

ENCYCLOPEDIA

The Six Sigma Encyclopedia of Business Tools and Techniques

Summary Tool Matrix

For easy navigation, use the Jump Table that follows, which lists the different tools and techniques featured in this book and organizes them by purpose and the key questions they answer.

The statistical and graphical tools include additional descriptors about their primary applications—describe, compare, and predict. In addition, the project management tools also include appropriate descriptors—scheduling, planning, scope, human resources (HR), deliverables, and tasks.

The Encyclopedia Summary Tool Matrix Jump Table

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Competitive Marketplace and Positioning</i>			
	What are the experts doing, and how do they do it?	Benchmarking	p. 160
	How does the market perceive the quality of the product and/or services offerings versus competition?	Market Perceived Quality Profile (MPQP)	p. 390

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
	How are we performing relative to the competitive business threats?	Porter's 5 Forces	p. 464
	How would a potential offering be valued in the marketplace, and positioned well against competition? Is it worth the investment to develop the idea? Would it be successful? Would the concept outpace competition?	Real-Win-Worth (RWW) Analysis	p. 560
	How do the organization's strengths and weaknesses compare with the competitive opportunities and threats?	SWOT (Strengths-Weaknesses-Opportunities-Threats)	p. 699
Financial			
	What is the payback time period for an investment?	Cost/Benefit Analysis	p. 238
<i>Predict</i>	What are the probabilities and risk associated with several financial possibilities? (that is, pricing, forecasting)	Monte Carlo Simulation	p. 435
Graphing			
<i>Describe</i>	What does the distribution of a set of data look like? Alternatively, what do the distributions look like and compare for multiple sample groups?	Boxplot—Graphical Tool	p. 164

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Describe</i>	How is the data of a process distributed; what does the data set look like?	Dotplot	p. 280
<i>Describe</i>	How is the data of a process distributed; what does the data set look like? Are the data normally distributed?	Histogram— 7QC Tool	p. 330
<i>Describe & Compare</i>	Across multiple sources of variability, which one contributes the most?	Multi-vari Chart	p. 439
<i>Compare & Predict</i>	Are the data distributed normally?	Normal Probability Plot (See Also “Control Charts”—Normal Versus Non-normal Data section p. 227)	p. 444
<i>Describe & Compare</i>	What are the vital few items with the biggest impact? Which 20% of items produce 80% of the impact (the 80/20 rule)?	Pareto Chart— 7QC Tool	p. 445
<i>Describe</i>	How does the data look over time? Are the data randomly distributed over time? Does the process look stable and random over time?	Run Chart— 7QC Tool	p. 610
<i>Describe & Compare</i>	Are these two factors correlated? What is the relationship between these two factors?	Scatter Diagram— 7QC Tool	p. 640
<i>Describe & Compare</i>	Are there any patterns in the data? Is the data set homogeneous?	Stratification— 7QC Tool	p. 697

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Governance</i>			
	What is the progress of the project and project team or the process and process players?	Scorecards	p. 653
<i>Idea/Solution Generation and Selection</i>			
	How can you elicit new ideas in a short period of time?	Brainstorming Technique	p. 168
	Which technical specifications for a product or services offering best meet a specific set of customer requirements?	House of Quality (HOQ) (See Also Quality Functional Deployment (QFD))," p. 543	p. 335
	Which design or potential solution option is best?	Pugh Concept Evaluation	p. 534
	Which technical specifications for a product or services offering best meet a specific set of customer requirements?	Quality Function Deployment (QFD)	p. 543
	Which solution option best meets requirements?	Solution Selection Matrix	p. 672
	What is the best solution to address this problem to create a competitive advantage?	TRIZ	p. 715

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Organization & Planning</i>			
	What activities or deliverables are required to meet requirements? Alternatively, what was observed?	Checklists—7QC Tool	p. 204
	What information is available about the current process, product, or services offering?	Data Collection Matrix	p. 248
	How do the activities of a function, program, or project align with the overall organizational strategy?	GOSPA (Goals, Objectives, Strategies, Plans, and Actions)	p. 320
	How do these two (or more) groups relate to one another?	Matrix Diagrams—7M Tool	p. 399
	What are the details behind this general topic breakdown into smaller components? How does it break down into its piece-parts?	Tree Diagram—7M Tool	p. 712
<i>Prioritization</i>			
	Which key variables (process steps or process inputs) best meet customer requirements (or the key process output variables)?	Cause-and-Effect Prioritization Matrix	p. 188
	What is the best option among the several possibilities for a crucial (often mission-critical) decision that carries risk of significant consequences if wrong?	Prioritization Matrices—7M Tool	p. 470

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Process Evaluation (Also see Variation Analysis)</i>			
<i>Describe & Compare</i>	Is the process able to meet customer requirements?	Capability Analysis (See Also "Process Capability Analysis," p. 486)	p. 173
<i>Describe & Compare</i>	How is the process behaving; is it in control?	Control Charts—7QC Tool	p. 217
<i>Describe</i>	What are the components of the process; what is involved?	Flowchart — 7QC Tool (See Also "Process Map," p. 522)	p. 316
<i>Describe & Compare</i>	Is the process able to meet customer requirements?	Process Capability Analysis	p. 486
<i>Describe</i>	What are the components of the process; what is involved?	Process Map—7QC Tool	p. 522
<i>Describe</i>	What is the yield of a process?	Rolled Throughput Yield (See Also "Process Capability Analysis," p. 486)	p. 610
<i>Describe</i>	Where is value being added in the process? Conversely, where does waste exist in the process?	Value Stream Analysis	p. 727
<i>Describe</i>	Where is value being added in the process? Conversely, where does waste exist in the process?	Value Stream Mapping (See Also "Value Stream Analysis," p. 727)	

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Project Management</i>			
<i>Schedule</i>	What is the most efficient way to complete this process or project?	Activity Network Diagram (AND)—7M Tool	p. 136
<i>Schedule</i>	What is the most efficient way to complete this process or project?	Arrow Diagrams (See “AND”)	p. 159
<i>Schedule</i>	What is the most efficient way to complete this process or project?	Critical Path Method (CPM) (See “AND”)	p. 242
<i>Schedule</i>	How long will the project take? What are the key milestones, and when should you expect them?	Gantt Chart	p. 317
<i>Schedule</i>	What are the probabilities and risks associated with several schedule possibilities?	Monte Carlo Simulation	p. 435
<i>Schedule</i>	What is the most efficient way to complete this process or project?	PERT (Program Evaluation and Review Technique) Chart	p. 453
<i>Planning</i>	What might go wrong during the planning of this complex, significant project?	Process Decision Program Charts (PDPC)—7QC Tool	p. 515
<i>Scope</i>	What are the project scope, boundary conditions, deliverables, budget and schedule?	Project Charter (See SMART Problem and Goal Statements for Project Charter p. 665)	

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>HR, Deliverables & Tasks</i>	Who is responsible for what?	RACI Matrix (Responsible, Accountable, Consulted, Informed)	p. 554
<i>Scope</i>	What is the scope of the project or process?	SIPOC (Supplier-Input-Process-Output-Customer)	p. 663
<i>Scope</i>	What is the most succinct description of the project's goal and problem statements?	SMART Problem & Goal Statement for a Project Charter	p. 665
<i>Risk</i>	Who supports the project, who doesn't, and why?	Stakeholder Analysis	p. 681
<i>Deliverables & Tasks</i>	What are the project deliverables, and what activities will produce them?	Work Breakdown Structure (WBS)	p. 753

Risk Management

	What are the potential risk response strategies to a potential risk or failure?	Cause and Prevention Diagram	
	What can go wrong? What can be done to prevent or minimize it? What are the potential failures that could occur, and what is the best response (action) plan to minimize its impact if it does happen?	FMEA: Failure Modes and Effects Analysis	p. 198

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
	What are the potential root causes of a single problem or problematic outcome and how can they be prevented or mitigated? Typically applied to a design of a system, product, or process that involves human interactions.	Fault Tree Analysis (FTA)	p. 309
	What are the probabilities and risk associated with several financial possibilities? (pricing and forecasting, for example)	Monte Carlo Simulation	p. 435
	How best to prevent or correct in-process errors (often human mistakes)?	Poka-Yoke	p. 462
	What might go wrong during the planning of this complex, significant project?	Process Decision Program Charts (PDPC)—7M Tools	p. 515
	How best to plan for, manage, and mitigate unforeseen risk?	Risk Mitigation Plan	p. 601
	Who supports the project and who doesn't, and why?	Stakeholder Analysis	p. 681
Root Cause			
<i>Compare & Predict</i>	What differences exist between two groups, if any?	Analysis of Variance (ANOVA)—7M Tool	p. 142

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
	What are the potential causals of a problem or problematic outcome?	Cause-and-Effect Diagram—7QC Tool (a.k.a. Fishbone, Ishikawa Diagram)	p. 173
<i>Compare & Predict</i>	Which variables or combination of variables proves as the best in producing the desired results, based on experimental data?	Design of Experiment (DOE)	p. 250
	What is the root cause of this problem or problematic outcome?	5-Whys	p. 305
	What are the potential root causes of a single problem or problematic outcome and how can they be prevented or mitigated? Typically applied to a design of a system, product, or process that involves human interactions.	Fault Tree Analysis (FTA)	p. 309
	What are the potential causals of a problem or problematic outcome?	Fishbone Diagram—7QC Tool (See also Cause-and-Effect Diagram)	p. 316
<i>Compare & Predict</i>	Is this population (or sample) of data different from another by chance alone, or because of an outside influence?	Hypothesis Testing	p. 335
	How do the various cause-and-effect ideas relate to one another in a complex situation?	Interrelationship Diagram—7M Tool	p. 369

Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Describe & Predict</i>	What is the cause-and-effect model that describes the process and its critical variables?	Regression Analysis	p. 571
<i>Describe & Compare</i>	Are these two factors correlated? What is the relationship between these two factors?	Correlation Analysis (See also Scatter Diagram—7QC Tool, p. 640)	
<i>Describe</i>	What are the critical parameters in the process?	$Y = f(x)$	p. 758
Sampling			
<i>Predict</i>	How best to collect a representative sample of the population?	Sampling	p. 618
Variation Analysis and Process Evaluation			
<i>Describe & Compare</i>	Is the process able to meet customer requirements?	Capability Analysis (See also Process Capability Analysis, p. 486)	p. 173
<i>Describe & Compare</i>	How is the process behaving; is it in control?	Control Charts—7QC Tool	p. 217
<i>Describe & Compare</i>	How accurate is the measurement system? Is the process truly performing the way the data seems to be reporting, or is the measurement system inaccurate?	Measurement System Analysis (MSA)	p. 412

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Generic Hypothesis Testing Schematic			
Purpose	Key Question	Tool Name	Page
<i>Describe, Compare & Predict</i>	Are the data distributed normally?	Normal Probability Plot (See also Control Charts—Normal Versus Non-normal Data section, p. 227)	p. 444
<i>Describe & Compare</i>	Is the process able to meet customer requirements?	Process Capability Analysis	p. 486
Voice of the Customer (VOC); Voice of the Business (VOB)			
	What are the major themes of ideas, opinions, issues, and so on found in large amounts of language data?	Affinity Diagram—7M Tool	p. 136
	What product and/or services features and functionality do customers prefer and are willing to buy?	Conjoint Analysis	p. 207
	How does my work relate to the customer requirements and how do I know when I have fulfilled them?	Critical to Quality (CTQ) Matrix	p. 242
	What matters to your customers? What are the natural groupings, categories, or affinities of a large number of topics, ideas, and quotations, and how best to translate the verbal input into requirements?	KJ Analysis	p. 375
	How best to capture the customer requirements?	Voice of Customer Gathering Techniques	p. 737

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Capability Analysis

See Also “Process Capability Analysis,” p. 486.

Cause-and-Effect Diagram—7QC Tool

What Question(s) Does the Tool or Technique Answer?

*What are the **potential** causes of a problem or problematic outcome?*

Cause-and-Effect diagramming helps you to

- Organize ideas and understand the relationship between potential causes and a problem by formatting, arranging, organizing, and parsing potential causes into themes and sub-themes in preparation for a future cause identification effort.
- Stimulate thinking when developing the list of the potential sources of a problem.
- Guide concrete action and track the potential causes during an investigation effort to determine if the item significantly contributes to the problem.

Alternative Names and Variations

This tool is also known as:

- C and E diagram
- Fishbone or fishbone diagram
- Ishikawa diagram

Variations on the tool include

- Cause-and-Effect matrix or Cause-and-Effect Prioritization Matrix (**See Also** “Cause-and-Effect Prioritization Matrix,” p. 188)
- Cause enumeration diagram
- Process Fishbone
- Time-delay Fishbone
- CEDAC (Cause-and-Effect Diagram and Cards)

- Desired-results Fishbone
- Reverse Fishbone diagram
- Cause and Prevention diagram
- Fault Tree analysis (**See Also** “Fault Tree Analysis,” p. 309)

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When Best to Use the Tool or Technique

Before any action is taken, this tool helps to organize and begins to analyze potential sources of problems.

The Fishbone is a good tool to use when multiple people (and/or disciplines) should be engaged in the problem-solving and there are many perspectives to capture.

Brief Description

The Cause-and-Effect diagram is one of the seven basic tools of quality. It goes by several names—a *Fishbone diagram* because a completed diagram resembles the skeleton of a fish and an *Ishikawa diagram* after its creator.

A professor at the University of Tokyo, Dr. Kaoru Ishikawa, developed the first Cause-and-Effect diagram in 1943. The original intent of the diagram was to sort out and depict the relationship among the several factors impacting Quality Control (QC), wherein the variables that cause dispersion, such as chemical composition, size of parts, or process workers, are called “factors” (causes). The quality characteristics describe the outcome, or effect, such as length, hardness, percentage of defects, and so on. As the tool grew in popularity, it was referred to as an Ishikawa diagram.

The Cause-and-Effect diagram is a member of the 7QC Tools (or *seven Quality Control tools*), attributed to Dr. Ishikawa. The 7QC Tools sometimes are called the *seven basic tools* because they were the first set of tools identified as the *core* quality improvement tools. Ishikawa’s original 7QC Toolset includes 1) Cause-and-Effect diagram, 2) Check sheet (or Checklist), 3) Control charts, 4) Histogram, 5) Pareto chart, 6) Scatter diagram, and 7) Stratification. More recently, the 7QC Toolset is modified by substituting the Stratification technique with either a flowchart (or process map) or a run chart (or time series plot).

A Fishbone diagram is a focusing tool. It starts with identifying all the ideas for potential causes and then groups and categorizes the potential causes into themes. It takes a snapshot to hypothesize the collective potential causes—what the team thinks is currently happening.

It displays *potential* causes of a problem, with the potential causes depicted as “off-shoots” or bones of a fish stemming from the problematic outcome as the “head” of the fish. Increasing detail about the potential

cause is displayed as the offshoot, or bone, branches further out from the main bone.

The relationships can be depicted as a matrix or Fishbone diagram, wherein the problem (or effect) is placed to the far right. The problem statement is placed in a box or diamond-shape to represent the head of a fish. This represents the “effect” that all the subsequent causes supposedly impact. The root cause themes and sub-themes are placed to the left of the problem.

There are two major types of Cause-and-Effect formats depending on the context in which the problem exists; one is a Dispersion, and the other is a Process format. There are some memory techniques that serve as checklists to trigger thinking about potential root cause categories—the 5Ms and P and the 4Ps. The former is typically applied to the Dispersion analysis, and the latter is applied to the Process approach.

Dispersion Analysis

Potentially, why does quality dispersion occur? This approach uses individual causes (or dispersion) grouped within a major cause category. The smaller categories on the skeleton of the fish drill down into sub-causes, identifying why this cause potentially happens.

Dispersion occurs typically due to differences in

- Raw materials’ composition, size, and so on
- Tools, machinery, equipment, technology—with respect to their operating performance
- Work method, process or procedure—potentially because it could be incomplete, inaccurate, inflexible (accommodating change or a special occurrence), misunderstood
- Measurement—potentially from operator-to-operator error, operator-to-part, or part-to-part.

When using the Dispersion analysis approach, there is no right answer or *set* of categories names or themes. They should be modified to fit the situation or problem. However, a convention that often is used as a starting point is referred to by the acronym, *5Ms and P*.

5Ms and P Memory Triggers

A standard categorization technique for manufacturing industries is called **5Ms and P** [pronounced “*five Ms and a P*”] and can be used as a checklist to identify common cause themes:

- **Machines** (equipment, technology—hardware and/or software)
- **Methods** (process, procedure, approach, policy, or practice)
- **Materials** (raw materials, components, information, or data)

- **Measurements** (input and output metrics for quality, quantity, process performance metrics, calibration, and inspection)
- **Mother Nature** (or a more encompassing term is *environment*), which includes external as well as workplace factors such as:
 - *Natural environment* [weather (and *acts of God*), temperature, humidity]
 - *Physical surroundings* (facilities, buildings, plant, workspace, office)
 - *Management surroundings* (organizational, social, political)
 - *Marketplace*
- **People** [those involved in the process (directly or indirectly)—customers, employees, managers, suppliers, partners, regulators and shareholders]

Sometimes this approach is called *The 6Ms*, where the term “People” (of 5Ms and P) is changed to **Manpower**.

Process Classification

The Process approach uses the major process steps, instead of major causal categories; however, this is rarely used. This diagram may be depicted in the Fishbone shape or as a Process map “spine” with potential causes linked to the appropriate process step.

When using the Process approach, again, there is no right answer or set of category names or themes. They should be modified to fit the situation or problem. However, the services industry has a convention that often is used as a starting point—*the 4Ps*.

4Ps Memory Triggers

Common categories that work well for the **service(s) industry** is called the **4Ps**, which represents

- **Policies** (company and HR policies, including roles and responsibilities, performance metrics, reward and recognition, promotion, overtime, comp-time/vacation, and so on, and organizational—cultural, training versus apprenticeship, and so on)
- **Procedures** (methodology, approach)
- **People** (employee profile, partners, sub-contractors, and so on)
- **Plant/Technology** (workspace, hardware, software, support tools)

Because the services industry is dependent on its human capital, the policies are critical to shaping its “personality” in the marketplace, and often it is the *make-or-break* for attracting the right talent. Hence, the Policy category often needs to be parsed further to get to the appropriate detail.

How to Use the Tool or Technique

When developing a Cause-Effect, Fishbone, or Ishikawa diagram:

- Step 1. Agree on the topic or problem to be analyzed—for example, a quality characteristic that needs improvement. Use data specifically to describe the problem.
- Step 2. Write the specific problematic outcome to the far right edge of the diagram and draw a box around the text to form the **“head” of the fish**.

Figure C-1 displays the general structure of the Cause-and-Effect diagram using the Fishbone analogy.

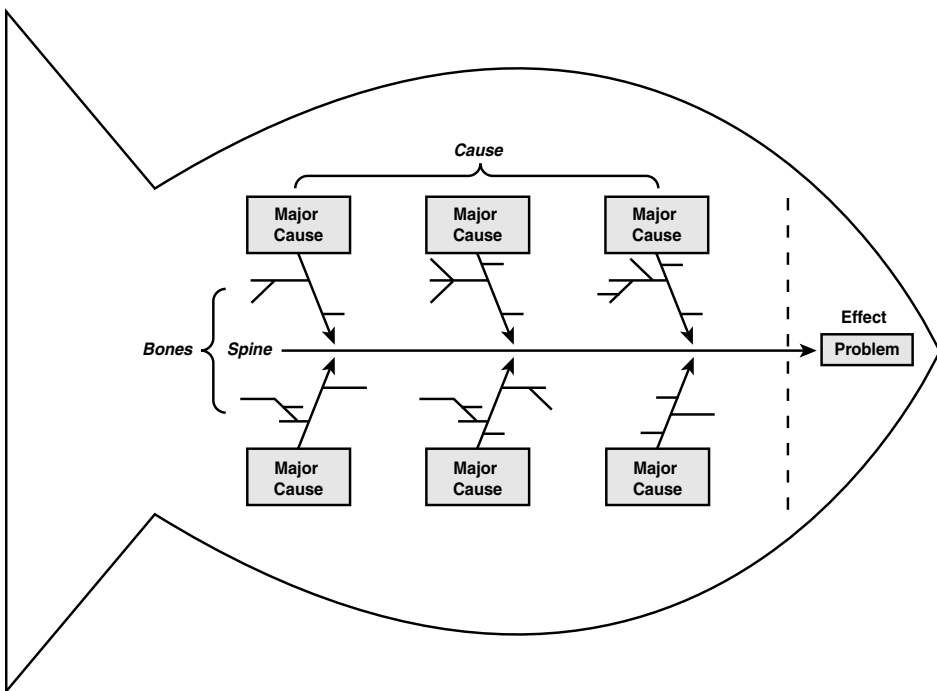


FIGURE C-1: Basic Cause-and-Effect Diagram (Fishbone) Using 5Ms and P for Dispersion Analysis

- Step 3. Draw a line extending from the left edge of the fish head to the left edge of the diagram to represent the **spine**.
- Step 4. Referencing data and experience, write the potential causes of the problem and group related topics. Have the participants bring to the meeting completed data collection sheets from their respective areas to inform the brainstorming activities. (See Also “Brainstorming Technique,” p. 168)

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- Step 5. Name the major themes of each grouping (or high-level process steps).
- Step 6. Draw a line extending from the spine for each theme and write the category name at the outermost end of the line (the end that is not attached to the spine) to represent a “**main**” **Fishbone**.
- Step 7. Draw one branch or offshoot to the main Fishbone for each sub-theme (or sub-process step). Label the end of each branch with the sub-theme name to represent **smaller bones** and to show the linkage to the “higher level” category with which it is affiliated.
- Step 8. Continue Step 7 to drill-down into as much detail as required, defining more bones and linking the relationship.
- Step 9. Review the diagram for completeness and clarity and then modify accordingly.
- a. Use the 5-Why technique to ensure the potential cause is documented (**See Also** “5-Whys,” p. 305).
 - b. Fill in gaps and streamline wording.
 - c. Eliminate unnecessary redundancy but document duplicity that represents the current situation.
 - d. Eliminate unrelated items.

How to Analyze and Apply the Tool's Output

- Review the final diagram and discuss the themes thought to represent the most critical source of the problem.
- Look for repeat causes across multiple categories.
- Prioritize and select—use the diagram as a checklist to explore further into those critical themes. You could use a QFD tool to prioritize the potential causals. A less desirable selection approach could be a form of voting technique, such as weighted voting.
- Investigate or study the prioritized causes and/or critical themes to verify that they are in fact causals. Some tools and techniques to begin the analysis include the following:
 - Force-field analysis
 - Scatter Plots (**See Also** “Scatter Diagram—7QC Tool,” p. 640)
 - Frequency Plots (**See Also** “Graphical Methods” and “Histogram —7QC Tool,” p. 323 and 330, respectively)

- Tables of Results (for attribute data)
- ANOVA (Analysis of Variance) (See Also “Analysis of Variance (ANOVO)—7M Tool,” p. 142)
- Regression Analysis (See Also “Regression Analysis,” pp. 571)
- Time Trap Analysis
- Design of Experiment (DOE) (See Also “Design of Experiment (DOE),” p. 250)

Note

This tool documents POTENTIAL causes, not proven causes; so *improvement* action plans cannot be developed until the causes are verified. Seek the causes thoroughly using the Cause-and-Effect diagram. When the Cause-and-Effect is detected, check and record it on the diagram, by writing the date of occurrence and its measurement next to its corresponding “labeled bone.” If the cause is not detected, then the “labeled bone” will lack any markings. This procedure highlights experienced data and focuses on the detected causes, which can lead to quicker error correction.

Examples

Dispersion Analysis example

An example of a Dispersion Analysis, as shown in Figure C-2, uses the “5Ms and P” technique to define the root causes as titles of the major bones off the spine of the Cause-and-Effect diagram. [Recall the 5Ms and P refer to **M**achine, **M**aterials, **M**ethod, **M**etrics, **M**other Nature, and **P**eople. See the “Hints and Tips” section later in this entry for more detail on 5Ms and P technique.]

Process Classification Analysis example

An example of a Process Classification Analysis, shown in Figure C-3, uses the high-level process steps as the titles of the major bones off the spine of the Cause-and-Effect diagram.

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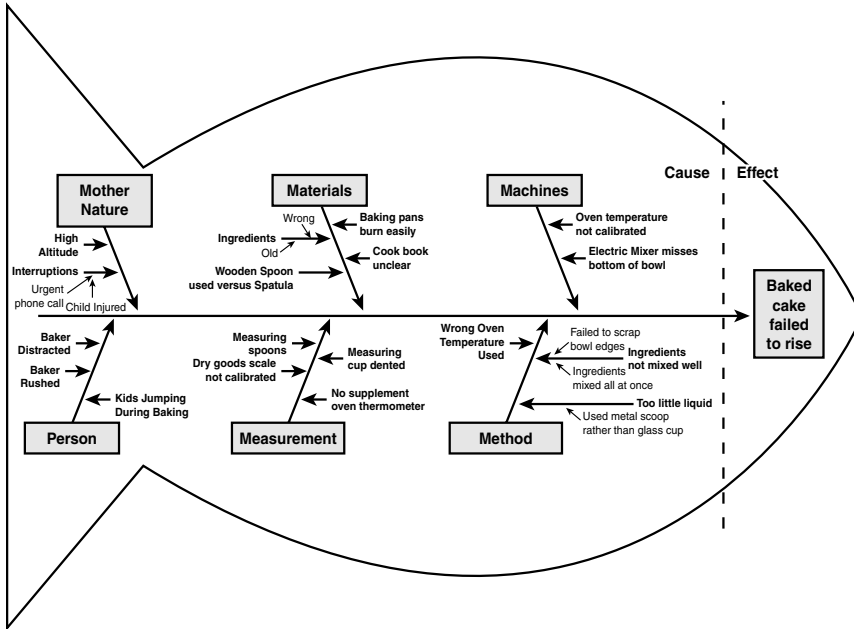


FIGURE C-2: Cause-and-Effect Diagram (Fishbone) Using 5Ms and P for Dispersion Analysis

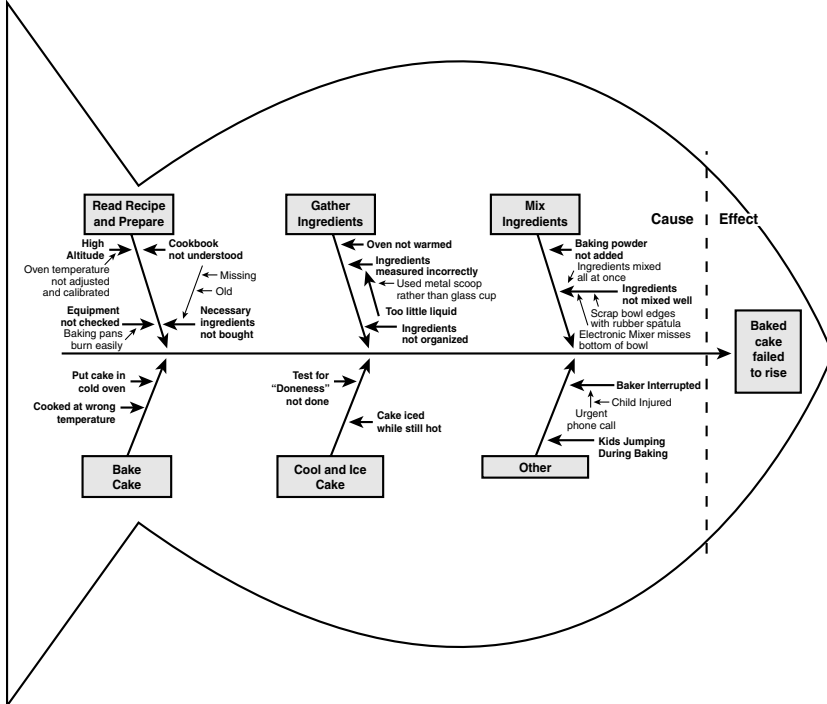


Figure C-3: Cause-and-Effect Diagram (Fishbone) — Using Process Steps for a Process Classification Analysis

Process Classification Analysis—a Second Example

Another example of a Process Classification Analysis, shown in Figure C-4, diagrams the high-level process steps as the actual spine of the Cause-and-Effect diagram. The bones off the spine align to the root causes directly linked to a particular process step.

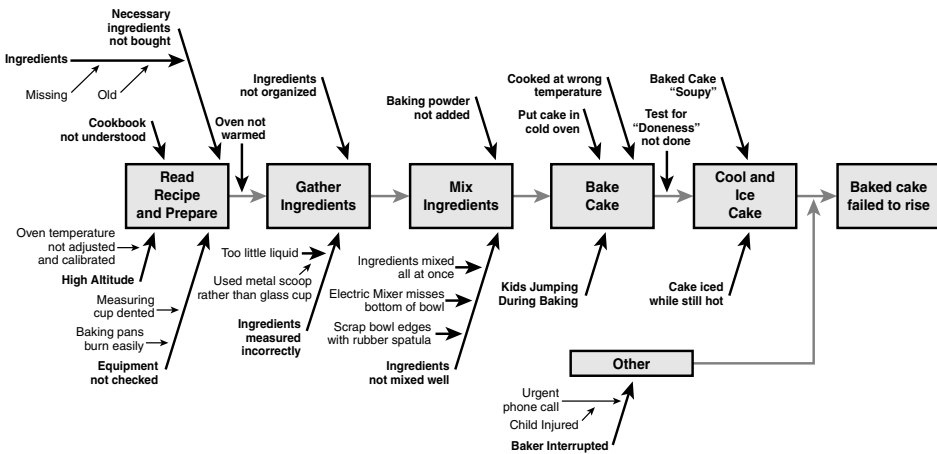


FIGURE C-4: Cause-and-Effect Diagram (Process Fishbone)—Using Process Steps for a Process Classification Analysis

Poorly Constructed C and E Diagram Example

A cause generally contains many complex elements. Therefore when building a Cause-and-Effect diagram, it is important to drill down into a cause to identify the potential root. The drill down can be achieved by using the 5-Whys technique. (See “5-Whys,” p. 305) The following Fishbone diagram is an example of a poor one. Even though the “form” is correct, the diagram simply lists eight items. It lacks detail, which indicates potential lack of knowledge of the process. The Fishbone diagram should be detailed, not too generalized or shallow. The example of a poor Fishbone fails to describe why ingredients are missing and why the batter was not mixed well. The baker could have had the blender working overtime, but if the beaters were not touching all parts of the bowl and the mixing process lacked manually scraping of the sides of the bowl with a rubber spatula, the potential root causes behind why the batter was not mixed well are more obvious. Moreover, the poor Fishbone diagram contains some symptoms—“Baked Cake Soupy,” rather than probing further to understand the driver as to why it’s soupy and document the causes. A well-constructed Fishbone diagram documents all the possible causes in an organized way, depicting the relationship of the *major* causes themes to subsequent or more detailed causes. Figure C-5 displays a poorly constructed Cause-and-Effect diagram.

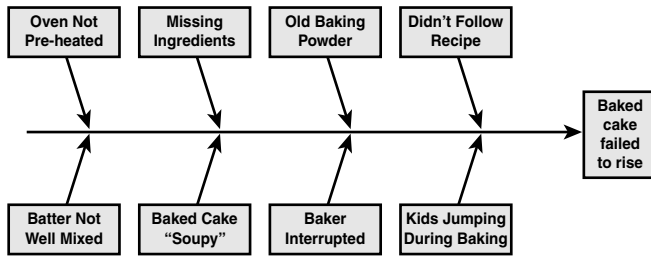


FIGURE C-5: Poor Cause-and-Effect Diagram (Fishbone)

Hints and Tips

Building a Cause-and-Effect diagram is best done with a group of people with diverse perspectives, to analyze the potential causes from multiple angles. Capture viewpoints from various roles and disciplines. Ensure everyone agrees on the problem statement first and focus on potential causes, not symptoms. Use the 5-Why technique to drill down and identify the potential source of the cause. (See Also “5-Whys,” p. 305) Capture all ideas (information on “what,” “where,” “when,” “how much...”). Consider all causes, not just those within the group’s control.

Use data to specify the problem. Do not criticize or debate ideas during brainstorming or when representing them on the Cause-and-Effect diagram.

Histograms can reveal the frequency of defects caused by certain items. Simply **test for understanding** to clarify that an idea is communicated succinctly. Look for duplicates and aggregate them together if possible. Some causes may fit into more than one category (particularly people-related topics). Ideally a cause should be aligned with one major category, but if it is not clear where it best fits, represent it in multiple categories. With further analysis, eventually its best fit may narrow to one area. Take time in developing the diagram, ask as many people as possible, and avoid trying to complete it in one work session. Allow people to study a *work-in-process* diagram to trigger additional ideas. Prioritizing can be done later using a QFD. The appropriate number of categories depends on the problem and related potential causes. There is no perfect number. For a Process

Fishbone, the process depicted should be **high-level**. Therefore, ideally the number of steps is three to five and generally should not exceed 10; otherwise, it becomes too detailed and cumbersome. Category naming can be done two different ways: predetermined categories prior to the brainstorming portion or determined after brainstorming as a “fall-out” from the grouping portion. There are pros and cons to both approaches. The predetermined categories may expedite and better organize the work. If experience determines the categories selection, then the theme titles probably will not inhibit the generation of ideas. However, the addition of an “other” category also will help to prevent the stifling of ideas. If category selection occurs after the brainstorming, it takes time to organize and arrive at a common agreement on the theme. It involves testing for understanding and potentially regrouping and/or further consolidation of the ideas.

As a rule of thumb, the drill-down into sub-causes usually stops when a cause is controlled by a different level of management than the main causal bone. Common sense should rule. **Rarely are people the root cause of process problems.** Often people are compensating for something that is not working, confused by something that is misunderstood, or handling an exception to the rule. Probe further to understand the cause behind a person’s given activity or behavior. Sometimes an “outside” person not involved in the development process can add a new perspective and identify gaps or patterns in the diagram.

Supporting or Linked Tools

Supporting tools that might provide input when developing a Cause-and-Effect diagram include

- Histogram (**See Also** “Histogram—7QC Tool,” p. 330)
- Pareto chart (**See Also** “Pareto Charts—7QC Tool,” p. 445)
- Process map to identify potential root causes (**See Also** “Process Map (or Flowchart—7QC Tool),” p. 522)
- VOC and VOB data (**See Also** “Voice of Customer Gathering Techniques,” p. 737)

- 5Ms and P technique or its variants such as 6Ms and 4Ps (described in detail earlier in this section)
- 5-Why Technique (See Also “5-Whys,” p. 305)
- Brainstorming technique (See Also “Brainstorming Technique,” p. 168)

A completed Cause-and-Effect diagram provides input to tools such as

- Brainstorming potential solutions and concept generation methods
- Root Cause Analysis Techniques [such as Correlation and Regression, Hypothesis Testing, and Design of Experiment (DOE)] (See Also “Design of Experiment (DOE),” “Hypothesis Testing,” and “Regression Analysis,” p. 250, 335, and 571, respectively)
- QFD (Quality Function Deployment) (See Also “Quality Function Deployment (QFD),” p. 543)
- FMEA (Failure Modes and Effect Analysis) (See Also Failure Modes and Effects Analysis (FMEA), p. 287)

Figure C-6 illustrates the link between the Cause-and-Effect diagram and its related tools and techniques.

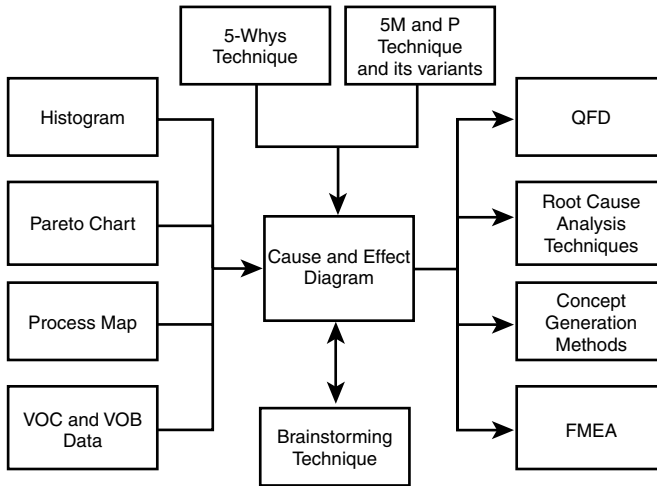


FIGURE C-6: Cause-and-Effect Tool Linkage

Variations

Cause-and-Effect Matrix

Links prioritize customer requirements with the steps of a process to understand which step(s) is more critical to meeting the customer needs. [See the Cause-and-Effect Matrix entry in this section for more detail.]

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Cause Enumeration Diagram

This tool first starts with a brainstormed, exhaustive list of all the possible causes and then groups the items into affinities categories—thus enumerating a large number of likely causes. The very last step is drawing the Fishbone diagram or a matrix that considers the Cause-and-Effect relationship.

Benefit: The potential causes listed should be more comprehensive.

Weakness: It may be difficult to relate the large number of causes to the problematic outcome, making the diagram difficult to draw.

Cause and Prevention Diagram

This variation is used as part of risk mitigation planning. Figure C-7 illustrates the general structure of a Cause and Prevention diagram. [See the “Cause and Prevention Diagram” entry in this section for more detail.]

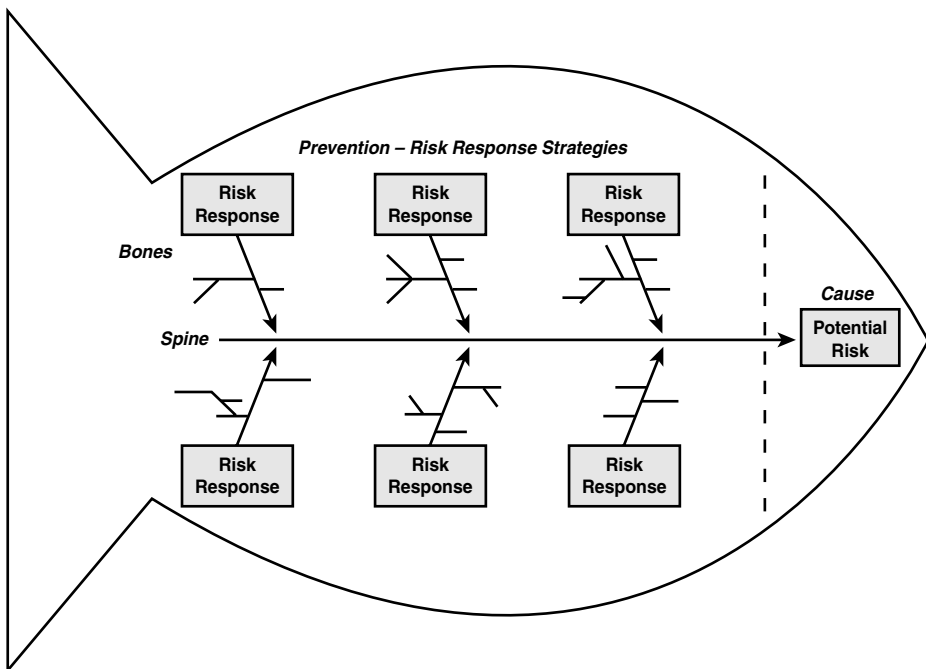


FIGURE C-7: Cause and Prevention Diagram (Fishbone variation)

CEDAC® (Cause-and-Effect Diagram and Cards)

Dr. Ryuji Fukuda (from Japan) developed this approach, which integrates problem-solving with the Fishbone diagram analysis, uses color cards, and prominently displays it to collect input from passers-by. The CEDAC approach includes the following steps:

- Step 1. Problem is identified and an improvement target and metrics are selected and agreed to.

- Step 2. Causes are brainstormed.
- Step 3. Causes are sorted into categories.
- Step 4. Using colored cards (or Post-It™ Notes); one color is assigned to a category.
- Step 5. The causes identified within a category are written on a card with the assigned color—one idea per card. This step is repeated until all the ideas are documented on a card with category color assigned to it.
- Step 6. The cards are placed on a Fishbone diagram.
- Step 7. Improvement ideas for each card are written on a different color card and posted on the Fishbone diagram.
- Step 8. The diagram is then placed in a high-traffic public area (similar to the time-delay Fishbone technique), wherein passers-by can write additional ideas on causes and/or improvements.
- Step 9. Each improvement idea is studied for potential value contribution.

Benefit: Similar to that of the time-delay Fishbone, plus the color cards contribute an additional communication technique that assists with identifying patterns.

Weakness: Similar to the time-delay Fishbone, plus this technique adds a level of complexity that may or may not add value to the process of identifying and sorting potential causes. Moreover, the technique blends improvement ideas with the original intent of an Ishikawa diagram. Thus, the natural tendency of people to jump to solutions may be more difficult to overcome using this technique. The potential causes identified in a Cause-and-Effect diagram should be further studied (using other techniques such as Hypothesis testing) to identify the actual root causes and which have the greatest impact. If the improvement ideas are simple in nature, it will boost worker morale and require little investment (either budgetary or procedurally), and so by all means the suggestion can be implemented.

Warning

Caution should be taken that implementing simple band-aid improvements might merely treat the symptom temporarily and not address the underlying root cause, which can lull people into thinking they have “fixed” the problem because they have “done something.” Keeping “busy” does not necessarily add value; avoid minutia.

Desired-results Fishbone

This technique uses the Ishikawa concept but uses a “desired result” as the focus, rather than a problem. Use the same procedure as when building a Cause-and-Effect diagram but write the desired outcome in the head of the Fishbone diagram and brainstorm ways to potentially achieve that goal.

Benefit: This technique helps to identify and organize a large number of improvement ideas.

Weakness: To avoid the natural tendency to “jump” to solutions before the root cause is understood, it is best to use this approach with new design or creation ideas, rather than solving a problem by rewording the problem in a “positive” way.

Fault Tree Analysis

This uses a top-down analytic method and Tree diagram structure with unique symbols to dissect a specific problem or problematic outcome into its related causes. (See Also “Fault Tree Analysis,” p. 309)

Process Fishbone

This tool is used to analyze the potential causes of a problem within a process, typically a production or assembly, but can also be used with any services process. Start with a high-level process flow as the “main line” or “spine,” with the problem identified in a box at the far right-end of the flow.

Draw the separate Fishbone (with its related potential causes) for each process step. Potential causes also can occur in the transition, or hand-off, between steps and should be drawn with a separate Fishbone.

Benefit: The tool follows the sequence of the process and thus is relatively easy to develop and easy for a “recipient” to understand.

Weakness: If similar potential causes recur throughout the process, they are repeatedly drawn. Thus, the compounding impact of a repeating cause or a combination of several related causes is difficult to illustrate.

Reverse Fishbone Diagram

This variation is used when identifying potential consequences to one or more solutions, improvement ideas, or possible actions. It also is called Backward Fishbone, Action and Effect diagram (AED), or Solution Impact diagram.

Similar to the desired-result Fishbone approach, the reverse Fishbone focuses on a proposed solution. Follow the basic Ishikawa diagram procedure but write the possible solution at the “head” of the fish. The bones identify possible effects the solution may have:

- You can initiate the brainstorming portion of the approach by answering, “What effect could this solution have?”

- Both positive and negative impacts of the solution should be explored.
- Categorizing techniques of the possible effects could include color-coding or marking the ideas to distinguish the positive from the negative.

If several options are being explored, develop one reverse Fishbone per possible solution.

Benefit: This approach leverages the knowledge of experienced people, particularly if a diverse cross-section of functional expertise participates.

Weakness: The results may fall victim to groupthink or paradigm paralysis, and potentially good solutions may be discounted too quickly, or a sub-optimal solution may slide through the scrutiny process too easily.

Time-delay Fishbone

This tool is used to collect input from people over time by posting a large (poster-size or bigger) Fishbone diagram in a high-traffic area (office break room or cafeteria) with pens available nearby. Passers-by are given a standing invitation to add to the diagram. Sometimes copies of the diagram posted in multiple locations are needed to capture a good cross-section of workers.

Benefit: More people can participate in building the diagram, and it extends beyond a meeting date and time, allowing people to reflect, research, and contemplate the causes over time while working. In addition, it can create some excitement (a “buzz”) in the office as people contribute.

Weakness: Sometimes documenting the final Fishbone requires interpretation without testing to understanding with the author of the idea. Interpretation may be needed because symptoms (rather than causes) are posted, poor handwriting, unclear comments, or apparent redundancy. Moreover, finding an adequate central location for all to see can be difficult if the work environment includes several office travelers or “remote” workers.

Cause-and-Effect Prioritization Matrix

What Question(s) Does the Tool or Technique Answer?

Which key variables (process steps or process inputs) best meet customer requirements (or the key process output variables)?

A Cause-and-Effect Prioritization matrix helps you to

- Understand the impact or effect of key process elements cause to key outputs, as defined by customer priorities.

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- Focus and prioritize activities according to what is important to customers, regardless if the resulting action improves a problem area or creates an innovation or delighter.

Alternative Names and Variations

This tool is also known as

- Cause-and-Effect matrix (or C and E matrix)
- Prioritization matrix

Variations on the tool include

- Cause-and-Effect diagram (**See Also** “Cause-and-Effect Diagram—7QC Tool,” p. 173)
- Decision matrix, or Pugh matrix (**See Also** “Pugh Concept Evaluation,” p. 534)
- QFD (Quality Function Deployment) or House of Quality (**See Also** “Quality Function Deployment (QFD),” p. 543)

When Best to Use the Tool or Technique

The Cause-and-Effect Prioritization matrix is an analysis tool to 1) evaluate the relative customer value of what is being provided today, 2) determine the biggest impact (or effect) on meeting customer requirements, and 3) determine where to potentially focus on opportunities for improvement.

This is best used when there are differing opinions about which process steps have the biggest impact on fulfilling requirements or when the number of input variables need to be narrowed.

Brief Description

The Cause-and-Effect Prioritization matrix identifies those potential root causes with the biggest impact on an effect, using customer requirements as its evaluation criteria. This analytical tool is similar to a Cause-and-Effect diagram in that it draws a relationship between the potential causes and an effect, but the C and E Matrix has an expanded purpose, which is to

1. Understand the relationship between output variables and customer requirements, based on what is important to the customer.

2. Understand the relationship between process steps (or input variables) and the key process output variables, based on what is important to the customer.

The C and E matrix examines the relationship of various process steps (or inputs) with prioritized customer requirements (or output variables). The purpose of this tool is to determine *which process steps (or inputs) have the strongest correlation to the requirements*, to determine areas of focus. This tool does not examine current performance.

This tool requires customers' input on not only their requirements, but also the relative priority ranking of each. Collecting this data is important to ensure the validity of the tool. If the data does not exist, the investment of time and money to collect this customer data is an opportunity to better understand customer needs and is a critical input that cannot be overlooked. The customer may be either external or internal.

If a known defect or problem is limited to a set of process steps (or input variables), the application of the C and E Prioritization matrix may be restricted only to those that are suspected to be causing variability (or nonconformance) to one or more of the key output variables. Hence, the C and E matrix prioritizes which of those process steps (or input variables) is likely to be causing the biggest impact.

How to Use the Tool or Technique

When developing a Cause-and-Effect Prioritization matrix, you must

- Step 1. Identify key customer requirements and their relative importance (or ranking). Potential Voice of the Customer (VOC) information sources include
 - Key outputs from the Process map
 - VOC studies (focus groups, interviews, surveys, and so on)
 - CTQ matrix or tree
- Step 2. List the key customer requirements across the top of a grid as column headings (one topic per column).
- Step 3. Place the customer's relative importance of each requirement in the row just beneath the column headings. These are collectively called the *Priority Score*. The scale usually ranges from 1 to 10 (with 10 being the most important or having the largest impact) and no duplicate ratings.
- Step 4. Create the following extra columns in the grid:

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- **Total Score**—as the last column in the grid, placed to the far right of the last key customer requirement column.
 - **Process steps** (or inputs)—as the first column in the grid, placed to the far left of the first key customer requirement column.
- Step 5. Identify all the process steps and key inputs from the Process map and list each one as an individual row heading, below the row containing the Priority Scores.
- Step 6. Divide each open cell in half, with a diagonal line from the upper right corner to the lower left.
- Step 7. Determine the *Correlation Rating*. Examine each step (or input) individually and evaluate how well the step (or input) influences or fulfills each customer requirement using the following rating scale:
- Blank or 0 = No correlation
 - 1 = Remote correlation
 - 3 = Moderate correlation
 - 9 = Strong correlation
- Step 8. Place the Correlation Rating score for each process step in the upper left of each cell.
- Step 9. Within each cell, multiply the Correlation Rating score times the Priority Score and write that product in the lower right corner of the cell. (*Correlation Rating x Priority Score*) For example
- Step 1 and Customer Requirement 1 = (3 correlation x 10 priority) = 30
 - Step 2 and Customer Requirement 2 = (9 correlation x 8 priority) = 72
 - Step 3 and Customer Requirement 3 = (1 correlation x 5 priority) = 5; until...
 - Step *n* : Customer Requirement 4 = (3 x 3) = 9
- Step 10. Determine the *Total Score*. Add the multiplication products (in the lower right corner) across each row to determine the Total Score for each process step (or input). Record that number in the far right column. Continuing with the preceding example
- Step 1 Total Score = 30 + 0 + 5 + 0 = 35

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- Step 2 Total Score = $0 + 72 + 0 + 9 = 81$
- Step 3 Total Score = $90 + 0 + 5 + 27 = 112$; being the highest total
- Step n Total Score = $10 + 0 + 15 + 9 = 34$

Step 11. Evaluate the Total Scores for each process step (or input) for reasonableness. The Total Scores should mirror the strength of the relative correlation that each process step (or input) has with the customer requirements. If something seems amiss, double-check to see if the following error conditions exist:

- Incorrect correlation rating score
- Missing process step or input variable
- Unrelated customer requirement (or output variables) with the process
- Unrecognizable linkage between the process and the customer requirements/deliverables

Table C-1 provides a Cause-and-Effect matrix template to display its generic structure using the example priority scores and calculations described in the preceding steps:

TABLE C-1: Generic Cause-and-Effect Matrix Template

Process Steps	Customer Requirement 1	Customer Requirement 2	Customer Requirement 3	Customer Requirement 4	Total Score
	10	8	5	3	
	Priority Scores				
Step 1	3 $3 \times 10 = 30$	0 0	1 $1 \times 5 = 5$	0 0	35 (30 + 5)
Step 2	0 0	9 $9 \times 8 = 72$	0 0	3 $3 \times 3 = 9$	81 (72 + 9)
Step 3	9 $9 \times 10 = 90$	0 0	1 $1 \times 5 = 5$	9 $9 \times 3 = 27$	112 (90+5+27)
•	SUMMATION				
•					
•					
Step n	1 $1 \times 10 = 10$	0 0	3 $3 \times 5 = 15$	3 $3 \times 3 = 9$	34 (10+15+9)

Correlation Scale: 0=None; 1=Remote; 3=Moderate; 9=Strong

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How to Analyze and Apply the Tool's Output

- The highest ranked process steps (or inputs) indicate the strongest influence on meeting customer requirements.
- You might wish to indicate the top Total Scores (by circling, bolding, or changing the color of the number). Alternatively, display the findings in a Pareto chart visually to depict the relative contributions of the process steps (or inputs) to the customer requirements (or outputs).
- Determine the current performance to determine if there is room for improvement to identify the areas with the largest correlation and the poorest performance.
- Confirm the results and determine the magnitude of impact. Tools to support this next step include:
 - Stratified Dot Plots
 - Scatter Plots
 - Testing “quick fixes”
 - Multi-vari charts
 - Correlation analysis
 - Hypothesis testing (that is, Regression, Logistic Regression, ANOVA, or Chi-Square Test)
 - Design of Experiment
- The results can serve as input to developing a Control Plan or FMEA.

Examples

Cause-and-Effect Matrix Example

Table C-2 presents a sample Cause-and-Effect matrix that explores the relationship between the selling process steps for *computer consulting services* and customer requirements.

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TABLE C-2: Cause-and-Effect Matrix Example for Computer Services Selling

Process Steps	Quality Product	Prompt Service	Professional & Knowledgeable People	Competitive Price	Total Score
	10	8	9	5	
Identify Prospect					
Understand Customer Needs	9 90		3 27	3 15	132
Present Value Proposition	9 90		3 27	9 45	162
Negotiate Deal				9 45	45
Deliver Offering	3 30	9 72	3 27	9 45	174
Support Offering	9 90	9 72	9 81	9 45	288

Poorly Constructed C and E Matrix Example

The following example examines the relationship between customer requirements for purchasing a high-end stereo versus the selling process steps at a retail store. Notice that many of the retail selling process steps have very low impact on the customer requirements. If the retail store owner wanted to better understand why the store was experiencing low sales, the owner might probe further into customer requirements that are more applicable to the selling process or examine other controllable processes at the store (such as brands inventoried versus those of discount stores). Moreover, when the requirements were gathered, the customer did not discriminate among all the needs, but simply gave them equal weight, which provides little insight. Table C-3 shows an ineffective use of a Cause-and-Effect matrix in that the answer is obvious and does not require a matrix to sort out the answer.

TABLE C-3: Ineffective Use of a Cause-and-Effect Matrix—Selling a High-end Stereo Example

Process Steps	Big Sound	Silver Exterior	Remote Control	Illuminated Dial	Lowest Purchase Price	Total Score
	10	10	10	10	10	
Identify Prospect						
Understand Customer Needs					1 10	10

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Process Steps	Big Sound	Silver Exterior	Remote Control	Illuminated Dial	Lowest Purchase Price	Total Score
Present Value Proposition	1 / 10				3 / 30	40
Negotiate Deal					3 / 30	30
Install Stereo						
Service Stereo	1 / 10					10

Hints and Tips

The number of key customer requirements should be limited to about five. Select the appropriate customer requirements driving the set of process steps (or input variables) being evaluated. The relationship between the process steps (or inputs) and the Customer Requirements may produce a grid with about a half to two-thirds of the grid with empty cells (a blank influence rating) showing no correlation. If the grid contains a majority of cells filled in with Correlation Rating scores, then evaluate whether a relationship presumption is being forced. If the grid contains too few cells filled, examine whether the customer requirements are appropriate for the given process steps (or input variables).

The Correlation Rating simply determines the **magnitude of impact** or correlation between a process step (or input) and customer requirements (or outputs) and is indifferent to a positive or negative relationship. Hence the scale should always be positive number—**no** negative numbers. The Correlation Rating scale conventionally used is “Blank, 1, 3, 9” to create a spread that better distinguishes high correlation relationships from the remainder of the considerations. This tool evaluates the magnitude of impact between a process step (or input) and customer requirements (or outputs); it does NOT evaluate current performance.

Supporting or Linked Tools

Supporting tools that might provide input when developing a Cause-and-Effect Prioritization matrix include

- Key outputs from the process map (**See Also** “Process Map (or Flowchart)—7QC Tool,” p. 522)
- VOC studies (focus groups, interviews, surveys, and so on) (**See Also** “Voice of Customer Gathering Techniques,” p. 737)
- CTQ matrix or tree (**See Also** “Critical to Quality (CTQ),” p. 242)
- Fishbone diagram (**See Also** “Cause-and-Effect Diagram—7QC Tool,” p. 173)

A completed Cause-and-Effect Prioritization matrix provides input to tools such as

- Stratified Dot Plots (**See Also** “Dotplot,” p. 280)
- Scatter Plots (**See Also** “Scatter Diagram—7QC Tool,” p. 640)
- Testing “quick fixes”
- Root Cause Analysis Techniques:
 - Multi-vari charts (**See Also** “Multi-vari Chart,” p. 439)
 - Correlation and Regression analysis (**See Also** “Graphical Methods” and “Regression Analysis” p. 323 and 571 respectively.)
- Hypothesis Testing (that is, Logistic Regression, ANOVA, or Chi-Square Test) (**See Also** Analysis of Variance (ANOVA)—7M Tool and “Hypothesis Testing” p. 142 and 335 respectively.)
- Design of Experiment (**See Also** “Design of Experiment (DOE),” p. 250)
- FMEA (**See Also** “Failure Modes and Effects Analysis (FMEA),” p. 287)
- Control Plan (**See Also** “Matrix Diagrams—7M Tool,” p. 399)

Figure C-8 illustrates the link between the Cause-and-Effect Prioritization matrix and its related tools and techniques.

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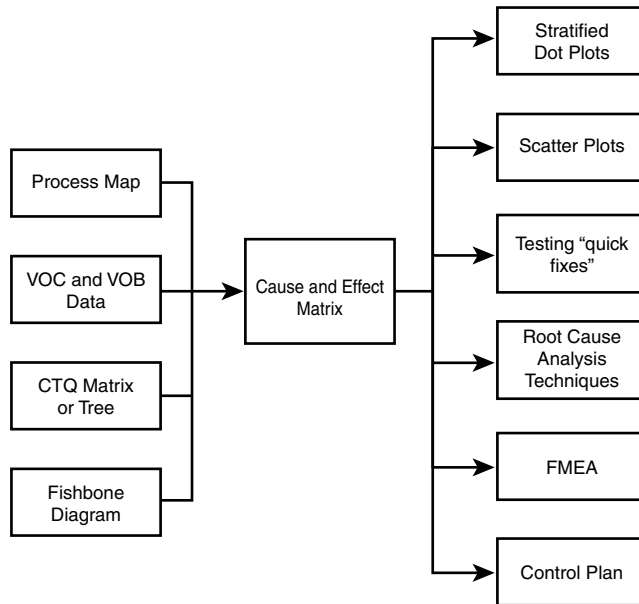


FIGURE C-8: Cause-and-Effect Tool Linkage

Variations

Cause-and-Effect Diagram

Depicts the relationship between a given problem and its potential causes. (See Also “Cause-and-Effect Diagram—7QC Tool,” p. 173 for more detail.)

Decision Matrix

Uses similar principles as the Cause-and-Effect matrix but has a slightly different purpose.

The Decision matrix (sometimes called the *Pugh matrix*) is a selection tool used to determine, from a list of options against a weighted set of criteria, which option to pick. (See Also “Matrix Diagrams—7M Tool,” p. 399 for details on different types of matrices.)

QFD (Quality Function Deployment)

QFD is a more in-depth tool than the Cause-and-Effect matrix but uses similar principles.

The QFD tool (sometimes called the House of Quality) translates customer requirements or needs (using CTQs—critical to quality) into actions and designs that build and deliver a quality offering (product and/or service). (See Also “Quality Function Deployment (QFD),” p. 543.)

Cause and Prevention Diagram

What Question(s) Does the Tool or Technique Answer?

What are the potential risk response strategies to a potential risk or failure?

A Cause and Prevention diagram helps you to

- Organize risk response strategies to understand the relationship between various response strategies to a potential failure (or risk) by formatting, arranging, organizing, and parsing the strategies into themes as part of risk mitigation planning.
- Stimulate thinking when developing the list of the responses to a potential problem.
- Guide concrete action. If the risk occurs, the diagram serves as a checklist or tracking tool for those responding to the given situation.

Alternative Names and Variations

Variations on the tool include:

- Cause-and-Effect diagram

When Best to Use the Tool or Technique

Before any action is taken, this tool helps to define and organize risk response strategies to a potential problem (or risk).

Brief Description

A preventative tool used for risk mitigation planning. It focuses people on the various response action plans, depending on the given situation, and is a variation on the Cause-and-Effect diagram (or Fishbone) tool. (See Also “Cause-and-Effect Diagram—7QC Tool,” p. 173) Though the two tools have a similar structure, the Cause and Prevention diagram warrants its own entry to highlight its purpose as a *proactive risk tool*, versus the C and E matrix’s post-mortem approach of examining potential root causes.

The Cause and Prevention diagram starts with the identification of a potential failure or problem and places it at the “head” of the Fishbone structure. Each major bone represents a major risk response category, stemming off the spine. The brainstorming technique is used to identify various risk response action plans. These response plans are mapped and organized with the corresponding risk response categories and depicted as the related “bones” stemming from the spine.

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It can be depicted as a matrix or Fishbone diagram wherein the problem (or risk) is placed to the far right. The problem is placed in a box or diamond-shape to represent the head of a fish. The prevention strategy themes are placed to the left of the problem.

There are three major types of risk response classification:

1. **Acceptance**—Accept the consequences passively or actively; retain the risk.
2. **Avoidance**—Eliminate a specific threat, usually by eliminating the cause.
3. **Mitigation**—Reduce the expected monetary value of a risk event by reducing the probability of occurrence.
 - a. Reduction—minimize its occurrence and effect
 - b. Transfer—all or a portion of it to another party by using or implementing the following:
 - i. Insurance for direct property damage
 - ii. Indirect consequential loss (often performed by a contractor, for example, debris removal or equipment replacement)
 - iii. Legal liability (design errors, public bodily injury, performance failure)
 - iv. Personnel (employee bodily injury/Worker's Compensation)
 - v. Employee replacement costs
 - vi. Resulting business losses

How to Use the Tool or Technique

When developing a Cause and Prevention diagram, consider the following:

- Step 1. Start with a prioritized list of potential risks or failures, which could come from an FMEA matrix. Agree on the risk or potential failure to be analyzed. (**See Also** "Failure Modes and Effects Analysis (FMEA)," p. 287)
- Step 2. Write the potential risk to the far right edge of the diagram and draw a box around the text to form the "head" of the fish, as shown in Figure C-9.

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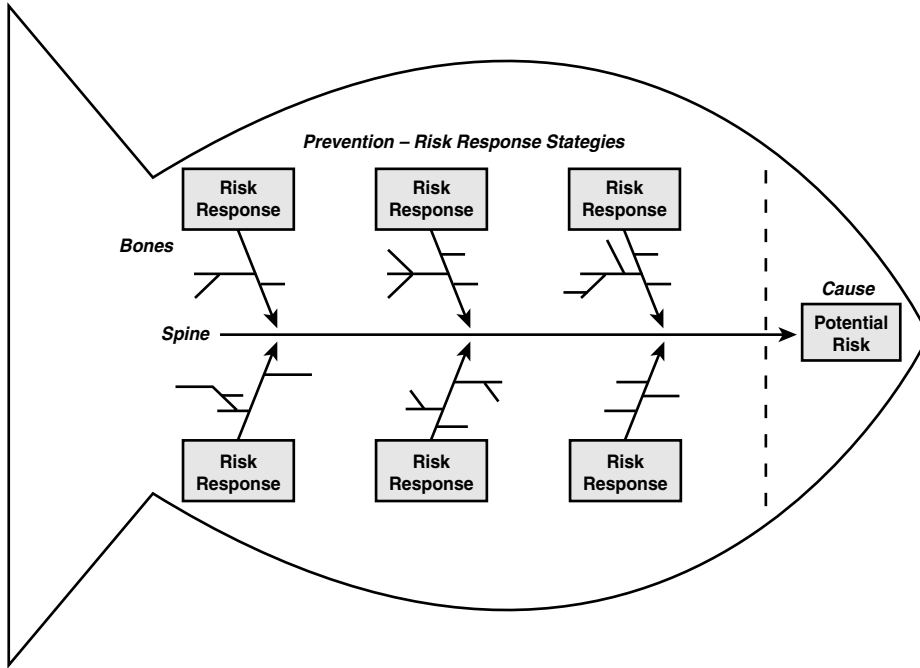


Figure C-9: Generic Cause and Prevention Diagram

- Step 3. Draw a line extending from the left edge of the fish head to the left edge of the diagram to represent the spine.
- Step 4. Agree on the major response categories: Acceptance, Avoidance, Reduction, Transfer, Other, and any additional major response approach theme.
- Step 5. Reference policies, standard operating procedures and experience, brainstorm and write down the potential response action plans, and group them within the related major response categories.

Hints and Tips

Have the participants attending the meeting bring policies, procedures, instructions, and guidelines from their respective areas to inform the brainstorming activities. (See Also “Brainstorming Technique,” p. 168)

- Step 6. Draw a line extending from the spine for each theme and write a major response category name at the outermost end of line (the end that is not attached to the spine) to represent a “main” Fishbone.
- Step 7. Draw one “branch” or offshoot to the main Fishbone and label the end of each branch with the specific response action plan idea to represent smaller bones and to show the linkage to the “higher level” category with which it is affiliated.
- Step 8. Continue Step 7 to drill-down into as much detail as required defining more bones and linking the relationship.
- Step 9. Review the diagram for completeness and clarity and then modify accordingly.
- a. Fill in gaps and streamline wording.
 - b. Eliminate unnecessary redundancy.
 - c. Eliminate unrelated ideas.

How to Analyze and Apply the Tool’s Output

- Review the final diagram for completeness and clarity.
- Incorporate this Cause and Prevention diagram in the appropriate control documentation:
 - Risk Mitigation Plan
 - Transition Plan
 - Implementation Plan
 - Communication Plan
 - Control Plan
 - Standard Operating Procedure manual.

Hints and Tips

Prioritize the most likely to occur negative events and develop one Fishbone per potential major “negative” outcome. This is a good tool to develop an action plan for the high-priorities following an FMEA. (**See Also** “Failure Modes and Effects Analysis (FMEA),” p. 287)

It might help to categorize the different types of risk according to the cause or source of risks: Business Risks (chances for a profit/loss associated with any business endeavor) and Pure (Insurable) Risk (only a chance for loss).

Rank the risk according to the ability to manage effective responses: **Opportunity** (probability of occurrence certainty) and **Threat** (magnitude if occurred and the amount of information you have about the risk). Then look at possible cumulative effect of several risk events occurring in conjunction with each other and/or dependencies. Identify the Tools and Techniques/Processes to organize, document, and respond to risk if it occurs.

Key Questions to ask during the response plan generation step are as follows:

1. How could this risk be avoided?
2. Can this risk be reduced?
3. Can the risk be shared or transferred?
4. Should we face the risk, and if so, should scheduling and financial allowances be made?
5. Can we contain the risk?

Benefits: Can be a thorough, in-depth analysis of possible response strategies.

Weakness: Need multiple Fishbone diagrams for the multiple possibilities of risk occurrences. This requires time to develop the analysis, and the planning may never be needed. It may be difficult to prioritize and identify the possible negative outcomes.

Supporting or Linked Tools

Supporting tools that might provide input when developing a Cause and Prevention matrix include

- FMEA (Failure Modes and Effect Analysis) (**See Also** Failure Modes and Effects Analysis (FMEA), **p. 287**)

A completed Cause and Prevention matrix provides input to tools such as

- Checklist defining an action plan or standard response procedure (**See Also** “Checklists—7QC Tool,” **p. 204**)
- Control Plan (**See Also** “Matrix Diagrams—7M Tool,” **p. 399**)
- Risk Mitigation Plan (**See Also** “Risk Mitigation Plan,” **p. 601**)
- Transition Plan (**See Also** “Matrix Diagrams—7M Tool,” **p. 399**)
- Implementation Plan (**See Also** “Matrix Diagrams—7M Tool,” **p. 399**)
- Communication Plan (**See Also** “Matrix Diagrams—7M Tool” **p. 399**)
- Standard operating procedure (SOP).

Figure C-10 shows the link between the Cause and Prevention diagram and its supporting tools and techniques.

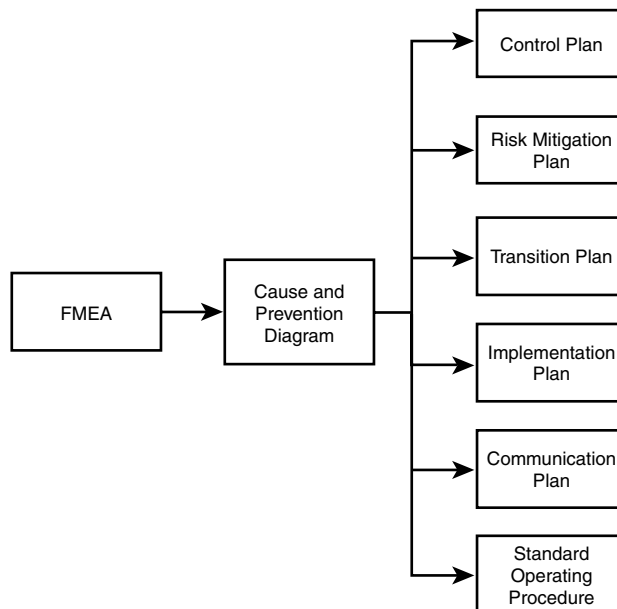


FIGURE C-10: Cause and Prevention Tool Linkage

Checklists—7QC Tool

What Question(s) Does the Tool or Technique Answer?

What activities or deliverables are required to meet requirements? Alternatively, what was observed?

Checklists help you to

- Outline (or list) the set of tasks or deliverables to be completed.
- Remind someone of the various components to fulfill requirements.
- List potential considerations to determine if appropriate or required for a given situation.
- Recap the standard operating procedure (SOP) activities or deliverables.
- Collect data about “how many” or “what type” of something occurred.

Alternative Names and Variations

This tool is also known as a *check sheet*.

When Best to Use the Tool or Technique

This tool **precedes** work and summarizes a set of pre-determined activities, action items, deliverables, or questions to be referenced before and/or during work.

Brief Description

The checklist is a generic tool that may provide recommendations or considerations of “best practices” or “options” to be evaluated for a given situation. Alternatively, the tool may outline the standard operating procedure (the set of required tasks) and/or outputs that must be completed to satisfy a given set of requirements. This generic tool can be as simple or as complex as the situation requires. It is a powerful tool in that it is flexible and customizable to reflect a range of complexity, depth, and breadth needed to complete a work procedure.

The checklist is a member of the original 7QC Tools, (or *seven Quality Control tools*), attributed to Dr. Kaoru Ishikawa. The 7QC tools sometimes are called the “seven basic tools” because they were the first set of tools identified as the *core* quality improvement tools. Ishikawa’s original 7QC Toolset includes: 1) Cause-and-Effect diagram, 2) Check sheet (or

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checklist), 3) Control charts, 4) Histogram, 5) Pareto chart, 6) Scatter diagram, and 7) Stratification.

Structure the checklist to include the critical parameters of a task, such as the following:

- Required procedure**—The sequence of activities or tasks to fulfill a certain standard or set of requirements. It can include who is to do what task or who is involved, as illustrated in Table C-4, and sometimes may include who the customers, decision-makers, and subject matter experts are.

Table C-4: Generic Procedure Checklist Example for Selling

Process Steps	Sales Rep	Sales Specialist	Field Engineer	Approver: District Manager
1. Identify Prospect	X			
2. Understand Customer Needs	X	X		
3. Develop Value Proposition, Price and negotiation boundaries	X	X		X
4. Present Value Proposition		X		X
5. Negotiate, if necessary	X	X		
6. Sign Contract				X
7. Deliver Offering			X	
8. Support Offering			X	

- List of deliverables or outputs**—This can include critical features or functionality aspects. Can include *who* is accountable for producing the deliverable, as seen in Table C-5. Sometimes may include who are the (internal or external) customers and subject matter experts.

TABLE C-5: Generic Deliverables Checklist Example for Selling

Deliverables	Sales Rep	Sales Specialist	Field Engineer	Approver: District Manager
1. Prospect identified and entered into sales tracking database.	X			
2. Customer needs understood and documented	X			
3. Offering value proposition and price documented in presentation format.	X	consulted		approved
4. Negotiation boundaries defined.	informed	informed		X

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TABLE C-5: Continued

Deliverables	Sales Rep	Sales Specialist	Field Engineer	Approver: District Manager
5. Value Proposition presented.	X	support		
6. Negotiations conducted, if necessary, final agreement reached. Customers signature secured on contract		X		
7. Contract signed by manager, copy, then sent to customer.	X			approved
8. Offering delivered and installed			X	
9. Customer trained and offering supported.			X	

- **List of planning considerations (best practices or conditional what-ifs to evaluate prior to or during an activity)**—If the added complexity is useful, the potential conditions should include the corresponding next steps or alternatives, as seen in Table C-6.

TABLE C-6: Generic Planning Checklist Example for Selling

Considerations to select appropriate selling support literature:	
1. Identify industry segment	
2. Identify role of key contact	
3. Who has budgetary responsibility? What is the relationship with the key contact?	
4. What is the total department budget?	
5. Are the funds allocated for this initiative? If so, how much?	
6. What is the timeframe for the initiative?	
7. What are the key issues (pain) trying to be solved?	
8. What are the departmental near term and long term goals? How are they performing against those goals?	
9. Do other departments have similar issues?	
10. Are there any critical (internal or external) suppliers?	
11. Who are the (internal and / or external) customers? What are their requirements? How does the key contact know? How recent is the information?	
12. How predisposed is the key contact to our solutions (exploring options, not sure if will buy; interested but undecided which is the best approach; ready to buy)	

- **A collection tool**—To capture frequency of events or conditions needing to be tallied (attribute data), such as number of something (for example, defects, phone calls, and so on) or type of something (categories, names, colors), as illustrated in Table C-7.

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TABLE C-7: Generic Tracking Checklist Example for Selling

Quarterly Selling Activity:	Q1	Q2	Q3	Q4
1. # incoming leads from trade shows and advertising				
2. # phone calls made				
3. # customer emails sent				
4. # exploratory appointments / meetings scheduled				
5. # Value proposition meetings conducted				
6. # deal negotiations in process				
7. # deals closed				
8. # customer contracts signed				
9. # offerings delivered and installed				
10. # of customer "relationship" building meetings conducted				

The power of the checklist comes about with active use. Its strongest attributes—simplicity, flexibility, and scalability—are also its weakness. It must be used and maintained to reflect the current thinking or *best practice* to reap its powerful benefits; otherwise, it could become obsolete or irrelevant. As with other soft tools, the checklist should be part of an evergreen process to maintain its applicability. The refresh process keeps people actively engaged using it because it will reflect the latest lessons learned and best practices.

Conjoint Analysis

What Question(s) Does the Tool or Technique Answer?

What product and/or services features and functionality do customers prefer and would be willing to buy?

A conjoint analysis helps you to

- Determine consumer preference and behavior by making trade-offs between choices.
- Understand price sensitivities to various product and/or services attributes and levels to determine the most appealing combinations.
- Characterize and verify customer requirements (both implicit and explicit).

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When Best to Use the Tool or Technique

A conjoint analysis collects the Voice of the Customer (VOC) and derives preference profiles from a portfolio of options to predict buying behavior. The technique is best used during the design phase of a new product and/or services offering or when an existing offering needs to be modified or refreshed to help drive sales and market share. It can also be used during the define phase of a project to determine what is important to the customer.

Brief Description

The conjoint analysis technique was developed in the early 1970s as a market research tool to assess the potential profitability, sale revenue, and market share for a new or modified offering. It employs a structured methodology to determine consumer preference and buying behavior by studying the joint effects of multiple attributes. The term “conjoint” means two or more items joined together or combined. The research subjects are asked to select their preference given a set of alternatives. The trade-off decisions indicate price sensitivity and determine the most appealing combination of attributes for an offering.

The conjoint analysis reveals the underlying preferences that guide purchasing decisions. It determines which features to offer that will appeal to maximum number of potential purchasers. It also identifies segments that will prefer a particular set of features and measure how desirable that combination may be to target.

The conjoint model decomposes a potential product and/or services offering into a few major attribute categories, wherein each attribute is further decomposed into different levels. The levels can be non-metric and metric levels. The potential offering scenarios are created by assembling different attribute combinations (or *bundles*) using a fractional factorial design (from the DOE technique) to create a subset of the possible options. The research respondents evaluate each “test” alternative combination to determine their preferences. This selection asks the respondents to trade-off various attributes for others to decipher **relative** degrees of importance and/or price sensitivities. The conjoint analysis defines a set of *part-worths* (also referred to as *utilities*) for each attribute to understand the relative importance of each feature and the value of its different levels when making a purchasing decision.

There are three different conjoint analysis methods: The *adaptive conjoint*, which is probably the most popular approach, employs a rough ordering of importance and then uses pair-wise tradeoffs to compute the part-worth. The *hybrid model* weighs each attribute from zero to ten, and then 100 points are allocated across all attributes and respective levels. The *bridging design* is used for a large number of attributes, and it evaluates bundles on a subset of attributes common across several respondents.

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The conjoint analysis examines the relative value of attributes considered jointly versus in isolation. This technique's power is that it more closely aligns to real-world trade-off scenarios, using a statistical approach to economically evaluate a fraction of the possible combinations, ultimately to predict consumer choice among multi-attribute offerings.

How to Use the Tool or Technique

The conjoint analysis procedure involves three steps, which build on the DOE fundamentals. As with a traditional DOE, the important and often the most time-consuming activity in the process is the planning step. The general conjoint analysis procedure is as follows:

Step 1. Design conjoint study.

a. Select attributes relevant to product (or service) category.

This refers to appearance, size, or price of an offering, for example. A good source of input is from the various data collection methods such as focus groups of targeted customers. Also consider utilizing secondary sources of data, such as desktop research, Web blogs, and periodicals.

Consider whether the target audience is segmented. If so, unique market segments may require additional or unique attributes.

b. Select levels for each attribute.

A level represents the values or options for each attribute, such as the different appearance options, different size options, or the different price options. The more options or levels introduced into the study, the greater the complexity for the respondents to select an option, and the greater the complexity of the test design and analysis.

Try to include the same number of levels for each attribute to simplify evaluation for respondents and to avoid misleading results on the importance of attributes. Consider picking similar ranges found in existing products or services to compare with their "delighters" and "dissatisfiers" (from a Kano Analysis). Figure C-11 illustrates potential attributes and respective levels for a new computer concept. Notice that although the design has a relatively large number of attributes, it features an equal number of levels per attribute, thereby simplifying the analysis.

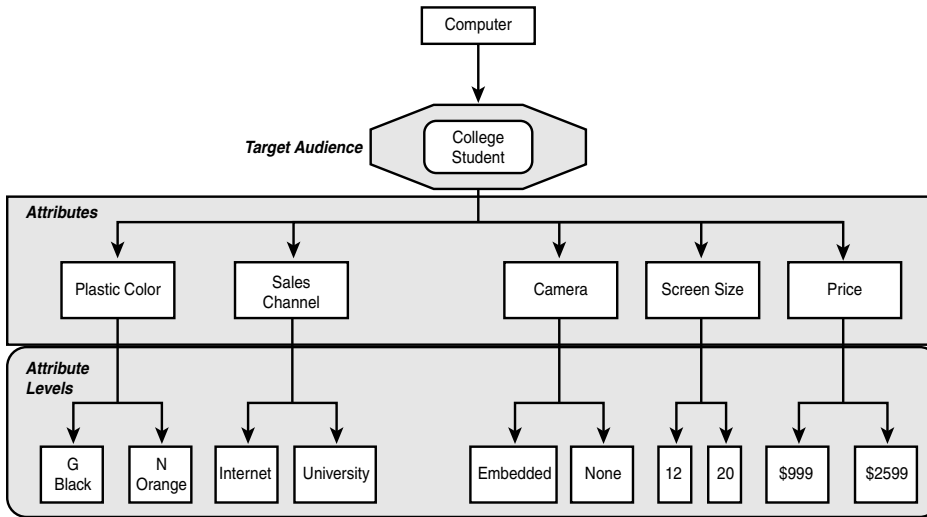


FIGURE C-11: Computer Example for Conjoint Attributes and Levels

c. **Develop relevant option bundles (or combinations) to be evaluated.**

Determine appropriate *bundles of attribute* profiles to define a potential offering to test. A bundle contains one option (or level) of each attribute selected for analysis. The combination of attribute options within a bundle defines the product or services offering.

The complete set of combinations defines the possible design options to be tested, using a fractional factorial (orthogonal array) design to reduce the number of evaluation options instead of full factorial design with all possible combinations. (See Also “Design of Experiment (DOE),” p. 250)

If every attribute at every level were to be tested in the computer example shown in Figure C-11 (a full factorial design), the test would involve 64 different possible combinations ($2 \times 2 \times 2 \times 2 \times 2 \times 2$). If the design were run at half-fractional factorial DOE, the number of unique runs reduces to 32. If the Taguchi Orthogonal Array were used, only 16 runs would be required.

The experimental design is based on the amount of acceptable confounding balanced by the available time, resources, and funding. In DOE terminology, the “resolution” must reflect the business conditions.

To double-check the number of runs required for a design, using MINITAB, follow the procedure outlined as follows:

- **Full Factorial Design** (for 6 attributes, 2 levels each)—The drop-down menu to highlight: *Stat>DOE>Factorial>Create Factorial Design...* to open the main screen. Select *2-level factorial (default generators)* and enter 6 into the Number of Factors dialog box. Click OK. The resulting session window display 64 runs.
- **Half-Factorial Design** (for 6 attributes, 2 levels each)—The drop-down menu to highlight: *Stat>DOE>Factorial>Create Factorial Design...* to open the main screen. Select *2-level factorial (default generators)* and enter 6 into the Number of Factors dialog box. Click the Designs... button and select the *1/2 fraction 32 VI 2**(6-1)* design option and click OK to close the Design window. In the main screen, click OK again. Click OK. The resulting session window displays 32 runs. (Note this is a Resolution IV design.)
- **Taguchi Orthogonal Array Design** (for 6 attributes, 2 levels each)—The drop-down menu to highlight: *Stat>DOE>Taguchi>Create Taguchi Design...* to open the main screen. Select *2-Level Design*, and enter 6 into the Number of Factors dialog box. Click the Designs... button and select the *L16 2** 6* design option and click OK to close the Design window. In the main screen, click OK again. The resulting session window displays 16 runs.

The MINITAB Worksheet can be used as the design structure and the data collection sheet for the respondents' "preference score." The design structure defines how to combine the various attributes and respective levels to ensure randomness. For those fractional factorial experiments, the design structure also identifies which runs to select while maintaining balance.

In addition, these procedures are illustrative and lack "replicates." **Replicates should be added to the design** to make the experiment more robust and improve the experiment's ability to predict.

If the design involved three levels for each attribute, the complexity would be compounded, resulting in 729 runs for a full factorial design ($3 \times 3 \times 3 \times 3 \times 3$); however, an Orthogonal Array design would result in only 27 runs.

Step 2. **Obtain data from a sample of respondents.**

a. **Choose the format to present the bundles.**

Select the form in which the respondents will receive the bundled options. Typically, the bundles can be represented as a verbal presentation, written description, pictorial presentation, or samples (that is, prototypes).

Often a “card” is used to display the configuration of bundled attributes and appropriate levels. Each run requires a unique “card,” whereby the set of cards represent the full portfolio of multiple configurations options. The respondent, then, sorts the cards in rank-order from highest preference to lowest.

b. **Design a data collection procedure.**

The respondents assign part-worth for each level of each attribute.

Rank-order approach: The product bundles could be rank-ordered (for example, one to sixteen), with one representing the highest or most preferred rank and sixteen the lowest.

Rating approach: If a ratings scale is used, respondents evaluate each product on scale of 0 to 100 points with larger sums indicating preference. The advantage of this approach is that the *Least Squares Regression* can be applied with dummy variables to compute part-worth functions. [A constant sum also can be allocated (100 points, for example) across 16 bundles.]

c. **Select computation method for obtaining part-worth function.**

The data is entered in the data collection worksheet of a statistical software application for analysis (MINITAB).

Obtain the part-worth functions by computing the preference score for an attribute and computing the average scores of the bundles that contain that attribute. For example, if four bundles contain one attribute, add up the respondent’s preference scores for those four bundles and divide by four to calculate its average. This computed number represents the part-worth.

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The part-worth model is one of the simpler models to define the various attributes. There are also linear models (using vectors) and quadratic models (using ideal-points).

Step 3. **Evaluate product design options.**

a. **Segment customers based on part-worth functions.**

Determine how to arrange and aggregate responses. Cluster the *part-worth* data to see if any patterns emerge. Cluster according to one of the following options:

- the individual responses
- the pooled responses from all the participants into a one *part-worth* function
- similar preferences

Let the *part-worth* data reveal the number of segments (or latent class), if any. Heterogeneous grouping assumes all customers belong to same segment but differ as specified in *part-worth* distribution.

b. **Design market simulations** to assess likely success of a proposed new product concept under various simulated market conditions.

c. **Select choice rule** to transform part-worth into choices customers are likely to make to determine the best product and/or services offering. The choice rules include

- **Maximum Utility**—Compute the market share by counting the number of customers for whom that offering provides maximum utility and divide by the number of customers in the study.
- **Share of Utility**—Select the higher the utility of a product corresponds with the higher likelihood that a customer will choose it.
- **Logit Choice**—Determine the proportion of times that product has maximum utility; the brand with the maximum utility varies randomly.
- **Alpha**—Weight the maximum utility and the share of preference wherein the chosen weight ensures that the simulated market share reflects the actual market share of existing products.

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Examples

Laptop Computer Functions Example

This scenario involves a computer manufacturing's marketing department trying to increase market share and brand loyalty by wooing a new target audience—high school students preparing to go to college. The target market wants mobility, “hip” design and functionality, and plenty of storage capacity for its large music files—all in all, the best value package. The marketing department wants to leverage current technology but create a new image that convinces the consumers that the product meets their needs.

To keep the example simple, presume the high school student population is homogeneous and that a sample size of three is sufficient. The study's design involves five attributes with two levels and two replicates. (Given the two replicates, each respondent will complete the study twice; however, the card deck must be placed in a different random order between runs.)

Design Elements—The computer attributes of interest are

- **Plastic color (2 levels)**—Graphite Black; Neon Orange
- **Sales Channel (2 levels)**—Internet; University
- **Camera (2 levels)**—Embedded; None
- **Screen Size (2 levels)**—12 inches; 20 inches
- **Price**—\$999; \$2599

Figure C-11 illustrates the attributes and their respective numbers of levels, which is unequal across the options.

The total possible number of combinations for these five attributes at two levels is 32 ($2 \times 2 \times 2 \times 2 \times 2$), and with two replicates, the runs increase to 64. Given economic and time pressures, the study will use a half-fractional factorial, Resolution V design, requiring only 32 runs.

Using MINITAB to build the study's worksheet, access the main screen by using the following drop-down menus: *Stat > DOE > Factorial > Create Factorial Design*.... Enter the study's attributes and level information in the main screen and its three “options” screens, as illustrated in Figure C-12. (See also “Design of Experiment (DOE)” p. 250 for more details.)

The respondents will rate the multiple configuration options using “cards.” Each card will contain a unique configuration option. The MINITAB Worksheet displays the bundle alternatives. The final Session Window and Worksheet for this example are shown in Figure C-13. Note that the Worksheet displays the attributes levels as coded integers (1, 2, 3, 4).

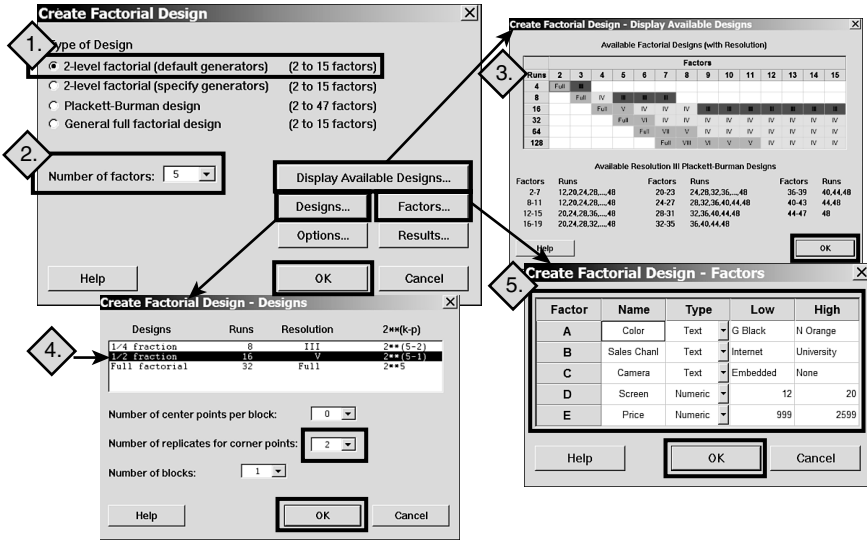


FIGURE C-12: MINITAB Set-up for Computer Example

Label the Worksheet column C10 as the “Response” column. Create the 32 response cards, following the design in the MINITAB Worksheet. (One card would feature Neon Orange, Internet sales, Embedded camera, 20 inch screen for \$2599 to mirror the first line in the MINITAB Worksheet.) Run the study with multiple respondents and record the results on the MINITAB Worksheet.

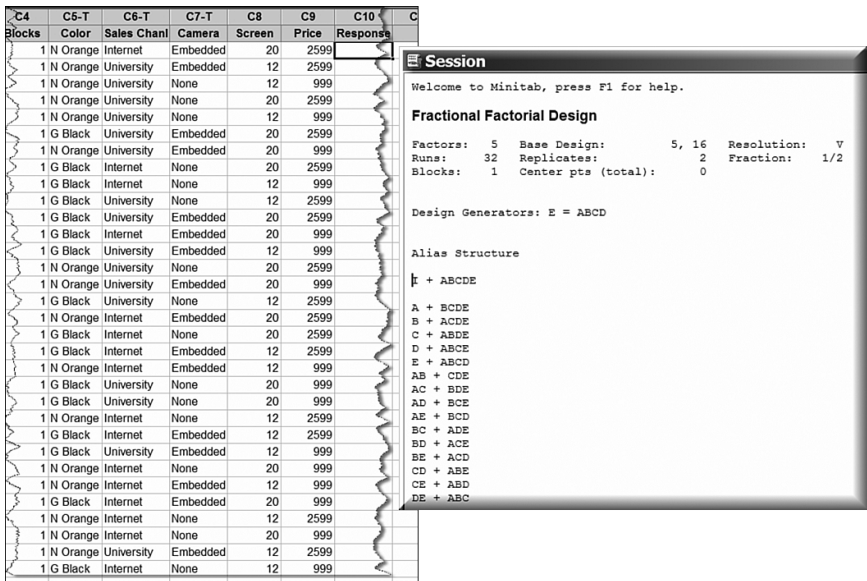


FIGURE C-13: MINITAB Worksheet and Session Window for Computer Example

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For purposes of this example, the conjoint will cover only four respondents with each respondent sorting the cards twice.

To analyze the results, from MINITAB's drop-down menu, select *Stat > DOE > Factorial > Analyze Factorial Design...* Enter the column containing the study's responses as the *response variable* in the dialog box. Click OK or select any of the analysis options of interest. The Graphs option screen contains the option to select a Pareto diagram.

The results of this study show that color has the most significant impact on preference, with all but the screen size contributing to preference, as shown in Figure C-14, which captures the session window and Pareto chart. The respondents indicated that they prefer a neon orange computer to graphite black. The students reported price sensitivity as the second largest impact on preference, favoring the lower of the two prices, at \$999.

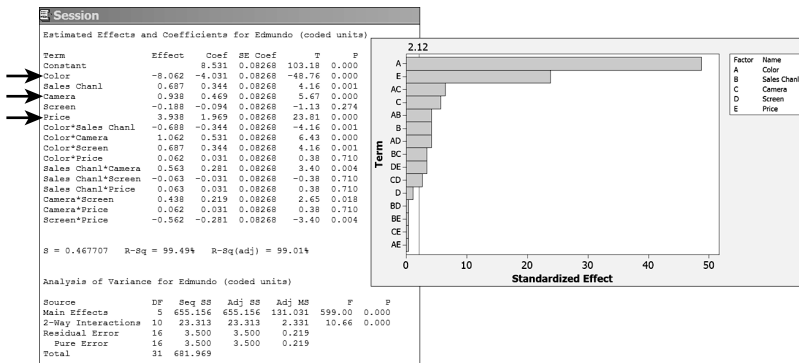


FIGURE C-14: MINITAB ANOVA Session and Pareto for Computer Example

The Session Window Output found in Figure C-14 contains additional terms not defined within this entry. For a discussion on the meaning of R-Sq and R-Sq(adj), reference the Regression Analysis entry. (See Also "Regression Analysis," p. 571) For a discussion on the meaning of the Analysis of Variance terms, reference the ANOVA entry. (See Also "Analysis of Variance (ANOVA)—7M Tool," p. 142)

Supporting or Linked Tools

Supporting tools that might provide input when developing a conjoint analysis include

- Fishbone (See Also "Cause-and-Effect Diagram—7QC Tool," p. 173)
- VOC/VOB data (See Also "Voice of the Customer Gathering Techniques," p. 737)
- CTQs (See Also "Critical to Quality (CTQ)," p. 242)

- QFD (See Also “Quality Function Deployment (QFD),” p. 543)
- Solution selection matrix (See Also “Solution Selection Matrix,” p. 672)

A completed conjoint analysis provides input to tools such as

- QFD (See Also “Quality Function Deployment (QFD),” p. 543)
- FMEA (See Also “Failure Modes and Effects (FMEA),” p. 287)
- Pugh matrix (See Also “Pugh Concept Evaluation,” p. 534)

Figure C-15 illustrates the link between the conjoint analysis and its related tools and techniques.

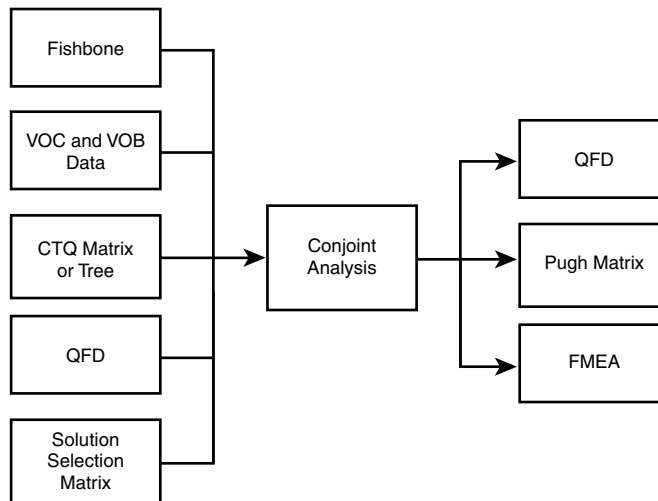


FIGURE C-15: Conjoint Analysis Tool Linkage

Variations

DOE (See Also “Design of Experiment (DOE),” p. 250)

Control Charts—7QC Tool

What Question(s) Does the Tool or Technique Answer?

How is the process behaving; is it in statistical control?

Control charts help you to

- Determine whether a process is stable (in statistical control) over time.

- Measure, monitor, and control processes.
- Determine what is a special cause event (unexpected variation) that needs to be identified and eliminated.
- Decipher common cause variation (predictable and expected) or the inherent variation in a process versus unexpected variation.
- Predict changes and indicate the need to improve process performance or determine if an *improvement* actually reduces process variation. (Key triggers include quality, cost, and capacity.)

Alternative Names and Variations

This tool is also known as

- Statistical process control (SPC) charts
- Process behavior charts

Variations on the tool that depend primarily on the type of data being plotted include

- Charts for variable data include
 - X-bar and R chart (or averages and range)
 - X-bar and S chart (or averages and standard deviation)
 - I and MR chart (or “*individuals and moving range*”, or I-MR, X-chart, X-R chart, IX-MR chart, XmR, moving range)
 - Moving average-moving range chart (or MA-MR)
 - Target charts (or difference charts, deviation charts, or nominal charts)
 - CUSUM charts (or “*cumulative sum*”)
 - EWMA (or “*exponentially weighted moving average*”)
 - Multivariate chart (or Hotelling T²)
- Charts for attribute data include
 - p-chart (or “proportion” or “percentage” chart)
 - np-chart (or number within a proportion (or affected units))
 - c-chart (or count chart)

- u-chart (or nit chart/counts-per-unit)
- P Prime SPC chart
- Charts for either type of data include
 - Short run charts (or stabilized charts/Z-charts)
 - Group charts (or multiple characteristic charts)

When Best to Use the Tool or Technique

Control charts should be used on a regular basis as part of the monitoring and management of a process to control variation. They ensure process stability over time—a **prerequisite for process capability analyses**. Control charts also aid in distinguishing between special cause variation and common cause variation as a guide for management.

Brief Description

A control chart often is referred to as a *super-charged* run chart or *time series plot* used to monitor a process over time. It is a frequency distribution plotted over time in the sequence that the data occurred or was produced and adds three reference lines for interpreting patterns in the data. These reference lines comprise a centerline (the average or mean) and control limits—an upper and lower control limit. The control limits are defined as three-sigma on either side of the collected data's mean. Why three standard deviations? It balances the likelihood of a false signal and maintains sensitivity to detect real signals. A *Statistical Process Control (SPC)* is the application of statistical methods to identify and control special cause variation in a process.

Control charts are a graphical tool used to monitor changes that occur within a process by distinguishing variation that is inherent in the process (*common cause*) from variation that indicates a change in the process (*special* or *assignable cause*). This change may be a single point or a series of points in time—each is a signal that something is different from what was previously observed and measured. Unusual variation is signaled by any point outside or specific patterns within the control limits.

Control limits are established at a distance of three standard deviations on either side of the centerline, or mean, of data plotted on a control chart. **Do not confuse control limits with specification limits.** Control limits help to identify special cause variation and confirm stability over time—the Voice of the Process (VOP) metric. Specification limits describe conformance to customer expectations—a Voice of the Customer (VOC) metric, which are utilized in process capability charts.

Recall that a “bad” part is determined by 1) dispersion in the process, where it is wider than the specified spread, or 2) off-target, where the process variation could be “skinnier” than the control limits but have drifted (that is, are off-center). (See Also “Process Capability Analysis,” p. 486) Therefore, it is important to note that whether or not a process is meeting its control limits depends on the desired outcome itself, whether

- larger is better,
- smaller is better, or
- nominal (target) is best.

As just stated, the type of control chart primarily depends upon the type of data being plotted. *Variable data* is quantitative results or data where measurements are used for analysis. Sometimes variable data is called *continuous* data because it is measured on a continuous scale such as temperature, distance, cycle time, profit, or mass and pressure, rather than in discrete units or yes/no options. Ranks are also a type of variable data, such as the customer satisfaction scores on a scale of one to ten. *Variable data control charts come in pairs*, with the top chart plotting the average or centering of the process data, and the bottom plot displaying the range of the data distribution. Continuous data is used to create an I-MR chart (or X-MR), X-bar and R chart, and X-bar and S chart.

Attribute data, on the other hand, is qualitative, rather than quantitative in nature. It can be counted for recording and analysis and is measured strictly by either conforming or not. Therefore, a specification is imbedded in the response as to whether or not a criteria was met. Attribute data (also called “discrete” data) is a characteristic that may take on only one value (0 or 1, for example) and be counted in discrete units such as items or and yes/no options. Discrete examples include binary responses, such as “yes/no” or “pass/fail,” and counted data, such as number of defects. Attribute data is used to create p-charts (percent chart), np-charts (number of affected units chart), c-charts (count chart), u-charts (counts-per-unit chart). Figure C-16 summarizes the breakdown of data types into the specific control chart produced.

In comparison, variable data is more informative than attribute data, as attribute data is more limited in describing a process. Plus, the sample size required for attribute data must be larger than an equivalent variable data measurement to be statistically significant. In the context of data type, control charts measure variation between samples for attribute data and variation both between and within sample groups over time for variable data.

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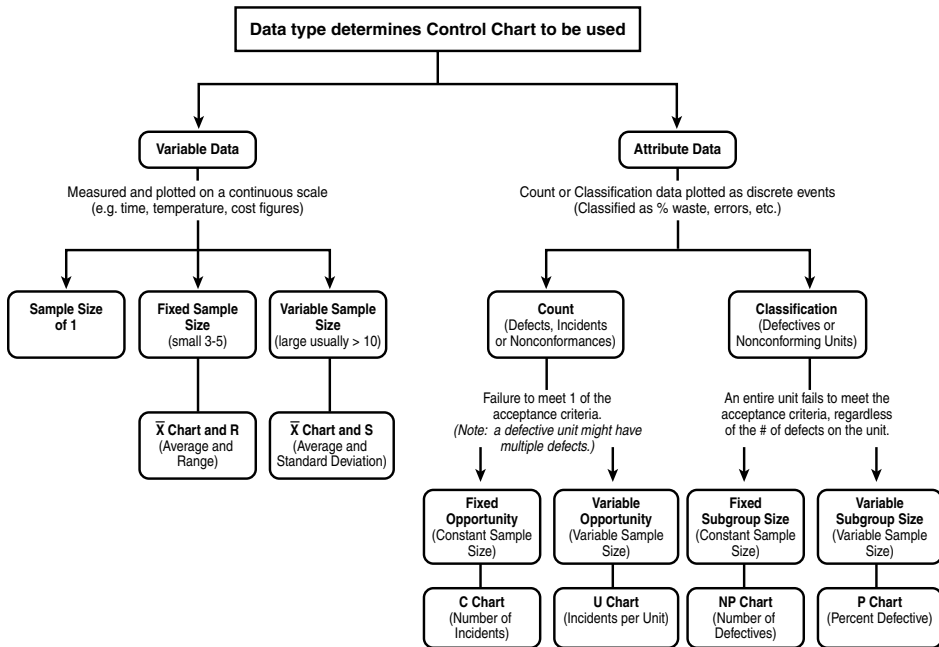


FIGURE C-16: Summary Tree of Different Control Charts

Guidelines or tests exist to identify unexpected patterns in data, wherein it is unlikely that these patterns occurred by chance alone. These special cause guidelines presume the observations are independent. Independence means the value of the given data point is not influenced by the value of another data point. If data are not independent, the data values will not be random. This means the rules for determining special cause variations cannot be applied (because they are based on rules of statistical probability). Different statistical authorities vary slightly on the exact guideline details; however, in general there are eight tests for special cause events. MINITAB's guidelines cover the following scenarios:

1. **1 point beyond control limit (3σ)**—Detects a shift in the mean, an increase in the standard deviation (σ), or a single aberration in the process. Check your R-chart to rule out increases in variation.
2. **9 points in a row on one side of the mean**—Detects a shift in the process mean.
3. **6 points in a row steadily increasing or decreasing**—Detects a trend or drift in the process mean. Small trends will be signaled by this test before the first test.
4. **14 points in a row alternating up and down**—Detects systemic effects, such as two alternately used machines, vendors, or operators.

5. **2 out of 3 points in a row @ 2 σ or beyond**—Detects a shift in the process average or increase in the standard deviation (σ). Any two out of three points provide a positive test.
6. **4 out of 5 points @ 1 σ or beyond**—Detects a shift in the process mean. Any four out of five points provide a positive test.
7. **15 points in a row on both sides of the centerline within the 1 σ “zone”**—Detects stratification of subgroups—appears when observations in a subgroup come from sources with different means.
8. **8 points in a row on both sides of the centerline all beyond 1 σ zone**—Detects stratification of subgroups when the observations in one subgroup come from a single source but subgroups come from different sources with different means.

MINTAB indicates the special cause pattern by plotting the unexpected event in red and places a footnote alongside the red data point to reference the specific rule. MINITAB provides the specific rule information about a given special cause event, which can be found on its session window. Figures C-17 and C-18 illustrate these different special cause guidelines.

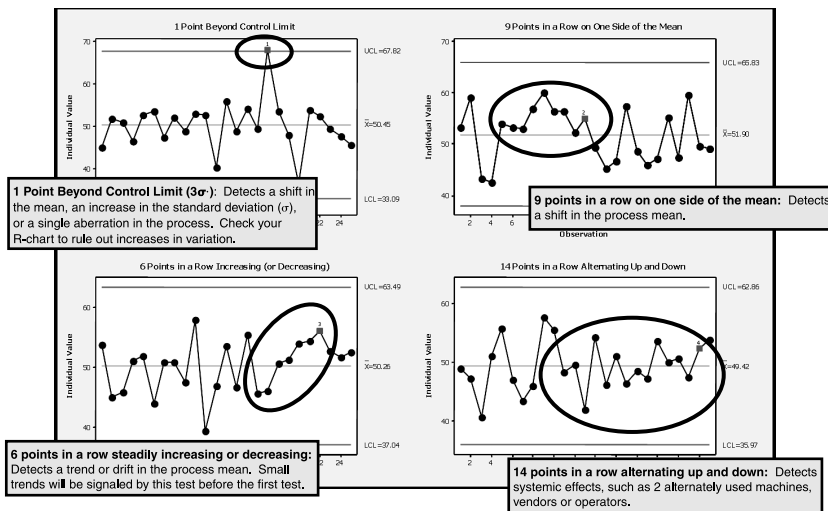


FIGURE C-17: Interpreting Control Chart Patterns for Variable and Attribute Data

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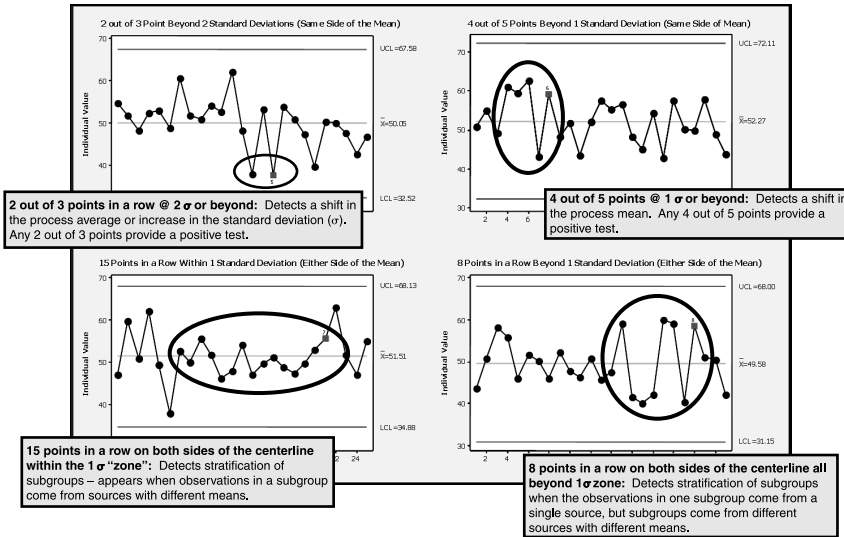


FIGURE C-18: Interpreting Control Chart Patterns for Only Variable Data

How to Use the Tool or Technique

When creating control charts, they can be drawn by hand on graph paper using special control limit factors unique to what is being plotted—or created using statistical software. For illustration purposes, MINITAB will be used in this section to plot each of the different types of control charts.

Individuals Control Chart

The Individuals control chart is one of the most commonly used tools, and variable data is used to construct it. It can go by several names other than Individuals chart—I-MR, Individuals-Moving Range, X-MR, or chart of individuals. I-MR charts are used in the following scenarios:

- Low volume manufacturing process (such as commercial airplanes)
- Batch-type processes (such as producing a vaccine)
- Infrequently reported transactional processes (such as monthly financials)

Scenarios wherein rational sub-grouping exists, I-MR charts do **not** apply.

I-MR charts assume that the observations are independent from one another. If the data are not normal, they need to be transformed using a constant such as lambda. MINITAB applies the Box-Cox as the default transformation function to the non-normal by simply selecting the utility. It is a good chart to use to gain a quick understanding of the process to help support improvement and control efforts.

The example scenario, illustrating the Individuals control chart, involves a company monitoring its invoice payments. In this case, a random sample of one paid invoice each day was selected and identified the number of days from when the invoice was sent to the customer.

Note

In this example, **smaller is better**; the fewer days between the invoice paid, the better the invoicing company's cash flow.

Given that variable data has been entered into the MINITAB Worksheet, the command to access the Individuals charts from its drop-down menu is *Stat > Control Charts > Variables Charts for Individuals > I-MR...* Figure C-19 displays sample MINITAB screens where the appropriate variable data set is selected (Area 1) and x-axis labels are identified (Area 2) to produce the final Individuals control chart in Figure C-20.

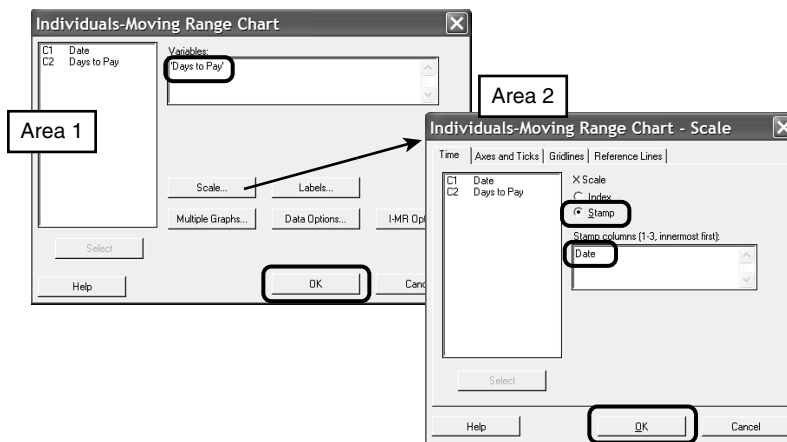


FIGURE C-19: Example MINITAB I-MR Main Screen

Notice that the top graph plots the *individual* data points, in this case the days it took for an invoice to be paid over time. The mean (denoted as \bar{x}) is 31.8 days, and the UCL (upper control limit) is 64.15 days, and the LCL (lower control limit) is -0.55 days. There is one data point out of control, as indicated by the point above the UCL with "1" footnote beside it. The special cause guideline that a MINITAB reference is "**1 Point Beyond Control Limit (3σ): Detects a shift in the mean, an increase in the standard deviation (σ), or a single aberration in the process. Check your R-chart to rule out increases in variation.**" Figure C-21 provides this example's MINITAB session window.

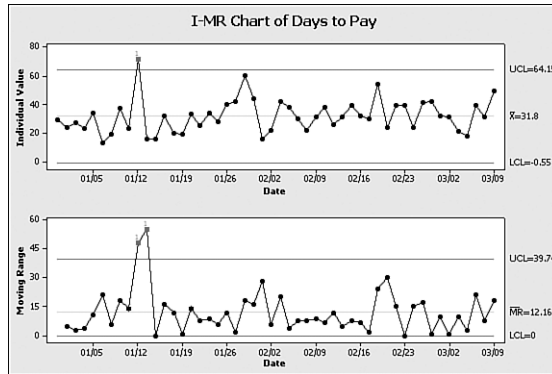


FIGURE C-20: Example MINITAB I-MR Control Chart

It is best to determine whether a process is in or out of control by checking the *moving range* chart because it is the average moving range (MR-bar) that defines the width of the control limits for both graphs. The bottom graph displays the “*moving range*” (MR), which is the difference between two consecutive individual data points, hence the MR graph has one less data point than the Individuals chart. The average moving range (denoted as MR-bar) is 12.16 days, and the UCL is at 39.74 days, and the LCL is at 0 days. There are two data points out of control (calculated by the absolute difference between the one out of control individual data point and those points collected on either side of it). They are indicated by the two points above the UCL with “1” footnote beside them—the same rule referenced in the top chart. Figure C-21 provides this example’s MINITAB session window.

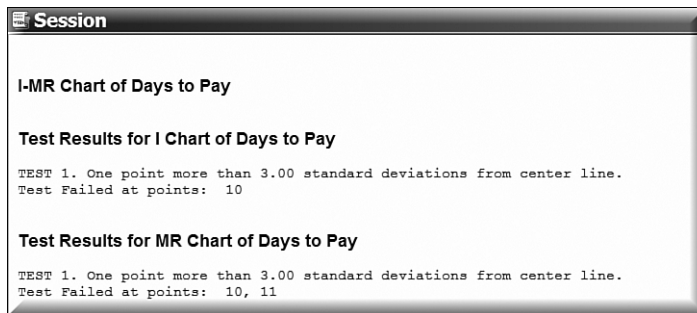


FIGURE C-21: Example MINITAB I-MR Session Window

Recalculated Control Limits

Control limits may be recalculated if and only if the process was intentionally modified; otherwise, the control limits should hold constant. If that is the case, the data collection sheet used to monitor the process should indicate when the special cause event occurred—the data of the changed process.

If this example scenario were unacceptable and an improvement to enhance cash flow were implemented, the control chart should indicate a “special cause” event because the process was changed. In this example, let’s say that the process improvement was a prominent “reminder” notice of the 45-day policy on the subsequent invoices after the March timeframe.

Follow the same procedure just detailed, using the following MINITAB drop-down menu sequence: *Stat > Control Charts > Variables Charts for Individuals > I-MR...* . Next, select the I-MR Options button and click the Stages tab, as shown in Area 3 of Figure C-22. The resulting Individuals control chart with the recalculated control limits is illustrated in Figure C-23.

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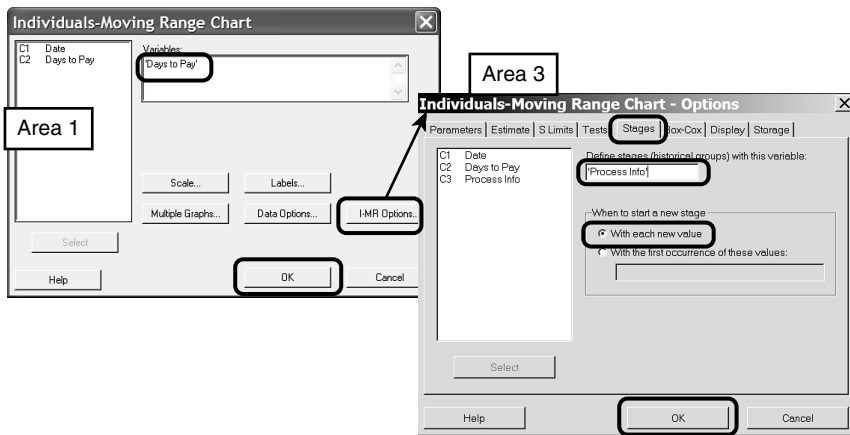


FIGURE C-22: Example MINITAB I-MR Main Screen and Stages Tab

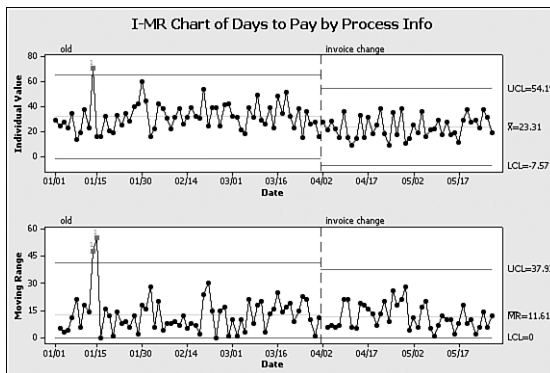


FIGURE C-23: Example MINITAB I-MR Control Chart with Recalculated Control Limits

Did the process improve, knowing that smaller is better? Notice that both the top and bottom graphs have a vertical dashed line to indicate where the process change occurred. Both of their means and the control

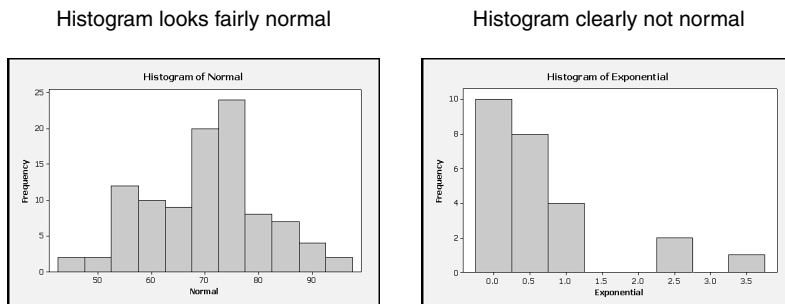
limits became smaller. In the top graph, the mean fell to 23.31 days (from 31.8), the UCL decreased to 54.19 days (from 64.15), and the LCL at -7.57 days (from -0.55). In the new period to the right of the dashed line, no points are identified as out of control. Similarly, in the bottom graph, the average moving range (MR-bar) fell to 11.61 days (from 12.16), the UCL at 37.93 days (from 39.74), and the LCL constant at 0 days—again with no points out of control. In conclusion, the improvements successfully reduced cash flow on average by 8.49 days.

Normal Versus Non-normal Data—Normal Probability Plots

Individuals control charts assume that the data are distributed normally; otherwise, it must be transformed. There are several ways to check if the data distribution is normal:

1. Visually, by examining a frequency plot such as a histogram, Dot-plot, or Boxplot. Figure C-24 illustrates a normally and non-normally distributed histogram. A definitive conclusion using only visual graphs is difficult. (See Also “Graphical Methods,” p. 323)

Visual check of Normal versus Non-normal



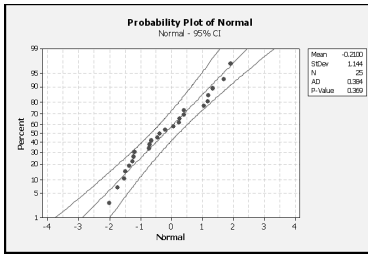
MINITAB® command: *Graph>Histogram>Simple...*

FIGURE C-24: Histograms of Normal and Non-normal Data

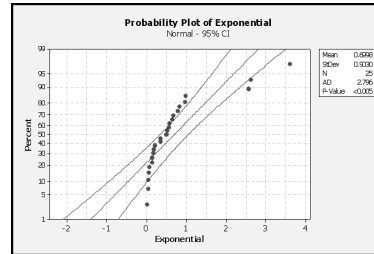
2. Statistically, by running a normal probability plot. If data are normal then a normal probability plot will show a linear relationship.

Using MINITAB to create a normal probability plot, simply select the following commands from its drop-down menu: *Graph > Probability Plot > Single...* Select the data to be analyzed and place it in the dialog box. Click OK. The resulting graph may look similar to either half of Figure C-25—showing normal data on the left and non-normal data on the right of the figure.

Normal data: Plot is linear



P-value is > 0.05 and > 95% of the data lies within the confidence bounds **suggesting the data is normal.**

Non-normal data: Plot is not linear

P-value is < 0.05 and < 95% of the data lies within the confidence bounds **suggesting the data is not normal.**

FIGURE C-25: Histograms of Normal and Non-normal Data

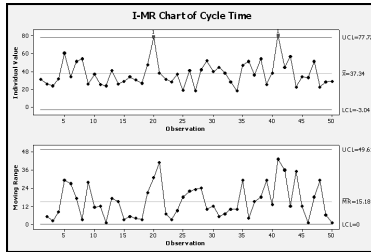
Transformation of Non-normal Data (Plus Normal Probability Plots)

The control limits on an Individuals charts are based on a normal distribution. If the data are not normal, then the control limits are not appropriate for assessing special cause variation. A transformation of the data usually will correct non-normality (symmetry) issues. Control limits can then be used to assess special cause variation patterns in the transformed data.

Hence, non-normal data must be transformed **before** constructing an Individuals control chart. A generic transformation method, called the *Box-Cox* (power) transformation, changes the shape of the exponential data to look normal. The form of the transformation is $Y_T = Y^\lambda$, wherein the constant of lambda (λ) is used. MINITAB applies the Box-Cox, as the default transformation function, to find the optimal value of lambda (λ) that minimizes the variability in the data.

The MINITAB applies Box-Cox method from several areas within the application software. It can be accessed directly through the main menu drop-down: *Stat > Control Charts > Box-Cox Transformation...* Another way to access the Box-Cox method is within the control chart area of the software with the following the drop-down procedure: *Stat > Control Charts > Variables Charts for Individuals > I-MR....* Next, select the I-MR Options... button and click the Box-Cox tab, (the tab just to the right of the Stages tab shown in Area 3 of Figure C-22). Two sample Individuals control charts, pre- and post-Box-Cox transformation, can be found in Figure C-26. Notice how the non-normal, non-transformed chart on the right shows the data “squished” toward the top of the graph—the data is skewed left. After the transformation, the data looks more randomly and evenly distributed (without a pattern) about the mean.

**Non-normal data *before*
Box-Cox transformation**



**Non-normal data *after*
Box-Cox transformation**

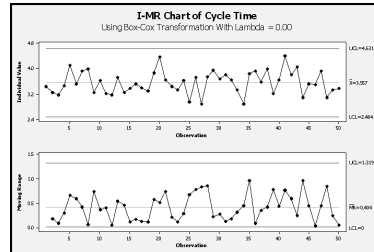


FIGURE C-26: Comparison of Non-normal Data not Transformed and Transformed Using Box-Cox

X-bar and R Chart

Variable data create the *X*-bar and R charts to comprised of a paired set of *averages and range* control charts. Typically these charts are used for high-volume processes, wherein sampling occurs on a regular time-based interval. The averages data is derived from a subgroup sampling scheme, such as a sample of two to five items taken at regular intervals, and the average of that subgroup represents a control chart data point. The criteria for sampling frequency focuses on ensuring the sample consists of homogeneous items (low variability) within the sample and allows for greater variability from sample to sample.

Note

The *Central Limit Theorem* purports that “averages” vary less than individual data points and tend to be normally distributed as the sample size increases. A distribution of the averages of sampling subgroups exhibits a tighter spread around the mean (standard deviation) than a distribution plot of the individual data points. Hence, testing for normally distributed data is unnecessary for this type of control chart.

The *X*-bar and R chart works for both normal and non-normally distributed data, wherein the process contains little to no changes and produces the data frequently. Manufacturing is a common process for *X*-bar and R charts since a sample of a few items can represent several hundred pieces.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: **Stat > Control Charts > Variables Charts for Subgroups > Xbar-R...** Figure C-27 displays a sample MINITAB screen where the appropriate variable data set is selected (Area 1) to produce the final *X*-bar and R control chart in Figure C-28.

The conclusions from studying Figure C-28 might entail the fact that the process appears stable and random—no apparent special causes. Hence, a capability analysis could be conducted next to compare the process with the customer specifications.

X-bar and S Chart

The X-bar and S chart is similar to the X-bar and R charts except that the sample data's standard deviation is plotted, instead of its range, to assess the sample to sample variability. These charts frequently are used when subgroup size is larger than the X-bar and R scenarios (that is, the sample size (n) is greater than five (> 5)). When the sample size is ten or more, the range is no longer an efficient statistic for measuring variability; hence, the less sensitive standard deviation calculation is used.

The X-bar and S chart work for both normally and non-normally distributed variable data. It is commonly used to quickly detect very small process changes. Healthcare scenarios often call for utilization of X-bar and S charts.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: *Stat > Control Charts > Variables Charts for Subgroups > Xbar-S...* Figure C-29 displays a sample MINITAB screen where the appropriate variable data set is selected (Area 1) to produce the final X-bar and S control chart in Figure C-30.

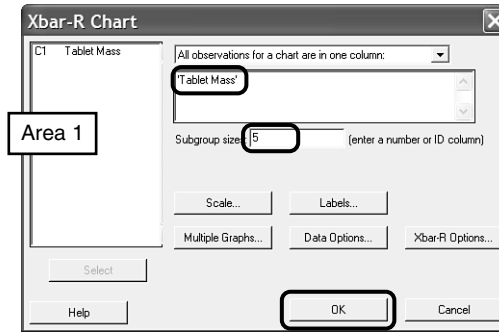


FIGURE C-27: Example MINITAB X-bar and R Main Screen

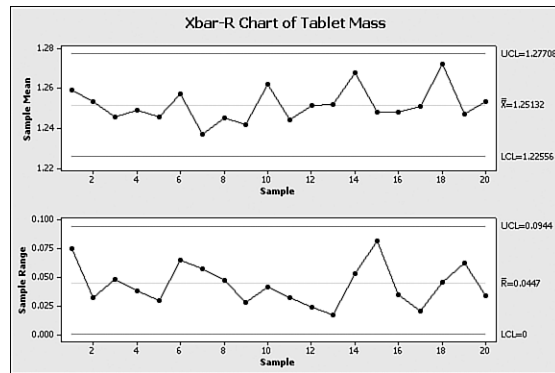


FIGURE C-28: Example MINITAB X-bar and R Control Chart

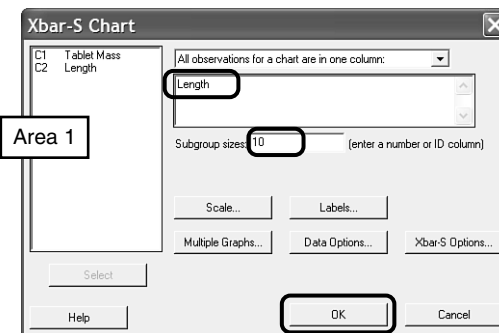


FIGURE C-29: Example MINITAB X-bar and S Chart Main Screen

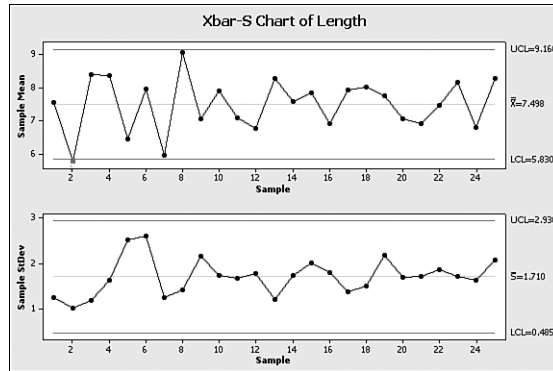


FIGURE C-30: Example MINITAB X-bar and S Control Chart

Figure C-30 displays a general, fairly random pattern. The sample sets two and eight in the top charts may require some investigation to verify the lack of any special cause event.

Attribute Control Charts

Attribute data contains less information and less granularity than variable data. Attribute data defines if a product is working or not working, but it fails to describe the magnitude of the failure. Attribute data may describe that the battery life failed, but it lacks the discriminating information as to how far from target. Moreover, attribute data represents “after-the-fact” information, causing the process players to be reactive. If an item fails to meet specifications, it needs to be scrapped or reworked. When possible, move upstream in the process to try to identify leading indicators (variable data) that enable proactive work to prevent failed products **before** they occur.

Only four of the eight guidelines to determine special cause variation are applicable for attribute control charts. Figure C-17 displays the appropriate four tests for attribute data. Attribute control charts only feature one graph and do not require normal data. Hence, MINITAB’s attribute control chart screens lack the final four special cause tests and the Box-Cox transformation option.

There are two types of control charts developed from attribute data. Data depicting the number or percentage of completely “bad” (or good) units—known as *defective* or *non-conforming units*—make up the first category to construct either the p or np charts. A defective is a unit that fails to satisfy requirements due to one or more defects. Hence, the entire product is classified as “good” or “bad,” and “rejected” or “un-ship-pable” describes a bad unit. These type of charts are based on a *binomial distribution*—a two-state scenario with constant probability of either state occurring.

The second type of attribute control chart is defined by collected data about flaws or defects when the unit (as a whole) is still “acceptable.” The c-chart and u-chart make up this category of defect attribute control charts. A *defect* is a single non-conforming quality characteristic. Hence, the data may represent a folded page of a book coming off the printing production line, but the entire book is classified as “shippable.” These type of charts are based on a *Poisson distribution*—describing the area of opportunity (time or space, for example). The Poisson distribution represents fairly large total populations (measured as discrete data) that are difficult or impossible to count and models random occurrences over time, distance, area, and volume.

Figure C-31 summarizes the scenario that requires which attribute chart.

p-Chart

The p-chart uses binary attribute data to monitor defective units. It is the most sensitive attribute control chart. The data may contain pass/fail of a test or errors detected or not detected. The p-chart plots the *proportion* (p) of data for either aspect (passed or failed) of criteria; hence the chart is based on the binomial distribution. A p-chart can accommodate unequal group sizes of non-conforming or defective items. Often the data is collected as a percentage or fraction of the total lot and may contain multiple types of non-conformity. The data collection sheet needs to identify the different types of non-conformity to better determine the cause(s) of variation.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: *Stat > Control Charts > Attribute Charts > P...* Figure C-32 displays sample MINITAB screen where the appropriate attribute data set is selected (Area 1) to produce the final p-chart in Figure C-33.



	Fixed Sample Size	Varying Sample Size	Supported Distribution
 Defects	c	u	Poisson
 Defective	np	p	Binomial

FIGURE C-31: Summary of Attribute Control Charts

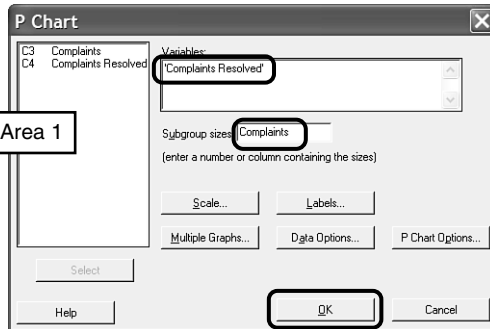


FIGURE C-32: Example MINITAB p-Chart Main Screen

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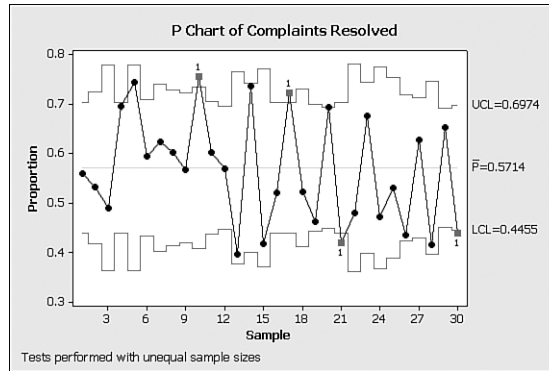


FIGURE C-33: Example MINITAB p-Chart

Figure C-33 illustrates the classic “city skyline” of the unequal sample size proportional display of a p-chart. Notice the vertical axis is labeled “proportion” because the chart uses percentage data to accommodate the unequal sample sizes. The changing limits is also a function of the changing sample size. Statistically there is more confidence with more data, thus tighter control limits. For smaller sample sizes, the confidence decreases; therefore, the control limits loosen (or get larger). Figure C-33 contains four flagged data points that require further investigation.

P Prime

The P Prime SPC chart is a variant that basically combines the Individual-Moving Range (I-MR) chart and a p-chart. This chart is used when the p-chart produces wrong control limits (that is, compresses) because it is not adequately showing the *within-sample variation*, typically resulting from a very large sample size with very few defects. This chart corrects the p-chart by using the moving range to adjust the control limits with an estimate of the within-sample variation. Dr. David Laney (of Stamford University) created this tool and has written much on the topic.

np-Chart

The np-chart uses binary attribute data to monitor defective units. The np-chart uses the same data structure as a p-chart (hence the binomial distribution applies); however, it plots the number of event occurrences rather than proportions. The equation can be written as

$$\# \text{ occurrences} = (\text{subgroup size}) \times (\text{proportion}) \text{ or } np = n \times p$$

Different from the p-chart, the np-chart’s subgroup size must remain constant.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: *Stat > Control Charts > Attribute Charts > NP...* Figure C-34 displays sample MINITAB screen where the appropriate attribute data set is selected (Area 1) to produce the final np control chart in Figure C-35.

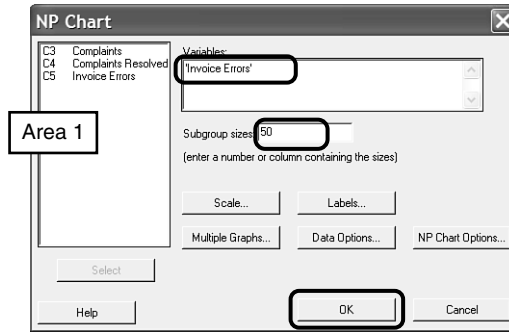


FIGURE C-34: Example MINITAB np-Chart Main Screen

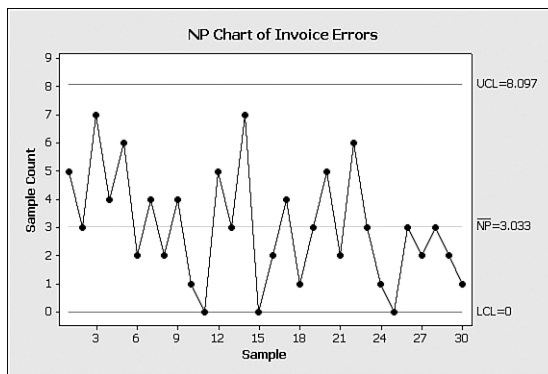


FIGURE C-35: Example MINITAB np-Chart

Figure C-35 illustrates the sample np-chart. Notice that the vertical scale on the graph is *count* versus the p-chart's proportion. The attribute data charted in Figure C-35 is Invoice Errors; therefore, smaller is better, and the graph indicates an improvement over time. A question arises as to whether this improvement is by random chance alone. It should be investigated, and if changes have been made, they should be standardized in order to maintain this downward trend.

c-Chart

The c-chart monitors the count (c) of defects in a process when an individual item may have multiple defects. The Poisson distribution is the basis for the construction of the chart, assuming an equal number of opportunities for defects must be reasonable; hence, the subgroup size must remain constant.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: *Stat > Control Charts > Attribute Charts > C...* Figure C-36 displays a sample MINITAB screen where the appropriate attribute data set is selected (Area 1) to produce the final c control chart in Figure C-37.

Figure C-37 illustrates the sample c-chart. Notice that the vertical scale on the graph is counted similar to the np-chart. There is one point out of control in this example, where bad solder joints is plotted. In this case, smaller is better, so the upward trend also may cause concern worth investigating. In addition, the upward trend includes seven points above the mean count, which is approaching the rule of “9 data points above (or below) the centerline” and may indicate a shift change.

u Chart

The u-chart uses the same data structure as a c-chart except that the number of defects per unit (u) is plotted instead of the counts of defects. Again, the Poisson distribution is the basis for the construction of this chart, so it assumes an equal number of opportunities for defects must be reasonable. The u-chart, considering it monitors the number of defects per unit, can accommodate unequal subgroup sizes.

Given that variable data has been entered into the MINITAB Worksheet, the drop-down menu sequence of commands is: *Stat > Control Charts > Attribute Charts > U...* Figure C-38 displays sample MINITAB screen where the appropriate attribute data set is selected (Area 1) to produce the final u control chart in Figure C-39.

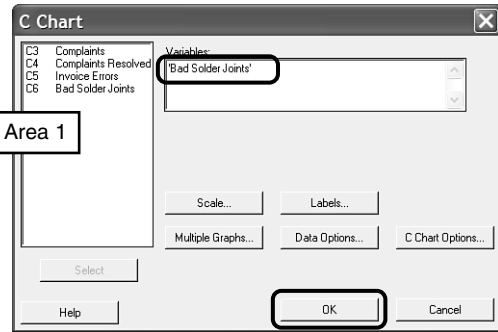


Figure C-36 Example MINITAB c-Chart Main Screen

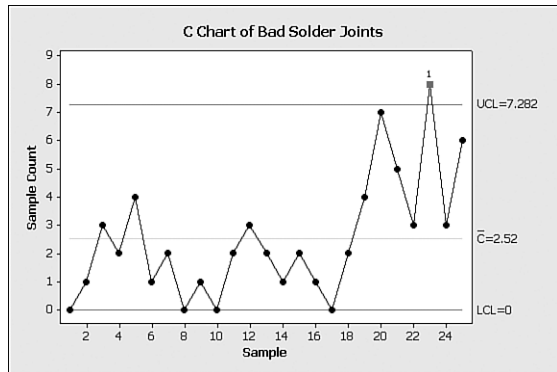


Figure C-37 Example MINITAB c-Chart

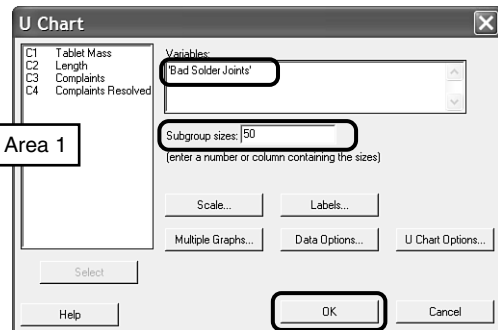


Figure C-38: Example MINITAB u-Chart Main Screen

Figure C-39 shows the sample u-chart whose vertical scale is “count per unit,” as a percent (or proportion) to the given sample size of 50 (as indicated in Figure C-38). As with the c-chart, this example indicates one point out of control, where bad solder joints is plotted. The scenario calls for a “smaller is better,” so the upward trend also may cause concern worth investigating. In addition, the upward trend includes seven points above the mean count, which is approaching the rule of “9 data points above (or below) the centerline” and may indicate a shift change.

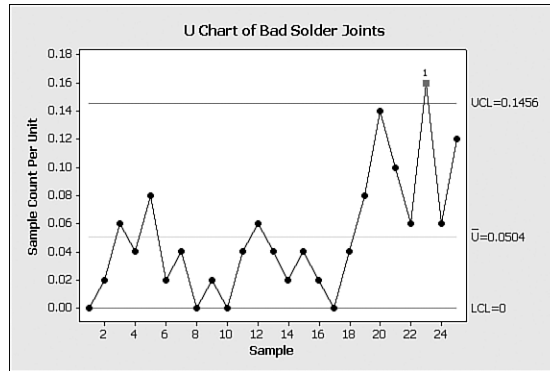


FIGURE C-39: Example MINITAB u-Chart

Hints and Tips

The process control limits are the only limits that belong on a control chart; **not** customer specification limits. Control charts should be constructed real time as data is produced in the process, not from inspection records. *Control* means the process is consistent, not necessarily that the results are meeting requirements. *Statistical control* means there are no special causes affecting a process—as indicated by randomly dispersed points within the control limits around the average line. Points within control limits that indicate a trend, shift, or instability are special causes requiring investigation. Points outside the control limits should be removed from control limit calculations (but still plotted) once cause is identified. Change control limits **only** when the process is changed for the data collected after the process change.

- **Sampling method and plan**

- To establish inherent variation and allow process to run without sampling.

- **Determine sample size**

- **Attribute at least 50.** (c and u-charts, samples to average 5+ defects)
- Variable at least three to five

- Ensure random samples
- Consistent conditions (same machine, operator, lot, and so on) when sampling
- Collect 20 to 25 different sample groups before calculating control limits.
- Patterns determine sampling frequency. If process is in “control,” frequency can be reduced.

Supporting or Linked Tools

Supporting tools that might provide input when developing a control chart include

- Data collection sheets (**See Also** “Data Collection Matrix,” p. 248)
- Graphical tools—particularly frequency plots such as a histogram, Dotplot, or Boxplot (**See Also** “Graphical Methods,” p. 323)
- Normal probability plot (Figure C-25)

A completed control chart provides input to tools such as

- Fishbone diagram (**See Also** “Cause-and-Effect Diagram—7QC Tool,” p. 173)
- Root cause analysis techniques (**See Also** “Hypothesis Testing” and “Regression Analysis” p. 335 and 571, respectively.)
- FMEA (**See Also** “Failure Modes and Effects Analysis (FMEA),” p. 287)
- Brainstorming technique (**See Also** “Brainstorming Technique,” p. 168)
- Concept generation methods
- Control plans (**See Also** “Matrix Diagrams—7M Tool,” p. 399)
- Risk mitigation plan (**See Also** “Risk Mitigation Plan,” p. 601)
- Transition plan (**See Also** “Matrix Diagrams—7M Tool,” p. 399)
- Implementation plan (**See Also** “Matrix Diagrams—7M Tool,” p. 399)
- Communication plan (**See Also** “Matrix Diagrams—7M Tool,” p. 399)
- Standard operating procedure (SOP)

Figure C-40 illustrates the link between a control chart and its related tools and techniques.

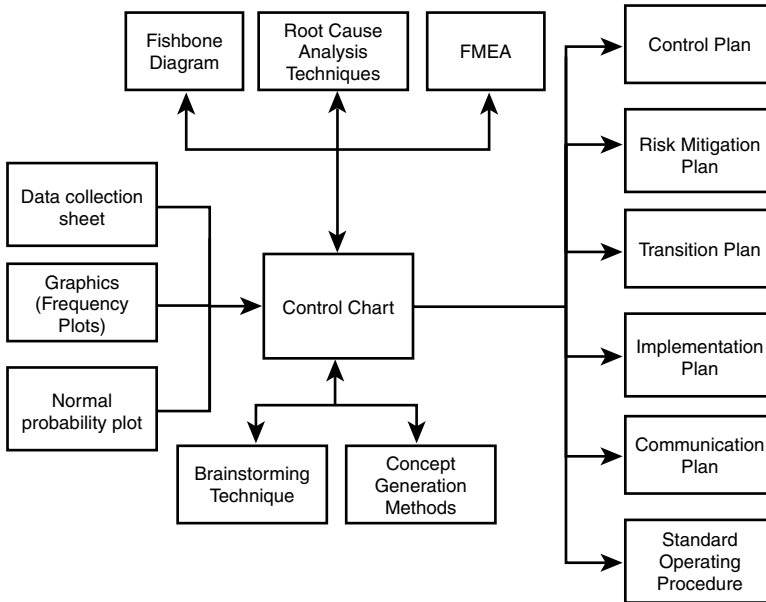


FIGURE C-40: Control Chart Tool Linkage

Cost/Benefit Analysis

What Question(s) Does the Tool or Technique Answer?

What is the payback time period for an investment?

A cost/benefit analysis helps you to

- Understand if and when net cash benefits are equal to or begin to out-weigh the net costs or outflows.
- Evaluate if the project is worthwhile and whether or not to proceed with an investment.

Alternative Names and Variations

This tool is also known as

- Benefit cost analysis

Variations on the tool include

- Internal Rate of Return (IRR)
- Return on Investment (ROI)

- Return on Assets (ROA)
- Net Present Value (NPV)

When Best to Use the Tool or Technique

Conducting a cost/benefit analysis is an important management tool to determine whether to proceed with a project and/or an improvement investment. This technique should be utilized at the onset of a project, during its planning stage, and re-evaluated throughout the project lifecycle (including the project close) to monitor the project's financial performance and healthiness and validate assumptions.

Brief Description

The cost/benefit analysis serves two key purposes: 1) determining financial healthiness of a decision and 2) helping to monitor risk of success and sustainability. The technique compares the cost or expenses associated with a process or project and contrasts it with its respective benefit to the organization. The cost/benefit analysis provides input to go/no go decisions and risk mitigation planning. If the benefits outweigh the costs, it generally leads to a "go forward" decision.

Conducting a cost/benefit analysis requires input from those familiar with the process, often supported by a finance expert if not an active member of the project team. The data may include hard and/or soft costs, which should be categorized based on accounting principles employed by the organization. *Hard costs* and savings easily are associated with money and are evident on the bottom-line of a profit and loss (P&L) statement. *Soft costs* or savings imply financial benefit and can be quantifiable in monetary terms but have a more nebulous impact on the bottom-line P&L. Soft benefits include time freed-up to do other activities and improved satisfaction and morale. However, depending on the root cause of a problem, some improvements such as improved organization or tidying-up may be a soft or hard benefit, given that those improvements are part of the Lean 5S strategy and may have direct positive safety or waste reduction impacts that are traceable to the bottom-line. (**See Also**, "5S," in Part I "Lean and Lean Six Sigma," p. 29) Thus, categorizing the hard and soft money should be done in conjunction with the organization's financial expert(s).

How to Use the Tool or Technique

Conducting a cost/benefit analysis generally consists of the following steps:

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Step 1. Gather and categorize the financial and non-financial impact of the project or potential investment as to the potential costs and savings.

- a. Document assumptions about the project/investment. They may include current problem, its metrics, the period of time involved, the root causes, any boundary conditions, the proposed improvements/investments, and expected impact (both positive and negative, financial and non-financial).
- b. Gather required cost factors: materials, labor, other resources and the cost of capital (interest rate or financing charge) if an investment is under consideration and identify when they will be incurred, as a one-time event or ongoing.
- c. Identify the benefits as monetary, time, or other and identify when they will be realized, as a one-time event or ongoing.

Step 2. Using the cost and savings factors, develop a calendar that schedules the net project gain (or loss) and calculate appropriate financial ratio(s).

Step 3. Decide whether to proceed with or kill the project/investment or make appropriate modifications to the assumptions and recalculate the financial ratios.

The various financial ratios used in a cost/benefit analysis include the following calculations. Consult with the organization's financial expert to assist in the selection of the appropriate ratio.

Return on Assets (ROA)

ROA = Net Income divided by Total Assets, where net income equals the expected revenue or earnings.

Return on Investment (ROI)

ROI = Net Income divided by Total Investment, where net income equals the expected revenue or earnings.

Net Present Value (NPV)

NPV = Sum of the ratios of cash flow in a time period divided by one plus the cost of capital for that same time period. The NPV formula is

$$NPV = \sum_{t=0}^n \left(\frac{CF_t}{(1+r)^t} \right)$$

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Where “n” is the number of time periods, “t” is the specific time period, “r” is the cost of capital (interest rate) for the given time period, and “CF” represents the cash flow in that time period.

Internal Rate of Return (IRR)

The IRR is used to evaluate a portfolio of projects. The IRR of one project (or opportunity) is compared with other projects. The go/no go decision for a project is based on the relative IRR ratios among a portfolio of opportune projects; wherein the larger IRR is preferred.

The IRR calculation defines the cost of capital (“r”) at the point when the NPV equals zero. The exact calculation is an iterative process to determine the exact IRR. The IRR formula is

$$IRR = NPV @ 0 = \sum_{t=0}^n \left(\frac{CF_t}{(1+r)^t} \right)$$

Where “n” is the number of time periods, “t” is the specific time period, “r” is the cost of capital (interest rate) for the given time period, and “CF” represents the cash flow in that time period.

Payback Period

This is a simple, thus commonly used cost/benefit calculation. It defines the fulcrum point at which the cash flow becomes positive, when the net cash benefits (inflows or revenues) outweigh the net costs (outflows).

The calculation for the breakeven point usually ignores the time value of money and simply determines the cumulative net cash flow over time:

$$\text{Payback} = \text{Investment divided by Cash Inflow}$$

Where the investment is both any initial one-time payment and any incremental ongoing outlays of cash. The cash inflow is any resulting savings or revenues on a one-time and ongoing basis.

Supporting or Linked Tools

Supporting tools that might provide input when developing a cost/benefit analysis include

- Data collection sheet (See Also “Data Collection Matrix,” p. 248)

A completed cost/benefit analysis provides input to tools such as

- Project charter (See Also “SMART Problem and Goal Statements for a Project Charter” for more on project charter, p. 665)
- Phase-gate reviews
- FMEA and risk mitigation planning (See Also “Failure Modes and Effects Analysis (FMEA),” p. 287)
- Control plan (See Also “Matrix Diagrams—7M Tool,” p. 399)

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Figure C-41 illustrates the link between a cost/benefit analysis and its related tools and techniques.

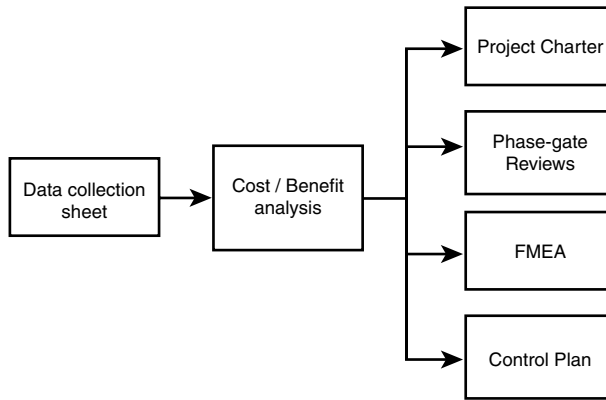


FIGURE C-41: Cost/Benefit Analysis Tool Linkage

Critical Path Method (CPM)

See Also “Activity Network Diagram (AND)—7M Tool,” p. 127

Critical-to-Quality (CTQ)

What Question(s) Does the Tool or Technique Answer?

How does my work relate to the customer requirements, and how do I know when I have fulfilled them?

CTQ helps you to

- Understand customer general requirements in more specific terms.
- Translate customer requirements into specific, actionable, measurable language for those who work in the process (process worker, for example).

When Best to Use the Tool or Technique

The Critical-to-Quality (CTQ) elements of a customer requirement should be defined as early in the project as possible, immediately following the Voice of the Customer (VOC) gathering activities.

Once customer input has been gathered and categorized, the requirements should be translated into specific, measurable terminology, referred to as a CTQ. CTQ can be used to evaluate how well the current process works or how well the current deliverables meet customer requirements. CTQ also can be used to select improvement options, such as process improvements or new features/functionality.

Brief Description

CTQ is a simple, yet powerful tool that *translates* customer needs into a *meaningful, measurable, and actionable* metric for the person or persons doing the work needed to deliver the requirement.

Customers typically describe their requirements using vague words or generalities. In addition, customers' descriptions may or may not mirror one another's value system or criteria given a strong likelihood of different perspectives. In the example of prepared food, the requirement of food to "taste good" may not be perceived the same from person to person. If the company making prepared food wants to meet customer requirements, it needs to understand the characteristic of "tastes good" and its qualities. To do so, the company needs to drill down and dissect its meaning and interpret the quality of "tastes good" until it arrives at meaningful and actionable terms for the process of cooking, packaging, and delivering the food to the marketplace. To eliminate ambiguity, CTQs translate customer needs into internally meaningful, specific, and measurable terms .

Understanding and interpreting a customer's requirements is important because they define or help identify the important elements to satisfy their own needs—that which is critical to providing or delivering the quality they expect. CTQs serve as a bridge between the internal process and its deliverables and customer satisfaction. Therefore, an accurate translation is critical to understanding the customer's perspective. A fully developed CTQ has four elements: 1) output characteristics, 2) output metric (or "Y"), 3) target value, and 4) specification/tolerance limit. The inclusion of these four elements eliminates ambiguity around the interpretation of the customer needs to help the business achieve customer satisfaction.

In a Six Sigma project, essentially there may be two types of CTQs. The first and most prevalent type addresses the process and its outputs that the project aims to improve. The second type of CTQ describes what must be done to meet the requirements of the project itself. This is a one-time set of CTQs needed to accomplish the specific project deliverables and may or may not exist. Ultimately, a CTQ translates a VOC requirement into a metric that is actionable by either a process player or project team member.

How to Use the Tool or Technique

Developing a Critical-to-Quality metric is fairly simple. The key is to arrive at a measure that is meaningful and actionable. Follow the subsequent procedural guidelines:

Step 1. Identify the customers and their requirements.

Gather the customer needs as verbatim input (using their language). If a large number of requirements exist, often it helps to organize the VOC input into an Affinity diagram. (See Also “Affinity Diagram—7M Tool,” p. 136)

Step 2. Translate the customer need into a CTQ.

- Addressing one customer need or category at a time, begin to parse it down into more specific meaningful descriptions, translating what is critical to the customer ultimately into an actionable metric for either a process player or project team member.
- Continue to break down and translate the VOC need until a **meaningful** and **actionable** measure exists for each of the process players involved in delivering that requirement. Stop when the last level of detail is measurable.
- Repeat this step until a CTQ is aligned with each VOC requirement or category.
 - A given CTQ can be aligned with multiple VOC requirements.
 - A given VOC need can elicit multiple CTQs to address multiple dimensions or multiple process player roles.

Step 3. Organize and document the drill-down work into a matrix or a Tree diagram, linking the CTQ to the original VOC requirement.

Step 4. Validate the CTQs with the customer to ensure proper understanding and translation of the original requirement.

Examples

CTQ Tree

Figure C-42 illustrates a CTQ tree for a restaurant patrons’ food requirements. Notice that one customer requirement, “Good Food,” generated two CTQs: “order taken correctly” and “cooked correctly.” Each of those CTQs link to a different process player. The order taking CTQ links to the wait staff, whereas the cooking properly CTQ links to the chef (or kitchen staff).

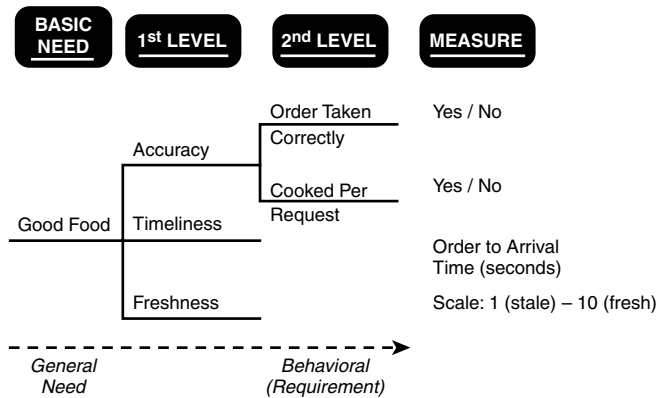


FIGURE C-42: Sample CTQ Tree

CTQ Matrix

Figure C-43 illustrates another example of a restaurant patron’s food requirements displayed as a CTQ matrix.

VOC	Issue Translation	Key Item	CTQ	Measure
I like my food hot.	Cooking	Temperature	Temperature when fully cooked	Fahrenheit
	Delivery	Quick Service	Transfer Time from kitchen to table	seconds

FIGURE C-43: Sample CTQ Matrix

Hints and Tips

Start with customer needs. Use nouns without adjectives; adjectives can introduce ambiguity, allowing for multiple interpretations or perspectives (that is, how hot is hot; what is good; how blue is blue). Using a CTQ tree approach, the branches to the right show increasing detail of that requirement, **not** a new requirement. The number of levels (in a matrix) or branches (in a tree) needed to define a CTQ depends on how specific the requirement is to the required work. For example, if the requirement is an internal customer requirement from an area manager, more than likely, the resulting CTQ would require

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less granular parsing to arrive at something meaningful, measurable, and actionable, than compared with a requirement from the external customer. A given CTQ can be aligned with multiple VOC requirements. A given VOC requirement may elicit multiple CTQs to achieve and address multiple dimensions or multiple process player roles, as illustrated in Figure C-42. CTQs centered around the process or product and/or services offering ultimately should be aligned to a process player's role and reflected in commensurate performance documents such as personnel job appraisal and standard operating procedure (SOP).

Process-specific CTQs: A CTQ developed for a process or product becomes part of standard work wherein the generic project requirements translate into something meaningful, measurable, and actionable for the process player and can become part of his/her job performance metrics. Process CTQs are relevant until customer requirements or the process is changed. An improvement project may aim to define, clarify, or refine the process CTQs as part of its improvement deliverables and incorporate them as part of the transition and control plan.

Project-specific CTQs: A CTQ can be developed for a project (for example, an improvement project), wherein it is achieved by completion of the project, thereby satisfying a customer requirement. Hence, the generic project requirements translate into something meaningful, measurable, and actionable for the project team member. Upon project completion, that CTQ is no longer relevant.

While on a project, if both process and project-specific CTQs exist, keep them separated to avoid confusion.

Supporting or Linked Tools

Supporting tools that might provide input when developing a CTQ include

- VOC and VOB data (See Also "Voice of the Customer Gathering Techniques," p. 737)
- Current Process map (See Also "Process Map (or Flowchart)—7QC Tool," p. 522)

A completed CTQ matrix or tree provides input to tools such as

- QFD (See Also “Quality Function Deployment (QFD),” p. 543)
- Root cause analysis techniques
- Concept generation methods
- FMEA (See Also “Failure Modes and Effects Analysis (FMEA),” p. 287)
- Standard operating procedure (SOP)

Figure C-44 illustrates the link between a CTQ and its related tools and techniques.

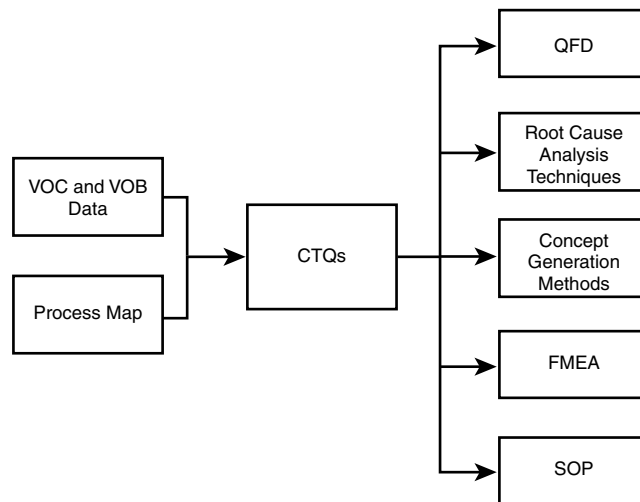


FIGURE C-44: CTQ Tool Linkage