. Preliminary budgets are commonly used for project justification and future business forecasts.

Most organizations expect to see some financial analysis regarding the payback of a project. IRR (Internal Rate of Return) and NPV (Net Present Value) are two very common and acceptable financial measures that can be used to justify a project.

Project Planning Activities: Communication Plan

Communication plans are used to establish communication procedures among management, team members, and relevant stakeholders. It is appropriate and necessary to determine the communication schedule and define the acceptable modes of communication with your project team, stakeholders and steering committee.

Communication Plan Template									
<u>Process/Function Name</u>	<u>Project/Program Name</u>			<u>Project Lead</u>	<u>Project Sponsor/Champion</u>				
Communication Purpose:									
Target Audience	Key Message	Message Dependencies	Delivery Date	Location	Medium	Follow up Medium	Messenger	Escalation Path	Contact Information

Fig. 1.42 Communication Plan Example

Effective communication and frequency of communication are vital to any project. Keeping participants, stakeholders, and customers updated with progress and forecasts helps ensure good communication.

Project Planning Activities: Risk Management Plan

Risk management plans help to identify the sources of project risks and estimate the effects of those risks. Risks may arise from new technology, availability of resources, lack of inputs from customers, business risks or other unexpected sources.

It is important to assess the impact of risk to customers and project stakeholders. Calculate the probability of risk occurrence based on previous or similar projects and industry benchmarks. Then put a plan together to manage the risks.

Most projects that fail are due to the lack of, or improper, risk management. Identify sources of risk as early as possible in the project. Determine the severity and frequency of possible risk

occurrences and establish controls or mitigation plans. Prioritize your energy and resources based on risk severity.

Project Planning Tools Advantages

Project planning tools are very useful to organize and communicate project plans, status, and projections. The project planning tools we just reviewed (WBS, Schedule, Gantt, PERT etc.) are some of the most popular and readily available tools and methods used by professionals today.

Project planning tool advantages:

- Help link tasks and sub-tasks or other work elements to get a whole view of what needs to be accomplished
- Allow a more objective comparison of alternative solutions and provide consistent coverage of responsibilities
- Allow for effective scope control and change management
- Facilitate effective communication with all project participants and stakeholders
- Help define management reviews
- Act as an effective monitoring mechanism for the project
- Establish project baselines for progress reviews and control points

1.4 LEAN FUNDAMENTALS

1.4.1 LEAN AND SIX SIGMA

What is Lean?

A Lean enterprise is one which intends to eliminate waste and allow only value to be pulled through its system. A Lean enterprise can be achieved by identifying and effectively eliminating all waste (which will result in a flowing, cost-effective system).

A Lean manufacturing system drives value, flows smoothly, maximizes production, and minimizes waste. Lean manufacturing is characterized by:

- Identifying and driving value
- Establishing flow and pull systems
- Creating production availability and flexibility
- Zero waste
- Waste elimination
- Waste identification and elimination is critical to any successful Lean enterprise
- Elimination of waste enables flow, drives value, cuts cost, and provides flexible and available production

The Five Lean Principles

The following five principles of Lean are taken from the book *Lean Thinking* (1996) by James P. Womack and Daniel T. Jones.

1. Specify value desired by customers.
2. Identify the value stream.
3. Make the product flow continuous.
4. Introduce pull systems where continuous flow is possible.
5. Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls.

Principle 1: Specify Value Defined by Customers

Only a small fraction of the total time and effort spent in an organization actually adds value for the end customer. With a clear definition of value (from the customer's perspective), it is much easier to identify where the waste is.

Principle 2: Identify the Value Stream

The value stream is the entire set of activities across all parts of the organization involved in jointly delivering the product or service. It is the end-to-end process that delivers the value to the customer. As stated above, once you understand what determines value to the customer, it is easier to determine where the waste is.

Principle 3: Create Flow

Typically, you will find that only 5% of activities add value, but the percentage can be as high as 45% in a service environment. Eliminating most or all of this waste ensures that your product or service flows better. Thus, bringing timely, desired value to the customer without interruption or waiting.

Principle 4: Create Pull

When possible, understand the customer demand on your product or service. Then, create a process to respond to it. In other words, only produce what the customer wants when they want it.

Principle 5: Pursue perfection

At first, reorganizing process steps can improve flow, and as this is done, layers of waste become exposed and exploited. Continuing the process of eliminating, reorganizing, and exploiting waste will continue to drive down the number of steps and time needed to serve the customer. This continuous cycle should be pursued to perfection.

Lean and Six Sigma

Lean and Six Sigma both have the objectives of producing high value (quality) at lower costs (efficiency). They approach these objectives in somewhat different manners but in the end,

both Lean and Six Sigma drive out waste, reduce defects, improve processes, and stabilize the production environment.

Lean and Six Sigma are a perfect combination of tools for improving quality and efficiency. The two methodologies complement each other to improve quality, efficiency, and ultimately profitability and customer satisfaction.

1.4.2 HISTORY OF LEAN

History of Lean

Lean thinking has been traced as far back as the 1400s but the concepts and principles of Lean were more rigorously and methodically applied starting in the early 1900s. The first person to truly apply the principles in a production process was Henry Ford. He established the first mass production system in 1913 by combining standard parts, conveyors, and work flow. In 1913, Ford brought together the concepts of consistently interchangeable parts, standard work, and moving conveyance to create what he called *flow production*.

Decades later, between 1948 and 1975, Kiichiro Toyoda and Taiichi Ohno at Toyota improved and implemented various new concepts and tools (e.g., value stream, takt time, Kanban etc.) many based on Ford's efforts.

Toyota developed what is known today as the Toyota Production System (TPS) based in Lean principles. TPS advanced the concepts of Ford's system through a series of innovations that provided the continuity of flow *and* a variety of product offerings.

The term Lean, was later coined in the 1990's by John Krafcik who was a graduate student at MIT working on a research project for the book The Machine That Changed the World by Jim Womack. Womack, the founder of the Lean Enterprise Institute helped to refine and advance collectively, the principles known today as Lean.

1.4.3 SEVEN DEADLY MUDA

The Seven Deadly Muda

Muda is a Japanese word meaning “futility, uselessness, idleness, superfluity, waste, wastage, wastefulness.” The seven commonly recognized forms of waste, also called the “Seven Deadly Muda,” as defined by Taiicho Ohno (the Toyota Production System), are:

1. **Defects**
2. **Overproduction**—Producing more than what your customers are demanding
3. **Over-Processing**—Unnecessary time spent (e.g., relying on inspections instead of designing a process to eliminate problems)
4. **Inventory**—Things awaiting further processing or consumption

5. **Motion**—Extra, unnecessary movement of employees
6. **Transportation**—Unnecessary movement of goods
7. **Waiting**—For an upstream process to delivery, for a machine to finish processing, or for an interrupted worker to get back to work

The Seven Deadly Muda: Defects

Defects or defectives are an obvious waste for any working environment or production system. Defects require rework during production or afterwards when the product is returned from an unhappy customer.

Some defects are difficult to solve and often create workarounds and hidden factories. Nobody likes defects. They are an obvious form of waste—wasted time, wasted materials, and wasted money. Defects take time and resources to be fixed, and can be especially costly if they get into the hands of a customer. Eliminating defects is a sure way to improve product quality, customer satisfaction, and production costs.

The Seven Deadly Muda: Overproduction

Overproduction is wasteful because your system expends energy and resources to produce more materials than the customer or next function requires. Overproduction is one of the most detrimental of the seven deadly muda because it leads to other wastes such as overproduction, inventory, transportation and it also exacerbates existing wastes already inherent in the process such as defects, waiting or needless motion.

The Seven Deadly Muda: Over-Processing

Over-processing occurs any time more work is done than is required by the next process step, operation, or consumer. Over-processing also includes being over capacity (scheduling more workers than required or having more machines than necessary).

Another form of over-processing can be buying tools or software that are more precise, complex, or more expensive than required. You might think of this as over-engineering a process or just doing more than is required at a specific step of the process (having more labor available than necessary, having more machines than are needed, or having tools that are not adding incremental value because they do more than the product requires).

The Seven Deadly Muda: Inventory

Inventory is an often-overlooked waste and one that needs to be managed meticulously in order to optimize turns and resources. Take this book for instance. Our distributors require inventory so that they can pack and ship this book when the customer orders it. Unfortunately, inventory is costly up front while revenues lag. If we print too many books and never sell them, then we have excess waste in the form of inventory.

If on the other hand, we create too little inventory and our distributors run out of stock leaving orders unfulfilled then we have an opportunity cost in the form lost or delayed revenues due to poor inventory management.

In either case, inventory has a significant impact on cash flow which is a vital resource for businesses to survive and prosper. Proper inventory management is important to managing waste and opportunity costs.

The 7 Deadly Muda: Motion

Motion is another form of waste often occurring as a result of poor setup, configuration, or operating procedures. Wasted motion can be experienced by machines or humans and is exaggerated by repetition or recurring tasks.

Wasted motion is very common with workers who are unaware of the impact of small unnecessary movements in repetitive tasks. This can result from an improperly planned setup, work area configuration, and operating procedure. Small movements of an employee probably do not seem very wasteful by themselves. But when you consider repetitive motion that occurs over a long period, your perspective may change.

The Seven Deadly Muda: Transportation

Transportation is the unnecessary movement of goods, raw materials or finished products. Transportation is considered wasteful because it does *nothing* to add value or transform the product.

Imagine for a moment driving to and from work twice before getting out of your car to go into work . . . That is waste in the form of transportation. Driving less is better! In a similar way, the less transportation a product must endure, the better. There would be fewer opportunities for delay, destruction, loss, damage etc.

Transportation is wasteful because it takes energy to move something. And, it may take costly tools to move it. Transportation also introduces the risk of something getting damaged, lost, misplaced, delayed etc. Unless something is being transported into the hands of the customer, it probably means it is going somewhere to be stored (which is also wasteful).

The Seven Deadly Muda: Waiting

Waiting is an obvious form of waste and is typically a symptom of an upstream problem. Waiting is usually caused by inefficiency, bottlenecks, or poorly-designed work flows within the value stream, but it can also be caused by inefficient administration.

Reduction in waiting time will require thoughtful applications of Lean and process improvement. Waiting is when a downstream process is being starved because there is something wrong upstream in the process (like a machine having to finish processing or a worker that has stepped away from his or her station). In other words, there is a “bottleneck” that inhibits the flow of the process.

1.4.4 FIVE-S (5S)

What is 5S?

5S is systematic method used to organize, order, clean, and standardize a workplace . . . and, to keep it that way! 5S is a methodology originally developed in Japan and is used for improving the Lean work environment. 5S is summarized in five Japanese words all starting with the letter S:

1. Seiri (sorting)
2. Seiton (straightening)
3. Seiso (shining)
4. Seiketsu (standardizing)
5. Shisuke (sustaining)

To separate the needed from the unnecessary and prioritize what is needed. Sorting in a 5s activity is accomplished by many practitioners using the red tag method whereby red tags are placed on items in a work environment that are no longer useful or need to be removed. A common mantra in the sorting stage is “when in doubt” “throw it out”.

Seiton (Set in order or straighten)

To set in order is to organize the work environment. This means to place all tools and equipment (those remaining from the sort stage) into the most useful, logical and accessible locations. Organization should be such that it promotes productivity and avails itself to the concepts of the visual factory.

Another common mantra used in 5S is “A place for everything and everything in its place”. This saying keeps the focus on orderliness and not just during the 5S activity but for many years thereafter.

One of the most memorable examples of proper “set in order” results is that of the tool outlines on a peg board. When a tool is removed from the board it becomes very evident that the tool is no longer in its storage location. If it’s not in use, then it should be where it can be found by other workers.

Seiso (Shine)

Shine means to clean the work area. This is not a casual sweep and “de-clutter” activity either. Shine in 5S calls for “getting dirty” while cleaning. Examples are machinery to be maintained, equipment cleaned and treated or painted, machinery vacuumed, equipment greased, lubed and brought to optimal performance levels.

This is the stage where a measure of pride becomes evident, when other departments and other work areas begin to express interest in conducting 5S on their own work environments.

Seiketsu (Standardize)

Standardizing is the stage where work practices are staged to be performed consistently. Clear roles and responsibilities are outlined and everyone is expected to know their role.

Standardize also means to make workstations and tool layouts common among like functions

and normalize equipment and parts across all workstations so that workers can be moved around to any workstation at any time and perform the same task.

Shisuke (Sustain)

Sustaining in 5S is also called self-discipline. It takes discipline to maintain 5S. Obviously, it takes time for new habits to form, and there needs to be a culture within the team to follow this methodology. It is critical not to fall back into old ways. Therefore, it is critical that the sustain stage of 5s:

- Creates the culture in the team to follow the first four S's consistently.
- Avoids falling back to the old ways of doing things with cluttered and unorganized work environments.
- Establishes and maintains the momentum of optimizing the workplace.
- Promotes innovations of workplace improvement.
- Sustains the first four stages using:
 - 5S Maps
 - 5S Schedules
 - 5S Job cycle charts
 - Integration of regular work duties
 - 5S Blitz schedules
 - Daily workplace scans to maintain and review standards

Goals and Benefits of 5S

The goals of 5S are to reduced waste, cut unnecessary expense, optimize efficiency and establish a work environment that is:

- | | |
|-------------------|-------------------|
| • Self-explaining | • Self-regulating |
| • Self-ordering | • Self-improving |

Thus, 5S should create a work environment where this is no more wandering and searching for tools or parts. Workers should experience fewer delays or wait time due to equipment down time and the overall workplace will be safer, cleaner and more efficient. Some of the more common benefits reported by 5S participants are:

- | | |
|-----------------------|--------------------------|
| • Reduced changeovers | • Reduced complaints |
| • Reduced defects | • Reduced red ink |
| • Reduced waste | • Higher quality |
| • Reduced delays | • Lower costs |
| • Reduced injuries | • Safer work environment |
| • Reduced breakdowns | • Greater capacity |

By following the disciplined 5S method and meeting the goals established by the 5S team, the following quantifiable benefits have been realized:

- Cut in floor space: 60%
- Cut in flow distance: 80%
- Cut in accidents: 70%
- Cut in rack storage: 68%
- Cut in number of forklifts: 45%
- Cut in changeover time: 62%
- Cut in physical inventory: 50%
- Cut in training requirements: 55%
- Cut in nonconformance: 96%
- Increase in test yields: 50%
- Late deliveries: 0%
- Increase in throughput: 15%

5S Disclaimer

As a method, 5S is one of many Lean methods that creates immediate and observable improvements. It is tempting and often attempted by organizations to implement 5S alone without considering the entire value stream. However, it is advisable to consider a well-planned Lean manufacturing approach to the entire production system.

2.0 MEASURE PHASE

2.1 PROCESS DEFINITION

2.1.1 CAUSE AND EFFECT DIAGRAM

What is a Cause and Effect Diagram?

A *cause and effect diagram* is also called a *fishbone diagram* or *Ishikawa diagram*. It was created by Kaoru Ishikawa and is used to identify, organize, and display the potential causes of a specific effect or event in a graphical way similar to a fishbone.

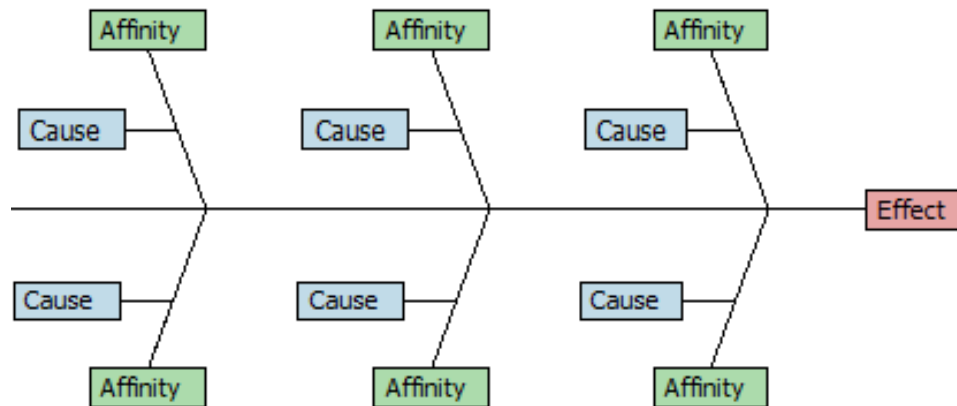


Fig. 2.1 Cause & Effect Diagram

A powerful brainstorming tool, the cause and effect diagram illustrates the relationship between one specified event (output) and its categorized potential causes (inputs) in a visual and systematic way.

Major Categories of Potential Causes

Typically, the possible causes fall into six major categories (or branches in the diagram). The acronym P4ME is a helpful way to remember the following standard categories which can be used when no other categories are known or obvious for your project:

- **People:** People who are involved in the process
- **Methods:** How the process is completed (e.g., procedures, policies, regulations, laws)
- **Machines:** Equipment or tools needed to perform the process
- **Materials:** Raw materials or information needed to do the job
- **Measurements:** Data collected from the process for inspection or evaluation
- **Environment:** Surroundings of the process (e.g., location, time, culture).

How to Plot a Cause and Effect Diagram

Step 1: Identify and define the effect being analyzed.

- Clearly state the operational definition of the effect or event of interest.

- The effect can be the positive outcome desired or negative problem targeted to solve.
- Enter the effect in the end box of the fishbone diagram and draw a spine pointed to it.
- Plotting a cause and effect diagram is a simple four-step process.

Step 2: Brainstorm the potential causes or factors of the effect occurring.

- Identify any factors with a potential impact on the effect and include them in this step.
- Put all the identified potential causes aside for use later.

Step 3: Identify the main categories of causes and group the potential causes accordingly.

- Besides P4ME (i.e., people, methods, machines, materials, measurements, and environment), you can group potential causes into other customized categories.
- Below each major category, you can define sub-categories and then classify them to help you visualize the potential causes.
- Enter each cause category in a box and connect the box to the spine. Link each potential cause to its corresponding cause category.

You can use P4ME, or you can use customized main categories to group the potential causes. Under each main category, you can define sub-categories if additional levels of detail are needed.

Step 4: Analyze the cause and effect diagram.

- A cause and effect diagram includes all the possible factors of the effect being analyzed.
- You can use a Pareto chart to filter the causes the project team needs to focus on.
- Identify causes with high impact that the team can act upon.
- Determine how to measure causes and effects quantitatively.
- Prepare for further statistical analysis.

Benefits to Using Cause and Effect Diagram

The benefits to using a cause and effect diagram to analyze an effect or event are:

- Helps to quickly identify and sort the potential causes of an effect.
- Provides a systematic way to brainstorm potential causes.
- Identifies areas requiring data collection for further quantitative analysis.
- Locates “low-hanging fruit.”

Limitation of Cause and Effect Diagrams

- A cause and effect diagram only provides qualitative analysis of correlation between each cause and the effect. More analysis is needed to quantify relationships between causes and effects.

- One cause and effect diagram can only focus on *one* effect or event at a time. Effects can have different causes.
- Further statistical analysis is required to quantify the relationship between various factors and the effect and identify the root causes.

Cause and Effect Diagram Example

Let us follow an example through the process of using a cause and effect diagram. A real estate company is interested to find the root causes of high energy costs of its properties. The cause and effect diagram is used to identify, organize, and analyze the potential root causes.

Step 1: Identify and define the effect being analyzed: In this example, the effect we are concerned with is high energy costs of buildings.

Step 2: Brainstorm the potential causes or factors of the high-energy costs: A team is assembled to brainstorm possible reasons for high energy costs of buildings. They provided the following list of possible causes:

- | | |
|-------------------------|----------------------------------|
| • Poor Maintenance | • Light Bulbs |
| • Bad Habits | • Inefficient Building Materials |
| • Lighting Schedule | • Meter Float |
| • HVAC Schedule | • Meter Accuracy |
| • Temperature Set Point | • Increasing Fuel Cost |
| • Old HVAC Units | • Building Air Leakage |
| • Open Dampers | • Humidity |

Step 3: Identify the main categories of causes and group the potential causes accordingly. The team used the standard P4ME categories for this exercise and bucketed the causes above based on the most appropriate categories.

Step 4: Analyze the cause and effect (C&E) diagram.

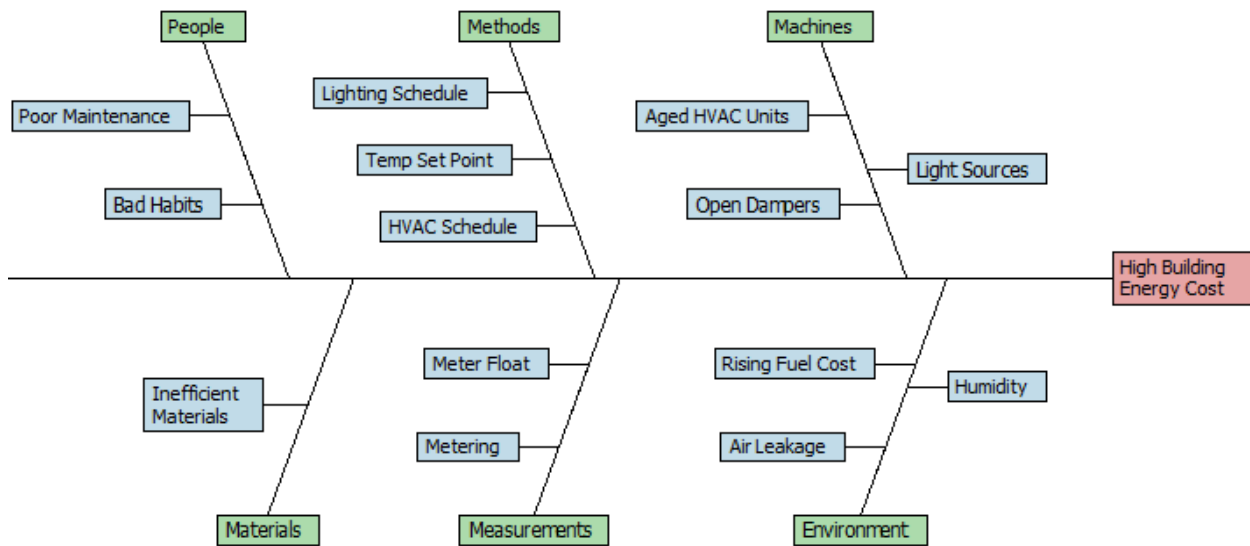


Fig. 2.2 Populated Cause & Effect Diagram with P4ME Categories

After completing the C&E diagram, the real estate company conducts further research on each potential root cause. It is discovered that:

- The utility metering is accurate
- The building materials are acceptable and there is no significant air leakage
- The fuel prices increased recently but were negligible
- Most lights are off during the non-business hours except that some lights have to be on for security purposes
- The temperature set points in the summer and winter are both adequate and reasonable
- The high-energy costs are probably caused by the poor HVAC maintenance on aged units and the wasteful energy consuming habits

Next, the real estate company needs to collect and analyze the data to check whether root causes identified in the C&E diagram have any validity. Data should be used to support this conclusion. Therefore, the team need to consider how to collect data to prove or disprove their assertion.

2.1.2 CAUSE AND EFFECTS MATRIX

What is a Cause and Effect Matrix?

The *cause and effect matrix* (XY Matrix) is a tool to help subjectively quantify the relationship of several X's to several Y's. Among the Y's under consideration, two important ones should be the *primary* and *secondary metrics* of your Six Sigma project. The X's should be derived from your cause and effect diagram. Let us take a peek as to what it looks like on the next page.

A cause and effect matrix is a powerful yet easy tool to transition from brainstorming (which you did using the cause and effect diagram) to estimating, ranking, and quantifying the

relationship between those things you found during brainstorming and the Y's that are important to the project.

Cause and Effects Matrix

Cause & Effects Matrix (XY Matrix)											
Date:											
Project:											
XY Matrix Owner:											
Output Measures (Y's)*	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉	Y ₁₀	
Weighting (1-10):											
Input Variables (X's)#	For each X, score its impact on each Y listed above (use a 0,3,5,7 scale)										Score
X ₁											0
X ₂											0
X ₃											0
X ₄											0
X ₂₉											0
X ₃₀											0
XY Matrix Premis: The XY Matrix or "Cause & Effect Matrix functions on the premis of the $Y=f(x)$ equation. *Rate each "Y" on a scale of 1 to 10 with 1 being the least important output measure #For each X rate its impact on each Y using a 0,3,5,7 scale (0=No impact, 3=Weak impact, 5=Moderate impact, 7=Strong)											

Fig. 2.3 Cause & Effects Matrix

Figure 2.3 represents a clean cause and effect matrix where you can translate all of the potential X's brainstormed during the creation of your cause and effect diagram session.

Once you have that information entered into the matrix you can add one or more Y's to the top of the matrix. The Y's should be weighted relative to each other based on their importance to the project.

Once this is complete, you can begin rating each X against each Y on a scale of 0, 3, 5, 7 (0 means no impact; 3 means weak impact; 5 is moderate impact; and 7 is strong impact). Try to use the whole spectrum of your scale during this process because you will need the resolution to help differentiate the X's from one another.

How to Use a Cause and Effect Matrix

1. Across the top enter your output measures. These are the Y's that are important to your project.
2. Next, give each Y a weight. Use a 1–10 scale, 1 being least important and 10 most important.
3. Below, in the leftmost column, enter all the variables you identified with your cause and effect diagram.
4. Within the matrix, rate the strength of the relationship between the X in the row and the corresponding Y in that column. Use a scale of 0, 3, 5, and 7.

5. Lastly, sort the “Score” column to order the most important X’s first.

Cause and Effect Matrix Notes

When complete, sort the X's based on their scores and graph them (use a Pareto chart). What the results will tell you should not be "taken to the bank" as this entire process from brainstorming X's to rating them against Y's is a subjective exercise.

However, if you have chosen your team wisely, it is very common that someone or several SMEs on your project team know the real solutions and/or the best way to narrow down to find them. Therefore, it is also important not to dismiss the results of your cause and effect matrix. Look at the image with comments embedded to summarize what you have just read.

After You Have Completed the C&E Matrix

After you have completed your cause and effects matrix, build a strategy for validating and/or eliminating the x's as significant variables to the $Y=f(x)$ equation.

- Build a data collection plan
- Prepare and execute planned studies
- Perform analytics
- Review results with SMEs, etc.

The combination of the C&E diagram and the C&E matrix is powerful. This is where some of the best ideas and theories about the $Y=f(x)$ equation begin.

Now, it is time to start eliminating and/or validating these variables. Put a plan together to do so. Use the resources and tools you have already learned as well as those that you are about to learn throughout this course.

2.1.3 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

What is FMEA?

Failure Modes & Effects Analysis - FMEA																			
Product or Process Step	Potential Failure Mode	Potential Failure Effects	S	Potential Causes	O	Current Controls	D	R	P	N	Recommended Actions	Responsible	Actions Taken	S	O	D	R	P	N

Fig. 2.4 Failure Modes & Effects Analysis Template

Figure 2.4 is a template of an FMEA. The *FMEA (Failure Modes and Effects Analysis)* is a tool and an analysis technique used to identify, evaluate, and prioritize potential deficiencies in a process so that the project team can design action plans to reduce the probability of those failures from occurring.

FMEA activity often follows process mapping. A process map is commonly used during the FMEA to determine where potential process breakdowns can occur. At each step, the team must ask, "What can go wrong?" A Pareto analysis may follow to quantitatively validate or disprove the results of the FMEA.

FMEA is best completed in cross-functional brainstorming sessions where attendees have a good understanding of the entire process or of a segment of it.

Important FMEA Terms

- *Process Functions* - Process steps depicted in the process map. FMEA is based on a process map and one step/function is analyzed at a time.
- *Failure Modes* - Potential and actual failure in the process function/step. It usually describes the way in which failure occurs. There might be more than one failure mode for one process function.
- *Failure Effects* - Impact of failure modes on the process or product. One failure mode might trigger multiple failure effects.
- *Failure Causes* - Potential defect of the design that might result in the failure modes occurring. One failure mode might have multiple potential failure causes.
- *Severity Score* - The seriousness of the consequences of a failure mode occurring. Ranges from 3 to 9, with 9 indicating the most severe consequence.
- *Occurrence Score* - The frequency of the failure mode occurring. Ranges from 3 to 9, with 9 indicating the highest frequency.
- *Detection Score* - How easily failure modes can be detected. It is a rating for how effective any controls are in the process. Ranges from 3 to 9, with 9 indicating the most difficult detection.
- *RPN (Risk Prioritization Number)* - The product of the severity, occurrence, and detection scores. It is a calculated value that ultimately is used to prioritize the FMEA. Ranges from 1 to 1000. The higher RPN is, the more focus the particular step/function needs.
- *Recommended Actions* - The action plan recommended to reduce the probability of failure modes occurring or at least enable better controls to detect it when failure occurs.
- *Current Controls* - Procedures currently conducted to prevent failure modes from happening or to detect the failure mode occurring.

How to Conduct an FMEA

Conducting an FMEA is not a difficult process, but can be time consuming when done correctly, particularly the first time it is performed on a process. To demonstrate how an FMEA is used we will be sharing a super-simple example.

Joe is trying to identify, analyze, and eliminate the failure modes he experienced in the past when preparing his work bag before heading to the office every morning. He decides to run an FMEA for his process of work bag preparation. There are only two steps involved in the process: putting the work files in the bag and putting a water bottle in the bag.

Failure Modes & Effects Analysis - FMEA

Product or Process Step	Potential Failure Mode	Potential Failure Effects	S	Potential Causes	O	Current Controls	D	R P N	Recommended Actions	Responsible	Actions Taken	S	O	D	R P N
								o							o
								o							o
								o							o
								o							o
								o							o
								o							o
								o							o

Fig. 2.5 FMEA Header

Figure 2.5 shows a clearer picture of the header of the FMEA template. For the example we are about to share, we will be starting in the left column and for the most part, we will work through the template from left to right.

FMEA Step 1: List the critical functions of the process based on the process map created. Here you see that the process steps are listed under the “Process Function” heading. In this case, the process is extremely simple so that we can focus on how to use FMEA as a tool. The two process steps populated are Joe putting work files in the bag and Joe putting his water bottle in the bag.

Product or Process Step	Potential Failure Mode	Potential Failure Effects
Place files in bag		
Put water bottle in bag		

Fig. 2.6 FMEA List Process Steps

FMEA Step 2: List all the potential failure modes that might occur in each function. In figure 2.7 you can see that we have chosen to list only one failure for each process step. In your case, be sure to be thorough and not overlook any possible failure modes. We could add other failure modes such as placed files in wrong pocket, placed bent/crumpled file in bag etc.

Product or Process Step	Potential Failure Mode	Potential Failure Effects
Place files in bag	Incorrect files put in the bag	
Put water bottle in bag	Water leaks	

Fig. 2.7 FMEA Potential Failure Modes

FMEA Step 3: List all the potential failure effects that might affect the process. In this situation, if Joe places the wrong files in his bag, his work will be delayed when he arrives at his

destination because he will have the wrong files. Or, his files will be destroyed because his water bottle leaked.

Product or Process Step	Potential Failure Mode	Potential Failure Effects
Place files in bag	Incorrect files put in the bag	Work is delayed
Put water bottle in bag	Water leaks	Files in bag damaged

Fig. 2.8 FMEA Failure Effects

FMEA Step 4: List all the possible causes that may lead to the failure mode happening. Joe may have had a loose cap on his water bottle or disorganized files which caused his failures. There can be more than one cause to the same failure. List each one separately.

Potential Failure Effects	S	Potential Causes	O
Work is delayed		Files are not organized well	
Files in bag damaged		Cap on water bottle not tight	

Fig. 2.9 FMEA Failure Causes

FMEA Step 5: List the current control procedures for each failure cause. In many cases, you'll find that there are no controls or weak controls relative to your failure causes. The FMEA will help you and your team identify these weaknesses.

Potential Causes	O	Current Controls	D
Files are not organized well		Check if files are needed	
Cap on water bottle not tight		Check bottle cap before inserting	

Fig. 2.10 FMEA Current Controls

FMEA Step 6: Determine the severity rating for each potential failure mode. At this point it is necessary to attempt to quantify the failure effects in terms of their severity. As you progress, will see that there will be 3 ratings to be assigned in an FMEA (Severity, Occurrence and Detection). These quantifications will result in a total "Risk Priority Number" (RPN) which will help you determine the failure modes that are most detrimental to your process.

For severity rankings. We recommend using a scale range of 3,5,7,9 with 9 representing the most severe and 3 being the least severe. If a failure mode has more than one cause, severity rankings should be the same for each cause because you're ranking the severity of the failure not of the cause.

Potential Failure Effects	S	Potential Causes	O	Current Controls
Work is delayed	9	Files are not organized well		Check if files are needed
Files in bag damaged	7	Cap on water bottle not tight		Check bottle cap before inserting

Fig. 2.11 FMEA Failure Effects Severity Rating

FMEA Step 7: Determine the occurrence rating for each potential failure cause. Using the same 3,5,7,9 scale. Rate each failure causes based on how frequently you believe they occur. A rating of 9 will represent a high occurrence rating and 3 will represent an infrequent or low occurrence rating. If there is more than one cause to a single failure mode, rate each cause based on how frequently the failure occurs due to that particular cause.

Potential Failure Effects	S	Potential Causes	O	Current Controls
Work is delayed	9	Files are not organized well	3	Check if files are needed
Files in bag damaged	7	Cap on water bottle not tight	5	Check bottle cap before inserting

Fig. 2.12 FMEA Failure Occurrence Rating

FMEA Step 8: Determine the detection rating for each current control procedure. Detection ratings are intuitively different and inverse of the others two ratings. High detection ratings mean that control procedure has a poor ability to detect the failure when it occurs. Conversely, a low detection rating of 3 indicates that the control procedure is very capable of detection. This ensures that the product of all 3 ratings will yield an RPN that when ranked, the highest RPN will indicate which failure mode is in need of the most attention.

S	Potential Causes	O	Current Controls	D	R P N
9	Files are not organized well	3	Check if files are needed	5	135
7	Cap on water bottle not tight	5	Check bottle cap before inserting	5	175

Fig. 2.13 FMEA Failure Detection Rating

FMEA Step 9: Calculate the Risk Prioritization Number (RPN). The RPN is calculated by multiplying all 3 ratings together $S \times O \times D = RPN$.

S	Potential Causes	O	Current Controls	D	R P N
9	Files are not organized well	3	Check if files are needed	5	135
7	Cap on water bottle not tight	5	Check bottle cap before inserting	5	175

Fig. 2.14 FMEA Risk Priority Number (RPN)

FMEA Step 10: Rank the failures using the RPN and determine the precedence of problems or critical inputs of process. Ranking should be from highest to lowest.

S	Potential Causes	O	Current Controls	D	R P N
7	Cap on water bottle not tight	5	Check bottle cap before inserting	5	175
9	Files are not organized well	3	Check if files are needed	5	135

Fig. 2.15 FMEA Sort by RPN

FMEA Step 11: Brainstorm and create recommended action plans for each failure mode. There can be multiple actions per failure mode, or cause or control procedure. The purpose is to thoroughly address root causes as well as your ability to detect failures. The goal would be to prevent failures.

Current Controls	D	R P N	Recommended Actions
Check bottle cap before inserting	5	175	Obtain new water bottle
Check if files are needed	5	135	Organize & Categorize Files

Fig. 2.16 FMEA Recommended Actions

FMEA Step 12: Determine and assign task owners and projected completion dates for each action item. This is an important accountability step and will be further supported by management routines that review progress and the effectiveness of the action items.

D	R P N	Recommended Actions	Responsible
5	175	Obtain new water bottle	Joe
5	135	Organize & Categorize Files	Joe

Fig. 2.17 FMEA Action Responsibility

FMEA Step 13: Determine new severity ratings after actions have been taken. FMEAs are often considered living and breathing documents because they should continuously address failure modes and require continued updating to actions, rankings and RPNs.

Recommended Actions	Responsible	Actions Taken	S	O	D	R P N
Obtain new water bottle	Joe					0
Organize & Categorize Files	Joe					0

Fig. 2.18 FMEA After Action Failure Severity

FMEA Step 14: Determine the new occurrence ratings after actions are taken.

Recommended Actions	Responsible	Actions Taken	S	O	D	R P N
Obtain new water bottle	Joe					0
Organize & Categorize Files	Joe					0

Fig. 2.19 FMEA After Action Failure Occurrence Rating

FMEA Step 15: Determine new detection ratings after actions are taken.

Recommended Actions	Responsible	Actions Taken	S	O	D	R P N
Obtain new water bottle	Joe					0
Organize & Categorize Files	Joe					0

Fig. 2.20 FMEA After Action Failure Detection Rating

FMEA Step 16: Update the RPN based on new severity, occurrence, and detection ratings.

Recommended Actions	Responsible	Actions Taken	S	O	D	R P N
Obtain new water bottle	Joe					0
Organize & Categorize Files	Joe					0

Fig. 2.21 FMEA List Process Steps

Make sure the corrective action plan is robust. Make sure it is clear what actions are to be taken, who owns the task, and what the completion date is for the task. Re-assess the severity, occurrence, and detection ratings if the corrective action plan is carried out, and update the RPN. Continue this cycle as needed.

2.1.4 THEORY OF CONSTRAINTS

What is Theory of Constraints (TOC)?

Processes, systems, and organizations are all vulnerable to their weakest part. Any manageable system is limited by constraints in its ability to produce more (and there is always at least one constraint).

A common analogy for the theory of constraints is, “a chain is no stronger than its weakest link.” This concept was introduced by Eliyahu M. Goldratt in his 1984 book titled *The Goal*.

Theory of Constraints (TOC) is an important tool for improving process flows. For most organizations, the goal is to make money. For some organizations (e.g., non-profits) making money is a necessary condition for pursuing the goal.

Constraints can come in many forms. Some examples are production capacity, material, logistics, the market (demand), employee behavior, or even management policy. The

underlying premise of TOC is that organizations can be measured and controlled through variation of three measures—throughput, operational expense, and inventory.

TOC Performance Measures

Making sound financial decisions based on these three measures is a critical requirement.

- Throughput—Rate at which a system generates money through sales
- Operational Expense—Money spent by the system to turn inventory into throughput
- Inventory—Money the system has invested in purchasing things it intends to sell

Why is throughput defined by sales? Goods are not considered an asset until sold. This contradicts the common accounting practice of listing inventory as an asset even if it may never be sold. Units that are produced but not sold are inventory.

The objective of a firm is to increase throughput and/or decrease inventory and operating expense in such a way as to increase profit, return on investment, and cash flow.

TOC Five Focusing Steps

The objective is to ensure ongoing improvement efforts are focused on the constraints of a system.

1. Identify the system's constraints.
2. Decide how to exploit the constraints.
3. Subordinate everything else to the decision in step 2.
4. Elevate the constraints.
5. If in previous steps a constraint has been broken, return to step 1, but do not allow inertia to cause a system's constraint.

TOC focuses on the output of an entire system versus a discrete unit of the components. The five focusing steps help to identify the constraint that towers above all others within the system. It is an iterative process. Once the largest constraint is addressed (strengthened), then the next weakest link in the chain should be addressed, and so on. It is an ongoing system of process improvement.

Logical Thinking Processes

	Focusing Step	Thinking Process	Tools
1	Identify the system's constraint(s)	- Identify the problems - Find the root causes	Cause and effect diagram
2	Decide how to exploit the constraint(s)	Develop a solution	Future reality tree
3	Subordinate everything else to the decision in step 2	- Identify the conflict preventing the solution - Remove the conflict	Evaporating cloud
4	Elevate the constraint	Construct and execute an implementation plan	Prerequisite tree Transition tree
5	If in previous steps a constraint has been broken, return to step 1, but do not allow inertia to cause a system's constraint		

Fig. 2.22 TOC Logical Thinking Processes

Used in conjunction with the five focusing steps. There are many logic tools to help a firm analyze and verbalize cause and effect:

- E-C-E (Effect-Cause-Effect) Diagramming
- Current reality tree, also known as cause and effect diagram -Root cause identification
- Future reality tree—Assess solutions
- Evaporating cloud—Conflict resolution tool
- Prerequisite tree—Implementation tool
- Transition tree—Implementation plan

Simulation Exercise

Resources needed:

- Three “production line” participants
- One timer per each production line participant
- Five small boxes of 15 widgets each (paperclips, pens/pencils, candy, etc.)

Widget Value Chain:

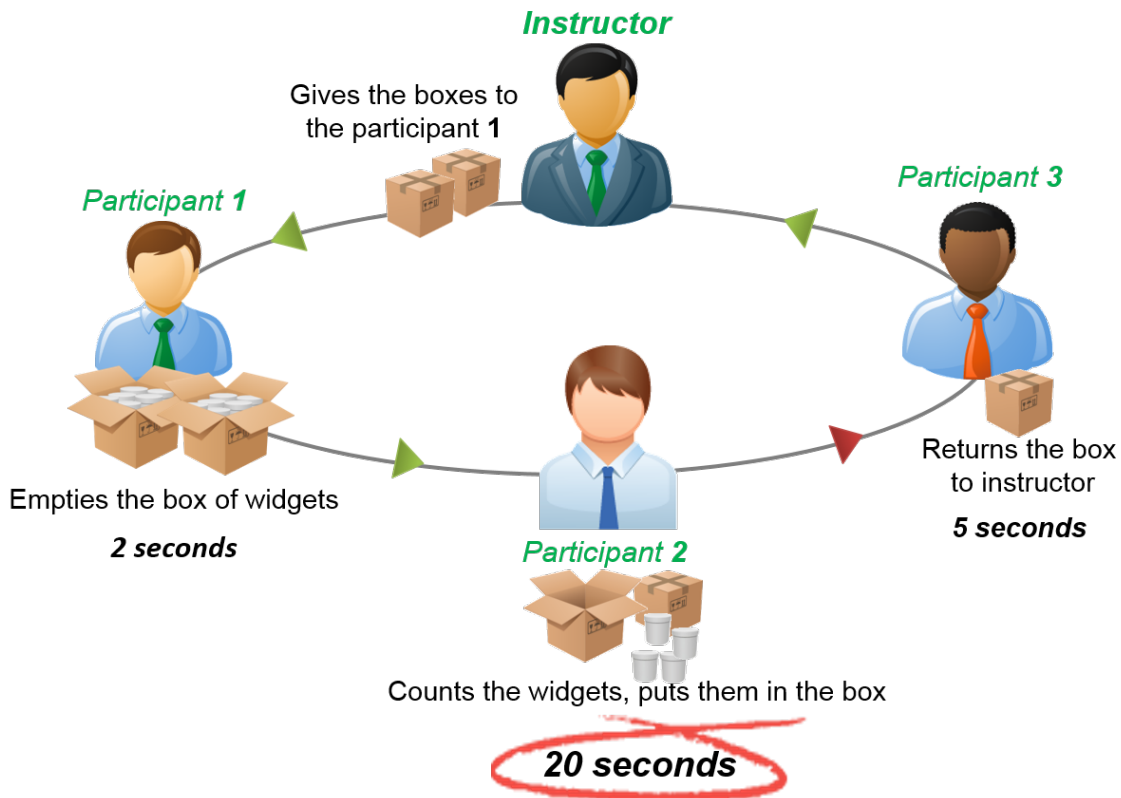


Fig. 2.23 TOC Widget Value Chain Simulation

Perform the process slowly the first time. The instructor gives the boxes, one at a time, to the first participant in the production line who empties the contents and hands the box and widgets to the next participant. The second participant counts the widgets, puts them in the box, and hands it to the third person who returns the box to the instructor. The instructor varies the rates at which the five boxes of widgets are handed to the first person in the “value chain” and times are recorded for each member’s part in the process.

Considerations or Observations:

- As the boxes are distributed slowly, it is clear that all participants have plenty of time to do their activities, but they are all being starved of work and the “bottleneck” is external to the process (the instructor).
- As the instructor speeds up the process and hands over the boxes at a much faster rate, all three participants start to work faster, with the person in the middle always busy as the other two participants are waiting for him or her. In essence, the bottleneck has now changed to Person B, and a process constraint or bottleneck has been identified.
- Have the timers provide an average time for each of the three steps. Calculate “throughput” for each step in the value chain (follow example below).

Participant 1: Time = 2 seconds (Throughput = 30 boxes/minute)

Participant 2: Time = 20 seconds (Throughput = 3 boxes/minute) ← Bottleneck

Participant 3: Time = 5 seconds (Throughput = 12 boxes/minute)

The efficiency of the process has slowed down to the slowest resource. In the example above, the output of the whole process is three boxes a minute; and Participant 1 and Participant 3 are not contributing to the overall efficiency. If they were to slow down, they would not have an adverse impact on the process, since they will always have idle time. Such resources with extra capacity are non-bottleneck resources.

Key question: What would you do to improve the efficiency of this system? Use the five focusing steps to lead to a conclusion and an action plan.

1. Identify the system's constraints.
2. Decide how to exploit the constraints.
3. Subordinate everything else to the decision in step 2.
4. Elevate the constraints.
5. If in previous steps a constraint has been broken, return to step 1, but do not allow inertia to cause a system's constraint.

Focusing Step 1: Identifying the constraint. In this exercise, "Count widgets and fill box" is the bottleneck; however, it is not always that easy to identify the bottleneck, so brainstorming tools like cause and effect diagrams are helpful.

Focusing Step 2: Determine how to exploit the constraint? This is where you would brainstorm potential solutions.

- More resources to perform step 2 (adds cost to the process).
- Sharing the work with Participant 1 or 3 (no added cost).
- Other ideas?

Focusing Step 3: Determine what conflicts prevent the solution?

- Perhaps there is resistance to spending more on additional resources?
- Maybe resources performing other steps require additional training/certification to perform another function?

Focusing Step 4: Determine the plan to implement?

- Hiring new resources? Training?
- What other considerations for implementing a solution?

Focusing Step 5: Implement the plan and then consider where the new bottleneck is.

2.2 SIX SIGMA STATISTICS

2.2.1 BASIC STATISTICS

What is Statistics?

Statistics is the science of collection, analysis, interpretation, and presentation of data. In Six Sigma, we apply statistical methods and principles to quantitatively measure and analyze process performance to reach statistical conclusions and help solve business problems.

sta•tis•tics (as defined on dictionary.com)

1. The science that deals with the collection, classification, analysis, and interpretation of numerical facts or data, and that, by use of mathematical theories of probability, imposes order and regularity on aggregates of more or less disparate elements.
2. The numerical facts or data themselves.

Types of Statistics

Descriptive statistics simply describe what is happening, while *inferential statistics* help you make comparisons, draw conclusions, or make judgments about data.

Descriptive Statistics

Descriptive statistics is applied to describe the main characteristics of a collection of data. It summarizes the features of the data quantitatively only and it does not make any generalizations beyond the data at hand. The data used for descriptive statistics are for the purpose of representing or reporting.

Inferential Statistics

Inferential statistics is applied to “infer” the characteristics or relationships of the populations from which the data are collected. Inferential statistics draws statistical conclusions about the population by analyzing a sample of data subject to random variation. A complete data analysis includes both descriptive statistics and inferential statistics.

Statistics vs. Parameters

The word *statistic* refers to a numeric measurement calculated using a sample data set, for example, sample mean or sample standard deviation. Its plural is *statistics* refers to the scientific discipline of statistical analysis.

Parameter refers to a numeric metric describing a population, for example, population mean and population standard deviation. Unless you have the full data set of the population, you will not be able to know population parameters. Almost always, you will be working with statistics, but they will allow you to make inferences about the population.

Continuous Variable vs. Discrete Variable

Data can take different forms, which is important to recognize when it is time to analyze the data. Continuous variables are measured and can be divided infinitesimally (they can take any

value within a range) and there is an infinite number of values possible. Examples are temperature, height, weight, money, time etc.

Discrete variables are sometimes referred to as count data which can literally be counted. Discrete data is finite with limited numbers of values available. Examples are count of people, count of countries, count of defects or count of defectives.

Types of Data

Nominal Data: Nominal Data are categorical but have no natural rank order. Examples of nominal data are colors, states, days of the week etc. Nominal comes from the Latin word “nomen” meaning “name” and nominal data are items that are differentiated by a simple naming system.

Be careful of nominal items that have numbers assigned to them and may appear ordinal but are not. These are used to simplify capture and referencing. Nominal items are usually categorical and belong to a definable category.

Ordinal Data: Ordinal Data are rank order data. Examples of ordinal data are the first, second and third place in a race or scores on an exam. Items on an ordinal scale are set into some kind of *order* by their position on the scale. The order of items is often defined by assigning numbers to them to show their relative position. Nominal and Ordinal data are categorical and thus referred to as discrete data.

Interval: Interval data are data measured on a quantifiable scale with equidistant values throughout the scale. Examples of interval data are temperature as measured on the Fahrenheit or Celsius scale.

Ratio Data: Ratio data are the ratio between the magnitude of a continuous value and the unit value of the same category. Examples of ratio data are weight, length, time etc.

In a ratio scale, numbers can be compared as multiples of one another. Thus, one person can be twice as tall as another person. Also important, the number zero has meaning. Thus, the difference between a person of 35 and a person 38 is the same as the difference between people who are 12 and 15. A person can also have an age of zero.

Interval and ratio data measure quantities and hence are continuous. Because they can be measured on a scale, they may also be referred to as scale data.

2.2.2 DESCRIPTIVE STATISTICS

Basics of Descriptive Statistics

Descriptive statistics

Descriptive statistics provide a quantitative summary for the data collected. It summarizes the main features of the collection of data (shape, location and spread). Descriptive statistics is a presentation of data collected and it does *not* provide any inferences about a more general condition. Instead, descriptive statistics describe what the data “looks like.”

Shape of the Data

When we describe the “shape” of the data, we typically refer to the *distribution* of the data. Distribution, also called frequency distribution, summarizes the frequency of an individual value or a range of values for a variable (either continuous or discrete). It is sometimes referred to as a “frequency distribution” because it depicts how often a particular value occurs within a data set. Distribution is depicted as a table or graph.

Simple Example of Distribution

We are tossing a fair die. The possible value we obtain from each toss is a value between 1 and 6. Each value between 1 and 6 has a $1/6$ chance to be hit for each toss. The distribution of this game describes the relationship between every possible value and the percentage of times the value is hit (or count of times the value is hit).

In this example, there is an equal probability for each value on the die occurring. If you were to roll the die a high number of times, what might the distribution look like? If you rolled it 600 times, you would likely get each value nearly 100 times.

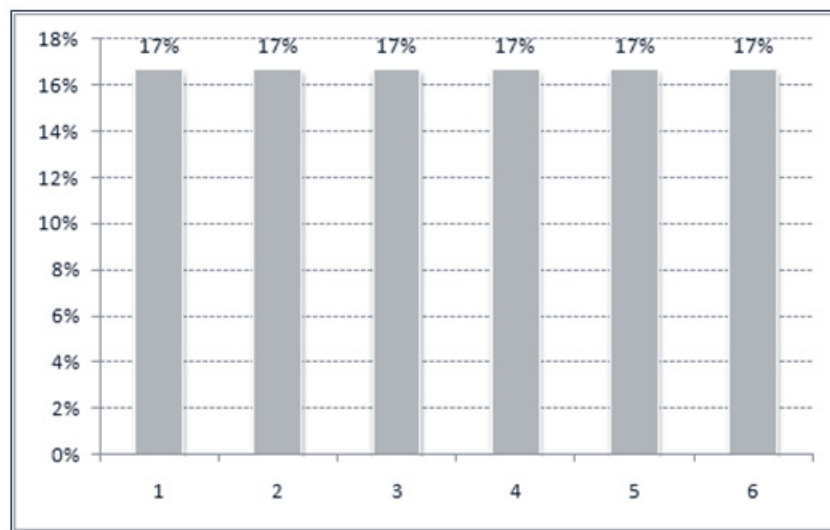


Fig. 2.24 Fair Die Distribution Probability

Common Types of Continuous Distributions

- Normal Distribution
- T distribution
- Chi-square distribution
- F distribution

Common Types of Discrete Distributions

- Binomial distribution
- Poisson distribution

There are different types of distributions that are commonly found in statistics. It is important to recognize that there are different types of data distributions because the statistics can tell you different things about the data and different inferential statistics have to be used for different situations.

Location of the Data

The location (i.e., central tendency) of the data describes the value where the data tend to cluster around. There are multiple measurements to capture the location of the data, the three most common and meaningful are Mean, Median and Mode.

Mean

The mean is the arithmetic average of a data set. It is easily calculated by dividing the sum of the data points by n (n is the number of values in the data set).

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

For example, we have a set of data: 2, 3, 5, 8, 5, and 9. The arithmetic mean of the data set is

$$\frac{2+3+5+8+5+9}{6} = 5.33$$

In the example above, there are six data points. The sum of the six data points is 32, and when dividing by the number of data points, 6, the arithmetic mean is 5.33.

Median

The median is the middle value of the data set in numeric order. It separates a finite set of data into two even parts, one with values higher than the median and the other with values lower than the median. For example, we have a set of data: 45, 32, 67, 12, 37, 54, and 28. The median is 37 since it's the middle value of the sorted list of those values (i.e., 12, 28, 32, 37, 45, 54, and 67). There are three values lower and three values higher than the median.

Mode

The mode is the value that occurs most often in the data set. If no number is repeated, there is no mode for the data set. For example, we have a data set: 55, 23, 45, 45, 68, 34, 45, 55. The mode is 45 since it occurs most frequently. The numbers 23, 34, and 68 occur once, 55 occurs twice, and 45 occurs three times.

Spread of the Data

The spread (i.e., variation) of the data describes the degree of data dispersing around the center value. There are multiple measurements to capture the spread of the data, the most common and meaningful are Range, Variance and Standard Deviation.

Range

The range is the numeric difference between the greatest and smallest values in a data set. Only two data values (i.e., the greatest and the smallest values) are accounted for calculating the range. For example, we have a set of data: 34, 45, 23, 12, 32, 78, and 23. The largest value is 78, and the smallest is 12. Therefore, the range is $78 - 12 = 66$.

Variance

The variance measures how far on average the data points spread out from the mean. More specifically, it is the average squared deviation of each value from its mean. All data points are accounted for by calculating the variance:

$$s^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2$$

Where: n is the number of values in the data set.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

You will notice that the variance and standard deviation are directly related to each other. Why is the term squared? First, because squared terms always give a positive value and we are only trying to measure the distance from the mean (positives and negatives will negate each other). Second, squaring emphasizes the larger terms (or differences) between the mean and each individual data point.

Standard Deviation

Standard deviation describes how far the data points spread away from the mean. It is simply the square root of the variance. All data points are considered by calculating the standard deviation:

$$s = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2}$$

Where: n is the number of values in the data set.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

2.2.3 NORMAL DISTRIBUTION AND NORMALITY

What is Normal Distribution?

Normal distribution, also called Gaussian distribution, is the probability distribution of a continuous random variable whose values spread symmetrically around the mean. A normal distribution can be completely described by using its mean (μ) and variance (σ^2).

When a variable x is normally distributed, we note $x \sim N(\mu, \sigma^2)$.

Z Distribution

The Z distribution, also known as standard normal distribution, is the simplest normal distribution with the mean equal to zero and the variance equal to one. Any normal distribution can be transferred to a Z distribution by applying the following equation:

$$Z = \frac{x - \mu}{\sigma}$$

Where: $x \sim N(\mu, \sigma^2)$ and $\sigma \neq 0$.

The standard normal distribution is important because the probabilities and quantiles of any normal distribution can be computed from the standard normal distribution if the mean and standard deviation are known.

Shape of Normal Distribution

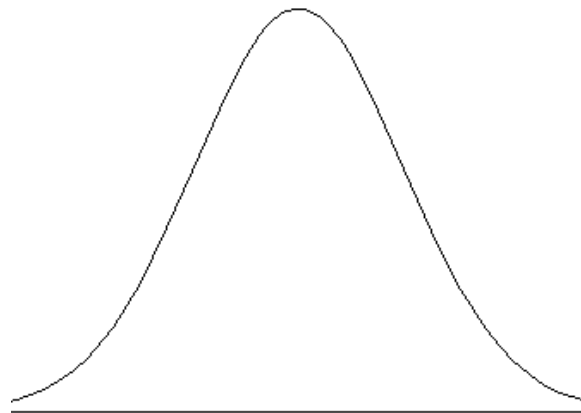


Fig. 2.25 Shape of a Normal Distribution

You might remember teachers from your academic days referring to “the curve” when talking about how they will grade performance. The probability density function curve of normal distribution is bell-shaped (see figure 2.25) and is expressed by the equation:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

The equation just means that within the population that is described by this distribution, the highest probability is for values closest to the mean, then the probability drops as you move further from the mean (in either direction).

Location of Normal Distribution

If a variable is normally distributed, the mean, the median, and the mode have approximately the same value. The probability density curve of normal distribution is symmetrical around a center value which is the mean, median, and mode at the same time.

Spread of Normal Distribution

The spread or variation of the normally-distributed data can be described using the variance or the standard deviation (which is the square root of the variance). The smaller the variance or the standard deviation, the less variability in the data set.

The 68–95–99.7 Rule

The 68–95–99.7 rule or the *empirical rule in statistics* states that for a normal distribution:

- About 68% of the data fall within one standard deviation of the mean
- About 95% of the data fall within two standard deviations of the mean
- About 99.7% of the data fall within three standard deviations of the mean

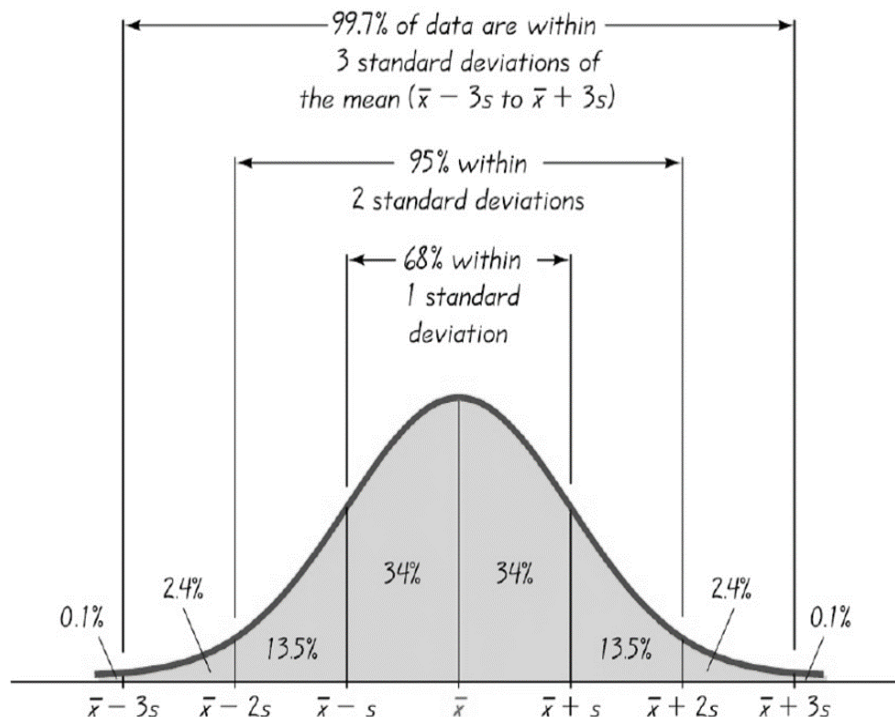


Fig. 2.26 Shape of a Normal Distribution

One way to think about this rule is to consider the area under the normal distribution curve. The 68–95–99.7 rule describes what percent of data fall within one, two, and three standard deviations from the mean, respectively. Most of the data values are grouped around the center.

Normality

Not all the distributions with a bell shape are normal distributions. It is important to understand whether or not data being analyzed fit the normal distribution because there are implications for how the data are analyzed and what inferences are made from the data.

To check whether a group of data points are normally distributed, we need to run a normality test. There are different normality tests available, such as Anderson–Darling test, Sharpiro–Wilk test, or Jarque–Bera test. More details of normality test will be introduced in the Analyze module.

Normality Testing

To check whether the population of our interest is normally distributed, we need to run normality test.

- Null Hypothesis (H_0): The data points *are* normally distributed.
- Alternative Hypothesis (H_a): The data points are *not* normally distributed.

Use SigmaXL to Run a Normality Test

Normality Test Case study: Using a data set provided, we are interested to know whether the height of basketball players is normally distributed. This example demonstrates how to perform this analysis using SigmaXL.



Data File: “One Sample T-Test” tab in “Sample Data.xlsx”

- Null Hypothesis (H_0): The height of basketball players is normally distributed.
- Alternative Hypothesis (H_a): The height of basketball players is not normally distributed.

Steps to run a normality test in SigmaXL:

1. Select the entire range of data
2. Click SigmaXL -> Graphical Tools -> Histograms & Descriptive Statistics
3. A new window named “Histograms & Descriptive” pops up with the selected range appearing in the box under “Please select your data”

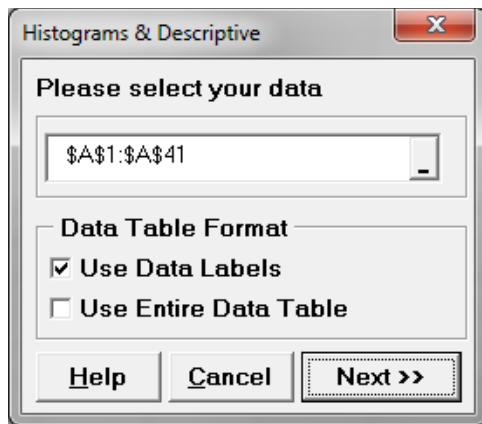


Fig. 2.27 Histogram & Descriptive data selection box

4. Click "Next>>"
5. A new window named "Histograms & Descriptive Statistics" appears
6. Select "HtBk" as the "Numeric Data Variables (Y)"

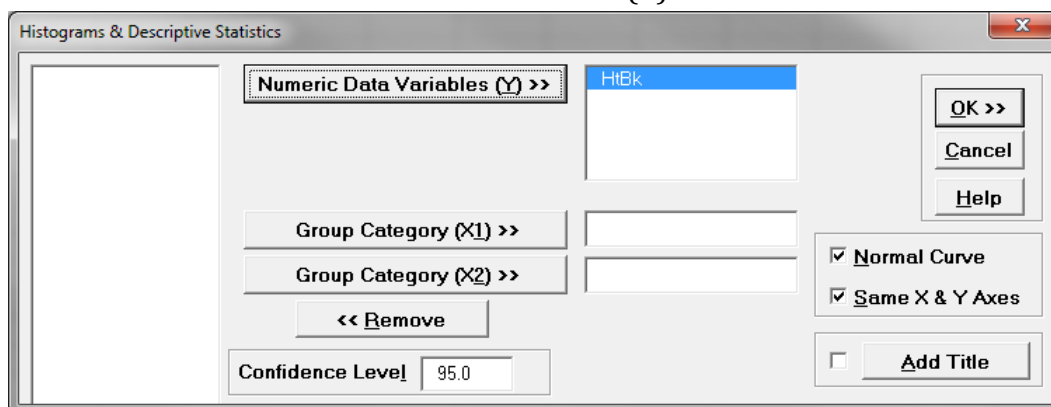


Fig. 2.28 Histogram & Descriptive Statistics with variable selection

7. Click "OK"
8. The normality test results appear in the newly generated tab "Hist Descript (1)"

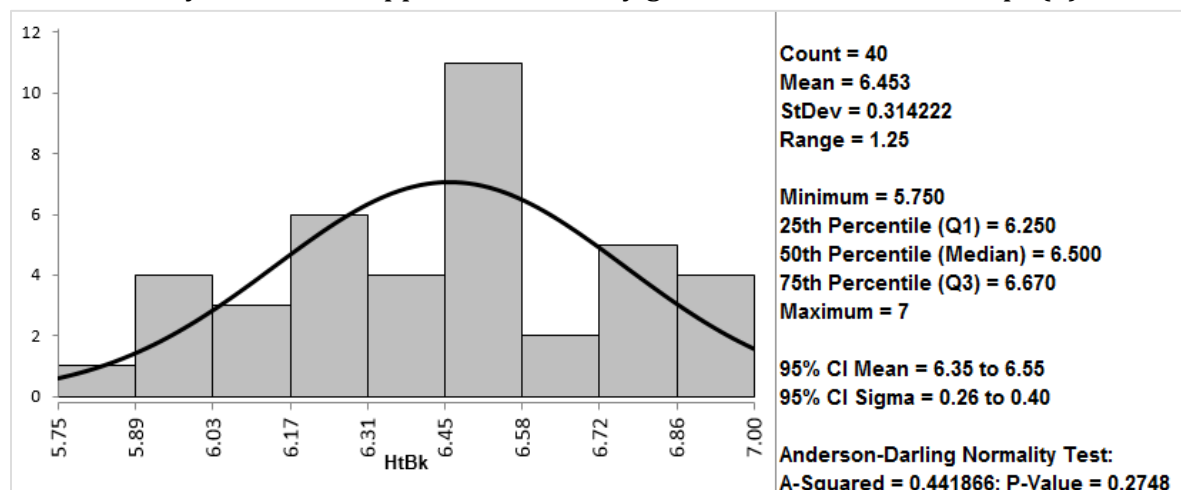


Fig. 2.29 Normality Test Result

Figure 2.29 shows the output from SigmaXL. We need to know the p-value to determine if we should accept or reject the null hypothesis. The p-value is 0.275 and is greater than alpha (or

significance level). Since $p > 0.05$, we fail to reject the null hypothesis, which was that the data is normal. Therefore, *the data are normally distributed*.

2.2.4 GRAPHICAL ANALYSIS

What is Graphical Analysis?

In statistics, *graphical analysis* is a method to visualize the quantitative data. Graphical analysis is used to discover structure and patterns in the data. The presence of which may explain or suggest reasons for additional analysis or consideration. A complete statistical analysis includes both quantitative analysis and graphical analysis.

When we think of statistics, we often think of numbers. However, graphical analysis is complementary to purely quantitative statistics because it allows us to visualize structure and patterns in the data. Often, the graphical presentation of data can tell a story on its own, but the total statistical analysis is important to complete the picture. Sometimes our eyes can deceive us. There are various graphical analysis tools available. The most commonly used and hence the ones we shall cover here are Box Plot, Histogram, Scatter Plot and Run Chart.

Box Plot

A *box plot* is a graphical method to summarize a data set by visualizing the minimum value, 25th percentile, median, 75th percentile, the maximum value, and potential outliers. A percentile is the value below which a certain percentage of data fall. For example, if 75% of the observations have values lower than 685 in a data set, then 685 is the 75th percentile of the data. At the 50th percentile, or median, 50% of the values are lower and 50% are higher than that value.

Box Plot Anatomy

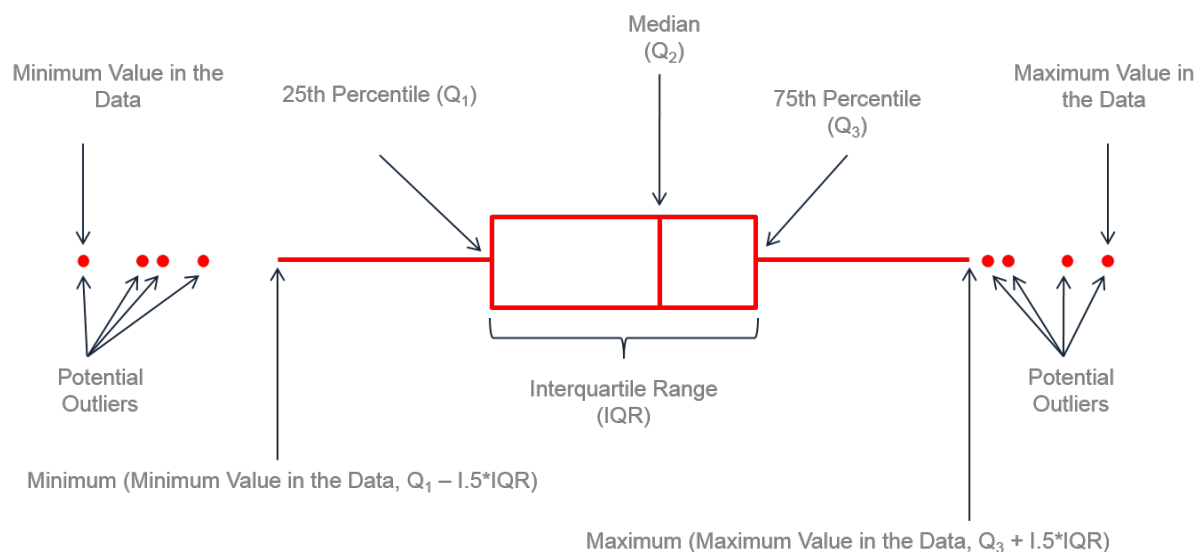


Fig. 2.30 Interpreting a Box Plot

Figure 2.30 describes how to read a box plot. Here are a few explanations that may help. The middle part of the plot, or the “interquartile range,” represents the middle quartiles (or the 75th minus the 25th percentile). The line near the middle of the box represents the median (or middle value of the data set). The whiskers on either side of the IQR represent the lowest and highest quartiles of the data. The ends of the whiskers represent the maximum and minimum of the data, and the individual dots beyond the whiskers represent outliers in the data set.

How to Use SigmaXL to Generate a Box Plot



Data File: “Box Plot” tab in “Sample Data.xlsx”

Steps to render a box plot in SigmaXL:

1. Select the entire range of the data.
2. Click SigmaXL -> Graphical Tools -> Boxplots
3. A new window named “Boxplots” pops up with the selected range appearing in the box under “Please select your data”

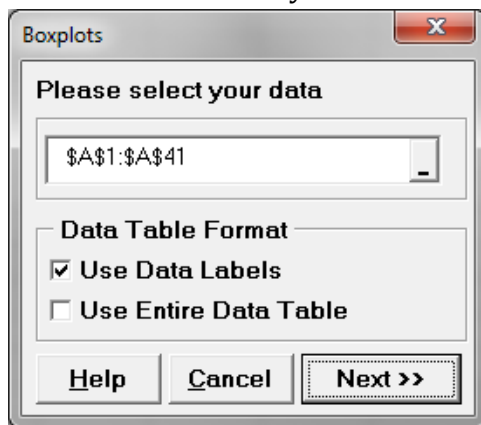


Fig. 2.31 Boxplots dialog box

4. Click “Next>>”
5. A new window also named “Boxplots” appears
6. Select “HtBk” as the “Numeric Data Variables (Y)”

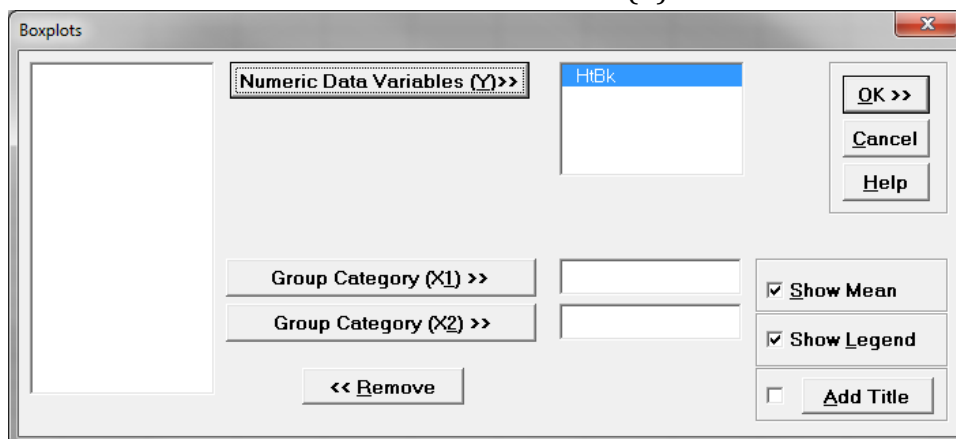


Fig. 2.32 Boxplots dialog box with variable selection

7. Check the check box “Show Legend”
8. Click “OK>>”
9. The Boxplot appears automatically in the new tab “Boxplot (1)”

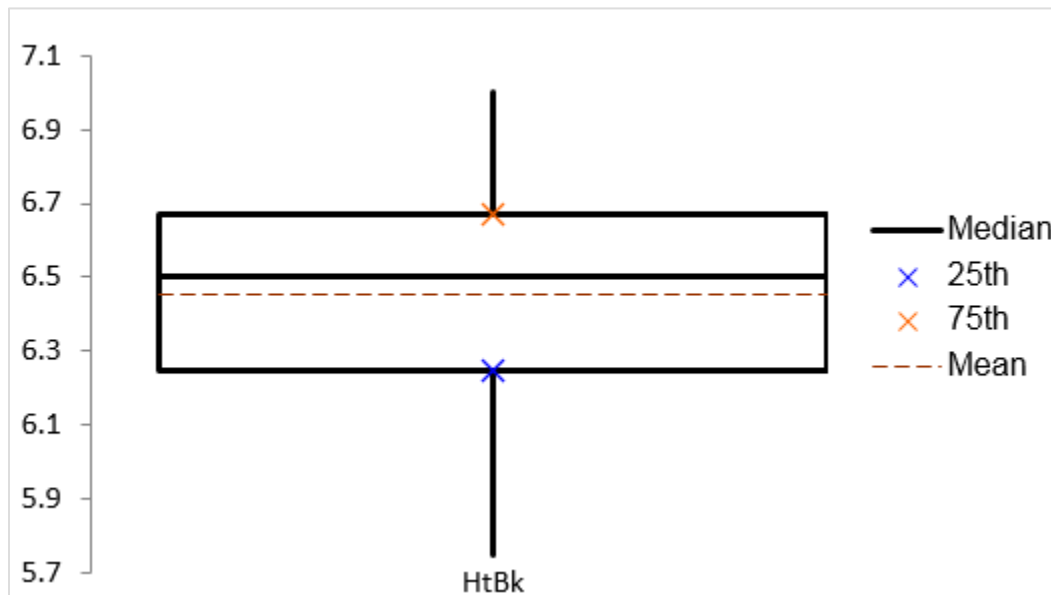


Fig. 2.33 Boxplot results

Figure 2.33 demonstrates the result of the boxplot after navigating through the SigmaXL menus to yield this output. Notice the interquartile range between the 25th and 75th quartiles, the median line, the mean, and the whiskers.

Histogram

A *histogram* is a graphical tool to present the distribution of the data. The X axis of a histogram represents the possible values of the variable and the Y axis represents the frequency of the value occurring. A histogram consists of adjacent rectangles erected over intervals with heights equal to the frequency density of the interval. The total area of all the rectangles in a histogram is the number of data values.

A histogram can also be normalized. In the case of normalization, the X axis still represents the possible values of the variable, but the Y axis represents the percentage of observations that fall into each interval on the X axis. The total area of all the rectangles in a normalized histogram is 1. Using histograms, we have a better understanding of the shape, location, and spread of the data.

How to Use SigmaXL to Generate a Histogram



Data File: “Histogram” tab in “Sample Data.xlsx”

Steps to render a histogram in SigmaXL:

1. Select the entire range of data

2. Click SigmaXL -> Graphical Tools -> Histograms & Descriptive Statistics
3. A new window named "Histograms & Descriptive" pops up with the selected range appearing in the box under "Please select your data"

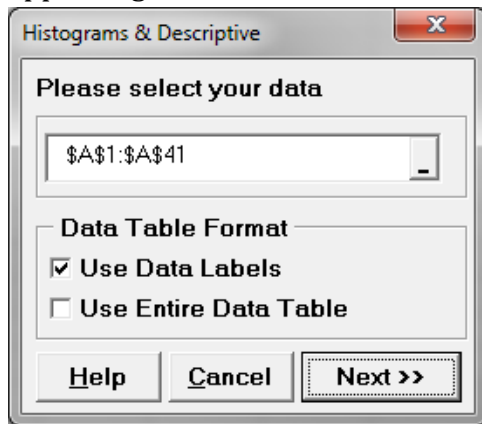


Fig. 2.34 Histogram & Descriptive data selection box

4. Click "Next>>"
5. A new window named "Histograms & Descriptive Statistics" appears
6. Select "HtBk" as the "Numeric Data Variables (Y)"

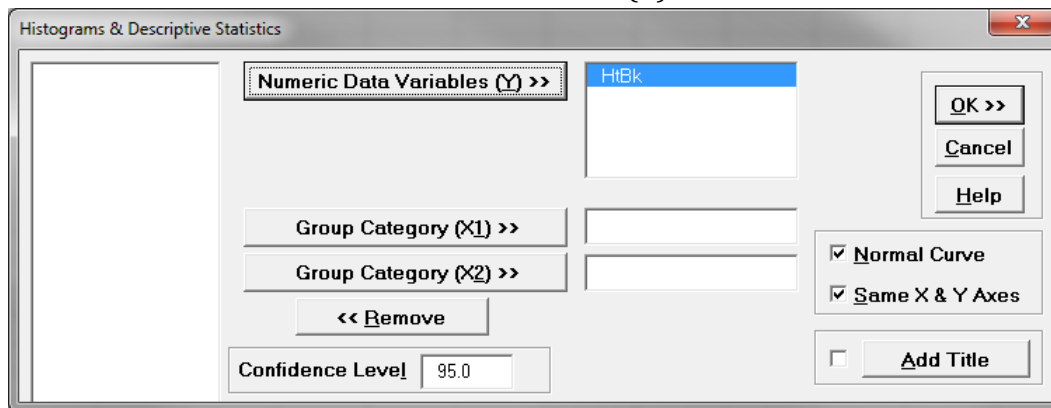


Fig. 2.35 Histogram & Descriptive Statistics with variable selection

7. Click "OK"
8. The normality test results appear in the newly generated tab "Hist Descript (1)"

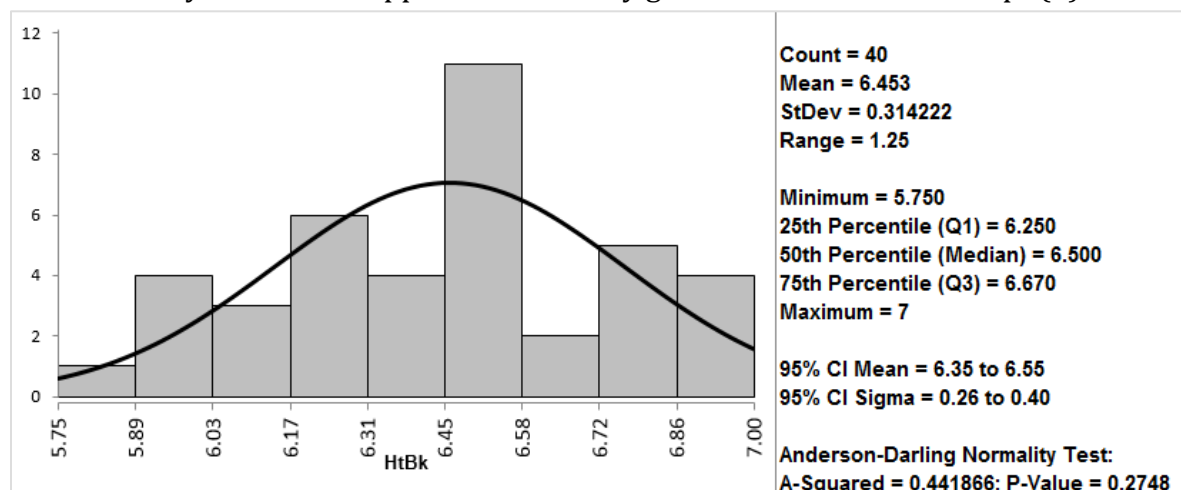


Fig. 2.36 Normality Test Result

The output from the previous steps has generated a graphical summary report of the data set HtBk. Among the information provided is a histogram. The image shows the frequency of the data for the numerical categories ranging from 5.7 to 7. You can see the shape of the data roughly follows the bell curve.

Scatter Plot

A *scatter plot* is a diagram to present the relationship between two variables of a data set. A scatter plot consists of a set of data points. On the scatter plot, a single observation is presented by a data point with its horizontal position equal to the value of one variable and its vertical position equal to the value of the other variable. A scatter plot helps us to understand:

- Whether the two variables are related to each other or not
- What the strength of their relationship
- The shape of their relationship
- The direction of their relationship
- Whether outliers are present

How to Use SigmaXL to Generate a Scatter Plot



Data File: “Scatter Plot” tab in “Sample Data.xlsx”

Steps to render a Scatterplot in SigmaXL:

1. Select the entire range of data (both “MPG” and “weight”)
2. Click SigmaXL -> Graphical Tools -> Scatter Plots
3. A new window named “Scatter Plots” pops up with the selected range of data appearing in the box under “Please select your data”

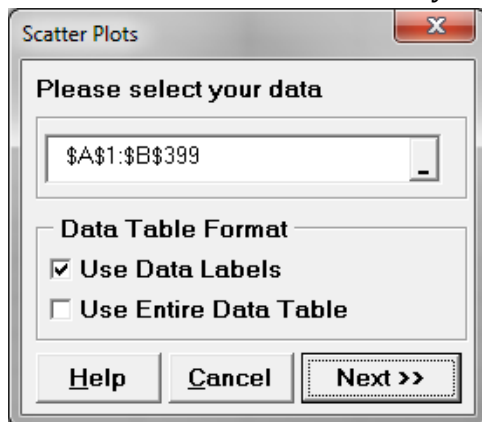


Fig. 2.37 Scatter Plots data selection box

4. Click “Next>>”
5. A new window also named “Scatter Plots” appears
6. Select “MPG” as the “Numeric Response (Y)”

7. Select “weight” as the “Numeric Predictor (X1)”

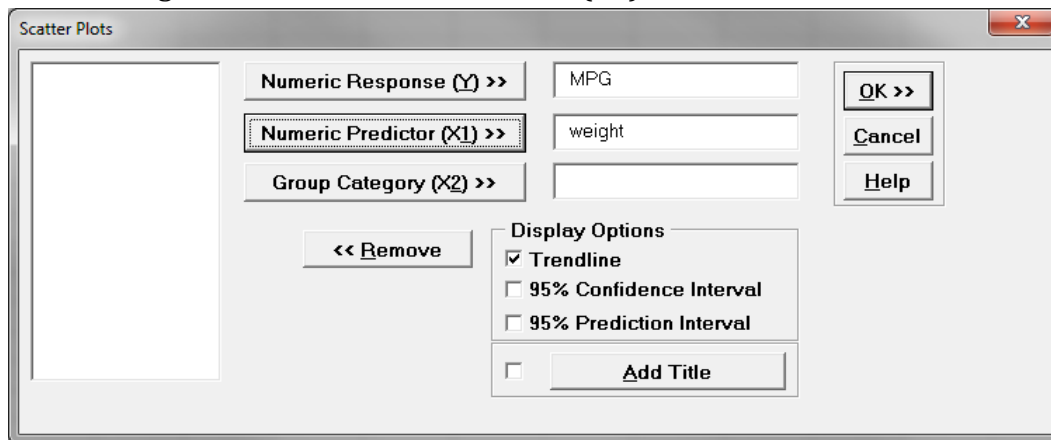


Fig. 2.38 Scatter Plots selection box with variables selected

8. Click “OK>>”
9. The scatterplot appears in the new tab “Scatterplot (1)”

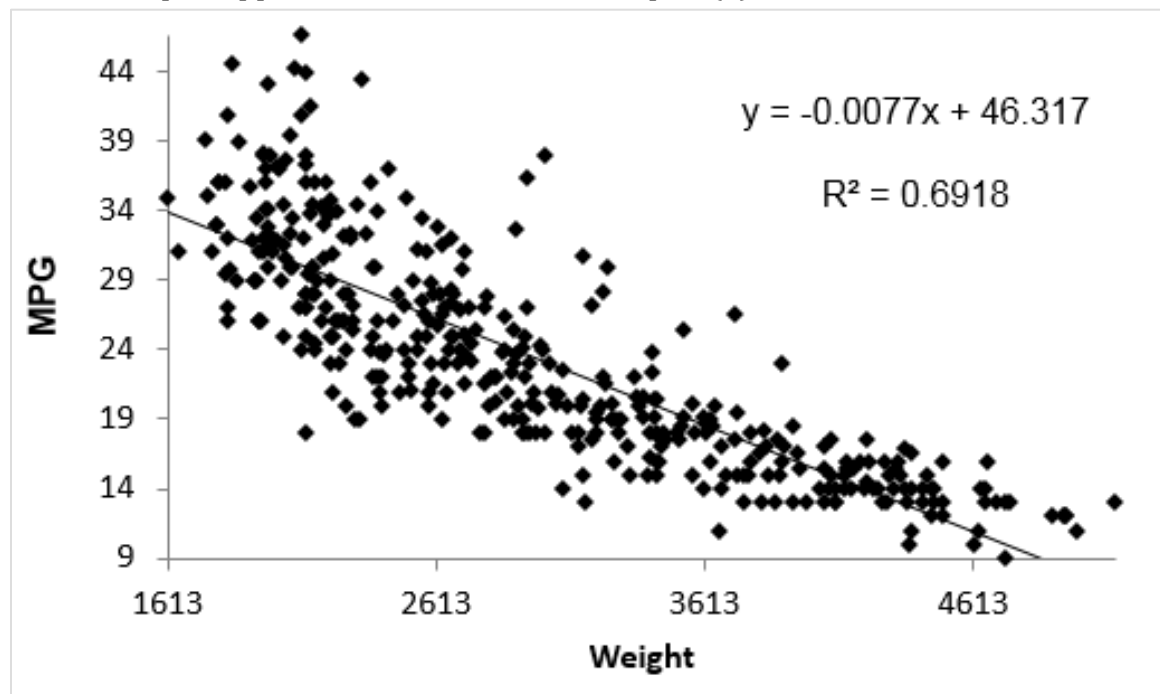


Fig. 2.39 Scatterplot Results

Figure 2.39 is SigmaXL’s output of the scatterplot data. You can immediately see the value of graphical displays of data. This information obtainable by viewing this output shows a relationship between weight and MPG. This scatterplot shows that the heavier the weight the lower the MPG value and vice versa.

Run Chart

A *run chart* is a chart used to present data in time order. Run charts capture process performance over time. The X axis of a run chart indicates time and the Y axis shows the observed values. A run chart is similar to a scatter plot in that it shows the relationship

between X and Y. Run charts differ however because they show how the Y variable changes with an X variable of time.

Run charts look similar to control charts except that run charts do not have control limits and they are much easier to produce than a control chart. A run chart is often used to identify anomalies in the data and discover pattern over time. They help to identify trends, cycles, seasonality and other anomalies.

How to Plot a Run Chart in SigmaXL

Steps to plot a run chart in SigmaXL:



Data File: “Run Chart” tab in “Sample Data.xlsx”

1. Select the entire range of the data (“Measurement”, “Cycle” and “Trend”).
2. Click SigmaXL -> Graphical Tools -> Run Chart

A new window named “Run Chart” pops up with the selected range of data appearing in the box under “Please select your data”

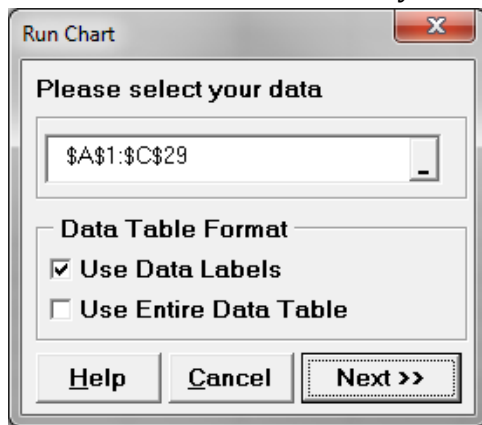


Fig. 2.40 Run Chart data selection box

3. Click “Next>>”
4. A new window also named “Run Chart” appears
5. Select “Measurement” as the “Numeric Data Variable (Y)”

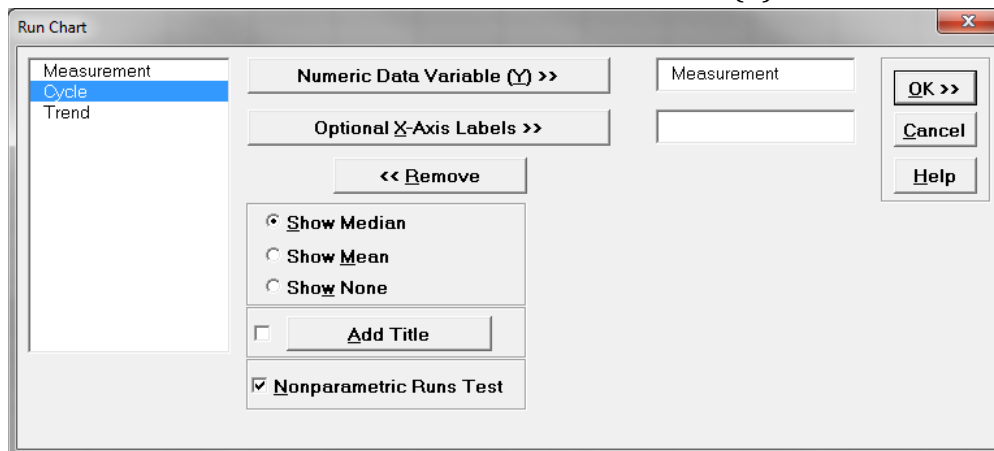


Fig. 2.41 Run Chart dialog box with variables selected

6. Click “OK”
7. The run chart appears automatically in the tab “Run Chart (1)”

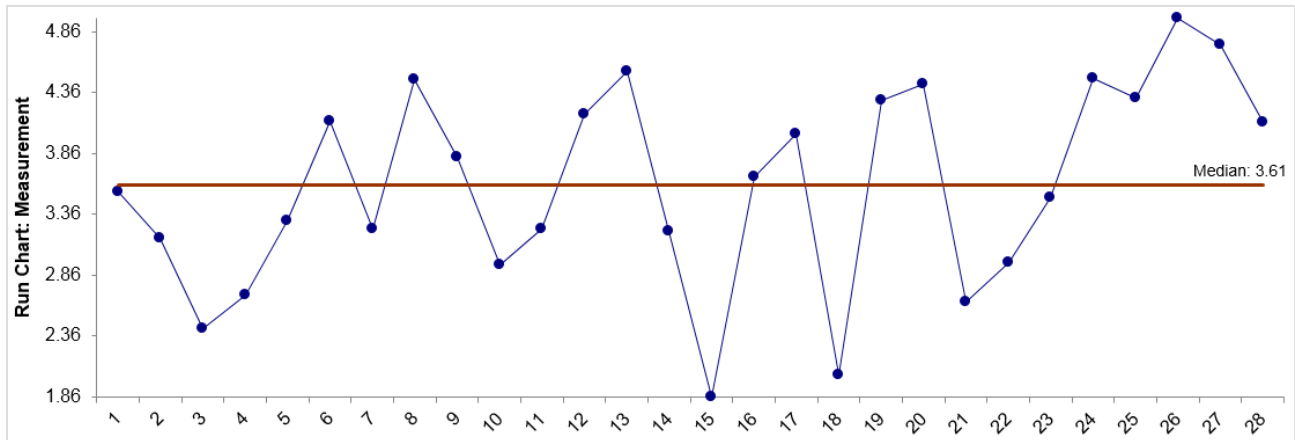


Fig. 2.42 SigmaXL Run Chart for the “Measurement” data

Figure 2.42 is a run chart created with SigmaXL. The time series displayed by this chart appears stable. There are no extreme outliers, no visible trending or seasonal patterns. The data points seem to vary randomly over time.

Now, let us look at another example which may give us a different perspective. We will create another run chart using the data listed in the column labeled “Cycle”. This column is in the same file used to generate Figure 2.42. Follow the steps used for the first run chart and instead of using “Measurement” use “Cycle” in the Run Chart dialog box pictured in figure 2.43.

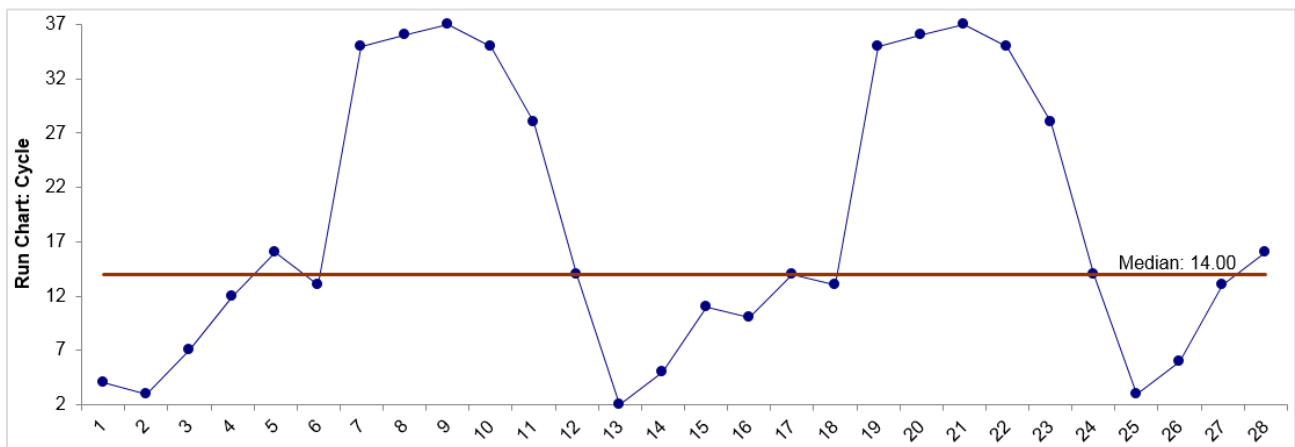


Fig. 2.43 SigmaXL Run Chart for the “Cycle” data

In this example (figure 2.43), the data points are clearly exhibiting a pattern. It could be seasonal or it could be something cyclical. Imagine that the data points are taken monthly and this is a process performing over a period of 2.5 years. Perhaps the data points represent the number of customers buying new homes. The home buying market tends to peak in the summer months and dies down in the winter.

Using the same data tab lets create a final run chart. This time use the “Trend” data. Again, follow the steps outlined previously to generate a run chart.

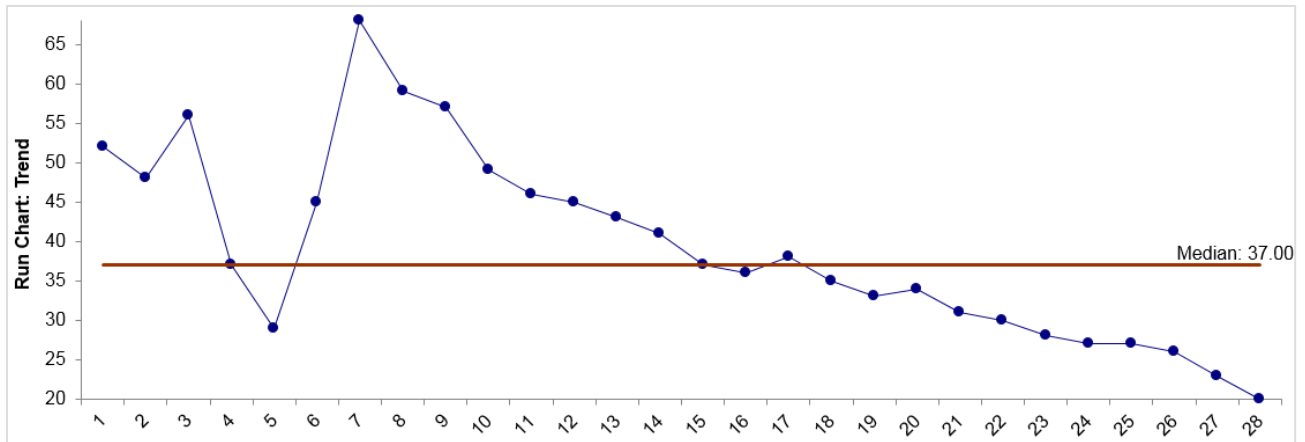


Fig. 2.44 Run Chart Using Trend Data

In this example, the process starts out randomly, but after the seventh data point almost every data point has a lower value than the one before it. This clearly illustrates a downward trend. What might this represent? Perhaps a process winding down? Product sales at the end of a product's life cycle? Defects decreasing after introducing a process improvement?

It should be clearly evident through our review of Histograms, Scatterplots and Run Charts, that there is great value in “visualizing” the data. Graphical displays of data can be very telling and offer excellent information.

2.3 MEASUREMENT SYSTEM ANALYSIS

2.3.1 PRECISION AND ACCURACY

What is Measurement System Analysis?

Measurement System Analysis (MSA) is a systematic method to identify and analyze the variation components of a measurement system. It is a mandatory step in any Six Sigma project to ensure the data are reliable before making any data-based decisions. A MSA is the check point of data quality before we start any further analysis and draw any conclusions from the data. Some good examples of data-based analysis where MSA should be a prerequisite:

- Correlation analysis
- Regression analysis
- Hypothesis testing
- Analysis of variance
- Design of experiments
- Statistical process control

You will see where and how the analysis techniques listed above are used throughout this training program. It is critical at this stage however to know that any variation, anomalies, or

trends found in your analysis are due to the data and not due to the inaccuracies or inadequacies of a measurement system. Therefore, the need for a MSA is vital.

Measurement System

A measurement system is a process used to obtain data and quantify a part, product or process. Data obtained with a measurement device or measurement system are the *observed* values. Observed values are comprised of two elements

1. True Value = Actual value of the measured part
2. Measurement Error = Error introduced by the measurement system.

The *true value* is what we are ultimately trying to determine through the measurement system. It reflects the true measurement of the part or performance of the process.

Measurement error is the variation introduced by the measurement system. It is the bias or inaccuracy of the measurement device or measurement process.

The *observed value* is what the measurement system is telling us. It is the measured value obtained by the measurement system. Observed values are represented in various types of measures which can be categorized into two primary types: discrete and continuous. Continuous measurements are represented by measures of weight, height, money and other types of measures such as ratio measures. Discrete measures on the other hand are categorical such as Red/Yellow/Green, Yes/No or Ratings of 1–10 for example.

A *variable MSA* is designed to assess continuous measurement systems while *attribute MSAs* have been designed to assess discrete measurement systems.

Sources of measurement errors

There are numerous ways to introduce error into a measurement system. The following are just a few common ones:

- Human Error - imagine reading a ruler or a scale, or think about systems where a person must make a qualitative judgment
- Environment - Sometimes the temperature of the air or humidity can affect how a measurement system reads or the equipment itself may need to be calibrated from time to time
- Equipment
- Sample - Sampling can introduce variation based on how or where or when we choose to sample a process
- Process
- Materials
- Methods

Fishbone diagrams can help to brainstorm potential factors affecting the accuracy or validity of measurement systems. The more errors a measurement system allows, the less reliable the observed values are. A valid measurement system brings in minimum amount of measurement error. Ultimately, the goal of a measurement system analysis is to understand how much error exists in the system by analyzing the characteristics of the system. Then, decisions can be made as to whether the system needs to be changed, replaced, modified or accepted.

Characteristics of a Measurement System

Any measurement systems can be characterized by two aspects:

- Accuracy (location related)
- Precision (variation related)

A valid measurement system is *both* accurate and precise. Being accurate does not guarantee the measurement system is precise. Being precise does not guarantee the measurement system is accurate.

Accuracy vs. Precision

Accuracy is the level of closeness between the average observed value and the true value. Accuracy tells us how well the observed value reflects the true value.

Precision is the spread of measurement values. It is how consistent the repeated measurements deliver the same values under the same circumstances.

To simplify, *accuracy* describes how close the average observed value is to the true value for what is being measured. *Precision* describes how close or repeatable the measurement is. Let us take a look at a few representations of accuracy and precision.

Accurate and precise (high accuracy and high precision)

Figure 2.45 represents a target with shots landing in the center and all shots close to one another. This is a depiction of both accuracy and precision. For the purposes of an MSA, think of the center of the target as the “true value” and the black dots as “observed values.” All six measurements are located at the center of the target and are grouped tightly together. This means that the measurements are both accurate and precise.



Fig. 2.45 Accurate and Precise

Accurate and not precise (high accuracy and low precision) Figure 2.46 is an example with all the observations located around the center of the target, but they are spread further apart from one another, more so than in figure 2.45. This measurement system would be described as accurate, but not precise.

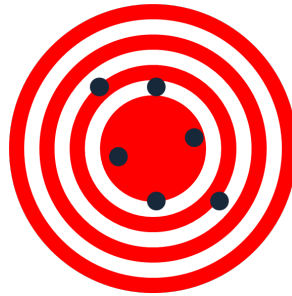


Fig. 2.46 Accurate but Not Precise

Precise and not accurate (high precision and low accuracy) Figure 2.47 shows all observations grouped closely together, but they are not located near the center of the target. This system is precise, but not accurate.



Fig. 2.47 Precise but Not Accurate

Not accurate and not precise (low accuracy and low precision) Lastly, figure 2.48 shows a system that is neither accurate nor precise. The observations are not located around the center and they are spread far apart from each other.



Fig. 2.48 Not Accurate and Not Precise

MSA Conclusions

If the measurement system is considered *both* accurate and precise, we can start the data-based analysis or decision making. If the measurement system is either not accurate or not precise, we need to identify the factors affecting it and calibrate the measurement system until it is both accurate and precise.

Stratifications of Accuracy and Precision

- Accuracy
 - Bias
 - Linearity
 - Stability
- Precision
 - Repeatability
 - Reproducibility

2.3.2 BIAS, LINEARITY, AND STABILITY

Bias

Bias is the difference between the observed value and the true value of a parameter or metric being measured. Think of it as a measurement system's absolute correctness versus a standard (or true value). Bias is calculated by subtracting the reference value from the average value of the measurements.

$$\text{Bias} = \text{Grand Mean} - \text{Reference Value}$$

where the reference value is a standard agreed upon value.

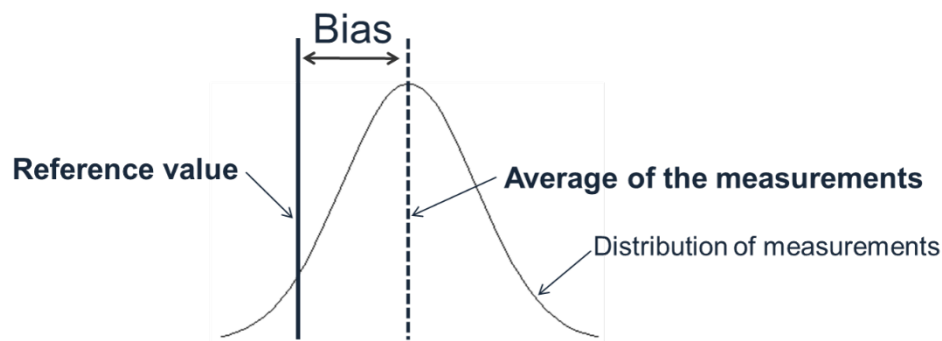


Fig. 2.49 Measurement Bias

In figure 2.49 you can see that the group of observations is consistently to the right of the reference value. The dotted line represents the grand mean described on the last page. The goal is to reduce the distance between the grand mean and the reference value, thereby reducing bias. The closer the average of all measurements is to the reference level, the smaller the bias. The reference level is the average of measurements of the same items using the master or standard instrument.

To determine whether the difference between the average of observed measurement and the reference value is statistically significant (we will explain more details about statistical significance in the Analyze module), we can either conduct a *hypothesis test* or *compare* the reference value against the confidence intervals of the average measurements. If the reference

value falls into the confidence intervals, the bias is not statistically significant and can be ignored. Otherwise, the bias is statistically significant and must be fixed.

Potential causes of bias are:

- Errors in measuring the reference value
- Lack of proper training for appraisers
- Damaged equipment or instrument
- Measurement instrument not calibrated precisely
- Appraisers read the data incorrectly

In the first case, for example, there could be something wrong with the standard (or reference value). For example, think about weight standards that are used to calibrate scales. If the weight is damaged in some way such that it no longer represents the standard, then obviously, we will not be able to measure the correct value.

Linearity

Linearity is the degree of the consistency of bias over the entire expected measurement range. It quantifies how the bias changes over the range of measurement. For example, a scale is off by 0.01 pounds when measuring an object of 10 pounds. However, it is off by 10 pounds when measuring an object of 100 pounds. The scale's bias is not linear.

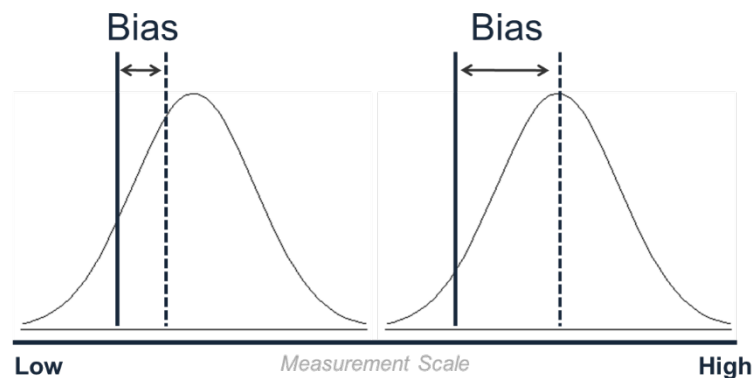


Fig. 2.50 Measurement Linearity

Figure 2.50 represents the bias of a measurement system across its measurement scale from low measures to high measures. The image suggests that as the measurement scale increases so does the bias. The linearity for this measurement system would be positive and undesirable.

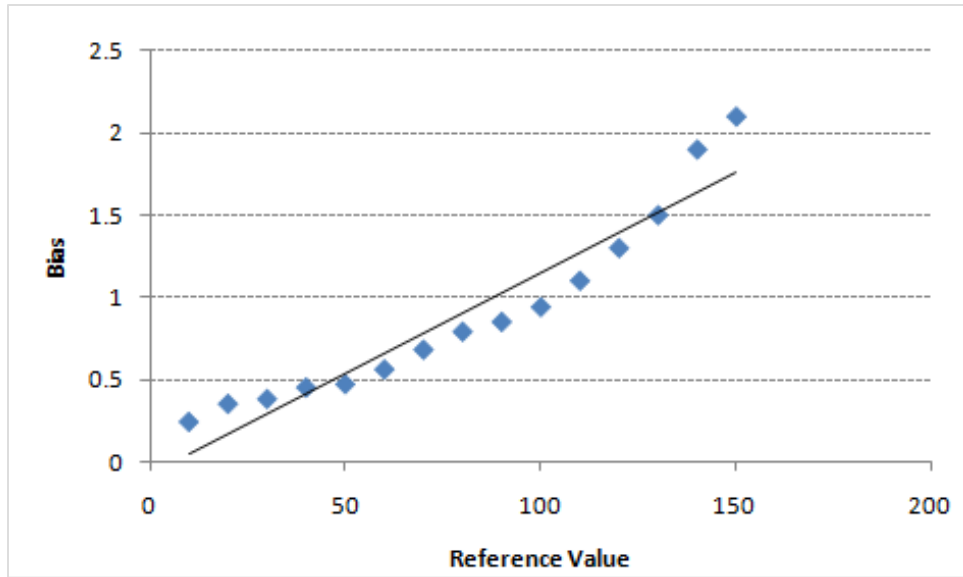


Fig. 2.51 Bias Scatterplot for Linearity

Figure 2.51 uses a scatterplot to demonstrate the linearity of a measurement system. The X axis represents references values for the measurement scale and the Y axis represents bias. The best fit line shows the slope of the bias. The ideal linearity of a measurement system would have a slope of zero which would imply no change in bias over the scale of the measurement system. The slope in figure 2.51 is positive suggesting that as the measurement scale increases so does the bias.

The formula of the linearity of a measurement system is:

$$\text{Linearity} = |\text{Slope}| \times \text{Process Variation}$$

Where:

$$\text{Slope} = \frac{\sum_{i=1}^n x_i y_i - \frac{1}{n} \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{\sum_{i=1}^n (x_i^2) - \frac{1}{n} (\sum_{i=1}^n x_i)^2}$$

and where:

- x_i is the reference value
- y_i is the bias at each reference level
- n is the sample size.

As demonstrated in the previous figures, we know that slope is an important computation in determining the linearity of a measurement system. This is based on the fact that the equation of a line defines the relationship between the bias and the reference values of the parts or samples.

Potential causes of linearity

The causes of linearity include:

- Errors in measuring the lower end or higher end of the reference value
- Lack of proper training for appraisers
- Damaged equipment or instrument
- Measurement instrument not calibrated correctly at the lower or higher end of the measurement scale
- Innate nature of the instrument

As you notice, some of the things we discussed as causes for bias are also potential causes for linearity issues: training, damaged or improperly-calibrated equipment. How these issues manifest themselves are the difference, because bias can become an issue at the low and high ends of a measurement range.

Stability

Stability is the consistency level needed to obtain the same values when measuring the same objects over an extended period. A measurement system that has low bias and linearity close to zero but cannot consistently perform well over time would not deliver reliable data.

Much like we discussed linearity being the degree of bias over the range of a measurement scale, stability is the degree of bias over time. Figure 2.52 demonstrates increasing bias as time passes.

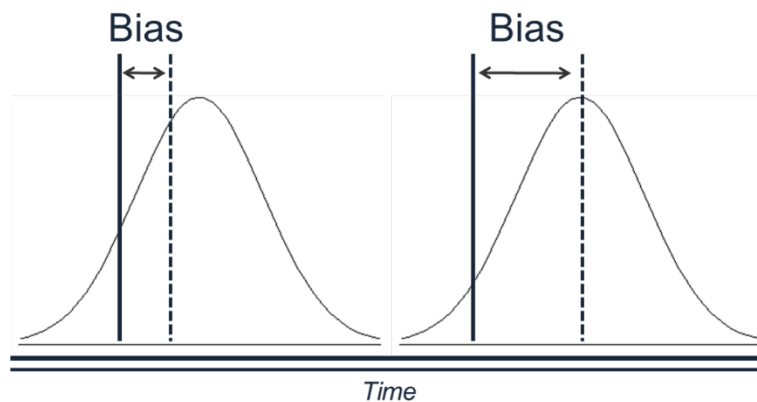


Fig. 2.52 Measurement Stability: Bias over Time

Control charts are the most common tools used to evaluate the stability of a measurement system. By plotting bias calculations of a measurement system over time and using a control chart to visualize scale and variation, it allows us to determine if bias is stable or out of control. As you will learn in the Control phase, if no measures on a control chart are “out of control” then we can consider bias to be stable.

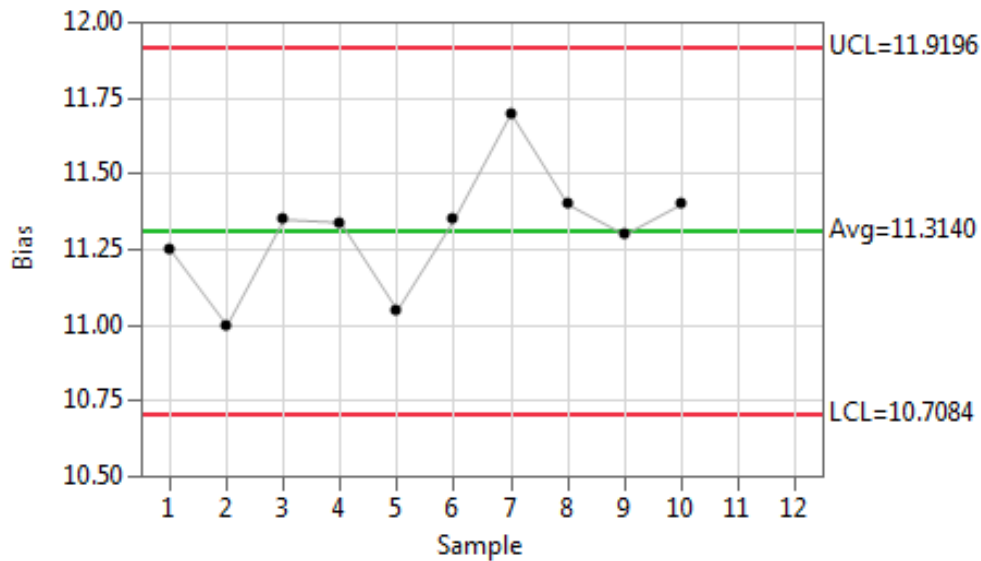


Fig. 2.53 Bias Control Chart: Measurement Stability

Potential causes of instability

The causes of instability include:

- Inconsistent training for appraisers
- Damaged equipment or instrument
- Worn equipment or instrument
- Measurement instrument not calibrated
- Appraisers do not follow the procedure consistently

Consider two appraisers who were trained at two different times, and they would measure differently, or consider two appraisers who do not follow the procedures in the same way. Measurement equipment can wear out over time, lose calibration, or even break, obviously affecting its ability to measure accurately over time.

2.3.3 GAGE REPEATABILITY AND REPRODUCIBILITY

Repeatability

Repeatability evaluates whether the same appraiser can obtain the same value multiple times when measuring the same object using the same equipment under the same environment. It refers to the level of agreement between the repeated measurements of the same appraiser under the same condition. Repeatability measures the inherent variation of the measurement instrument. To simplify repeatability, think of it as your own personal ability to measure something 3 times and get the same answer all three times. If you can't then you're unable to successfully "repeat" a measurement.

Reproducibility

Reproducibility evaluates whether different appraisers can obtain the same value when measuring the same object independently. It refers to the level of agreement between different appraisers. While repeatability is inherent to the measurement system, reproducibility is not caused by the inherent variation of the measurement instrument. It reflects the variability caused by different appraisers, locations, gauges, environments etc. The simple explanation of reproducibility is best described by asking, can you and someone else measure something and get the same answer. If not, the reproducibility of the measurement system is inadequate.

Gage Repeatability & Reproducibility

Gage R&R (Gage Repeatability & Reproducibility) is a method used to analyze the variability of a measurement system by partitioning the variation of the measurements using ANOVA (Analysis of Variance). Gage R&R primarily addresses the precision aspect of a measurement system. It is a tool used to understand if a measurement system can repeat and reproduce and if not, help us determine what aspect of the measurement system is broken so that we can fix it.

Gage R&R requires a deliberate study with parts, appraisers and measurements. Measurement data must be collected and analyzed to determine if the measurement system is acceptable. Typically Gage R&Rs are conducted by 3 appraisers measuring 10 samples 3 times each. Then, the results can be compared to determine where the variability is concentrated. The optimal result is for the measurement variability to be due to the parts.

Data collection of a gage R&R study:

Let k appraisers' measure n random samples independently and repeat the process p times. Different appraisers perform the measurement independently. The order of measurement (e.g., sequence of samples and sequence of appraisers) is randomized, as evidenced by the representative letters k , n , and p .

Potential sources of variance in the measurement:

Appraisers: $\sigma_{appraisers}^2$

Parts: σ_{parts}^2

Appraisers $\times$ Parts: $\sigma_{appraisers \times parts}^2$

Repeatability: $\sigma_{repeatability}^2$

Variance Components: $\sigma_{total}^2 = \sigma_{appraisers}^2 + \sigma_{parts}^2 + \sigma_{appraisers \times parts}^2 + \sigma_{repeatability}^2$

As can be seen in this equation for total measurement variance, there are several components: the appraisers, the parts being measured, the interaction between the appraisers and parts, and the repeatability. A valid measurement system has low variability in both repeatability and

reproducibility so that the total variability observed can reflect the true variability in the parts being measured.

$$\sigma_{total}^2 = \sigma_{reproducibility}^2 + \sigma_{repeatability}^2 + \sigma_{parts}^2$$

Where:

$$\sigma_{reproducibility}^2 = \sigma_{appraisers}^2 + \sigma_{appraisers \times parts}^2$$

Gage R&R variance reflects the precision level of the measurement system.

$$\sigma_{R\&R}^2 = \sigma_{repeatability}^2 + \sigma_{reproducibility}^2$$

As you can see, we can also show the total variance of the measurement system is a function of the reproducibility, the repeatability, and the variance in parts. It ties back to the equation on the previous page when you substitute variance in the appraisers and the variance in interaction between appraisers and parts with reproducibility. The goal is to minimize reproducibility variance and repeatability variance so you are only left with variance in parts—the variance in the parts is the “true” variance.

The *precision* of the measurement system is represented by the sum of the repeatability variance and reproducibility variance.

Variation Components

The variation of each component can be represented by the standard deviation (or sigma) for each component multiplied by Z_0 , which is a sigma multiplier that assumes a specific confidence level for the spread of the data. This is important because we will use the variation to calculate each component’s contribution to the total measurement variation of the system.

$$Variation_{total} = Z_0 \times \sigma_{total}$$

$$Variation_{repeatability} = Z_0 \times \sigma_{repeatability}$$

$$Variation_{reproducibility} = Z_0 \times \sigma_{reproducibility}$$

$$Variation_{parts} = Z_0 \times \sigma_{parts}$$

Where:

$$\sigma_{total}^2 = \sigma_{reproducibility}^2 + \sigma_{repeatability}^2 + \sigma_{parts}^2$$

The percentage of variation R&R contributes to the total variation in the measurement:

$$Contribution \%_{R\&R} = \frac{Variation_{R\&R}}{Variation_{total}} \times 100\%$$

Where:

$$Variation_{R\&R} = Z_0 \times \sqrt{\sigma_{repeatability}^2 + \sigma_{reproducibility}^2}$$

The goal for the Contribution %_{R&R} calculation is to determine how much variation is contributed by repeatability and reproducibility. As you can imagine, the lower the contribution from these components the better, but there are some guidelines for how to assess the quality of the measurement system. Table 2.1 represents the standard interpretations of varying degrees of contribution percentages.

Contribution % _{R&R}	Interpretation
Less than 1%	Satisfactory – Measurement System is Acceptable
Between 1% and 9%	Grey Area – Requires Decisions and Trade-offs
Greater than 10%	Unsatisfactory – Measurement System is Unacceptable

Table 2.1 Gage R&R Contribution% Interpretation Guidelines

2.3.4 VARIABLE AND ATTRIBUTE MSA

Variable Gage R&R

Whenever something is measured repeatedly or by different people or processes, the results of the measurements will vary. Variation comes from two primary sources:

- Differences between the parts being measured
- The measurement system

We can use a gage R&R to conduct a measurement system analysis to determine what portion of the variability comes from the parts and what portion comes from the measurement system. There are key study results that help us determine the components of variation within our measurement system.

Key Measures of a Variable Gage R&R

- %Contribution - The percent of contribution for a source is 100 times the variance component for that source divided by the total variance.
- %Study Var (6*SD) - The percent of study variation for a source is 100 times the study variation for that source divided by the total variation
- %Tolerance (SV/Tolerance) - The percent of spec range taken up by the total width of the distribution of the data based on variation from that source
- Distinct Categories - The number of distinct categories of parts that the measurement system is able to distinguish. If a measurement system is not capable of distinguishing at least five types of parts, it is probably not adequate.

Variable Gage R&R Guidelines (AIAG)

The guidelines for acceptable or unacceptable measurement systems can vary depending on an organizations tolerance or appetite for risk. The common guidelines used for interpretation are published by the Automotive Industry Action Group (AIAG). These guidelines are considered standard for interpreting the results of a measurement system analysis using Variable Gage R&R. Table 2.2 summarizes the AIAG standards.

Measurement System	% Study Var	% Contribution	Distinct Categories
Acceptable	10% or less	1% or Less	5 or Greater
Marginal	10% - 30%	1% - 9%	
Unacceptable	30% or Greater	9% or Greater	Less than 5

Table 2.2 Variable Gage R&R Guidelines

Use SigmaXL to Implement a Variable MSA



Data File: “Variable MSA” tab in “Sample Data.xlsx”

Let’s take a look at an example of a Variable MSA using the data in the Variable MSA tab in your “Sample Data.xlsx” file. In this exercise, we will first walk through how to set up your study using SigmaXL and then we will perform a Variable MSA using 3 operators who all measured 10 parts three times each. The part numbers and operators and measurement trials are all generic so that you can apply the concept to your given industry. First, we need to set up the study:

Step 1: Set up your data collection worksheet

1. Click on SigmaXL -> Measurement Systems Analysis -> Create Gauge R&R (Crossed) Worksheet
2. A new window named “Create Gauge R&R (Crossed) Worksheet” appears
3. Enter 10 as the “Number of Parts/Samples”
4. Enter 3 as the “Number of Operators/Appraisers”
5. Enter 3 as the “Number of Replicates/Trials”
6. Uncheck the checkboxes for both “Randomize Parts/Sample” and “Randomize Operators/Appraisers”

Create Gage R&R (Crossed) Worksheet

Number of Parts/Samples: 10

Number of Operators/Appraisers: 3

Number of Replicates/Trials: 3

☐ Randomize Parts/Samples

☐ Randomize Operators/Appraisers

Part/Sample Names:

1: Part 01

2: Part 02

3: Part 03

4: Part 04

Operator/Appraiser Names:

1: Operator A

2: Operator B

3: Operator C

OK >> Cancel Help Reset

Fig. 2.54 Create Gage R&R (Crossed) Worksheet dialog box

7. Click "OK>>"
8. A new tab named "Gage R&R (Crossed) WKS" is generated

Gage R&R Study (Crossed) Worksheet				
Gage Name:				
Date of Study:				
Performed By:				
Notes:				
Run Order	Std. Order	Part	Operator	Measurement
1	1	Part 01	Operator A	
2	2	Part 01	Operator A	
3	3	Part 01	Operator A	
4	4	Part 02	Operator A	
5	5	Part 02	Operator A	
6	6	Part 02	Operator A	
7	7	Part 03	Operator A	
8	8	Part 03	Operator A	
9	9	Part 03	Operator A	
10	10	Part 04	Operator A	
11	11	Part 04	Operator A	
12	12	Part 04	Operator A	
13	13	Part 05	Operator A	
14	14	Part 05	Operator A	
15	15	Part 05	Operator A	
16	16	Part 06	Operator A	
17	17	Part 06	Operator A	
18	18	Part 06	Operator A	

Fig. 2.55 Gage R&R (Crossed) WKS

Step 2: Data collection

In the newly generated data table, SigmaXL has provided the template where we can organize the data. We will need to enter test results into the measurement column. In the “Sample Data.xlsx” file under the “Variable MSA” tab there are already “Measurement” values collected by the three operators (i.e., operator A, B, and C). The data are listed in Run order.

Run Order	Part	Operator	Measurement
1	Part 01	Operator A	0.29
2	Part 01	Operator A	0.41
3	Part 01	Operator A	0.64
4	Part 02	Operator A	-0.56
5	Part 02	Operator A	-0.68
6	Part 02	Operator A	-0.58
7	Part 03	Operator A	1.34
8	Part 03	Operator A	1.17
9	Part 03	Operator A	1.27
10	Part 04	Operator A	0.47
11	Part 04	Operator A	0.5
12	Part 04	Operator A	0.64
13	Part 05	Operator A	-0.8
14	Part 05	Operator A	-0.92
15	Part 05	Operator A	-0.84
16	Part 06	Operator A	0.02
17	Part 06	Operator A	-0.11
18	Part 06	Operator A	-0.21

Fig. 2.56 Pre-Populated Variable MSA data in Sample Data.xlsx file

Step 3: Enter the data into the MSA template generated in SigmaXL

Transfer the data from the “Measurement” column in “Variable MSA” tab of “Sample Data.xlsx” file to the last column in the MSA template that SigmaXL generated from the steps above.

Gage R&R Study (Crossed) Worksheet

Gage Name:	
Date of Study:	
Performed By:	
Notes:	

Run Order	Std. Order	Part	Operator	Measurement
1	1	Part 01	Operator A	0.29
2	2	Part 01	Operator A	0.41
3	3	Part 01	Operator A	0.64
4	4	Part 02	Operator A	-0.56
5	5	Part 02	Operator A	-0.68
6	6	Part 02	Operator A	-0.58
7	7	Part 03	Operator A	1.34
8	8	Part 03	Operator A	1.17
9	9	Part 03	Operator A	1.27
10	10	Part 04	Operator A	0.47
11	11	Part 04	Operator A	0.5
12	12	Part 04	Operator A	0.64
13	13	Part 05	Operator A	-0.8
14	14	Part 05	Operator A	-0.92
15	15	Part 05	Operator A	-0.84
16	16	Part 06	Operator A	0.02
17	17	Part 06	Operator A	-0.11
18	18	Part 06	Operator A	-0.21

Fig. 2.57 Populated Variable MSA data in SigmaXL file

Step 4: Implement Gage R&R

1. Click SigmaXL -> Measurement Systems Analysis -> Analyze Gage R&R (Crossed)
2. A new window named "Analyze Gage R&R (Crossed)" appears with the data range automatically selected in the box right below "Please select your data"

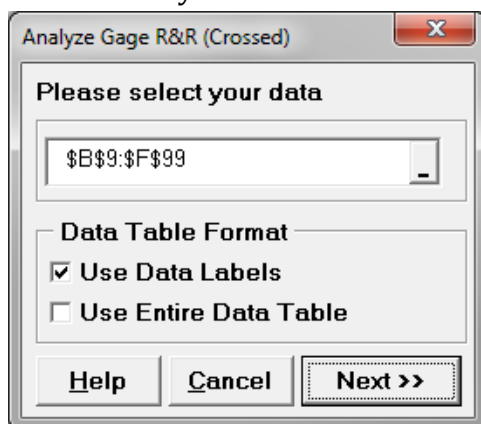


Fig. 2.58 Analyze Gage R&R (Crossed) data selection box

3. Click "Next>>"
4. A new window also named "Analyze Gauge R&R (Crossed)" pops up.
5. Select "Part" as "Part"
Select "Operator" as "Operator"

Select “Measurement” as “Measurement”

- Enter 5.15 as the “Standard Deviation Multiplier” and enter 95% as the “Confidence Level”.

The value 5.15 is the recommended standard deviation multiplier by the Automotive Industry Action Group (AIAG). It corresponds to 99% of data in the normal distribution. If we use 6 as the standard deviation multiplier, it corresponds to 99.73% of the data in the normal distribution.

Fig. 2.59 Analyze Gage R&R (Crossed) Variable selection box with selected variables

- Click “OK”

Step 5: Interpret the MSA results

Gage R&R Metrics	StDev	StDev Lower 95% CI	StDev Upper 95% CI	5.15 * StDev	% Total Variation (TV)	% TV Lower 95 % CI	% TV Upper 95 % CI
Gage R&R:	0.302	0.227	1.457	1.557	27.86	13.70	81.64
Operator (AV Appraiser Variation):	0.227	0.114	1.443	1.168	20.90		
Part * Operator (INT Interaction):	0.000	0.000	0	0	0.00		
Reproducibility (SQRT(AV^2 + INT^2)):	0.227	0.114	1.443	1.168	20.90		
Repeatability (EV Equipment Variation):	0.200	0.173	0.237	1.030	18.42		
Part Variation (PV):	1.042	0.715	1.906	5.368	96.04		
Total Variation (TV):	1.085	0.776	2.106	5.589	100.00		

Gage R&R Metrics	Variance Component	% Contribution of Variance Component
Gage R&R:	0.0914	7.76
Operator:	0.0515	4.37
Part * Operator:	0.0000	0.00
Reproducibility:	0.0515	4.37
Repeatability:	0.0400	3.39
Part Variation:	1.0864	92.24
Total Variation:	1.1779	100.00

Gage R&R Metrics	NDC	NDC Lower 95% CI	NDC Upper 95% CI
Number of Distinct Categories (Signal-to-Noise Ratio: 1.41 * PV/R&R):	4.9	1.0	10.2

Fig. 2.60 Analyze Gage R&R (Crossed) results

The result of this Gage R&R study leaves room for consideration on one key measure. As noted in previous pages, the targeted percent contribution R&R should be less than 10% and study variation less than 30%. With % contribution at 7.76% it is below our 10% unacceptable threshold and similarly, Study variation at 26.86% is also below the threshold of 30% but this result is at best marginal and should be heavily scrutinized by the business before concluding that the measurement system does not warrant further improvement.

Use SigmaXL to Implement an Attribute MSA



Data File: “Attribute MSA” tab in “Sample Data.xlsx” (an example in the AIAG MSA Reference Manual, 3rd Edition).

Steps in SigmaXL to run an attribute MSA:

Step 1: Reorganize the original data into four new columns (i.e., Appraiser, Assessed Result, Part, and Reference).

1. Select the entire range of the original data (“Part”, “Reference”, “Appraiser A”, “Appraiser B” and “Appraiser C” columns)
2. Click SigmaXL -> Data Manipulation -> Stack Subgroups Across Rows
3. A new window named “Stack Subgroups” pops with the selected data range appearing in the box under “Please select your data”

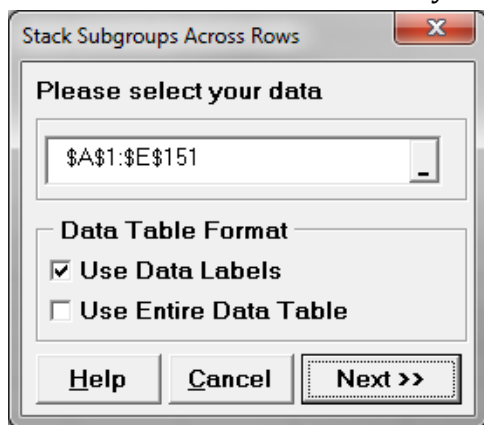


Fig. 2.61 Stack Subgroups Across Rows data selection box

4. Click “Next>>”
5. A new window named “Stack Subgroups Across Rows” appears
6. Select “Appraiser A”, “Appraiser B” and “Appraiser C” as “Numeric Data Variables”
Select “Part” and “Reference” as the “Additional Category Columns”
Enter “Assessed Result” as the “Stacked Data (Y) Column Heading (Optional)”

Enter “Appraiser” as the “Category (X) Column Heading (Optional)”

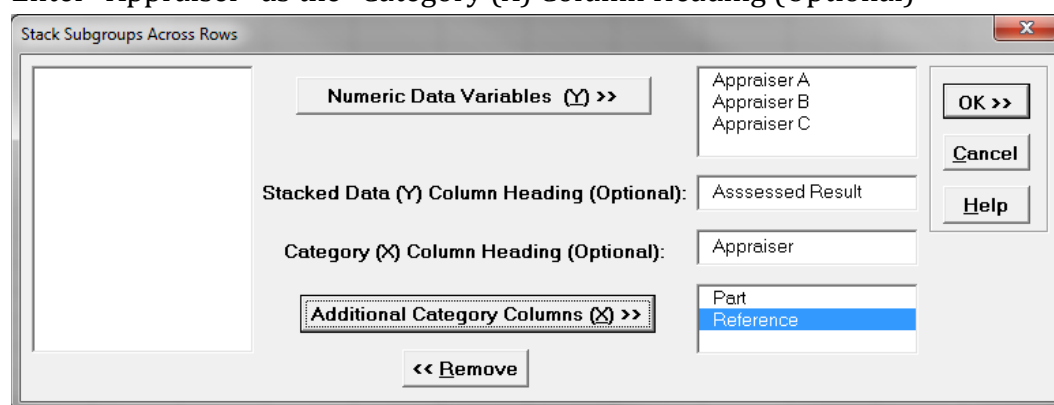


Fig. 2.62 Stack Subgroups Across Rows variable selection box with variables selected

7. Click “OK>>”
8. The stacked data are created in a new worksheet.

Step 2: Run a MSA using SigmaXL

1. Select the entire range of the data (“Part”, “Reference”, “Appraiser” and “Assessment Result” columns)
2. Click SigmaXL -> Measurement Systems Analysis -> Attribute MSA (Binary)
3. A new window named “Attribute MSA (Binary)” pops with the selected data range appearing in the box under “Please select your data”

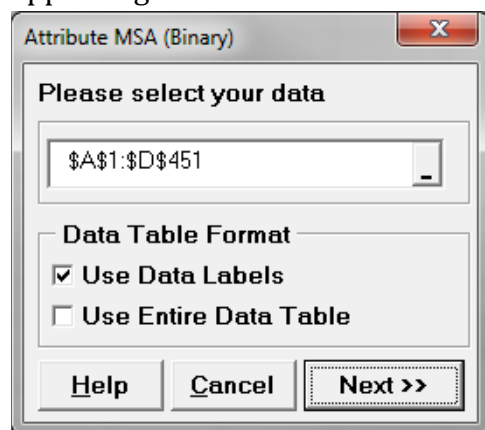


Fig. 2.63 Attribute MSA (Binary) data selection box

4. Click “Next>>”
5. A new window named “Attribute MSA (Binary)” appears
6. Select “Part” as “Part/Sample”
Select “Appraiser” as “Appraiser”
Select “Assessed Result” as “Assessed Result”
Select “Reference” as “True Standard (Optional)”

Select “1” as “Good Level”

Fig. 2.64 Attribute MSA (Binary) variable selection box with variables selected

7. Click “OK”

The MSA results appear in the newly generated tab “Att_MSA_Binary”.

Within Appraiser Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
Appraiser A	50	42	84.00	71.49	91.66	0.7600	0.0000	0.6000	0.9200
Appraiser B	50	45	90.00	78.64	95.65	0.8451	0.0000	0.6850	1.0000
Appraiser C	50	40	80.00	66.96	88.76	0.7029	0.0000	0.5429	0.8629

Each Appraiser vs. Standard Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
Appraiser A	50	42	84.00	71.49	91.66	0.8802	0.0000	0.7202	1.0000
Appraiser B	50	45	90.00	78.64	95.65	0.9226	0.0000	0.7626	1.0000
Appraiser C	50	40	80.00	66.96	88.76	0.7747	0.0000	0.6147	0.9347

Fig. 2.65 Attribute MSA Results

The rater scores represent how the raters agree with themselves. Appraiser A, for instance, agreed with himself on 84% of the measurements made.

Between Appraiser Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
	50	39	78.00	64.76	87.25	0.7936	0.0000	0.7474	0.8398

All Appraisers vs. Standard Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
	50	39	78.00	64.76	87.25	0.8592	0.0000	0.7668	0.9516

Fig. 2.66 Attribute MSA Results Broken Down

The important numbers are called out here. Of the 50 total measurements performed, for 78% of those (39) the appraisers agreed with both themselves and the other appraisers.

Kappa statistic is a coefficient indicating the agreement percentage above the expected agreement by chance. Kappa ranges from –1 (perfect disagreement) to 1 (perfect agreement). When the observed agreement is less than the chance agreement, Kappa is negative. When the observed agreement is greater than the chance agreement, Kappa is positive. Rule of thumb: If Kappa is greater than 0.7, the measurement system is acceptable. If Kappa is greater than 0.9, the measurement system is excellent.

Within Appraiser Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
Appraiser A	50	42	84.00	71.49	91.66	0.7600	0.0000	0.6000	0.9200
Appraiser B	50	45	90.00	78.64	95.65	0.8451	0.0000	0.6850	1.0000
Appraiser C	50	40	80.00	66.96	88.76	0.7029	0.0000	0.5429	0.8629

Each Appraiser vs. Standard Agreement	# Inspected	# Matched	Percent	95.0% LC (Score)	95.0% UC (Score)	Fleiss' Kappa	Fleiss' Kappa P-Value	Fleiss' Kappa 95.0% LC	Fleiss' Kappa 95.0% UC
Appraiser A	50	42	84.00	71.49	91.66	0.8802	0.0000	0.7202	1.0000
Appraiser B	50	45	90.00	78.64	95.65	0.9226	0.0000	0.7626	1.0000
Appraiser C	50	40	80.00	66.96	88.76	0.7747	0.0000	0.6147	0.9347

Fig. 2.67 Fleiss' Kappa Statistic in Attribute MSA Results

In all cases the Kappa indicates that the measurement system is acceptable.

2.4 PROCESS CAPABILITY

2.4.1 CAPABILITY ANALYSIS

What is Process Capability?

Process capability measures how well the process performs to meet given specified outcome. It indicates the conformance of a process to meet given requirements or specifications. *Capability analysis* helps to better understand the performance of the process with respect to meeting customer's specifications and identify the process improvement opportunities.

Process Capability Analysis Steps

Step 1: Determine the metric or parameter to measure and analyze.

Step 2: Collect the historical data for the parameter of interest.

Step 3: Prove the process is statistically stable (i.e., in control).

Step 4: Calculate the process capability indices.

Step 5: Monitor the process and ensure it remains in control over time. Update the process capability indices if needed.

Process Capability Indices

Process capability can be presented using various indices depending on the nature of the process and the goal of the analysis. Popular process capability indices are:

- C_p
- P_p
- C_{pk}
- P_{pk}
- C_{pm}

Capability of the Process (C_p)

C_p can be calculated with the formula:

$$C_p = \frac{USL - LSL}{6 \times \sigma_{within}}$$

Where:

$$\sigma_{within} = \frac{s_p}{c_4(d + 1)}$$

$$s_p = \sqrt{\frac{\sum_i \sum_j (x_{ij} - \bar{x}_i)^2}{\sum_i (n_i - 1)}}$$

$$d = \sum_i (n_i - 1)$$

$$c_4 = \frac{4(n - 1)}{(4n - 3)}$$

The C_p index is process capability. It assumes the process mean is centered between the specification limits and essentially is the ratio of the distance between the specification limits to six process standard deviations. Obviously, the higher this value the better, because it means you can fit the process variation between the spec limits more easily. C_p measures the process' potential capability to meet the two-sided specifications. It does not take the process average into consideration.

High C_p indicates the small spread of the process with respect to the spread of the customer specifications. C_p is recommended when the process is centered between the specification limits. C_p works when there are both upper and lower specification limits. The higher C_p the better, meaning the spread of the process is smaller relative to the spread of the specifications.

Performance of the Process (P_p)

P_p can be calculated with the formula:

$$P_p = \frac{USL - LSL}{6 \times \sigma_{overall}}$$

Where:

$$\sigma_{overall} = \frac{s}{c_4(n)}$$

$$s = \sqrt{\sum_i \sum_j \frac{(x_{ij} - \bar{x})^2}{n - 1}}$$

$$c_4 = \frac{4(n - 1)}{(4n - 3)}$$

Like C_p , P_p assumes the process mean is centered between the spec limits and essentially is the ratio of the distance between the spec limits to six process standard deviations. Obviously, the higher this value the better, because it means you can fit the process variation between the spec limits more easily. Similar to C_p , P_p measures the capability of the process to meet the two-sided specifications. It only focuses on the spread and does not take the process centralization into consideration. It is recommended when the process is centered between the specification limits.

C_p considers the within-subgroup standard deviation and P_p considers the total standard deviation from the sample data. P_p works when there are both upper and lower specification limits. P_p is a more conservative method for determining capability because it considers the total variation of a process instead of a subgroup of data.

Capability of the Process with a k Factor Adjustment (C_{pk})

C_{pk} can be calculated with the formula:

$$C_{pk} = (1 - k) \times C_p$$

Where:

$$k = \frac{|m - \mu|}{\frac{USL - LSL}{2}}$$

$$m = \frac{USL + LSL}{2}$$

The m is essentially the center point between the spec limits (it is calculated like an average). When calculating k , the numerator is the absolute value of the difference between the center point between the spec limits (m) and the process mean (μ); the denominator is half the

distance between the specs. As you can guess from the calculation of k , it takes into consideration the location of the mean between the spec limits. The formulas to calculate C_{pk} can also be expressed as follows:

$$C_{pk} = \min\left(\frac{USL - \mu}{3 \times \sigma_{within}}, \frac{\mu - LSL}{3 \times \sigma_{within}}\right)$$

Where:

$$\sigma_{within} = \frac{s_p}{c_4(d + 1)}$$

$$s_p = \sqrt{\frac{\sum_i \sum_j (x_{ij} - \bar{x}_i)^2}{\sum_i (n_i - 1)}}$$

$$d = \sum_i (n_i - 1)$$

$$c_4 = \frac{4(n - 1)}{(4n - 3)}$$

The expression for C_{pk} is indicating that the limiting factor is the specification limit that the mean is closest to. C_{pk} measures the process' actual capability by taking both the variation and average of the process into consideration. The process does not need to be centered between the specification limits to make the index meaningful. C_{pk} is recommended when the process is not in the center between the specification limits. When there is only a one-sided limit, C_{pk} is calculated using C_{pu} or C_{pl} . C_{pk} for upper specification limit:

$$C_{pu} = \frac{USL - \mu}{3 \times \sigma_{within}}$$

C_{pk} for lower specification limit:

$$C_{pl} = \frac{\mu - LSL}{3 \times \sigma_{within}}$$

Where:

- USL and LSL are the upper and lower specification limits.
- μ is the process mean.

Performance of the Process with a k Factor Adjustment (P_{pk})

P_{pk} can be calculated with the formula:

$$P_{pk} = (1 - k) \times P_p$$

Where:

$$k = \frac{|m - \mu|}{\frac{USL - LSL}{2}}$$

$$m = \frac{USL + LSL}{2}$$

Where:

- USL and LSL are the upper and lower specification limits
- μ is the process mean.

P_{pk} is to P_p as C_{pk} is to C_p . The k factor is the same used earlier to calculate C_{pk} .

The formulas to calculate P_{pk} can also be expressed as follows:

$$P_{pk} = \min\left(\frac{USL - \mu}{3 \times \sigma_{overall}}, \frac{\mu - LSL}{3 \times \sigma_{overall}}\right)$$

$$\sigma_{overall} = \frac{s}{c_4(n)}$$

$$s = \sqrt{\sum_i \sum_j \frac{(x_{ij} - \bar{x})^2}{n - 1}}$$

$$c_4 = \frac{4(n - 1)}{(4n - 3)}$$

Similar to C_{pk} , P_{pk} measures the process capability by taking both the variation and the average of the process into consideration. P_{pk} solves the decentralization problem P_p cannot overcome. C_{pk} considers the within-subgroup standard deviation, while P_{pk} considers the total standard deviation from the sample data. When there is only a one-sided specification limit, P_{pk} is calculated using P_{pu} or P_{pl} . P_{pk} for upper specification limit:

$$P_{pu} = \frac{USL - \mu}{3 \times \sigma_{overall}}$$

P_{pk} for lower specification limit:

$$P_{pl} = \frac{\mu - LSL}{3 \times \sigma_{overall}}$$

Where:

- USL and LSL are the upper and lower specification limits
- μ is the process mean.

Taguchi's Capability Index (C_{pm})

C_p , P_p , C_{pk} , and P_{pk} all consider the variation of the process. C_{pk} and P_{pk} take both the variation and the average of the process into consideration when measuring the process capability. It is possible that the process average fails to meet the target customers require while the process still remains between the specification limits. C_{pm} (Taguchi's capability index) helps to capture the variation from the specified target. Rather than only telling us if a measurement is good (between the spec limits), C_{pm} helps us understand *how good* the measurement is. C_{pm} can be calculated with the formula:

$$C_{pm} = \frac{\min(T - LSL, USL - T)}{3 \times \sqrt{s^2 + (\mu - T)^2}}$$

Where:

- USL and LSL are the upper and lower specification limits
- T is the specified target
- μ is the process mean.

Note: C_{pm} can work only if there is a target value specified.

Capability Interpretation

Interpreting the results of a capability analysis is dependent upon the nature of the business, product and customer. The Automotive Industry Action Group (AIAG) suggests that P_p and P_{pk} should be > 1.67 while C_p and C_{pk} should be > 1.33 . The reality is that anything greater than 1.0 is a fairly-capable process but your business needs to assess the costs vs. benefits of achieving capability greater than 1.67 or even higher. If you're dealing with customer safety or life and death influences then obviously the product necessitates a capability greater than 2.0. Below is a simple table for quick interpretation with sigma level references.

Index	Value	Interpretation	Sigma Level
C_{pk}	<1.0	Not Very Capable	<3
C_{pk}	1.0-1.99	Capable	3-6
C_{pk}	>2.0	Very Capable	>6

Table 2.3 Capability Index Interpretation

Use SigmaXL to Run a Process Capability Analysis



Data File: "Capability Analysis" tab in "Sample Data.xlsx"

Steps in SigmaXL to run a process capability analysis:

1. Select the entire range of data (i.e. the column "HtBk")
2. Click SigmaXL -> Process Capability -> Histograms & Process Capability

3. A new window named “Histogram & Process Cap” pops up with the selected range of data appearing in the box under “Please select your data”

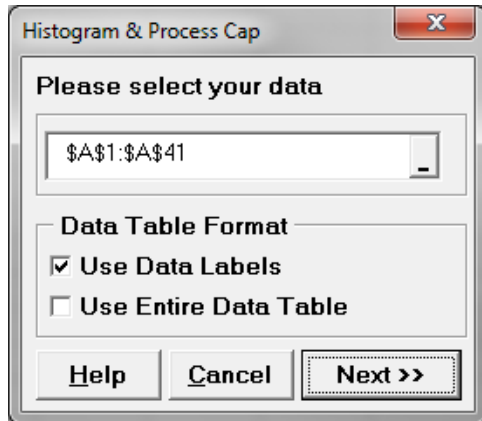


Fig. 2.68 Histograms & Process Capability dialog box

4. Click “Next>>”
5. A new window named “Histograms & Process Capability” appears
6. Select “HtBk” as the “Numeric Data Variables”
7. Enter 6 in LSL, 6.5 in T and 7 in USL into the boxes for “Lower Spec Limit”, “Target” and “Upper Spec Limit” respectively

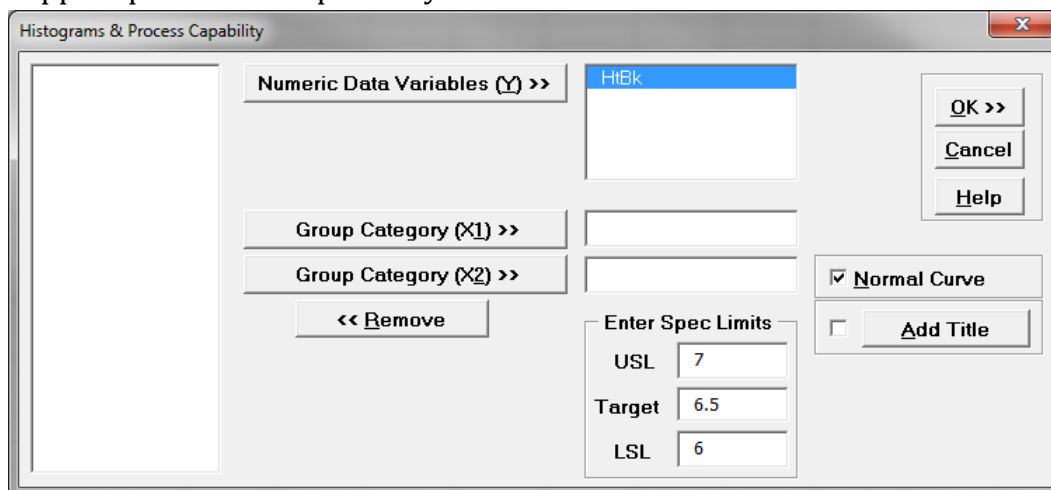


Fig. 2.69 Histograms and Process Capability variable selection box with variables selected

8. Click “OK”.
9. The histogram and the process capability analysis results are in the newly generated tab “Hist Cap (1)”

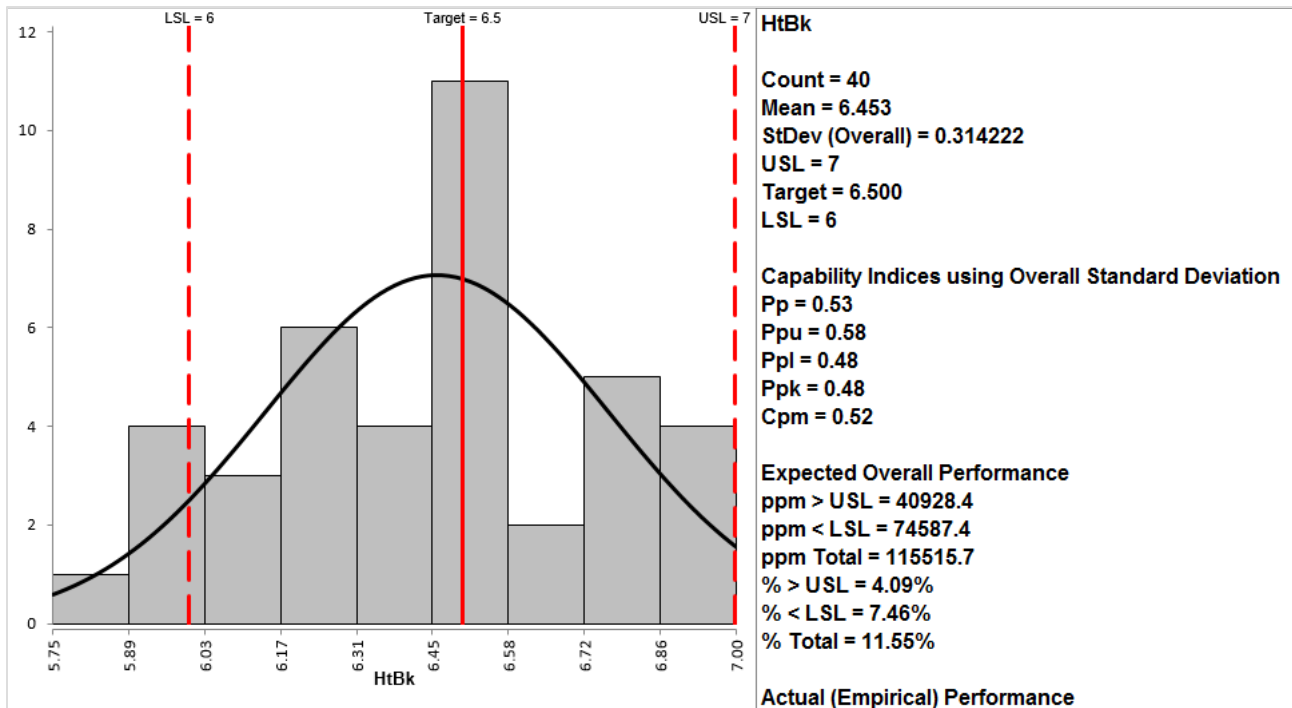


Fig. 2.70 Process Capability Results

With P_{pk} of less than 1.0 we can conclude that the capability of this process is not very good. Anything less than 1.0 should be considered not capable and we should strive for P_{pk} to reach levels of greater than 1 and preferably over 1.67.

2.4.2 CONCEPT OF STABILITY

What is Process Stability?

A process is said to be stable when:

- The process is in control
- The future behavior of the process is predictable at least between some limits
- There is only random variation involved in the process.
- The causes of variation in the process are only due to chance or common causes
- There are not any trends, patterns, or outliers in the control chart of the process

Stability means that the process is in control; there are no special causes (only random variation) influencing the process outcome. Future process outcomes are predictable within a range of values, and there are no trends, patterns, or outliers in a control chart of the process.

Root Causes of Variation in the Process

To discuss stability, it is important that we define and differentiate common cause and special cause variation. Common causes are unable to be eliminated from the process. Typical common causes are:

- Chance
- Random and anticipated
- Natural noise
- Inherent in the process

Special causes are:

- Assignable cause
- Unanticipated
- Unnatural pattern
- The signal of changes in the process

Special causes are able to be eliminated from the process. Common cause variation is left to chance. It is random, it is expected, and inherent to the process; therefore, it is unable to be eliminated. Special cause, on the other hand, can be attributed to an “assignable cause.” It is not expected (or anticipated) and is external to the process. These causes signal changes in the process and can be eliminated.

Control Charts

Control charts are the graphical tools to analyze the stability of a process. A control chart is used to identify the presence of potential special causes in the process and to determine whether the process is statistically in control. If the samples or calculations of samples are all in control, the process is stable and the data from the process can be used to predict the future performance of the process.

Popular Control Charts

- I-MR Chart—Individuals and moving range
- Xbar-R Chart—Xbar is the average and R is range
- Xbar-S Chart—Xbar is the average and S is standard deviation
- C Chart—Uses count data to chart non-conformances or defects)
- U Chart—U stands for units. It is the same as a C chart, but a C chart assumes subgroup size is constant, while a U chart assumes uneven subgroup sizes.
- P Chart—Proportions chart, which shows the proportion defective
- NP Chart—Shows number defective (with equal subgroup size)
- EWMA Chart—Exponentially weighted moving average
- CUSUM Chart—Cumulative sum

Process Stability vs. Process Capability

Process stability indicates how stable a process performed in the past. When the process is stable, we can use the data from the process to predict its future behavior. Process capability indicates how well a process performs with respect to meeting the customer’s specifications.

The process capability analysis is valid only if the process is statistically stable (i.e., in control, predictable). Being stable does *not* guarantee that the process is also capable. However, being stable is the prerequisite to determine whether a process is capable.

2.4.3 ATTRIBUTE AND DISCRETE CAPABILITY

Process Capability Analysis for Binomial Data

If we are measuring the count of defectives in each sample set to assess the process performance of meeting the customer specifications, we use “%Defective” (percentage of items in the samples that are defective) as the process capability index. %Defective is given by a very simple calculation: determine the number of defective units divided by the number of units overall.

$$\% Defective = \frac{N_{defectives}}{N_{overall}}$$

Where:

- $N_{defectives}$ is the total count of defectives in the samples
- $N_{overall}$ is the sum of all the sample sizes.

Process Capability Analysis for Poisson Data

If we are measuring the count of defects in each sample set to assess the process performance of meeting the customer specifications, we use Mean DPU (defects per unit of measurement) as the process capability index:

$$DPU = \frac{N_{defects}}{N_{overall}}$$

Where:

- $N_{defects}$ is the total count of defects in the samples
- $N_{overall}$ is the sum of all the units in the samples.

2.4.4 MONITORING TECHNIQUES

Capability and Monitoring

In the Measure phase of the project, process stability analysis and process capability analysis are used to baseline the performance of current process. In the Control phase of the project, process stability analysis and process capability analysis are combined to monitor whether the improved process is maintained consistently as expected.

3.0 CONTROL PHASE

3.1 LEAN CONTROLS

3.1.1 CONTROL METHODS FOR 5S

What is 5S?

5S is a methodology that is applied in a Lean workplace. It is a systematic method to organize, order, clean, and standardize a workplace . . . and keep it that way! 5S is summarized in five Japanese words, all starting with the letter S:

- *Seiri* (sorting)
- *Seiton* (straightening)
- *Seiso* (shining)
- *Seiketsu* (standardizing)
- *Shisuke* (sustaining)

Originally developed in Japan, 5S is widely used to optimize the workplace to increase productivity and efficiency.

5S Goals

1. Reduced waste
2. Reduced cost
3. Establish a work environment that is:
 - Self-explaining
 - Self-ordering
 - Self-regulating
 - Self-improving.

Where there is/are no more:

- Wandering and/or searching
- Waiting or delays
- Secrets hiding spots for tools
- Obstacles or detours
- Extra pieces, parts, materials, etc.
- Injuries
- Waste

5S Benefits

By meeting the goals of 5S, the following benefits are achieved.

- Reduced changeovers
- Reduced defects

- Reduced waste
- Reduced delays
- Reduced injuries
- Reduced breakdowns
- Reduced complaints
- Reduced red ink
- Higher quality
- Lower costs
- Safer work environment
- Greater associate and equipment capacity

5S Systems Reported Results

Organizations that have implemented 5S systems have reported some very impressive results: reduction in waste, improved safety, reduced costs, and improved performance.

Cut in floor space:	60%
Cut in flow distance:	80%
Cut in accidents:	70%
Cut in rack storage:	68%
Cut in number of forklifts:	45%
Cut in machine changeover time:	62%
Cut in annual physical inventory time:	50%
Cut in classroom training requirements:	55%
Cut in nonconformance in assembly:	96%
Increase in test yields:	50%
Late deliveries:	0%
Increase in throughput:	15%

Sorting (Seiri)

- Go through all the tools, parts, equipment, supply, and material in the workplace.
- Categorize them into two major groups: needed and unneeded.
- Eliminate the unneeded items from the workplace. Dispose of or recycle those items.
- Keep the needed items and sort them in the order of priority. When in doubt . . . throw it out!

Straightening (Seiton)

Straightening in 5S is also called setting in order.

- Label each needed item.
- Store items at their best locations so that the workers can find them easily whenever they needed any item.
- Reduce the motion and time required to locate and obtain any item whenever it is needed.
- Promote an efficient work flow path.

- Use visual aids like the tool board image on this page to remind employees where things belong so the order is sustained.

Shining (Seiso)

Shining in 5S is also called *sweeping*.

- Clean the workplace thoroughly.
- Maintain the tidiness of the workplace.
- Make sure every item is located at the specific location where it should be.
- Create the ownership in the team to keep the work area clean and organized.

Standardizing (Seiketsu)

Standardize the workstation and the layout of tools, equipment, and parts.

Create identical workstations with a consistent way of storing the items at their specific locations so that workers can be moved around to any workstation any time and perform the same task.

Sustaining (Shisuke)

Sustaining in 5S is also called self-discipline.

- Create the culture in the team to follow the first four S's consistently.
- Avoid falling back to the old ways of cluttered and unorganized work environment.
- Keep the momentum of optimizing the workplace.
- Promote innovations of workplace improvement.
- Sustain the first four S's using:
 - 5S Maps
 - 5S Schedules
 - 5S Job cycle charts
 - Integration of regular work duties
 - 5S Blitz schedules
 - Daily workplace scans

Simplified Summary of 5S

1. *Sort* - "When in doubt, move it out"
2. *Set in Order*—Organize all necessary tools, parts, and components of production. Use visual ordering techniques wherever possible.
3. *Shine*—Clean machines and/or work areas. Set regular cleaning schedules and responsibilities.
4. *Standardize*—Solidify previous three steps, make 5S a regular part of the work environment and everyday life

5. *Sustain*—Audit, manage, and comply with established five-s guidelines for your business or facility

3.1.2 KANBAN

What is Kanban?

The Japanese word *Kanban* means signboard. *Kanban system* is a “pull” production scheduling system to determine when to produce, what to produce, and how much to produce based on the demand. It was originally developed by Taiichi Ohno in order to reduce the waste in inventory and increase the speed of responding to the immediate demand.

Kanban system is a demand-driven system.

- The customer demand is the signal to trigger or pull the production.
- Products are made only to meet the immediate demand. When there is no demand, there is no production.

It is designed to minimize the in-process inventory and to have the right material with the right amount at the right location at the right time.

Principles of the Kanban System:

- Only produce products with exactly the same amount that customers consume.
- Only produce products when customers consume.

The production is driven by the *actual* demand from the customer side instead of the *forecasted* demand planned by the staff. The goal is to match production to demand.

Kanban Card

The *Kanban card* is the ticket or signal to authorize the production or movement of materials. It is the message of asking for more. The Kanban card is sent from the end customer up to the chain of production. Upon receiving of a Kanban card, the production station would start to produce goods. The Kanban card can be a physical card or an electronic signal.

Kanban System Example

The simplest example of a Kanban system is the supermarket operation.

- Customers visit the supermarkets and buy what they need.
- The checkout scanners send electronic Kanban cards to the local warehouse asking for more when the items are sold to customers.
- When the warehouse receives the Kanban cards, it starts to replenish the exact goods being sold.

If the warehouse prepares more than what Kanban cards require, the goods would become obsolete. If it prepares less, the supermarket would not have the goods available when customers need them.

Kanban System Benefits

- Minimize in-process inventory
- Free up space occupied by unnecessary inventory
- Prevent overproduction
- Improve responsiveness to dynamic demand
- Avoid the risk of inaccurate demand forecast
- Streamline the production flow
- Visualize the work flow

3.1.3 POKA-YOKE

What is Poka-Yoke?

The Japanese term *poka-yoke* means mistake-proofing. It is a mechanism to eliminate defects as early as possible in the process. It was originally developed by Shigeo Shingo and was initially called “baka-yoke” (fool-proofing). Poka-yoke is an extremely effective control method because it means to prevent, correct, or draw attention to a mistake as it occurs.

Two Types of Poka-Yoke

- Prevention
 - Preventing defects from occurring
 - Removing the possibility that an error could occur
 - Making the occurrence of an error impossible
- Detection
 - Detecting defects once they occur
 - Highlighting defects to draw workers’ attention immediately
 - Correcting defects so that they would not reach the next stage

The best way to drive quality is to prevent defects before they occur. The next best solution is to detect defects as they occur so they can be corrected. Poka-yoke solutions can aim to either prevent or detect defects.

Three Methods of Poka-Yoke

Shigeo Shingo identified three methods of poka-yoke for detecting and preventing errors in a mass production system.

1. Contact Method—Use of shape, color, size, or any other physical attributes of the items

2. Constant Number Method—Use of a fixed number to make sure a certain number of motions are completed
3. Sequence Method—Use of a checklist to make sure all the prescribed process steps are followed in the right order

Poka-Yoke Devices

We are surrounded by poka-yoke devices daily. Prevention Devices (Example: The dishwasher does not start to run when the door is open). Detection Devices (Example: The car starts to beep when the passengers do not buckle their seatbelts)

Poka-yoke devices can be in any format that can quickly and effectively prevent or detect mistakes: visual, electrical, mechanical, procedural, human etc.

Other examples:

- Tether on a car's gas cap to keep driver from leaving it behind.
- Inability to remove the key from car ignition until transmission is in park.
- Safety bar on lawn mower must be engaged to start engine.
- Hole near the top of a bathroom sink to keep it from overflowing.
- Clothes dryer stops when the door is opened.

Steps to Apply Poka-Yoke

Step 1: Identify the process steps in need of mistake proofing.

Step 2: Use the 5-why's to analyze the possible mistakes or failures for the process step.

Step 3: Determine the type of poka-yoke: prevention or detection.

Step 4: Determine the method of poka-yoke: contact, constant number, or sequence.

Step 5: Pilot the poka-yoke approach and make any adjustments if needed.

Step 6: Implement poka-yoke in the operating process and maintain the performance.

3.2 SIX SIGMA CONTROL PLANS

3.2.1 COST BENEFIT ANALYSIS

What is Cost-Benefit Analysis?

For a project to be feasible, the benefits must outweigh the costs. The *cost-benefit analysis* is a systematic method to assess and compare the financial costs and benefits of multiple scenarios in order to make sound economic decisions.

A cost-benefit analysis is recommended to be done at the beginning of the project based on estimations of the experts from the finance team in order to determine whether the project is

financially feasible. It is recommended to update the cost-benefit analysis at each DMAIC phase of the project.

Why Cost-Benefit Analysis?

In the Define phase of the project, the cost-benefit analysis helps us understand the financial feasibility of the project. In the middle phases of the project, updating and reviewing the cost-benefit analysis helps us compare potential solutions and make robust data-driven decisions. In the Control phase of the project, the cost-benefit analysis helps us track the project's profitability.

Return on Investment

A common financial measure of a project's impact to profitability, *return on investment* (also called ROI, rate of return, or ROR) is the ratio of the net financial benefits (either gain or loss) of a project or investment to the financial costs.

$$ROI = \frac{TotalNetBenefits}{TotalCosts} \times 100\%$$

Where:

$$TotalNetBenefits = TotalBenefits - TotalCosts$$

Return on Investment (ROI)

The return on investment is used to evaluate the financial feasibility and profitability of a project or investment.

- If $ROI < 0$, the investment is not financially viable.
- If $ROI = 0$, the investment has neither gain nor loss.
- If $ROI > 0$, the investment has financial gains.

The higher the ROI, the more profitable the project. Any value over 100 percent means the project has a return greater than the cost, and the higher the ROI, the more profitable the project.

Net Present Value (NPV)

The *net present value* (also called NPV, net present worth, or NPW) is the total present value of the cash flows calculated using a discount rate. The NPV accounts for the time value of money.

$$NPV = \frac{NetCashFlow_t}{(1 + r)^t}$$

Where:

- $NetCashFlow_t$ is the net cash flow happening at time t
- r is the discount rate
- t is the time of the cash flow.

Often projects do not have immediate returns and it takes time to recover the costs incurred during the project.

Cost Estimation

There are many types of costs that can be incurred during a project. Some are one-time investments, such as equipment, consulting, or other assets, while others are incremental costs to be incurred going forward.

Examples of costs triggered by the project:

- Administration
- Asset
- Equipment
- Material
- Delivery
- Real estate
- Labor
- Training
- Consulting

Benefits Estimation

Benefits can take many forms: additional revenue, reduced wasted, operational resource costs, productivity improvements, or market share increases. Other types of benefits that are harder to qualify include customer satisfaction and associate satisfaction.

Examples of benefits generated by the project:

- Direct revenue increase
- Waste reduction
- Operation cost reduction
- Quality and productivity improvement
- Market share increase
- Cost avoidance
- Customer satisfaction improvement
- Associate satisfaction improvement

Challenges in Cost and Benefit Estimation

Different analysts might come up with different cost and benefit estimations due to their subjectivity in determining:

- The discount rate
- The time length of the project and its impact
- Potential costs of the project
- The tangible/intangible benefits of the project
- The specific contribution of the project to the relevant financial gains/loss

3.2.2 ELEMENTS OF CONTROL PLANS

Control Plans

A key component of a solid DMAIC project, the *control plan* ensures that the changes introduced by a Six Sigma project are sustained over time.

Benefits of the Control phase:

- Methodical roll-out of changes including standardization of processes and work procedures
- Ensure compliance with changes through methods like auditing and corrective actions
- Transfer solutions and learning across the enterprise
- Plan and communicate standardized work procedures
- Coordinate ongoing team and individual involvement
- Standardize data collection and procedures
- Measure process performance, stability, and capability
- Plan actions that mitigate possible out-of-control conditions
- Sustain changes over time

The Control phase ensures new processes and procedures are standardized and compliance is assured.

What is a Control Plan?

A *control plan* is a management planning tool to identify, describe, and monitor the process performance metrics in order to meet the customer specifications steadily. It proposes the plan of monitoring the stability and capability of inputs and outputs of critical process steps in the Control phase of a project. It covers the data collection plan of gathering the process performance measurements. Control plans are the most overlooked element of most projects. It is critical that a good solution be solidified with a great control plan!

Control Plan Elements

There are many possible elements within a control plan. All of these need to be agreed to and owned by the process owner—the person who is responsible for the process performance.

Control Plan—The clear and concise summary document that details key process steps, CTQs metrics, measurements, and corrective actions.

Standard Operating Procedures (SOPs) —Supporting documentation showing the “who does what, when, and how” in completing the tasks.

Communication Plan—Document outlining messages to be delivered and the target audience.

Training Plan—Document outlining the necessary training for employees to successfully perform new processes and procedures.

Audit Checklists—Document that provides auditors with the audit questions they need to ask.

Corrective Actions—Activities that need to be conducted when an audit fails.

Control Plan

The control plan identifies critical process steps that have significant impact on the products or services and the appropriate control mechanisms. It includes measurement systems that monitor and help manage key process performance measures. Specified limits and targets for these performance metrics should be clearly defined and communicated. Sampling plans should be used to collect the data for the measurements.

Lean Six Sigma Control Plan

Process: _____ Customer: _____ Stakeholder: _____ Business: _____				Preparer: _____ Email: _____ Phone: _____ Owner: _____				Page: _____ of _____ Reference No: _____ Revision Date: _____ Approval: _____			
--	--	--	--	---	--	--	--	--	--	--	--

Process	Process Step	CTQ/Metric	CTQ / Metric Equation	Specification/ Requirement		Measurement Method	Sample Size	Measure Frequency	Responsible for Metric	Link or Report Name	Corrective Action	Responsible for Action
				LSL	USL							

Fig. 3.1 Control Plan Key Process and Critical Measurements

Business: _____			
Process	Process Step	CTQ/Metric	CTQ / Metric Equation

Fig. 3.2 Process and Metrics portion of Control Plan

- Key processes and process steps are identified.
- Critical information regarding key measurements is documented and clarified.

Owner: _____						
CTQ / Metric Equation	Specification/ Requirement		Measurement Method	Sample Size	Measure Frequency	Responsible for Metric
	LSL	USL				

Fig. 3.3 Measurements portion of Control Plan

- Measurements are clearly defined with equations.
- Customer specifications are declared.
- Other key measurement information is documented: sample size, measurement frequency, people responsible for the measurement, etc.

Approval: _____		
Link or Report Name	Corrective Action	Responsible for Action

Fig. 3.4 Corrective Actions and Responsible Parties Portion of Control Plan

- Where will this measurement or report be found? Good control plans provide linking information or other report reference information.
- Control plans identify the mitigating action or corrective actions required in the event the measurement falls out of spec or control. Responsible parties are also declared.

Not only does a control plan spell out what is measured and what the limits are around the measurement, but it also details actions that must be taken when out-of-control or out-of-spec conditions occur.

Standard Operating Procedures (SOPs)

Standard Operating Procedures (SOPs) are documents that focus on process steps, activities, and specific tasks required to complete an operation. SOPs should not be much more than two to four pages and should be written to the user's level of required detail and information. The level of detail is dependent on the position's required skills and training. Good SOPs are auditable, easy to follow, and not difficult to find. Auditable characteristics are: observable actions and countable frequencies. Results should be evident to a third party (*compliance to the SOP must be measurable*). Standard operating procedures are an important element in a control plan when a specific process is being prescribed to achieve quality output.

SOP Elements

SOPs are intended to impart high value information in concise and well-documented manner. There are many components to maintain currency, ensure that employees understand why the SOP is necessary and important, and other supporting information to make scope very clear for the SOP.

- **SOP Title and Version Number**—Provide a title and unique identification number with version information.
- **Date**—List the original creation date; add all revision dates.
- **Purpose**—State the reason for the SOP and what it intends to accomplish.
- **Scope**—Identify all functions, jobs, positions, and/or processes governed or affected by the SOP.
- **Responsibilities**—Identify job functions and positions (not people) responsible for carrying out activities listed in the SOP.
- **Materials**—List all material inputs: parts, files, data, information, instruments, etc.
- **Process Map**—Show high level or level two to three process maps or other graphical representations of operating steps.
- **Process Metrics**—Declare all process metrics and targets or specifications.
- **Procedures**—List actual steps required to perform the function.
- **References**—List any documents that support the SOP.

SOP Template

Standard Operating Procedures

SOP Name/Title:		
Document Storage Location/Source:		Document No:
SOP Originator:	Approving Position:	Effective Date:
Name:	Name:	Last Edited Date:
Signature:	Signature:	Other:

1. Purpose

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

2. Scope

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

3. Responsibilities (RACI)

Responsible	Accountable	Consulted	Informed
John Doe	Jane Doe	Jack Doe	Jill Doe
Pam Doe	Paul Doe	Phil Doe	Peggy Doe

4. Materials

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

5. Related Documents

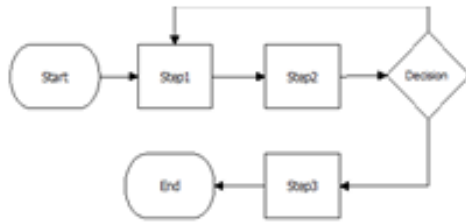
"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

6. Definitions

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

Fig. 3.5 SOP Example part 1

7. Process Map



8. Procedures

Step	Action	Responsible
1		
2		
3		

9. Process Metrics

- "Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut
- "Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

10. Resources

- "Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut
- "Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut

Fig. 3.6 SOP Example part 2

Communication Plans

Communication plans are documents that focus on planning and preparing for the dissemination of information. They organize messages and ensure that the proper audiences receive the correct message at the right time. A good communication plan identifies:

- Audience
- Key points/message
- Medium (how the message is to be delivered)
- Delivery schedule

- Messenger
- Dependencies and escalation points
- Follow-up messages and delivery mediums

Communication plans help develop and execute strategies for delivering changes to an organization.

Communication Plan Template

Communication Plan Template									
Process/Function Name		Project/Program Name		Project Lead		Project Sponsor/Champion			
Communication Purpose:									
Target Audience	Key Message	Message Dependencies	Delivery Date	Location	Medium	Follow up Medium	Messenger	Escalation Path	Contact Information

Fig. 3.7 Communication Plan Template

Training Plans

Training plans are used to manage the delivery of training for new processes and procedures. Most GB or BB projects will require changes to processes and/or procedures that must be executed or followed by various employees. Training plans should:

- Incorporate all SOPs related to performing new or modified tasks
- Use and support existing SOPs and do not supersede them
- Include logistics
 - One-on-one or classroom
 - Instruction time
 - Location of training materials
 - Master training reference materials
 - Instructors and intended audience
 - Trainee names

Different components of training plan include: training delivery method, training duration, location of materials and references, instructor names, and intended audience.

Training Plan Template

[illegible]

Audits

ISO 9000 defines an audit as “a systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.”

Audit Guidelines

Auditors must:

Audit Checklists

Audit checklists:

- Serve as guides for identifying items to be examined
- Are used in conjunction with understanding of the procedure
- Ensure a well-defined audit scope
- Identify needed facts during audits
- Provide places to record gathered facts.
- Checklists should include:
- A review of training records
- A review of maintenance records
- Questions or observations that focus on expected behaviors
- Questions should be open-ended where possible
- Definitive observations yes/no, true/false, present/absent, etc.

Audit Checklist Template

Audit Checklist			
Target Area:	Statement of Audit Objective:	Auditor:	Audit Date:
Audit Technique	Auditable Item, Observation, Procedure etc.	Individual Auditor Rating (Circle Rating)	
Observation	Have all associates been trained?	YES	NO
Observation	Is training documentation available?	YES	NO
Observation	Is training documentation current?	YES	NO
Observation	Are associates wearing proper safety gear?	YES	NO
Observation	Are SOP's available?	YES	NO
Observation	Are SOP's current?	YES	NO
Observation	Is quality being measured	YES	NO
Observation	Is sampling being conducted in random fashion	YES	NO
Observation	Is sampling meeting it's sample size target?	YES	NO
Observation	Are control charts in control	YES	NO
Observation	Are control charts current?	YES	NO
Observation	Is the process capability index >1.0?	YES	NO
Number of Out of Compliance Observations			
Total Observations			
Audit Yield			■ #DIV/0!
Corrective Actions Required			
Auditor Comments			

Fig. 3.9 Audit Checklist

3.2.3 RESPONSE PLAN ELEMENTS

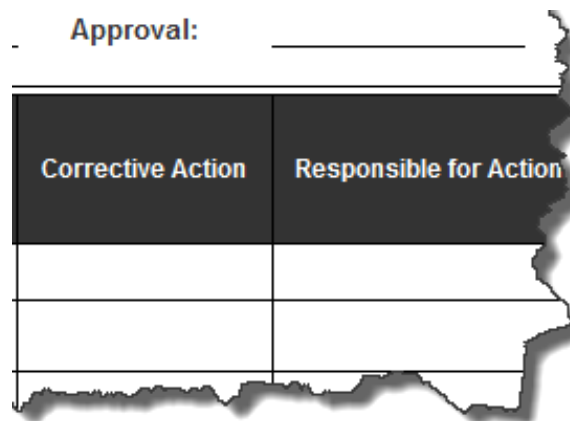
What is a Response Plan?

A *response plan* should be a component of as many control plan elements as possible. Response plans are a management planning tool to describe corrective actions necessary in the event of out-of-control situations. There is never any guarantee that processes will always perform as designed. Therefore, it is wise to prepare for occasions when special causes are present. Response plans help us mitigate risks and, as already mentioned, should be part of several control plan elements.

Response Plan Elements

- Action triggers
 - When do we need to take actions to correct a problem or issue?
- Action recommendation
 - What activities are required in order to solve the problem in the process? The action recommended can be short-term (quick fix) or long-term (true process improvement).
- Action respondent
 - Who is responsible for taking actions?
- Action date
 - When did the actions happen?
- Action results
 - What actions have been taken?
 - When were actions taken?
 - What are the outcomes of the actions taken?

A good response plan clearly describes when the response plan is acted upon, what the action is, who is responsible for taking action and when, and what the results are after the action is taken.



Approval: _____	
Corrective Action	Responsible for Action

Fig. 3.10 Corrective Action and Responsible Party portion of Control Plan

A response plan denotes what the action is to be taken and who is responsible. Note the response plan element in this control plan template.

Escalation Path	Contact Information

Fig. 3.11 Escalation contact information for communication plan

The communication plan has a section denoting how information is disseminated. Note the response element by the identification of escalations and contact information.

Audit Checklist			
Target Area:	Statement of Audit Objective:	Auditor:	Audit Date:
Audit Technique	Auditable Item, Observation, Procedure etc.	Individual Auditor Rating (Circle Rating)	
Observation	Have all associates been trained?	YES	NO
Observation	Is training documentation available?	YES	NO
Observation	Is training documentation current?	YES	NO
Observation	Are associates wearing proper safety gear?	YES	NO
Observation	Are SOP's available?	YES	NO
Observation	Are SOP's current?	YES	NO
Observation	Is quality being measured	YES	NO
Observation	Is sampling being conducted in random fashion	YES	NO
Observation	Is sampling meeting it's sample size target?	YES	NO
Observation	Are control charts in control	YES	NO
Observation	Are control charts current?	YES	NO
Observation	Is the process capability index >1.0?	YES	NO
Number of Out of Compliance Observations			
Total Observations			
Audit Yield		#DIV/0!	
Corrective Actions Required			
Auditor Comments			

Fig. 3.12 Audit Checklist

An audit checklist denotes corrective actions necessary as a result of the audit. The is a form of response plan.

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