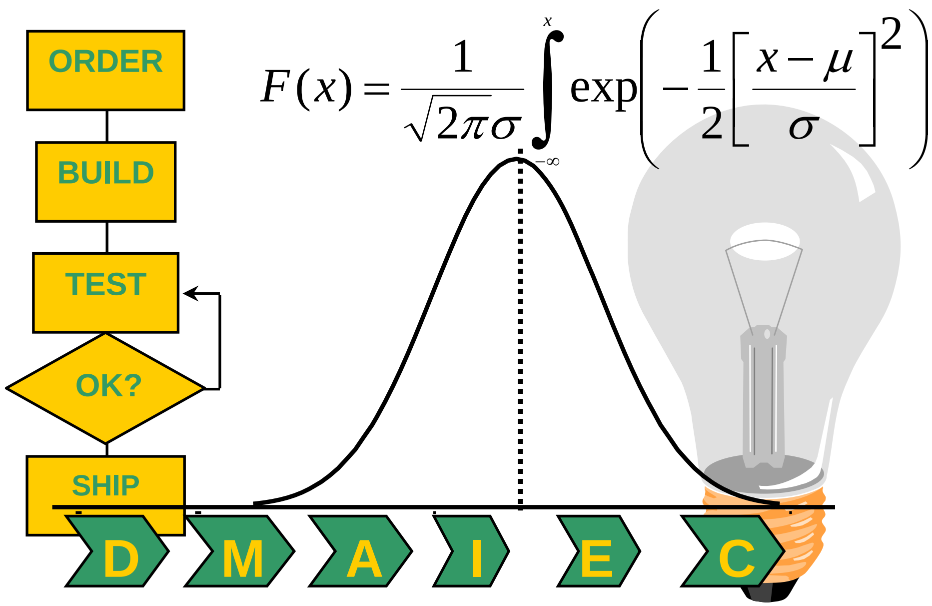
The Green Belt Six Sigma Toolkit



SIGMA QUALITY MANAGEMENT

The Green Belt Toolkit - Table of Contents

INTRODUCTION TO THE *GREEN BELT TOOLKIT*

Welcome to the world of Six Sigma and the cadre of "Belts!" We'll assume you are reading this manual because you've been selected or "volunteered" to become a Green Belt for your company. We're not going to try and tell you what a Green Belt is – hopefully, your company has a well-defined roles and accountability description (*if not, start yelling right now!*).

Let's focus on the basic premise of this manual: *In today's business world, the only sustainable strategy for growth and success is the continual improvement of products and services and their associated "production*[1] *processes."* In a nutshell, that's what Six Sigma is *really* all about (if your company is using Six Sigma *just* for cost-cutting, you can be sure the program will be short-lived).

In Frederick Taylor's day, improvement was the sole province of management. Workers and their suggestions didn't really count. Today, we have to engage everybody in improvement. All minds are important. Everybody from the company CEO to entry-level employees must be active in moving the organization forward (*yeah, that includes YOU!*).

One of our friends, Bill Conway, used to tell the "nuclear" people at Florida Power & Light,

"*As a Vice-President, it would take me at least two or three years to foul up this plant, one of you maintenance folks could do it in a heartbeat, with one wrong turn of a wrench*!"

Now, we've seen many companies that are good at *changing,* but *change does not necessarily equal improvement* (i.e. most re-organizations don't count!). To improve our odds in this game, we need to understand the variables that affect performance, implement changes that address these variables and check the effects of our changes - in short, we need to practice the *scientific method* when attempting improvement.

But this doesn't mean that we have to learn very complicated methods. Fortunately, many, many "opportunities" faced by organizations can be solved with a few basic improvement tools and methods. That's where you, the Green Belt, will play an important role.

Almost 20 years ago, Japanese counselors working with Florida Power & Light told us that over 90% of a company's problems can be solved with just 7 basic tools (*Graphs, Check-sheets, Pareto Analysis, Cause & Effect, Histogram, Control Charts* and *Scatter Diagrams*). Well, we believed them (sort of!), but it took us a while to understand how right they were.

So, *practically,* how do we go about improving our products, services & "production" processes? There are a few basic elements:

First, we need a method to guide us. Section 1 presents several methods of process improvement, with a focus on the DMAIEC approach. Although we're mindful of Dr. Deming's warning that "*All models are wrong, some are useful*," this is a general-purpose approach, one that has gained fairly wide acceptance in the Six Sigma community. The Black Belts in your company are likely using a similar process improvement approach – y'all can then talk the same language.

[1]The term "production" fits whether you produce a product or a service. We're definitely not limiting this discussion to manufacturing. In fact, we like to challenge our service-business clients with the concept of their "production processes!"

Measurement plays a critical role in process-focused improvement - it helps us listen to the “Voice of the Process” and compare that to the “Voice of the Customer.” We will need some tools to help us understand how our products and services are performing and where there are “problems.[2]” Section 2 will cover this topic.

Section 3 describes some ways of picturing the process. Sitting down and creating a flowchart of how some work process occurs can often generate many suggestions for improvement. There are also some specialized process pictures used by different industries that may help you develop a “picture” that best suits your process.

Sections 4 and 5 are the core of this manual. If you walk away from this manual understanding and *practicing* only two tools, please let them be *Pareto* and *Cause & Effect.* Dr. Kaoru Ishikawa, one of our heroes, said that over 80% of problems could be solved with just these two tools. We’d agree.

In Section 6, we focus on selecting and planning and making changes to the process that will hopefully improve performance. There are some minor issues, such as costs and benefits that we may want to consider as we try to “sell” and implement our solutions. We don’t want to be getting rid of mosquitoes with elephant guns!

You’ll find that it takes hard work to change a process. After you’ve improved the process, you don’t want to see your hard work “slip-slidin’ away!” Section 7 talks about how to ensure your changes become a “permanent” part of the way you do business.

While we don’t advocate teams just because they are popular, sometimes you’ll need to bring a group of people together to work on a problem. Section 8 provides you with some ways of helping these groups work together more effectively.

Over the years, we’ve been fortunate to have been part of many improvement efforts. Section 9 will share some of these with you; in Section 10 you’ll have the chance to “practice” with some practical exercises.

We hope you find these methods useful.

John J. O’Neill, Jr.
President, Sigma Quality Management

P.S. We’ve read too many of these books that were written in a third-person, boring style. We prefer the first-person-plural, corny, but friendly style. We hope that you agree, but if you don’t, at least we had fun!

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[2] A “problem” for us is merely a gap between where something is now and where we’d like it to be - one of our products could be doing great now, but if we expect it to do even better, then there is a “gap,” and hence a “problem.”

1. IMPROVEMENT METHODS

This section's purpose is to provide you with *methods* to improve your products and services. Now, just why do we need an improvement method?

Well, if you've ever baked a cake, changed a car's engine oil, rewired a traction motor on a diesel locomotive, or performed open-heart surgery, you know that having a method to do the work is very helpful. The method helps guarantee the success of the project. In essence, the method is our *plan* that helps make sure we've covered all the bases and done so in the right sequence.

The same thing is true with improvement. If we get our improvement "recipe" out of sequence or skip steps, then we may not be successful in our goal of improved performance. Most of us are already good at jumping from a problem to solution. That works if you're changing a light bulb. But if you're not sure what's causing the problem, you might want to do a bit of *analysis* first.

Another reason for adopting a "standard" improvement method lies in its *communication* power. Often, an organization's improvement efforts will require bringing people together from different departments to address an issue. Manufacturing, engineering and purchasing may work together, nursing, pharmacy and the laboratory may address an issue, sales, billing and shipping may need to work on a problem affecting them all.

A common improvement method can help accelerate the project. Right from the start, everybody knows *how* we're going to work through this effort. Now this appears to be a somewhat intangible benefit, but we've experienced it so often, that we've come to value its importance.

> *Example: A rehabilitation unit in a hospital was having trouble making progress on improving their scheduling system. We gave them a simple "design process" to follow; the supervisor later said that once the team saw that this was a "fill-in-the-blanks" framework, they got excited and worked through the process in less than one month. They had struggled for six months prior to receiving the "design process."*

There's another *communication* issue to address. Often, a manager will charter a team of people to work on a specific improvement project. Periodically, that manager will want to review the progress of the project. When it comes time to implement the recommendations of the project team, he or she will want to know the basis for the recommendations.

The common improvement method not only facilitates work *within* and *across departments*, but also helps communication *up-and-down* the chain-of-command. We've seen maintenance technicians stand up in front of company vice-presidents and be able to clearly tell their improvement "story" because they all spoke the same improvement "language."

Before we jump into the actual methods, though, there's a danger we must point out. One of our heroes, the late Dr. W. Edwards Deming, had a saying,"*All theories are wrong, some are useful."*

An improvement method is a "theory." We prefer to think of improvement methods as **frameworks**, and ***not*** as "cookbooks." They help us frame the way we think about solving a performance problem that we have with our products or services. We've seen too many "quality police" out there proclaiming that if the team doesn't do this step or use this tool here, then the whole effort will be "wrong."

For a long time at Florida Power & Light, if the "Current Situation" step of our improvement method *did not contain a Pareto diagram,* the team "must" have done something wrong. Teams would make up Pareto diagrams and put them in their improvement stories, just to avoid this criticism.

This kind of lock-step thinking is totally against what we're trying to achieve. Beware of the Quality Bureaucrats!!!

1.1 PROBLEM SOLVING

Let's spend a few minutes addressing a common activity, that of *problem-solving*. Problem-solving is both a *precursor* to improvement and also contains some of the necessary *elements* of improvement.

Captain James T. Kirk of the starship *Enterprise* was great at problem-solving. So are Superman, Wonder Woman, Batman, Miss Marple, Sherlock Holmes, and most CEOs and managers. The fact that the "superheroes" generally take 30 minutes to an hour to solve problems and their corporate counterparts take slightly more time is merely a constraint of television programming; of no consequence here.

Now, problem solving is a necessary part of life. We solve so many problems each day, we're not even conscious of the process we follow. But let's examine the basic steps of problem-solving:

Step	**Example**
The Problem	It's Monday morning, you've got a staff meeting in 30 minutes and you've just put the meeting notes in the copier. Nothing happens when you push the "Start" button.
Your Analysis	Since you feel resourceful, you start looking around to see what the problem might be. The copier is on; you've pushed the right buttons for number of copies, collation, stapling, etc. So what's the problem? You finally notice the "OUT-OF-PAPER" light blinking on the control panel. Great! You've found the problem's cause.
Your Solution	You look around for the usual box of copy paper sitting next to the machine, but it's not there. So you run down to the supply room, grab a few reams of paper, run back and refill the copier.
The Result	You now push the "Start" button, the copier does its thing, and you're ready for the staff meeting with 10 minutes to spare. Success - you've solved the problem!

Now this is a pretty simple act of Problem-Solving, but it illustrates several points:

The first point is simple - there is a *process* that we follow. This is important because a good problem-solving *process* can be applied to many, many problems. In fact, we can *improve* our ability to solve problems by getting better at applying this process. One responsibility of managers is to help their people grow in *their* ability to solve problems. We help our children learn how to solve problems, why not our employees and staff?

A manager that we called the "Lone Ranger" was very, very good at solving problems. He would hold back while everybody else mucked about, and would not contribute until the rest of us were desperate for help. Then, he would ride over the hill; solve the problem and sit back waiting for the credit. Unfortunately, he never thought it important to teach his people *how* to solve problems.

Second, the problem-solving process because it is the *precursor* to our improvement method. We broke problem-solving down into four steps:

Identify the Problem - We first have to recognize that there is a problem (sometimes, we live with problems so long that they are not recognized as such!). In our example, it was simple. There was a *gap* between what we wanted to happen and what did happen. There was also *"pain"* - if we didn't get the copies made, we wouldn't be ready for the meeting, presumably with some consequences (wasted time, confusion, etc.).

Analyze the Problem - After recognizing the problem, we have to analyze the *cause* of the problem. If we don't know "why," then we don't really know what to do about it. In our everyday lives, this step sometimes does not occur, or is not done well. We often tend to "jump to solution" without going through an analysis of "why." Can you recall examples where people in your organization jumped right from the problem to the solution? How many times has this resulted in the problem ***not being solved?***

Develop a Solution - Of course, once we know why the problem occurred, we need to identify and implement a solution that addresses the cause. This path, too, is fraught with peril. We've got to make sure that the solution does, in fact, address the cause of the problem *and* will lead to the desired result. If your solution was to call someone from Supply, the paper *may* have been delivered, but perhaps not in time for you to make the copies for the meeting.

Check the Results - Finally, we need a "check" step - did we solve the problem? In our example, the feedback was immediate; in many cases, feedback may occur days, weeks, or months later.

Our third point will help us transition to our improvement method. In the copier example, you solved the problem, but we'll claim that all you did was implement an *immediate remedy.* This particular instance of the copier being out of paper was resolved.

Nothing you did, though, will *prevent the reoccurrence* of the problem. What do you think the odds are of finding the copier out of paper ***next Monday?*** Although there are many similarities between problem-solving and true improvement, this is one of the key differences we'll need to address.

Finally, we don't want to fool you into thinking that these few pages tell you all there is to know about problem-solving. For example, the process we described here follows the "break-the-problem-down" or *analytic* approach. We started with some symptoms and diagnosed the cause of these symptoms. We changed one part of the "system" that produces copies. For this problem the analytic approach was appropriate.

There is also a *synthetic approach* to problem-solving. This is often referred to as getting "outside the box," or "outside the nine dots," depending on which "game" introduced you to the concept.

The history of invention is full of this kind of problem-solving: The Swiss got better and better at making mechanical watches, until the quartz watch blew the old watches out of the water, FEDEX™ institutes over-night shipping and takes a big piece of the US Mail's business away, the personal computer replaces the mainframe (and the central information management department!), etc., etc.

1.2 GENERAL IMPROVEMENT PRINCIPLES

Let's start with some basic principles that should apply to a process improvement method:

First, what are our requirements for an improvement method? Well, the first two are somewhat conflicting: *Easy to Use* and *General.* Some methods we've seen that are easy to use (usually because they are more "cookbook-ish") are only good for a certain *class* of improvement efforts. For example, one method called FOCUS-PDCA is primarily useful for improving the processes that "produce" services.

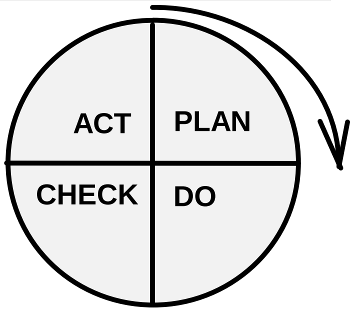
On the other hand, we've developed improvement methods for organizations whose main focus has been on the root cause of equipment failures. This takes a different kind of thinking and, hence, a different improvement method.

Second, the improvement method must be both *customer* and *process-focused.* The *customer-focus* must be there, since our improvements should aim towards achieving "faster/better/cheaper" for our products and services. The *process-focus* must be there because the actions that we take are directed at the *production processes* that "make" our products and services.

The third requirement is that the improvement method *must* incorporate the business equivalent of the *scientific method* - the **Plan-Do-Check-Act Cycle**, or **PDCA**.

A form of this PDCA cycle was first articulated by Walter Shewhart, a statistician/engineer working at Bell Laboratory during the 1920's and one of Dr. Deming's mentors. In fact, the PDCA cycle is often called the Deming-Shewhart cycle, since Deming popularized it:

Deming-Shewhart Cycle



The PDCA cycle is the "engine" of process-focused improvement. PLAN-DO-CHECK-ACT is both the basis for an improvement method and a *philosophy of management.*

PDCA asks that we *Plan* our products, services and their production processes, that we *Do* the work of production, sales and delivery to customers, that we *Check* the performance of the product and service at meeting customer needs and requirements and that, based on "gaps" discovered, we *Act* to revise the product, service and production process (thus revising the *Plan* and bringing us full-circle).

Now we can use the PDCA cycle to design new products and services. But, to improve an existing product or service, we'll make use of the "CAP-DO" cycle:

CAP-DO recognizes that you are already producing products and services. You are already "DO-ing" the work. The CAP-DO cycle will ask you to first "CHECK" the performance of the product or service and, based on "gaps" in its Quality, Cost, Service (Delivery) or Safety characteristics, you will study the process and its variables.

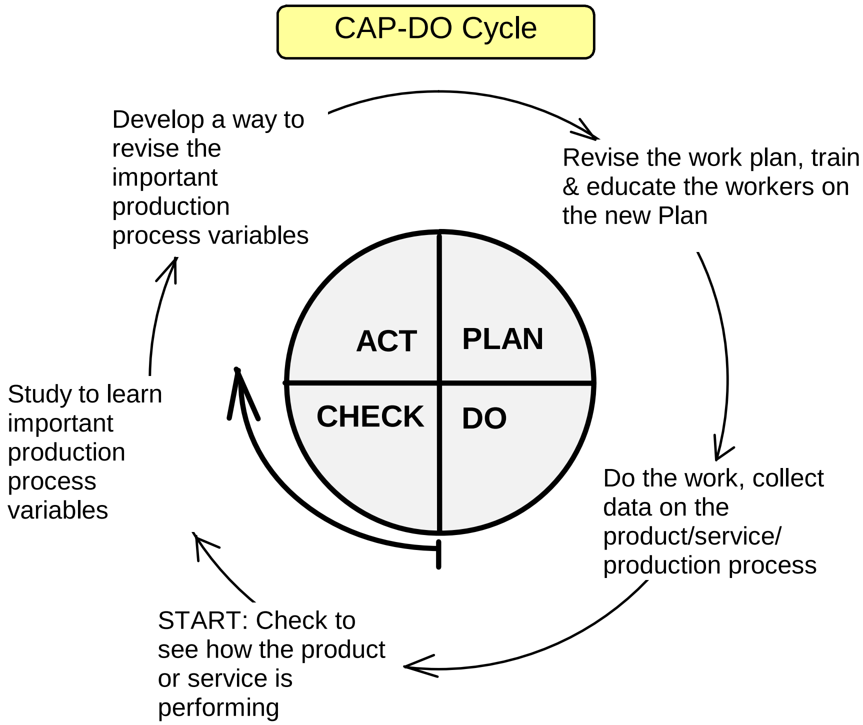
You will then "ACT" to change the important variables, thus revising the "PLAN." "DO-ing" the work brings you back to the "CHECK" phase, where you will see how well your process changes worked. Sound simple? It really is, but it takes discipline to practice.

For instance, we often see many different performance measures in place in organizations (financial, quality, reliability, safety, etc.). Although there may be an understanding that a "gap" exists, the organization may be reluctant to analyze why the "gap" is there (*you* know them - those chronic problems your organization has suffered with for years).

There may be reluctance to take action even if the important process variables are understood (sometimes, "politics" stands in the way). Even if action is taken and changes are made, the "CHECK" step is often skipped (note that a change does **not** necessarily equal improvement!).

We also know several organizations that like to practice the "PCA" cycle: *They PLAN, PLAN, PLAN and then they CHECK the Plan and ACT to revise the PLAN. They never seem to get to the DO phase!*

We'll use the steps of CAP-DO as the foundation of our improvement method in the next section.



1.3 DMAIEC PROCESS IMPROVEMENT STEPS

We've translated the PDCA cycle into a practical 6-step approach for teams and individuals to employ during problem solving/process improvement efforts. The method is described on the next few pages. The PDCA wheel is "rotated" more than once in this six-step approach.

Define

- Launch The Project
- Define Outcomes
- Identify Stakeholders
- Select Team
- Determine Project Approach
- Create Project Plan

Measure

- Define The Current Process
- Address "Low-Hanging Fruit"
- Obtain Customer CTQ's
- Gather Initial Metrics
- Determine Current "Sigma"
- Stratify Data
- Determine Initial Value Proposition

Analyze

- Develop Cause & Effect Hypotheses
- Gather Causal Data
- Determine & Validate Root Causes (X's)

Identify

- Identify Breakthroughs
- Select Practical Approaches
- Design Future State
- Predict New "Sigma"
- Perform C/B & Risk Analysis

Execute

- Develop Control Methods
- Develop Dashboards and Scorecards
- Train
- Execute
- Measure Results
- Manage Change

Control

- Report Dashboard and Scorecard Data
- Create Feedback Loop & Adjust Process
- Identify Replication Opportunities
- Develop Future Plans

Define the Reason for Improvement

PURPOSE:	There are many problems could be addressed. You must build the case for why this problem is important to address **now**. Does the problem relate to the most important product/service of your department or is it strategically important to your organization? What is the "gap," what's the "pain?" If the problem is not seen as important, there won't be much enthusiasm to work on it. Also, in this step, the project is planned, team members identified, resources approved.
METHODS:	• **Launch The Project -** Brainstorm a list of problems. Select the most important one to address. Collect customer feedback to identify problems with your products and services. Select the most important one to address. Collect performance data on your products and services (quality, cost, delivery, safety). Pick a product/service with the largest performance "gap." Obtain a copy of your organization's strategic plan. Where and how can your department contribute to the overall plan? Which of your products/services must be improved? As the output of this step, develop a "theme" or "mission" statement for the effort. • **Define Outcomes** – How will the success of the project be measured? What aspect of the product or service needs improvement - quality, cost, delivery or safety? • **Identify Stakeholders** – Who are the key people who will be impacted by (or who can influence) the project's direction and success? Where do they stand relative to changes that may occur as a result of this project? • **Select Team** – Who should be represented? Full-time? Part-time? • **Determine Project Approach** – DMAIEC provides a general project approach; what specific modifications or additions are needed? • **Create Project Plan** – Develop a work breakdown structure, PERT and/or Gantt chart.
TOOLS:	• Customer Feedback/Complaint Data • Line Graphs, Run Charts, Control Charts • Project Charter • Organization Strategic Plan • Project Planning Worksheet
NOTES:	The first few efforts (practice time!) at improvement may address problems that are not the most important. As improvement skill increases, the problems can become more challenging.

Measure & Observe the Current Situation

PURPOSE:	This is the "clue-gathering" step. How does the process work that "produces" the product or service to be improved? Here, we should understand the 5W1H (Who, What, Where, When, Why and How) about the process. The problem should be broken down into different aspects or categories - these may be ranked by priority and perhaps only one selected for solution in this improvement cycle.	
METHODS:	• **Define The Current Process** - Clarify how the process that "produces" the product or service works. Develop flowcharts or other "pictures" of the process. • **Address "Low-Hanging Fruit" -** Opportunities to improve the process may be identified at this point. Clean up the obvious problems, but don't make changes unless the root causes are obvious. • **Obtain Customer Needs, Develop CTQ's** – If it's not clear what the customer wants from this process, do the necessary research. Interview or survey the customer. Translate the customer's needs into measurable characteristics of your product or service. If these CTQs differ greatly from your initial theme, discuss changing the project's direction with your champion or sponsor. • **Gather Initial Metrics** – Measure current performance relative to the CTQs. Is the process in control? • **Determine Current "Sigma" -** Determine the capability of the process. Express this as a "Sigma." • **Stratify Data** - Examine the problem from different "angles." Study the variation in the problem. Does the problem occur more often on one shift, with one machine or operator? Look for differences by time, place, type & symptom of the problem. Pareto Analysis can be extremely helpful in isolating one aspect of the problem to address. • **Determine Initial Value Proposition** - Clarify the Problem Statement. Often the initial theme or mission statement is very broad. After this step, you should have a more specific problem on which you will continue to work. Write this down before the *Analysis* step. Try to estimate dollar savings or revenue enhancements based on what you know about the problem now. Determine or refine improvement targets.	
TOOLS:	• Process Flowcharting, Layout Diagramming, Process Watch • Voice of Customer - Interviewing • Stratification – Bar, Pie, Radar Charts, Pareto Analysis	• Variation Studies (Line Graphs, Control Charts, Histograms, Capability Analyses)
NOTES:	Don't try to answer the "why" question here. We sometimes refer to this step as the process "immersion." When we work with clients on improvement projects, we spend time in this step just watching the work and asking questions along the 5W1H train of thought.	

Analyze the Process

PURPOSE:	This is the "why" or diagnostic step. Where the *Current Situation* step helped us understand the 5W1H of the process, here we will develop hypotheses regarding the variables that are causing the problem or "gap." These hypotheses must then be confirmed or refuted and the "true causes" of the problem identified.
METHODS:	• **Develop Cause & Effect Hypotheses -** Develop hypotheses about why the problem occurs. These may include *Material, Machine/Equipment, Method, People, Measurement* and *Environment* factors. Cause and Effect analysis is the most basic (but powerful!) approach to developing these hypotheses. • **Gather Causal Data** – Plan how you will gather evidence to support your hypotheses. Gather evidence to establish the "guilt" or "innocence" of the different factors. This may be done through analysis of product or service outputs and "production" process factors, or through experiments performed that deliberately change the value of factors in the "production" process. • **Determine & Validate Root Causes (X's)** – Study the results of your cause and effect analysis. Which of the potential root causes contribute most to the problem you are attempting to solve? If you eliminate the root cause, by how much will the problem be reduced?
TOOLS:	• Cause and Effect Analysis • Pareto Analysis of Causes • Histograms/Hypothesis Tests • Scatter Diagram/Regression • Process Analysis • Value Analysis/Value Engineering • Twenty Questions • Error Modes and Effects Analysis • Design of Experiments
NOTES:	Understanding *Cause and Effect* is fundamental to the PDCA cycle. In some "advanced" organizations, we've heard the company's everyday language change. When a problem occurred, people used to ask, "*Well, do you know **who** did it?* Now they ask "*Do you understand cause and effect?"*

Identify & Evaluate the Countermeasures

PURPOSE:	Here, changes will be identified that impact the important variables discovered during *Analysis* and that we think will improve performance. The changes should be evaluated for their benefits, costs and possible side effects. The changes must be "sold," planned and then implemented.
METHODS:	• **Identify Breakthroughs** - Identify possible countermeasures to address the process variables affecting performance. Select one or more that have the highest likelihood (and lowest cost) of impacting the variables. Benchmark "best" practices and select the aspects of these that address your situation. Once the countermeasures have been selected, they must be "sold" to the stakeholders (customers, staff, management, etc.). Then, detailed planning and implementation follow. A pilot or demonstration effort may occur prior to "full-scale" implementation. • **Select Practical Approaches** – Translate the countermeasure to a set of changes that can be implemented. *Experiments* may be performed to determine the best "level" for the key causal factors. • **Design Future State** - Design a new product/service or associated production process. In some cases, either the existing product or service is inadequate, or the "production" process is not capable of producing at the required quality and cost levels. A "clean sheet" design effort may be necessary (see Section 2.4 – *Designing New Products & Services*). • **Predict New "Sigma"** – Given what you know about the countermeasures, what improvement do you expect to see? Will the problem be reduced by 40%, 90%? What will the new "Sigma" of the process be? • **Perform Cost/Benefit & Risk Analysis** – Are the changes you are suggesting justified by the economics? What risks (business, technical, legal, etc.) are created by the changes? How will the important risks be prevented or mitigated?
TOOLS:	• Root Cause/Countermeasure Matrix • Benchmarking • Cost/Benefit, Risk Analysis • Design Process • Project Planning Worksheet
NOTES:	Making the changes is often the hardest part of the project. Develop a plan to address the expected change resistance. Revisit your stakeholder analysis performed in the *Define* step.

Execute Countermeasures & Check the Results

PURPOSE:	After the changes are made, what effect have they had on performance - has the "gap" closed, or has the problem been eliminated? Do we understand that the changes we made caused the change in performance?
METHODS:	• **Develop Control Methods** – Create or revise the necessary procedures, protocols, drawings, instructions, specifications or other methods employed to control the process. • **Develop Dashboards and Scorecards** – Determine how you will measure the results. The CTQs you have focused on should be measured. Process variables and supplier metrics may also be required. • **Train** – Train workers on the changes to the process. • **Execute** – Implement the changes. You may first make the changes on a pilot scale, prior to full-scale implementation. • **Measure Results** - Collect and Analyze Performance Data to determine if the change has had a measurable impact. Collect data on both the *output* - that aspect of the product or service that you were trying to improve (quality, cost, etc.) and on the *variables* that you changed through the *countermeasures.* Conduct Customer Interviews/Collect Customer Feedback to determine if the problem addressed has "gone away" or has been reduced in frequency. Determine if the *results* (observed changes in performance) are due to the *effects* of the changes you made to the process (sometimes other variables may be acting on the process that are outside your control). Three outcomes are possible here: 1. The results are due to our changes and performance is as expected. Here, move to the *Control* step. 2. The results are much less than expected. Here, go back to *Analyze* and understand why. 3. The results are much better than expected. Here, too, go back to *Analyze* and understand why. • **Manage Change** – Make sure that the necessary changes are being implemented. Address sources of resistance; try to ensure a "win-win" for process stakeholders.
TOOLS:	• Line Graphs, Run Charts, Control Charts • Pareto Analysis • Histograms, Capability Analyses • Procedures, Instructions
NOTES:	One of the most common problems with this step is that organizations do not establish a "baseline" performance - what was performance before the changes were made?

Control the Process & Plan Next Steps

PURPOSE:	The changes may have been done on a pilot basis, or under temporary procedures. If the changes actually improved the process, then we must ensure that they are repeated each time the product or service is "produced." They must be built into the PLAN, training & education performed and responsibilities clarified. Monitoring tools should be put in place.
METHODS:	• **Report Dashboard and Scorecard Data** – Continue to measure and report on process performance. On-going measurement may occur less frequently and with fewer measurement points than during the pilot phase of the improvement. Monitor *performance* to ensure that the changes aren't *Teflon-coated,* i.e. that they don't "stick." • **Create Feedback Loop & Adjust Process -** Ensure that the performance metrics are acted upon if they go awry. Help staff understand the difference between actions to address process *instability* (e.g. special causes) and process *incapability* (e.g. process not centered or excessive variation relative to specifications). • **Identify Replication Opportunities** – Given that the process improvement has worked well, are there other products/services/processes that could benefit from the changes? • **Develop Future Plans** – What portion of the original problem remains? Is there benefit to be gained by tackling the next "bar on the Pareto?" At the end of the project, don't forget to reward the team and celebrate!
TOOLS:	• Procedures, Protocols, Standards • Training • Line Graph, Run Chart, Control Chart • Quality Improvement Story Review Form • Project Planning Worksheet
NOTES:	"Old habits die hard." Enough said!

1.4 ALTERNATE APPROACHES

While the basic steps of DMAIEC are pretty "fixed," here are some specialized applications that you may find fit your situation.

The "No-Process" Problem

Many businesses and industries are notorious for their lack of "process-thinking." Service-type industries are especially guilty of this. In many cases, when faced with a *Reason for Improvement*, the project team will discover in the *Current Situation* that there is no process for performing the work.

This usually means that we've never sat down and thought out how the particular product or service should be "produced." In these cases, we can "bypass" the *Analysis* step and proceed to *Countermeasures.* The team can then spend their time designing and implementing a production process that meets the needs of the customers.

When management reviews this kind of improvement effort, one of their key questions **must be** "Why was there no process, and what other products and services are being 'produced' without a process?" If enough of these exist, the organization may decide that a *Standardization* effort is worthwhile. ISO-9000 is an example of a standardization program; hospitals have developed *Clinical Pathways* to standardize care of patients.

If you face this situation, you may want to employ a "DIM-AIEC" approach. Given a problem (Define Step), you discover there is "no process" in place. In the first Improve Step, develop and implement the "best" process you can. This can involve bringing the people who work the process together and getting them to agree on the "best method." Document this on a flowchart or procedure. Measure the performance of this process and, after a while, decide if you need to further analyze and improve the process (the remaining AIEC steps).

A variation on this theme is the "*Process Exists, but not Followed*" kind of problem. The reasons for this often fall into one of two categories:

> 1) A "good" process exists (one that can "produce" the product/service at the required quality levels), but it is not being followed. The term "organizational discipline" comes to mind, here. One of the characteristics of a well-managed organization is that they have established and practice their "habits" of how to do things well. Does staff understand the importance of the "standards?" Does management emphasize their importance?
>
> 2) A "bad" process exists (one that is too difficult to follow). Of course, the process must be revised, but the general question remains of *Why are processes difficult to follow?* Are suggestions for improvement not offered, or taken? Again, are the process "standards" not held as important? Inquiring minds want to know!

"Production" Process Analyses

Several methods have been used effectively to improve the quality and cost of the *entire* "production" process. These include:

Twenty Questions

Twenty Questions was introduced to us through a quality improvement effort conducted by a hospital in Thailand. A team of nurses working the in Surgical Intensive Care Unit (SICU) had a problem with the time it took to transfer a patient from SICU to a step-down unit (less intensive care required).

The team systematically questioned every step of the process, asking all of the 5W1H questions. Once they "tore down" the process, they rebuilt it, making improvements to virtually all the steps of their "production" process. Their *tangible* results were to reduce a process that took over 90 minutes, to one that took a little over 20 minutes! Section 3, *Pictures of the Process,* describes this approach.

Error Reduction Methods

For many services, one important customer need is that the service be provided free from errors. Brain surgery comes to mind. Mortgage loan processing and other financial transactions, travel reservations, order-taking, shipping, nuclear plant operations procedures are some other examples of processes that should not "produce" errors.

While errors can be addressed one category at a time (using a Pareto Analysis to prioritize the categories), the entire process can be examined using a method called *Failure/Error Modes and Effects Analysis.* This improvement method takes each process step or task and asks the basic question, *"What failures or errors could occur (or have occurred) here?"* These are prioritized, and then specific process changes identified to prevent or mitigate the problems. For example, *Error-proofing* is applied to prevent the occurrence or mitigate the consequences of process errors. Section 3 will describe this method.

Critical Path/Non-Value Added Analysis

When the *time* to complete a process is important, a method employed by project managers can be used to improve the process. Any process is, of course, composed of a series of steps and tasks. The *time to complete the process* is determined by a specific set and sequence of steps called the *Critical Path.* For many processes, not all steps are on the critical path. Many steps do not add value to the customer.

Critical Path Analysis first consists of understanding which steps are on the critical path, and then working to reduce the time associated with these steps, rearranging the steps or eliminating "non-value added" steps or delays from the process. Hospitals have recently adopted *Critical (or Clinical) Pathways* as means to manage and reduce the length of stay of patients, using this critical path thinking. See Section 3 for details.

Hand-offs and other Problems

Many companies have assigned "production" responsibilities to different departments. Order-taking is done by Customer Service, processing the order is done by Warehousing (or "Order Fulfillment"), shipping by Shipping, billing by Accounting, etc. With each "hand-off" though, there is usually an associated delay and opportunity for error.

Hallmark Cards, for example, had a card design process that took over two years from concept to production, with 25 different hand-offs in the process. They adopted a team approach that follows the card through the entire process and cut the process time to less than one year.

We spoke with some members of a nuclear utility's engineering department once. They told us that over 75 signatures were required to "release" a design from their department. No wonder the Board of Directors and stockholders were worried about delays and cost overruns in the nuclear construction effort. One staff member of the US Government's General Accounting Office told us that they don't *release* reports, they *escape*!"

A *responsibilities flowchart* is a good way to begin to layout and understand processes like these. This kind of flowchart describes not only *what* is done, but *who* does it. Section 3 will cover this.

1.5 THE IMPROVEMENT STORY & STORYBOARD

Improvements made to products and services and production processes should be documented. There are three important reasons why:

1. If a team is working on the improvement project, they need to keep track of where they are in the effort; what progress has been made, what's left to do. While this can be done in an *Improvement Storybook*, some organizations encourage the use of *Improvement Storyboards.*

2. When presenting the improvement work to management and/or colleagues, some common method of communication has been found to be helpful.

3. Improvements generally result in an increase in the company's *technology inventory.* We now know how to do this better because. . . . The improvement story is an important way of capturing this increase in technology.

There are other reasons to document improvement, some companies like to recognize improvement work through "quality fairs" or "expos;" the improvement stories are then displayed in common areas for review by staff and management. Many companies use the improvement stories as selling points in their presentations to customers. One "impure motive" is to "prove" to an outside agency (i.e. government regulator or industry accreditation agency) that the organization is addressing problems and working on improving quality, safety, etc.

The Improvement Story

As a working document, a binder with the following tabs can be kept by the leader and members of the project:

1. *Problem Definition*
2. *Current Situation & Performance Measures*
3. *Process Analysis*
4. *Countermeasures Identification & Evaluation*
5. *Countermeasures Implementation*
6. *Results*
7. *Process Control Plan and Implementation*
8. *Next Steps*
9. *Team Meeting Minutes & Notes*
   (including Improvement Project Plan)

The team leader often takes responsibility for keeping the improvement story up to date and for distributing copies of important documents, charts, graphs, etc. Today's networking & communication software provides the opportunity for the team to keep a "virtual storybook" without the need for paper copies.

For presentation purposes, the important aspects of the improvement story should be prepared in a "storybook" form. There's a lot of confusion about these storybooks. The essential purpose of the storybook is just that, to tell a story. Think of the customers of your story - generally, they will include management and your co-workers.

If you only had 10 - 15 minutes to tell what you've done, what would you put into your story? You would keep it simple, remembering that not everybody is as familiar with the details of the project as you are, you would stick to the main points and not divert into all the dead-end paths that the team might have followed, and you would try to convince your listeners that you understand the problem, its causes and that your countermeasures are going to (or have) solve the problem. This is your chance to *sell* and *shine!*

We prefer very little text in improvement stories. You can tell your improvement story almost completely with the graphs and charts prepared during the analysis work. Figure 1-1 shows an improvement story on one page, mainly communicated through pictures.

The Improvement Storyboard

The Improvement Storyboard is merely a large version of the storybook, suitable for hanging in the hallway or meeting room. Sometimes the Storyboard is used for presentation purposes, as a working document, it supplements the notebook.

One purpose of displaying the team's progress in public is to solicit ideas from other members of the department or organization. If, for instance, the team's Cause and Effect Diagram appears on the storyboard, others can note additional causes that the team may have missed. This helps give the rest of the department a chance to "participate" in the improvement work. Figure 1-2 is a possible format for an Improvement Storyboard.

Figure 1-1 FUEL OIL SYSTEM LEAK REDUCTION

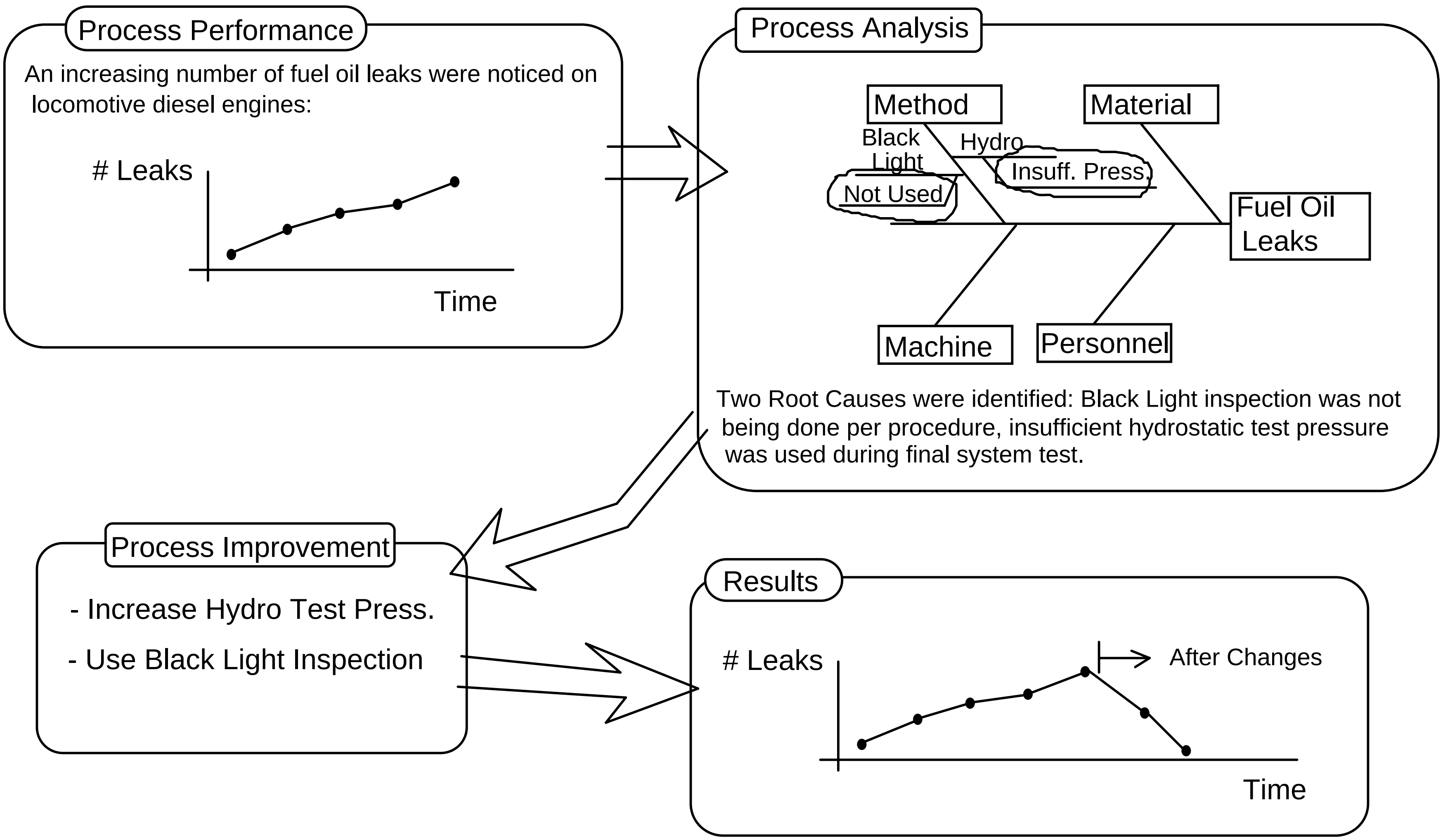


Figure 1-2 Improvement Storyboard Layout

Suggested Dimensions: 36” High x 48” Wide

Problem Definition	Current Situation & Performance Measures		
Process Analysis		Countermeasures	
Results	Process Control Plan	Next Steps	Team Meetings/Notes

2. MEASURING PERFORMANCE

Measurement is critical to improvement. We quote one of our heroes, Lord Kelvin[3] who said (approximately):

If you can't measure it, you don't understand it.

Let's focus on your improvement efforts. At the very least, you should measure *before* and *after* you make changes. How else can you know that what *you* did caused an improvement to the product or service?

One day, a member of an Emergency Room improvement team came to us with some data. They were trying to reduce the time it took to administer medication to patients diagnosed with myocardial infarctions (AKA *heart attack*). They had made three changes to the process, over a four month period. When we looked at their data, though, *there was no change in the administration time!* Important lesson: change does not equal improvement!

Measurement will also play a role when you try to understand the variables that are affecting the performance of the process. We'll save this discussion, though, for later (see Sections 4 and 5).

For many improvement efforts, measuring performance is fairly simple. Once you've established the *reason for improvement*, you should develop an *indicator* of performance. Since the vast majority of data comes from your "production" processes, there will be an *order* or *time sequence* to the data. This widget was produced at 9:00 am, this at 10:00 am, etc. Or this patient was admitted at 6:30 am, this one at 7:00 am, etc.

Your first step is to examine how your process is behaving as it *"produces" products/services over time*. To do this, you can put your data on a *line graph, run chart* or *control chart.* This gives you a picture of the data that let's you see the overall level and variability of your process.

These pictures also help you look for trends, spikes and other patterns. In general, they help you understand the *variation* in performance. We'll cover the *line graph* here, the *run* and *control charts* deserve a special treatment and are discussed in Sigma Quality Management's Black Belt Manual.

The next general question you should ask is "Are there differences?" This will lead you to try and break the data into categories, looking for differences in this or that category, or looking for the "most important" category. *Very* often, a general "problem" can be broken down into several different categories. You can then follow the strategy of "divide and conquer" - tackling one problem at a time, from most important to least.

> *Example: A manufacturer of irrigation products collected data on problems with assembled sprinkler heads. Each week, they stratified the data by type of problem (missing springs, missing gears, gears installed upside down, etc.) and also by assembler. They found that missing leaf springs were the most common defect.*

[3]Nineteenth century scientist, did *not* invent the Kelvinator refrigerator!

Example: A travel agency collected data on problems with tickets delivered to customers. Each month, they stratified the data by type of problem (wrong reservation, wrong location, wrong date, etc.) and by travel agent. They found that "customer changing reservations" was the most common source of a returned ticket.

Notice how the same line of thought is applied to both a manufacturing and a service industry?

To answer some of these "difference" questions, we'll take the data and display it on a *Bar Chart, Pie Chart,* or *Radar Chart.* There's a special kind of Bar Chart, called a *Pareto Chart* that we'll save for Section 4. It's used as part of an overall analysis that we'll call, surprisingly, *Pareto Analysis.*

When it comes to measuring performance, we find that the tools mentioned above are used over and over and over. It really pays to have these in your quality toolkit.

2.1 PERFORMANCE MEASURES & INDICATORS

Selecting Performance Measures

Since your focus is to *improve performance,* you should pick one or more performance *measures* based on the stated *Reason for Improvement* (i.e. the first step of the improvement method). There should be a strong link between the *objective* of your project and the performance measure(s) you select. Here are some questions you can ask that will lead to a good, "linked" performance measure:

- *Why are we working on this project?*
- *Are we trying to reduce cost, improve quality, reduce defects, or improve safety?*
- *Who are the customers of the product or service we're working on improving?*
- *What needs improvement from their perspective?*
- *How will we know if the project is a success?*

You may already have data relating to the performance of your products and services. Most organizations track financial performance, some also track *quality* performance. Before you design a new data collection program, look around to see if somebody is not already collecting performance data that's useful to you.

Here are some good examples of performance measures:

- A clinical laboratory was receiving complaints about how long it took to get "stat" lab requests back up to the nursing units. They picked *Stat Lab Turnaround Time* as their performance measure.
- A power plant was experiencing failures of their Emergency Diesel Generators to start. The system engineer picked *Starting Reliability* as his performance measure.
- A hospital was concerned about the costs associated with certain Medicare cases. They picked *Cost per Case* as the measure of performance.
- A manufacturing firm was concerned about injuries experienced by their employees. They picked *Lost Time Injuries* first, when these were significantly reduced, they changed the measure to *Doctor Cases*, since these were precursors to lost time injuries.

So what's good about these examples? Well, primarily, the measures picked all relate to the problem being addressed. If these measures can be "moved" in the right direction, then the problems faced by these organizations will be minimized or eliminated.

Another feature of these measures is their ability to be *stratified.* For instance, the lab staff could stratify the "stat" lab turnarounds by time of day, shift, day of week, etc. Lost time injuries can be stratified by department, job, day of week, type of injury, etc.

This will help you identify possible differences or variations that may help you focus better on the real problem. If a company found, for instance, that 80% of the injuries occurred in the company's offices, then they could focus on reducing these first, and worry about the "field" injuries later.

Now for some “not-so-good” examples:

- A supplier of clean linen to a hospital measured their performance by the *quantity of linen supplied each day.* The hospital’s surgery department cared more that the linen was supplied *on-time.*
- A manufacturing plant’s assembly crews were given incentives based on the *production volume for each shift.* The sales representatives were constantly receiving customer complaints about the *quality* of the products.
- A consulting firm’s president only measured “on-the-road” *billable days* for his consultants, despite the fact that he required the consultants to work on many *in-house* development projects.
- In an “attempt” to improve power plant reliability, an engineer monitored the *frequency of failures* of a particular control valve’s automatic controller.

In the first two examples, there’s a lack of alignment between the customer’s needs and what is being measured. This happens frequently for several reasons.

We are often tempted to keep track of what’s *easy* to measure or to measure things that make us *look good.* The linen supplier could show that they delivered the required *quantity* of linen to the hospital 100% of the time - so they looked great on paper! One of our friends frequently asks managers - ”*Do you want to be good, or just look good?”*

The third example’s pretty obvious, but the fourth needs some explanation. On the surface, it looks good - frequency of failures relates to reliability. But, when he was questioned during a team review, the engineer admitted that the controller failures had never caused a plant shutdown. When the automatic controls failed, the operators could always shift to manually control the valve. When this happened, though, they would immediately call the engineer to come repair the valve. Since this often happened late at night, the engineer was really trying to improve the “reliability” of his sleeping the entire night!

Summarizing – the indicator you choose should be both ***feasible*** – *capable of being measured* and ***relevant*** – *related to the problem you are trying to address!*

Who are the Customers of the Product/Service/Process & What Do They Want?

For many improvement efforts, the problem and its associated indicator can be easily identified, as noted above. In some cases, though, you might want to check with the customer(s) of the process before assuming that you know what the problem is. In a GE Capital example, one business was faced with declining market share in a given region for a leased product. The sales people were adamant that their product was priced too high. Taking this tack, the team could have worked on cost reduction opportunities in the business. However, the team decided to go out and “listen” to the customers. Their research led them to discover that the purchase decision for their product was often made *based on which company’s salesperson was last to visit.* Armed with this knowledge, the team focused on the *sales contact process* and *frequency of visits* as the indicator. Quite a different project!

In a similar example, at Florida Power & Light, we put a lot of effort into minimizing the customer’s outage time by improving reliability and restoration times of equipment. One improvement, though, focused on developing a call system that would *predict* how long the customer’s power would be out. The "voice" we heard here is that, although the customers want power restored quickly, they were also uncomfortable with the *uncertainty* of the power outage (especially if it's Thanksgiving and there's a turkey in the electric oven!).

For your project then, you may want to gather some Voice of Customer (VOC) information. We'll focus on a simple approach here. If your VOC needs get more complicated, see a Black Belt or your friendly neighborhood Market Research department.

First, identify and segment your customers. Your product or service may have a number of different customers:

- *External Customers* – those outside the company who purchase products and services (also, "bystanders" who may be affected by the product/service – noise, pollution)
- *Internal Customers* – "The next process is your customer." Who receives the output of your process?
- *Stakeholders* – Others who may be affected by the process or have a "stake" in the outcome of the process (management, employees, regulators, shareholders).

Should you consider different customer segments (i.e. within one major customer group)? Typical segmentation strategies include customers by revenue, deal size, geography, age, income, purchase habits, and many others. Consider *all* customers who touch the product.

Example: Who's the "Customer" of a Home Air Conditioner? Answer: The homeowner, the store selling the units, the installer and, oh, yeah, the *repairman.* While working with an air conditioning manufacturer, we happened to have a random conversation with a repairman in a sandwich shop in Palmetto, Florida - *"What Do You Think About Company Y's Air Conditioners?"*

"They're too complicated; they put a fancy circuit board in where Brand X just puts a starting relay. Also, their coils are aluminum. They pit real quick here in Florida and I have a hard time fixin' them."

Next, you'll naturally want to start "talking" to these customers. Before you engage in a time-consuming study, recognize that your company may already be hearing lots of "voices" – known as reactive VOC. Go seek these out before moving to *proactive* research.

Types of Reactive Customer Voices

- Complaints
- Hang-ups
- Product Returns
- Contract Cancellation
- Loss Of Market Share
- Customer Defections
- Loss Of Potential Repeat Business
- High Rejects On Sales Calls
- Behavior

Potential "Locations" For Gathering VOC

σ **Customer Research** – Formal collection of information from customers about their "wants."
Examples: Existing Market studies, behavioral observations

- σ **Transactions –** All interactions between the business and paying customers that are the direct result of what the customer has paid the business to provide.
  Examples: Installation of equipment, service calls

- σ **Casual Contacts** – Unplanned contacts between customers and the business that yield information relevant to the continued satisfaction of wants, needs and unperceived delighters.
  Examples: Meeting accidentally or socially with a customer

- σ **Inbound Communications** – Customers contacting the business for information or requests for assistance that fall outside what the customer has paid the business to provide.
  Examples: A customer calls in about a product, or visits the company's web site

- σ **Outbound Communications** – The business contacting customers for information, assistance or to offer a product/service that naturally extends from products/services already sold/leased.
  Examples: Official sales call, customer satisfaction survey

- σ **Internal Intelligence** – Knowledge of customers' needs, data on competitors and/or the market environment that exists within individual members of the business that can be systematically captured.
  Examples: "Mining" sales staff information, competitive benchmarking, industry research, and the reservoir of data collected over time as a result of business contacts

Armed with this *reactive* information, you can then determine your remaining questions and plan your *proactive* research. Customer interviews can be a very effective means of answering your questions. It's amazing how few companies (and improvement projects) actually sit down and talk with their customers. Be careful, though, you want to "listen" during the interviews – the interview should not turn into a sales' call!

Interviewing

Purpose: To identify problems, needs & requirements from process customers, useful when "little" is known about customer needs. For internal customer/supplier relationships, the interview can also help break down functional barriers.

Process:

1. Determine The Knowledge Needed And Question Areas
2. Determine The Objective Of The Interview
3. Determine The Number Of Customers to Interview
4. Determine The Number Of Interviews
5. Draft Interview Guide
6. Determine The Time Limit For Interviewers
7. Test Interview Guide
8. Train Interviewees

9. Finalize The Interview Guide And Gain Approval
10. Schedule Appointments
11. Conduct Interviews
12. Analyze Interview Results

Interview Analysis:
"Two-Way" Analysis (Within a Given Interview, Across Interviews), Extracting Verbatim Comments

Interview Types

Individual
- Individual Unique Perspectives
- Senior Level
- Large Volume Customer

Group
- Group Similar Products And Services
- Mid-To Lower-Level
- One Organization

Telephone
- Telephone Customers Are Widely Dispersed
- Basic or Simple Issues

Product/Service Quality Characteristics & *Critical-to-Quality* Requirements

Once you've obtained and analyzed the necessary VOC, you may need to "translate" customer needs into measurable characteristics of your product. For any product and service, the quality characteristics are the features, traits, qualities etc. that correlate to the customers' needs and expectations.

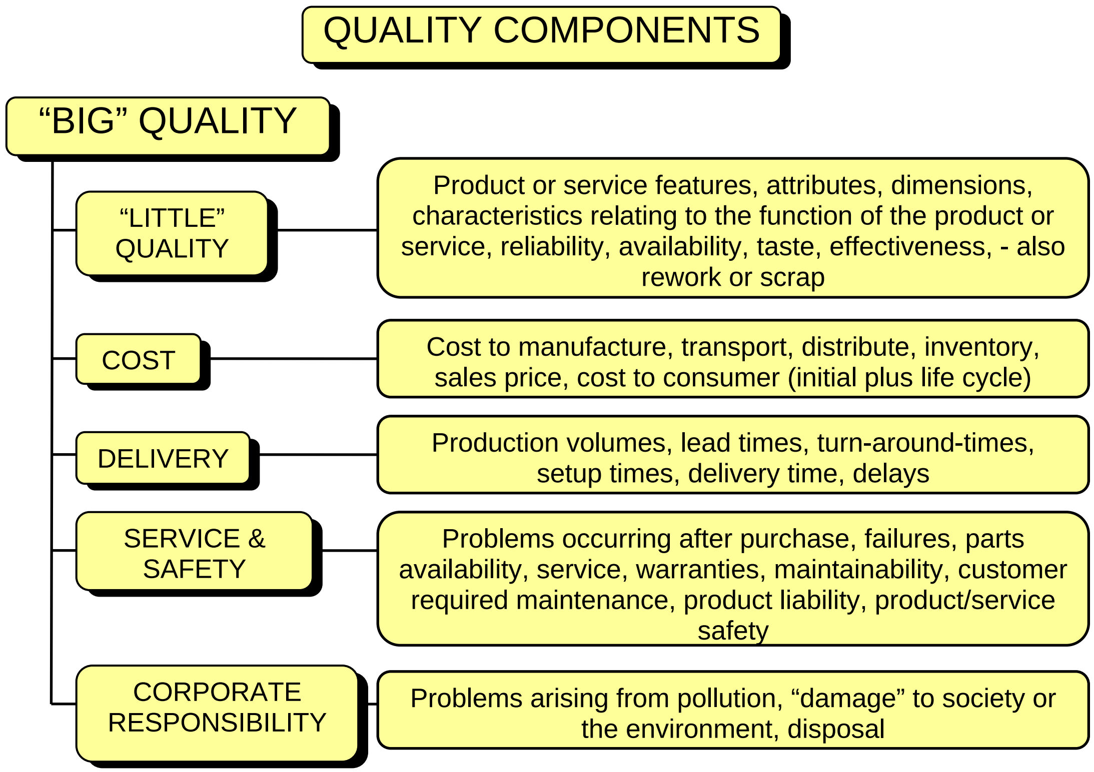
Customer Need	Quality Characteristic
Fast package delivery	Shipping Time
On-time Arrival	Departure from Schedule
Durable Product	Reliability
Accurate Orders/ Reservations	Order/Reservation Errors

In manufacturing or engineering applications, *specifications* serve as the way of communicating both customer needs and quality characteristics - *this gear must have an inner diameter of 3.750 inches.*

Quality characteristics are the *causes* that result in the *effect* of customer satisfaction (or dissatisfaction) with our product or service. Although it's sometimes a challenge, quality characteristics can *always* be measured (the ghost of Lord Kelvin backs us up here!). Although it's likely you've heard many different needs from your customers, which (for this project) are the most important or *critical-to-quality*? These "CTQs" become the focus of your improvement efforts. Typical service CTQs will include *accuracy, cycle time, on-time-delivery, offer acceptance.* Product CTQs are, of course, dependent on the specific product type:

σ **Locomotive** – *horsepower, mean time to failure, mean time to repair, fuel consumption rate*.
σ **Surgical Stapler** – *force to fire, number of staples, length, diameter (to fit in a trocar), staple form (geometry)*
σ **Air Conditioner** – *cooling capacity, footprint (dimensions), energy efficiency, mean time to failure*
σ **Sanitary Napkin** – *capacity, leak rate or probability, comfort (hard to measure), thickness*

When we say ***Quality* characteristics,** we're using QUALITY in a "Broad" sense. We can break this "Big Q" down into five components:



One of our improvement challenges is to maintain a *balance* among these quality characteristics, e.g. how can we improve "*little" quality*, without increasing *cost,* or *delivery.*

2.2 DATA AND STATISTICAL CONCEPTS

The Nature of Data

The *first* question we ask when presented with data is "*What kind of data is it?"* Here, we want to classify the data into one of two distinct types: *Measurement* or *Count.*

These two data types are often treated differently by our improvement tools. Some tools work better with one kind of data. For instance, we found it's generally easier to create a *Line Graph* with *measurement data* than with *count data.*

Measurement data (synonyms for *Measurement* include *Variables, Continuous, Analog*) can be subdivided infinitely and often requires some device or instrument to measure its value. Time, speed, costs, length, pressure are examples of measurement data.

Count data (synonyms for *Count* include *Attribute, Discrete, Digital*) comes to us in the form of individual events that we count. There is some basic unit that cannot be divided further. Errors, volumes (number of sales or procedures), defects, defectives, number of employees are examples of count data. Count data is often "disguised" as ratios, proportions or rates.

Don't get confused by the *precision* with which you measure your data in this classification exercise. For example, if you measure hospital stays to the nearest *day,* you might be tempted to think of this as *count* data (0, 1, 2, 3, 4, . . . etc. days). Time, though, is *always* measurement data.

Single Point Measures of Process Performance

The charts presented below (Line Graphs, Run Charts, etc.) are pictures" of the process' performance. In addition to these pictures, we often characterize a set of data by measures that help us understand where the **center** of a set of data lies (*Central Tendency*) and how much the data **varies** (*Variability*). Three popular measures for each of these are presented on the following page.

Measures of Central Tendency

Measure	Description & Use	How to Calculate
Mean	The Average of a set of numbers. The most commonly used measure of the data's center. Remember, when you calculate an average, about half of the raw data will be above and half will be below the average - this does not translate into one half good and one half bad!!	$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ where: Σ is the symbol for "sum of" n is the number of data, and x_i are the data values
Median	The midpoint of a set of numbers placed in rank order. The median is a preferred measure of the data's center when there are very large or small values, i.e. when the data is skewed.	for an odd number of data: $x_{(n+1)/2}$ for an even number of data: $\frac{x_{n/2+1} + x_{n/2}}{2}$
Mode	The most frequently appearing number(s) in a set of data. Useful when data displays wide variation, perhaps due to mixed processes.	For the data set: 1,2,2,3,3,3,3,4,4,5,5,6,7 three is the mode

Measures of Variability

Measure	Description & Use	How to Calculate
Range	The difference between the largest and smallest values in a data set.	$R = x_{\max} - x_{\min}$
Variance	The sum of the squared differences of the data from the mean, divided by the number of data less one.[4] Forms the basis for the standard deviation.	$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$
Standard Deviation	The square root of the variance. The Standard Deviation can be thought of as a "distance" measure - showing how far the data are away from the mean value.	$s = \sqrt{s^2}$

[4] This is the *sample* standard deviation. If the entire *population* is known, there is no need to subtract one from *n,* the number of data.

2.3 LINE GRAPHS & RUN CHARTS

Purpose

Line graphs are basically graphs of your performance indicator/CTQ taken over time. They help you see where the “center” of the data tends to be, the variability in performance, trends, cycles and other patterns. Line graphs are very simple to construct.

One of the most important factors to keep in mind for line graphs is that the data must be plotted *in the order in which it occurs.* Losing this order will prevent you from seeing patterns that are time dependent.

Application

Virtually any data can be placed on a line graph (as long as you’ve kept it in order of occurrence).

Some typical line graph applications include:

- Quality Indicators/CTQs - Turn-around Times, Errors, Defect Rates, Defective Proportions, Physical parameters - Condenser Vacuum, Machine Start Times, Setup Times, Pressure, Temperature Readings taken periodically, chemical or drug concentrations (peak and trough levels),

- Personal data - Weight, heart rate,

- Financial Data - Salary Expense, Supply Costs, Sales, Volumes.

Construction of Line Graphs

1. Draw a vertical and a horizontal axis on a piece of graph paper.

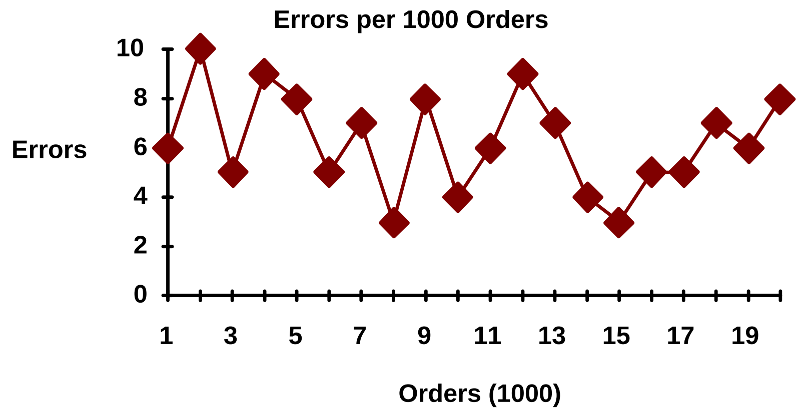
2. Label the vertical axis with the variable being plotted.

3. Label the horizontal axis with the unit of time or order in which the numbers were collected (i.e. Day 1, 2, 3, . . ., Customer 1, 2, 3, . . . etc.).

4. Determine the scale of the vertical axis. The top of this axis should be about 20 percent larger than the largest data value. The bottom of this axis should be about 20 percent lower than the smallest data value. This let’s you see the best picture of the process’ variability. Label the axis in convenient intervals between these numbers.

5. Plot the data values on the graph number by number, preserving the order in which they occurred.

6. Connect the points on the graph.



7. (Optional) Calculate the mean of the data and draw this as a solid line through the data. This turns the *line graph* into a *run chart* - trends and patterns are often easier to see with a *run chart.*

Construction Notes

Try to get about twenty five (25) data points to get a line graph running. If you have less, go ahead and plot them anyway. It's good to start trending performance no matter how many points you currently have (i.e. if you process only "produces" one data per month - *salary expense, supply costs, etc.* - don't wait two years to start your line graph!).

Now, here's how you actually get these 25 points for a line graph. If you are dealing with **measurement data** (time, cost, etc.), then *each* event you measure represents a data point to be plotted. Each patient's *temperature* measurement could be plotted on a line graph: 98.5, 98.7, 98.6, 99.0, 98.4, etc.

If you are dealing with **count data**, though (or even worse, percentages made up of count data), then there are a few guidelines that may cause some data "heartburn."

For typical count data, the guideline is that the **mean** of the data you plot should at least equal to 5, and no *less* than 1. Let's say you are counting the number of errors that occur on a daily basis. You get these numbers for a week's worth of errors: 7, 10, 6, 5, 8, 7, 6. The mean of errors (daily) is 7. This number is greater than 5, so you can plot the daily values as individual point.

We apply this rule for two reasons. First, to "see" variation in the process, we need to keep the data away from the horizontal (0 value) axis. The second reason lies in why you are taking the data in the first place: *to take action*. If you want to detect whether your change has had an effect, you'll want to see its impact on the line graph.

Now let's look at a different set of values. In counting orders for a particular specialty magazine (again, daily), a publications distributor finds that their first week gives this data: 0, 1, 0, 2, 1, 0, 1. Here, the daily mean value is less than 1. This *mean* doesn't meet the guidelines and plotting these data won't produce a very useful line graph.

The distributor could group the data by combining enough days to make the mean equal or better than 5. In this case, there are 5 orders occurring per week. So, instead of plotting the daily occurrence of orders, they plot the weekly orders. To get a line graph going here, note that they are going to have to observe at least 125 events (25 points x 5 - mean).

This is difficult since it's now going to take about 25 weeks to get a *complete* line graph instead of only 25 days. This kind of thing happens often when we start to stratify processes that are low volume to begin with for the company down to an individual department. The process just doesn't give us enough data for a line graph.

One way of getting around this problem is to plot the *time between events*. For example, one company was studying employee injuries. They measured the time between injuries. Since this is measurement data, it "only" took 26 injuries to get a good line graph going.

Percentage (or Proportion) Data - The guideline for plotting one point on a line graph (where the percentage is count data divided by count data, i.e. errors per 1000 orders) is that the *numerator's* mean should be greater than or equal to 3 and the *denominator's* mean should be greater than or equal to 50. You can see the implications of this on the amount of data and time needed to get a line graph going.

Run Charts

Run charts are also graphs of data over time or sequence. They are used to display variation and determine if special cause and/or common causes of variation are present.

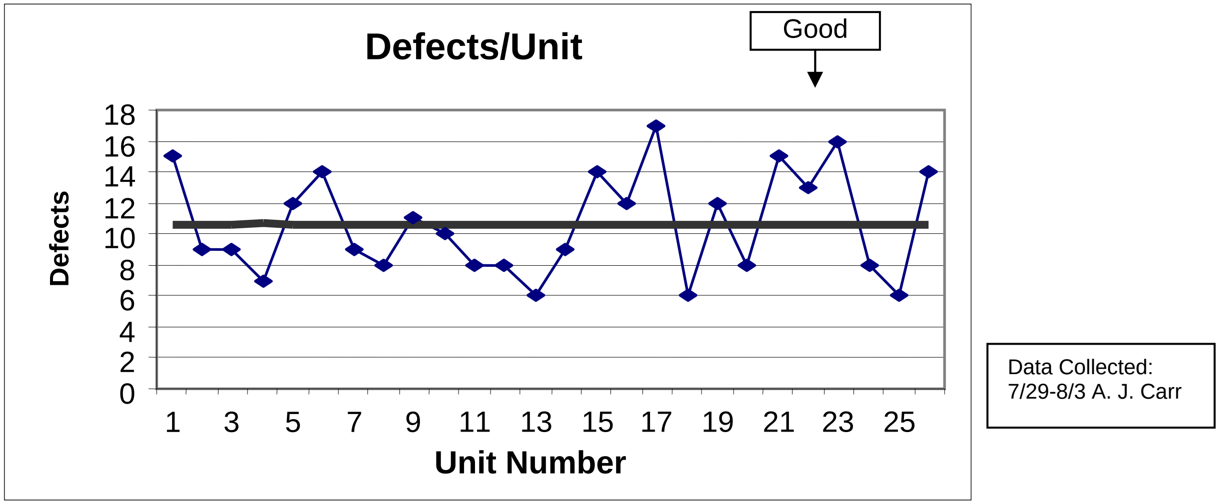
Construction of Run Charts

1. Draw a set of axis and label them with the time or sequence of the data on the X-axis and the measure on the Y-axis.

2. Scale the Y-axis so it shows values 20% above and zero or 20% below the values to be plotted.

3. Plot the data in the sequence they occurred and connect the data points with lines. These lines denote that the data is sequential. In order to evaluate variation, at least 25 data points are needed. More is better.

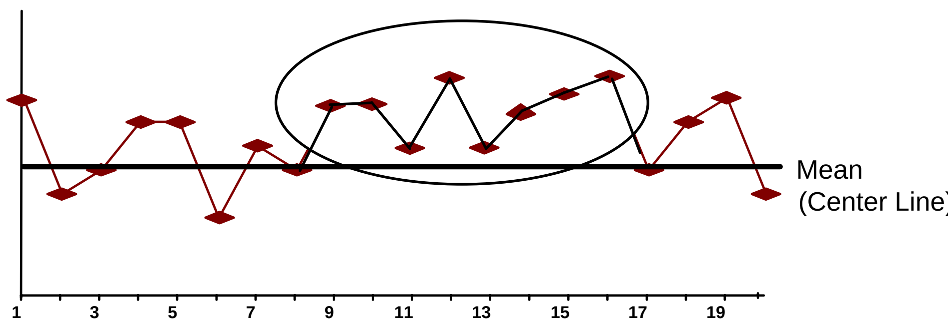
4. Calculate the mean and plot it on the graph as a reference. Be sure to label the graph and show the source of the data. Note the mean value should be at least 5 or greater to be able to interpret the run chart for special causes. It's always good to show a target and the direction of improvement on graphs.



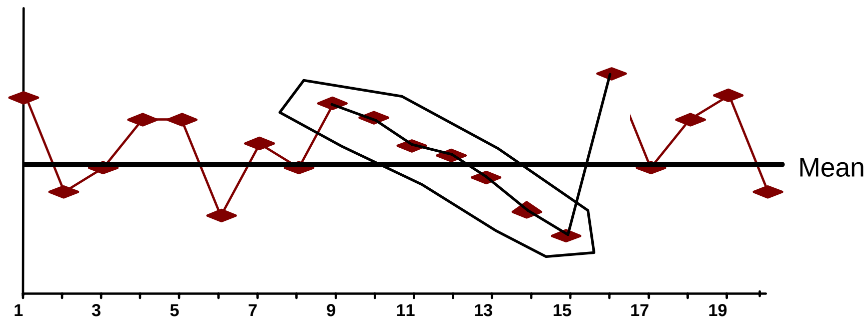
Run Chart Interpretation

Random patterns of data on run charts note common cause variation. Common cause variation is always present. Non-random patterns note special causes or that something has changed in the process. **Patterns to look for include:**

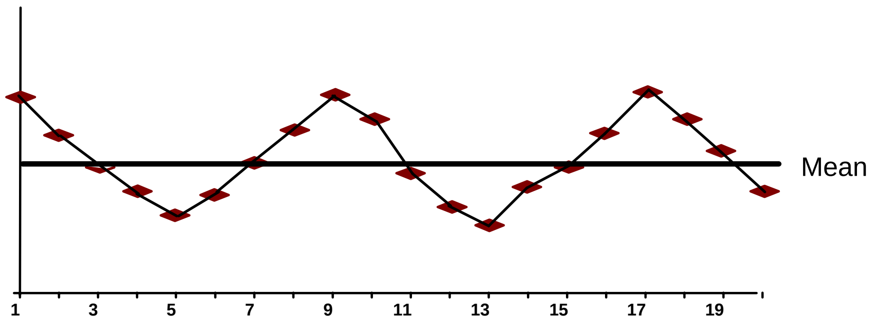
- Shifts, 8 or more consecutive data points either above or below the centerline. Points on the centerline are ignored and do not make or break a shift.



- Trends, 7 or more consecutive data points going up or down. Equal consecutive values are ignored and do not make or break a trend.



- Repeating patterns, any non-random pattern may be a special cause signal. Generally if the pattern occurs 8 or more times it should be investigated.



- Extreme Values, isolated values that are extremely high or low with respect to the rest of the values may be a special cause. Single values can be difficult to interpret with run charts. Control charts are better for identifying single points.

Dealing with special causes

When a special cause is noted in the data, you should investigate what caused it. A change in the process is a prime suspect. Look for different materials, equipment, people or procedure. Special causes may not be "bad," they could be something that you want to repeat. You may also take the next step in analyzing this kind of data – *Control Charts (Section 7).*

2.4 BAR CHARTS

Purpose

The purpose of a bar graph is mainly to show *differences* between categories. Some special bar graphs can be used to show trends over time, but please don't use bar graphs where a *line graph* is more appropriate. In the early PC days, once somebody loaded *Harvard Graphics™* on their personal computers, all you'd see for the next year were bar graphs, appropriate or not!

Application

Some typical bar graph applications are listed below. Today, newspapers and magazines are great sources of bar graph examples. We always look forward to seeing how *USA Today™* will show the results of surveys or other data!

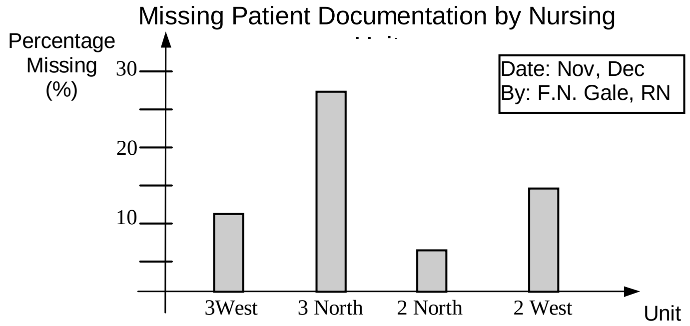
- Defects categorized by type, location, assembly stage, etc.
- Any variable stratified by categories: Hospital Length of Stay by physician, Sales by Region or Store, power generation by fuel (nuclear, coal, oil, or gas), alcohol consumption by age group, etc., etc.

Construction & Examples

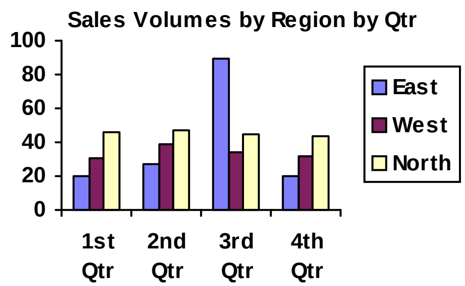
"Basic" construction steps are very simple:

1. Gather the data and sort it into categories of interest.
2. Draw a vertical and horizontal line on a piece of graph paper.
3. For a *vertical* bar graph, label the vertical axis with the performance measure. Label the horizontal axis with the categories.
4. Scale the vertical axis from zero to a value 10 - 15 % higher than the largest category.
5. Draw the bars, title and label the graph.

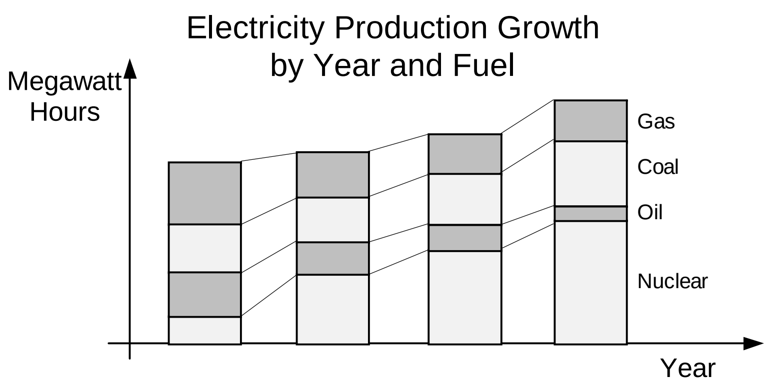
Here's a simple bar chart displaying differences between nursing units:



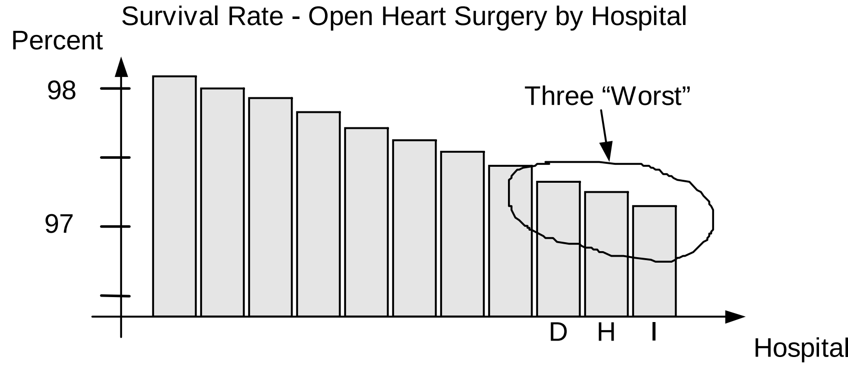
Combining two or more categories on a bar chart can communicate a great deal of information in a single picture:



Stacked Bar Charts are also compact, powerful communicators of information:



There's one caution we'd like to point out with bar charts. It's very easy to enter some performance data and arrange it on a bar chart in increasing or decreasing order. The eye is then drawn to those categories that are the highest or lowest and we may think that the "top three" or "bottom three" categories need to be improved:



Would you be reluctant to have open-heart surgery at hospitals *D, H,* or *I?* Well, first of all, looking at the vertical scale, your survival chance at these hospitals is about 97.25%, versus about 98% at the three "best" hospitals. Three quarters of a percent isn't a big difference.

Second, there will be variation in every process. Are the survival rate differences *significant*, or are they just the result of random and expected variation? (see *your Black Belt* to answer these questions)

We can order any set of data and calculate the average value. But remember this important and astonishing fact:

In any set of data, about half the data will be above the average and half will be below!!!

We see advertisements like this all the time. Of course they're trying to sell us something, but we've got to look beyond the surface.

2.5 PIE CHARTS

Purpose

The Pie Chart takes a set of data divided into categories and displays the relative proportions as “slices.” Categories appearing as larger slices make up a larger fraction of the whole.

The Pie Chart is often used during improvement projects to help prioritize which piece of the problem will receive further attention and study.

Application

Any variable that can be broken down into categories is a candidate for analysis through a Pie Chart – needle-sticks broken down by type, product assembly defects broken down by type, shift, or assembly point, injuries broken down by type, job, or department, total sales by region, department or store are just a few examples.

Construction

1. Collect the data and organize it by category. Total the number of events by category, or sum the performance measure for each category (e.g. add the sales for each store within one region, then the next, etc.).

    Note: If there are some categories that contribute very little to the total, you can group their contributions into an “Other” category.

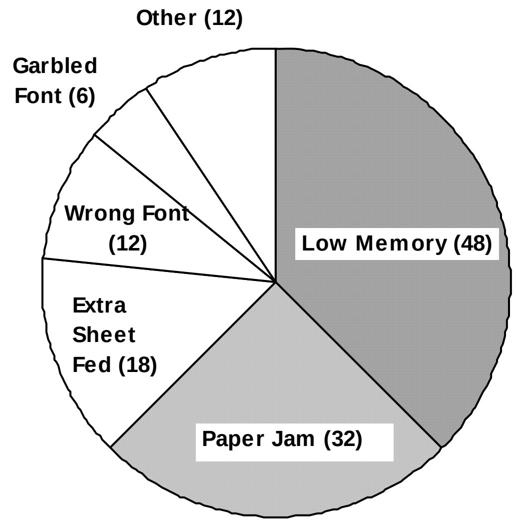
2. Calculate the category fractions by dividing each category’s total by the grand total (i.e. divide the Northern Region’s sales by the Total Sales).

3. If you can divide a circle into one hundred parts, then multiply each fraction by one hundred. Starting at the 12:00 position, mark off the slices, from largest category to smallest (or the “Other” category).

    Note: If your circle is divided into 360 degrees, then multiply each fraction by 360. This will give you the number of degrees associated with each category’s slice.

4. Title and label the Pie Chart.

Here’s a Pie Chart of printer errors that occurred during a development test of a new laser printer:



Pie Chart of PC Printer Errors - Model PH-6

You can see that the engineers should improve the printer’s memory and paper handling qualities before sending Model PH-6 to production.

2.6 RADAR CHARTS

Purpose

Sometimes, we may want to display several different variables on one chart, perhaps to compare their relative performance. The Radar Chart helps us do this.

Application

Customer and employee surveys often measure several different variables or quality characteristics. The Radar Chart is used to display the performance of these individual characteristics and to look for relative strong or weak areas in the product or service's performance.

Construction

1. Collect the data for the different variables or quality characteristics.

2. Draw a circle and put a dot at its center. Draw a radius for each variable to be shown on the Radar Chart. Space these radii equally:

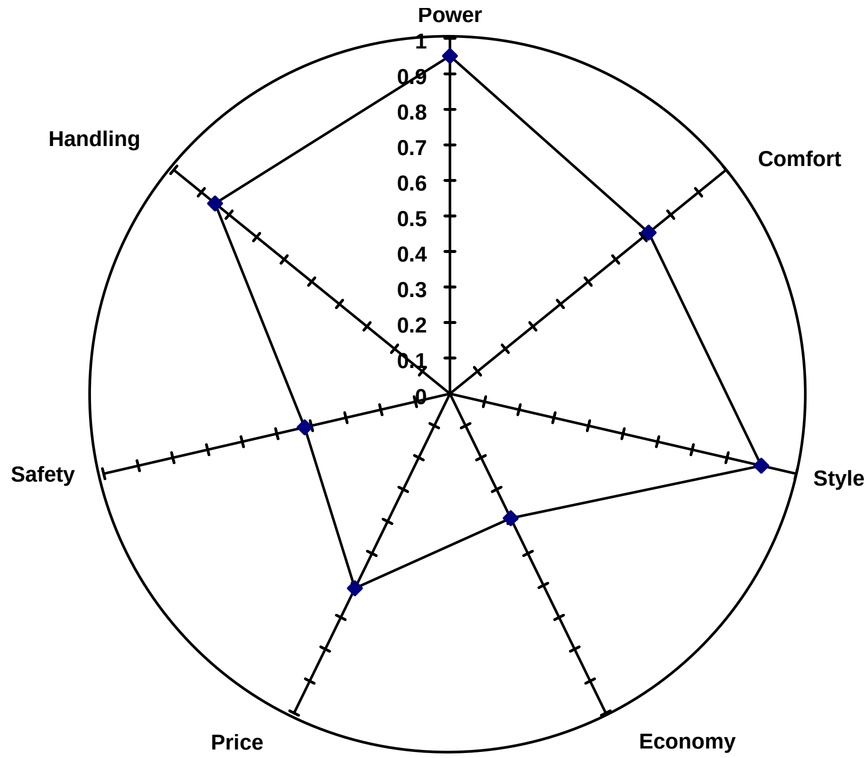
Number of Variables	Degrees between Radii
4	90
5	72
6	60
7	51.4
8	45
9	40
10	36
11	32.7

3. Scale each radius. For survey data, the responses are often obtained using a Likert scale (e.g. 1 to 5). For this data, scaling should start with the center of the circle labeled 1 and the circumference labeled 5. If the data is percentage type, a similar procedure is followed with 0% at the center and 100% at the circumference.

4. For each variable, draw its value as a point on its radius (the results of multiple surveys may be averaged and the averages plotted).

5. Join each point with a line, title and label the Radar Chart.

Rallye Motor Company
"*Stallion*" Sports Coupe Customer Survey



For most products and services, the Radar Chart should be "unbalanced." That is, certain quality characteristics are perceived as stronger than others by customers. These are the "selling points" of the product or service. The market research, planning and design processes should identify these selling points and build them in to the design.

Of course, characteristics that are unusually or unexpectedly weak or poor performers are candidates for improvement.

Two or more products or services may be compared on one Radar Chart. This can be an effective way of comparing your performance to your competitors or an old product or service to a new one.

2.7 COMPARISON OF LINE, BAR, PIE AND RADAR CHARTS

Here's a quick comparison of the charts and graphs we've introduced so far:

Chart	Advantages	Disadvantages
Line Graph	Makes trends and data variation over time easy to track. Good for highlighting changes in some variable. Can be used to track more than one variable at a time.	Can lead to "overreaction" to changes that aren't really there. Control charts are the best tool for studying variation.
Bar Chart	Good for comparing one category to another. Many different styles can be constructed (stacked bar, "3-dimensional" bar chart, etc.) Easy to construct.	Sometimes inappropriately used for tracking data over time. Similar danger to overreaction as line graph.
Pie Chart	Useful for showing relative proportion of each category to the whole. Several layers of stratification can be shown on one graph.	Should not be used for tracking data over time.
Radar Chart	Useful for showing performance of many variables or characteristics on one chart. Useful for comparing two or more products/services across many characteristics.	Not useful for tracking data over time, although "before & after" comparisons can be made.

2.8 PROCESS CAPABILITY

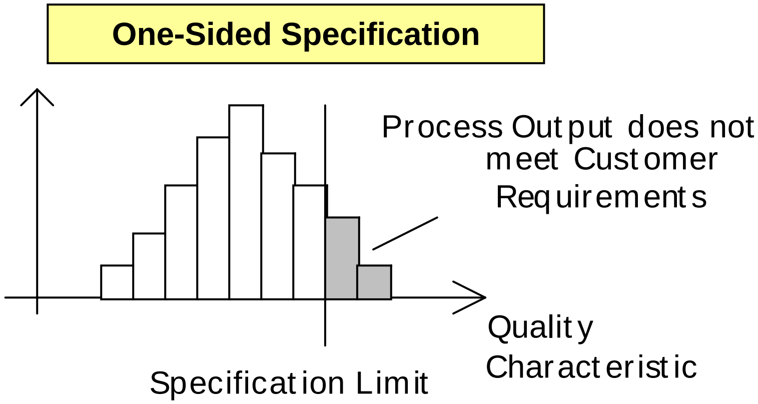
Process Capability is a ***concept*** with associated ***metrics*** that addresses the issue

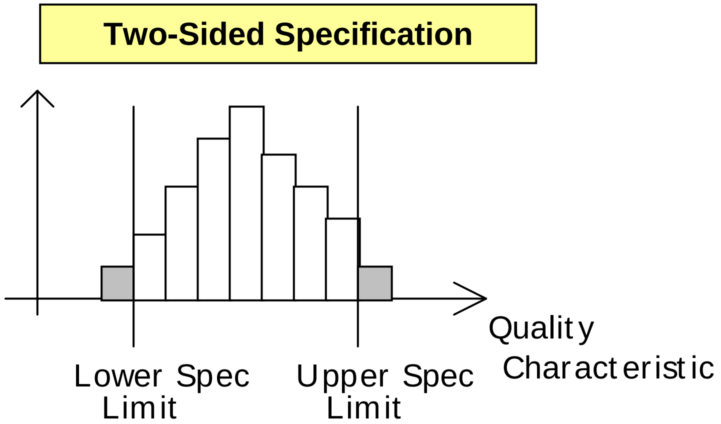
"How well does our process' output (product or service) meet the valid requirements of the customer?"

We'll explore one way of graphically depicting Capability and three *measures* of Capability. Process Capability is one of the crucial links between **process control** and **process improvement.**

A Picture of Process Capability

The Histogram (see Section 4) is the best tool to examine the *capability* of our processes, especially when we are dealing with measurement data. Here's the picture:





Through our knowledge of the customer, we have set a target or specification limit(s) for the individual outputs of our process. We see from this picture that some fraction of our process' output does not meet our customer's expectations. Sometimes, our customers have requirements that set both an upper and lower specification on our process (Papa Bear's porridge was too hot, Mama Bear's was too cold, but Baby Bear's porridge was just right!). In this situation, our process can fail in two ways to produce an output that meets customer requirements. The distance between these two specifications is known as the customer's *tolerance*. Let's turn these pictures into a measure that is called the Process Capability Index.

Measures of Process Capability

There are several measures of process capability. We will provide you with three that you can use to calculate a process capability index.

Inherent Process Capability Index – C_P

The first measure is called the *Inherent* Process Capability Index and is given the symbol "C_p." This index is a ratio of the customer's *tolerance* (i.e. maximum variation that the customer is currently willing to accept) to the process' *dispersion* (i.e. variation that our process is currently producing). If our customer cares about both an upper and lower specification limit for the outputs of our process, then the *tolerance* is simply the difference between these two values:

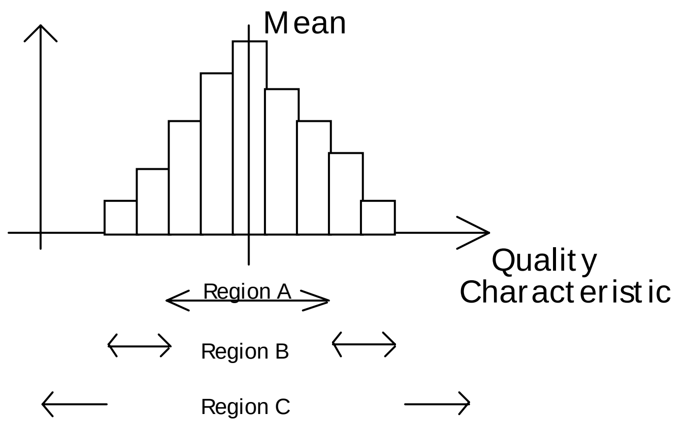
Customer's Tolerance = Upper Specification Limit - Lower Specification Limit

Previously, we mentioned three measures of *variability*: the Range, the Variance and the Standard Deviation. For this process capability index, we are going to use the Standard Deviation and will use a value of 6 times the standard deviation as the measure of our process' dispersion. Where does this value of "6" come from?

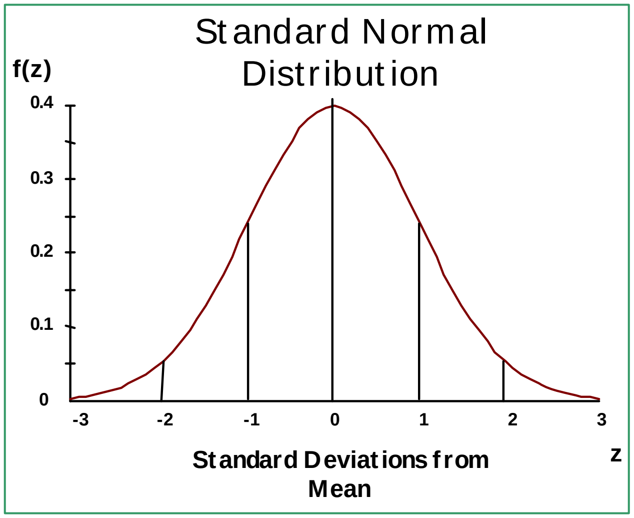
The Standard Deviation gives us a measure of the dispersion of the process. If one process has a standard deviation of 6 "arglebargles" and another a standard deviation of 3 "arglebargles," then we understand that the second process has less dispersion than the first.

The Standard Deviation can also help us in another important way. As we've seen, the individual outputs of our processes will tend to gather around some central point that we measure using the mean or the median. As we move away from this central point (on either side), the chances of finding an output from the process get smaller and smaller.

The process shown to the right is fairly likely to produce an output in **Region A**, less likely to produce outputs in **Region B**, and highly unlikely to produce outputs in **Region C**. It turns out that we can estimate the chances of having an output of our process occur as a function of the *number of standard deviations we are away from the process mean or average.*



Look at the nice smooth, symmetrical (i.e. a normal or Gaussian or "Bell Curve") distribution that you see below. For this situation, consider a band that goes from one standard deviation to the left of the mean to one standard deviation to the right of the mean. Observing a process with this type of distribution, we would find that about 68% of the process outputs would fall into this band.



If we stretched this band to two standard deviations on either side of the mean, about 95% of our process output would be observed to fall here. Finally, stretching to three standard deviations on either side of the mean, about 99.7% of our process output would be found in this band. For this last case, only 0.3% (about 3 in 1000) of our process outputs would be found outside a band that includes plus or minus three standard deviations from the mean.

Now you can see how we chose 6 times the standard deviation as the measure of our process' dispersion. If the difference between the upper and lower specification limits of our process is the same as plus or minus three standard deviations around the mean, then only 3 in 1000 process outputs would **not** meet customer requirements. We would say that our process is "fairly" capable of meeting customer requirements.

The Inherent Process Capability Index is now easily defined:

$$\textit{Inherent Process Capability} = \frac{\text{Upper Specification} - \text{Lower Specification}}{6 \times \text{Process Standard Deviation}}$$

If our process has only one specification (an upper or lower), we simply calculate the inherent process capability like this:

$$\underset{\text{(One Spec Only)}}{\textit{Inherent Process Capability}} = \frac{|\text{Specification} - \text{Process Mean}|}{3 \times \text{Process Standard Deviation}}$$

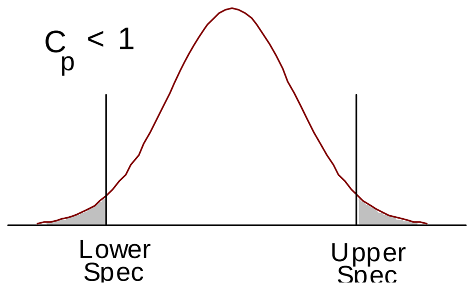
Note that the absolute value of the specification-process mean difference is taken for the one-sided spec case. You can see that the index is essentially a ratio of "distances" - the numerator is the "distance" (tolerance) of the customer, the denominator is the "distance" (variation) of our process.

Values of Process Capability

When we first learned about process capability in the mid-1980's, a process capability index of 1.33 was considered to be very good. Now, we read reports of process capabilities in excess of 2 or 3. For example, *Six Sigma* aims for a process capability of 2. If you reach this state for one of your processes, then you're probably among the world-class performers for this process and should probably consider picking another process to improve!

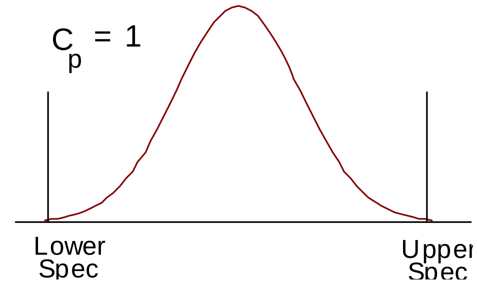
Ratio < 1

If this ratio for our process is less than 1, then that means that a significant fraction of our process output is not meeting customer requirements; i.e. our process is not very capable.



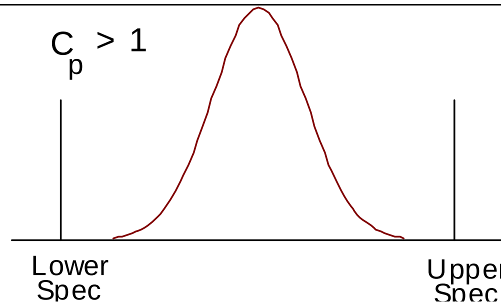
Ratio = 1

If the Process Capability Index is equal to 1, then, as we said above, only about 3 in 1000 process outputs are not meeting customer requirements.



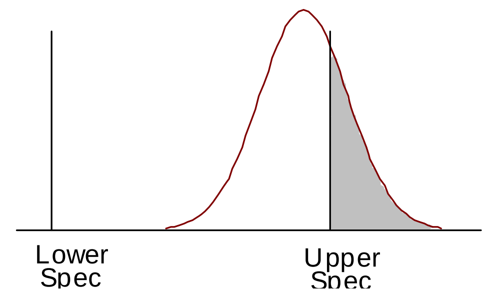
Ratio > 1

Finally, if the Process Capability Index is greater than 1, then there is a very small chance of our process producing an output that does not meet our customer's requirements.



Process Not Centered

Here, the inherent capability is good, but the picture shows that the process is producing defects due to centering problems.



The Operational Process Capability - C_{pk}

In the *Process Not Centered* situation, the calculated *inherent* process capability index could be greater than one, but there may be a large fraction of the process being produced outside the upper specification. The process is said to have an *inherent* capability; if we could shift the mean of this process and center it between the specification limits, then the process would truly be capable. This issue reinforces the Second Law of Statistics - “Draw the Picture.” If a tabular report of *inherent* process capabilities came to your desk, you would not know which processes were centered and which were not.

The “centering” difficulty with the *inherent* process capability index leads us to another measure of process capability: the Operational Process Capability Index (C_{pk}). This measure is not much more difficult to calculate, and it handles the situation where the process is not centered between the specification limits. We will use a technique called the “Z-min Method” to calculate the Operational Process Capability (C_{pk}).

For a one-sided tolerance (only upper or lower specification limit), first calculate Z-min:

$$Z_{\min} = \left| \frac{SL - \overline{X}}{s} \right|$$

where :

$Z_{\min}$ - number of standard deviations the proces mean is from the specification limit

SL - Upper or Lower Specification Limit

$\overline{X}$ - Process Average

(use the formula presented earlier in this section)

s - Process Standard Deviation

(use the formula presented earlier in this section)

For a two-sided tolerance interval (both upper and lower specifications), calculate Z-min as follows:

$$Z_{USL} = \frac{USL - \overline{X}}{s} \qquad Z_{LSL} = \frac{\overline{X} - LSL}{s}$$

and

$$Z_{\min} = Minimum(Z_{USL}, Z_{LSL})$$

where :

$Z_{\min}$ - minimum number of standard deviations the process mean is from a specification limit

USL - Upper Specification Limit

LSL - Lower Specification Limit

$\overline{X}$ - Process Average

(use the formula presented earlier in this section)

s - Process Standard Deviation

(use the formula presented earlier in this section)

The Operational Process Capability Index is then calculated as follows:

$$C_{pk} = Z_{\min}/3$$

where:

C_{pk} - Operational Process Capability

Note how this index compares to the Inherent Process Capability Index. If the Z-min value is 3.0, then the distance from the mean to the closest specification limit is 3 process standard deviations and the Operational Process Capability index is 1.0. This is the same result we would get if we calculated an Inherent Process Capability index for a one-sided specification limit. Although we can't say that less than 3 in 1000 items will be produced within the spec limits (because we've "ignored" the distance from the mean to the farther spec limit), the Operational Process Capability is similar in concept to the Inherent Process Capability index. Some organizations report a process capability as compared to the Upper Specification limit and the Lower Specification Limit. The Z-min formulae shown above (and divided by three) can be employed to calculate these capability indices.

Process Capability Studies

Process Capability Studies are a long-term evaluation of a total process. Data is collected periodically in subgroups of consecutive pieces. In many cases, it is convenient to use the data gathered for statistical process control purposes. The process capability study will include the effect of all sources of variation:

- Raw material sources,
- Operators,
- Gauge users,
- Production rates, and
- Environmental conditions.

Also included in the total process variation will be the effect of the process control method. For example, we could be controlling the process with a control chart using subgroups of three. This will permit the process average to wander more without a high probability of detection than if we were using a subgroup of five or six. The process capability assessment estimates the variability of dimensions or characteristics and compares this variation to the specification in terms of Process Performance Index (P_{pk}). If the Process Performance Index is greater than or equal to 1.33, the specification will be satisfied. The larger the ratio, the less we are using of the available tolerance. For Process Performance Index, we use the computation:

$$P_{pk} = \frac{\left(USL - \bar{\bar{x}}\right)}{3\hat{\sigma}} \quad \text{or} \quad \frac{\left(\bar{\bar{x}} - LSL\right)}{3\hat{\sigma}_x}$$

The Process Performance Index takes into account both the special and common cause sources of variation over time. The variability of the processes and how well the process is centered are both considered. We use the minimum value to determine our index.

To compute P_{pk}, we should use the estimate of standard deviation based on individuals rather than average range. P_{pk} is based on standard deviation of individual measurements and estimates the total variation of the total process. This is the best estimate of what is coming from the process and being shipped to the assembly line or customer.

P_{pk} is computed with the standard deviation based on average range predicts the potential of the process based on existing common cause variation.

Steps for Assessing Process Capability (PC)

1. Accumulate data in subgroups of consecutive parts taken periodically from production runs. If the same process produces a variety of part numbers with different target dimensions, each different part should be treated as a separate process unless we have evidence that the variation about the targeted dimension is not affected by the normal value.

   For example, if we are grinding shafts and from previous machine capability studies we know that the inherent variation of the machine is a function of the nominal dimension, such that a 1.000" shaft has a standard deviation of 0.0002" but a 1.250" nominal shaft has a standard deviation of 0.0004", we must treat these two shafts as two distinct processes each with their own PC. However, if the machine standard deviation is unchanged regardless of which nominal diameter is ground, the overall PC for the entire family of shafts can be assessed. The easy way to do this is to record the data as a deviation from nominal dimension. In other words, if we are processing shafts with a nominal print dimension of 1.000", a shaft measuring 1.002" would be recorded as a "plus .002". If another shaft had a nominal or targeted dimension of 1.200" and it measured 1.202", it too would be a "plus .002".

2. Data should be accumulated over a long enough period of time that all sources of variation have an opportunity to be exhibited (25 subgroups of 4 taken over a "long" period of time is a guide). Check for process stability.

3. Test the data for shape of distribution.

4. If the distribution is normal, compute the standard deviation based on individuals. If the data is not normal, either transform the data or perform a capability analysis using the Weibull distribution (see Minitab, Help topics, *process capability: non-normal data* for more information).

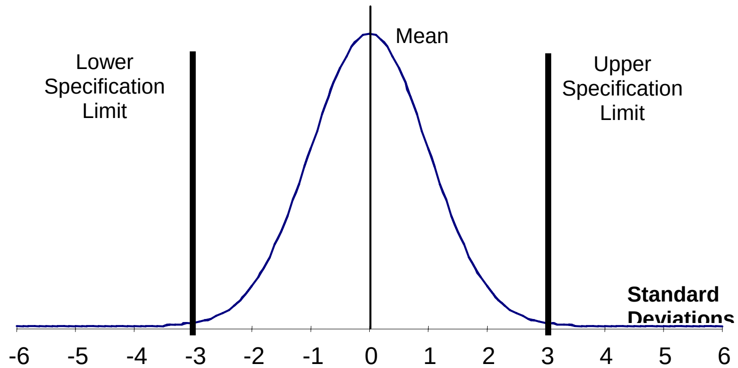
5. Calculate PC based on six standard deviations divided into the available tolerance.

6. Calculate PC using standard deviation based on the average range. Compare this with the value obtained in step 5 to see what the potential of the process is given better controls or improved stability of mean performance.

Capability and Six Sigma

Sigma is a measure of process capability that builds on the preceding discussions. Recall that the process' distribution is characterized by three main elements:

1) The center of the data (as measured by a mean, median, or mode),
2) The spread of the data (as measured by a range, standard deviation, or variance), and
3) The shape of the data (characterized by some mathematical function that best fits the data, such as the exponential, normal, log-normal, Weibull, or Raleigh).



For a given distribution, the distance from the mean to the specification limits expressed as standard deviation multiples will correspond to a given fraction defective. For the normal distribution, about 34% of a process' output will fall outside one standard deviation (above and below) the mean and only 3.4 parts per million fall outside 4.5 standard deviations. Since sigma (σ) is statistical shorthand for the standard deviation, we can express the capability of a process in terms of a number of "sigmas." The higher the sigma of a process, the lower the fraction defective, the more capable the process is of meeting its specifications.

Shifts and Drifts

We stated that only 3.4 parts per million (ppm) falls outside 4.5 standard deviations "units" away from the mean. "Six Sigma," though, is associated with the fraction defective of 3.4 ppm. What's the difference? The answer lies in how data is collected from a process and the variation inherent in the process.

Often, data will be collected over a "short" time span. During this time, some, but not all, sources of variation will be present in the process. In a manufacturing process, a variable such as *tool wear* will generally not be seen in a short time. In a service process, there may be seasonal variation. Studies of process variation indicate that the process may *shift and drift* by up to 1.8 standard deviations over the long term. 1.5

standard deviations is a typical, widely used value of shift, although each process owner is encouraged to understand their process' "shifts and drifts".

So if the *short term* data shows that we are 6 sigma multiples from the specification limits, we will *subtract* a 1.5 sigma shift and state that the *long term* capability of the process is 6 – 1.5 = 4.5 sigma. This corresponds to a long-term fraction defective of 3.4 ppm. See the *Additional Topics* section below.

Measuring Capability With Sigmas

The following procedures show how to calculate the capability of a process in *sigma* units for a single characteristic of the process.

A. Basic Method for Continuous Variables

If the data is continuous, perform these calculations to estimate the characteristic's *sigma.*

Inputs – Upper/ Lower Specification Limits, a minimum of 25 –30 data points from the process.

Process

1. Create a histogram of the data. Does the data "look" normal (or roughly so)? If yes, proceed to step 2. If not, see **Additional Topics** below.

2. Calculate the mean and standard deviation of the data:

$$\text{Mean}: \bar{x} = \sum_{i=1}^{n} x_i / n$$

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

$$\text{where}:$$

$$x_i - data\, values$$

$$n - number\ of\ data$$

Note: in Excel, the AVERAGE and STDEV functions perform the above calculations.

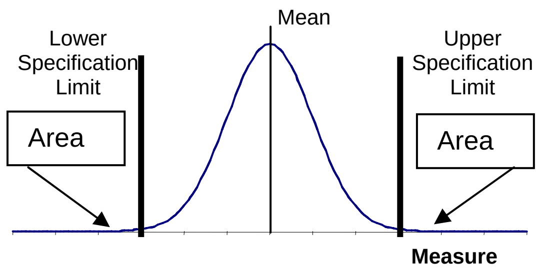
3. Find the area under the normal distribution curve to the right and left of the Upper (USL) and Lower (LSL) Specification Limits (respectively):

$$Area-1 = 1 - CumNorm\left(\frac{USL-\overline{x}}{s}\right)$$

$$Area-2 = CumNorm\left(\frac{LSL-\overline{x}}{s}\right)$$

$$\text{where}: CumNorm -$$

$$\text{Cumulative Normal Distribution}$$



Notes:

a) Some processes may have only one specification limit. Here, calculate only the appropriate area outside the spec limit.
b) In Excel, the function NORMDIST(Value, 0, 1, TRUE) provides the cumulative normal distribution.

4. Add the two areas together (Total Area = Area-1 + Area-2) and calculate the Process Yield:

$$Yield = (1 - Total\ Area) \times 100\%$$

5. Look up the Process Sigma (see the end of this Section).

Basic Method for Discrete Variables

If the data is *discrete,* perform these calculations to estimate the characteristic's *sigma:*

Inputs – Number of Units (*n*), Number of Defects (*d*), Number of Defect Opportunities (*o*).

Process

1. Calculate the Defects per Million Opportunities (DPMO):

$$DPMO = \frac{d}{n \times o} \times 10^6$$

2. Look up the Process Sigma (see the end of this Section).

Notes:

a) Both the Number of Defects and *Non*-Defects (*n* – *d*) should be greater than 5. This ensures that the DPMO/Sigma conversion of Table One, which is based on the normal distribution, is valid.
b) The Number of Defects produced should include both those that were detected prior to receipt by the customer and those defects reaching the customer.

c) A Defect Opportunity is any event which can be measured and where there is a chance of not meeting a customer requirement. Many processes have multiple opportunities to create defects.

B. Calculating the Yield of a Process

Many products and services are "produced" through a series of processes, where each process has *opportunities* to create defects. Here, the producing organization has generally assigned accountability for the different processes to different levels of management (*Note: the organization may still want to adopt the process owner concept – an individual or committee that "owns" an end-to-end process, such as derivatives trading*). One more factor comes into play here – for what *purpose* are the capability measurements being taken? Does the purpose involve reporting to external agencies (i.e. stockholders), or is the purpose to prioritize improvement opportunities? Three capability measures are used to address these issues: *1) First Pass Yield, 2) Normalized Yield, and 3) Rolled Throughput Yield.*

First Pass Yield (Y_{FP})

First Pass Yield (Y_{FP}) is the fraction of units produced by a sub-process without a defect, considering all the defect opportunities and including all defects, whether or not they are detected prior to reaching the customer:

$$Y_{FP} = 1 - \frac{d}{n \times o}$$

For a given sub-process, then, the defect opportunities (*o*) are defined (based on customer needs & requirements), a given number of units (*n*) are chosen, and the total number of defects (*d*) counted. For discrete attributes, the number of opportunities where a "Pass/Fail" judgment was made is counted, for continuous attributes; the number of opportunities where the specification limit(s) were exceeded is counted. These are summed to obtain the total number of defects. First Pass Yield will be used to calculate process sigmas, as shown below. This is consistent with the general Six Sigma philosophy of focusing on total quality costs and that the payback to the company is generally bigger to keep defects from occurring in the first place. For some reporting, though, a *Final Pass Yield* may be useful. This is simply the Yield of the process *after* detected defects have been reworked or otherwise corrected.

$$Y_{FINALPASS} = 1 - \frac{d - d'}{n \times o}$$

$$\text{where}: d' \text{ - number of defects detected and eliminated prior to reaching the customer}$$

Normalized Yield (Y_{NORM})

Normalized Yield (Y_{NORM}) is a "rolled-up" weighted average of the sub-process First Pass Yields for an end-to-end process. This measure permits comparisons across different business processes and across processes of varying complexity. It is calculated as follows:

$$Y_{NORM} = 1 - \frac{\sum_i d_i}{n \times \sum_i o_i}$$

$$\text{where}: i \text{ - number of subprocesses}$$

A "rolled-up" process sigma can be calculated from Normalized Yield (convert the yield value to a percentage and use Table One to obtain the *short-term sigma*). Y_{NORM} and associated sigma is used to communicate process capability *externally* and for *benchmarking* purposes.

Rolled-Throughput Yield (Y_{RTP})

Rolled-Throughput Yield (Y_{RTP}) is the probability of a "unit" going through all the processes without a defect. Y_{RTP} is the *product* of the First-Pass Yields of each sub-process:

$$Y_{RTP} = \prod_i Y_{FPY-i}$$

Rolled-Throughput Yield is generally used for *internal monitoring of business processes* and for *prioritizing improvement projects.* It is considered the best measure of the effectiveness and efficiency of business processes. This measure is not converted to a sigma value generally because it results in a negative sigma.

Additional Topics

Long-Term, Short Term

Continuous Attributes – Practically, the capability of continuous attributes such as time, cost, length, etc. can be calculated with "small" amounts of data (25 – 30 data). For a high-volume process, this data is then often representative of its *short-term* capability.

Discrete Attributes – When defects are "plentiful," the data required to assess capability may be considered as short-term (recall that at least 5 defects should be detected). When defects are "rare," the number of units produced may be large enough to consider the data long-term.

Reporting - The short term capability includes the effects of the common or random sources of variation and is considered to reflect the *inherent* capability of the process, whereas the long-term capability includes the additional impact of assignable causes of variation - factors which influence the process from time-to-time. Short Term capability is generally reported.

Non-Normal Data

The sigma and yield relationships shown on Table One are based on the normal distribution. If the data is *non-normal* and the process characteristic is continuous, then an alternate method of calculating sigma must be used. In some cases, the data can be *transformed* a normal distribution (e.g. time to complete a process is often skewed, this data may be transformed via logarithms to a normal distribution). *Note: Some misinterpret this issue to state that only normally distributed data can be used to calculate a sigma – this is **not** the case.*

Continuous vs. Discrete Data Measurement

Often, the customer desires that some target value be consistently achieved, although they are willing to *tolerate* some variation from the target. The simplest example is that of a plane schedule, where the need is to depart and arrive *on time.* The customer may have some *tolerance* for variability in this process; for example, arrival within 10 minutes of the schedule may be tolerable. 10 minutes, then, is the upper specification limit for the CTQ of arrival time.

Given this situation, it is easy for a company to shift it's focus from *on time performance* to just *meeting specifications* - i.e. as long as the plane arrives before the 10 minute spec limit, then things are OK. Although process owners may become defensive if we focus on their performance *inside* the spec limits, this represents a "goalpost" mentality. Taguchi's *Quality Loss Function* challenges this by postulating that any departure from the target causes some *loss* to the customer. If the plane arrives 30 minutes late, each passenger will have suffered some loss (e.g. the value of 30 minutes work at the office). In his model, the specification limit is merely the point at which deviation from the target becomes *unacceptable* to the customer.

The Six Sigma approach does incorporate Taguchi's thinking through its focus on variation reduction, but the "goalpost" mentality can creep in through the way process data is collected. In the arrival example, we could either record actual arrival times (*continuous data*) and compare them to the target and spec limits, or simply record the number of times we failed to meet the specification limits (*discrete data*). Consider the following data:

Airline A

Flight	12/1	12/2	**12/3**	12/4	12/5	12/6	12/7	12/8	12/9	12/10
Δ	+9	+4	**+14**	+7	+2	+6	+9	+8	+3	+7

Airline B

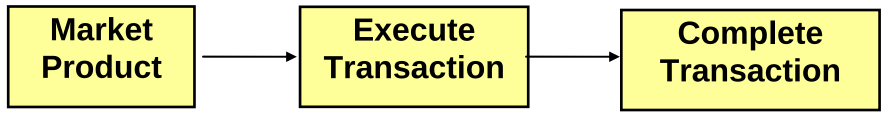
Flight	12/1	12/2	12/3	12/4	12/5	12/6	12/7	12/8	**12/9**	12/10
Δ	0	0	0	+1	0	0	+2	0	**+12**	+1

Δ = Actual Departure Time - Scheduled Departure Time

Both airlines have a defect rate of 10% - one flight of ten left beyond the 10-minute departure spec limit. Inspection of the "Δ's," though, reveals that airline B typically departs close to schedule and that the variability of departure times is much less for B than A. Also, since Airline A's performance is often close to the spec limit, we would expect to see defects produced from their process. The 12/9 Δ of 12 minutes for Airline B appears to be a special instance, one not to be ordinarily expected from their process. To summarize, the *continuous data* gives us a better picture of the performance of the process than the *discrete data*. For reporting purposes, we may choose to use the defect rate since it provides a quick picture of performance; for analysis, the continuous data displayed on a histogram with associated targets and spec limits is preferable.

Process Sigma Calculation Example

Here, we'll examine a "simple" transaction process (such as selling a client an air conditioner); develop sigma/yield estimates for individual characteristics/CTQs and the overall process. The three steps of the trading process are:



For simplicity, we will consider transactions involving existing products for existing clients. The *deal* is the unit produced; a few of the opportunities to create defects are listed below by process:

Process Step	Defect Opportunities	
Market Deal	• Misunderstand client requirements • Recording errors	• Inaccurate Price • Deal not compliant with Regulations
Execute Transaction	• Error-caused amendments • Recording Errors	• Sales/Order Transaction Mismatch
Complete Transaction	• Order Errors • Fulfillment Errors	• Confirmation Timeliness • Client/Company Confirmation Mismatch
Overall	• Lost Sale	

The following page shows the calculations performed to estimate process sigma. Note that this data is assumed to represent the *long-term* performance of the process, but short-term sigma values are *reported*, per the discussions above. The sigma values were calculated using the Excel NORMINV(Yield, 0, 1) function, to which 1.5 is added to obtain the short-term sigma value.

Some Notes on Capability Calculations

Although you can do the index calculations, if the process is not *stable*, then we really don't recommend examining the process' capability. This surfaces an "old" philosophy of process improvement that still has validity. **First** understand the performance of the process (run or control chart). Then work to eliminate assignable causes of variability. When the process is stable, then assess the process' capability and if it is not capable, work to identify the common causes of variation and improve the process from this perspective.

Yet another note: We have been dealing with measurement data for these calculations. For count data, the measure of process capability is easier. If we are dealing with *defective* items, then either the average number of defectives (per sample) or the average fraction (or percent) defective gives us a measure of the process' capability.

If we are dealing with *defects*, then the average number of defects (per area of opportunity) or the average defect rate gives us the capability of the process. Note that if you have a control chart for your process, the Center Line of the chart tells you your process' capability.

Transaction Process Sigma Spreadsheet

Process Step	Defect Opportunities	Data Type	No. of Units	No. of Opp's.	Defects	Avg.	Std. Dev.	Upper Spec	DPMO	Yield	Sigma (ST)	Step Yield	Step Sigma
Market Product	Misunderstand client requirements	D	1000	1	120				120000	88.00%	2.67	93.83%	3.04
	Recording errors	D	1000	1	90				90000	91.00%	2.84		
	Inaccurate Price	D	1000	1	25				25000	97.50%	3.46		
	Deal not compliant with Regulations	D	1000	1	12				12000	98.80%	3.76		
Execute Transaction	Error-caused amendments	D	1000	1	100				100000	90.00%	2.78	93.23%	2.99
	Recording Errors	D	1000	1	58				58000	94.20%	3.07		
	Sales/Order Transaction Mismatch	D	1000	1	45				45000	95.50%	3.20		
Complete Transaction	Order Errors	D	1000	1	8				8000	99.20%	3.91	97.58%	3.47
	Fulfillment Errors	D	1000	1	22				22000	97.80%	3.51		
	Confirmation Timeliness	C	1000	1		2.5	0.7	3	237525	76.25%	2.21		
	Client/Company Confirmation Mismatch	D	1000	1	67				67000	93.30%	3.0		
Overall	Lost Sale	D	1000	1	89				89000	91.10%	2.85		
											Overall (Normalized) Process Yield:	95.55%	
											Rolled Throughput Yield:	77.76%	
											Overall Process Sigma:		3.20

Calculated Using Basic Sigma Method for Discrete Data

Calculated Using First Pass Yield Formula and Short Term Sigma

Calculated Using Basic Sigma Method for Continuous Data

The Product of Sub-Process Yields (and Failed Trade Yield)

Calculated Using Normalized Yield Formula and Short Term Sigma

Table 1 - Yield/Sigma/DPMO Values

Long-Term Process Yield (%)	Short-Term Sigma	DPMO	Long-Term Sigma
6.68	0	933,193	Negative
8.08	0.1	919,243	Negative
9.68	0.2	903,199	Negative
11.51	0.3	884,930	Negative
13.57	0.4	864,334	Negative
15.87	0.5	841,345	Negative
18.41	0.6	815,940	Negative
21.19	0.7	788,145	Negative
24.20	0.8	758,036	Negative
27.43	0.9	725,747	Negative
30.85	**1**	**691,462**	**Negative**
34.46	1.1	655,422	Negative
38.21	1.2	617,911	Negative
42.07	1.3	579,260	Negative
46.02	1.4	539,828	Negative
50.00	1.5	500,000	0.0
53.98	1.6	460,172	0.1
57.93	1.7	420,740	0.2
61.79	1.8	382,089	0.3
65.54	1.9	344,578	0.4
69.15	**2**	**308,538**	**0.5**
72.57	2.1	274,253	0.6
75.80	2.2	241,964	0.7
78.81	2.3	211,855	0.8
81.59	2.4	184,060	0.9
84.13	2.5	158,655	1.0
86.43	2.6	135,666	1.1
88.49	2.7	115,070	1.2
90.32	2.8	96,801	1.3
91.92	2.9	80,757	1.4
93.32	**3**	**66,807**	**1.5**

Long-Term Process Yield (%)	Short-Term Sigma	DPMO	Long-Term Sigma
94.52	3.1	54,799	1.6
95.54	3.2	44,565	1.7
96.41	3.3	35,930	1.8
97.13	3.4	28,716	1.9
97.73	3.5	22,750	2.0
98.21	3.6	17,864	2.1
98.61	3.7	13,903	2.2
98.93	3.8	10,724	2.3
99.18	3.9	8,198	2.4
99.38	4	6,210	2.5
99.53	4.1	4,661	2.6
99.65	4.2	3,467	2.7
99.74	4.3	2,555	2.8
99.81	4.4	1,866	2.9
99.87	4.5	1,350	3.0
99.90	4.6	968	3.1
99.93	4.7	687	3.2
99.95	4.8	483	3.3
99.97	4.9	337	3.4
99.98	**5**	**233**	**3.5**
99.98	5.1	159	3.6
99.989	5.2	108	3.7
99.9927	5.3	72	3.8
99.9951	5.4	48	3.9
99.9968	5.5	32	4.0
99.9979	5.6	21	4.1
99.99866	5.7	13	4.2
99.99914	5.8	8.5	4.3
99.99946	5.9	5.4	4.4
99.99966	**6**	**3.4**	**4.5**

Notes:

a) Yields lower than 6.68% are not included since both short and long-term Sigmas are negative.

b) The table is arranged so that Long-Term Process Yields and DPMO correspond to Long-Term Sigma values. For example, a Long-Term Yield of 99.99966% (or defect rate of 3.4 DPMO) corresponds to a Long-Term process Sigma of 4.5. Assuming a 1.5 Sigma "shift," the corresponding Short-Term Sigma would be 6.0

2.9 GATHERING DATA FROM A PROCESS

We always get nervous when preparing to discuss this topic in front of a class or team. Inevitably, the questions boil down to "*How much data do I need?"* This is the least favorite question of statisticians, since everybody wants a simple thumb rule that they can apply to every situation. We'd like to oblige, folks, but unfortunately it's not that simple.

Some general principles for collecting process data:

MORE IS BETTER - This is the "First Rule of Statistics." The more "good" data you have, the better off you are.

COST IS AN ISSUE - This is the corollary to the First Rule. Reality kicks in and tells you that you can't have "all the data."

HOW FAST DOES YOUR PROCESS "PRODUCE" DATA? - If your process produces 20,000 items a year, you will likely need to collect more data than if it produces 20 items a year. A corollary to this is that, for some types of sampling, the amount of data required does not increase "linearly" with the amount produced.[5]

"TOOL" GUIDANCE - Some of the quality improvement tools presented in this manual will offer suggestions for 'minimum" requirements to "feed" the tool.

SAMPLING - Sampling is almost always an option, but, in our experience, people seem reluctant to use this handy, labor-saving data collection device. The next few pages provide some basic guidance on collecting samples of data from your process (or products/services).

[5]Case in Point: Most political or opinion surveys require only about 1200 - 1500 people to get a pretty good picture of what the 250 million US population will say or do.

2.10 CHECKSHEETS

Purpose

Today, much information is collected directly into electronic form. For example, manufacturing inspection and process monitoring data can be measured on a gauge whose output is sent directly into a personal computer data base. In healthcare, "electronic charts" are making their way into hospitals. Bar coding has greatly facilitated automatic data collection. Even data collected through review of manual charts or records can be entered directly into a spreadsheet, without the need for an intermediate manual form.

There still exists, though, a need to design temporary data collection forms for improvement projects or permanent forms where computers are not yet available. The *Checksheet* is still an important tool of quality improvement.

Types

There are various types of checksheets used to collect data. As mentioned above, with the widespread use of computers, the *Summary Checksheet* described below has essentially been replaced by the modern spreadsheet:

Individual Events - These checksheets are designed to collect data on individual events. They may be as simple as the short customer survey found by the cash register in a chain restaurant, or as complicated as medical records forms or power plant maintenance record forms.

Summary Checksheets - Summary checksheets are used to summarize data collected from many individual events checksheets, or to record one or more variables from multiple products or services. For example, inspectors will sample several "widgets" from a box, measure one or two quality characteristics and record the data on a summary checksheet.

Concentration Checksheets - These checksheets not only serve to collect the data, but also to analyze the data. The concentration checksheet usually is a "picture" of the area where events of interest may occur. Several examples of concentration checksheets include:

- *Power plant boiler tube failures are noted on maps of the boiler tube arrangements. Areas of high failure concentration can provide clues as to why the failures are occurring.*
- *Hospital needle stick locations are mapped on a picture of the hand. Concentrations of needle sticks have provided clues as to why the sticks are occurring.*
- *Integrated circuit lead failures are noted on a map of the chip, in a search for processing problems.*
- *Patient falls and employee injuries are plotted on hospital unit or office maps, in search of areas where unsafe conditions may exist, or unsafe acts are performed.*

- *Locomotive low voltage wiring failures are mapped to determine if high temperature in the engine compartment or other variable may be causing the failures.*

Designing a Checksheet

Each checksheet is different, depending on the data that is to be collected. Some general principles apply to the design and use of a checksheet:

- *Keep it simple, statistician (KISS principle)* - most manual data collection efforts are done by people who work in the "production" process. They do not have time to fill out complicated forms.
- *Use "check-offs" where possible* - If you are collecting performance data and also category information (e.g. certain pre-defined defect or non-conformity categories), provide check boxes for the category data rather than having the collector write in the category each time. Leave a space for the collector to write in a category that was not identified in advance.
- *Follow the "flow" of the work* - We designed a data input form for an improvement team that was collecting schedule information. When we tried the form, we realized that we had placed the data elements out-of-sequence; the collectors had to jump around on the form to fill in the required information.
- *Leave room for comments* - Leave a block for the data collector to record unusual or explanatory remarks.
- *Test the form* - Try the form out before you go "live" with the data collection effort.
- *Train the data collectors* - Explain to the collectors *why* they will be collecting this data, *how* to use the form, *how* the data will be used. Ask them if they have any suggestions on how to make the form better, easier, etc.

2.11 SAMPLING FROM A PROCESS

Sampling (taking a portion of the data from a process) is sometimes employed when the process "produces" a lot of data, and it's too expensive or time-consuming to look at all of the data. Sampling can improve the *accuracy* of your estimates of process characteristics or variables if collecting the data is boring or tedious.

Some sampling situations may include:

- *A hospital "produces" over 30,000 Medical Records a year. The Medical Records department is interested in the accuracy of their coding process.*
- *A manufacturing plant produces 5000 plastic injection pieces a week. The Quality Control department is interested in the defect rate of the pieces.*
- *A utility maintenance department "produces" about 1000 work orders a month. The maintenance supervisor is interested in the fraction of work orders that were held up waiting for spare parts.*
- *A pharmaceuticals firm has been cleared by the FDA to begin testing of a new arthritis medication.*
- *A railroad engineer wants to determine if a new type of bearing will have a longer life on freight cars.*
- *A pharmacologist wants to determine if a new procedure will reduce the "trough" level of a certain antibiotic in sick newborn babies.*

One of your first decisions in the sampling arena is the *type* of study or question(s) you have. In the first three examples, the question being raised was "*How Many?"* How many records have errors, how many pieces are defective, how many work orders are held up for parts?

For these situations, you should employ some type of *Random Sampling* method. We'll present two commonly used techniques here.

For the last three situations, the question is of a "*Why*" or "*How*" variety. Here, experiments will be designed to collect data to confirm or refute some theory. Although the experiments may be performed in a *randomized* order, we will not be taking any random samples from the process. We are looking for the differences: *with* and *without.*

Simple Random Sampling

Purpose

Simple Random Sampling is a way to collect a portion of the data produced by a process and do so objectively. We need to make a strong point here. There is no way to collect a random sample from an ongoing process. The conditions we'll outline below will make this obvious.

The situation arises, though, where we have a "bunch" of things already produced by the process. Using one of the previous examples, we can go to the Medical Records department and review last year's records. This "bunch" is usually called a *lot* in statistical work. We can take a random sample from this "bunch" or lot of records.

Simple Random Sampling will help ensure that the each item in the "bunch" had an equal chance of being selected into the sample. This minimizes the chance that only an isolated portion of the process' output is contained in the sample.

Application

Simple Random Samples could be taken of the following "bunches:"

- Employee records (to see what percentage were up-to-date),
- A box of electronic components (what percentage meet specifications),
- A drawer full of maintenance records (to determine what types of equipment are most often failing),
- A group of patients who have been seen at an outpatient facility in the last month (to determine satisfaction levels).

Procedure

1. Create a numbering system for the items to be sampled. Each item must be given a unique number.

2. Select an appropriate sample size. This will often be determined by the tool you are going to employ to analyze the data.

3. Select random numbers that can range from 1 to the highest number in your numbering system. This can be done from a random number table, or a random number generator, found on many calculators. For example, if the highest number in your system is 980, then you'll want to select three digit random numbers.

Select as many random numbers as you need to meet your sample size of Step 2. If duplicate random numbers appear, or numbers higher than the highest number in your system (i.e. 995), just pick another.

4. Associate the random numbers to the items' numbers. Pick these items and measure the characteristics of interest to you.

Random Number Table - Example

1640881899141535338179401
1862981953055209196204739
7311535101474988763799016
5749116703231674932345021
3040583946237921442215059
1663135006859009827532388
9122721199319352702284067
5000138140663211992472163
6539005224729582860981406
2750496131839444157510573

To use this table, close your eyes and put your pencil down anywhere on the table. Say you need random digits of size two. Pick the two digits next to your pencil and pick additional digits by going down, left, right, up, diagonally, any way you want. The numbers you pick are random.

Interval (Systematic) Sampling

Purpose

Interval Sampling is a process by which items are selected for the sample at some regular interval. The first item in the sample is usually selected at random.

Interval Sampling is a kind of "hybrid" sampling technique. Like Simple Random Sampling, it can be used when a "bunch" of items is being sampled. But Interval Sampling can also be used to collect data from an ongoing process. Every tenth patient that enters the doctor's office can be included in the Interval Sample.

Application

The same examples presented under Simple Random Sampling are candidates for an Interval Sample. In addition, the Interval Sample can be applied to these type situations:

- Every third passenger entering an airplane is asked to fill out a survey,
- Every hour, one item is pulled off the assembly line and inspected,
- Every hour, readings are taken from a set of instrumentation installed on a process,
- Every fifth customer phone call is monitored for "quality assurance purposes."

Procedure

1. Identify the number of items from which a sample will be taken (N).

2. Determine the size of the sample desired (n).

3. Determine the sampling interval (k) by dividing the number of items by the sample size (k = N/n) and rounding *up.*

Note: This procedure applies when the "bunch" already exists. It can be modified slightly for collecting process data by estimating the number of items (N) to be "produced" that day, week or whatever time period is of interest.

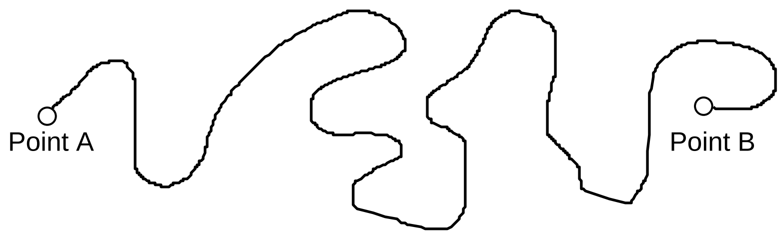
4. Randomly select the first item in the sample between 1 and k. Call this item "j."

5. Pick items *j, (j + k), (j + 2k), (j + 3k), etc.* until you've obtained your sample size. Note that sometimes you'll have to "cycle back" to the beginning of the item numbers to get the last sample item.

Note: Interval Sampling can lead to a distorted picture if there is any "periodicity" in your data. If the interval equals the period of the data, then the data will not be random. Silly example: Say you collected temperature data at an interval of 24 hours. This would not well represent the "average" daily temperature.

3. PICTURES OF THE PROCESS

One of our "quality" friends from West Virginia tells a story of how he thinks many work processes come into being. He calls it "*Paving the Goat Path:"* Many years ago, the mountain goats wore a path in the hills, perhaps seeking the meadows with the sweetest grass. Along come the settlers and they, of course, followed the path of the goats. Years later, when it was time to build a road (you guessed it), the county *paved the goat path.* People driving the road often wonder why the particular route was chosen!



You may currently be working in a paved goat path (watch out for those ol' goat patties!). Your work processes may have changed incrementally, without much thought given to the overall performance of the process. Your work may be one piece that must fit in with that of many other departments. There's often a lot of resistance to change these *cross-functional* work processes, since each department is usually trying to protect their "turf."[6]

In this section, we'll introduce some methods of "picturing" the *production process*. In many, many improvement efforts, this "picturing" is one of the first steps taken to understand the production process. Often, improvement opportunities can be identified just by analyzing these pictures in light of the goal of the process. We'll examine some of these analysis methods, too.

[6]One of our CEO friends calls her organization a "sod farm," and her goal is to break up the turf!!

3.1 SIPOC (Suppliers-Inputs-Process-Outputs-Customer)

Purpose

The SIPOC flowchart provides a high-level view of the overall process producing the defects. To the “basic” flowchart, SIPOC includes the steps of the process and adds customer and supplier information as well as what inputs and outputs are associated with the process.

Application

SIPOC flowcharts are often used early in DMAIEC to help:

- Scope the process that is producing the defects
- Identify customers – for planning Voice of Customer activities
- Identify process variables that may contribute to the defects

Construction

1. Name the process.

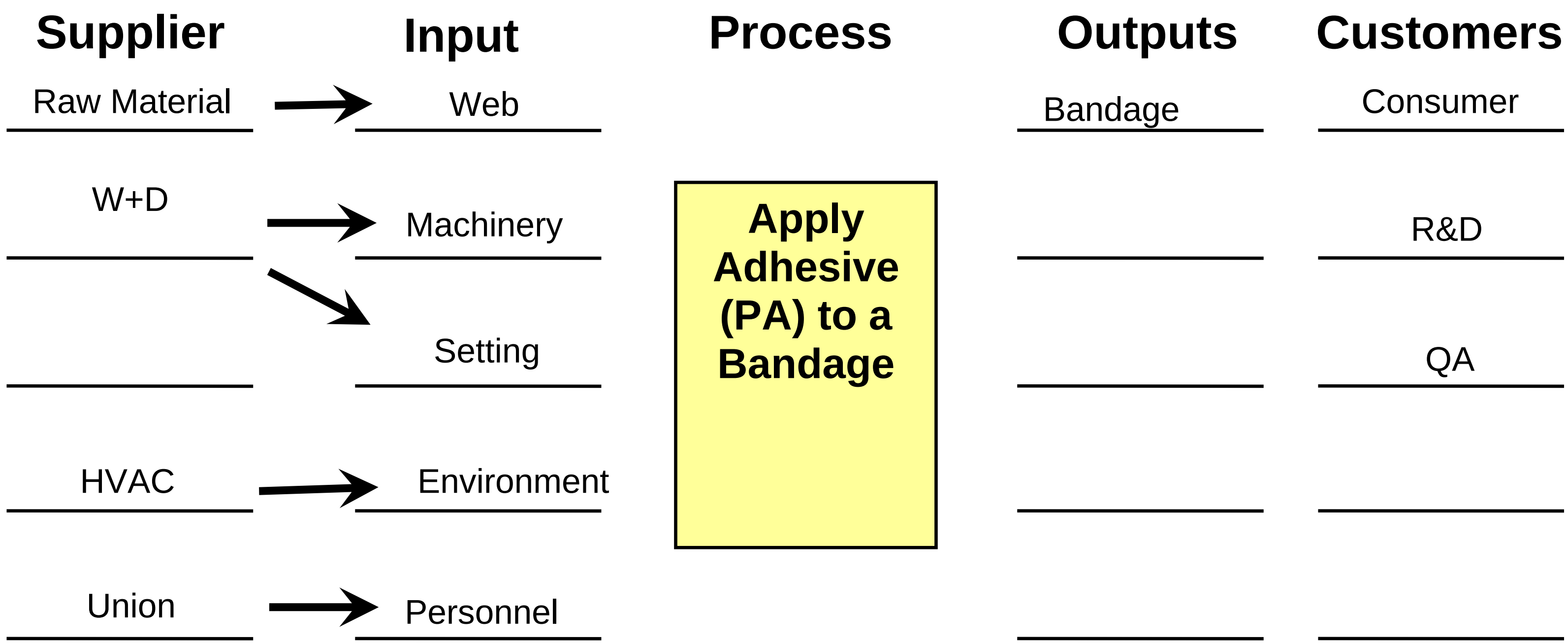
2. Clarify the start and the stop (boundaries) of the process.

3. List key outputs and customers.

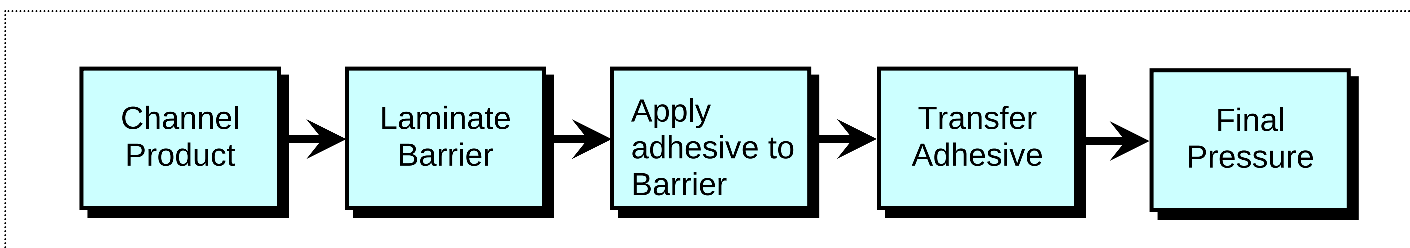
4. List key inputs and suppliers.

5. Identify, name, and order the major process steps (guideline: 5 – 7 maximum).

This SIPOC describes the high level process for applying adhesive to a Sanitary Napkin



Process



3.2 THE HUMBLE FLOWCHART

Purpose

The flowchart is one of the simplest, yet most powerful tools for understanding how a product or service is *produced.* The flowchart is a picture that shows the steps or tasks required to accomplish something, whether that "something" is building an automobile engine, obtaining a travel reservation, or changing the dilithium crystals on the starship *Enterprise* (every 5 years or 50,000 light-years!).

Application

Improvement (Measure/Analyze Steps) - The Flowchart is used to understand how the production process is currently performed. We've seen flowcharts on basically any work process that exists:

- *Admitting patients to a hospital,*
- *Manufacturing an axle shaft,*
- *Cleaning a hotel room,*
- *Transferring funds in a bank's "back-office,"*
- *Purchasing "non-stocked" spare parts,*
- *Repairing telephones in a large corporate headquarters building,*
- *Setting temporary security posts at a nuclear power plant,*
- *"Harvesting" organs and tissues from a deceased donor.*[7]

Improvement (Identify/Implement Steps) - The Flowchart is also helpful when redesigning an existing production process, or developing a new one. Here, the steps of the process can be laid out and the design "optimized" for whatever quality characteristics are important (time, accuracy, volume, etc.).

Standardization - Many companies have transformed their old policy and procedures manuals into simple flowcharts describing the work processes. They have found flowchart-based procedures easier to develop, easier to understand, and easier for training new employees. At *Sigma Quality Management*, we have all our *core* and *support* work processes laid out on flowcharts. It works for us.

Construction

"Basic" construction of a flowchart is relatively simple; however, *make sure you know the purpose of your flowcharting exercise*. For example, flowcharting a process to identify *wastes* may require a much greater level of detail than developing one to use as an instruction guide. There are some problems that people typically encounter when flowcharting the first time; we'll point these out after the construction steps.

[7] No, we won't be showing that one here!

1. Identify the process to be flowcharted. Most of the time, you're dealing with the *production process* that makes some *product* or *service*.

2. Identify the *ending* point of the process. For a *production process,* this will generally be the point where the service is provided to the customer, or the product is made or received by the customer.

3. Identify the *starting* point of the process. For service-type processes, this point is generally where the customer requests a particular service. For manufacturing-type processes, it may be where the raw material enters the "factory,"[8] or it may be where parts are gathered for assembly.

Steps 2 and 3 clarify the ***boundaries*** *of the process being flowcharted.*

4. Identify the major steps of the process. If a very large, complex process is being flowcharted, you'll want to start at the "50,000 foot" level. Pretend you're viewing the process from a high altitude. What do you "see" from this height? Generally the high-level *functions* are identified first.

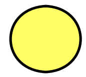
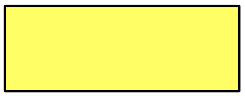
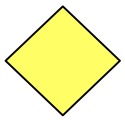
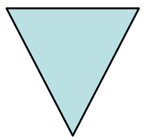
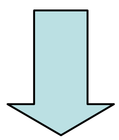
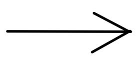
Example: For a manufacturing process, Casting, Machining, Heat Treatment, Assembly might be high-level functions. For a service process, Order Receipt/Entry, Order Filling, Packing, Shipping, and Billing are high-level functions.

Once these are clarified, the "onion-peeling" approach can be taken. Depending on the purpose of your flowchart, the major steps required to perform the functions can then be identified, and then the tasks required for each step identified.

Think of these detail levels as a book. The high-level functions are the book's chapters, the steps are the paragraphs, and the tasks are the sentences. Some organizations will assign "owners" to these high-level processes, generally at a vice-president, or director level. Managers and supervisors then assume ownership for the next level processes.

5. Organize the activities into a flowchart. The basic symbols of a flowchart are presented below:

[8]"Factory" must be in quotes, here. We once described a Medical Records department as a "factory," since they took the raw material of patient charts, "processed" and "assembled" the charts, and "manufactured" a completed chart as well as a patient bill. Thinking about the process in this way gave us great insight on how the process worked and what we could do to improve it.

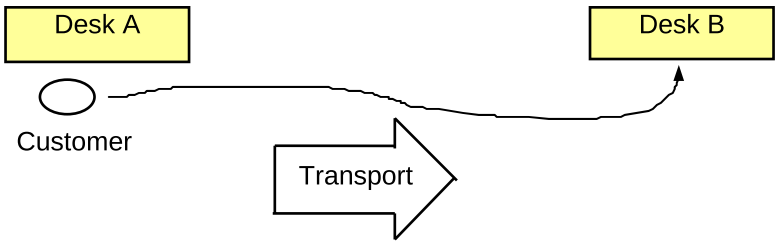
BASIC FLOWCHARTING SYMBOLS	
	CIRCLE - Used to indicate starting and endpoints of the flowchart. The circle should always enclose the first step and the last step.
	RECTANGLE - Used to indicate activities performed as part of the process. The statement inside the rectangle should begin with a verb, an action being taken.
	DIAMOND - Used to indicate decision or inspection points of the process. There will always be two directional arrows - one for "Yes," one for "No" decisions.
	TRIANGLE - Used to indicate where some "Thing" is stored during the process.
	ARROW - Used to indicate transport or movement of some "Thing" during the process.
	LINE - Used to connect flowchart symbols.

There are several approaches to developing the flowchart. Two of the most commonly used are discussed below:

The Walkthrough - This is often used when an existing process is being flowcharted. Draw a circle and describe the starting point inside the circle. Then, ask what happens next. If this is an activity, draw a rectangle and describe the activity. Continue to “walkthrough” the process, from start to end point (the ending activity is also drawn in a circle).

Where there are decisions to be made (options, or inspection points), draw a diamond with the decision question written inside. The flowchart will now branch in two. Remember to complete all branches (i.e. resolve both decision possibilities).

The table shows symbols for “Storage” and “Transport.” Consider the meaning of these symbols broadly. A customer waiting to be served is, at a minimum, being “stored.” Similarly, if a customer has to pick up a form at Desk ***A***, then fill it in and deliver it to Desk ***B***, a “transport” step is involved.



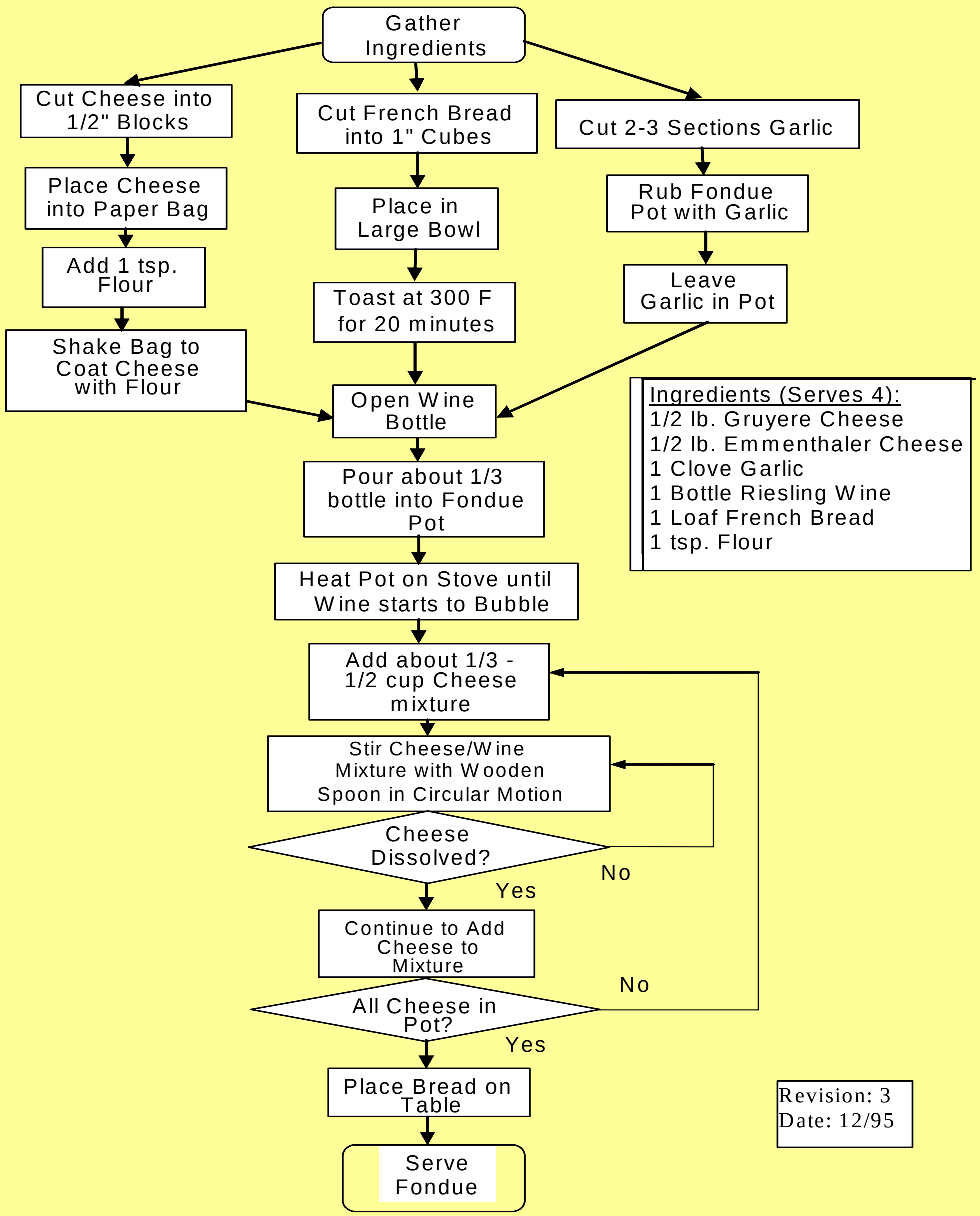
A variation on this process combines the “onion-peel” with the “walkthrough.” After the high-level functions are identified, each function is flowcharted individually (often, sub-teams can be assigned to flowchart each function). They are then joined together to develop the complete flowchart.

The Brainstorm - This approach is often used when designing a new process via flowchart. Brainstorm all of the activities/steps that are necessary to “produce” the product or service. Then arrange the steps logically, considering which steps must occur before others.

6. Label and date the completed flowchart. Undoubtedly, you will be changing the flowchart as you make improvements to the production process. It’s helpful to know the most current method of producing the product or service.

An example follows that we hope you’ll find both illustrative of flowcharting *and* delicious:

O'Neill's Famous Fondue



Flowchart Example: O'Neill's Famous Fondue

Some Notes on the Example:

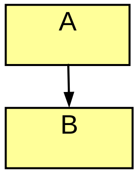
1. This is a *manufacturing-type* process. The aim of this process is to take raw materials and turn them into a finished "product."

2. The purpose of this flowchart is to show *how* the ingredients are processed and assembled. Hence, the *starting point* for the process was chosen to be "Gather Ingredients." We did not include the activities associated with purchasing or shipping the "raw materials."

3. The processing steps for the *cheese, bread,* and *garlic* are shown as parallel paths. This indicates that they can be done simultaneously (if there is only one "chef," though, the available "resources" may cause these activities to be done in series, i.e. one after another).

This is an important point for flowcharting that, unfortunately, is often ignored. When we connect one activity to another in *series,* the following implicit statement is being made:

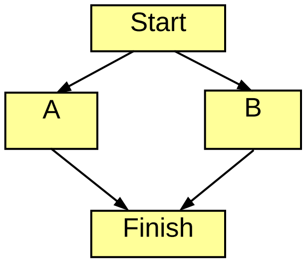
The preceding activity (A) must be completed before the succeeding activity (B) can be started.[9]



For example, the cheese and flour must be in the paper bag *before* the bag is shaken.

On the other hand, activities shown in parallel can be performed at the same time:

Activities 'A' and 'B' can occur at the same time:



4. There are only two decision points in this example and both are essentially "DO" loops (Do this activity until some result is achieved). Often, though, decision points will result in different activity paths being followed.

Flowcharting Tips

1. *Boundaries* - In the fondue example, above, we made an easy decision about where to start the flowchart, based on the *purpose* of the flowchart. This guideline is applicable to most flowcharts. Clarify the purpose of the chart!

[9]In certain circumstances, we'll relax this requirement - the succeeding activity can't be *finished* until the preceding activity is *finished*.

If the chart is being prepared as part of an improvement effort, review the charter or *reason for improvement* before starting the flowcharting effort. What are you trying to improve?

Sometimes, data can help pinpoint the portion of the production process that needs to be flowcharted. For example, a team working on improving an outpatient admissions process initially set their starting boundary where the patients signed in at the admitting desk.

When they asked the patients about problems with the process, though, they found that many patients were having trouble just getting to the admitting desk. The team then revised the starting point to where the *patient was driving up to the outpatient facility.*

2. *Level of Detail* - This is one of the most difficult areas of flowcharting. Often, teams will get bogged down in the "flowchart session from hell," as they detail every step of the process. We mentioned the "onion-peeling" philosophy, above. This is one of the best strategies to follow.

When we work with teams, we try to get them to describe the process in about 10 - 15 steps, initially. This is the outline or "skeleton" of the process. At this point, we'll try to decide if the entire process needs to be fleshed out, or should we gather some data to determine what part of the process needs further study.

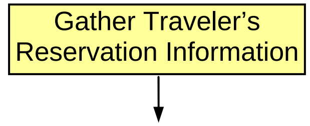
For example, if errors are a concern, gather data on where in the process most of the errors seem to be occurring (see Pareto Analysis, Section 7). Usually, two or three segments of the process will be responsible for up to 80 percent of the errors. Chart these steps in detail.

What ***NOT*** to do: One of our friends decided that his team needed to flowchart *in detail* the procurement process for nuclear power plant spare parts. The flowchart took one month to prepare and stretched forty feet in length! When we asked him what he was going to do with it, his only response was "Hang it on a long wall and look at it."

3. *Multiple Choices* - Service-type processes often have multiple paths or branches, depending on choices made by the customer, or situations that arise in the service process. For example, taking a reservation for a hotel room involves the following decisions:

- *How many people?*
- *Adults? Children?*
- *Number of Rooms?*
- *Handicapped-Equipped Room Needed?*
- *Arrival Date? Time?*
- *Departure Date?*
- *Type of Bed(s) desired?*
- *Smoking/Non-Smoking?*
- *Guarantee with Credit Card?*

Now it would be possible to flowchart all of these decisions and the resulting choices, but the *purpose* of our flowchart may not require this detail. For example, if we are trying to understand how the reservation process works in order to improve the *timeliness* of this service, then all of the above questions may be "collapsed" into one activity on the flowchart:



Even if you want to flowchart various alternative paths for your production process, consider the *Pareto principle* and flowchart only those paths that occur 80 - 90% of the time. Those paths that occur "once in a blue moon," while interesting, can distract you from the work of improving the main process.

4. *Sticky Notes* - One of the quickest ways to develop a flowchart (either with a team or individually) is to use sticky notes such as *Post-it Notes™*. Write the process steps on the notes and then arrange them in proper order on a flipchart or other flat surface. Square sticky notes can be turned 45 degrees to make decision diamonds.

3.3 THE RESPONSIBILITY FLOWCHART

Purpose

In most organizations, *responsibility* for various functions has been divided by department or section (Billing, Shipping, Purchasing, etc.). While this division of labor may bring certain efficiencies, it can also be the source of delays and errors. In fact, every time a “hand-off” occurs in a production process, there is an opportunity for a delay, for “inventory” buildup and, in many cases, for error.

An important variation of the “humble” flowchart, the *responsibility flowchart* can provide a good picture of not only ***what*** is done, but also ***who*** does it. The responsibility flowchart adds a second dimension to the flowchart, the department or person responsible.

Application

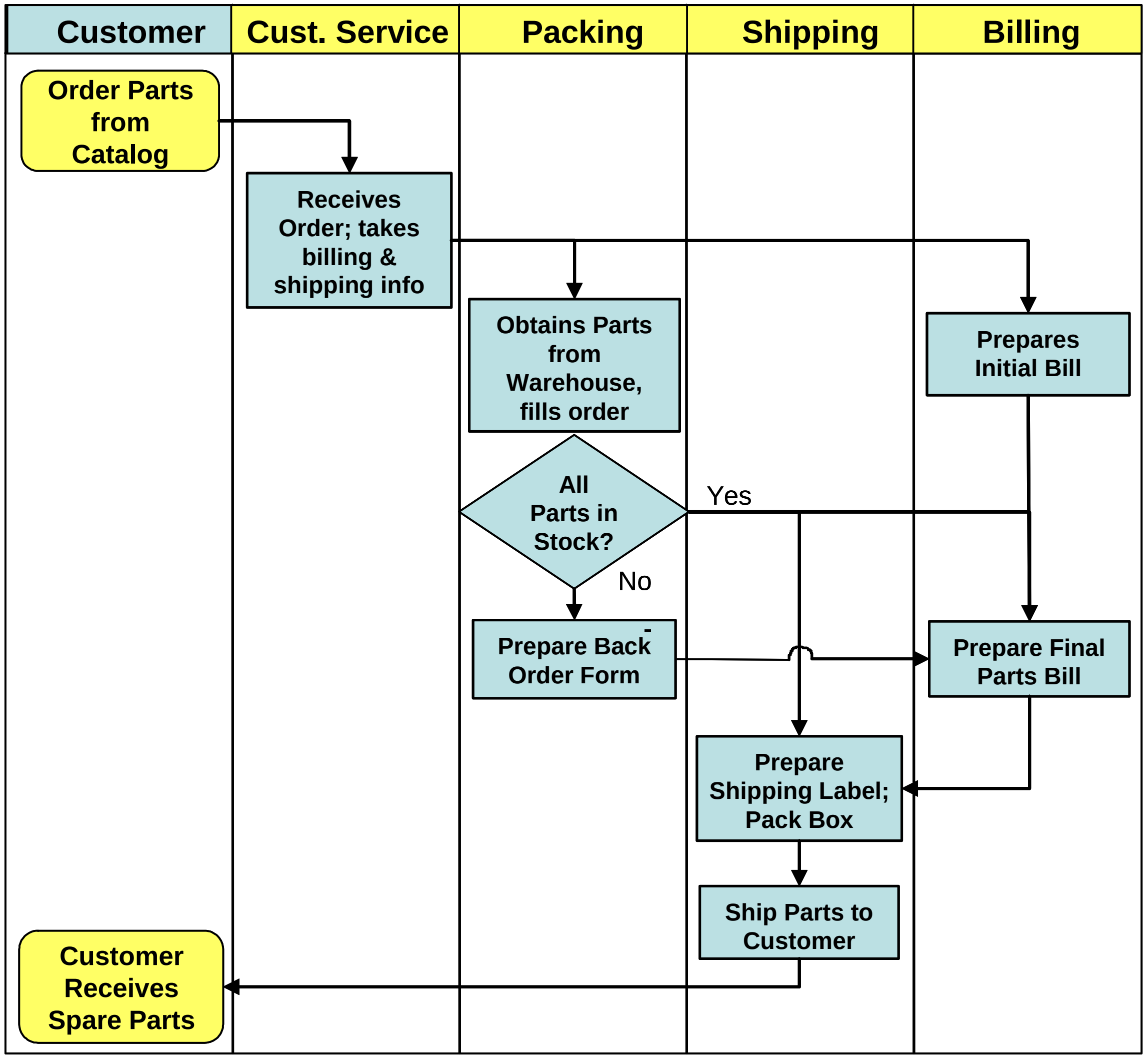
Whenever more than one individual is responsible for a production process, the *responsibility flowchart* is useful. Examples of *responsibility flowcharts* include:

- *Manufacturing,*
- *Patient Care,*
- *Purchasing,*
- *Budget Preparation,*
- *Mortgage Loan Processing,*
- *Quality Assurance Systems,*
- *Product Design,*
- *Legislative/Lawmaking*
- *Stock Trading*

Construction

The flowcharting steps for the responsibility flowchart are no different than the process described previously. The difference is in the “second dimension” added by creating columns for the responsible departments or individuals:

Spare Parts Catalog Orders



The responsibilities flowchart is often drawn at a high-level, with each activity the possible subject of a more detailed flowchart. The main point is to show the activities and their relationships (inputs and outputs) across departments, sections or individuals.

By convention, the *Customer* is given the left-most column; any *Suppliers* external to your organization would be assigned the right-most column(s).

3.4 LAYOUT DIAGRAMS

Purpose

The flowchart shows the steps required to do the work. Often, you will be interested in *where* the work is performed and how the work flow occurs. The *layout diagram* is a graphical method of picturing the physical flow of work through a process.

The location of work stations, storage facilities and transportation requirements can be clearly shown on the layout diagram. The layout diagram also appears as various *drawings* of a product to picture equipment or component arrangements.

Once the physical layout is understood, opportunities for improvement often become apparent.

Application

Virtually any process can be pictured on a layout diagram (it is a good idea to do both a flowchart and a layout diagram, they are complementary pictures).

The layout diagram should be developed as part of the *Measure the Current Situation/Analysis* steps of improvement to understand the current process. If changes to the production process include physically rearranging equipment or other aspects, these may be "tested" using a layout diagram.

Some layout diagrams we've seen include:

- *Locomotive Overhaul Layout*
- *Plastic Component Part Fabrication, Assembly and Packing Plant*
- *Hospital Emergency Room Layout*
- *Same Day Surgery Nurse and Patient Flow*
- *Laboratory Specimen Processing Flow*
- *Naval Recruiting Station - Recruit Testing Area*

The most common application for a layout diagram is a manufacturing plant. Often, plant equipment is located by *function*; all the milling machines are in one area, the lathes in another, the heat treatment equipment and assembly areas in another.

One of our quality friends worked in an aerospace plant, where he measured the distance a rocket engine turbine rotor had to travel from raw material to finished product. The result - *5 miles!* The company was able to rearrange its equipment and drop this distance to *1200 feet*, with a corresponding reduction in storage and transport required.

Construction

The most common layout diagrams of work processes are those which picture the process from a "birds-eye" view, looking "down" on the process. Don't forget, though, that the work area is a *three-dimensional* volume. Other "slices" of the work area may provide a better picture for you.

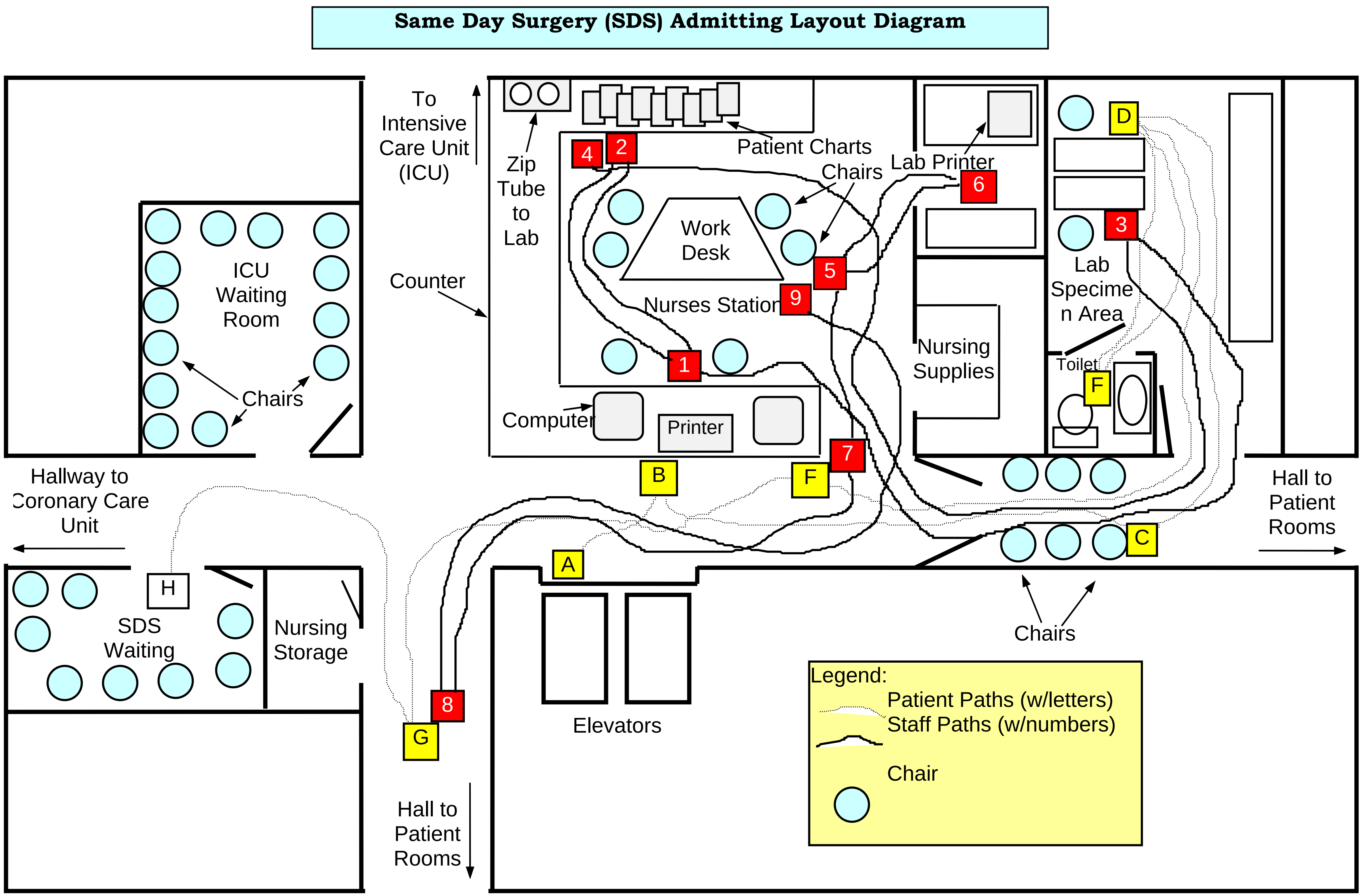
1. Sketch the general area of interest, including walls, equipment, fixtures, desks, doors, and other items as necessary.

2. Observe the flow of work through the area. Draw arrows to indicate how the product (for manufacturing-type processes) or customer (for service-type processes) flows through the area.

Use the flowchart symbols (activity = rectangle, transport = arrow, storage = triangle, inspection = diamond) to distinguish the "things" that happen to the product or customer.

3. (Optional) Measure various characteristics of the work flow. The two most common include *time to complete steps* and *distance traveled* through the process. Label the diagram with these measurements (average and range values may be calculated from several observations).

4. Title and date the layout diagram. Changes to the work flow should be reflected on the layout diagram.


Same Day Surgery (SDS) Admitting Layout Diagram
To Intensive Care Unit (ICU)
Zip Tube to Lab
Patient Charts
Chairs
Lab Printer
Work Desk
Nurses Station
Counter
ICU Waiting Room
Chairs
Computer
Printer
Lab Specimen Area
Nursing Supplies
Toilet
Hallway to Coronary Care Unit
Hall to Patient Rooms
SDS Waiting
Nursing Storage
Elevators
Chairs
Legend:
Patient Paths (w/letters)
Staff Paths (w/numbers)
Chair
Hall to Patient Rooms
A
B
C
D
F
G
H
1
2
3
4
5
6
7
8
9

Notes on the Layout Diagram Example:

1. We chose this example of a service-type process, since it makes many manufacturing processes seem simple in comparison. Let's go through the play-by-play on this process:

The Patient & Family's Path:		
From	**To**	**Description**
A	B	The patient & family exit the elevator and try to get to the nurses' station counter. There's usually a large group of people in front of the counter.
B	C	After the patient is registered, they are sent to get lab specimens taken. The family waits in the hallway (clogging up the hall).
C	D	The patient enters the lab specimen area. A blood sample is taken.
D	E	The patient goes into the bathroom to obtain a urine specimen. They then return to the lab specimen area.
D	F	The patient (picking up their family along the way) returns to the nurses' station.
F	G	A nurse takes them to their room, where they are prepped for surgery.
G	H	When the patient has been prepped and transported to surgery, the family goes to the SDS waiting room, until the patient returns from surgery.
The Staffs' Path:		
From	**To**	**Description**
1	2 (and return to 1)	After the patient arrives and is confirmed on the schedule, the nurse retrieves the patient's medical chart. Additional paperwork is completed and necessary signatures are obtained.
1	3	The chart is walked to the lab specimen area so the lab techs can determine what specimens are required.
3	4	After the specimens are collected, the lab tech walks the specimens to the "zip tube" (for transport to the lab) and returns the chart to the nurses' station.
5	6	When the lab work has been analyzed, the lab sends the results to the lab printer. The nurse picks up the results and places them in the chart at the work desk.
5	7	When the patient returns from the lab specimen area, a nurse comes to escort them to their room.
7	8	The nurse takes the patient and family to the room where they will be prepped for surgery.
8	9	The nurse returns to the station and prepares to repeat the process on the next patient.

2. This layout chart was developed by doing a *Process Watch* (see later in this Section) at the request of the SDS Supervisor. She knew that there were "production" problems in her process and needed an outside set of eyes to view the work. When we reviewed the layout chart with her and her staff, it was like playing the children's game, *How Many Things are Wrong in this Picture?* They came up with over 20 suggestions to improve their work process. How many can you identify?

3.5 COMBOS & OTHER PROCESS PICTURES

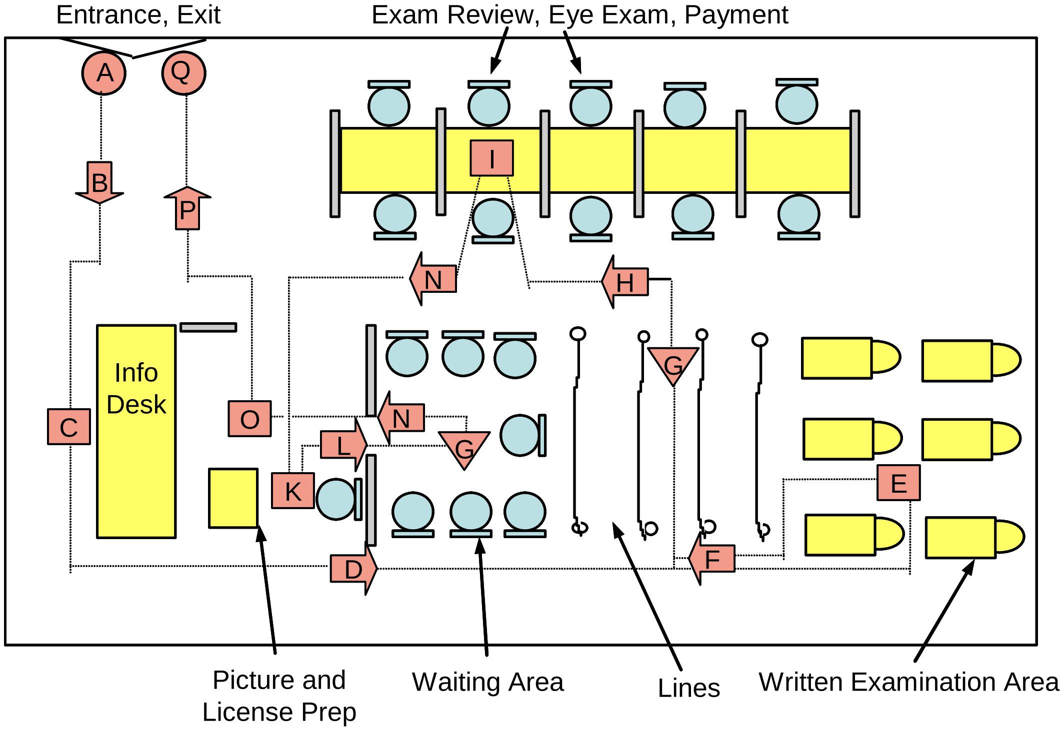
The Flowchart and Layout Diagram are the most used and most useful pictures of processes. Combinations or variations of these pictures have been used, though. Here are a few suggestions that may be useful to you or that may give you ideas about how best to picture your process.

- *Flowchart/Layout Diagram*
- *Critical Pathways*
- *The Process Watch*
- *Physical Models*
- *Computer Simulation*

Flowchart/Layout Diagram

The flowchart and layout diagrams can be combined to provide a model of *what happens* and *where it happens.* Here's a simple example:

Driver's License Office Layout



This production process can be summarized in terms of its *value-added* and *non-value added* activities. There are five value-added activities from the driver's perspective:

C - Get directions and pick up examination,

E - Complete written examination,

I - Review exam, take eye test and pay for license,

K - Have picture taken, and

O - Receive completed license

(you might challenge which of these steps *actually* adds value – who's the customer?)

The remaining *storage (G & M)*, and *transport steps (B, D, F, H, J, L, N, & P)* are all *non-value added steps*, that is, they do not contribute to accomplishing the process of getting a driver's license.

This "combo" picture is the start of an analysis of the process, where you would begin to look for ways of minimizing or eliminating *non-value added activities* from your process.

The Critical Pathway

When we discussed the flowchart, the notion of *series* and *parallel* activities was presented. This concept can be taken one step further to develop a picture of a process that is specifically designed to focus on the *time (and/or resources) required to complete a process.*

The Critical Pathway Method was originally developed to help manage large development projects. Critical Pathways are tools that allow project managers to "model" the development effort, arrange the development tasks in the most "optimum" manner, and understand how well the project is proceeding as the different tasks are completed.

The *critical path* is defined as the sequence of specific activities that must occur for the project to finish and that takes the *longest* to complete.

Let's illustrate this concept with a simple example. Every morning, we complete the following "project" - *Getting Breakfast Ready.* The following tasks are involved, with their times included:

Task	Time
Get Newspaper from front porch	20 seconds
Get Yogurt from refrigerator	10 seconds
Open and stir yogurt	20 seconds
Get coffee mug, fill with water	15 seconds
Heat coffee water in microwave	120 seconds
Mix Swiss Mocha in coffee	20 seconds
Transport coffee & yogurt to table	10 seconds

Now let's say all these tasks are done in *series*, that is, the second task would not start until we'd finished the first (this is called a *finish-to-start* relationship), the third doesn't start until the second is done, etc.

The total time to finish all the tasks would then be the sum of the individual task times: 215 seconds, or a little over three and a half minutes. This *series* sequence of tasks would be the current *critical path*.

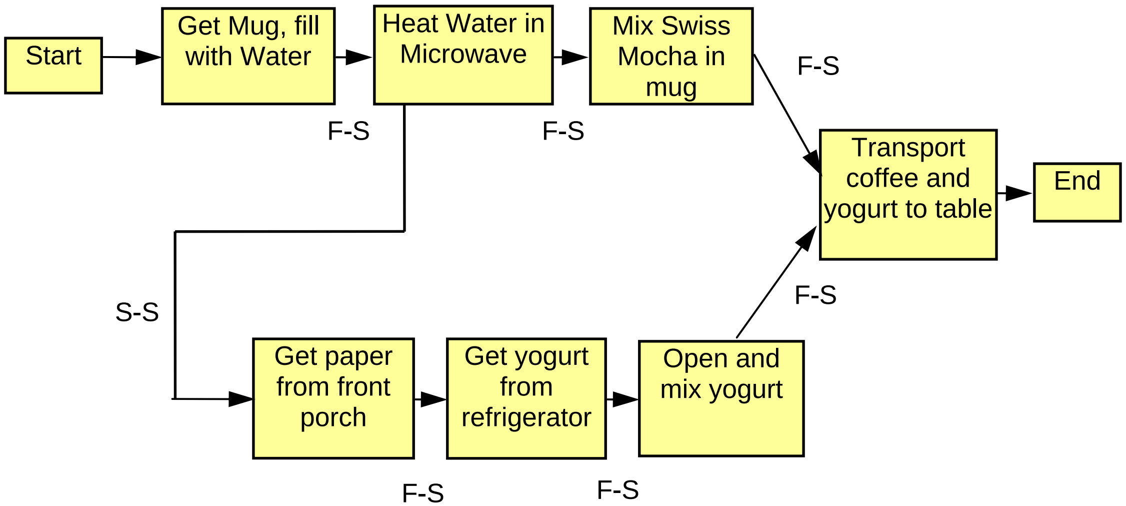
But must all the tasks be done in *series*? Perhaps, while the water is heating in the microwave, some of the other things could be done, like getting the paper, the yogurt, etc. We've now put some of the tasks in *parallel*, and have cut the total time. There are still some *finish-to-start* relationships, i.e. the Swiss Mocha can't be mixed until the water is heated, but we've taken some of the tasks *off the critical path.*

There is a graphical picture called a PERT[10] diagram (some call it an *Arrow* diagram) that you can construct for your processes, analyze and improve and actually manage by as you proceed through your projects.

Here's what our "improved" Breakfast preparation process would look like on a PERT chart:

[10] PERT - Program Evaluation and Review Technique.

How do you interpret the PERT chart? Well, the boxes are all tasks/activities that require some *duration.* The arrows, combined with the *F-S, S-S, etc.* notes describe the *relationship* between tasks. For example, we would not START heating the water until we've FINISHED filling the mug. *F-S* stands for *Finish-to-Start, S-S* stands for *Start-to-Start, F-F* for *Finish-to-Finish*.[11]



Note how we've described the relationship between heating the water and getting the paper as a *Start-to-Start.* As soon as we put the water in the microwave, we can go get the paper. We don't have to wait for the heating task to *finish* before we *start* after the paper.

We can predict the effect of our improvement from this picture. There are essentially two *paths* that must be completed for our breakfast to be ready. By calculating how long each of these paths take and finding the *longest time (i.e. the new Critical Path),* we will know how long the entire process takes, start to finish.

Although you might want to check our work (by calculating the time through the other path), the new *Critical Path* is:

Critical Path Task	**Time**
Get coffee mug, fill with water	15 seconds
Heat coffee water in microwave	120 seconds
Mix Swiss Mocha in coffee	20 seconds
Transport coffee & yogurt to table	10 seconds

The time to perform these tasks is <u>165 seconds</u>, or about two and three quarter minutes. We've cut the process time by about 50 seconds.

Analyzing Your Process Using *Critical Path Thinking*

You can directly apply this kind of thinking to your production processes, especially relating to the *time* quality characteristic:

[11]No, we won't discuss any *Finish-to-Norwegian* relationships!

Evaluating Improvements - If time is an important quality characteristic for your process, then the PERT diagram (combined with Critical Path thinking) can be used to evaluate ideas for improvement.

Suppose our "significant other" offers to get the paper while we work on the yogurt. Does this cut the overall process time? Here, the answer is no, because we **have not changed any of the critical path tasks!** The only changes that will improve the overall time are those that affect the critical path tasks or their times!

Slack Times - While it takes 140 seconds to heat the water and mix the coffee, it only takes 50 seconds for us to get the paper and the yogurt. There are 90 seconds of *slack time* in this path.

Often, a PERT chart will be analyzed for these slack times when there are constraints on the *resources* available to complete the work. People or machines can be shifted from project paths with slack time to those on the critical path (we need to be careful that such shifting doesn't create a *new critical path!)*.

Wasted Times - Suppose we were reading the newspaper when the microwave bell rings? If we continued to read and not begin the mixing task, then we're adding to the critical path time. Delays, "down-time," etc. are all factors that increase the critical path time, without adding any value to the process. These must be eliminated or minimized in both duration and frequency.

In the "real world," coordination between two departments often contributes to delays and wasted time.

Resources - The PERT diagram can be "resource-loaded," that is, specific departments, personnel, machines, etc. can be included in this process model.

Notice in the PERT chart that if we're mixing the yogurt when the hot water is ready, we can't really start mixing the coffee until the yogurt is finished. This is an example of how a resource can constrain the completion of a project, even though there is no relationship between the actual tasks.

Unnecessary Tasks - This one seems so obvious, but we'll include it anyway. Let's say we have a habit of pulling a dirty coffee mug out of the dishwasher. This would add an unnecessary task of cleaning the cup before we filled it with water. This task should be done the night before, not during our "breakfast project's" critical path.

Differences between Similar "Projects" - Of course, if there are several of us out there getting breakfast ready, and there are differences in our processes' performance, we can compare the critical paths to see what's happening within the process.

The Process Watch

The *Process Watch* is not so much a picture of the production process, as it is a way of obtaining a detailed understanding of the process. The purpose of a process watch is simple:

> *Immerse yourself in the production process. Understand everything there is to know about the process. Include the 5W1H (Why, What, Who, When, Where, & How).*

George Butts, former vice president of Chrysler manufacturing, tells this story to illustrate the concept of a process watch:

"One day, I received a request from two young Japanese engineers to review the Chrysler car body painting process. Since we had a technical exchange agreement with their company, I approved the request. I expected them to spend about a half day touring the paint shop.

Well, two weeks later, they visited me to say 'thanks' and 'good-bye!' When I asked them what they'd learned, I was astounded. They had walked through the entire paint process, asking questions and taking notes all the way. For example, they asked the man who wipes the body panels prior to priming what kind of cloth he used, where he obtained it, why did he use a side-to-side instead of up-and-down motion, how much pressure he used, how long he used the cloth before getting a new one, etc., etc., etc. Every other detail of our process was noted as well.

Although they expressed themselves with typical Japanese humility, I could sense their pride when they said, 'Chrysler has the best body paint of all US manufacturers. But you do not understand why. We now understood your process and will take it back to Japan and make it better.' I believed that they would do just as they said."[12]

Application

Improvement (Measure Current Situation/Analysis) - The process watch is used to help understand how the current production process operates. The Chrysler paint process watch is a good example of this application.

Improvement (Identify Countermeasures) - Before "reinventing the wheel," an improvement effort may decide to investigate other, similar production processes and gather ideas that may help redesign their process. Some authors refer to this application of the process watch as *process benchmarking.*

Planning and Executing a Process Watch

The five key questions that must be part of any process watch are simply: *Why, What, Who, When, Where, & How.* Some planning and execution suggestions follow:

Develop a high-level understanding of the process, first. This may be as simple as laying out the key functions of the process in a "macro-flowchart." This helps provide some organization to the watch. Prepare a notebook, whose tabs are labeled with each of the functions.

[12]From notes taken at a Palm Beach, Florida ASQC meeting in 1988. The Japanese term for Process Watch is a *Gemba Visit – meaning go to the place of work.*

If you are going to develop a layout diagram, sketch the physical area on paper before the actual watch. In the Same Day Surgery Admitting process example, we prepared the area sketch the night before. The morning of the process watch, we could then begin to trace the paths of staff, patients and families easily.

Get permission to do the process watch. Explain to the workers you are watching or interviewing *why* the watch is being done. Sometimes, misunderstanding or fear will lead them to act "by the book" instead of how they normally do the work.

Pretend you are a customer or the "product." For service-type processes, this is a very useful strategy. A management engineer followed fourteen customers through a process one day, what she learned that day was more useful than all the data the team had collected up to that point.

Process the results of your watch as soon as possible. Despite all the notes you will take, there will be a great deal of information that will be caught not on paper, but in your mind. Draw out the flowcharts, layout diagrams, and prepare your write-ups immediately. Note any questions that you still have, and go back to the process to answer these questions. Don't assume anything, or make up information that you thought you saw.

Review the results of the process watch with the workers. Make sure you've captured exactly what goes on. Change any details that were captured incorrectly.

Physical Models

In the "old days," scale or full-size models of complex engineered systems would be built from wood, plastic or other materials. These models provide a three-dimensional view of the system that can be checked for a number of features, such as constructability (interferences), maintainability (how are we going to repair the system), and operability (can we operate this system). Today, physical modeling is still done, but the trend is toward the following "virtual" modeling.

Computer Simulation

Boeing's 777 aircraft was the first to be designed completely on computer. Engineers could view any section of the aircraft, from any angle as the design progressed. Many previous problems with design, such as interferences (two objects "designed" into the same physical volume) were eliminated by this innovative approach.

PC-based programs are available to simulate simpler systems. Architectural software is available that allows a home or office to be created on computer, the prospective owner or occupant can then take a "virtual walkthrough," examining the structure from any angle. For processes, ProModel's *ProcessModel* software can be used to simulate the performance of manufacturing and service work processes.

3.6 ANALYZING THE PROCESS' PICTURE

Perhaps you've heard of the "Quality Tree?" On this tree grow fruit that represent our opportunities for improvement. Now some of the fruit is lying on the ground (be careful, don't step on these, but *do* pick them up!), some fruit is on the lower branches, easy to reach, some grows on the higher branches, and we'll have to climb a ladder to get to this fruit.

When you *first* develop a picture of your process, we recommend that you examine the picture(s) critically. Experience has shown that you will often identify the "low-hanging fruit" of improvement, here.

Several types of process analysis are presented here; they are characterized by the fact that "only" a picture of the process is needed to support the analysis.

- *Low Hanging Fruit*
- *The 5 S's*
- *Was the Process Followed?*
- *Comparative Process Analysis*
- *Twenty Questions*
- *What Can Go Wrong?/Error-Proofing*

Low Hanging Fruit

There are some general categories of "inefficiencies" that you should look for in your process. Don't just look for the "big stuff." One company held a campaign where any suggestion that *reduced wasted motion by at least 0.6 seconds* was considered.

Inefficiency	Description/Example	Action
Duplication	When we make reservations with most hotel chains, we provide them with our name, address, etc. When we arrive at the actual hotel, the probability that we will have to give that same information is usually very high.	Eliminate unnecessary duplication
Misplaced Activity	At a famous car manufacturer, the glove box was installed at point "A" on the line. At point "C," down the line, the glove box was removed to install some electrical wiring.	Reorder process steps
Storage	Stored material, supplies, etc., takes up space and incurs cost. Examples range from manufacturing *in-process inventory* to the "vast" amount of pens, pencils, and stationery "stored" in office buildings.	Minimize storage, implement Just-in-Time delivery
Transport	Transportation does not add value to the material or product being transported (consider also the "transport" of customers through your processes)	Minimize wasted transports
Motion	Often people do things a certain way because of habit, not because it's the best way to perform a task.	Minimize wasted motion
Inactivity	There's an old saying, "*A person watching a machine is not working.*" One of our quality friends was curious to know why an automated production line was shut down when the workers went on break.[13]	Minimize or eliminate.

[13] It turned out there *was* a "good" reason - the automatic line produced so many defective items, it needed to be constantly watched!

The Five "S's"

One approach to obtaining quick improvements and to prepare the process for further analysis is to perform the Five "S's." Implementing these "S's" is often the beginning of a journey towards a *lean* organization.

Sort	Go through the workplace and *sort* all materials, equipment, etc. that is not needed to perform the work. Get rid of this *stuff!*
Shine	Clean the workplace. Remove grease and dirt from equipment, scraps and offal lying around. Hang necessary tools in appropriate places – make it easy to obtain tools for the job.
Set-in Place	Establish responsibilities for maintaining the clean, clutter-free workplace (e.g. Joe and Jill clean up the lathe area once a shift, Jack and Jean clean up the tool bin).
Standardize	Develop a common method for performing the process.
Sustain	Ensure that the common method is employed each time the process is performed and that improvements made to the process are built into the common method.

Was the Process Followed?

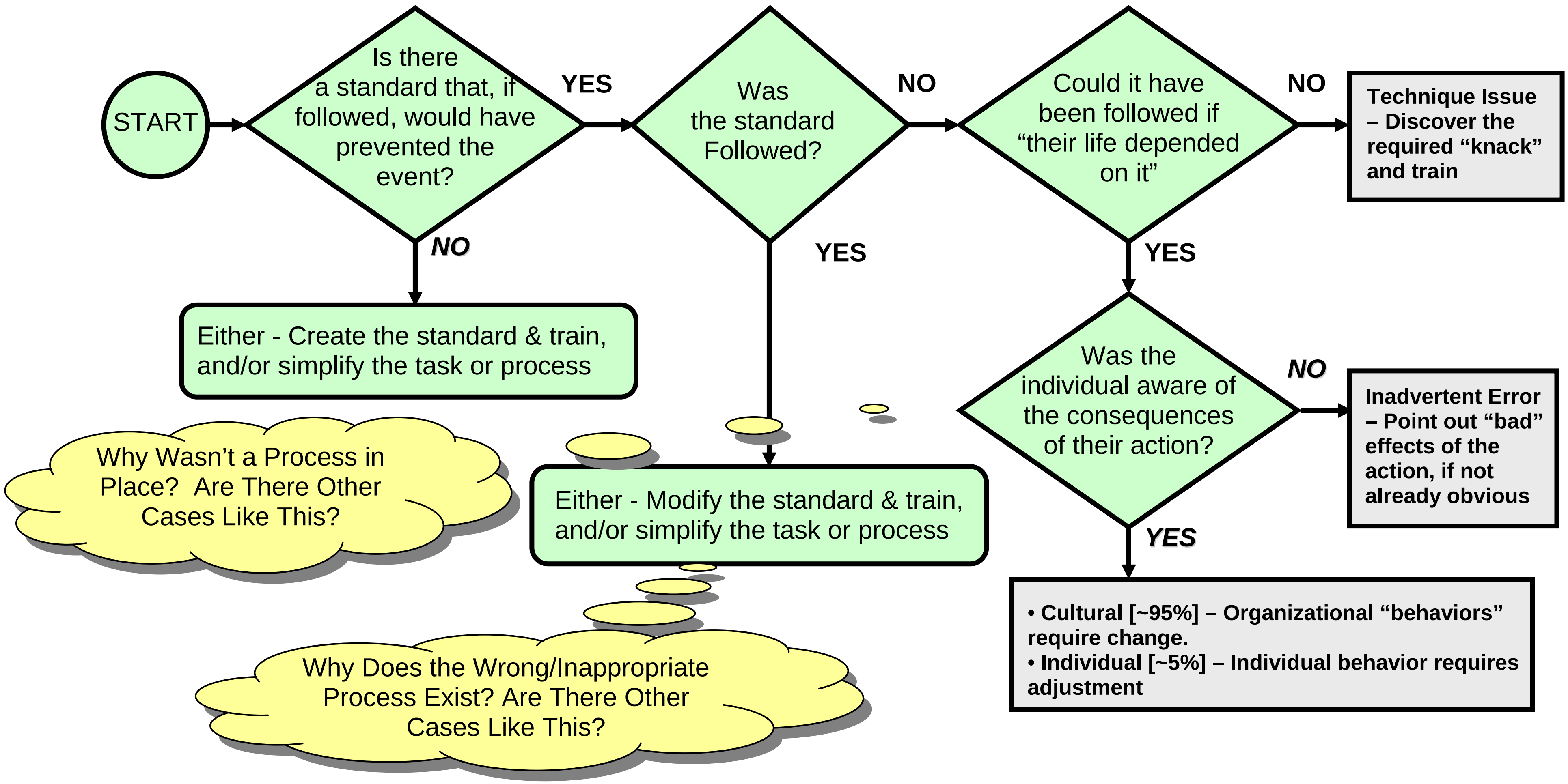
Many improvement opportunities arise because either:

a. a process does not exist to ensure the required quality of the product or service, or

b. a process does exist, but is either not followed or is too difficult to follow.

The flowchart on the next page presents a series of questions when “problems” occur. Notice that there is both a *specific* response to the problem being addressed and a *broader* response that questions whether other situations like this exist in the organization. These broader questions often arise when an organization is just beginning to implement the philosophy of quality control & improvement.

Was the Process Followed?



STANDARD means policies, procedures, training, checklists and other items that are supposed to prescribe the way specific tasks are to be done.

The items shown in the gray boxes are "human factors" issues. Appropriate countermeasures would be generated directly from this analysis without the need for additional root cause analysis work.

Comparative Process Analysis

Comparative Process Analysis is often used when a specific problem occurs as a result of some work process. The analysis has three steps:

1. Identify how the process operated when the problem occurred,

2. Identify how the process operates when *no* problem occurs, and

3. Seek out the differences between the two. Adopt the best method of performing the process.

This type of analysis is especially useful in accident or injury investigations, although, it has broader application.

Examples

Sand Barge Overturning - During a "fill" operation of a barge with river sand, the barge capsized and sank. Only a few minutes before, a barge crewman was on the deck of the barge.

Although the crane operator was experienced, a team of operators identified several key differences between other fill processes and the one that resulted in the capsizing. As a result of the investigation, changes were adopted by all the operators. Some of the changes improved the efficiency of the fill operation; some addressed the safety of the process.

Medium Voltage Electric Lines - Lineman Injury **-** During a routine repair of insulators on a 13.6 kV distribution line, a lineman fell from the pole. His harness caught him, but he still sustained a back injury.

The process he used during the repair operation was documented and compared to that of other lineman. Several differences were noted, changes were adopted by the injured lineman in his work process.

Fuel Injector Failures During Application to Locomotive Diesel Engines - As part of the locomotive overhaul process, rebuilt fuel injectors are "applied" to the diesel engine. During a one week period, it was noticed that a large fraction of the injectors appeared to be frozen when the engine was tested. All injectors came from one railroad vendor.

The vendor's injector rebuild process was documented and compared to other vendors. It was found that they had adopted a new shipping container (required by the railroad!) that packed the injectors in an upright position (previously, they had been shipped "loose."). Fuel oil introduced to the injector during the vendor's test was not draining from the injector when stored upright as it did when they were shipped "loose."

Twenty Questions

Twenty Questions is a method of breaking down a process and asking the *What, When, Where, Who* and *How* questions for each step. This describes the current reasoning behind the step. Each step is then subject to the *Why* question, i.e. *why* do the step, *why* do it then, *why* do it there, *why* do these people do it, and *why* do it this way?

The next round of questioning challenges the improvement team to either eliminate the step, do it another way, at another time, by another individual, etc. The results of the process step questions are then integrated into the new process. *Twenty Questions* is used to address both the quality of a service or production process, as well as the delivery (timeliness) of the process.

"Twenty" Questions
(Applied to Each Task of the Process)

	Present Method	**Reason**	**Other Choices**	**Method Chosen**	**Improvement**
Purpose	*What Happens?*	*Why do it?*	*Can something else be done?*	*What should be done?*	*List changes to the current process here.*
Place	*Where is it done?*	*Why there?*	*Can it be done some-where else?*	*Where should it be done?*	
Time	*When is it done?*	*Why is it done at that time?*	*Can it be done another time?*	*When should it be done?*	
Person	*Who does it?*	*Why that person?*	*Can another do it?*	*Who should do it?*	
Procedure	*How is it done?*	*Why do it this way?*	*Is there another way?*	*What should be done?*	

What Can Go Wrong?

For some processes, eliminating or preventing failures & errors is an important objective. The *Failure/Error Modes & Effects Analysis (F/EMEA)* is a systematic way of identifying problems that can or could occur in the process. The results of an F/EMEA are then addressed by identifying process changes that eliminate or mitigate the problems. For human errors, use the principles of *Error Proofing* to identify means of preventing the errors or mitigating their effects.

Failure/Error Modes and Effects Analysis (F/EMEA)

After the current process is clarified, investigate each step, asking what could go wrong and what effect could it have **-** i.e. does the error/problem in the process step result in the overall process errors being experienced?

For human errors, consider both error types:

- *Omission* - Here, the task or step is not performed.
- *Commission* - Here, the wrong task or step is performed.

F/EMEA Steps

1. Determine the F/EMEA Purpose – *Why are you doing the F/EMEA; how will the results be used?*
2. Organize the F/EMEA Effort – *Try to get a number of people who have experience with the process to help you.*
3. Review the Product, Service Or Process – *Make sure you know how the current process works.*
4. Determine Item Failure Modes and Process Step Error Modes – *"Modes" are* ***how*** *an item or process step can fail.*
5. Determine Effects of Failure/Error Modes – *What goes wrong when the failure/error mode occurs?*
6. Determine Causes of Item Failure Modes/Step Error Modes – *Identify actionable causes; things you can change in the process.*
7. Determine Failure Mode/Error Mode/Cause Detectability – *Is there someway the failure/error can be detected before impacting the customer?*
8. Prioritize the Failures/Errors – *Which are most frequent; which are most severe; which will "escape" and impact the customer?*
9. Carryout the F/EMEA Action Feedback Loop – *Determine what actions will occur; who is responsible; when the actions will be done.*
10. Validate the F/EMEA – *Review the F/EMEA with "real-life" experiences.*

An example of a Failure/Error Modes and Effects Analysis for an "everyday" process is shown on the next page.

Process: *Changing Engine Oil*

Step Description	Possible Failure/Error	Effect of Error	Frequency of Error	Action to Prevent Error
1. Gather Tools	Wrong Tools	Unable to perform one or more tasks below	Low	None
2. Obtain Oil Filter	Wrong Oil Filter	Unable to install Inadequate engine lubrication	Medium	Check filter number against old filter
3. Obtain New Oil	Wrong quality, viscosity Wrong quantity	Inadequate engine lubrication Added time for process (if insufficient oil quantity)	Medium Low	Check oil container against specifications None
4. Drain Old Oil	Not all oil drained Oil spilled on ground	Sludge buildup in engine Environmental pollution	High High	Include engine heat-up step Provide wide collection pan
5. Remove Old Filter	Filter Seal sticks to oil filter flange Oil spilled on ground	Oil sprays from filter when engine started Environmental pollution	Low High	None Provide wide collection pan
6. Apply New Filter	Threads crossed Inadequate torque applied Too high torque applied	Filter leaks Filter leaks Filter seal damaged, difficult to get filter off	Low Medium Low	None Provide instructions: 1 1/2 turns, check for leaks after oil change Same as above
7. Replace Drain Plug	Threads crossed Inadequate torque applied Too high torque applied Wrong wrench used	Drain plug leaks Drain plug leaks Drain plug threads stripped, leaks Plug head stripped, unable to remove	Low Low Low Medium	None None None Design twist-off drain plug
8. Add New Oil	Insufficient oil added Too much oil added	Inadequate engine lubrication Engine damage	Low Low	None None
9. Replace Filler Cap	Forgot Forgot to tighten	Oil leaks when engine running Minor oil leaks	Medium Low	Include final check step in instructions None

Error-Proofing

When an error occurs in a process, it's often tempting to insert an *inspection step* in the process. Nuclear power plant procedures are full of inspection steps, often due to "one-time" occurrences.

The principles of *error-proofing*, though, provide guidelines that result in process changes that prevent or mitigate the error without adding an inspection step. These principles were derived from examining many hundreds of human errors and the actions taken by organizations to prevent their reoccurrence.

Whenever possible, adopting one of the "error prevention" strategies is preferred, since the error is prevented from happening in the first place. The "error confinement" strategies are more "downstream" in nature, and they try to detect the error before it has a chance to result in an undesirable effect.

Error Prevention

A. *Error Elimination* - Take action to eliminate the possibility of the error occurring. *Examples: 1) To prevent burns, instead of a "Do Not Touch" sign; insulate pipes carrying high temperature fluids. 2) Provide switches to keep an operator's hands away from dangerous stamping machines.*

B. *Decision Delegation* - Take action to eliminate the need to make a routine decision. *Examples: 1) Provide a torque wrench with an audible "click" when the desired torque is reached, instead of requiring an operator to read a torque value. 2) Automate the cash register to subtract the amount received from the customer from the bill to prevent change errors.*

C. *Task Facilitation*

1. Match the task to the operator's abilities - *Examples: 1) Attach carrying handles to bulky objects. 2) Provide easy-to-read instructions with graphics for assembly, or provide a video tape of assembly instructions.*

2. Task stratification and specialization - *Example: Separate similar tasks spatially (performed in different locations) or time-wise (Task "A" this week, Task "B" next week); place similar parts in different bins.*

3. Task Distinguishment - *Example: Color coding of similar parts (e.g. wiring, drug containers); different color identification tags for equipment on adjacent power plants.*

Error Confinement

A. *Error Detection Methods* - Design means of detecting errors (as close to the source of the error as possible):

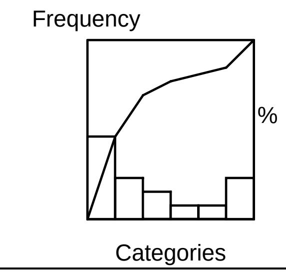
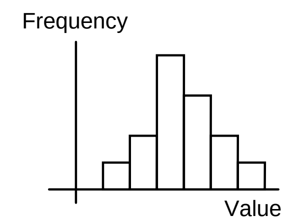
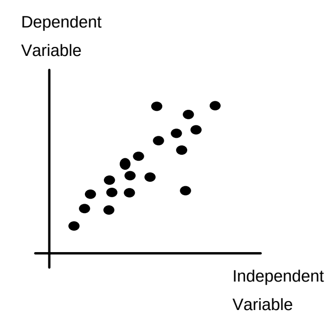
1. Methods based on physical movement - *Example: An assembly process requires 10 drillings. If the proper number of holes is not drilled, an automatic alarm will sound.*

2. Methods based on detecting errors post-installation - *Example: Use different bolt patterns for assembly work (e.g. exhaust manifold to engine block).*

B. *Error Mitigation Methods* - Employ methods that mitigate the effects of the error - *Examples: 1) If driver error causes the automobile to crash, safety belts and airbags mitigate the effects of the error. 2) If gloves are required to be worn near rotating machinery, make sure they "tear-away" if the operator's fingers are caught in the machine.*

4. TOOLS FOR IMPROVEMENT

This section will introduce you to three tools that are *very, very* helpful in process improvement work. Although they are simple tools to use, they are very powerful. We've got a lot of statistical tools in our quality tool chest, but these seem to be the ones that are used the most. Here's the kinds of questions they'll help you answer:

Question	***Analysis Type***	***The Picture***
What's most important? *Example*: A Pareto Analysis of Locomotive Failures showed Low Voltage problems to be most frequent.	***Pareto***	
How do the values of a data set vary, what is the shape of the data? *Example*: A Histogram of Axle Inner Sleeve Diameters showed possible out-of-spec conditions.	***Variation/ Histogram***	
Are two variables related to each other, perhaps through a cause and effect relationship? *Example*: The reaction rate of the chemical process is *positively* related to the temperature of the process.	***Correlation/ Scatter Diagram***	

4.1 PARETO ANALYSIS

The Pareto Principle

Back in the late 1800's, an Italian economist, Vilfredo Frederico Pareto, came up with an interesting finding: *About 80% of the wealth of his country was held by fewer than 20% of the people.* Let's fast forward to the 1930's. In studying manufacturing defects, Dr. Joseph Juran observed that often over 80% of the problems were caused by only a few factors or variables in the production process.

His familiarity with the work of V. F. Pareto led him to name this empirical observation *The Pareto Principle.*[14]

The Pareto Principle has broad application in quality improvement. A few examples of the Pareto Principle at work:

- *Most of a hospital's admissions are due to a relatively few physicians,*
- *A large fraction of power plant failures are due to boiler tube problems,*
- *Seventy percent of assembly defects on irrigation sprinklers are due to problems inserting only two components,*
- *Over 75% of a printing company's sales are to just three customers.*
- *Wasted days in a hospital are due mainly to problems transferring patients to Skilled Nursing Facilities,*
- *Medical Record errors occur most often in three parts of the form,*
- *Delays receiving spare parts are most often associated with one vendor,*
- *Over 90% of Mutual Fund transaction errors fall into four categories,*
- *Sixty-five percent of employee injuries are back strains and sprains,*
- *Over 70% of airline accidents are due to human error.*

Although most of the examples apply to *problems* encountered in production processes, Pareto can also apply to *sales, volumes, costs* and other quality characteristics of a product or service.

[14] Dr. Juran humorously laments that he didn't name it after himself. He says that he was there, he had the opportunity, but he blew it!

Now we won't guarantee that the Pareto Principle will appear in every situation, but it does pretty often. In fact, it appears often enough that we've found it worthwhile to include an attempt at Pareto Analysis in almost every process improvement effort in which we're involved.

There's even a sort of Pareto Principle that's applied to quality tools: *With just Pareto and Cause & Effect (see Section 5), over 80% of quality problems can be addressed.*

Pareto Analysis

Geologists are always studying *strata* of rock structures found around the Earth. *Strata* are *layers.* When we perform a Pareto Analysis, we are trying to *stratify* the problem or process, looking for the *Vital Few* factors that contribute the most to the problem.

When we find these *Vital Few* factors, we'll concentrate on finding their causes and eliminating these as sources of problems. We'll leave the rest of the factors, or *Useful Many* for later. This is the essence of Pareto Analysis - stratify and prioritize!

The Pareto Analysis Process

The Pareto Principle is simple and widely applicable, yet we've seen many quality improvement efforts that could have, but did not employ Pareto Analysis. One of our hypotheses is that while the Pareto Chart is taught in most quality courses, *Pareto Thinking* is not.

Let's explore the basic thought process behind *Pareto Analysis.* The process is "exploratory" in nature; we may start out on a certain train of thought, and the data may or may not confirm our thinking. Although it's sometimes frustrating, if an initial Pareto Analysis doesn't pan out, you should view this positively - take another shot at it and you might actually learn something new!

What's the Effect or Problem? - Pareto Analysis starts with some effect or problem that you're investigating. The typical Pareto Analysis is done on an effect that is stated as a *problem:*

- *Manufacturing Defects*
- *Medical Record Errors*
- *Power Plant Failures*
- *Ordering Mistakes*
- *Shipping Delays*
- *Employee Injuries*
- *Contracts not Awarded*
- *Construction Errors*
- *Customer Complaints*
- *Wrong Diagnoses (car repair, patients, TV/VCR's, etc.)*

We'll generalize this below (see *Types of Problems*), but these examples are a good place to start.

***How should the Effect be measured?* -** The next question addresses how we'll measure the problem. Often, *frequency* is used, simply, how many times has the problem occurred? *Cost,* though, is a better measure of the problem.

For example, some manufacturing defects may be possible to rework, the cost of these defects is the rework cost. Others may require that the product be scrapped at a higher cost. Likewise, an ordering mistake that sends the customer a higher quantity than ordered may not be as costly as a mistake that sends the order to the wrong customer.

***How can the Effect be stratified?* -** If you are just beginning to understand your problem, then you should use the "4W" categories:

- *What* types of problem are there? Are there different types of problems that occur more frequently than others?
- *When* do the problems occur? Are there differences by day of week, shift, or time of day?
- *Where* do the problems occur? Are there differences by location, area, plant, or production line?
- *Who* performs the work that produces the problems? Are there differences by operator, physician, teller, technician, manager?

If you are trying to use Pareto Analysis to understand the causes of the problem, then you'll be looking for *why* or *how* categories. Your Cause and Effect diagram (see Section 5) will have identified these *why* or *how* categories. This is an important distinction. Pareto is often used early in an improvement to stratify by *phenomena* or *symptom*. Later, Pareto is used to stratify by *cause (method, machine, material, personnel, etc.)*.

For many industrial problems, categories will already exist that you can use to start your Pareto Analysis. For example, employee injuries are categorized by type (or *what*) such as strains, sprains, lacerations, breaks, shocks, etc. Often, there will be some initial, logical categories you can use.

These categories are good to start with, but we've seen their use lead to many "mechanical" Pareto analyses. Even though these categories don't lead to a good 80/20 split, the improvement effort will still simply pick the highest frequency category and attempt to work on preventing this category of problem.

You should try, though, to stratify the data in different ways. You may learn something. For instance, one company stratified employee injuries by *where* they occurred. They found that over 90% of the injuries were occurring in the office buildings, not in the "field" as they expected.

***What does the Data tell you?* -** Collect or organize your "problem" data according to the categories you've chosen. Construct the Pareto Chart. Do you "see" an 80/20 split? Have you identified the *Vital Few* categories that contribute the most to your problem?

If so, then move on to find out *why* these vital few are occurring. Leave the *Useful Many* for later (unless some of these are very easy to address).

If not, then go back and think of your problem from a different angle. How else could you stratify the problem? As one of our friends says, "*Lather, rinse, repeat.*"

Types of "Problems"

Pareto Analysis works best with a *zero-type problem.* This is a problem whose desired "level" is *zero.* Errors, defects, injuries, accidents are all *zero-type problems.* Ideally, we would like to have none of these problems occur (regardless of the current practicality of *zero defects*).

If you have a zero-type problem, then Pareto Analysis can be used directly. Collect the data by category or strata, and construct the Pareto Chart.

There are two other kinds of "problems" that you'll deal with, though. The first is a *decrease-type problem.* For example, you may want to minimize the time required to perform some process. The "ideal" process time here is *not* zero, but you would like to eliminate any wasted time or non-value added time.

You can still do a Pareto Analysis, but you'll want to transform your *decrease-type problem* into a *zero-type problem.*

> *Example: A hospital wanted to decrease Lengths of Stay for certain types of patients. They began their analysis by collecting data on "Lost Days;" days where the patient was in the hospital, but didn't need to be. Ideally, the number of Lost Days is zero, so they transformed a decrease-type problem into a zero-type problem.*

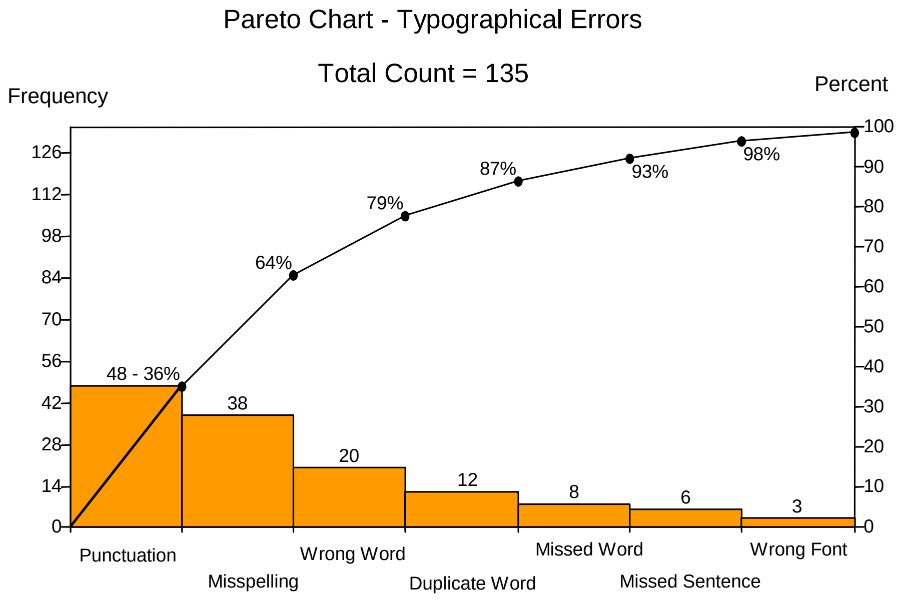
The other type of problem is an *increase-type problem.* *Sales* or *volumes* are examples of increase-type problems. Here, too, you'll want to transform the increase-type problem into a *zero-type problem* as part of your Pareto Analysis.

> *Example: A utility was promoting the sale of water heater heat pumps. Based on their market research, they had predicted the number of sales by geographic area, customer type and income. When the expected sales did not materialize, they performed Pareto Analysis by measuring the "gap" between actual vs. predicted sales, using the different categories. Measurement of the "gaps" turned the increase-type problem into a zero-type problem.*

The Pareto Chart

Purpose

The Pareto Chart is a special kind of bar chart that displays the results of a Pareto Analysis. The Chart shows, at a glance, the *Vital Few* categories that contribute the most to the problem. A simple Pareto Chart of typographical errors is shown below:



There are two parts to the Pareto Chart. The bar chart portion shows the contribution of the *individual categories* (in order) to the overall problem. The line graph shows the *cumulative impact* of the categories, from largest to smallest. Three *types* of typographical errors, *Punctuation, Misspelling,* and *Wrong Word* make up almost 80% of all errors. These are the *Vital Few*.

By the way, some statistical tools are "Ah-hah!" tools. For instance, when you take some data and construct a histogram, there is an "Ah-hah!" at the moment the histogram appears. The Pareto Chart is not like that. The "Ah-hah!" comes when you collect the data and organize it by category. The Pareto Chart's purpose is to communicate the results of your analysis to others.

Application

The Pareto Chart is applied whenever a Pareto Analysis is performed. Generally, the Pareto Analysis will be performed during these steps of a quality improvement effort:

- *Defining the Problem* - Of all the problems currently faced by the organization, which is most important to address *now*?
- *Measuring the Current Situation* - For the problem being addressed, which are the most important categories? Which are the *Vital Few* versus the *Useful Many*?
- *Analysis* - For the problem being addressed, which causes of the problem appear most often?
- *Results* - After changes have been made, has the problem been reduced in frequency or cost? Was the particular category of problem reduced? Has the cause of the problem been eliminated?

- σ *Future Plans* - What are the remaining problems to be addressed? Which are most important?

You can see that Pareto is widely applicable - almost every step of improvement can make use of Pareto Analysis!

Construction

Note: These construction steps assume the Pareto Chart is being prepared as part of a Pareto Analysis.

1. Collect data on the frequency or cost of the problem, stratified by the categories you think are important.

2. Order the categories from largest to smallest contributor to the problem.

   Note: If several categories are very small contributors to the problem, you can group them into an "Other" category. Just make sure that this "Other" category doesn't make up more than about 20 - 25% of the total. Even if the "Other" category is larger than some of the individual categories, always put it last.

3. Add up the individual categories, from largest to smallest to obtain the cumulative values.

   Note: You can also calculate the cumulative percentages if you want to label the "cum line" with these.

The following table summarizes these calculations:

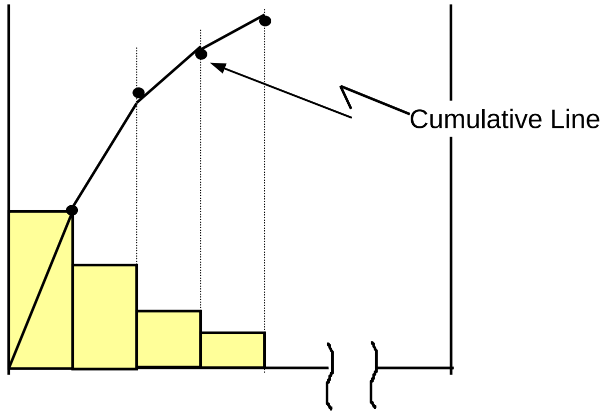
Category	Contribution	Cumulative	Cumulative Percent
Punctuation	48	48	36%
Misspelling	38	86	64%
Wrong Word	20	106	79%
Duplicate Word	12	118	87%
Missed Word	8	126	93%
Missed Sentence	6	132	98%
Wrong Font	3	135	100%
Total	135	-	-

4. Draw the left vertical axis and scale it from zero to the total of all categories. Draw the horizontal axis, and divide it equally into the number of categories you have.

Draw the right vertical axis and scale it from zero to 100 percent (make the 100% point even with the total on the left vertical axis).

5. Draw the individual categories as bars on a piece of graph paper. If you have grouped several categories into the “Other” category, draw this as the right-most bar.

6. Draw the cumulative line as a series of line segments, starting from the “0” point on the left vertical axis and finishing at the 100% point on the right vertical axis. The segments end at the right side of each bar:



7. Title, label and date the Pareto Chart. Note when the data was collected and who prepared the chart.

Interpretation and Action

Interpretation of the Pareto Chart is simple: Does the Pareto Principle appear with the stratification strategy you've employed? If it does, then you can take the next steps in your improvement effort. If not, try to identify a different stratification scheme.

Even if the Pareto Principle appears on your first try, you may want to examine the data from other angles. It never hurts.

After you've gone to the trouble to collect the data and perform the Pareto Analysis, now what? Let's return to the basic purpose of Pareto Analysis - *stratify* and ***prioritize!*** If you're trying to pick the most important problem to address through an improvement effort, the "big bars" on the Pareto are the ones on which to focus. If you've gathered data on the *causes* of your problem, these same "big bars" are the variables you should change to reduce the frequency or cost of your problem.

Pareto causes us to make two important and related choices:

> *We **will** work on the Vital Few factors, and we **will not** work on the Useful Many.*

Too often, organizations expect their people to work on everything, with little prioritization. Pareto forces us to make choices.

> ***Don't try to improve more things than you have fingers on one hand (A good thumb rule[15]).***

One of our CEO friends implemented this philosophy beautifully and simply - He asked each of his VP's to identify the three most important issues in their departments each month and tell him what their plans were to address them.

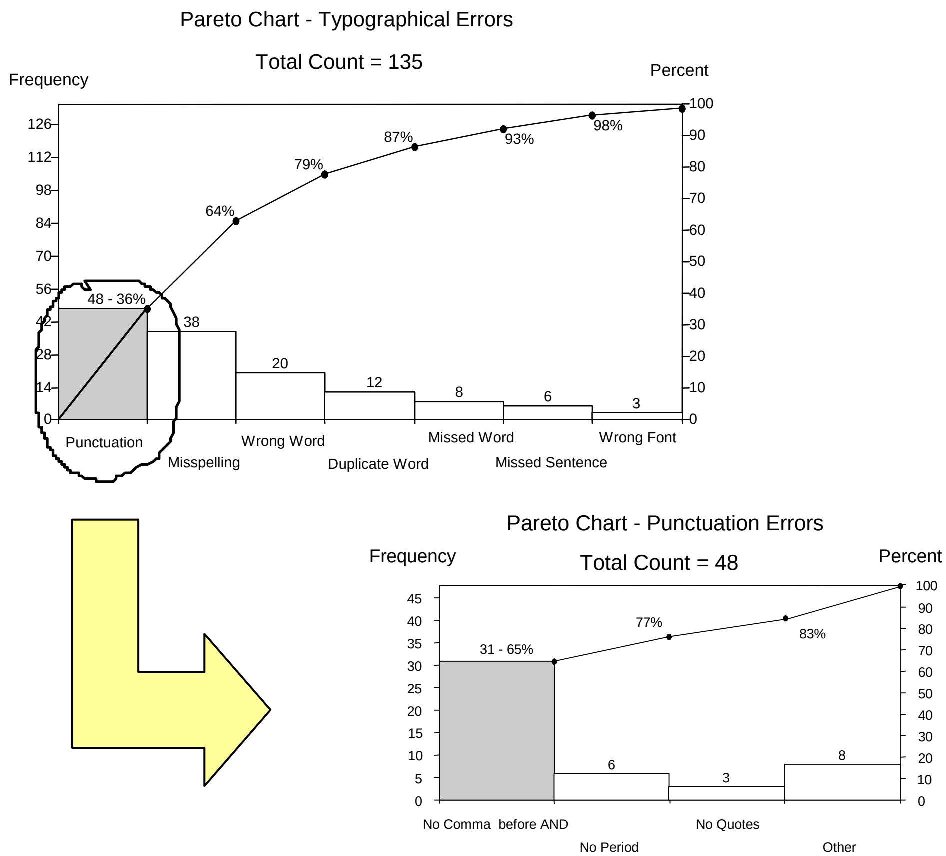
[15]Pun intended!

Pareto Pointers

Here are a few pointers on the practice of Pareto Analysis that we've found helpful in quality improvement work:

Multiple Stratifications

You may find that, after your first "level" of stratification, that the data can be stratified further. This can be a great strategy for really focusing in on the problem. Be careful, though. If you stratify too many levels, you're in danger of entering the *Pareto Death Spiral.* You don't want to wind up focusing on a very tiny portion of the overall problem.



In this example, we find that most of the punctuation problems (that is the “big bar” of the typographical errors) are due to that insidious error: *not adding a comma before the word “and.”* We’re now at a point where the problem has become specific enough to solve.

Two Way Stratifications

The basic Pareto Chart gives us a picture of a “one-way” stratification - we’ve sliced the problem in one dimension or direction. You may learn something by creating a Pareto Table, to examine the problem from two dimensions.

	Injury					
Job Type	Laceration	Bruise	Strain	Sprain	Burn	**Totals**
Office	*36*	*22*	*2*	*8*	*15*	83
Shipping	*14*	*6*	*25*	*12*	*0*	57
Assembly	*2*	*11*	*19*	*6*	*0*	38
Machining	*18*	*9*	*1*	*2*	*6*	36
Inspection	*0*	*2*	*0*	*1*	*0*	3
Totals	70	50	47	29	21	217

Overall, the highest injury frequency occurs in the office, with lacerations being both a frequent injury type overall and one that occurs in the office. What’s going on here? Later in this section, we’ll introduce a method known as *Contingency Table Analysis* that you can use to analyze this data.

Before and After Comparisons

Some people have a hard time understanding why the *cumulative line* is needed on the Pareto Chart. They argue that the Pareto Principle can be seen from just the bar chart portion of the chart. One use of Pareto is to compare *before* and *after* we’ve changed the process. The cumulative line is important here. Figure 4-1 illustrates this concept.

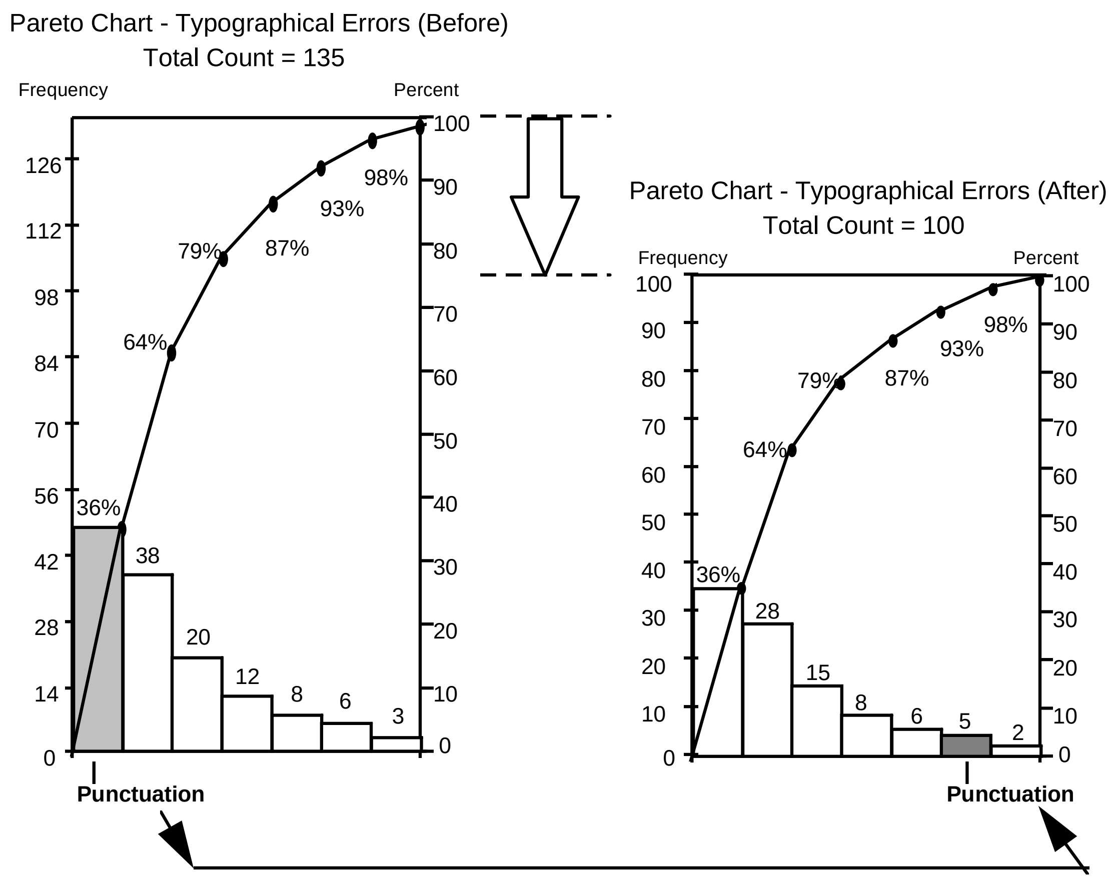
Young and Old Mountains

An initial stratification of the data may yield a very good Pareto; we can call this the “young mountain.” After a while, though, improvement efforts will “wear down” the young mountain. Using the same stratification strategy will produce an “old mountain.” When this happens, it’s time to rethink the stratification strategy. Try to examine the problem from different angles.

Pareto Humor

What do you call it when you get a flat Pareto chart? (*a Flatato*) Do you remember Mr. Spock’s greeting, “*Live long and Pareto?”* What does a Pareto enthusiast say? (*I love a Pareto, or Don’t rain on my Pareto*) You’ve heard of the tasty dish named after this tool? (*Fettuccini Pareto)* We’re sure you can think of more!

Figure 4-1 Before and After Improvement Pareto Charts



Differences among Categories - The Contingency Table

Purpose of a Contingency Table

The Pareto Diagram allows us to perform a *one-way* stratification of data. We take some effect, identify categories and then see how much of the effect is due to each of the categories.

A more general approach to attacking the stratification issue, especially if we are dealing with a quality characteristic that falls in the *count* data category is the *Contingency Table*. This allows us to employ a *two-way* stratification of a group of items.

Contingency Tables and Their Use

The easiest way to introduce Contingency Tables is show a few examples and how they can be used in process improvement.

In this first example, we are trying to determine if administering two different types of flu vaccine made a difference in the proportion of people contracting flu. This use of a contingency table is to explore a *cause and effect* relationship:

2 x 2 Contingency Table
2 Rows, 2 Columns
Flu Vaccine Type

	Shanghai	Malaysian	Total
Contracted Flu	673	816	1489
Did Not Contract Flu	2880	2194	5074
Total	3553	3010	6563

Here, the contingency table examines the differences in infection rates across hospital units. This may be done to aid in understanding the *current situation:*

2 x 5 Contingency Table
2 Rows, 5 Columns
Hospital Units

	2E	2W	3N	3W	4E	Total
Infections	5	3	6	4	7	25
No Infection	124	212	186	134	303	959
Total	129	215	192	138	310	984

Here, again, we are examining a *cause and effect* relationship, but the contingency table shows its power by allowing us to determine four different levels of the factor, *Number of Quality Improvement (QI) Courses*, against three different levels of the effect, *post-test performance:*

4 x 3 Contingency Table
4 Rows, 3 Columns
Post-Test Performance

	Bad	Average	Good	Total
0 QI Courses	20	20	10	50
1 QI Courses	10	30	15	55
2 QI Courses	5	30	15	50
3 QI Courses	5	20	20	45
Total	40	100	60	200

Contingency Table Notation

Let's generalize the example Contingency Tables shown above. There is an established notation for the elements of the Contingency Table, as shown below:

n COLUMNS

m ROWS

	A_1	A_2	...	A_n	Total
B_1	X_{11}	X_{12}	...	X_{1n}	$X_{1.}$
B_2	X_{21}	X_{22}	...	X_{2n}	$X_{2.}$
B_3	X_{31}	X_{32}	...	X_{3n}	$X_{3.}$
.	.	.	...	.	.
B_m	X_{m1}	X_{m2}	...	X_{mn}	$X_{m.}$
Total	$X_{.1}$	$X_{.2}$	...	$X_{.n}$	$X_{..}$

The *X's* are the values of the variable we are measuring. Each element of the matrix is the value of the variable for the particular combination of *attributes* (*A's* and *B's*) we are exploring. In the first example, X_{11} = 673, this represented the number of people who contracted the flu *and* that received the Shanghai vaccine.

We'll use these *X's* in the Contingency Table Analysis to calculate something called a χ^2 statistic and perform an hypothesis test to see if there is a significant difference among the attributes.
Although not strictly required, a good convention is to assign the *rows* to be the *effects*, or *dependent variable;* the *columns* then become the *factor* or *independent variable.*

Contingency Table Analysis

The contingency table analysis process is performed in five steps:

1. Establish the Null (H_o) and Alternative (H_a) Hypotheses. Two hypotheses are established that follow the general form presented below:

Null Hypothesis (H_o) **-** There is no relationship (i.e. independence exists) between Attribute A and Attribute B.

Alternative Hypothesis (H_a) **-** There is a relationship (i.e. dependence exists) between Attribute A and Attribute B.

In the flu vaccines example, the hypotheses can be stated as follows:

Null Hypothesis (H_o) - There is no relationship between the type of flu vaccine administered and the occurrence of flu.

Alternative Hypothesis (H_a) - There is a relationship between the type of flu vaccine administered and the occurrence of flu.

Hypotheses should always be formulated in this fashion. The procedure for hypothesis testing relies on us establishing enough evidence to "convict" the null hypotheses, that is, to "convict" the factor of relating to the effect.

2. Choose the Significance Level of the Test (α). This is a risk level that we are willing to accept. The formal statement is "The Significance Level is the probability that we will reject the *null hypothesis*, when in fact it is *true*."

We will generally be drawing a sample of data from a population, calculate some statistic and make some inference about the population from the statistic. There is, of course, some chance that the sample of data could lead us to make a wrong conclusion about the population. There are two kinds of errors that we can make with this process:

- *Type I* - We could reject the null hypothesis, when in fact it is true, or

- *Type II* - We could accept the null hypothesis, when in fact it is false.

The Significance Level is associated with the *Type I* error.

Many hypothesis tests "default" to a significance level of 0.05 (five percent). This is bad practice. Depending on the *consequences* of making the Type I error, we may want to increase the significance level (hence, increase our chance of making an error) or decrease the significance level (and decrease our chance of making the Type I error).

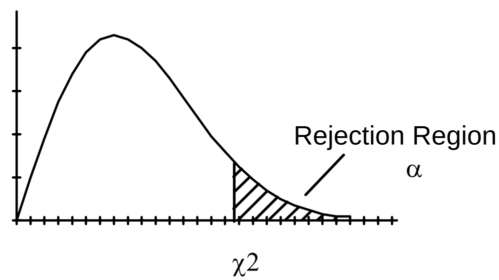
Setting the significance level of the test ***should always*** be a management decision (i.e. be made by someone who is *accountable* for the decision to be made).

Although the details are beyond the scope of this procedure, in general, the less willing we are to make the Type I error, the more data we need to plan on collecting.

3. Determine the Rejection Region. In Step 4, we will be calculating a *test statistic* from the contingency table data. We will compare that calculated value to a *table* value obtained from a χ^2 table (see page 4-19).

If the test statistic falls in the *rejection region*, we will claim that sufficient evidence has been accumulated to *reject* the null hypothesis.

Chi-Square DISTRIBUTION



The table value that should be obtained is the value for *(m - 1)(n - 1)* degrees of freedom at the α level of significance.

For example, for a *4 row, 3 column* contingency table, *m = 4, n = 3* and the χ^2 value for 6 {(4 - 1) x (3 - 1) = 3 x 2 = 6} degrees of freedom at the 0.05 level of significance would be obtained from the look up table (this value is 12.59).

4. Collect the Data and Calculate the Test Statistic. Data should then be collected and sorted into the cells.

The *test statistic* is calculated using the following formula:

$$\chi_0^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where:

k = number of cells in the table

O_i = observed count for cell i

E_i = expected count for cell i

(assuming H_o is true)

To help perform this calculation (without a computer program); it is helpful to set up an *Expected Counts Table*, right below the Contingency Table:

Observed Counts
Flu Vaccine Type

	Shanghai	Malaysian	Total
Contracted Flu	673	816	1489
Did Not Contract Flu	2880	2194	5074
Total	3553	3010	6563

Expected Counts
Flu Vaccine Type

	Shanghai	Malaysian	Total
Contracted Flu	806.1	682.9	1489
Did Not Contract Flu	2746.9	2327.1	5074
Total	3553	3010	6563

The cell values in the *Expected Counts* table are those that would be expected to arise if there *were no difference in the treatments* (i.e. the null hypothesis).

The easiest way to obtain the *expected* cell values is to calculate the proportions from the totals column of the observed counts table and "back calculate" the expected counts cell values:

Expected Proportion Contracting Flu = 1489/6563 = 0.227

leads to:

Expected Count for Shanghai Vaccine = 3553 x 0.227 = 806.1

Expected Count for Malaysian Vaccine = 3010 x 0.227 = 682.9

and:

Expected Proportion Not Contracting Flu = 5074/6563 = 0.773

leads to:

Expected Count for Shanghai Vaccine = 3553 x 0.773 = 2746.9

Expected Count for Malaysian Vaccine = 3010 x 0.773 = 2327.1

One condition we impose on this analysis is that the *expected cell counts* should be greater than or equal to 5. As we saw above, the expected cell counts are influenced by the *relative proportions* and the total number of events. Practically, if the relative proportions are small (e.g. 0.001), then to meet this condition, a large sample size will be required (e.g. 0.001 x 5000 = 5).

Now the test statistic can be calculated:

$$\chi_0^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

$$\chi_0^2 = \frac{(673 - 806.1)^2}{806.1} + \frac{(816 - 682.9)^2}{682.9} + \frac{(2880 - 2746.9)^2}{2746.9} + \frac{(2194 - 2327.1)^2}{2327.1}$$

$$\chi_0^2 = 21.98 + 25.94 + 6.45 + 7.61$$

$$\chi_0^2 = 61.98$$

5. Draw the Conclusion. The last step is to compare the *calculated value* of the test statistic to the *table value* obtained from the chi-squared table. If the calculated value is greater than the table value, then it falls into the *rejection region.* The null hypothesis would then be rejected in favor of the alternative hypothesis.

In the example, 61.98 (calculated value) > 12.59 (table value). We would then *reject* the null hypothesis and conclude that there is a relationship between the type of flu vaccine and the occurrence of the flu.

On the other hand, if the calculated value was less than the table value, then we would conclude that we could not reject the null hypothesis. Note that we *do not* conclude the null hypothesis is *true,* merely that we have insufficient evidence to reject the hypothesis.

We'll bring the court analogy back into this discussion. When a person is acquitted of a crime, the jury does not conclude that the person is innocent, but rather that they are *not guilty.*

χ^2 Critical Values

Degrees of Freedom	α = 0.2	α = 0.1	α = 0.05	α = 0.01
1	1.64	2.71	3.84	6.64
2	3.22	4.61	5.99	9.21
3	4.64	6.25	7.82	11.34
4	5.99	7.78	9.49	13.28
5	7.29	9.24	11.07	15.09
6	8.56	10.65	12.59	16.81
7	9.80	12.02	14.07	18.48
8	11.03	13.36	15.51	20.90
9	12.24	14.68	16.92	21.67
10	13.44	15.98	18.31	23.21
11	14.63	17.28	19.68	24.73
12	15.81	18.55	21.03	26.22
13	16.99	19.81	22.36	27.69
14	18.15	21.06	23.69	29.14
15	19.31	22.31	25.00	30.58
16	20.47	23.54	26.30	32.00
17	21.62	24.77	27.59	33.41
18	22.76	25.99	28.89	34.81
19	23.90	27.20	30.14	36.19
20	25.04	28.41	31.41	37.57
25	30.68	34.38	37.65	44.31
30	36.25	40.26	43.77	50.89

4.2 VARIATION/HISTOGRAM ANALYSIS

Variation in a Product or Service

Variation exists everywhere you look. No two products are *exactly* alike - each time a service is performed, there will be differences. Even if we type seven "identical" letters on a line, no two will be exactly alike, although for these, you'll probably have to use a magnifying glass to see the differences:

A A A A A A A

Remember that these letters were formed by a "production" process, here involving a computer and printer and paper. There are many factors at work to make these letters. Each of them will vary and the sum of the factors' variation results in the overall variation.

There is profit, though, in studying the variation in our products and services. In fact, this is the key idea behind *statistical quality improvement.* The data you collect from your products and services is the "Voice of the Process."

If you become skilled at listening to this voice, you'll be able to discover the factors that are responsible for variation in products and services. You're on the road to improvement!

This section will provide you with some basic tools that help you understand the variation that exists in your products and services. After you become acquainted with these tools, we hope that you'll never again be satisfied with just an *average* value from a set of data. One of our much respected quality teachers, Dr. Teiichi Ando, began his lectures with this statement:

"We must leave the world of Averages and learn to enter the world of Variation!"

There's one caution we need to insert here. The tools of this section, the *frequency chart* and *histogram* are "static" pictures of variation. They should be used in combination with run or control charts to be most effective.

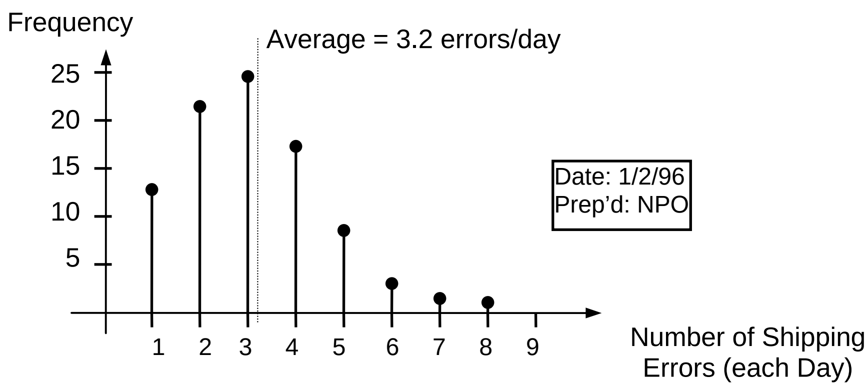
The Frequency Chart

Purpose

The frequency chart helps you display the variation in a set of *count* data. The count data could be the number of defects or defective items identified in samples (or lots) of your product.

In general, when you record the number of *events* that occur in a given time period, or in a given sample, and you do this repeatedly, the frequency chart will be useful. You might display the variation in *volumes* (i.e. number of surgeries performed each day, number of customers, number of telephone calls, etc.) on a frequency chart.

Frequency Chart - Daily Shipping Errors



Here, the Shipping Department has kept a daily tally of the number of errors made. The horizontal axis of the chart shows the range of errors, each day had at least one error, but no day had more than eight errors.

The vertical lines show *how many times* a day that number of errors occurred. For example, it appears that on thirteen days *one error* was made, on 22 days *two errors* were made, etc. Stepping back and looking at all the lines, you get a picture of the *shape* or *distribution* of the data.

Note that if your count data can assume many different values, the *histogram* might be a better tool. Generally, if there are more than about 20 - 25 different data values, the histogram should be used.

Application

Frequency charts are applied in various steps of quality improvement:

Define Reason for Improvement - The frequency chart can help show that there is a need to improve a product or service. If the average number of errors is too high, or if the pattern shows some unusual shape (such as outliers), there may be a need to improve the process.

Measure Current Situation/Analysis - Frequency charts may be prepared for various *strata* of the process. Different machines, methods, personnel, plants or departments may be examined. Here, you are beginning to break down the variation that you see in the process' output.

Check the Results - Before and after frequency charts will show the effects of changes made to the process.

Construction

1. Collect the *count* data to be displayed on the frequency chart. At least 25 - 30 data should be available, preferably closer to 50 data. Be careful that the events you're recording come from approximately the same *area of opportunity.*

In the example above, if the number of shipments varied widely from day to day, the shipping errors (events) would not be coming from the same area of opportunity. The Shipping Department might want to display the number of errors *per 100 shipments* to make the area of opportunity the same.

2. Determine the range of the events - the smallest number and the highest number. Develop a tally sheet to record the number of times each value appears:

SHIPPING ERRORS - TALLY SHEET

# Errors	Tally	Frequency
1	~~////~~ ~~////~~ ///	13
2	~~////~~ ~~////~~ ~~////~~ ~~////~~ //	22
3	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~	25
4	~~////~~ ~~////~~ ~~////~~ ///	18
5	~~////~~ ///	8
6	////	4
7	//	2
8	//	2

3. Draw a horizontal and vertical axis. Label the horizontal axis with the values (i.e. number of errors) and the vertical axis with a convenient scale to display the frequencies.

4. For each value, draw a vertical line from the horizontal axis to the appropriate frequency value. Draw a small circle at the top of the line.

5. Title and label the chart. Include the date the chart was prepared and who prepared the chart.

6. Optional: Calculate the average number of events. Draw this as a dotted line on the frequency chart. If you are calculating the average by hand, the tally sheet can help simplify the calcs:

SHIPPING ERRORS - TALLY SHEET

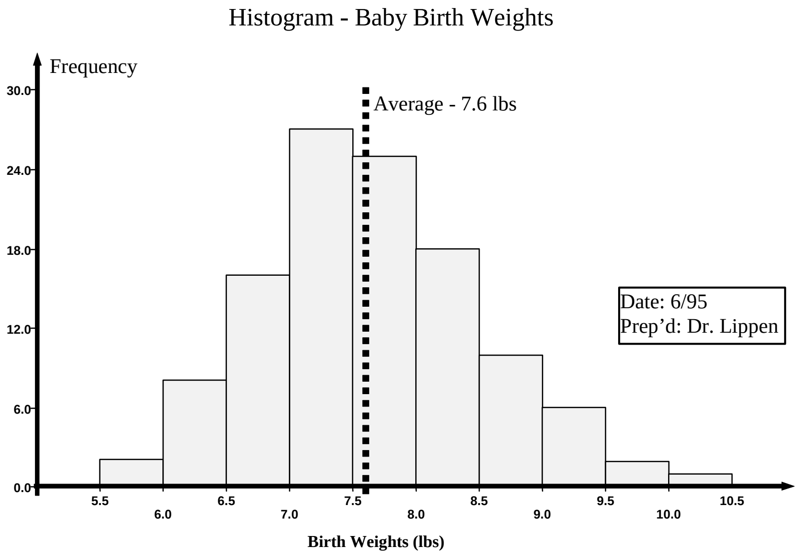
# Errors	Frequency	# Errors x Frequency
1	13	1 x 13 = 13
2	22	2 x 22 = 44
3	25	3 x 25 = 75
4	18	4 x 18 = 72
5	8	5 x 8 = 40
6	4	6 x 4 = 24
7	2	7 x 2 = 14
8	2	8 x 2 = 16
Totals	94	298
Average = 298/94 = 3.2 errors/day		

7. Interpret the frequency chart (see ***Interpretation***, later in this section).

The Histogram

Purpose

The histogram helps you display the variation in a set of *measurement* data (or if your *count* data can assume many different values). The histogram provides a picture of the *distribution* of the data.



In this example, a one month sample of birth weights was collected from a Labor and Delivery unit. The horizontal axis shows the range of birth weights, from 5.5 to 10.5 lb. The height of each "cell" represents the number of babies whose birth weight fell in the range of that cell. For example, 18 babies were born with birth weights between 8.0 and 8.5 lb.

Here, the shape of the data is fairly symmetric around the average value of 7.6 lb. and tails off rapidly as we move away from the average on either side. This kind of data may be described (or modeled) by the *Normal Distribution.* If this data had a different shape, another distribution such as the *Log-Normal, Weibull* or *Exponential* could be used to model the process.

These models are mathematical descriptions of the data and are the next step beyond the histogram. If the process which produced this data is influenced only by the random variation of its factors, then we may be able to *predict the future* of the process.

We could make statements about the likelihood of a baby being born within a certain weight *range*, or what fraction of babies will be born above or below a certain weight. These are important applications in the study of *variation.*

Application

Histograms are applied in various steps of quality improvement:

Define Reason for Improvement - The histogram can help show that there is a need to improve a product or service as part of a *Process Capability Study* (i.e. is the process *capable* of meeting customer requirements?).

If the average value is too high (compared to the customer's requirement or specification), or if the variation (spread) of the data is too high, or if the pattern shows some unusual shape, there may be a need to improve the process.

Measure Current Situation/Analysis - Histograms may be prepared for various *strata* of the process. Different machines, methods, personnel, plants or departments may be examined to break down the variation seen in the process' output.

Check the Results - Before and after histograms will show the effects of changes made to the process.

Construction

Note: The histogram's construction is bit complicated, due to two important issues that relate to obtaining the best picture of your data: 1) applying the "right" number of cells to the data, and 2) ensuring that the data falls into the cells "appropriately."

1. Collect the *measurement* data to be displayed on the histogram. At least 25 - 30 data should be available, preferably closer to 50 data. Count the number of data (we'll call this *n*). Also, note the *measurement unit* of your data - did you measure to the nearest whole unit (i.e. 1 pound), or to the nearest tenth or hundredth (i.e. 0.1 lb., or 0.01 lb.)?

2. Calculate the range of the data:

$$Range = x_{\max} - x_{\min}$$
$$\textit{where}:$$
$$x_{\max} \text{ - Largest Data Value}$$
$$x_{\min} \text{ - Smallest Data Value}$$

3. Calculate the *approximate number of cells:*

$$\text{\# Cells } = \sqrt{n}$$
$$\text{(approximate - don't round off!)}$$
$$\textit{where}:$$
$$n \text{ - number of data in sample}$$

This rule works very well. As the number of data increase, the number of cells will increase, but at a slower rate:

# Data	# Cells (Approx.)
25	5
50	7
100	10
150	12
200	14

4. Steps 2 and 3 are now used to determine the *width of each cell.* This is a two step process. First, we'll calculate an *approximate cell width*:

$$\text{Cell Width (approx.)} = \frac{Range}{\#Cells\,(approx.)}$$

Next, we'll round this off to the *nearest multiple* of your data's *measurement unit.* Here are a few examples:

Cell Width (approx.)	Measurement Unit	Cell Width (Corrected)
0.54 lb.	0.1 lb.	0.5 lb.
14.3 minutes	1 minute	14 min.
0.263 inches	0.05 inch	0.25

5. Now that we know how *wide* the cells are, we'll determine where to *start* the first cell. This is called the *Lower Bound of the First Cell (LBFC):*

$$LBFC = x_{\min} - \frac{Data\ Precision}{2}$$

This correction factor prevents any of your data from falling on a cell boundary.

6. Now, prepare the following tally sheet to identify the range of each cell and record the number of times the data falls in each cell:

Histogram Tally Sheet

Cell #	Cell Boundaries	Tally	Frequency
1	LBFC - C2	~~////~~ /	6
2	C2 - C3	~~////~~ ~~////~~ ///	13
3	C3 - C4	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~	25
4	C4 - C5	~~////~~ ~~////~~ ~~////~~	15
5	C5 - C6	~~////~~ ///	8
6	C6 - C7	////	4
7	C7 - C8	//	2
8	C8 - C9	/	1

The first cell's lower boundary is the *LBFC.* Its upper boundary (C2) is the *LBFC plus the cell width...* Each of the remaining cell boundaries (C3, C4, etc.) is obtained by adding the *cell width* to the upper boundary of the previous cell.

Continue creating cells until the largest data value is "contained" by a cell. Tally the number of data that fall into each cell.

7. Draw a horizontal and vertical axis. Label the horizontal axis with the variable being measured and divide and scale the axis into the number of cells. Label the vertical axis with a convenient scale to display the cell frequencies.

8. For each cell, draw a bar from the horizontal axis to the appropriate frequency value.

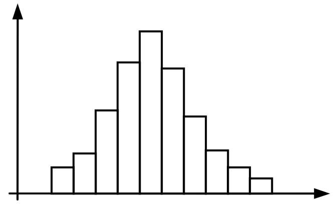
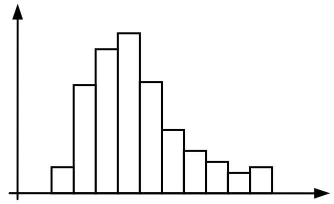
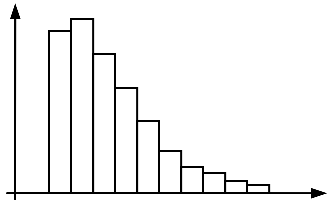
9. Title and label the chart. Include the date the chart was prepared and who prepared the chart.

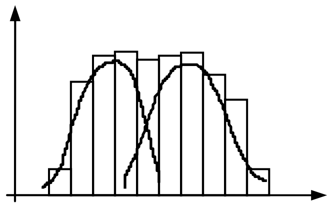
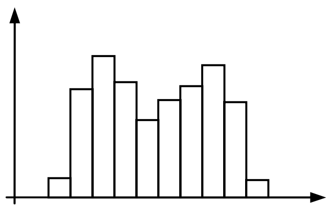
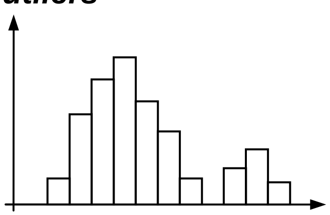
10. Optional: Calculate the average number of events. Draw this as a dotted line on the histogram. Calculate the standard deviation of the data. Record these three quantities on the histogram.

11. Interpret the frequency chart (see ***Interpretation***, later in this section).

Frequency Chart and Histogram Interpretation

The shapes of these charts can give us clues about what might be happening in our process. Here are some common shapes and their interpretation. The first four are shapes that "appear in nature," depending on the type of process that is at work. The last four are indications of something odd in either the data or the process.

Shape	Interpretation
Symmetrical 	Many processes' outputs take this shape, especially those where an attempt is being made to produce the product or service at some target or nominal value. If a data sample is periodically obtained from a random process and the average of the sample is calculated, the histogram of averages will always assume this shape.
Skewed 	The time to complete a process will often appear skewed. Most of the events will fall in a clump to the right or left, with only a few data in a "tail." Other data that often appear skewed are times or cycles to failure.
Extreme Skewness 	Here the data appears to be pushed up against some boundary. This is often the case when there is a lower or upper limit that the data can assume. For example, some time data can appear extremely skewed when it is possible to complete the process in very short times (close to zero). If a product is inspected and rejected if it does not meet a specification, the "good" products will take on this shape after inspection.

Shape	Interpretation
Plateau 	This is a shape where we suspect that two processes are being mixed together, whose mean values are not very far apart. Another time this shape can appear is when an automatic compensating control is fitted to a machine or process. When the process output reaches a certain value, the control adjusts the machine to a lower (or higher) value.
Twin-Peaked 	This is an example of two processes, whose outputs are mixed together. For example, two production lines' outputs are mixed and the histogram data is collected at a final inspection point. This is an invitation to stratify the data. Usually, one of the processes will perform better than the other. If you can understand why, then the other process can be changed to perform as well.
Outliers 	Sometimes, special circumstances will cause the production process to produce outliers. For example, during a colonoscopy procedure, some patients become rather resistant. The time required to "produce" these colonoscopies will show up as an outliers when combined with data from normal procedures.

Combining Factors' Variation

The Problem

The frequency chart and histogram provide us with pictures of the data; they tell you three key features your process:

- The Center of the Process
- The Variability of the Process
- The Shape of the Data

With these three pieces of information, you've captured the essence of your process. Now, most of the time, improvement will drive us to try and break down the variation in the process; what causes the variation that we see? Occasionally though, you may want to combine the variation that exists in two or more factors:

- A manufacturing example: Two parts are to be joined into one component. If the individual parts are produced with the following dimensions, what will be the average and standard deviation of the combined parts? This will determine if the component can meet customer specifications.

Part	A	B
Average Value	1.500"	2.000"
Standard Deviation	0.015"	0.020"

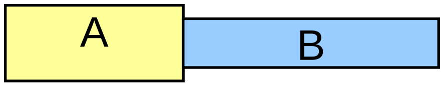
- A service example: A new fabrication procedure has three basic time segments, Setup, Fabricate, and Inspect. If the individual segments are "produced" in the following times, can we predict the overall average time and standard deviation? This will be helpful in determining how to schedule for this procedure.

Segment	Setup	Fabricate	Inspect
Average Value	15 min.	35 min.	20 min.
Standard Deviation	5 min.	10 min.	7 min.

Combining Average Values

Average values can simply be added together (or subtracted, depending on how the variables are combined). For our two examples:

Combining Parts:



The average length of the component (A + B) is:

$$L_{A+B} = 1.500" + 2.000" = 3.500"$$

Combining Procedure Segments:

Setup	Fabricate	Inspect

The average procedure length is:

$$T_{Setup + Fabricate + Inspect} = 15 \text{ min.} + 35 \text{ min.} + 20 \text{ min.} = 70 \text{ minutes}$$

Combining Variation

The process is not as easy if we want to combine variation. Adding the standard deviation values, as we did with the averages may seem to be a practical method, but it turns out that this gives us too large an estimate of the combined variation. The proper method of combining individual variations is to add the variances of the components. This holds regardless of whether the average values are being added or subtracted:

$$\sigma^2_{A+B} = \sigma^2_A + \sigma^2_B$$

where:

$$\sigma^2 \text{ - Variance of the Data}$$

The standard deviation is then the square root of the combined individual variations. For our examples:

Combining Parts' Variation:

$$\sigma^2_{Component} = (0.015)^2 + (0.020)^2$$
$$= 0.000625 \, inches^2$$
$$and$$
$$\sigma_{Component} = \sqrt{0.000625}$$
$$= 0.025''$$

Combining Fabrication Segments' Variation:

$$\sigma^2_{Procedure} = (5)^2 + (10)^2 + (7)^2$$
$$= 174\,\text{min}^2$$
$$and$$
$$\sigma_{Procedure} = \sqrt{174}$$
$$= 13.2\,\text{min}$$

From this information, we could make some predictions about the possible range of values for the combined parts or entire procedure. For example, we would expect very few components to be produced outside a band that extended +/- 3 standard deviations from the average size. The component variability could then be stated as:

3.500" +/- 3 x 0.025" or 3.500" +/- 0.075"

This could be compared to the customer's specifications to determine if the component can be produced inside the specs.

Likewise, very few fabrication procedures would be completed outside the following time band:

70 min. +/- 3 x 13.2 min. or 70 min. +/- 39.6 min.

This could be input to the scheduling system to determine how long to schedule a fabrication procedure.

Caution – The method shown above for combining variation only applies when the relationship between the Y and the X's is linear. For non-linear situations, Monte Carlo simulation or other advanced methods are required.

4.3 CORRELATION/SCATTER ANALYSIS

Relationships between Variables

In all quality improvement efforts, we are interested in discovering which *factors* or *variables* influence the *effect* that we're trying to improve:

- *What factors will help us increase the life of this bearing?*
- *What factors will help us reduce the cost of care to these patients?*
- *What factors will help us reduce the time to provide loans to our customers?*
- *What factors will help us reduce the defects observed in our manufacturing process?*
- *What factors will help us increase the yield of this chemical reaction?*

In many cases, the *type* of relationship that we're looking for can be described as *absence/presence.* We will create a *hypothesis* that if the factor is present, the product or service performs better than it does when the factor is not present:

- *Changing the bearing material will improve the life of this bearing.*
- *Eliminating these unnecessary tests will reduce the cost of care.*
- *Eliminating these unnecessary approvals will reduce the loan processing time.*

For the *absence/presence* relationships, tools such as line graphs, Pareto Charts and Histograms can be used to examine if our hypotheses are to be accepted or rejected.

In other cases, though, the type of relationship we're investigating can be described as *variable.* These hypotheses are stated a bit differently. *Changing* the *value* of one (or more) factors will result in a change in product or service performance:

- *Increasing the pressure in the plastic injection molds reduces the number of defective parts.*
- *Increasing temperature and catalyst concentration improves the yield of the chemical reaction.*

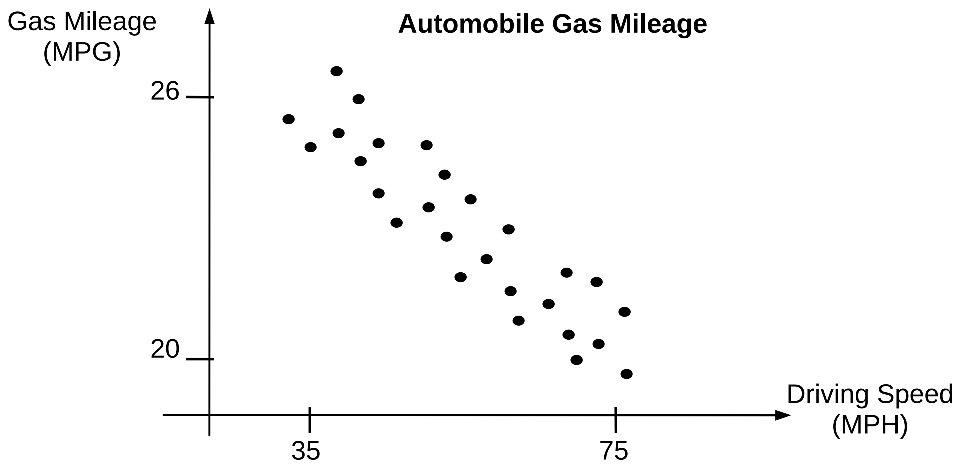
To test these hypotheses, a different sort of tool is required. Here, we'll introduce the Scatter Diagram as the basic (yet powerful!) method of testing these *variable* relationships.

We'll also introduce some rather natural extensions of the Scatter Diagram, providing you with the ability to *measure* correlation and also to build a model of relationships through *linear regression.*

The Scatter Diagram

Purpose

The Scatter Diagram shows the relationship between two variables, usually of the *measurement* type. These two variables are often suspected of being tied together through a *cause & effect* relationship.



Here, the *speed* at which an automobile is driven is the *causative* (or *independent*) variable. The *gas mileage* (number of miles per gallon of gasoline) is the *effect* (or *dependent* variable).

Each point on the scatter diagram represents an *observation* - for a given driving speed, what gas mileage was observed? From the diagram, you can see that there is a *negative* relationship[16] (or *correlation*) between these variables - as driving speed increases, the gas mileage decreases.

Notice that the points do not fall on a straight line. This indicates that there are other sources of variability at work in this process. Very rarely will a “real world” process display perfect correlation between the variables.

The “Punch line” of the Scatter Diagram is important. If there exists a correlation between two variables, then you should be able to change the performance of the *effect* (perhaps this is some important quality characteristic), by changing the *independent variable.* The gas mileage example shows us that we could increase our gas mileage by decreasing our driving speed. Driving speed is something we can *control.*

[16]The term *negative* refers to the kind of relationship, as the independent variable *increases*, the dependent variable *decreases*. “Negative” doesn’t mean it’s a *bad* or undesirable relationship.

The Scatter Diagram also shows you *how much* benefit you'll get from changing the *independent variable.* In the gas mileage example, it appears that we could gain an additional 6 miles per gallon if we could *control* our speed at 35 MPH instead of 75 MPH.

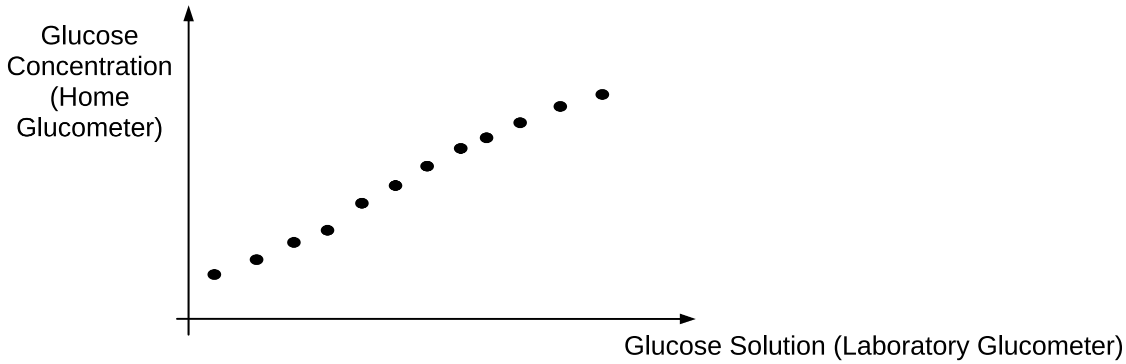
Application

The Scatter Diagram is typically used in the *Analysis* step of improvement. Suspected cause and effect relationships can be verified through use of this tool.

In *Countermeasures*, the Scatter Diagram can be used to determine where the *independent variable* should be controlled. At what level should you set this variable to achieve the desired improvement in the *effect?*

The Scatter Diagram is also used when it's necessary or desirable to develop a *surrogate indicator*; one that is perhaps cheaper or easier to obtain.

Blood Glucose Monitoring
(Home vs. Laboratory Models)



In this example, we are testing to see if a "home" glucometer (the *surrogate indicator*) can perform as well as the laboratory version. Glucose solutions of different concentrations are prepared and both the laboratory and home glucometers are used to measure a given solution. If the home glucometer displays close correlation to the laboratory glucometer, then we can feel confident in using this as the surrogate indicator.
The example scatter diagram shows that there is very good correlation in the "middle" range of glucose solutions, but toward the "tails" (very high and low concentrations), the correlation is not as good.

Construction

1. Define the two variables that you think are correlated. Determine which is the *causative* (or *independent*) variable) and which is the *effect* (or *dependent* variable). If there is some confusion over this, ask the question, "Which variable will *move* the other variable?"

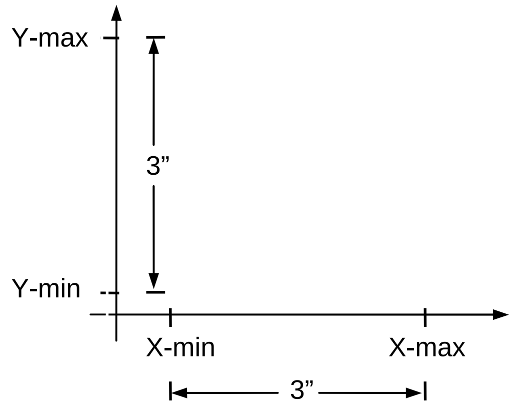
2. Collect the data in pairs. For some processes, the *independent* variable may vary "naturally." Examples of naturally varying *independent* variables include air temperature, humidity, rainfall and sunlight.

For some processes, you may have control of the independent variable. Here, you will have to adjust the values of the independent variable to obtain the scatter diagram points. You will want to define some adjustment range for this variable. The correlation you'll be examining, then, will be limited to this adjustment range.

Chemical, drug, or antibiotic concentrations, furnace or processing temperatures, processing times are examples of "adjustable" variables.

3. Draw a horizontal and vertical axis. Label the horizontal axis with the name of the *independent* (or *causative*) variable, the vertical axis with the *dependent* variable (or effect).

4. Scale these axes so that both the *independent* and *dependent* variables' *range* is about the same *distance.* This ensures that you get the best picture of the correlation between the variables:



5. Plot the data pairs as points on the scatter diagram. If there are identical points, draw a circle around the first one plotted.

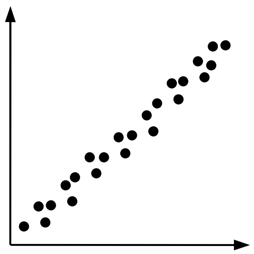
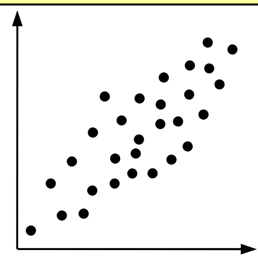
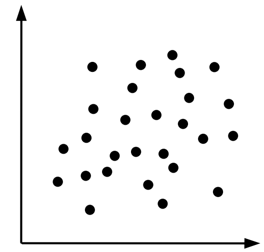
6. Title and label the scatter diagram. Include the date(s) the data was collected and who prepared the diagram.

7. Interpret the scatter diagram for possible correlation between the variables.

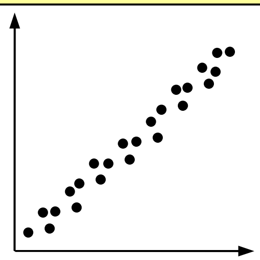
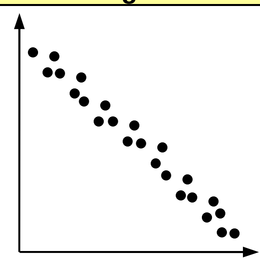
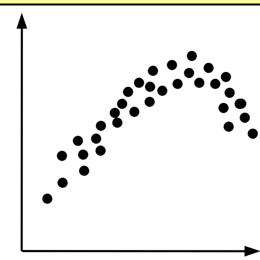
Interpretation

There are two dimensions to scatter diagram interpretation. First, you want to determine if there is any "worthwhile" correlation between the two variables. Second, you want to determine the *type* of relationship between the variables.

Correlation

Strong	Medium	Weak - None
		
The pattern of dots is very tight. You can almost "see" a line that could be drawn through the dots. Carefully controlled process experiments may display this correlation.	There is still some relationship between the variables, but it appears that there are other variables at work, influencing the variation in the *effect.* This is typical of many processes.	No relationship exists between these two variables.

Relationship Type

Positive	Negative	Non-Linear
		
Here, the dependent variable *increases* as the independent variable increases.	Here, the dependent variable *decreases* as the independent variable increases.	Here, the dependent variable first increases, but then begins to decrease as the independent variable increases.

The Correlation Coefficient

Purpose

The Scatter Diagram gives you a picture of the correlation between two variables. Often, this is all that is needed. The Correlation Coefficient provides you with a *measure* of the *strength* of the relationship between two variables.

The term "Perfect" Correlation means that all the data fall on a straight line, in essence, there is no variation from this line. Negative correlation indicates that the dependent variable *decreases* as the independent variable increases; positive correlation indicates that the dependent variable *increases* as the independent variable increases.

Application

The Correlation Coefficient is used in support of a Scatter Diagram. But make sure that you ***always*** draw the picture! It's very easy to obtain correlation coefficients that indicate one thing, with the Scatter Diagram giving you another picture.

Calculation

Most quality software packages today will calculate one or more correlation coefficients. Here is the "simple" correlation coefficient calculation:

$$r = \frac{SS(xy)}{\sqrt{SS(x) \times SS(y)}}$$

where:

r - Simple Correlation Coefficient

$SS(xy)$ - Sum of Squares of xy

$SS(x)$ - Sum of Squares of x

$SS(y)$ - Sum of Squares of y

The Sums of Squares are calculated as follows:

$$SS(xy) = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) \quad = \quad \sum_{i=1}^{n} x_i y_i - \frac{\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n}$$

$$SS(x) = \sum_{i=1}^{n}(x_i - \bar{x})^2 \quad = \quad \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x\right)^2}{n}$$

$$SS(y) = \sum_{i=1}^{n}(y_i - \bar{y})^2 \quad = \quad \sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y\right)^2}{n}$$

where:

$\bar{x}$ - average of x's

$\bar{y}$ - average of y's

n - number of data

Interpretation

As mentioned above, the closer *r* is to either -1 or +1, the stronger the correlation between the variables. If the absolute value of the correlation coefficient (|*r*|) is greater than about 0.8, the *independent variable* can be considered a good *predictor* of the *dependent variable.*

If the correlation coefficient is less than 0.8, then there are likely to be other variables at work influencing the dependent variable. An *r*-value close to zero indicates that there is little to no relationship.

If you suspect that other variables are at work, it may be profitable for you to examine the correlation of multiple factors to the dependent variable through a *designed experiment.*

The *square* of *r* is called the *Coefficient of Determination.* This coefficient's values range from 0 to 1, and there is a special interpretation you can make of r^2:

r^2 is the relative proportion of the variation in the dependent variable that can be explained by the independent variable.

The closer r^2 is to 1, the larger the proportion of the variation is explained. For example, an r^2 of 0.81 (equivalent to an *r* of 0.9) indicates that over 80% of the variation in the dependent variable is explained by the independent variable.

Correlation versus Cause & Effect

There is an old saying, attributed to Mark Twain:

There are liars, damn liars, and then there are statisticians!

In today's world of instant media, we hear frequent reports of "correlations" that have been discovered by this or that research group. Some of these are relatively harmless ("laboratory rats who eat more than 1000 Twinkies a day get fat"), some of these have major implications for the human race ("increases in fossil fuel burning are leading to global warming"), and some of these are irresponsible, raising fears among people who don't have the experimental or statistical knowledge necessary to distinguish the "true" from the "not-so-true" correlations.

> *A few years ago, when our daughter and her playmates were about two years old, the "Alar" pesticide scare was reported. There was little we could do to comfort the mothers who were terrified that the apple juice they had given their children could cause cancer. This correlation was later proven false by responsible scientists.*

Although there are several issues associated with "responsible correlation" analysis, we will only tackle one important issue here. We'll assume that you are like Diogenes, holding up a lantern in search of truths that will help you improve the quality of your products and services.

Not all correlations correspond to a cause and effect relationship.

Consider the following examples:

- *The population of Paris was positively correlated to the number of stork nests in the city.*
- *The homicide rate in Chicago is positively correlated to the sales of ice cream by street vendors.*
- *At one time, the Dow Jones stock market index was positively correlated to the height of women's hemlines.*

These are all examples of "nonsense" correlations. There is no cause and effect relationship between any of these variables.

For the first two examples, though, there is a *third* variable that drives both of the supposedly correlated variables. In Paris, as the population increased, more houses were built. Guess where storks like to build their nests? In chimneys!

You've probably already identified the second example's "hidden" variable - *outside temperature*.

When a correlation appears on your Scatter Diagram, make use of your knowledge of your business' technology and science. Does the correlation make sense from a cause and effect standpoint? The ultimate measure, though, is *repeatability.* If a "true" cause and effect relationship exists, you'll be able to adjust the independent variable and see the corresponding change in the dependent variable.

Introduction to Linear Regression

Purpose

We mentioned above that, for two correlated variables, the Scatter Diagram could be used to determine the impact of changing the independent variable (i.e. process factor) on the dependent variable (i.e. process outcome or effect).

If you simply draw a line "through" the Scatter Diagram's points, then you are on the way to creating a model of how one variable affects another. You have taken on the role of a scientist, discovering physical "laws" that become part of your organization's *technology.*

But there are many lines that could be drawn through the data. How do we judge the "best" line? *Linear Regression* is the method used to calculate the parameters of a line that best fits your data.

Application

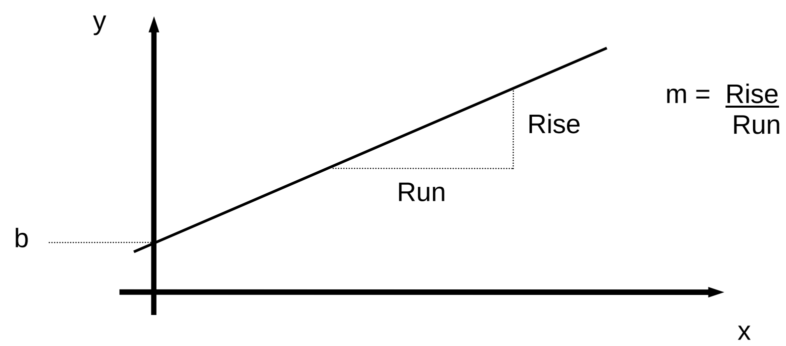
Linear Regression creates a model that predicts changes in the dependent variable (process output) as a function of the independent variable (process factor). In *Countermeasures,* you can use this model to determine the best "setting" or level of this factor.

Linear Regression Theory

There are several different types of regression analysis; we will employ the method of *least squares.* From basic algebra, we recall the equation of a line:

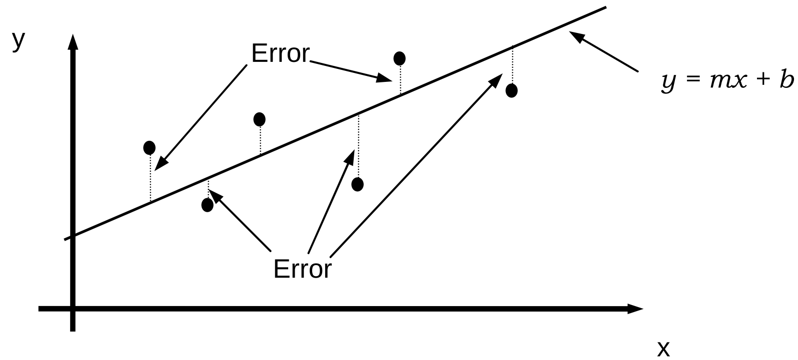
$$y = mx + b$$

A picture of this line helps us identify the purpose of the two parameters, *m* and *b:*



The slope of the line is *m,* found by dividing the rise over the run. The y-intercept is *b,* where the line passes through the y-axis (equivalent to an x-value of zero).

The Scatter Diagram consists of points that are, of course, “scattered” on the x - y plane. Let’s pass an arbitrary line through the data. From any point, then we can draw a vertical line to our arbitrary line. We’ll call this the “error:”



Now we can actually calculate the error (e_i) for any point, x_i, y_i :

$$e_i = y_i - (mx_i + b)$$

The method of *least squares* determines estimates of the line’s parameters (*m* and *b*) by minimizing the sum of squares of the errors:

$$SS(e) = \sum_{i=1}^{n} (e_i)^2$$

where:

$SS(e)$ - Sum of Squares of Error Terms

Calculations

1. Collect the data pairs, or obtain them from the raw data used to create the Scatter Diagram.

2. Calculate the average of the dependent variable and independent variable:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

and

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

where:

y_i - "ith" value of independent variable

$\bar{y}$ - independent variable average

x_i - "ith" value of dependent variable

$\bar{x}$ - dependent variable average

3. Calculate the estimate of the slope of the regression line $\hat{m}$:

$$\hat{m} = \frac{SS(x)}{SS(xy)}$$

where:

$SS(x)$ - Sum of Squares of x

$SS(xy)$ - Sum of Squares of xy

These Sums of Squares are calculated the same as those used for the correlation coefficient:

$$SS(x) = \sum_{i=1}^{n}(x_i - \bar{x})^2 \quad = \quad \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x\right)^2}{n}$$

$$SS(xy) = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) \quad = \quad \sum_{i=1}^{n} x_i y_i - \frac{\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n}$$

where:

$\bar{x}$ - average of x's

$\bar{y}$ - average of y's

n - number of data

4. Finally, calculate the estimate of the y-intercept, $\hat{b}$:

$$\hat{b} = \bar{y} - \hat{m}\bar{x}$$

5. Plot the regression line on the scatter diagram. Visually check the line to see if it is a good fit and that no calculation errors were made.

Note: If you think a regression analysis will help your project, see your Black Belt. First, they will have access to software that will make the job easier. Second, there are some regression assumptions that they will check for your. Ask them about “residuals analysis.”

5. CAUSE & EFFECT

Cause and Effect is a critical element of quality improvement. Throughout this manual, the concepts of *process factors* and *process output* have been discussed over and over. The process (methods, machines, materials, personnel, environment, and information) *produces* your products and services.

To improve quality, we *must* understand the factors that contribute to variation in quality. Through this path we can identify *countermeasures* that have a high probability of improving the quality of our products and services. It's easy to "jump to solutions," harder to understand the real factors that affect performance.

Here are two examples of where this thinking was not applied and the subsequent consequences:

The Case of the Leaky Pump Seal*: A nuclear power plant was having problems with the seal on a pump required for plant safety. The seal would begin to leak after only 1100 hours (on average) of operation. A "brief" analysis led to the conclusion that the seal's design needed changing. $40,000 and six months later, the new seal was installed. After 100 hours of pump operation, the new seal was leaking just like the old.*

A more thorough cause and effect analysis revealed that the pump motor's thrust bearing was not being properly aligned during overhaul. Correction of this problem resulted in no more leaky seals. The cost of the new change: just the revision of one procedure!

The Case of the Clinical Assistants *- At one large hospital, a new role, the Clinical Assistant, had been established as part of cost and service-quality improvement efforts. The Clinical Assistant was a multi-function role, including clinical duties, housekeeping, nutrition and environmental services. Unfortunately, after a few months, administration found that the turnover rate for these assistants was high in some units of the hospital.*

The hospital's Business Leaders met one week to "fix" the problem. They concluded that the Clinical Assistants did not like to do the housekeeping duties, and so their "countermeasure" was to create a new position, the Unit Assistant, to perform the "undesirable" duties. Three months later, the Clinical Assistants were still leaving the same units of the hospital. The problem still exists today.

5.1 CAUSE AND EFFECT ANALYSIS

Cause and Effect Analysis is designed to focus on the *causes*, rather than the *symptoms* of the quality problem. The Cause and Effect Diagram is often used to help identify and evaluate the potential causes of quality problems.

Cause and Effect Analysis consist of two basic steps:

1. Develop an Understanding of the Potential Causes of a Problem, and

2. Determine or Verify which Potential Causes are the Actual Causes.

Sometimes, Cause and Effect Analysis will put you in the role of a detective. You will look for "clues" from your process, trying to discover which of the process factors are responsible for the quality problems or variation.

- *A railroad conducted a root cause analysis of locomotive engine leaks. They discovered that the wrong size bolts were being used that connected a "Y-pipe" to the engine block. The bolts were too long, allowing the "Y-pipe" to flex, resulting in leaks.*

- *A hospital conducted an investigation of a high infection rate for cardiac surgery patients. They found that antibiotics were being administered too early in the surgery preparation process. During the actual surgery, the antibiotics were significantly reduced in their effectiveness.*

Cause and Effect Analysis can also put you in the role of a scientist. Here, you will design experiments to determine which factors are important to the quality of your products and services and what are the best "levels" to set these factors.

- *A manufacturer of plastic components was experiencing excessive "flash" - extra plastic on the component formed when plastic squeezed between the injection mold halves. They conducted experiments to determine the optimal injection pressure that would produce a quality component without flash.*

- *Utility customers were experiencing outages during lightning storms. Utility engineers suspected that changing the time delay on a certain protective relay could prevent many of these outages. They conducted experiments to determine the optimal time delay for the relay and reduced the interruptions.*

5.2 THE CAUSE & EFFECT DIAGRAM

Purpose

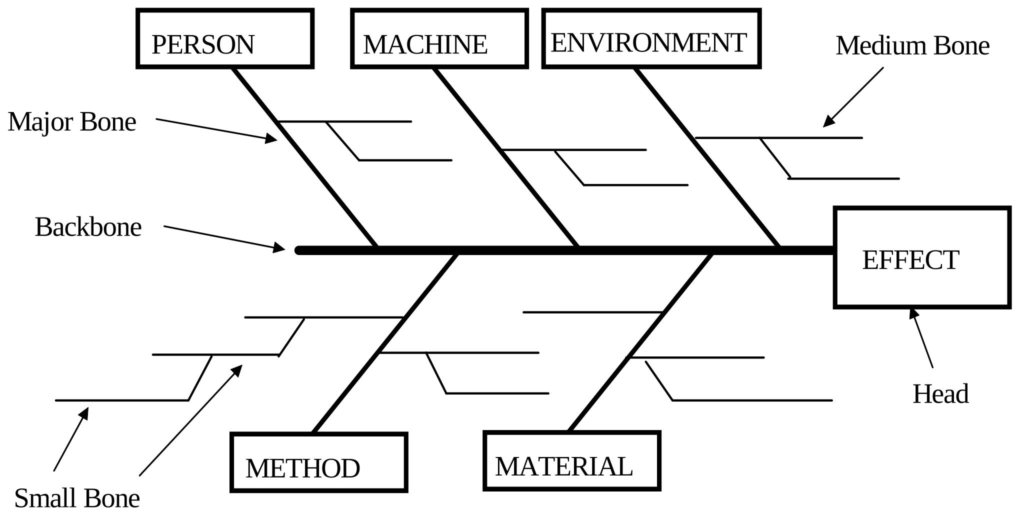
The Cause and Effect Diagram (sometimes called the *Fishbone* or *Ishikawa Diagram*) is used as the starting point of a Cause and Effect Analysis. Here the Diagram is used to develop hypotheses about the causes of variability or poor performance of the product or service. The Cause and Effect Diagram is also used to record data and to note "discoveries" made during the verification step of Cause and Effect Analysis.

The advantage of the Cause and Effect Diagram is that it provides you with a picture of *all* the possible causes. Ideas from many different people can be captured on the diagram and the search for important causes then planned systematically. The Cause and Effect Diagram helps you avoid the tendency to think of only one possible cause at a time and go searching for that one cause.

Form of the Cause and Effect Diagram

The Cause and Effect Diagram is also called the *Fishbone* because of its appearance. The *Effect* is shown on the right side of the diagram. The "Major Bones" are general categories of causal factors, with the medium and small bones identifying more and more specific causes or factors:

The Cause and Effect Diagram can be adapted to many different situations. Several different types of Cause and Effect Diagrams are shown later in this section.



Application

The Cause and Effect Diagram is used most often in *Analysis*, to discover the important factors that relate to performance of the product or service.

Cause and Effect Diagrams are also used to *educate* new employees in the process. They quickly summarize the key factors that are important to assure the quality of the product or service.

Cause and Effect Diagrams do not belong only to "formal" improvement projects. They can be employed whenever a "problem" is identified:

One day, a sales representative from a large printing company visited our offices. When she found that we *were in the "quality" business, she described how her company had a "quality program." Later in the conversation, she started describing a problem the company was having with "bubbles" between cardboard backing and leather covers for their expensive books.*

We started sketching a Cause and Effect diagram as she talked. By the end of the conversation, she was surprised when we gave her a fairly complete cause and effect diagram that she could take back to her company. Her company's "quality program" had apparently not included Cause and Effect as one of its elements.

Constructing the Cause and Effect Diagram:

1. State the problem as the Effect. Some preliminary data collection or process observation may help focus this statement. A Pareto Analysis of the problem is often a good prelude to the Cause and Effect. A good "Effect" statement:

- *states what is wrong, not why it is wrong,*
- *focuses on the gap between what is and what should be, and*
- *is measurable and specific.*

2. Identify possible causes of the Effect. Review the occurrences of the problems; try to understand how they occurred and what the process situation was when they occurred. Brainstorm a list of causes based on knowledge of the production process.

The phrase *"Ask Why Five Times"* is often applied to this step of the cause and effect analysis. The object is to identify causal factors that can be corrected by changing one or more process factors.

In developing the Cause and Effect Diagram, try to avoid:

- *Solutions* - Solutions are not causes. Solutions will be addressed after the root causes are understood.
- *"Lack of" Statements* - These are similar to solutions. The "Lack of X" statement implies that if "X" was present, then the problem would not occur.
- *"Fuzzy" causes* - Causes such as *attitude* and *morale* can be important issues, but the cause and effect analysis should try to focus on the *process factors* that contribute to the effect.

3. Define the major categories to be used on the Cause and Effect diagram. The "default" categories of *Person, Machine, Material, Method*, *Information,* and *Environment* are often used for small problems or when just starting to use the Diagram. Major categories such as the process steps associated with *producing* the product or service should be used for larger problems.

4. Draw the diagram. Write the effect clearly and objectively in a box. Build the diagram by organizing the brainstormed causes under appropriate categories. Lines should flow toward the effect. Refine the causes where necessary and continue asking:

- What causes this?
- Why does this condition exist?

5. When the diagram appears complete, walk through the logic in both directions: a) proceed from the effect to the causes, making sure that the effect can result from the causes and b) proceed from the causes to the effect making sure that the causes can result in the effect. Often, an illogical statement will not surface until the second direction is tried.

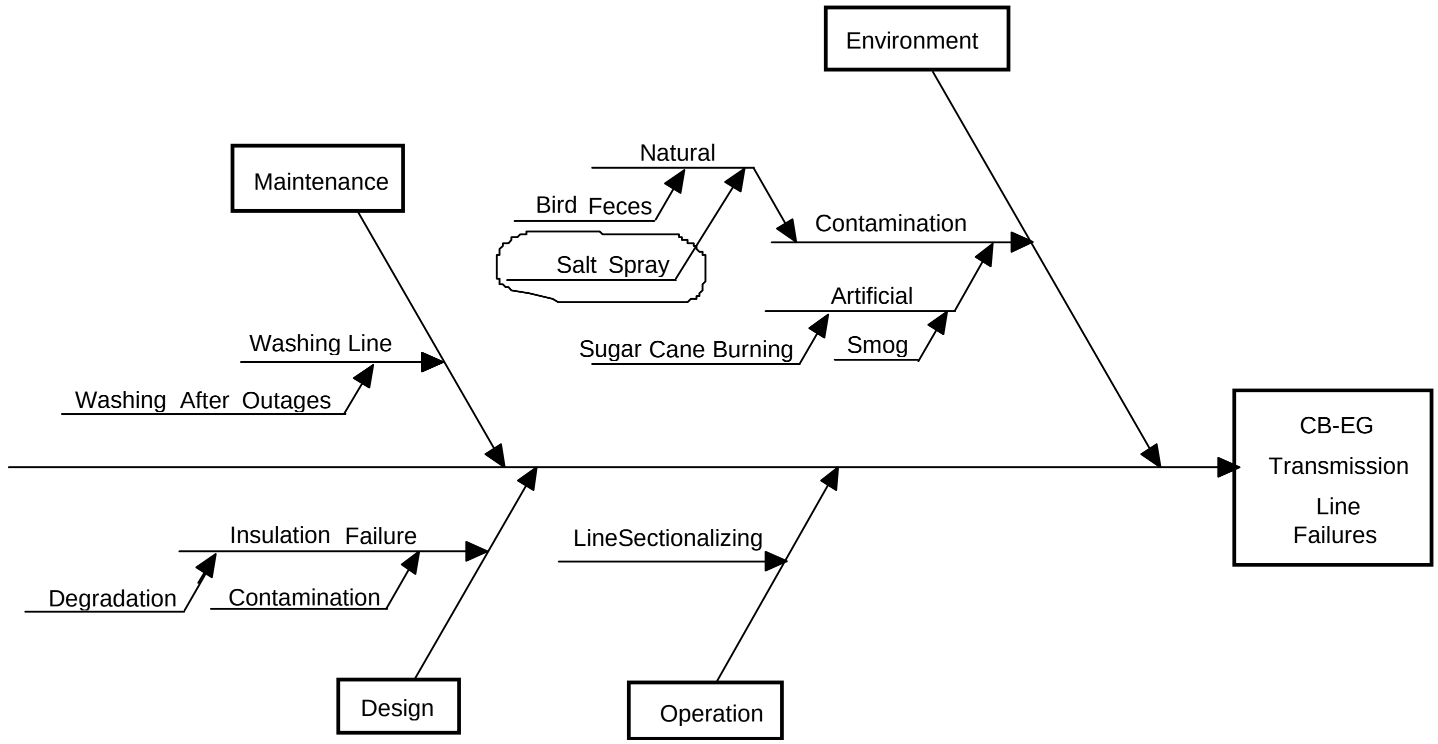
5.3 TYPES OF CAUSE AND EFFECT DIAGRAMS

Cause and Effect Diagrams are not limited to a specific form. Several different types are presented below:

Variation or Problem Analysis Type

This is one of the most common applications of Cause and Effect. The quality improvement project has identified a specific problem where the *cause(s) are not understood.* The purpose of this type is to determine the factors that could cause the problem or variability in the process' output.

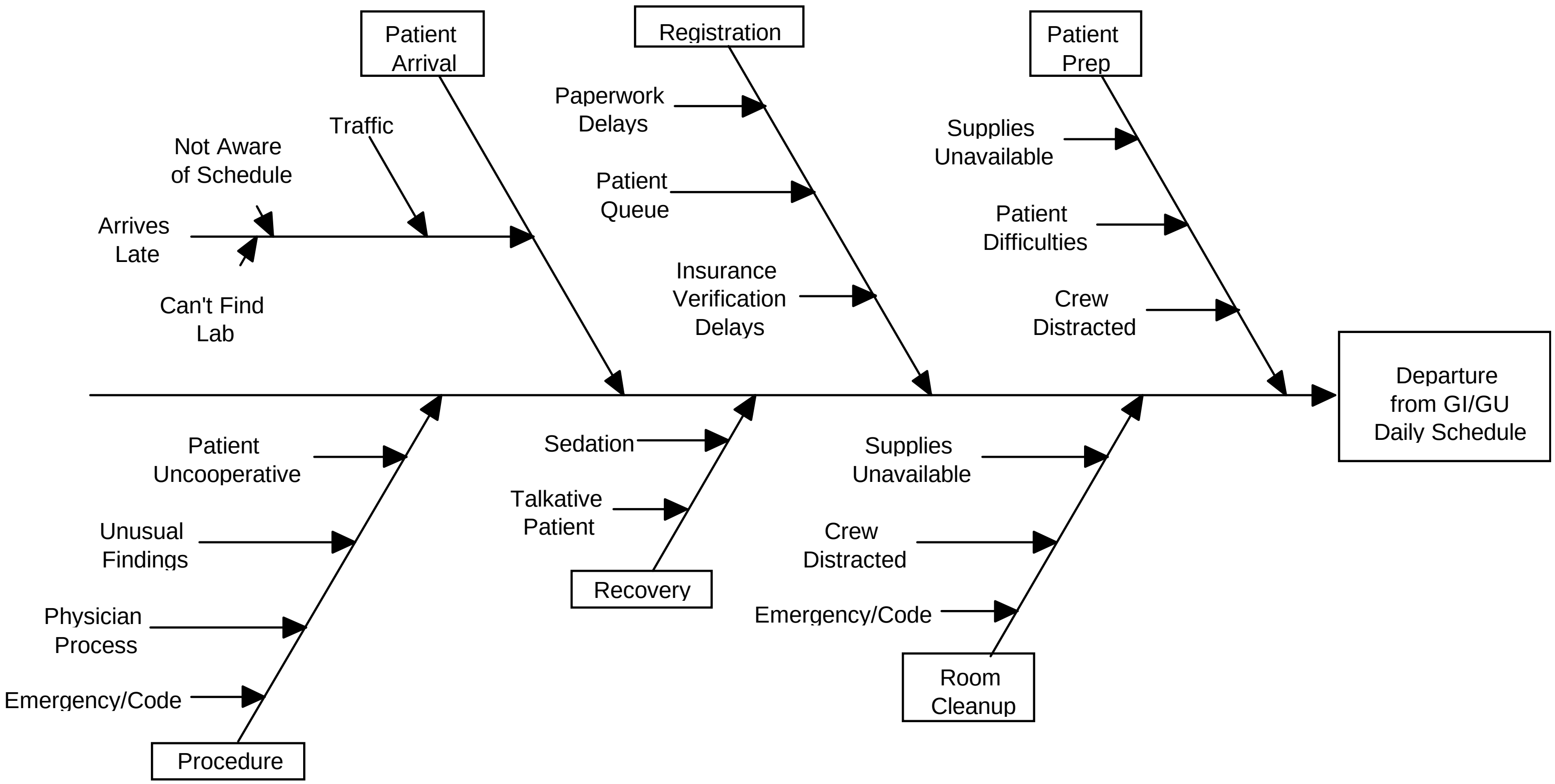
Its strength is that it quickly helps organize and relate the different potential causes of the problem. In this example, a utility was experiencing a high number of failures on a specific transmission line. The Cause and Effect Analysis isolated salt spray as the key factor contributing to the outages.



Production Process Type

This type of Cause and Effect Diagram focuses on the steps of the process and tries to identify the factors in each step that can contribute to the problem or variability.

Its strength is that it is easy to create and understand, since each Major Bone considers only one step of the process. It does have a weakness in that similar causes can appear over and over, and it's difficult to illustrate situations when the problem is due to more than one factor. Here, a Gastrointestinal/Genitourinary (GI/GU) Laboratory staff was exploring reasons why their schedule ran late each day. They identified the six segments of the process: *Patient Arrival, Registration, Patient Preparation, Procedure, Recovery & Room Cleanup.* The Cause and Effect Diagram was then organized with each process segment as a Major Bone.



Comparative Cause & Effect Type

This is a strategy to help identify the factors that cause the problems to occur. Two cause and effect diagrams are created. The first lists the factors that are present when the problem occurs, the second lists the factors that are present when the problem *does not* occur. The differences can then be investigated to determine the important factors. This is similar to *Comparative Process Analysis*, described in Section 3.

Planning Cause and Effect

We have seen teams make use of the Cause and Effect Diagram as a Planning tool. They list the desired effect and then begin to brainstorm the factors that must be present for this effect to occur. Although there are other planning tools that support this purpose, we have seen enough good examples of this application to mention it here.

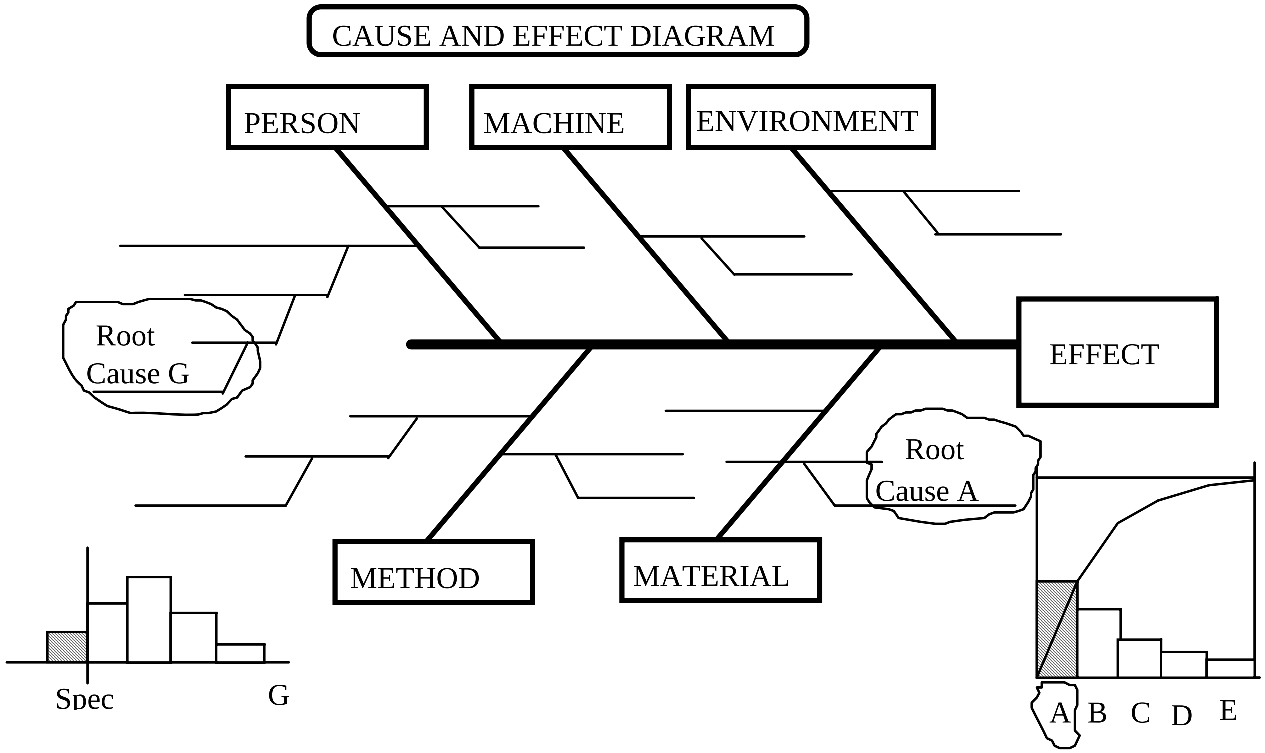
Failure/Error Modes & Effects Analysis

In Section 3, we presented the Failure/Error Modes & Effects Analysis – a tool that is actually a "combo" of a Cause & Effect, a Pareto Analysis and a Countermeasures Matrix.

5.4 CAUSE AND EFFECT ANALYSIS - VERIFICATION

Purpose

Verifying Root Causes is the second step of the Cause and Effect Analysis, here you are looking for evidence that one or more factors are contributing to the quality problem or variability. These *key* factors are often called the *Root Causes* of process performance. The Pareto Principle applies here: *look for the Vital Few causes of variation or problems in your process*.



Facts and data must now be gathered to help "convict" one or more potential causes as the actual (or most probable) causes. The verification step generally proceeds by selecting the most likely causes based on the evidence, our experience and "gut-feel."

Then, some method of proving or disproving the potential cause must be determined, data collected and analyzed and the decision made: *"Have we found the cause(s)?"* If not, then the next set of likely causes is identified and the proving/disproving process repeated.

Methods for Verifying Causes:

One of the first choices you'll make is whether to "play detective" or "play scientist." If you "play detective," then you'll generally be gathering data from the ongoing production process, looking for clues as to which factor is present when the problems occur.

If you "play scientist," you will design and conduct experiments, trying to determine which of your process' variables are important and also to determine the best "level" at which to set the important variables.

In addition, these general strategies are used to determine the tool that may help you discover the important factors in your process:

Absence/Presence - If a potential cause is present when the problems (the effect) have occurred, *and* it is not present when the problems do not occur, this may be evidence of a cause/effect relationship.

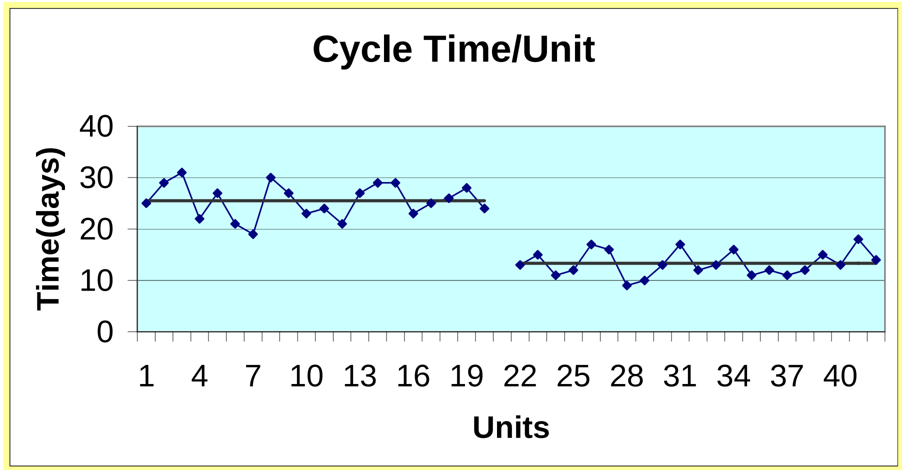
EXAMPLES:

- A pump coupling failed due to the *type* of material used in the coupling. Mild Steel was used in a salt water environment instead of Stainless Steel.
- Respiratory infections in an office decreased significantly when the air conditioning filters were *cleaned* periodically.
- Construction crews were not aware of the *availability* of an underground cable locator service, contributing to telephone cable cuts during trenching operations. Publishing this information periodically dramatically reduced the number of cable cuts.
- Seventy-nine percent of electric meter-reader dog bites were due to the "dangerous dog present" field *not* being entered on the meter-reader's electronic recorder.
- *Improper lifting technique* was found to be the cause of back injuries in one healthcare organization.
- *Human spittle* introduced through operators talking to each other during integrated circuit testing operations caused corrosion and failure of the circuits.
- Pipe leaks were found to be caused by the application of longer bolts than specified. These bolts "bottomed out" before proper compression of the "Y" pipe-engine flange/gasket could occur. Locomotives with short bolts did not experience these "Y" pipe leaks.
- Silica accumulation in power plant condensers following sandblasting operations was found to lead to power plant outages.

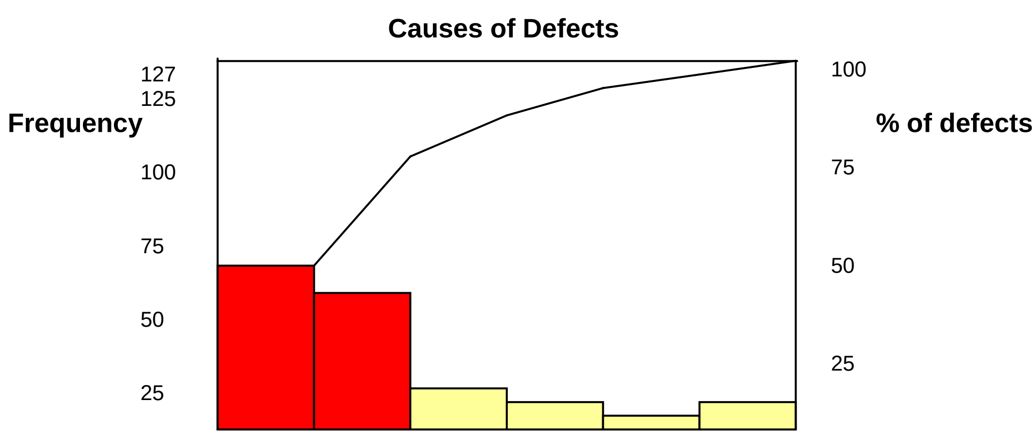
- Mixing of two different oils in locomotive axle support bearing sump caused the formation of soap/grease byproducts which clogged the lubricating wicks, leading to inadequate lubrication of the support bearing and overheating. Axle support bearings without mixed oils were not experiencing this problem.

Tools Supporting the Absence/Presence Method

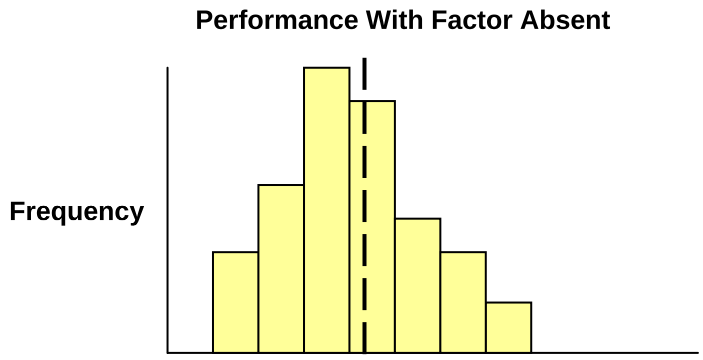
Line graphs or run charts and histograms can be used to show cause and effect relations in the absence/presence method by comparing performance with or without the causal factor present.

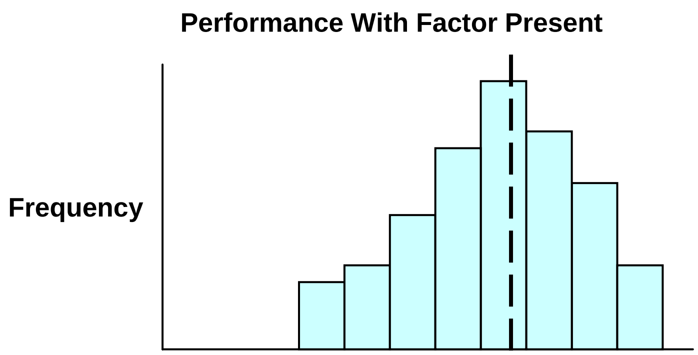


Pareto charts can be used to prioritize the known causal factors.



Comparative histograms can show the distribution of data with or without a cause. They are typically shown up and down with the same scale for ease of visual comparison. A frequency chart can be used in the same way for count data. **Hypothesis tests** may help you distinguish between "significant" differences, versus those that arise due to sampling error.





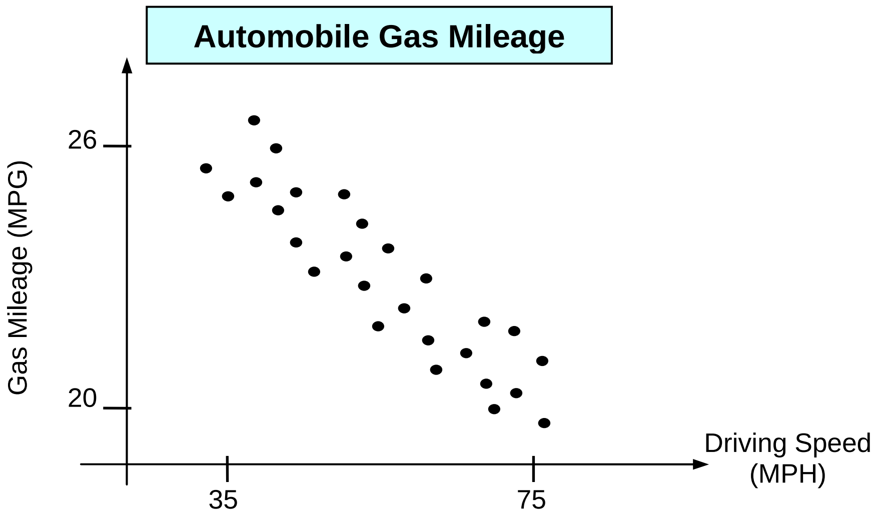
Variable Level - The value (i.e. physical measurement or dimension) of a particular factor influences the occurrence of the problems (or effect). Many variables are correlated, that is, if one changes, the other also changes. Here, though, we are attempting to determine either the necessity (the first variable must change for the second to change) or sufficiency (everything else held "constant," changes in the first result in changes in the second). These are not always easy conditions to satisfy. Examples include:

- Cable insulation was found to degrade faster in high temperature locations within the heating unit (i.e. near burners and hot gas exhaust), requiring more frequent replacement to prevent grounds and shorts.

- An increased workload was found to lead to overheating of X-Ray tubes in a welding inspection machine, causing the tubes to fail prematurely.
- Reduced spacing of lightning arrestors on electricity distribution lines was found to reduce the frequency of lightning-related outages.
- Oil analysis revealed the presence of high levels of silicon (sand) in gas compressor bearings. This, combined with physical inspection of the inner race sleeves (pitting evidence) and metallurgical analysis of sleeve cracks led to the accumulation of sand into the bearings as the root cause of inner race sleeve failures.
- The boiler superheat temperature was found to be a factor that could be used to control the turbine metal temperature during power plant startup. This control was necessary to avoid high thermal stresses (leading to cracking) in the turbine.
- The number of stress cycles was found to be a factor contributing to leaks in a high-pressure control valve.

Tools Supporting the Variable Level Method

Scatter diagrams are simple graphical pictures showing relationships between variables. Here, the speed at which an automobile is driven is the causative (or independent) variable. The gas mileage (number of miles per gallon of gasoline) is the effect (or dependent variable). Each point on the scatter diagram represents an observation - for a given driving speed, what gas mileage was observed? From the diagram, you can see that there is a negative relationship[17] (or correlation) between these variables - as driving speed increases, the gas mileage decreases.



Notice that the points do not fall on a straight line. There are other sources of variability at work in this process. Very rarely will a "real world" process display perfect correlation between the variables. The "Punch line" of the Scatter Diagram is important. If there exists a correlation between two variables, then you should be able to change the performance of the effect (perhaps this is some important quality characteristic), by changing the independent variable. The gas mileage example shows us that we could increase our gas mileage by decreasing our driving speed. Driving

[17]The term *negative* refers to the kind of relationship, as the independent variable *increases*, the dependent variable *decreases*. "Negative" doesn't mean it's a *bad* or undesirable relationship.

speed is something we can control. The Scatter Diagram also shows you how much benefit you'll get from changing the independent variable. In the gas mileage example, it appears that we could gain an additional 6 miles per gallon if we could control our speed at 35 MPH instead of 75 MPH.

Correlation and Regression Analysis helps you explore the strength of the "X and Y" relationship and to develop a mathematical relationship between the two variables. A **Designed Experiment** (advanced topic – see your Black Belt) can help you plan a rational set of tests to determine relationships when a number of factors are at work in your process.

5.5 CAUSE & EFFECT ANALYSIS - VERIFICATION MATRIX

The Verification Matrix can help plan and track root cause verification efforts. The potential root causes to be investigated are listed and appropriate tests and/or verification activities are then determined ("X's" mean the test in that column will *not* verify that particular root cause). Test results are recorded in the box that represents the intersection of the potential root cause and its associated verification test.

This example documents some of the verification tests conducted to uncover the cause of locomotive axle bearing “inner sleeve” cracking and failure occurring at one US railroad:

Problem: Inner Sleeve Cracking

Potential Causes	Tests/Verifications: Mat'l Test	Oil Sample	Weibull An'l.	Fracture An'l.	Dimensioning
Batch of Sleeves with poor material properties	Mat'ls Tested OK	X	X	X	X
Mixing of Lubricating Oils	X	Not a Problem for Journal Box Lubr.	X	X	X
Case Hardened vs. Through Hardened steel	Other Roads use Case, ours uses Through	X	X	X	X
Replacement interval too long	X	X	B-10 Life is 38 Mo., we repl. on 60 Mo.	X	X
Contamination in Lube Oil	X	High Sand levels found in J.B. Oil	X	X	X
Excessive Stress on Sleeves	X	X	X	Fracture Rpt. indicates High Stress on Axle	X
Inadequate Interference Fit - Combination Sleeve too Large and Axle too Small (specs)	X	X	X	X	1% Chance of too small inter. fit (30 data)
Axle Upset due to Wheel Pulling Stresses	X	X	X	X	Axles meas'd. no taper or out of round

6. SELECTING, PLANNING & IMPLEMENTING COUNTERMEASURES

We divide quality improvement into three broad activities:

What is the problem; what are its causes?

What can we do about them?

Now let's do it!

The preceding sections have addressed the first question, now it's time to turn to the second and third parts. It's funny, this quality "stuff" doesn't come easy, and each stage of improvement has its own set of difficulties.

For example, one company did a survey of the status of their improvement efforts a few years after introducing a quality improvement program. They found that their improvement teams had done well learning how to determine the answer to the first question.

They were even pretty good at figuring out what to do about the problems. Many of the projects, though, were stuck at the *do it!* part. For several reasons, including middle management resistance[18] the good work of analysis was going for naught.

Here are some methods that are useful to help you work through these last two critical activities of improvement.

[18] Of course, they had to ask *why* there was resistance to change. "Resistance" is *not* a root cause!

6.1 IDENTIFYING POSSIBLE COUNTERMEASURES

You've just gone through an analysis of your process, and feel confident that you understand the *factors* that are affecting the performance of your product or service. It's time to identify possible *Countermeasures* that will change your process for the better.

Just in case we didn't mention it in Section 5, *Cause & Effect Analysis,* make sure that you have identified *causes* and not *symptoms*. You can buy a remedy for your cold that attacks the symptoms of your runny nose, watery eyes, sore throat, etc. But the cold remedy does nothing to prevent the reoccurrence of the root cause of the problem, the cold virus.

Now, of course, if you are experiencing problems with your products and services, some form of *inspection* and *rework* may have to be put in place to make the products or services "right." But these actions are only *immediate remedies.*

The *Countermeasures* should be designed to *prevent the reoccurrence* of the problem you're addressing. They should focus on changing the *production process* that makes your products or services. This is quality improvement.

One note is in order, though. *Countermeasures* that address root causes are generally more expensive than the "Band-Aids" of immediate remedies. You'll have to be prepared to "sell" your countermeasures to the appropriate "approval" bodies. A solid analysis of the problem and its causes is the best "sales pitch." The QI storybook or storyboard (see Section 1, *Improvement Methods*) are effective means of quickly and succinctly telling your story.

Some general ideas and methods associated with developing countermeasures are discussed below:

Identify Countermeasures that address the causes found - This may seem obvious, but many root cause analyses have been found to have poor "linkage" between the cause found and the preventive countermeasures.

Don't reinvent the wheel - Check around (with vendors, "old-timers," literature searches or other organizations) to see what has been done in other cases where the problem has occurred. There may already be proven, cost-effective solutions to your problem.

Consider costs as well as benefits of the countermeasures - Try to identify several different countermeasures and then evaluate them against their potential benefits and their costs. Select the countermeasures that provide the best "bang-for-the-buck." The *Countermeasures Matrix* is used to evaluate several different alternatives.

Consider temporary and long-term countermeasures - If the long-term solution to the root cause will take some time to implement (because of budget or other constraints) consider what might be temporary countermeasures to prevent the problem from occurring until the longer-term solution can be implemented.

Countermeasures for human-related causes - When a Human-Related Cause is identified, there is a tendency to select an "INSPECTION-type" countermeasure. For example, if frequent mistakes are identified in time-keeping or payroll, then a check (or double-check) of the reports may be considered.

Consider the *Error-Proofing Principles* (see Section 3, *Pictures of the Process*) to identify *process-oriented* methods of preventing mistakes or errors. In some cases, though, inspections will be necessary, especially if the current process cannot guarantee mistake-free performance and the consequences of process failure are high.

6.2 COST/BENEFIT ANALYSIS

Purpose

Generally, there is more than one way to address the causes of your problem. The potential *countermeasures* you've identified should be evaluated for both their *costs* and *benefits*.

Dr. Juran talks about the different "languages" spoken in organizations. Staff speaks the language of *technology*, Senior Management understands the language of *finance*, and Middle Management must be "bilingual." Since Middle and Senior Management approval will often be required for process changes, the *costs* and *benefits* should be expressed in dollar amounts, if possible.

Quantifying Benefits

Changes that reduce or eliminate defects - Here, the challenge is to estimate the cost of the defect and to estimate the reduction in defects that will be achieved by your countermeasure(s). These costs are often slippery, and can be inflated or deflated depending on the assumptions you make. Dr. Deming often said that *the "most important figures are unknown and unknowable*."

> *Example: The "Cost" of a needle stick to a healthcare worker was once quoted to us at $600. This included the evaluation and testing to determine if a variety of possible diseases (including HIV) were transmitted to the worker. The worker's mental distress during the evaluation period was not included in the $600 figure.*

Costs associated with *failures* should include, for instance, not only the part and labor costs, but also the costs of lost or replacement production due to the equipment downtime. For instance, when power plant failure occurs, the cost of *replacement power* is measured.

You may already have some clues as to the reduction in defects your countermeasure will achieve. For instance, a Pareto Chart of causes will provide you with the current frequency of defects *by cause.* If your countermeasure will completely eliminate one of the bars, then this becomes your reduction estimate.

Changes that reduce machine, material or labor costs - Here, the challenge generally is to estimate *how much* material, machine time or labor will be saved by the countermeasure, *how often* the resource is demanded, and how much the resource *costs* on a per hour or per demand basis. This can be multiplied by the expected demand over a year to identify the yearly savings:

Example: A team estimated that their process change would reduce the number of trips to fill incomplete case carts for surgery by 10 per day. Each trip took 1 hour and was performed by a technician earning $16.00 per hour. Estimated savings are then:

10 trips/day x 1 hr./trip x $16.00/hr = $160.00 per day

This was extrapolated over the year, assuming savings only occurred during weekdays (weekend surgery volume was very low):

\$160.00/day x 5 days/week x 52 weeks/year = \$41,600.00 per year.

Of course, the natural "business" question is, *"Does the hospital now require one fewer full-time-employee (at 10 hr./day savings) or will the staff be assigned to other duties?"*

Changes that improve customer satisfaction **-** These are the most difficult to quantify monetarily, but, are usually the most *beneficial* changes. The *immediate* benefits of improved satisfaction are generally intangible, but these can translate into *long-term* repeat business or referrals from customers who "brag" about your organization.

Some organizations have developed "balanced scorecards," where customer satisfaction (as measured by some periodic survey, for instance) is one indicator tracked and targeted for improvement. Some organizations have also tracked customer satisfaction as a "negative" indicator, the *number of complaints,* and actively attempted to reduce complaints.

The benefits of changes to improve satisfaction may be measured here in terms of expected reductions in complaints or improvements in satisfaction indices.

Quantifying Costs

If the change requires increased expenditure of materials, equipment time or labor hours, the cost can be quantified just like the counterpart *benefits.*

For purchases of *capital equipment*, though, the cost calculation is more complicated, since it will include the initial *purchase price, setup and training costs, operating* and *maintenance costs.* In addition, *depreciation* and *salvage value* of capital equipment usually enters into the cost equation.

Each organization's accounting department has access to the cost equations that can be applied. For organizations wishing to include these figures in the cost/benefit evaluation, we recommend that a simple worksheet be prepared to help improvement project teams estimate these costs.

Many organizations will establish specific guidelines for quantifying Six Sigma project costs and benefits. Several companies we've worked with have designated individuals to be "Money Belts" or "Finance Buddies" – their role is to help you with the "dollar-side" of your improvement project.

Addressing Risks

Look at your change from a risk perspective. What can go wrong. Do either a simple "risk brainstorming" with your team, or use the Failure Modes & Effects Analysis tool to systematically identify and prioritize the risks of your change.

6.3 THE COUNTERMEASURES MATRIX

Purpose

The *Countermeasures Matrix* summarizes the problem, the causes and those countermeasures considered by the improvement project. It helps prioritize the countermeasures in terms of their costs, benefits, and feasibility and can be a simple graphic to display the recommendations of the improvement team.

Problem	Cause(s)	Counter-measure	Practical Method	Evaluation: Benefit	Cost	Feasible	Score	Action
Fan Blade Cracking	Operating at Resonant Frequency	Change Fan Rotor Natural Frequency	Modify Rotor with Doubler Plate	8	3	7	168	Yes
		Change Operating Frequency	Reduce Fan Operating Speed	2	5	4	40	No
	Operating above Yield Strength	Reduce Operating Stresses	Reduce Fan Operating Speed/ Cycles	2	4	4	32	No
		Improve Yield Strength of Fan	Design New Fan Rotor	6	3	8	144	Yes

This example summarizes recommendations to prevent the reoccurrence of a power plant fan blade cracking problem. Two causes were identified; each cause had two possible countermeasures.

One countermeasure for each cause was evaluated as being the most cost-beneficial over the remaining life of the power plant. Both countermeasures were combined into the new fan rotor design.

Notes on the Countermeasure Matrix

- By laying out the *Problem, Cause, Countermeasure* and *Practical Method* on the matrix, it's easy to see if there is a logical "linkage" among the issues.
- The Countermeasure is the "WHAT," the Practical Method is the "HOW."
- The Evaluation boxes are usually given scores based on the benefit of the countermeasure, its cost and its feasibility to implement (i.e. the practicality of implementing this countermeasure).
- For simple problems, the scores may be obtained by general agreement of the project team, for complex or expensive countermeasures, more detailed cost/benefit analysis is performed:

FACTOR	RANGE	
BENEFIT	1 - Low Benefit	10 - High Benefit
COST	1 - High Cost	10 - Low Cost
FEASIBILITY	1 - Not Practical to Implement	10 - Easy to Implement

- The individual scores are multiplied to get the overall score. Note how the *COST* factor is scored the reverse of the *BENEFIT* and *FEASIBILITY* factors (High Cost - Low Score).
- The Action box indicates the decision to adopt the countermeasure (YES) or not (NO).

6.4 SELLING THE SOLUTION

After the proposed countermeasures have been selected, the job of "selling" them to management and co-workers begins (actually, it is a good idea to keep management and your co-workers involved during the selection process).

The best way to "sell" countermeasures and gain needed support and approval is by explaining the facts and data that support your decisions.

Organize your analysis using the quality improvement steps described in Section 1. Summarize the results of each step and be prepared to backup the summary with the more detailed work performed (*see the QI Story Review Form in the Forms Section)*.

This is a good time to check your entire analysis. Does it make sense? Is there "linkage" between the steps - have the causes been verified, do the countermeasures address the most probable causes, are the countermeasures the most cost-beneficial?

Explain the work to your co-workers (especially those who will be involved in implementing the countermeasures and who may have to change their work practices) and obtain any final input from them.

Request a time for management to review the project work and recommendations. If you have a storybook (see Section 1) of your work, send copies to the reviewers about one week in advance of the meeting.

During the review, present a summary of the project work and your recommendations. Answer questions that may arise. Before the meeting ends, ask for a management decision on your recommendations, or set a mutually agreed upon date when the decision will be communicated to you and your team. *Do your best to “close the sale.”*

6.5 ACTION PLANNING

Now that the countermeasures have been determined, they have to be planned and implemented. An Action Plan may be necessary to decide what steps are necessary, who is going to do them and when will they be completed.

In the Action Plan, consider what procedures or instructions must be revised, what material or tools must be ordered (or changed), what training must occur in the new method.

ACTION PLAN

Project: Fan Rotor Redesign - Franklin Units 3 & 4			
What	***How***	***Who***	***Date***
Write technical specs for Fan	Develop specifications for fan which address problems found through cause & effect analysis	SL	9/96
Evaluate current manufacturing processes	Visit several fan manufacturers to learn about fan design and evaluate quality control systems	JLB, RPF	6/96
Develop Spec Package for Bids	Finalize specifications	TGK	10/96
Select Vendor	Evaluate Bids for Compliance with specifications	ALL	12/96
Ensure Vendor complies with specifications	Provide engineering representative to monitor fabrication Conduct design review at completion of detailed design	SL	TBD
Establish Schedule for Fan Installation	Work with vendor to formulate project schedule, Power Supply Department to determine next outage available	SL, RPF	TBD
Install Fans on one unit for evaluation	Remove existing fans on unit 3 and install new fans	RPF	TBD
Test Fan for compliance with specs	Gather fan performance data and evaluate	SL	TBD
Purchase Unit 4 Fans	Review fan performance evaluation and issue purchase order	ALL	TBD
Install fans on Unit 4	Remove existing fans on unit 4 and install new fans	RPF	TBD
Test fans for compliance with specs	Gather unit 4 fan performance data and evaluate	SL	TBD

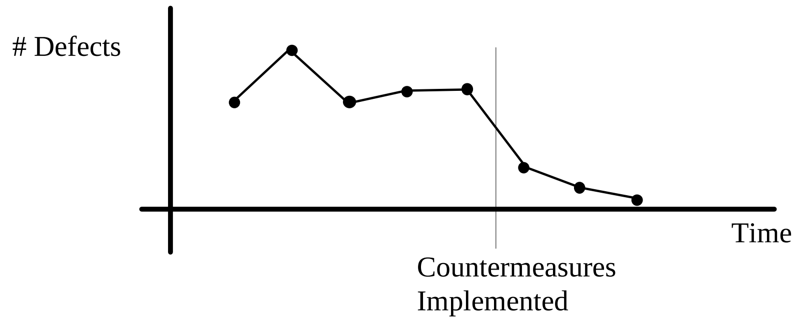
In this action plan, notice that the team planned both the changes to the process *and also* how they intend to measure the *effectiveness of the changes.* They are thinking "*PLAN-DO-CHECK-ACT.*"

As the tasks are implemented, keep track of any problems or deviations from the Action Plan. Determine whether these problems are going to impact either the effectiveness or cost of the countermeasures.

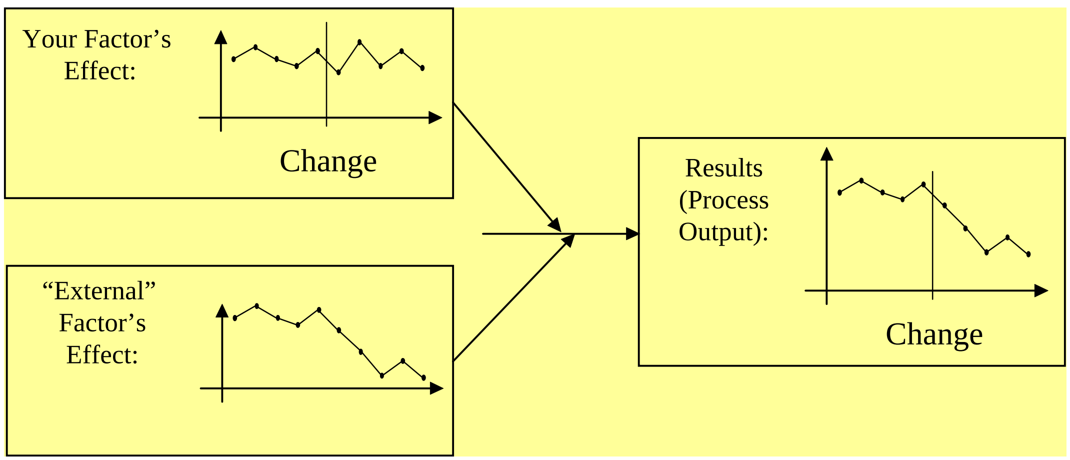
6.6 TRACKING RESULTS

RESULTS AND EFFECTS

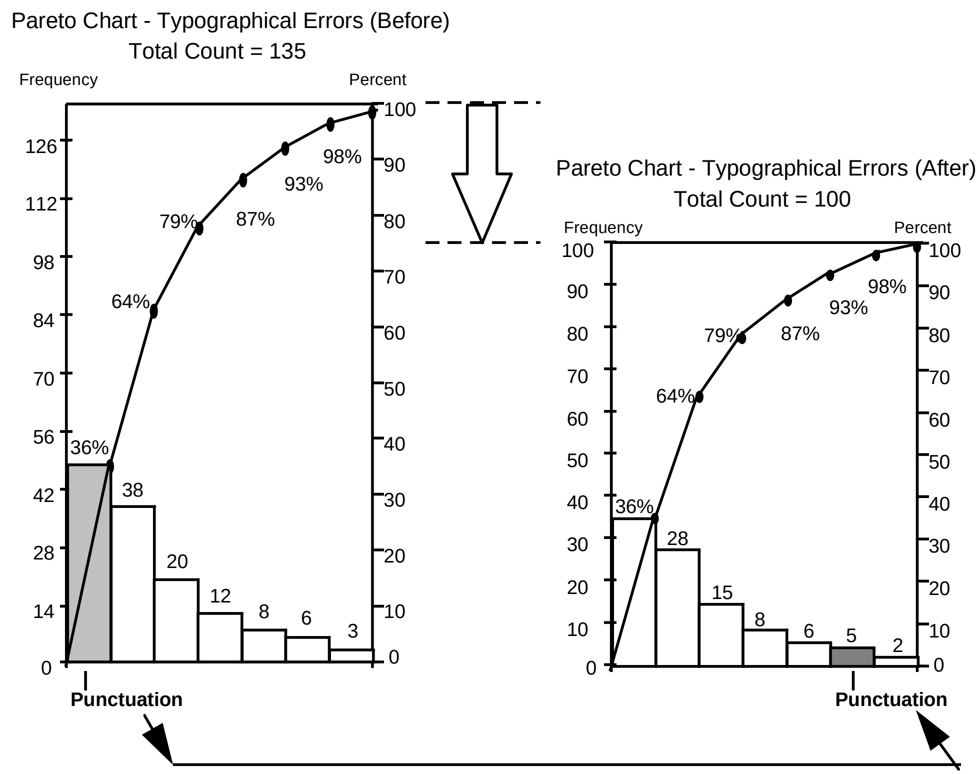
After the countermeasures are implemented, the problem should either decrease significantly in frequency or be eliminated:



The indicator you identified at the beginning of the project should be used to examine the results of your changes. Pareto analysis (see *Pareto - Before and After,* Section 4) should be applied to show that the factor you addressed has, in fact, been decreased in frequency or eliminated. There is a difference between *results* and *effects. Results* are what you observe to happen after the changes were made. But you are interested in the *effects* of the changes *you've* made to the process. It's possible that other factors, either *internal* or *external* to your process, could have achieved the *results:*



This is why a *before and after Pareto* analysis is useful. You see both the change in the *output* and the change in the *process factor.* Here's a Pareto showing how both the total number of errors decreased (output) *and* that the factor which was addressed (punctuation) has moved to the "Trivial Many:"



Be careful of "side effects" that occur as a result of your change. One of our friends was discussing the issue of *Cesarean Section (C-Section) births* with an obstetrician. Insurance companies don't like C-Sections because they tend to cost more than natural deliveries.

The obstetrician was curious to know whether his practice should try to reduce the number of C-Sections they performed. Our friend replied that, yes, that would be a good idea, but make sure that the other important indicators such as *Complications, Infant & Maternal Mortality* were not adversely affected (i.e. "*Big-Quality"* is considered, see *Section 2*).

We've got to keep the big picture in mind, even while we're focused on one aspect of improvement. Dr. Martin Luther King, Jr. said:

"All progress is precarious, and the solution of one problem brings us face to face with another problem."

6.7 QUALITY IMPROVEMENT "REWORK"

In some cases, the countermeasures applied do not have the desired effect of eliminating the problems. Suggestions to address this issue generally include a review of the improvement analysis steps, although in reverse order:

Review the new problems - Are these the same type of problems experienced in the past? If so, why aren't the countermeasures preventing these problems? If not, do the countermeasures have any relationship (cause and effect) to the new problems?

Revisit the countermeasures - Were all the countermeasures implemented? Is everybody involved following the new process? Do the countermeasures selected address the identified causes of the problems? If not, these may need to be reexamined. If the countermeasures turn out to be faulty, develop an action plan to "un-implement" them.

Review the cause/effect analysis - Were the real causes identified? Use the new problem information to help answer this question.

External factors - Has something else changed in the process? This could be either internal or external to your organization.

6.8 STANDARDIZING THE COUNTERMEASURES

STANDARDIZATION

If the countermeasures are effective, then the final action is to make sure that they are incorporated into the daily work processes. Here, the "hand-off" occurs between *quality improvement* and *quality control.* How does your organization *control* or *manage* the quality of daily operations?

Written instructions may need to be revised. If you make use of flowcharts to describe work processes, then these should be revised to show the new process. Make sure that training and education programs in your organization reflect the new work process.

Examples:

For a large US railroad, changes that improve the reliability of locomotives are captured in the following "standards:"

- *M-Sheets (M01 - 6, M60, M90 worksheets). These define the scheduled maintenance program for the locomotives.*
- *Diesel Maintenance Procedures (DMP's). These define how maintenance activities are conducted, by type of maintenance (e.g. engine removal and overhaul, power head reconditioning, etc.).*
- *Maintenance Instructions. These are vendor-supplied maintenance procedures for specific locomotive equipment.*

For a large US hospital, changes that improve quality or cost of patient care are captured in the following "standards:"

- *Clinical Pathways. These define the care process for patients, by type of diagnosis.*
- *Clinical Protocols. These define how specific patient care activities were performed (dialysis treatment, respirator management, etc.).*
- *Preference Cards. These were surgeon-supplied materials and equipment lists for specific surgery procedures.*

OK, we apologize! We're not implying that locomotive maintenance and human "maintenance" have many of the same characteristics. It's just that we get tired of hearing how every industry is *different!*[19]

REPLICATION

Often, countermeasures found to be successful in one area of an organization can be applied elsewhere. Each organization should consider how to address the *replication* issue. This is another reason the Quality Storybook is useful. It can be placed in a "Quality Library," for review by other improvement efforts.

[19]Of course, we've seen a lot of consultants make a lot of money by feeding on this idea. "Oh, yes, you need a quality improvement course just for *your* company. That manufacturing stuff just won't work in *your industry!*" Yeah, Right!! By the way, there's this bridge in Brooklyn that's for sale!

A database of quality improvement projects, indexed by keywords, is easy to set up today. With today's computer systems, the full text/graphic version of the story can be placed "on-line" for review by anybody in the organization.

Replication outside your organization should also be considered. There may be competitive issues to address, but a prime method of increasing "general" technology is the system of standards (ISO, IEEE, etc.) that are maintained by various professional organizations. Submit a copy of your improvement to the appropriate standards committee if you think there is a general replication potential.

> *Example: The Nuclear Regulatory Commission prepares Information Notices and Bulletins that distribute information regarding issues and events that have occurred in the nuclear industry that may be applicable to all or some subset of operating reactors. Failures, operating events, quality assurance system issues are the subject of these documents.*

7. MAINTAINING THE IMPROVEMENT

One of our good friends tells this story – "*We had these projects where we'd go into a particular business, work with the staff to improve their "numbers" and actually get to the point where we'd see real improvement. Where their on-time delivery was 50%, now they'd routinely achieve 95%, where they used to get the right crew to the job at the right time 60% of the time, now it's 99%. So the business would be happy and we'd be happy since we'd actually done something good. Well, after about six months, we'd get a phone call from the business. For some reason, their numbers were slipping – deliveries were down to 75%, crews weren't showing up at the right job. We'd go back and do a diagnosis – the results were always the same – no one continued to measure performance, there was little accountability to "maintain the gains" and no incentives to back up the metrics!*

If you don't want that to happen to your improvement, then this chapter is for you. We'll help you set up a *process control system* – shorthand for a way of ensuring that the process sustains its improved quality levels.

Although we've introduced the idea of variation in a process earlier, we'll nail it down here with an important set of tools – the family of *control charts* developed by Walther Shewhart back in the 1920's. When used simply to track the process' performance, they help us distinguish between common and special causes of variation – *so that we react appropriately.*

Control chart also have a very powerful role in process analysis – when used with the concept of *subgrouping*, they can help us identify process factors that drive the variation we see.

7.1 PROCESS CONTROL SYSTEMS

One way to standardize the improvements you've made (and provide a basis for future process improvements) is to develop and implement a **Process Control** or **Process Management System.**[20]

There are several aims of a "control" system:

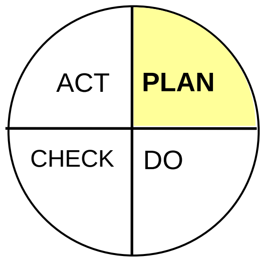
- To establish and communicate the objectives of a production process and to "standardize" the production methods, materials, machines, information and environment,
- To provide a feedback mechanism so that the performance of the product and service can be understood as well as that of variables critical to the performance of the production process,
- To provide a basis for continual improvement of the product, service and associated production processes, and
- To "hold the gains" achieved through the hard work and effort of improvement.

Here, we'll present the elements of a process control system, show how to "construct" a control system and manage using this system.

Process Control System Elements

In Section 1, we introduced the Plan-Do-Check-Act cycle. A Process Control System should include all of these steps:

The PLAN



1. The first step in PLAN is to determine the objectives of the process through our customer research. What products and services should be produced? What are the customers' needs and expectations (both "stated" and "hidden" -those that they don't know about)?

2. Next, how can we meet these with our product or service? As we begin to develop the product or service, which characteristics should be emphasized (consider all aspects: quality, cost, delivery, sales & service, safety, corporate responsibility)? At what quality level should the products or services be produced?

3. Based on knowledge of the process' objectives, targets or goals must be set. Quality control is impossible without knowing the "level" at which the process must perform. The targets should not be arbitrarily set, but must be

[20]Both "Control" and "Management" terms come with some negative baggage. The object of a Process *Control/Management* System is to assure the quality of our products and services. It is **not** designed to *control* people, nor is it the sole the province of management - *everybody's involved!*

a "negotiated settlement" considering what the customer's needs and expectations are and what is currently "technologically" feasible. Since the customer has both *needs* (must-be requirements) and *expectations* (requested or delighted requirements), some of the process targets must be met, others are desirable to meet.

Target or goal setting cannot be considered in isolation by one department. Their processes are part of a system and the targets should aim to optimize the system. For instance, if *Marketing* sets sales targets that the *Production* people cannot meet, shipments will be delayed or backlogged, quality may suffer in the rush to fill orders.

4. The process objectives/targets should be put in writing and communicated widely. Decisions should be made on how to measure the performance of the process (i.e. what indicators are to be set, how these indicators will be measured. A Quality Table can help summarize this phase of the PLANNING cycle. Information from this Quality Table can be combined with the actual process flow and work standards to construct a Process Control System.

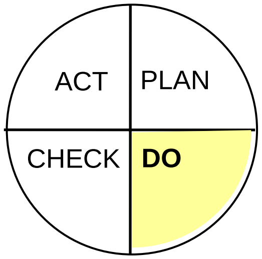
QUALITY TABLE

PRODUCT/SERVICE: *CONTROL CHART TRAINING COURSE*					
Customer	***Needs/ Expectations***	***Quality Characteristics/CTQs***	***Indicator/ Target***	***Process***	***Responsible Department***
Green Belts	Control Chart Theory	• Variation • Measures of Central Tendency, Variation • Sub-grouping Concept • Special Cause Rules	Included in Course Material, Easy to Understand (Pre, Post Test)	Course Development Process	Corporate Training & Quality Services Dept's
	Control Chart Construction	- -	- -	- -	- -
	Control Chart Application to Manufacturing	- -	- -	- -	- -

5. The next step in PLAN is to determine what methods (or "standards") will be used to achieve the objectives. For an existing process, a *flowchart* of the process will at least document **how** the process works and maybe **who** performs the work (a Tischer or responsibility chart shows this explicitly). A *Cause and Effect Diagram* can help organize knowledge about the important factors that affect the quality of the process. Since the process may have multiple quality characteristics, multiple cause and effect analyses may be needed.

There are many, many factors that can affect the output of the process. The Pareto principle tells us that there are generally only a few, *key* process variables that must be managed to ensure the quality of the product or service. The quality control system must clearly identify these key process variables and the methods established to manage them (i.e. make sure they are at the correct level or "setting," or to minimize their variation). These key process variables may also be measured as part of the control system. As with the process' objectives/targets, the process methods must also be documented. The process flowchart and Cause and Effect diagram(s) are basic documentation. Procedures or instructions manuals are also helpful.

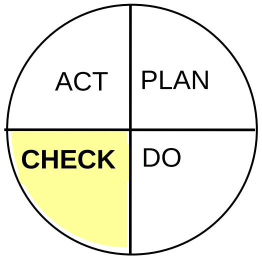
The DO



1. The first step in DO is to educate and train workers on the methods developed as part of the PLAN. This is a major job of management and, if possible, should not be delegated to the "training department." There are two reasons for this: a) by giving management a "teacher" role, they can actually learn what the methods are requiring the workers to do. This can often help accelerate improvement by itself. b) If management assumes the "teacher" role, the workers will understand the importance of following the established methods. This too, helps clearly point out where the established methods are deficient.

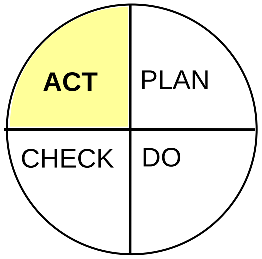
2. The second step of DO is simply to do the work according to the methods/ standards. Data is collected to determine how the process is performing and how the key process variables are "behaving." This helps promote "upstream" control of the process.

The CHECK



1. Based on the data collected from the process (quality characteristics and process variables), compare the process' performance to the objectives/targets. Is there a performance "gap?" Are there special causes of variation present? If there is a "gap," or if special causes of variation are detected, then the process should be studied to understand why the gap exists and what to do about it. DMAIEC projects may be needed to close the gap.

The ACT



1. Once an understanding is reached of how to close the gap, action must be taken. Depending on the process variables at work, this could include improved training, revising the methods, machines, materials, information, etc. This is where the "narrow" PDCA cycle kicks in. The change must be planned, implemented and checked to see if it is an improvement.

Process Control Chart

One day, a manager at FPL was describing his plans for a major power plant upgrade to Dr. Noriaki Kano (a conversion from oil-fired to both oil and gas-fired capability). After listening for a while, Dr. Kano asked the manager where his Quality Process Chart was. Our plant manager didn't know what he was talking about, but all Dr. Kano was looking for was the PLAN (the "5W1H") for the project. Many Process Control System examples that we've seen look confusing. They usually depict the details of specific industrial processes (and often just a portion of a complex process). Let's take a very simple "production" process to illustrate the concept and application of the Process Management Chart - we'll make instant coffee!

Process Control Chart Elements

Since we're the customers, we'll ask ourselves how we like our coffee (the customer needs):

Customer Needs: Hot, Sweet (but not too sweet), Smooth, not Bitter, Served in a Mug, Slight "Chocolaty" taste, and Enough to last through Breakfast. Also, the price per cup should be less than 25 cents/cup.

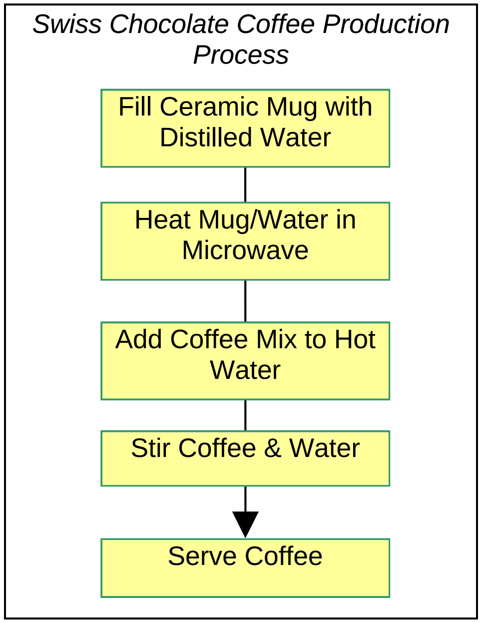
Product Quality Characteristics (some are CTQs!): We've developed a product called *Swiss Chocolate Coffee* that we think meets "our" customer's needs. The quality characteristics of the product include:

Customer Need	Quality Characteristic	Measure/Target/Specification Limits	*C. Sigma Target*
Sweet (but not too)	Sweet	3 +/- 0.5 (on 1 - 5 Sweet Scale)	6
Smooth	Smoothness	5 + 0, -0.5 (on 1 - 5 Smooth Scale)	5
Not Bitter	Bitterness	1 + 0.5, - 0 (on 1 - 5 Bitter Scale)	5
Chocolaty Taste	Chocolate-ness	2 +/- 0.5 (on 1 - 5 Chocolate Scale)	4.5
Hot	Temperature	160 F, ± 10 F	3
Enough	Volume	7 oz, ± 0.5 oz.	6
Served in a Mug	Served in a Mug	8 oz Mug + 1, - 0.2 oz.	5
Price	Sales Price	25 cents/cup	N/A

Now that we know what we're trying to produce, we move to the production process. We've identified a supplier (Major Foods) who makes an instant coffee powder mix that meets the first four quality characteristics.

The city water supply has too high a mineral content, we've done experiments to show that we can't meet the *Bitterness* quality characteristic with city water, so we have decided to purchase distilled water in bottles to meet this need (OOPS, the cost just went up!). We've also purchased a nice 8 oz. ceramic mug that has a picture of our favorite commercial air conditioning system on the side.

Having obtained the raw materials, the production process can now be laid out:



Swiss Chocolate Coffee Production Process

This picture assumes the availability of the coffee mix and distilled water. We could add the steps of obtaining these supplies from our vendors, but let's keep the example simple.

The next steps in constructing our Process Chart are iterative. Since we've established the *How*, we could address the *Who.* For this example, we'll assemble the following work force: *Filler/Heater* and *Mixer/Server.*[21]

With this "organization," we have assigned authority for the production operations and can then think about how to control production so that the quality characteristics (and their targets) are achieved.

Let's take each step and determine what needs to be controlled there and how control will be accomplished.

Fill Ceramic Mug with Distilled Water - The quality characteristics that this step affects are Served in a Mug and Volume. Our Filler/Heater must then obtain the correct mug and fill the mug with 7 oz. of distilled water. These become his control points. One of his checkpoints may include "Mug with Commercial Air Conditioner Picture" to assure the correct mug is obtained. Production engineers have decided to mount the distilled water bottle on a stand with a spigot. Since the same mug is used every time, they've also scribed a fill line inside the mug - this is the Filler/Heater's check point to assure that 7 oz. of water are added.

Heat Mug/Water in Microwave - Here, the *Filler/Heater* uses the microwave to heat the mug and water. Experiments have determined that the *Filler/Heater* must actually heat the water to 175F so that the actual *served* temperature is 160F (for temperature losses due to adding room temperature coffee mix and the ambient losses during the mixing/serving process steps). The 175F becomes his control point for this operation; his checkpoint is to set the microwave at "2 minutes, High Power setting."

Add Coffee Mix to Hot Water - Given that the vendor has provided us with the right coffee mix, our *Mixer/Server* is responsible for adding the correct *quantity* of mix to the heated water. We've determined that three teaspoons of coffee mix in the 7 oz. of hot water will satisfy the taste-related characteristics. The amount then becomes the *Mixer/Server's* checkpoint.

Stir Coffee Mix/Water - This step's main purpose is to assure that the coffee mix is dissolved in the hot water. Since the coffee mix has been found to float on the water surface, the mixing must continue until no "lumps" of coffee mix are on the surface. This is the control point for this process. The *Mixer/Server* achieves this by first pushing the mix into the water and then stirring the mix.

Serve Coffee - This is a transportation step. Control items include *not spilling* the coffee, *not dropping* the mug and *delivery to the right customer*.

Note that for these last three steps, the *processing time* is a control item. If this is too long, the water will have cooled too much, if too short, it may be too hot for the customer. Again, experiments have determined that processing time should be 1 minute (plus/minus 10 seconds) to meet the

[21]We know that you "downsizers" want to combine these jobs, but come on, it's just an example!

quality characteristic of coffee temperature. Note that the *"factory environment"* plays a role here - the ambient temperature of the production area is a major factor influencing heat loss during this time - does it need to be "controlled" or could we make the production process "robust" by insulating the mug during production?). Measurements of the current process' capability indicate that this can be achieved. If not, the previous process' target level for temperature could have been increased.

All of this information can now be summarized on our Process Management Chart for *Swiss Chocolate Coffee Production (next page).*

Now, although this chart looks complicated, you can track how the word descriptions of each process step are summarized on the Process Chart. The chart is a form of "shorthand" for the Who, What, When, Where, Why and How (5W1H) of the process. With a little practice, these charts can become an effective way of designing a production process or standardizing a current process. A few notes on the Process Management Chart:

1. **Do Not** get trapped into one format (or even try to copy the one shown below). The basic questions you want answered on the chart are the 5W1H, but think through how each application should be designed. Some process management charts also include a "response" column. How will special causes of variation be addressed? How will process capability improvements be prioritized and worked?

2. For manufacturing-type processes, the Process Chart may be developed in two stages - during design, the production process is "roughed out" on a Process Chart; as the production planning moves closer to actual production, the details are fleshed out in the actual production Process Chart.

3. In the process chart shown above, the actual "how-to" do a certain process step was listed as a Work Standard (SCC-001, SCC-002, etc.). The development of both the process chart and the work standards needs to be coordinated.

4. The Process Chart should be followed during actual "production." It should identify not only what should happen when the process is going along smoothly, but also who and what actions are to be taken when something "bad" happens. You've probably seen the Saturn™ TV commercial where the production worker talks about the first time he "pulled the cord" and shut the production process down. This is an example of authority delegated to the best place on-the-line. Response plans for assignable causes of variation may be different from those associated with common causes.

5. Notice that, although there are many factors that could affect the quality of our *Swiss Chocolate Coffee*, only the most important factors have been identified on the process chart. Here's the Pareto Principle at work.

6. We've included the QCD (Quality, Cost, Delivery) column in our process chart. We put it there to help remind us that QUALITY is multi-dimensional and that we need to think about how we control all the important dimensions.

Process Control Chart Example

Process: Swiss Chocolate Coffee Production | **Date:** 1 Oct -- | **Rev:** 2

Process Step	Control Items		Measurements				Control Methods	
	Description	Q,C,D (1)	Sampling	How	Target	Chart/ Report	Who	How
Fill Ceramic Mug with Distilled Water	Served in a Mug	Q	Each Serving	Checklist	0 Incorr. Mugs	Failure Rpt.	Filler/Heater	Process Standard SCC-001
	Volume	D	Every 10th Serving	Calibrated Measuring Cup	7 oz. ± 0.5 oz.	X,mR Control Cht.		
Heat Mug/Water in Microwave	Water Temperature	Q	Every 10th Serving	Calibrated Digital Thermometer	175F ± 10F	X, mR Control Chart	Filler/Heater	Process Standard SCC-002
Add Coffee Mix to Hot Water	Mix Amount	Q	Each Serving	Standard Teaspoon	3 Level Tsp.	X, mR Control Chart	Mixer/Server	Process Standard SCC-003
	Process Time	D	Every 10th Serving (2)	Kitchen Digital Clock	60 ± 10 Sec.	X,mR Control Chart		
Stir Coffee Mix/Water	Surface Lumps	Q	Each Serving	Visual	None Visible	C Control Chart	Mixer/Server	Process Standard SCC-003
	Process Time	D	Every 10th Serving (2)	See Above				
Serve Coffee	Spills	D	Each Serving	Visual	None	C Control Chart	Mixer/Server	Process Standard SCC-004
	Dropped Mug	QCD	Each Serving	Visual	None	Failure Rpt.		
	Process Time	D	Every 10th Serving (2)	See Above				

Notes: 1) QCD - Quality, Cost, Delivery
2) - Process Time to be measured for total of these three process steps

The Process Management Book

One of our “wildest” training courses involved a group of nurse managers at a hospital in Alabama (no, it’s not what you’re thinking). Facilitating this group was like “herding cats.” At the end of the week, they were happy with the statistical methods course, but we weren’t sure what had sunk in. A month later, during a consulting visit to the hospital, the case manager director called us into his office. “Let me show you what we’ve done,” he said. Each one of his case managers had developed a book with the tabs shown below. They weren’t all filled in, but they were busy changing the way they worked to one based on *process* and *statistical thinking:*

1. Customer Survey Information (Needs and Expectations, current process performance feedback).

2. List of Prioritized Quality Characteristics/CTQs.

3. Process Flowchart.

4. Process Cause and Effect Diagram(s).

5. Current Measures of Performance (Graphs, Charts of Quality Characteristics/CTQs, Key Process Variables).

6. Applicable Procedures/Instructions.

7. Training Records.

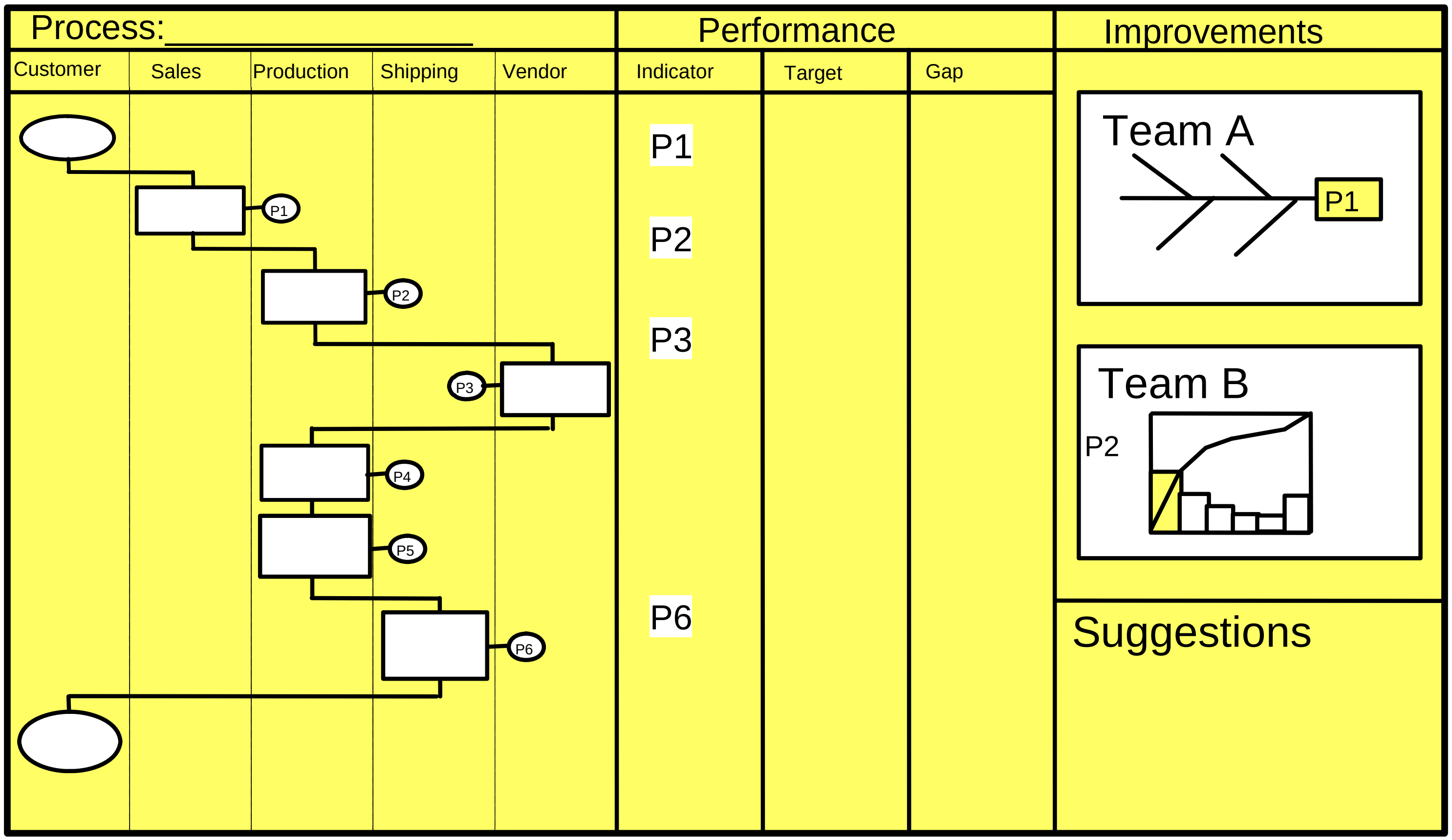
8. Current Process Action Plan - What are the current problem priorities, the status of improvements being analyzed, and the results from changes implemented.

This book is useful for several reasons. It helps the manager keep track of what's "most important." It is invaluable for management reviews and to help put a perspective on things when the latest "flap" emerges. It serves as the "corporate history" of the process, documenting the problems addressed and improvements made to the process.

The Process Storyboard

Bruce Sharp, of Duncan Enterprises, gave us this idea for a simple form of a Process Management Chart. The main purposes of this chart are to publicly display the current process (how), the indicators being used to measure performance (and any “gaps”), as well as the status of improvements being worked.

This is a simple approach to the Process Chart that may be useful when you’re just getting started in process management. Note how it “links” the two pillars of quality *improvement* and quality *control.* Some organizations also employ quality storyboards that visually document the progress of improvement efforts. If a large area is available, these two tools can be merged.



Reviewing a Process Control System

Here are some questions that will help you review a process control system (yours or someone else's).

DETERMINING THE OBJECTIVES

- What is the purpose of this process? What products/services are "produced?"
- Who are the customers of the product/service? What are their needs and expectations?
- Translate these needs and expectations into quality characteristics/CTQs. Which are "must-be's," which are "requested" or "delighted?" Which are most important (Dr. Kano's structure of needs and characteristics)?
- How can these quality characteristics be measured? At what level should these quality characteristics be set? What are the target values?
- Who is accountable, responsible for achieving the process objectives?

DETERMINING THE METHODS

- How is the current process performed? What are the important factors that affect the important quality characteristics?
- If necessary, revise the current method to accommodate "new" quality characteristics identified above. Are there characteristics of the existing process that are not necessary? Delete these.
- How will the important or "key" quality characteristics and "key" process variables be measured or checked? What will be the allowable defect rate or *sigma level* for the characteristic?

EDUCATING AND TRAINING

- How are the people currently working in the process educated and trained in their jobs? Does the training match the method used to do the work? What new or additional training is needed?

CHECKING THE RESULTS

- How does the process perform relative to the objectives/targets? How are the process variables performing? Are there special causes of variation present? Why?
- What is the best method to study the gap? Team, individual, or management effort?
- What process variables are key to affecting the process output?

ACTING

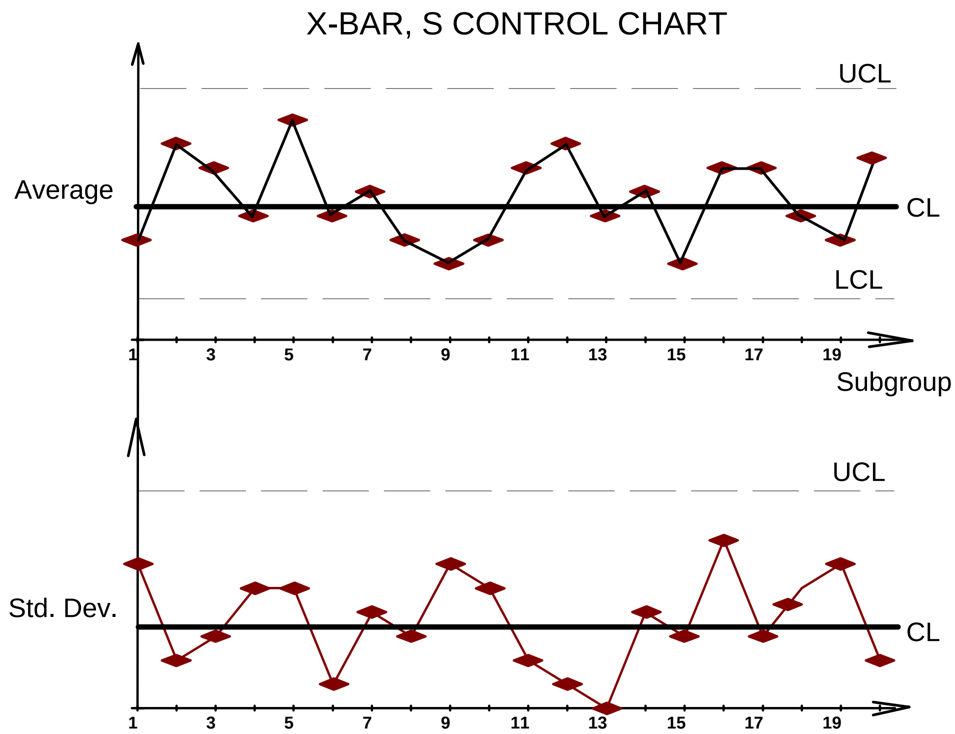
- What alternatives exist to modify the process variables? Costs? Benefits?
- How will the chosen alternative be measured for its effectiveness?
- What effects were seen from the process change?

7.2 INTRODUCTION TO CONTROL CHARTS

In Section 2, you learned how run charts can help you "peel apart" variation in a process. Now let's add a bit more complexity, and a *lot* more power. A Control Chart is (again) a graph of some quality characteristic or process variable. For Control Charts, though, we will add lines to the graph called *Control Limits (Upper and Lower)* that are calculated based on the data from our process.

Although they are most often used to track a process over time, we'll relax this requirement. When we use control charts to help us analyze a process, a more general concept called **subgrouping** will be invoked. In fact, Walter Shewhart indicated that just putting the "over-time" data on a control chart was the least preferable strategy.

Here's what a typical control chart will look like:



Choosing the Best Control Chart

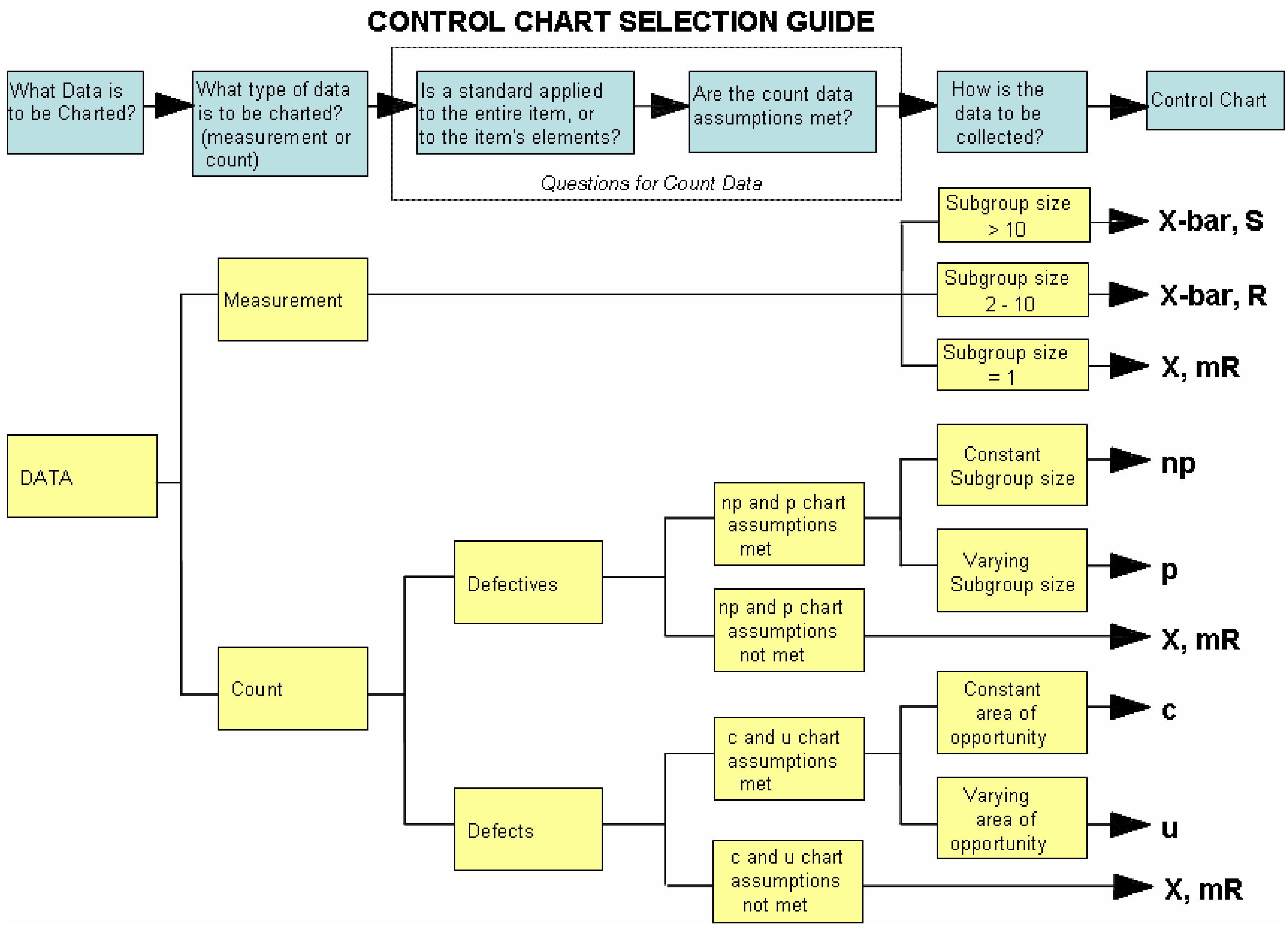
We will present six different kinds of control charts here that are widely used. To choose the correct control chart for your application, you will have to answer several questions.

Type of Data - Is your data *Measurement* or *Count*? This is the major “divide” for the control charts. Three charts can be applied to measurement data situations: *X-Bar, R* and *X, mR*. Four charts are applied to count data: *np, p, c,* and *u.*

Measurement Data Criteria - If you are dealing with measurement data, we'll ask you whether it makes sense to gather data in a “small” sample (generally of size 4 - 5 - leads to the *X-Bar, R* control chart), or does it make more sense to collect the data one point at a time (the *X, mR* control chart). There is an X-Bar, s control chart for “large” subgroup sizes (n > 10), but it is not often used.

Count Data Criteria - If you are working with count data, you need to think about whether you are dealing with **defectives** (leading to the *np* or *p* control charts) or with **defects** (leading the *c* or *u* control charts). We'll define the difference between defectives and defects later. For count data, the last question will involve the size of the sample you will take to get your data and, most importantly, does the sample size *change* from time to time. The latter criteria will lead us to choose between the members of the two count data control chart families.

On the following page is a “cheat sheet” for selecting the best chart. Use it the first few times you have to select a control chart for your application and you’ll quickly get the hang of the selection process.


CONTROL CHART SELECTION GUIDE
What Data is to be Charted?
What type of data is to be charted? (measurement or count)
Is a standard applied to the entire item, or to the item's elements?
Are the count data assumptions met?
Questions for Count Data
How is the data to be collected?
Control Chart
DATA
Measurement
Subgroup size > 10
X-bar, S
Subgroup size 2 - 10
X-bar, R
Subgroup size = 1
X, mR
Count
Defectives
np and p chart assumptions met
Constant Subgroup size
np
Varying Subgroup size
p
np and p chart assumptions not met
X, mR
Defects
c and u chart assumptions met
Constant area of opportunity
c
Varying area of opportunity
u
c and u chart assumptions not met
X, mR

Subgroup Strategies

This is an important control chart concept and we'll address it right up front. Shewhart coined the term **Rational Subgroup** to describe how to organize the data for a control chart. The concept is actually quite easy, but it is a departure for those who are used only to plotting data over time, or in sequence. Let's illustrate Rational Subgrouping with a few examples:

Hypothesis: There is a difference in defects for units that are built on first shift vs. the second shift. Here, our "rationing" is that the first shift employees either are or are not part of a common cause system that "produce" defects. A sample of units produced by the first shift in our study would then be a rational subgroup. Comparisons would then feasible **between** shifts. Does the proportion or rate of defects *really* differ between shifts?

Hypothesis: There is a difference in Metal Quality (i.e. Hardness, Toughness, or Ductility) among Suppliers to our Company. Here, too, our "rationing" is that the suppliers may not be a common cause system in their sheet metal production. We would obtain samples from each supplier, test them for their metal qualities and then the data would be plotted on the appropriate control chart. Questions regarding the central tendency or variability of the metal qualities could be answered.

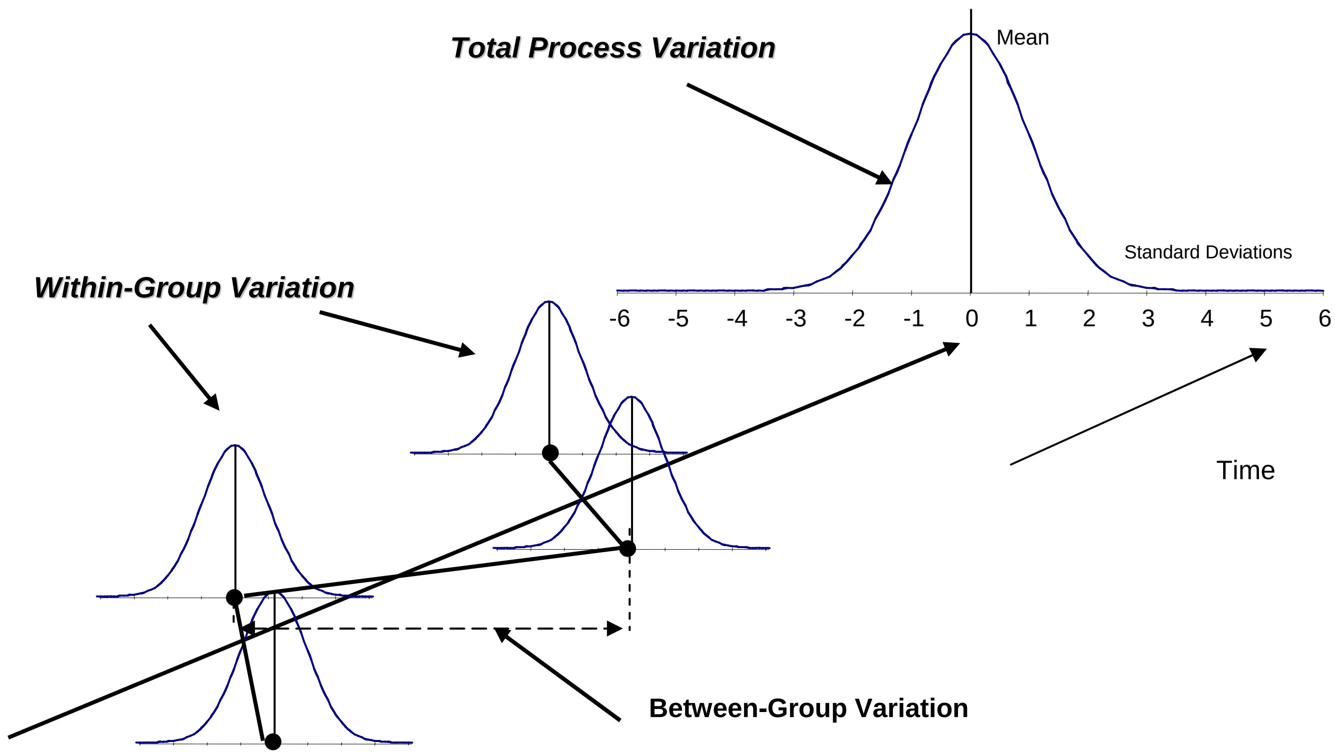
Hypothesis: We want to see if Response Times to customer requests differ by type of request. The "rationing" here is that the type of request causes a difference in the response time. We would obtain samples of response times for each request type and plot these on the control chart.

You can see that the idea of Rational Subgrouping is to identify possible factors that may be **assignable causes of variation**. As we organize the data, we'll keep data from these suspected causes in one subgroup and not mix data together from different subgroups.

A Subgroup's Impact on Control Chart Limits - Here's what goes on "inside" the control chart and how subgrouping impacts the "sensitivity" of our control chart.

Let's consider 5 numbers and pretend they are a sample from one of our processes taken, say, early in the day: 10, 24, 9, 18, and 13. The average is 14.8. We'll use the range as our measure of variability; in this case the range is 15 (max. - min. or 24 - 9). Let's focus on the range for a minute. This value of 15 is an estimate of the variation *within* these numbers. We give this a specific term: the *within group variation*. There are certain process variables that influence this type of variation. If we took another sample from the process, say, later in the same day, we would get a different set of numbers and could calculate a new average and range. The range gives us a new estimate of the within group variation. But now (you guessed it), we can look at the two averages and think about what they are telling us in terms of the *between group variation.* There are process variables that can affect this kind of variation.

In choosing how we sample from the process (our *subgrouping strategy*), we want to try and get samples that are as homogeneous as possible. Our objective is to try and let the special causes show up as between group variation, not within group variation. In fact, we calculate our control limits with this philosophy. The upper and lower control limits are based on an estimate of the *within-subgroup variation*. The more homogeneous our subgroups are, the smaller this estimate of variation will be. Hence, the tighter our control limits will be. This increases the *sensitivity* of the control chart to detecting special causes!



Practical Example: Let's say we know the output of our process depends on shift. We would *not* want our subgroups (for one data point) to include data from two different shifts. We would take a sample from one shift, plot that point and then take another sample from the second shift and plot that point. This way, most of the variation will show up *between points* as *between group variation.*

This issue of subgrouping is one of the most important for successful control charters. Think about this issue when you are setting up your control chart. It may take some trial and error to identify a good subgrouping scheme for your process. Several years ago, we decided to control chart our gas mileage. At that time, we were driving a Mustang GT. We decided to take samples of size 5, which represented about a month's worth of driving (5 fill-ups/month). This scheme worked. We were able to see a special cause in our process - increased gas mileage traceable to a speeding ticket we had received (lightened up the ol' lead foot) - show up as between group variation.

When we bought a more economical car, a Topaz, this scheme did not work as well. The Topaz gas mileage depended on a process variable - city driving vs. highway driving - to which the Mustang was not very sensitive. Since a month's worth of driving included city and highway trips, the sample was not very homogeneous. We wound up keeping two control charts, one for city driving, and one for highway trips.

Interpreting the Control Chart

To determine the state of our process, we will look for special patterns that appear in the data, just as we did when we used run charts. When using the measurement data charts (X-Bar, R or X, mR Chart), the rule is to first look at the Range chart (that displays the process' **variability)** for special causes of variation and work on eliminating these. Then examine the X-Bar or X charts for special causes and work on eliminating them (or stratifying them, see two paragraphs down).

If the variability of the process is being influenced by special causes of variation, then the variation we see in the averages of our samples is affected by both the *within-subgroup* and *between-subgroup* variation. Trying to determine what is going on in our process with both these kinds of variation present can be very difficult.

We said that we want our special causes to show up as *between group* variation. Well, with this philosophy, we want to try and get rid of one kind of variation first; the within-group type is the best place to start. Additionally, since our control limits are based on the within group variation, we want to make this as small as possible to improve our chances of detecting actual "out-of-control" conditions affecting the subgroup averages.

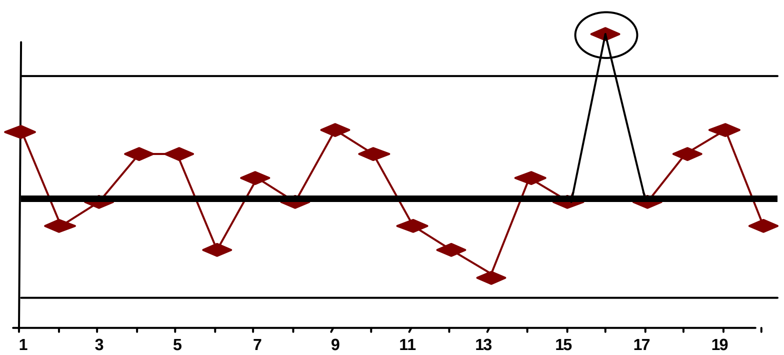
Note that sometimes "special cause" indications may arise when we combine the output of two processes on one graph or, equivalently, the output from one process that has multiple paths. The processes should be stratified in these cases and control charts prepared for the individual processes.

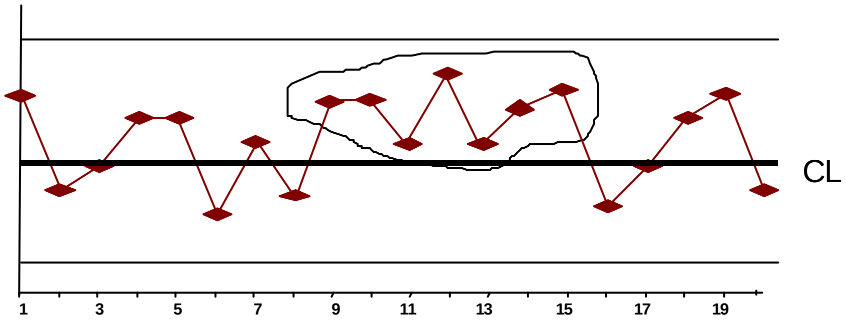
As an example, if we measure the time it takes to repair equipment, the type of equipment (pumps, valves, heat exchangers, circuit breakers, etc.) may be a significant process variable. Preparing a control chart that mixed these types of equipment together may be a mistake.

How do we detect special causes of variation using our new control charts? Here are eight rules that indicate the presence of special causes (three of which can be used with run charts).

The first four rules only require that the "basic" control chart be constructed:

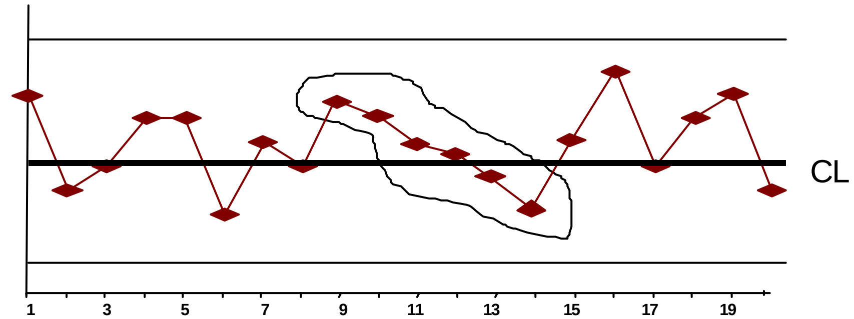
Rule 1 - Any point that is outside the control limits on either side. This is Shewhart's "classic" rule and may be applied to any control chart, whether it measures the central tendency or variability of the process.

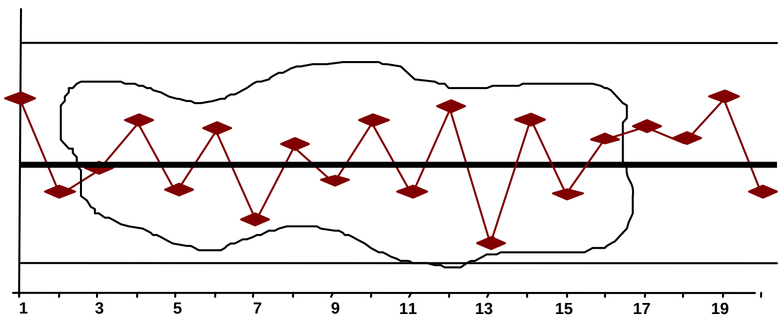




Rule 2 - A run of at least seven points either above or below the Center Line. This indicates that the process average has shifted or, (if the signal appears on the R or s-chart), that the process variability has shifted. Other runs that are interpreted as special cause signals include at least 10 of 11, 12 of 14 and 16 of 20 consecutive points on one side of the centerline.

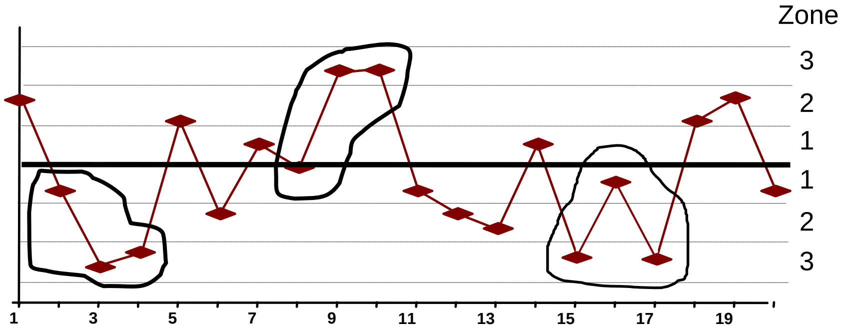
Rule 3 - A trend of at least 6 consecutive points either increasing or decreasing. A drastic trend downward (even though not all points are consecutively decreasing) is also evidence of a special cause.





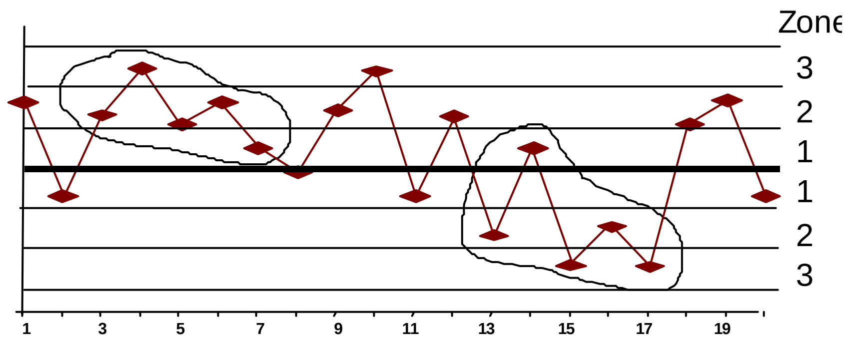
Rule 4 - Fourteen points in a row, alternating up and down. This often indicates two processes where the output from the first process is alternated with the second, back to the first, etc. This signal is often called the "hour-glass" effect - measuring the time for the sand to flow alternately from one glass to the other will produce this effect.

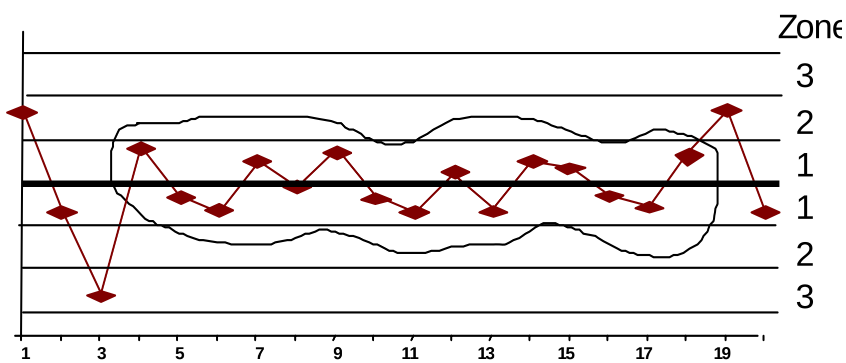
The next four rules require that we divide the distance between the chart's centerline and the control limits into Zones, each zone being one third of the distance from the centerline to the control limit (each zone, then, is one SIGMA!).



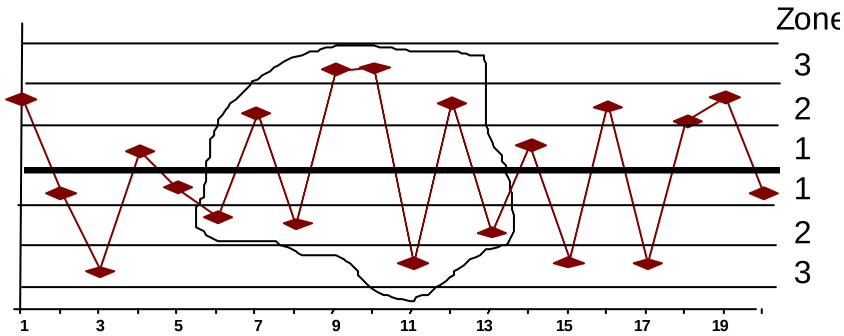
Rule 5 - Any two out of three points in a row on the same side of the average and in Zone 3 or beyond. This signal often indicates a temporary shift in the process average, although it is somewhat sensitive to variability shifts.

Rule 6 - Four out of five points in Zone 2 or beyond, but on the same side of the centerline. This signal often indicates a temporary shift in the process average.





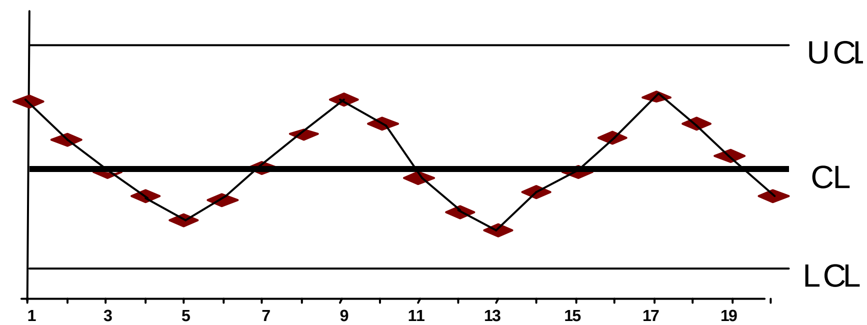
Rule 7 - Fifteen points in a row in Zone 1, above and below the centerline. This is known, affectionately in control chart circles as "hugging" (some refer to it as "stratification"). It may seem at first that this is a good situation. This signal most often tells us that we have mixed two processes together, and that each process is "equally represented" in each subgroup (for simplicity, suppose a subgroup of size 2, where each data comes from one of the different processes). Since the control limits are based on the average range, the limits will be wide, and the data will appear to "hug" the centerline. Bottom Line: look for a mixture of two processes contributing to the data for this chart.



Rule 8 - Eight points in a row on both sides of the centerline, with none in Zone 1. This signal is the same as rule 7; we've mixed processes together. This difference in the signal, though, comes from the fact that each subgroup consists of data entirely from one process or the other - no mixing of data within the subgroups has occurred. Again, look for two process streams being captured on this chart.

This last rule is somewhat of a "catchall." There may be non-random patterns that exist in your data that do not generate the signals described above. Be careful, though, of trying to detect a signal that is not really there. If you look at a set of data on a chart long enough, you **will** detect something, even if the data is random.

Rule 9 - A repeating pattern over time is known as Cycling. Look for seasonal influences on the process. This often appears when weekday and weekend data is mixed (a five and two pattern), or when shift-to-shift data is mixed (a three pattern).



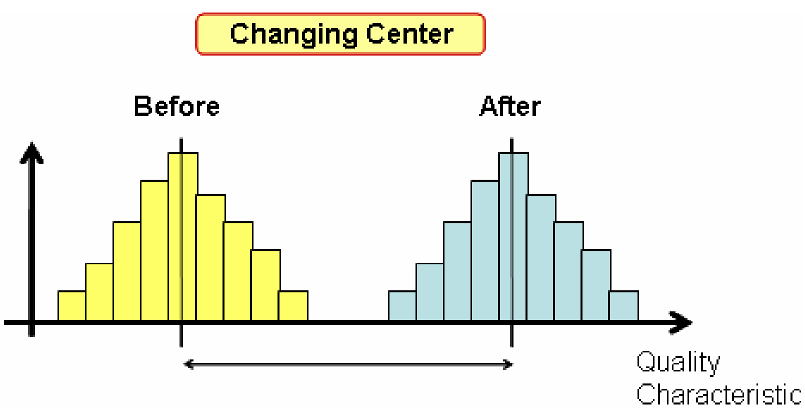
7.3 MEASUREMENT CONTROL CHARTS (X-BAR, R & X, mR)

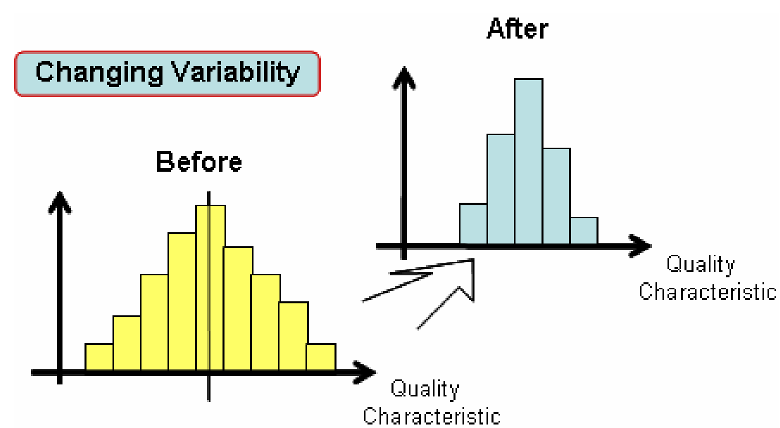
X-BAR, R CONTROL CHART FOR SMALL SUBGROUP SIZES (n < 10)

Purpose

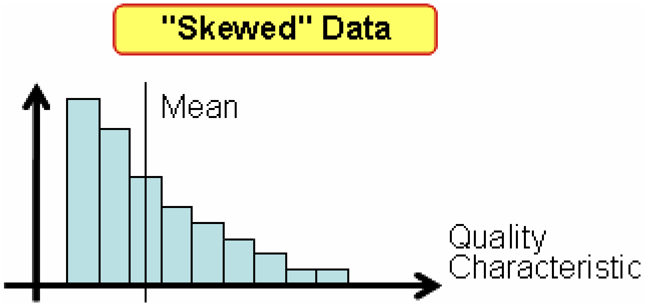
This chart is useful for measurement data, when we are taking small subgroups (generally, < 10) from the process. This chart can track changes in both the central tendency and variability of the process. The X-Bar, R chart is the “classic” manufacturing chart - every hour or so, an operator can measure some quality characteristic (i.e. a critical dimension) of four or five components coming “down-the-line.” These component measurements form a subgroup for the chart. The X-Bar, R chart and its “cousin” the X-Bar, S chart are the most powerful control charts for several reasons. The first reason is that the X-Bar, R (and S) chart really consists of two graphs, the "X-Bar" graph tracks how the average (central tendency) of the data is doing, and the "R" (or Range) graph tracks how the variability is doing.

Changes in the process can result in either the center of the data moving or can result in the dispersion of the data changing. The X-Bar, R chart can pick up either kind of change. The X-Bar chart generally will be quick to detect a change in the center of the data and the Range chart will be quick to detect a change in process variability:

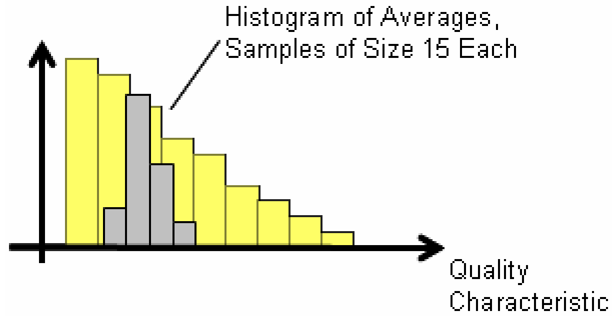




The second reason the X-Bar, R and S charts are powerful is that they track how the *average* of the process output is doing, not just the individual output values. Some process quality characteristics (especially those where we are interested in the time to complete an activity) may have some funny shapes when we plot the individual data values on a histogram:



Note that there are some events that take on relatively high values compared to the mean. If we plotted some individual data from that process, we might be tempted to believe a special cause was present if one of the very high values occurred. Instead, our strategy will be to take several samples of data from this process and calculate the average for each sample. We might expect that the histogram of these *averages* would have a rather smoother and tighter shape than that presented above:



By plotting the sample averages on a control chart, the chances of us thinking that a special cause is present when there really isn't one are reduced (this is a good thing!). X-Bar, R and X-Bar, S control charts make use of this property. Statisticians refer to the Central Limit Theorem to explain this – a sum of "enough" random variables will assume the shape of a Normal Distribution, regardless of the shape of the individual distributions.

Applications

The X-Bar, R control chart is used in the following situations:

Manufacturing Production Line - As described above, any high volume production line is a candidate for monitoring via an X-Bar, R control chart.

High Volume Service "Production" Lines - Similarly, services that are "produced" in high volumes are candidates. Examples include: Turn-around Times for Laboratory results and Time to respond to customer requests.

Inspections of Received Material - Each shipment or box of material received from a vendor may be considered a subgroup. Four or five items from each lot may be considered a subgroup.

High Volume Instrument Readings - For continuous processing applications (power plant, chemical or refinery plants), a sample of four or five process variable readings (pressures, temperatures, concentrations, etc.) can be considered a subgroup. One caution here, though. These processes are sometimes auto-correlated - that is, the readings are not independent. There are ways of treating this kind of data that "extract" the auto-correlation factor.

Construction of X-Bar, R Chart

1. Collect the Data - Decide on the subgrouping strategy you will use (shift, day of week, etc.). Decide on the subgroup size you will use. Four or five data per sample is a good general rule, although X-bar, R charts have been developed with anywhere from 2 to 10 data per sample.

It's a good idea to use a constant sample size for your first few X-Bar, R control charts. You can develop a control chart with varying subgroup sample sizes, but the control limits have to be calculated for each subgroup.

Data Needed: Try to get at least enough data for 25 points. If your sample size per point is 4, then you will need to measure at least 100 events. Don't get too concerned if you only have 40 or 50 data. Go ahead and develop the X-Bar, R chart, but you should recalculate the control limits as you accumulate more data.

Arrange the data into a table that looks something like that pictured below. In addition to the table, get a piece of graph paper ready so you can plot the data.

Subgroup	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**.**	**.**	**.**	**.**	**.**	**.**	**.**	**25**
Data 1																	
Data 2																	
Data 3																	
Data 4																	
Subgroup Average																	
Subgroup Range																	

R Chart

We'll work on the R chart first, since several values calculated here are needed for the X-Bar chart.

1. Calculate the ranges for each subgroup. Record these ranges on the last row of the table.

$$R_j = X_{j-\max} - X_{j-\min}$$

where:

$X_{j-\max}$ - the largest value of the "jth" subgroup

$X_{j-\min}$ - the smallest value of the "jth" subgroup

R_j - "jth" subgroup Range

2. Calculate the average Range. Add up all the subgroup ranges and divide by the total number of subgroups you have.

$$\overline{R} = \frac{1}{k}\sum_{j=1}^{k} R_j$$

where:

R_j - "jth" Subgroup Range

k - number of Subgroups

$\overline{R}$ - Average Range

3. Now calculate the Upper and Lower Control Limits for the Range chart:

$$UCL_R = \overline{R} \times D_4, LCL_R = \overline{R} \times D_3$$

where :

D_4, D_3 - Coefficients

UCL_R - Upper Control Limit for Range Chart

LCL_R - Lower Control Limit for Range Chart

The values of the coefficients D_4 and D_3 depend on the size of the sample you are using for each subgroup. For a sample of size 4, D_3 is not applicable (this means that there is no Lower Control Limit) and D_4 is 2.282. Since there are several more coefficients, we have provided a summary table at the end of this procedure.

4. Draw the average Range as a **solid** line on your graph. Draw the Upper and Lower Control Limits as *dashed* lines on the graph. Plot the subgroup Ranges.

5. Check the Range chart for special causes (see below for control chart interpretation). If you see special causes here, it means that some process variable is causing the *dispersion* of your process to change over time.

> *NOTE: It's worthwhile to stop here and investigate this type of process variation. In the "old days" (pre-computers), statisticians would recommend that you not even bother proceeding with the X-Bar chart until your process' variation was under control.*

X-Bar Chart

6. Now, calculate the average of each subgroup and record it on the second to last row.

$$\bar{x}_j = \frac{1}{n_j}\sum_{i=1}^{n_j} x_{ij}$$

where:

n_j - "jth" subgroup size

x_{ij} - "ith" element of the "jth" subgroup

$\bar{x}_j$ - "jth" subgroup average

7. Now calculate the *grand average*. This is just the average of all the subgroup averages.

$$\bar{\bar{x}} = \frac{1}{k}\sum_{j=1}^{k} \bar{x}_j$$

where:

$\bar{\bar{x}}$ - Grand Average of Subgroups

8. Calculate the Upper and Lower Control Limits for X-Bar:

$$UCL_{X-Bar} = \bar{\bar{X}} + (\bar{R} \times A_2) \; and \; LCL_{X-Bar} = \bar{\bar{X}} - (\bar{R} \times A_2)$$

where:

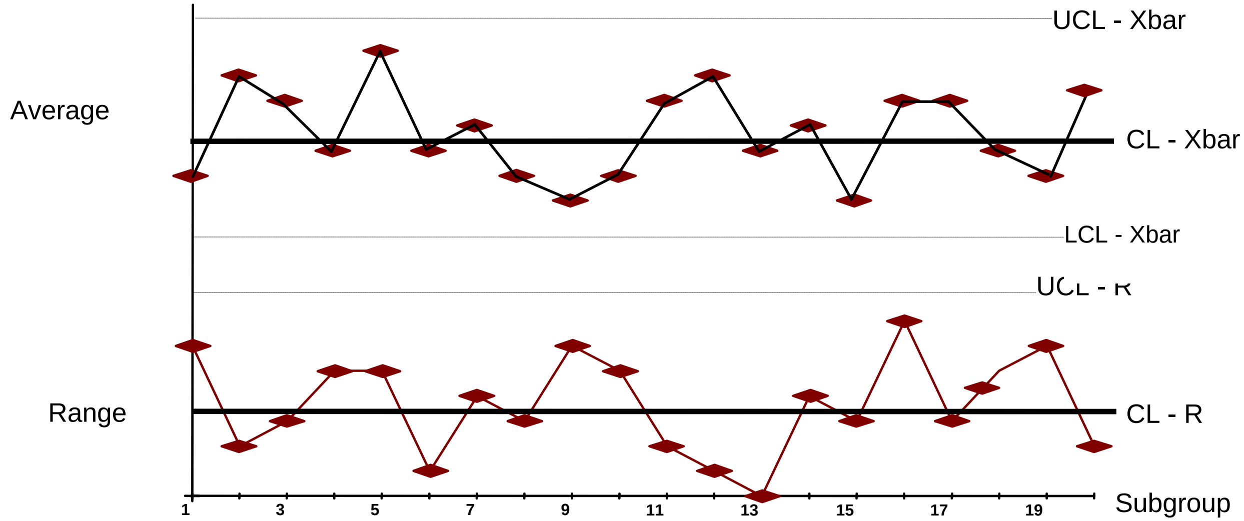
A_2 - Coefficient

UCL_{X-Bar} - Upper Control Limit for X - Bar

LCL_{X-Bar} - Lower Control Limit for X - Bar

Again, the coefficient A_2 will vary depending on your sample size. For a subgroup size of four, A_2 is 0.729.

9. Plot this grand average as a *solid* line on the X-Bar part of the chart. Draw the control limits as *dashed* lines on your graph. Plot the subgroup averages on your graph. By this time, your graph should look something like this:



10. Interpret the charts for assignable causes of variation. Use the rules presented at the end of this unit.

COEFFICIENTS FOR X-Bar, R CONTROL LIMITS

Sample Size (1)	A_2	D_3 (2)	D_4	d_2
2	1.880	-	3.268	1.128
3	1.023	-	2.574	1.693
4	0.729	-	2.282	2.059
5	0.577	-	2.114	2.326
6	0.483	-	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078

Notes:

(1) This is the number of data points that are combined into one subgroup.

(2) For sample sizes 2 through 6, the Lower Control Limit of the Range is not applicable.

Once you have decided on your sample size, just use the coefficients from the corresponding row of this table. You might be wondering what purpose that last column serves. Well, remember that the Range is the value we are using to measure the dispersion of the process. There are other measures of dispersion, including the variance and standard deviation. The d_2 *coefficient can be used to give us a good estimate of the process' standard deviation:*

$$\text{Standard Deviation} = \text{Average Range} / d_2$$

This is a useful conversion to have when we start to consider the capability of a process to meet customer specifications. We'll mention it here and return to this concept later.

X-Bar, R Control Chart Example

Scenario - A manufacturer of pressure-treated lumber tests for the chemical concentration (in percent) of the treatment. A sample of 4 pieces is taken from each batch after the treatment process and the concentration obtained. Data from the last few batches appears below:

	Batch					
Data	**A**	**B**	**C**	**D**	**E**	**F**
1	3.42	3.34	3.41	3.25	3.40	3.25
2	3.61	3.30	3.33	3.30	3.35	3.35
3	3.22	3.26	3.28	3.28	3.37	3.34
4	3.38	3.32	3.35	3.27	3.30	3.28

The basic calculations are straightforward. The subgroup Ranges are easily found:

Subgroup A - R = 3.61 - 3.22 = 0.39
Subgroup B - R = 3.34 - 3.26 = 0.08
|
Subgroup F - R = 3.35 - 3.25 = 0.10

The Average Range is then equal to 0.14. With this information, we can calculate the Upper Control Limit (for a subgroup of size 4, there is no Lower Control Limit):

$$UCL_R = 0.14 \times 2.282 = 0.32$$

We see that Subgroup A's Range is out of control and should investigate this instability in the *variability* of the treatment process. The Subgroup Averages are then calculated; we'll use Subgroup A as an example:

$$\bar{x}_A = \frac{3.42 + 3.61 + 3.22 + 3.38}{4} = \frac{13.63}{4} = 3.41$$

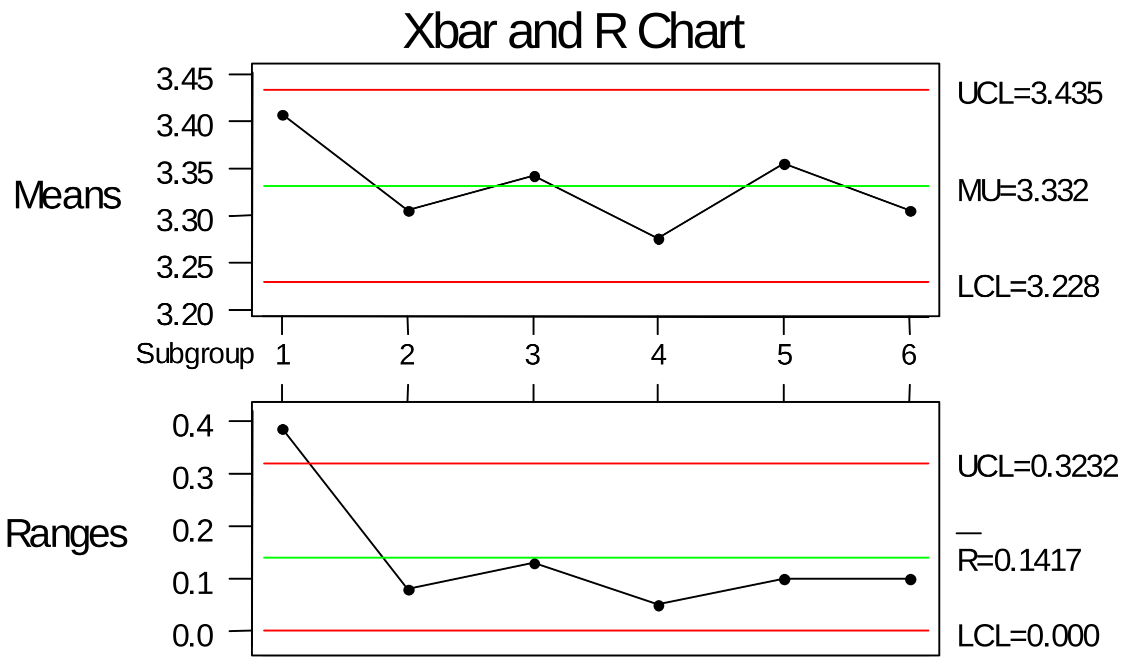
The remaining calculations are provided below:

Subgroup	**A**	**B**	**C**	**D**	**E**	**F**
Average	3.41	3.31	3.34	3.28	3.36	3.31
Range	0.39	0.08	0.13	0.05	0.10	0.10

Grand Average: 3.34
Upper Control Limit - Average: 3.44
Lower Control Limit - Average: 3.24

None of the Averages are out of control, but with the Range out of control, we can't be sure what's happening with the averages. Investigate the Range Chart first!

Note: The Graph below was developed using Minitab statistical software. Some of the calculations may differ slightly from those in the text due to rounding.



X, mR CONTROL CHART FOR INDIVIDUALS DATA (n = 1)

Purpose

The X, mR (mR stands for *moving Range*, some books call this the sequential range) chart is similar to the X-Bar, R chart, except our subgroup size is going to be one (1). The X, mR chart is useful when our process does not produce a large volume of data, maybe only one point a week or a month. The X, mR chart is composed of two graphs, the X and the mR charts. Sometimes, people refer to this chart as the *Individuals* chart.

The immediate question we have to address is how to get a measure of within-group variation when our sample size is only one. We wind up "creating" subgroups by treating sequential "X" values as a subgroup. The X, mR chart is not quite as good at differentiating within group vs. between group variation as the X-Bar, R chart, but it is still useful.

Application

Financial Report Data - Virtually all financial data that periodically comes to you in spreadsheet form today can be converted to X, mR Control Charts. Salary & Supply Expense, Productivity measures, Sales Figures (volumes and dollars), etc. are all candidates.

Periodic Equipment Measurements - If your operating procedures or preventive maintenance program includes periodic measures of equipment or system performance (e.g. once a shift, or weekly/monthly testing), the critical parameters can be plotted on an X, mR chart (in our experience, here the “X” part of the chart is often the only one used).

Process Data “Samples” - Very often, our first attempt a “playing” with a set of data from a process will be to prepare an X, mR control chart of the data. This will directly identify special causes in the data as well as provide clues that may lead to further, “better” analysis. For example, if the X, mR control chart shows several runs above and/or below the mean, there may be a subgrouping strategy lurking behind these runs. The data could then be examined for stratifications or displayed on an X-Bar, S chart.

Construction of X, mR Chart

1. Collect the data. Again, about 25 individual data values are recommended to get this chart going, but you can start with less. Recalculate your control limits as you collect more data. Subgrouping rears its ugly head here as a stratification question. Try not to mix data from different processes or from the individual paths of a process.

2. Organize the data on a table that looks like the one below:

Subgroup	1	2	3	4	5	6	7	8	9	.	.	.	.	.	.	.	25
Data																	
Range	x																

3. Calculate the ranges by taking the absolute value of the difference between sequential "X" values. Note that the "first" range is associated with the second subgroup.

$$R_2 = |x_2 - x_1|$$
$$R_3 = |x_3 - x_2|$$
$$R_4 = |x_4 - x_3|$$
$$etc.$$

where:

$|x_2 - x_1|$ - Absolute Value of $x_2 - x_1$

R_i - "ith" Subgroup Range

4. Calculate the average Range. Note that you have one fewer ranges than you do "X" values, so divide the total of the ranges by "k - 1" to get the average range.

$$\overline{R} = \frac{1}{k-1}\sum_{i=2}^{k} R_i$$

where:

$\overline{R}$ - Average Range

k - Number of Subgroups

5. Calculate the Upper Control Limit for the Ranges (the Lower Control Limit is not applicable) as follows:

$$UCL = 3.268 \times \overline{R}$$

(3.268 is the "D_4" coefficient for the X, mR Chart)

6. Prepare the graph paper as you did for the X-Bar, R Chart. Plot the average range on the graph as a *solid* line. Plot the Upper Control Limit on the graph as a *dashed* line. Plot the ranges, with the first range appearing under the second "X" value.

7. Check the mR chart for special causes using the same "rules" you used for the X-Bar, R chart.

X Chart

8. Calculate the average of the individual values ("X's"):

$$\overline{X} = \frac{1}{k}\sum_{i=1}^{k} X_i$$

where:

$\overline{X}$ - Average of X_i's

k - Number of Subgroups

9. Calculate the Upper and Lower Control Limits for the X's:

$$UCL_x = \overline{X} + 2.66 \times \overline{R}$$
$$LCL_x = \overline{X} - 2.66 \times \overline{R}$$

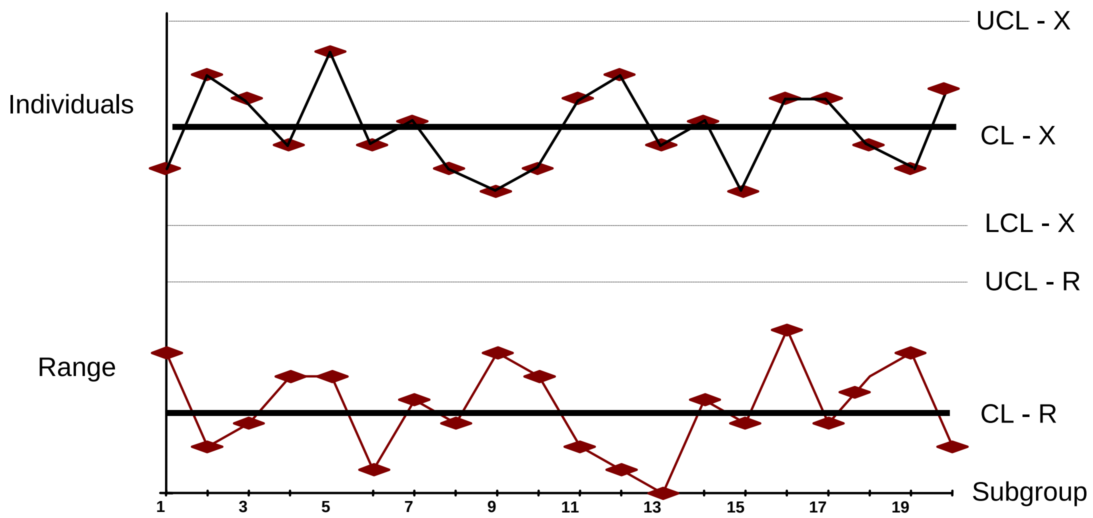
where:

UCL_X - Upper Control Limit for X

LCL_X - Lower Control Limit for X

(Again the "2.660" is the coefficient, except here it's known as E_2, not A_2.)

7. Now plot the average as a *solid* line on the X part of the chart. Plot the control limits as *dashed* lines on the X graph. Plot the X values and interpret the graph to determine the presence of special causes of variation in the process. Take action as appropriate.



A note on the X, mR Control Chart: If the data from your process is seriously skewed, then the chart may look a little funny. For example, if the data is skewed left, a broad gap may appear between the smallest values and the lower control limit. Take your data and plot it on a histogram to see if it is skewed. For more information, see Unit 6.9 – Additional Control Chart Topics – *Non-Normal Data and X, mR Charts.*

Example X, mR Control Chart

Scenario - A manufacturing plant monitors *offal* produced by a particular production line (data below divided by 10,000 lbs) leakage. One data point is collected every shift. The last six days' data is presented below:

Day	Mon		Tue		Wed		Thurs		Fri		Sat	
Shift	1	2	1	2	1	2	1	2	1	2	1	2
Offal (/10,000 lb)	0.10	0.08	0.10	0.12	0.11	0.13	0.13	0.14	0.17	0.18	0.17	0.18

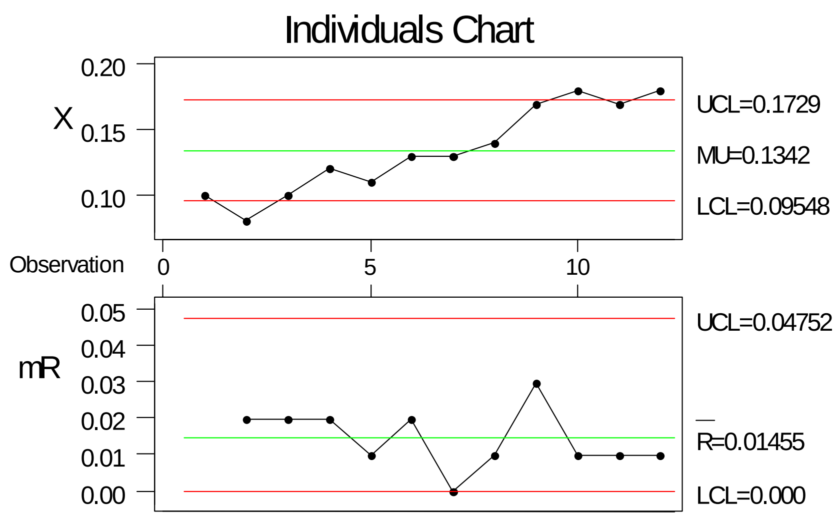
Here, the Range calculations are based on adjacent data points. The first Range is found by taking the absolute value of the difference between the first two points:

$$Range_1 = |0.10 - 0.08| = 0.02$$

The remaining calculations are shown below:

Average Range:	0.015
Upper Control Limit - Range:	0.048
Average of X's:	0.134
Upper Control Limit - X's:	0.173
Lower Control Limit - X's	0.095

Several points are out of control on the X-Chart. It's obvious from the data, though, that a long term increasing trend is occurring. Investigate! Investigate!



7.4 ATTRIBUTE CONTROL CHARTS (Binomial - np, p & Poisson - c, u)

Now let's introduce the charts to use if you are dealing with attribute (synonyms: *count* and *discrete*) data. Two “families” of count data charts exist: the *np & p,* and the *c* & *u* charts. Before we start, there is one issue and one concept we need to address.

The issue has to do with how the control limits are calculated for these charts. They are based on an *assumption* that the data being plotted can be accurately modeled by one of two types of probability distribution: the Binomial or the Poisson. In some cases, it will be difficult to assure that all the assumptions surrounding these distributions are met.

You have a "bail-out" option. The **X, mR** Chart can be used as an effective substitute for any of these charts (Review the control chart selection guide - you’ll see these paths). We’ll list the specific assumptions before each pair of count data charts.

Now let's proceed to the additional concept - the difference between *defects* and *defectives*.

Say that we have a standard (or specification) for a part dimension. If the part is manufactured within the specification limit, we treat it as OK, if not, then it's not OK and is reworked or scrapped. We could sample 100 parts, measure their dimensions and then count the number that did not meet the standard. Through this experiment we would have identified the number of *defectives*. The same concept applies to customer orders compared to a delivery time standard. Those that do not meet the standard (e.g. those that are not delivered on time) are *defective.*

In general, if we can look at an event or a thing and judge it to be OK or not OK, then we are dealing with defectives. Parts outside spec limits, errors, incorrect bills, late shipments, and “bad order” parts can all be considered as defectives. We will use the *np* or *p* control charts to deal with defectives.

Let's now consider a different situation. Inspect a completed air conditioner. Are there any leaks? Are all the electrical wires terminated correctly? Are all the features the customer ordered present? Are there any coating scratches or undercoating areas? Here, we can count the number of problems with the unit. We will consider each of these problems to be a *defect*. The unit could have 0, 1, 2, 3 or more defects.

We can apply the same thinking to a Bill of Materials prepared by an engineer. Are all parts & materials listed? Are they all the correct parts/materials? Are standard part numbers correct? Are the amounts correct? Here, too, we can count the number of *defects* on the Bill of Materials and the BOM could have 0, 1, 2, 3 or more defects.

To generalize, when we examine a "thing" and can count the number of things "wrong" with the thing, we are dealing with defects. The "thing" we are examining is given a special term: the *area of opportunity*. In our first example, the order form was the area of opportunity, in the second, the piece of equipment.

In many cases, especially in manufacturing situations, we actually do look at a surface area and count the number of defects. Take a painted surface of 1 square foot and count the number of scratches or pinholes; take a polished or finished surface and count the number of blemishes.

For situations where we are dealing with defects, the *c* and *u* charts will be our control charts of choice.

The manufacturing world coined the terms *defective* and *defect*. Let's consider these somewhat different examples from the *service world*:

1. *A customer service office was interested in the number of customers to use their "Hot Line" each day.*

2. *A warehouse was interested in the number of parts ordered by different technicians for a particular repair.*

3. *A manufacturer was interested in the fraction of customers who chose a certain type of option.*

Now these indicators are neither "defectives" nor "defects," but we would treat them using the concepts described above. The first two examples are count data that would be considered under the "defect" category, the third is an example of a "defective" type of data.

Assignable Cause Tests for Attribute Control Charts

The following assignable cause tests are generally accepted to be applicable to attribute control charts:

Rule 1 - Points outside the control limits

Rule 2 – Seven points in a row on the same side of the center line

Rule 3 - Six points in a row, increasing or decreasing

Rule 4 - Fourteen points in a row, alternating up and down.

Binomial Assumptions for *np* and *p* Control Charts

To test if your data meets the assumptions for a Binomial model, and hence is a candidate for the *np* or *p* control charts, ask these questions:

1. Can you identify a sample (subgroup) of items? (YES is Good)

2. Will each item in the sample (subgroup) be classified as either having, or not having some characteristic? (YES is Good)

3. Does the fact that one item possesses the characteristic affect the probability of the other items having the characteristic? (NO is good)

The first two tests are usually easy to pass. You've identified items to inspect and you will either pass or fail each item in the group.

The third test is a little tricky. The concept here is one of **independence**. In many practical cases, the items *are* independent of each other. The fact that one item possesses the characteristic doesn't affect any others in the sample.

Here's an example where this Binomial test would not pass, though. A plant has a shutdown due to a tornado that causes a number of customer orders to be delayed. Here, the probability of one shipment being delivered late is not independent of the others.

Remember, if the data doesn't meet these assumptions, then the **X, mR** control chart may be a useful alternative.

THE np CONTROL CHART FOR YES/NO ATTRIBUTES – CONSTANT SUBGROUP SIZE

The *np* chart is used where we are interested in the number of *defectives* resulting from a process. In addition, the number of items that we look at to count the number of defectives must be relatively constant. Here's two ways this can occur: 1) The volume of the process (say, weekly) stays about the same (i.e. every week, about 50 shipments are sent out) or, 2) we deliberately take samples of constant size from the process.

Why is this called an *np* chart? The *n* stands for the size of the subgroup that we take from the process. The *p* stands for the fraction of the process' output that is defective (0.2, 0.3, 0.002, etc.). The *np* taken together is simply the number of defectives.

Applications

The np chart is very popular in situations where we inspect the output of the process (or a sample of the output) and make a go/no go decision. In fact, this gives us a clue that we are using the correct control chart. When we look at the output from the process, at a *minimum*, all items could potentially be OK; at a *maximum*, all items could be not OK. Inspecting material received from a vendor, on-time order filling, incorrect bills, number of accounts receivable greater than 60 days old are candidates for an np chart.

A coil assembly process improvement team was concerned with the need to rework assemblies. To measure the performance of this process, the team took a subgroup of 100 coils assembled each week and counted the number of coils with leaks. They tracked this number using an *np* control chart.

Construction of np Chart

1. Collect the data. Here, it is important to make the number of items we will look at in each sample as constant as possible.

   If you can set up a sampling procedure, then you can decide to look at a constant sample size each day or week or month. If you are looking at the entire process' output, then the volume of the process should be fairly constant from week to week or month to month. Here's a thumbrule: The individual sample sizes should not vary by more than about +/- 25% from the average sample size. If the average volume of a process is 100 "widgets" per week, and the individual weekly volumes are never more than 125 per week nor less than 75 per week, then you're OK. If this is a problem, use the p chart instead[22]*.*

2. Count the number of defective items in each sample and record them in a table such as appears below. Notice that we still call each sample of data a "subgroup."

Subgroup	1	2	3	4	5	6	7	8	9	.	.	.	.	.	.	.	25
Number Defective																	
Size of Subgroup																	

[22]Most computer programs don't cut you any slack on this. If your subgroup sizes are not exactly the same, they'll force you to use the *p* chart.

3. Calculate the average number of defective items per subgroup. Add up all the defectives and divide by the number of subgroups to get this average.

$$\overline{np} = \sum_{i=1}^{k} np_i \Big/ k$$

where:

np_i - Number of Defective Items, "ith" subgroup

k - Number of Subgroups

$\overline{np}$ - Average Number of Defectives per subgroup

4. Calculate the Upper and Lower Control Limits for the np Chart. If your subgroup size has varied, calculate the average subgroup size first:

$$\overline{n} = \frac{1}{k}\sum_{i=1}^{k} n_i$$

where:

n_i - "ith" Subgroup Size

k - Number of Subgroups

and

$$UCL_{np} = \overline{np} + 3\sqrt{\overline{np}(1-\overline{np}/\overline{n})}$$

$$LCL_{np} = \overline{np} - 3\sqrt{\overline{np}(1-\overline{np}/\overline{n})}$$

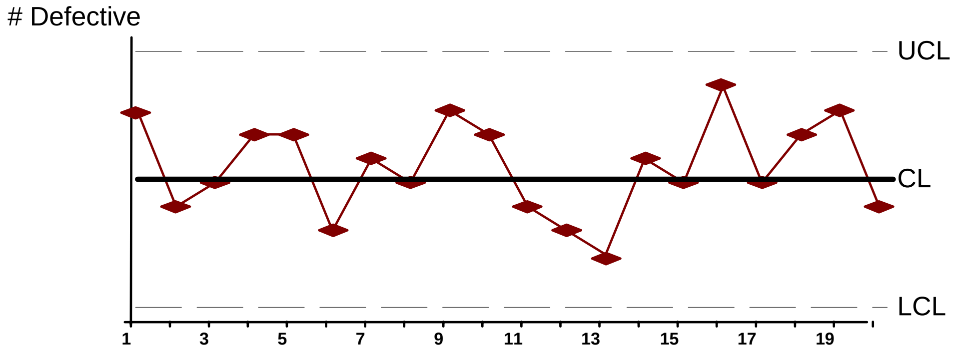
where:

UCL_{np} - Upper Control Limit

LCL_{np} - Lower Control Limit

$\overline{n}$ - Constant (or Average) Subgroup Size

4. Plot the average number of defectives as a *solid* line on your graph. Plot the Control Limits as *dashed lines* on the *np* chart. Plot the number of defectives on the graph for each subgroup. Note that sometimes the Lower Control Limit is calculated to be less than zero. In these cases, the Lower Control Limit is not applicable. Your control chart should look something like this:



6. Interpret the control chart. Look for special causes using the rules presented above (applicable to attribute control charts). Take action as appropriate.

Example np Control Chart

Scenario - A manufacturer of electronic controllers screens components purchased from vendors. Each month, a batch of 10,000 Integrated Circuit chips is received from a particular vendor. Automatic machinery tests each chip, accepting or rejecting the chip. The number of rejected chips for the last few months is provided below:

Month	J	F	M	A	M	J	J	A	S	O	N	D
# Rejects	10	8	14	6	23	15	11	8	12	13	17	14

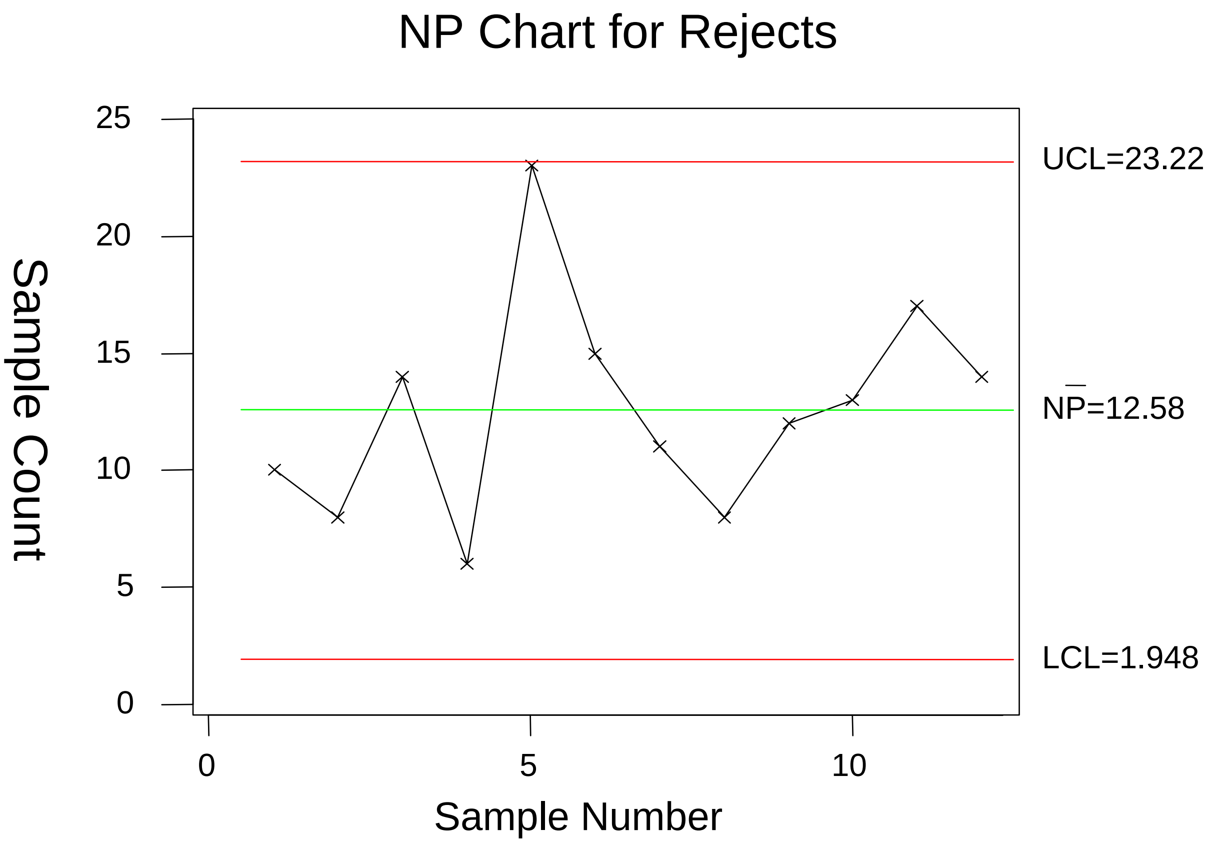
We first find the average number of defective chips:

$$\overline{np} = \frac{10+8+14+6+23+15+11+8+12+13+17+14}{12}$$
$$= \frac{151}{12}$$
$$\overline{np} = 12.58 \text{ defectives / batch}$$

The Upper and Lower Control Limit calcs are the only "interesting" part of this chart:

$$UCL = 12.58 + 3 \times \sqrt{12.58 \times (1 - 12.58/10000)}$$
$$= 12.58 + 3 \times \sqrt{12.58 \times (1 - 0.00126)}$$
$$= 12.58 + 3\sqrt{12.56}$$
$$= 12.58 + 3 \times 3.54$$
$$= 12.58 + 10.63$$
$$UCL = 23.21 \text{ defectives / batch}$$
$$\textit{and}$$
$$LCL = 12.58 - 3 \times \sqrt{12.58 \times (1 - 12.58/10000)}$$
$$= 12.58 - 10.63$$
$$LCL = 1.95 \text{ defectives / batch}$$

Even though one of the points (May - 23 defectives) is close to the UCL, we would call this process in-control. We can expect the in-coming defective percentage from this vendor to be about 0.13%, based on our screening test. The Minitab output for this data is shown below:


NP Chart for Rejects
25
20
15
10
5
0
Sample Count
UCL=23.22
NP=12.58
LCL=1.948
0
5
10
Sample Number

THE p CHART FOR YES/NO ATTRIBUTES – VARIABLE SUBGROUP SIZE

Purpose

The *p* chart is very similar to the *np* chart. By tracking the *fraction defective*, it handles the situation where you either can't or don't want to keep the size of your sample constant. There's a price to pay for a varying sample size, though. The Control Limits are going to vary from subgroup to subgroup. This makes calculations a bit more tedious and makes interpretation of the chart a bit more difficult. PC programs take the drudgery out of this task. If you find yourself doing lots of p-charts, you'll most definitely want to invest in a good SPC package.

Applications

Any of the *np* applications can also be charted using a *p* chart, if the subgroup size varies. Some like to use the *p* chart even if the subgroup size is held constant, since the percent or fraction defective has more meaning to them.

Number of incorrect shipments per week - The number of shipments (and, hence, the sample size) varies widely from week to week. The fraction defective - number of incorrect shipments divided by the number of shipments per week would be an appropriate application of the *p* chart.

Fraction of Lost Orders - Parts - The number of orders received by a service location will vary from day to day. The *p* chart may be used to track this fraction.

Fraction of incorrect repairs performed by technicians - When a repair is performed, a test is run to determine its effectiveness. On occasion the repair performed is incorrect. A comparison here may be done across technicians - each technician's repairs form a subgroup.

Construction of p Chart

1. Collect the data. Record both the number of defective items and subgroup size on a table such as appears below:

Subgroup	1	2	3	4	5	6	7	8	9	.	.	.	.	.	.	.	25
Number Defective																	
Subgroup Size																	
Fraction Defective																	
Upper Control Limit																	
Lower Control Limit																	

2. Calculate and record the fraction defective for each subgroup. Divide the number defective by the subgroup size to obtain these values. If you want, you can change these to *percent defective*. The calculations are slightly different:

Fraction Defective (or Percent Defective):

$$p_i = \frac{np_i}{n_i} \qquad p_i = \frac{np_i}{n_i} \times 100\%$$

where:

np_i - Number defective - "ith" subgroup

n_i - Subgroup size - "ith" subgroup

p_i - Fraction defective - "ith" subgroup

3. Now calculate the average fraction defective. Sum the number of defectives from each subgroup. Sum the subgroup sizes. Divide the first by the second[23]:

$$\overline{p} = \sum_{i=1}^{k} np_i \Big/ \sum_{i=1}^{k} n_i$$

where:

$\overline{p}$ - Average fraction defective

or, percent defective = $\overline{p} \times 100\%$

4. Finally, calculate and record the Upper and Lower Control Limits for **each** subgroup:

$$UCL_p = \overline{p} + 3 \times \sqrt{\overline{p}(1-\overline{p})/n_i} \text{ and } LCL_p = \overline{p} - 3 \times \sqrt{\overline{p}(1-\overline{p})/n_i}$$

or, for percent defective:

$$UCL_p = \overline{p} + 3 \times \sqrt{\overline{p}(100-\overline{p})/n_i} \text{ and } LCL_p = \overline{p} - 3 \times \sqrt{\overline{p}(100-\overline{p})/n_i}$$

where:

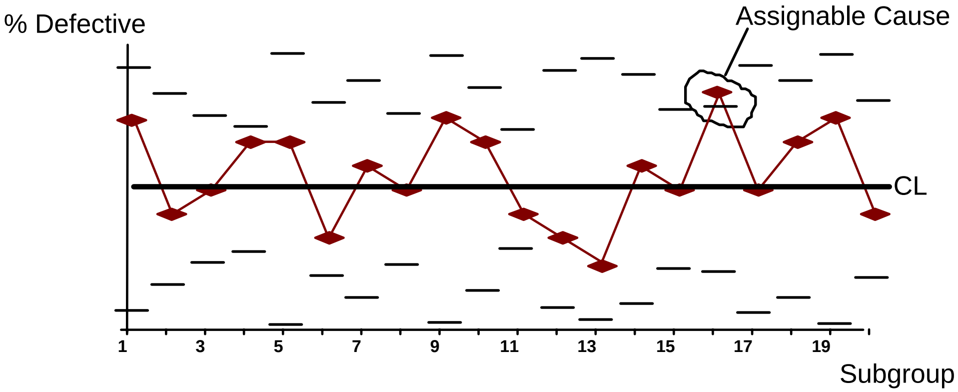
UCL_p, LCL_p - Upper & Lower Control Limits

n_i - "ith" subgroup size

Notice the equation for the Upper and Lower Control Limits. Since the subgroup size is in the denominator, the larger the subgroup size, the tighter the control limits. The larger the subgroup size, the less uncertainty we have about the "true" value of the fraction defective coming from our process. If a special cause of variation does change the process' fraction defective, the more data we collect, the easier it will be for us to see the effect of the change (i.e. as a point outside of the control limits).

5. Plot the average fraction defective as a *solid* line on your graph. Plot the fraction defectives. Draw the individual control limits as *dashed lines* above and below the points. Again, if the Lower Control Limit is calculated to be less than zero, then it is not applicable. Your control chart should look something like this:

[23] Remember, with different subgroup sizes, you can't average the individual subgroup fractions or percentages!



6. Interpret the chart. Use the rules for detecting special causes of variation discussed above (that are applicable to attribute control charts). Take action as appropriate.

Example p Control Chart

Scenario - A QC group was concerned about their efficiency. One of their indicators is the *Percentage of Units Delayed.* For the last few weeks, they've collected data on the number of inspections performed in the plant and the number that were delayed (operationally defined to have taken more than 15 minutes to inspect). Here's their data:

Week	1	2	3	4	5	6	7	8	9	10	11	12
# Delayed	8	10	11	5	14	8	6	6	8	12	11	9
# Inspections	44	60	54	35	60	48	63	72	42	38	49	58

The calcs are a bit more complicated here, since we have to keep straight when we're dealing with the individual subgroups and when we have to combine all the data. Here's the procedure:

First, calculate the subgroup fractions (or percentages). Here, we'll use the data from the individual subgroups:

$$\text{Week 1: } p_1 = \frac{8}{44} = 0.182 \text{ or } 18.2\%$$

$$\text{Week 2: } p_2 = \frac{10}{60} = 0.167 \text{ or } 16.7\%$$

. . . .

$$\text{Week 12: } p_{12} = \frac{9}{58} = 0.155 \text{ or } 15.5\%$$

Now, to calculate the average fraction delayed, we go back to the raw data:

$$\overline{p} = \frac{8+10+11+5+14+8+6+6+8+12+11+9}{44+60+54+35+60+48+63+72+42+38+49+58} = \frac{108}{623}$$

$$\overline{p} = 0.173 \text{ or } 17.3\%$$

The Upper and Lower Control Limits get calculated for each subgroup:

Week 1:

$$UCL_1 = 0.173 + 3 \times \sqrt{\frac{0.173(1-0.173)}{44}} = 0.173 + 3 \times \sqrt{\frac{0.143}{44}}$$
$$= 0.173 + 3 \times \sqrt{0.00325} = 0.173 + 3 \times 0.0570$$
$$= 0.173 + 0.171$$
$$UCL_1 = 0.370 \text{ or } 37.0\%$$

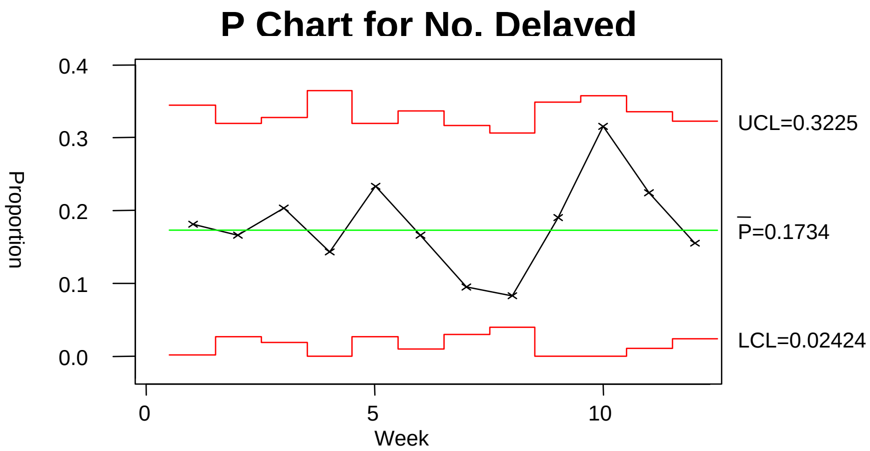
$$LCL_1 = 0.173 - 3 \times \sqrt{\frac{0.173(1-0.173)}{44}}$$
$$= 0.173 - 0.171$$
$$LCL_1 = 0.002 \text{ or } 0.2\%$$

Here's a summary of the remaining calculations for this control chart:

Week	1	2	3	4	5	6	7	8	9	10	11	12
# Delayed	8	10	11	5	14	8	6	6	8	12	11	9
# Cases	44	60	54	35	60	48	63	72	42	38	49	58
Fraction Defective	0.182	0.167	0.204	0.143	0.233	0.167	0.095	0.083	0.19	0.316	0.224	0.155
UCL	0.344	0.319	0.327	0.365	0.319	0.337	0.316	0.307	0.348	0.357	0.335	0.322
LCL	0.002	0.027	0.019	NA	0.027	0.009	0.03	0.039	NA	NA	0.011	0.024

None of the data fall outside the varying control limits here. Based on this evidence, we would declare this system to be stable at "producing" delayed inspections and look for the common causes of variation present in the system.

The Minitab output for this data appears below:



Poisson Assumptions for c and u Control Charts

To test if your data meets the assumptions for a Poisson model, and hence is a candidate for the *c* or *u* control charts, ask these questions:

1. Are you counting discrete events? (YES is Good)

2. Do these events occur within some well-defined area of opportunity (characterized by at least a *spatial* dimension and possibly by a *time* dimension)? (YES is Good)

3. Does the occurrence of one event affect the likelihood of another? (NO is Good)

4. Are the events rare? (YES is Good)

The first assumption is usually easy to address. The second one (area of opportunity) was discussed earlier - defining it well may take some thought about the factors influencing the occurrence of the events (i.e. if we are not brazing today then it will be difficult to observe brazing defects).

The third assumption is similar to the **independence** issue raised for the Binomial model.

The fourth assumption takes a little thought. One way to test this assumption is to consider the "theoretical" number of events that could occur within "one" area of opportunity. For instance, if we considered a square foot of painted surface, there *could* be millions of scratches or nicks. In a one month period, "*billions and billions"* of errors in records or warranty claims could occur. If the actual occurrence rate, though, is less than 10% of the "theoretical," then the events may be considered "rare."

If these assumptions are not met, the **X, mR** control chart may be used as an alternative.

THE c CHART FOR "HOW MANY" ATTRIBUTES – CONSTANT AREA OF OPPORTUNITY

Purpose

The last two charts help us track the number (or rate) of *defects* produced by our processes. Remember the difference between defects and defectives. When we look at a process output and decide whether it's OK or not OK, we are working with defectives. When we look at a process output and count the number of problems with the output, we are dealing with *defects*. The *c* Chart is used when we are counting the number of defects *and* the *area of opportunity* is constant from subgroup to subgroup. What does this mean?

Applications

Employee injuries can be candidates for a c chart. *Billing errors* are also candidates. What is the area of opportunity for these quality characteristics? How can we make the area of opportunity "constant?"

The *area of opportunity* usually includes both a *time* and *place*. For the injuries, the place could be the warehouse and the time could be one week or one month. So our indicator would be the *number of injuries per week in the warehouse.*

For billing errors, the "place" is the bill and "time" could be a sample of 100 bills. An indicator could be the *number of errors per 100 bills.* These could be considered as constant areas of opportunity.

You might be thinking that there are some other factors besides time and place that may affect the of employee injuries, such as the number of employees. We might better define the injury indicator to include some measure of this number (i.e. injuries per 100,000 hours worked). This addition might improve the "constancy" of our area of opportunity.

Defining the area of opportunity is one of the most important aspects of both the c and u charts.

Construction of the c Chart

1. Collect the data. As discussed above, define the area of opportunity as carefully as possible. Sometimes sampling from the process output can help make the area of opportunity "constant." For instance, if we are tracking the number of errors per customer record, we might chose to sample 100 records per week and count the number of errors in these records. Record the data on a form like the one below:

Subgroup	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**.**	**.**	**.**	**.**	**.**	**25**
Number of Defects															

2. Calculate the average number of defects. Add up all the defects and divide by the number of subgroups.

$$\bar{c} = \frac{1}{k}\sum_{i=1}^{k} c_i$$

where:

c_i - Number of defects, "ith" subgroup

k - Number of subgroups

$\bar{c}$ - Average number of defects

3. Calculate the Control Limits. They are pretty easy for this chart:

$$UCL_c = \bar{c} + 3 \times \sqrt{\bar{c}}$$

$$LCL_c = \bar{c} - 3 \times \sqrt{\bar{c}}$$

where:

UCL_c - Upper Control Limit

LCL_c - Lower Control Limit

4. Draw the average number of defects as the *solid* Center Line on the graph. Plot the data. Plot the control limits as *dashed* lines on your graph. This chart should look about the same as the *np* chart.

5. Interpret the control chart. Use the rules discussed in above (that are applicable to attribute control charts). Take action as appropriate.

Example c Control Chart

Scenario - A manufacturer of X-Ray film for industrial applications has been receiving complaints of defects found on the film by customers. As they begin to analyze the problem, they sample film rolls from the production process and inspect the film for defects. Here's the data they collected from 24 rolls of X-Ray film:

Film	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
# Def.	8	16	14	19	11	15	8	11	21	12	23	16
Film	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
# Def.	9	25	15	9	9	14	11	9	10	22	7	28

The c control chart is the simplest of all. We first find the average number of defects/roll:

$$\bar{c} = \frac{8+16+14+19+11+15+8+11+21+12+23+16+...+10+22+7+28}{24}$$

$$= \frac{342}{24}$$

$$\bar{c} = 14.25 \text{ defects / roll}$$

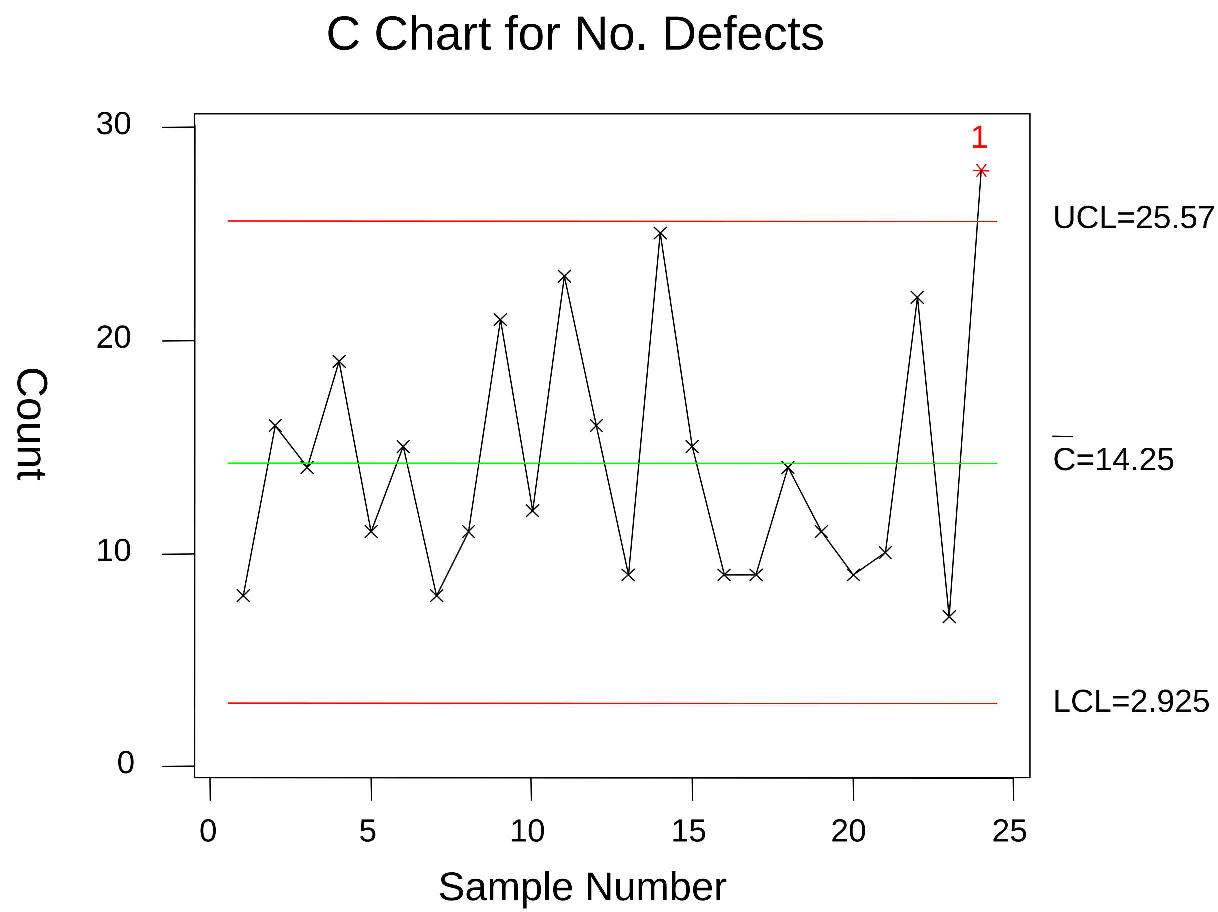
The upper and lower control limits are then very easy to calculate:

$$LCL = 14.25 + 3 \times \sqrt{14.25}$$
$$= 14.25 - 11.31$$
$$LCL = 2.94$$

$$UCL = 14.25 + 3 \times \sqrt{14.25}$$
$$= 14.25 + 3 \times 3.77$$
$$= 14.25 + 11.31$$
$$UCL = 25.56$$

The last X-Ray roll's number of defects (28) is above the Upper Control Limit and should be investigated as an assignable cause. The rest of the points fall inside the limits (and there are no patterns) indicating that film defects are ordinarily produced by the "production" system.

The Minitab output for this data appears below:


C Chart for No. Defects
30
20
10
0
Count
1
UCL=25.57
C=14.25
LCL=2.925
0
5
10
15
20
25
Sample Number

THE u CHART FOR "HOW MANY" ATTRIBUTES – VARIABLE AREA OF OPPORTUNITY

Purpose

The *u* chart tracks the *rate* of defects occurring in our processes. The *u* chart and *c* chart are related the same way as the *p* and *np* charts. The *p* chart was used when we could not or did not want to keep the subgroup size the same. The *u* chart is used *in lieu of* the *c* chart when we cannot or do not want to keep the area of opportunity the same from subgroup to subgroup.

The *u* chart suffers from the same difficulty as the *p* chart in that the control limits will have to be calculated for each subgroup and the interpretation of the chart is a bit more difficult. Again, an SPC software package will make this job easier.

Applications

Any application that fits the *c* chart can also be charted on a *u* chart.

Let's take an example that we used for the *c* chart and turn it into a *u* chart. If we were interested in developing a control chart for billing errors that were occurring and wanted to plot a point each day, we would be faced with the issue of a varying number of bills per day.

To address this issue, we could record both the number of billing errors per day **and** the number of bills prepared per day. From these data, we could calculate the *rate* of billing errors (total billing errors per day). Even though one aspect of our area of opportunity varies, the u chart can handle the problem.

Construction of the u Chart

1. Collect the data. Here, we have to collect both the number of defects and some measure of the changing area of opportunity. For example, we could collect the number of falls as the defects and the daily patient census as the area of opportunity. Record the data on a table that looks like the one below:

Subgroup	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**.**	**.**	**.**	**.**	**.**	**.**	**.**	**25**
Number of Defects																	
Subgroup Size																	
Defect Rate																	
Upper Control Limit																	
Lower Control Limit																	

2. Calculate and record the defect rate for each subgroup. Divide the number of defects for each subgroup by the size of that particular subgroup:

$$u_i = \frac{c_i}{n_i}$$

where :

c_i - Number of defects, "ith" subgroup

n_i - Area of opportunit y, "ith" subgroup

u_i - Defect rate, "ith" subgroup

3. Calculate the average number of defects. Sum the number of defects. Sum the subgroup sizes. Divide the first by the second:

$$\bar{u} = \sum_{i=1}^{k} c_i \Big/ \sum_{i=1}^{k} n_i$$

where :

$\bar{u}$ - Average number of defects

k - Number of subgroups

4. Calculate the Upper and Lower Control Limits for each point:

$$UCL_u = \bar{u} + 3 \times \sqrt{\bar{u} / n_i}$$

$$LCL_u = \bar{u} - 3 \times \sqrt{\bar{u} / n_i}$$

where :

UCL_u - Upper Control Limit

LCL_u - Lower Control Limit

5. Draw the average defect rate as a *solid* Center Line on the graph. Plot the individual defect rates and the individual upper and lower control limits as *dashed* lines above and below the points. This chart should look like the *p* chart.

If any of the Lower Control Limits are negative, disregard these values.

6. Interpret the Control Chart. Use the rules for detecting special causes of variation. Take action as appropriate.

Example u Control Chart

Scenario - An insurance company has gathered employee injury data from 8 plants operated by a company. The insurance company has ranked the injury rates from highest to lowest and wants the company to come up with a plan to reduce the rates at the top three plants. As the risk manager for the company, how would you respond? Here is the data:

Plant	North Hills	Jonson	Foggy Bottom	Fairview	Crab Apple	Ithaca	Ricker's Corners	Davis Hill
Injuries	23	20	19	17	16	16	14	10
Employee Hours	200,000	210,000	185,000	230,000	170,000	190,000	350,000	314,000

Before we jump to conclusions about the "top three," let's see if there's evidence to single these plants out. We'll construct a *u* control chart of this data:

As with the *p* control chart, we have to be careful about how we calculate the *u* control chart's components. We'll first calculate the injury rates:

$$\textit{North Hills Plant :}$$
$$u_{North Hills} = \frac{23}{200{,}000}$$
$$u_{North Hills} = 0.00012 \textit{ injuries/hour}$$

Then, we'll calculate the average injury rate:

$$\bar{u} = \frac{23+20+19+17+16+16+14+10}{200{,}000+210{,}000+185{,}000+230{,}000+170{,}000+190{,}000+350{,}000+314{,}000}$$
$$= 135/1{,}849{,}000$$
$$= 0.000073 \textit{ injuries/hour}$$

Now we have to calculate the Upper and Lower Control Limits for each subgroup:

North Hills Plant :

$$UCL_{North\,Hills} = 0.000073 + 3 \times \sqrt{\frac{0.000073}{200{,}000}} = 0.000073 + 3 \times \sqrt{3.65E-10}$$

$$UCL_{North\,Hills} = 0.000073 + 3 \times 0.000019 = 0.000073 + 0.000057$$

$$UCL_{North\,Hills} = 0.000130$$

$$LCL_{North\,Hills} = 0.000073 - 3 \times \sqrt{\frac{0.000073}{200{,}000}} = 0.000073 - 0.000057$$

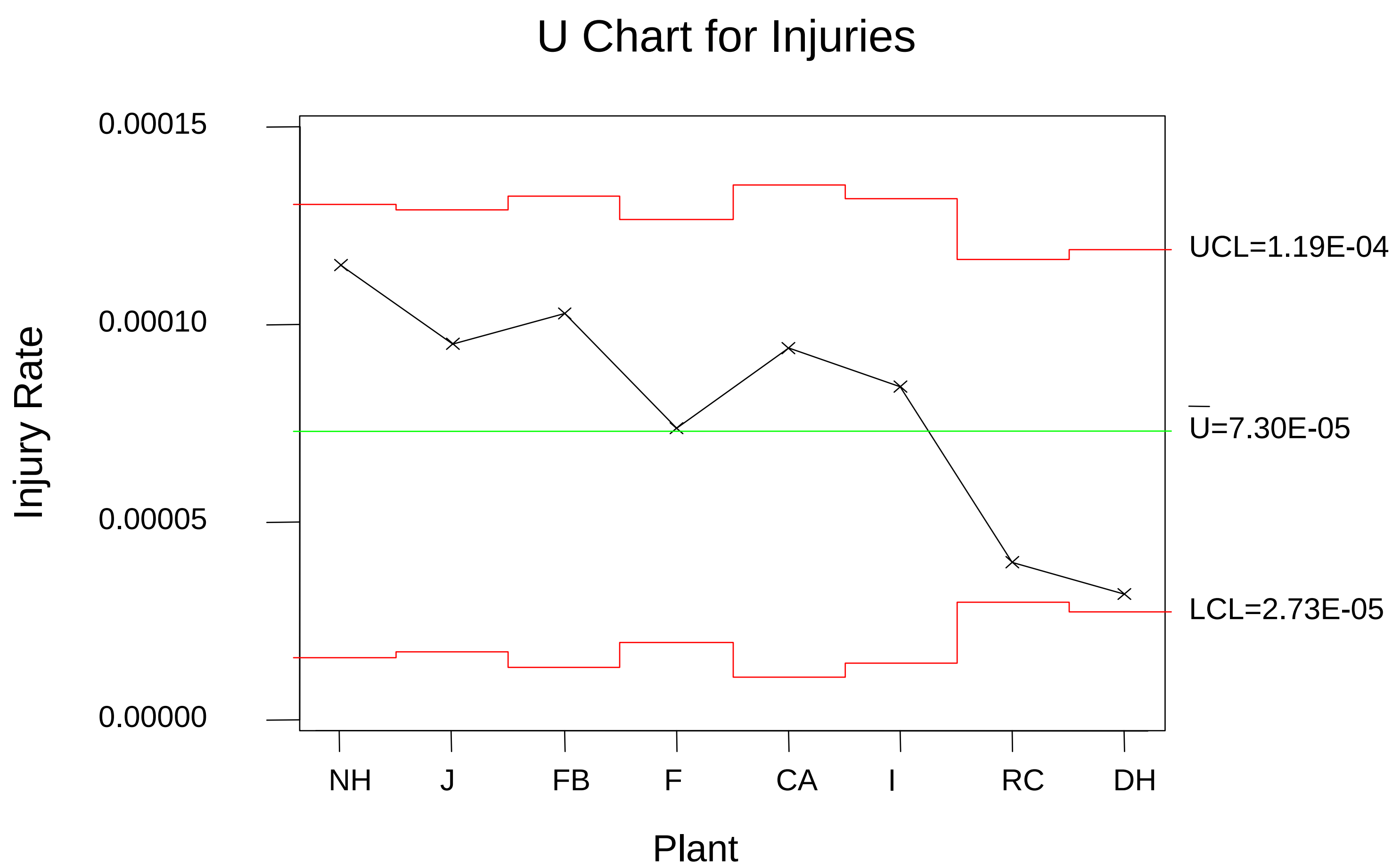
$$LCL_{North\,Hills} = 0.000016$$

You can see that the calculations get messy when we're dealing with very small rates such these injury rates. We could have applied a multiplier (i.e. injuries per 1000 hours) to make the calcs easier. Here are the rest of the calculations:

Plant	North Hills	Jonson	Foggy Bottom	Fairview	Crab Apple	Ithaca	Ricker's Corners	Davis Hill
Injuries	23	20	19	17	16	16	14	10
Employee Hours	200,000	210,000	185,000	230,000	170,000	190,000	350,000	314,000
u	0.000115	0.000095	0.000103	0.000074	0.000094	0.000084	0.00004	0.000033
UCL	0.00013	0.000129	0.000133	0.000126	0.000135	0.000132	0.000116	0.000119
LCL	0.000016	0.000017	0.000013	0.00002	0.000011	0.000014	0.00003	0.000027

None of the plants fall outside the control limits. Our response to the insurance company would be that it is inappropriate to rank the plants and demand that the "top three" improve their rates. They are making a "Hasty" type of error; treating common cause variation as if it was special cause. We might decide, though, to begin a program of improvement across **all** the plants to reduce employee injuries.

The Minitab output for this data appears below:


U Chart for Injuries
0.00015
0.00010
0.00005
0.00000
Injury Rate
UCL=1.19E-04
U=7.30E-05
LCL=2.73E-05
NH
J
FB
F
CA
I
RC
DH
Plant

8. WORKING ON A TEAM

The columnist, George F. Will, once commented, "*Football combines the two worst features of American life. It is violence punctuated by committee meetings.*"

You've probably been on at least one committee that just doesn't seem to be much more than a forum for gossip, whining, psychoanalyzing each other, or reading the minutes from the last committee meeting.

Worse, yet, are those committees "chartered" to make some decision when it turns out that the decision has already been made by the "higher-ups."

Even though we've seen the "worst" of teams, we've also been on some pretty darn good teams. We've been fortunate to have been part of teams that have been given a *mission,* the *responsibility, authority* and *resources* to get it done, and have "crossed the goal line," successfully completing the mission.

When the *right organizational conditions* are in place, teams can be a very good way of making improvements *happen.* There's nothing better than the feeling of having accomplished something with a group of strangers who have turned into your friends.

This section will describe our "philosophy" of teams, and provide you with some methods that can help your team experiences be positive *and* productive.

8.1 TEAM PHILOSOPHY

Let's establish one thing right away. A quality improvement team is a *method* of getting something accomplished. Teams don't exist just for fun.

In fact, there really is *no such thing* as a team. There is, however, a group of people that have come together for a purpose, hopefully a *common* one. We always try to remember that it's the *people* who are going to accomplish the goal. How can we balance their needs with the needs of the improvement effort?

Teams also *consume resources.* Meeting time, data collection and analysis work all take time. Therefore, without sounding too much like a bean-counter, we should expect some *return on this time investment.*

You should consider the *efficiency* of your teams, just as you would any other *production process.* If your teams are taking a year or more to solve simple problems, then something is rotten in Denmark! What's going on? Teams and the improvement process can and should be improved, just like any other.

Having made the preceding nasty, business-like statements, we'll back off a bit. If you are just starting to use teams for quality improvement in your organization, we'll "allow" for a growth curve. It takes people a while to get used to working together, to practicing the steps of quality improvement, to using the statistical tools and improvement methods.

Florida Power and Light started the teams' program in the early 1980's. It took us about six or seven years to get to where our teams were "efficiently" producing quality improvements. Along the way, much improvement occurred, and when we compared the early QI Stories to those of the late 1980's, it was like Stone Age to Space Age.

Miliken, the textile company, shared a similar experience. One of their managers told us that early on, they had a very formal "chartering" process for teams, requiring approvals of management and help from designated "facilitators." After a few years, though, if a problem arose that needed a team, it became a "natural" action to gather a group of staff who could address the problem and "*just do it.*"

8.2 DIFFERENT KINDS OF TEAMS

Four basic kinds of *improvement* teams are observed “in nature.” The matrix summarizes these:

Project	*Departmental*	*Cross-Departmental*
Picked by Team	**A**	**C**
Assigned to Team	**B**	**D**

A - *Departmental Team, Picks own Project* - One of our good friends is a laboratory director at a hospital in Georgia. He maintains a “Wish Board” in the lab’s break area. On this board, people pin small slips of paper that start with “*I wish we could . . . “* Most of these are minor process problems that get in the way of the staff doing their best work.

He encourages his laboratory staff to organize small (two or three people) teams, pick any one of the *“I wish”* statements and work them through to completion. There are always four or five small teams at work on the “*I wish”* projects.

What our friend has created is a very simple, yet effective *quality circle* program in his lab. The people on these teams are all from one *department* or *function,* and they *pick their own projects.*

Now George has several purposes to this program. First, the staff learns how to work together. Second, they learn how to *practice* process improvement. Third, they solve local departmental problems.

The order of these purposes is important. For these teams, the first two are most important. *Education* and *practice* are the key words here.

In some organizations, these are “standing” teams, continuing from project to project. For each project, a different leader may be picked, again, to develop leadership skills in the group. People in the department may rotate on and off the team, depending on the problem being tackled.

B - *Departmental Team, Assigned a Project* - Because the improvement is important to the *department* or to the *organization* (but involves just the one department), management has assigned a group of people to work on the effort. This is a common application of quality improvement teams.

Much of the remaining discussion in this section will pertain to these and type “D” teams.

C - *Cross-Departmental, Picks Own Project* - Typically, this kind of team will be a group of managers working on *cross-functional* issues that affect the organization. These teams can be a very important means of improving the organization’s overall *quality assurance system,* as well as addressing important quality issues.

For example, an Engineering department formed the *Nuclear Cross-Functional Team*, to identify and address issues that were common to all the engineering disciplines. This was a group of supervisors, who self-selected their projects and reported progress periodically to the engineering management. They accomplished some major improvements in the department, such as standardizing the format of engineering "packages" developed by the department for nuclear plant modifications.

In one hospital, two groups of managers formed *service line teams.* These cross-functional teams addressed quality, cost and service issues for the *cardiac* and *perinatal* service lines.

Often, this kind of team will "spin-off," or charter improvement projects that support the major themes they are addressing.

D - *Cross-Departmental, Assigned a Project* - Improvements worked on by these teams cross departmental boundaries, and are often among the most important affecting the organization. These teams are often chartered as part of the *strategic improvement process*, which focuses the organization's resources on the highest priority improvement needs.

8.3 BEFORE STARTING A TEAM

Carefully consider the need for a team before you start one. From a management perspective, here are some criteria we've applied to this decision:

Problem known, but cause of problem unknown - This *used to* be our toughest reason to start a team. As a manager, it was an admission that we didn't know the answer to a problem. These days, though, we enjoy it when we can say "I don't know." It means that there's an opportunity to learn something new.

Time restraints and resource requirements - This is an obvious one. We need to accomplish something and one person can't do it, or there are a variety of skills necessary for the project to succeed.

Need to leverage problems - One of our heroes is a nurse who runs an "AM Admit" unit at a hospital. She is always working on making the unit a better place for her patients and staff. But she's only got so much time in the day. She could accelerate the unit's improvement journey if she could get her staff involved in identifying and making improvements (see the lab director's strategy, for example, in *Types of Teams*).

Need to solve cross-departmental quality problems - Teams are practically the only effective way of addressing quality issues that cross department boundaries.

Philosophy of delegating authority - Many organizations have found that they are more successful when authority is delegated to the lowest level possible. Modern quality management incorporates this delegation "philosophy." Teams are simply one means of practicing this philosophy.

The idea of delegation, though, can sometimes be a difficult balance for management. For example, although the manager has delegated authority to a team, he or she still retains *responsibility* for the outcome of the team's work. The manager cannot approve of a solution that he/she knows will have a negative impact on the organization.

On the other hand, managers should be flexible and learn to accept solutions that can work, but are not necessarily the same as they might have chosen. Speaking from experience, although we were sometimes skeptical of our teams' solutions, we were "forced" to learn that their solutions often worked better than our ideas.

Want to help staff develop technically and personally - One oft-neglected responsibility of management is to develop and mentor their people. Teams are one way of accomplishing this. The team's leader, for instance, will develop management and leadership skills. Critical thinking skills develop. Project management skills develop. The staff brings their minds to work, instead of just "their hands and feet." One of our greatest pleasures is to see someone stretch and develop beyond their current capabilities.

On the other hand, here are some reasons *to not form a team:*

Have a solution that you want proved - On our very first team, the manager handed us a solution, and then told us to prove that this was *the* solution. We didn't even know what the problem was!

Want a team to "rubber-stamp" a decision - In organizations where teams are popular, some managers may think that having a team reach their conclusion will lend credence to the decision or action.

When you don't intend to take action on the problem - We worked at a nuclear plant which had developed a wonderful, but short-term solution to plant safety issues. Whenever the regulator (the NRC) would come around, management could always point to a team that was working on a particular problem. After a while, though, the regulator began to wonder where the *products* of all this team activity were. Management had used the teams as a delaying tactic, but it only worked for a while.

Like to have consensus on all decisions, think a team will achieve this - We worked for a manager once who seemed to think that *consensus* was necessary on all things. Teams weren't formed to *analyze* a problem, but as the manager's way of *forcing consensus* on his decision. He'd just keep talking about the issue until we gave up and "agreed with" his conclusion.

Can't make a decision yourself - If you have a hard time making critical management decisions, don't think that a team will help.

Like to get a team started, then confused, then "save them." - Some managers like to play the role of the "cavalry." They will start a team, give them poor direction or a fuzzy objective to begin with, watch the team flounder around[24] for a while, and then come in and "save" the team. We suppose their ego gets a boost, but . . .

Organization says you must have a certain number of teams - Early in many organizations' quality journeys, they will measure the number of teams doing something in the organization. Of course, this puts pressure on managers to have teams, regardless of whether they need them or not.

[24]One of our friends has a strange expression for this: *"The team was flopping around like a dead mackerel!"*

8.4 BEGINNING TEAM ACTIVITIES

Do you remember the TV show *Mission: Impossible?* The team always got their mission through a tape recorded message: "*Your mission, should you choose to accept it, is. . . . "* Of course, they always accepted the mission. There wouldn't be a show if they threw the tape recorder away and said, "*Nah, let's go to the beach today!"*

Beginnings are a delicate time for teams. Let's examine some of the issues you'll have to address. We're going to suggest some general pointers, but you decide for your organization and specific team what you think will work best. There's no *right* answer, only suggestions for what we've seen work and not work in the past:

Before the First Meeting

Who will lead the Team? - It's easy to say, *"Get your* best *person to lead the team*," but what does that mean? Our best definition is "*somebody who can herd cats."* Leadership is an art. We've seen a variety of leadership styles, we've seen people of who little was expected achieve great things, and we've seen "hot runners"[25] miss the target.

Some general characteristics we look for: *is respected by, and respects others, can focus on the mission, flexible, can handle the "rough and tumble" of the team, sense of humor.*

Sometimes, it makes sense to think first about who will be on the team, and then ask the question, "*Who might be capable of leading this team?"* One of our poorer choices was to put a young secretary in charge of an administrative team. Although she was capable, an older, dominating member made life very difficult for the leader. We really didn't "engineer success" into her leadership opportunity.

We'll give you the other side of this coin. Pick the leader, explain the mission and then trust them to decide who needs to participate.

Who will participate? - Probably the most important criterion is to identify people who know something about the problem being addressed. We've been on teams where it's been difficult for us to participate simply because of our lack of technical knowledge. This is hard for a leader, but don't just pick your "buddies" to be on the team.

One NASA manager learned to "like" having at least one "left fielder" on his teams. These were the people who challenged everything, who kept the team away from "groupthink" and who sometimes came up with the off-the-wall ideas that proved fruitful.

Try to keep the team as small as possible. Although we've seen teams of 20 people who were successful, the old saying, "*More than three people can't figure out where to go to lunch!"* is often true.

[25] Submariners' term for a live torpedo. Often applied to hot shot young officers.

If you can, it's always nice to ask someone if they want to participate on the improvement effort, rather than sending a memo or e-mail message telling them to be in such-and-such a meeting on a certain date.

"Chartering" **-** Some organizations get all hung up over this "chartering" thing. They think that some formal mechanism needs to be created to "give permission" to start a team.

Now, as you *begin* to promote the use of teams in your organization, there may be some need to identify which teams are out there, what they're doing, and what progress they're making. We recommend, though, that you move as soon as possible to the Miliken model described in *Team Philosophy.*

How much time is required and who's going to do the "real work" **-** Dr. Juran talks about the need to "budget for improvement." For many organizations, there is no "slack time" provided for improvement. Companies where work occurs in shifts or on assembly lines or where customer needs cannot be interrupted for any significant time (healthcare falls into this category) are challenged to make time for improvement work.

Senior management needs to consider how this issue will be addressed in their organization. Some companies have decided that the work of improvement is important enough to pay overtime to shift employees. Physicians have been compensated for time spent on improvement efforts for the hospital, etc. The solutions are generally not complicated, they just need to be identified and implemented.

The First Few Meetings

How do you break the ice? **-** While we're not trying to mix alcohol and quality improvement, one of the best icebreaking meetings we attended was at the lounge of the *Holiday Inn* in Homestead, Florida. Sure, the team had plenty of subsequent battles, but it was a good way to start. On the other hand, in one of the worst icebreakers we experienced, the team leader asked us all how we *felt* about the particular issue and then had us play some cute, "getting to know you" exercise. We'll also never forget facilitating a kick-off meeting for a project, getting an hour into the meeting and suddenly realizing that most people in the room *didn't know why they were there!*

Figure out some way to break the ice that's appropriate for your organization and its current *culture.*

Gaining commitment to the mission **-** Make sure this is clear before you go charging off after the windmills. Oftentimes, management will hand your team a broad charter. When you realize this, go back and get some clarity on what they are *really* looking for.

One team was charged by management to *reduce supply expense.* Well, turns out, they didn't have much control over a major piece of supply expense, since most of the supply contracts were negotiated through the corporate office and they were part of one division. They did have control over utilization of supplies in their local area, and could make improvements in this aspect of supply expense.

Jim Walden, former VP of Power Resources at Florida Power & Light, had a favorite phrase: "*The GOTTAWANNA."* Management and the team leader need to consider how to motivate the people on the team to tackle their problem. How did Moses get the Israelites to wander in the desert for 40 years?

What's in it for me? - This issue is a very careful balancing act and relates closely to the *commitment* issue above. Recent research on motivation has shown that the American worker on a team wants the project to succeed, but also wants to *shine* individually as a result. This is contrary to management's typical expectation that the project succeed to achieve corporate success (this motivation style is often applied in Japanese companies with success in *their culture*).

Here's a contrast: One company designed a quality tools handbook where each team member's signature appeared on the inside cover. Another company produced a similar handbook where several quality "gurus" were thanked for their wonderful influence, but the forward was "signed" by the "Staff of XYZ, Inc." Which approach do you prefer?

How will the team work together? - Early on, the team should decide how they want to work together. Issues such as meetings (should we, how often, when, where, how long, etc., also, see *Team Meeting Process*), work assignments, confidentiality, etc. can be captured in a set of ground rules adopted by the team.

"Penalties" for breaking the ground rules are definitely encouraged. Many teams have a consequence for showing up late at the meeting - a dollar or more in the team "kitty or having to bring the "munchies" for the next meeting are common. Our favorite ground rule is the one on celebration of accomplishments or milestones.

It's the little things that get you. Often, teams are crammed into a long, thin conference room. It's hard to have a sense of meeting cohesiveness when people are stretched out on both sides of a long table.[26] Try to get a room where a round table or at least a square arrangement of tables can be achieved. Everybody's facing each other and side conversations tend to be limited under these conditions.

How much time is required? **-** Make sure everybody knows what they are getting into here. Even more important, make sure their management is aware of the commitment. If somebody can't support the time commitment, they may still be able to contribute as a "guest" (see *Team Organization*).

What support will the team need? - Many organizations provide some sort of support structure for their improvement teams. The *facilitator* (see *Team Organization*) is a popular method of providing the team with guidance through their first improvement project. The facilitator may offer advice on tools, methods, or team "dynamics" issues.

Additional support may include information from the data processing department, laboratory support, vendor support and others.

Planning the project - One VP of Quality was in a position to see the difference in productivity between teams who did not plan their projects and those who did (see *Project Planning*). His insightful comment: "*The teams that did a project plan got results, those that did not floundered."*

"Outside" Issues

Those "left out" - What about those people in the department who are not on the team? Dr. Kaoru Ishikawa used to comment that "*The whole department is on the team, there are just some who go to the meetings."* There are several strategies to address this.

[26] Have you ever noticed that most boardroom meeting tables are long and narrow?

The Storyboard posted in a public area can serve as a *two-way* communication vehicle. From the team to the rest of the department, it communicates progress made on the problem. From the department to the team, "sticky notes" can be left on the storyboard with suggestions or ideas.

During periodic department meetings, the team can spend a few minutes (again, the Storyboard is helpful, here) presenting the progress they're making, and "alligators" they're wrestling with.

A pharmacy director from a North Florida hospital once made a presentation that brought a few tears of "quality joy" to our eyes. This woman did not seem like a strong advocate of quality improvement, but her story was simple and inspiring. Her hospital had started a quality improvement effort and she was "volunteered" to be on the first team. She described how their team "fussed through" an improvement in filling Crash Carts,[27] leading to a breakthrough in performance for this process.

Then she "got to figurin'" how she could apply this in her department. She asked her staff what they thought the key problems were in the department and they picked one. She put a team together to go address this issue. Well, the rest of the department got to see how much fun this team was having, and, one day, a pharmacist came up to her and asked her if she could start a team on another problem. Within about six months, the director had gotten so deep into improvement; she was the hospital's champion!

She concluded her presentation with the comment that "it was sure easier to get to sleep at night, since she wasn't the only one worrying about these problems anymore!"

***Communication* -** Depending on the scope of the project (who are the "stakeholders," how much of the organization will be affected by this project, etc.) the team should consider what their *communication plan* will be.

We were fortunate to lead an improvement effort where one of the team members taught us about "salesmanship." Since our project was not well understood by most of the organization, we scheduled as many meetings as we could to explain what we were doing and what progress we were making (the potential to impact the organization was large!). By the time our recommendations came out, everybody was comfortable with our work and the recommendations were accepted without any objections. *Salesmanship!*

***Reviews* -** This message is to both management and the team. Make sure that the project is reviewed, even informally, every so often (if more than a month goes by and nobody asks you about the project, that's a warning sign!). Use the *QI Story Review Form*, in the Forms Section.

Reviews should be a simple presentation of the project (that ol' Storyboard helps here, too) followed by a question and answer session to clarify issues. Action items should be recorded at the review and followed up as soon as possible.

[27] "Crash Carts" are filled with medication, equipment and supplies needed for emergency patient care (i.e. when a patient "codes" on a nursing unit).

8.5 PROJECT CHARTERS

Developing a project charter can be an effective way of getting the team up and running (*toward the goal*). The core elements of a charter include:

- Objective- A statement that describes what the team is being asked to accomplish.
- Indicators and targets for improvement
- Impact- benefits to the company of the improvement.
- Process and Boundaries- The beginning and ending points of the process to be improved.
- Limitations- Specified constraints of the project. Deadlines, budget, regulations, paybacks, etc.
- Key Assumptions- Assumptions of the sponsors as to the outcome of the project; includes the deliverables.
- Resources - The people, equipment, space, support, data, etc. that projects expects to use.

Other items may be added to the charter as the situation warrants. Some teams have included the business reasons for doing the project and the customers whose needs are to be met.

8.6 TEAM ORGANIZATION

Some basic team roles are defined below:

Team Leader - The Leader of the team coordinates and directs the work of the team as it moves through the quality improvement effort.

Team Member - The team members share responsibility for the work of the team (both inside and outside team meetings) during the project. Some specific team member duties *during* team meetings are described below:

Recorder - The recorder is a rotated meeting role assigned to help keep the record of the team's work. The recorder logs significant meeting content on a flip chart in front of the team.

Timekeeper - The timekeeper is a rotated meeting role assigned to help the team manage time. The timekeeper informs the team of when agenda items have run their "budgeted" time and may also call out the time remaining for agenda items.

Facilitator - The facilitator is a team advisor or consultant who has expertise in the improvement process, tools and methods. The facilitator supports the team leader in planning next steps and in providing support and feedback to the team's effort.

Guests - People may be invited from time to time to participate in one meeting, or to work with team members for a short time during the project. Physicians, for instance, who may not be able to participate in the entire project, can be involved in clinical quality improvement efforts as guests. When the project is completed, make sure these people receive the recognition they deserve.

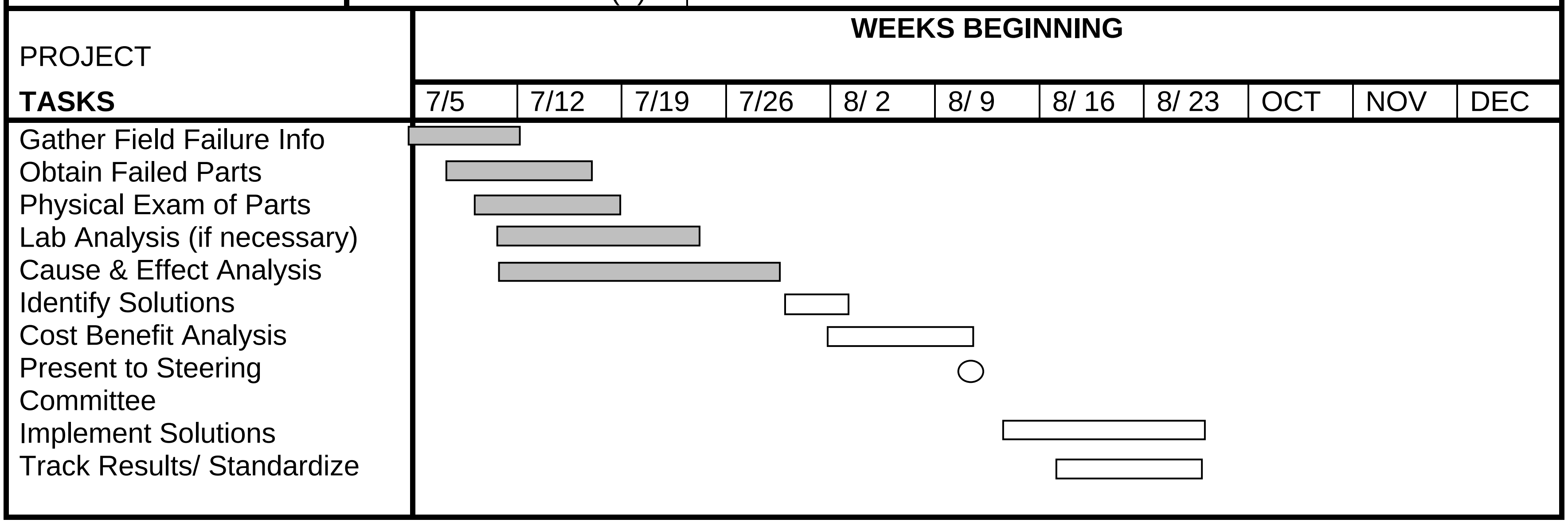
8.7 PROJECT PLANNING

As part of the team's *getting started* activities, a project plan should be created. Teams that develop a plan seem to do better than teams who "wander in the wilderness." A simple *Gantt chart* example is shown below. The plan should be updated as progress is made.

PROJECT PLAN

Project:	**Locomotive Low Voltage Wire Insulation Failure Analysis**

TEAM MEMBERS:	B. J. TRIM	C. E. RASHER
	R. L. YOUNG	J. B. HARSTAD (F)
T - TEAM LEADER	R. L. HAVRANEK	C. M. LAIN
F - FACILITATOR	J. F. MASTERSON (T)	



8.8 THE MEETING PROCESS

One of our best teams *hated* meetings. They loved doing the work associated with the project, communicated frequently in their offices, the hallway, and after work at the local "watering hole." As the project leader, we tried to oblige them by *minimizing* the number of "whole team" meetings.

If you feel you simply *must* meet, though, here's a process that can help make your meetings short, sweet and productive. An example meeting agenda appears on the next page.

Seven Steps of a Meeting:

1. Clarify Objectives: Make sure that everybody present has a clear understanding of what is to be accomplished in this meeting.

2. Review Meeting Roles: Assign the roles of recorder and timekeeper. Decide how time feedback will be given. Look over the doughnuts, bagels and croissants.

3. Review the Agenda: Review the items listed in step 4. Make sure that everybody agrees with the agenda and the items are consistent with the objective.

4. Work through the Agenda: Try to stick to the agenda. Manage the time spent on each agenda item and "bank" or "borrow" time consciously.

5. Review the Meeting Record: Review the flip chart or other records generated during the meeting. Decide which ones represent the "record" of the meeting.

6. Plan Next Steps & Next Meeting Agenda: Decide what actions are needed before the next meeting. Determine the objective and agenda items for the next meeting.

7. Evaluate the Meeting: How well did the meeting go? What improvements could the team make to the meeting process? Build these ideas into the next meeting.

Team The Leakers
Place B Conference Room

Date 8/17/96
Time 2:00 – 3:00 PM

Item Time		**Content**
5 Min.	**1.**	**Clarify Meeting's Objective** Begin building Cause and Effect Understanding of Air Compressor Head leaks
	2.	**Review Roles** A. Einstein Team Leader B. Franklin Recorder A. Lincoln Timekeeper T. A. Edison Facilitator
	3.	**Review Agenda Items**
	4.	**Agenda Items:**
15 Min.		A. Review Lab Analysis
5 Min.		B. Clarify Problem Statement
25 Min.		C. Develop Air Comp. Head Leak Cause and Effect Diagram
10 Min.	**5.**	**Review Meeting Record**
	6.	**Plan Next Steps & Meeting Agenda**
	7.	**Evaluate Meeting**

8.9 METHODS OF GENERATING IDEAS

Generating Ideas (Brainstorming)

Often a team will need to generate ideas as part of the quality improvement effort. Developing the Cause and Effect Diagram is one example where a large number of ideas are needed. Brainstorming allows a group to quickly develop a large list of ideas without spending time "beating each idea to death."

Brainstorming Steps:

1. Clearly state the purpose of the Brainstorming session.

2. Select Recorder(s) to capture ideas on flip charts.

3. Call out ideas in a "round robin" style (each person gets a turn, going around the group - it's OK to "Pass").

   - *Don't discuss or criticize ideas (sometimes, the ideas "from left field" turn out to be the most useful),*

   - *Build on ideas of others. Listen to the others' ideas, you may be inspired!*

   - *Note: There is a variation of Brainstorming that asks each member to write down their list of ideas before the session begins.*

4. When the "round robin" has slowed down, open the brainstorming session up to any additional ideas.

5. When the brainstorm has ended, review the list. Clarify the remaining ideas (add additional words) making sure that everybody understands each idea. Delete any duplicate ideas.

8.10 METHODS OF REACHING DECISIONS

Reducing the Number of Ideas (Multi-voting)

Along with generating ideas, a team may find the need to reduce a long list of ideas to one more manageable, or one that further action will be taken upon. For example, a brainstorming session has identified twenty different countermeasures that could be applied to the root causes.

Rather than discuss each one, in turn, the Multi-voting method can be used to reduce the list to a more manageable size. If the Multi-voting process leaves you with about 10 ideas, then you can use Rank Ordering to further reduce the list (see next page).

Multi-voting Steps

1. Clarify the purpose of the Multi-voting activity.

2. Decide the criteria to be applied to the voting (most cost-beneficial, most probable root causes).

3. Decide how many votes each member gets (usually 20 - 25% of the total number of ideas, for example, if you brainstormed a list of 25 ideas, each member would get 5 or 6 votes.).

4. Each member votes for the ideas that best fit the criteria.

5. Votes are recorded - the ideas that get most votes are circled and pursued further.

   - *Voting may occur again, if a large list still remains, or Rank Ordering can be used.*

   - *Never Multi-vote down to one item - Use Consensus to decide on the one item from the multi-voted list.*

Reducing the Number of Ideas (Rank Ordering)

Rank Ordering is often used to reduce a list of 10 or *fewer* ideas. Rank Ordering can be used by itself, or following a Multi-voting session.

Rank Ordering can be used to reduce the list to three to five ideas that will be pursued further in detail through a consensus process.

Rank Ordering Steps

1. Clarify the purpose of the Rank Ordering activity.

2. Decide the criteria to be applied to the ranking (most cost-beneficial, most probable root causes).

3. Label each idea with a *letter.*

4. Each member ranks the ideas from “best fit” (rank of 1) to “least fit” (rank of “*n*,” where *n* is the total number of ideas). All ideas on the list are ranked.

5. The rankings are recorded from each team member and summed by idea - the ideas that get *fewest* votes are circled and pursued further.

   - *Never Rank Order down to one item - Use Consensus to decide on the one item from the ranked list.*

Reaching Agreement on One Idea (Consensus)

Deciding on the best Countermeasure from several alternatives can be difficult for a group. Consensus is a method used to obtain support for an idea from the members of the group and their agreement to help carry it out, if it requires that action be taken.

Consensus is sometimes hard to achieve and takes time (more than that needed by one person to make a decision or for the group to vote on a decision), but it is worthwhile, since the agreement is generally considered to be a WIN-WIN for everybody in the group.

Consensus Process

1. Clarify what is to be decided and why consensus is important for the decision.

2. Members prepare their own positions, using the facts and data available (this is usually done prior to a consensus meeting).

3. Members share their positions (and the supporting facts and data), with the group actively listening and note taking.

4. General discussion then follows, until agreement is reached.

    - *From time-to-time, stop, seek out, and record the issues that the group agrees upon, also record the points of difference. Further discussion, then, can focus on the differences.*

    - *Avoid "giving-in," just to save time. Remember, the group will have to live with the decision.*

    - *A facilitator, detached from the emotions of the decision, can help support the group trying to reach consensus.*

8.11 CONFLICT AND OTHER WONDERS OF TEAMS

Conflict

Quality improvement means *CHANGE.* Change is difficult; and it just may bring out some conflict from time to time.

Now here, we're talking about *unhealthy conflict.* The healthy interchange of ideas in a team, where people are free to express opinions (the statistician's credo, though is *In God we trust, all others must bring data!*) is not conflict. In fact, if your team members don't have disagreements from time to time, then something else is wrong!

Now we will admit to *not* being experts on conflict resolution. But we have learned (painfully!) to ***not*** avoid conflict in team situations. One way or the other, we'll try to surface it, understand it, and address it through:

Solution - Make a decision that addresses the problem's symptoms, but not its causes (some corporate personal relationships have had years to fester; we are not going to turn enemies into friends in one or two months).

Resolution - Try to reach a compromise that satisfies both sides (everybody gives in, but nobody is really happy), or

Dissolution - Remove the conditions which caused the conflict (as close to a *WIN-WIN* as practical).

There is one last option that we've exercised only once - we had to *dismember* an individual from the team (actually, he dismembered himself).

Loss of Mission Accident

Machiavelli pointed out that any walled fortress only need stock provisions for one year. The invading force would usually lose interest if the siege lasted longer than that. He has been proven correct over and over.

Most quality improvement efforts should take much less than one year. But be careful of the passage of time, personnel changes, etc. that can cause the team to wake up one day and ask: "*Why in the heck are we working on this project"*

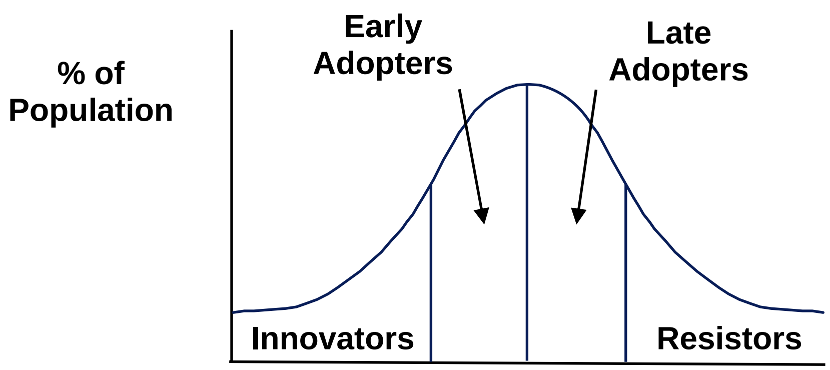
One of our friends is in the painful position of trying to implement the last pieces of an organizational restructuring effort. She's about the only one left who remembers why they decided to do the restructuring and why many of the change decisions were made. She's also about the only champion of the change in the organization. It's an uphill battle for her, every step of the way.

8.12 WORKING WITH STAKEHOLDERS

One day, we saw two of our "Belts" walk by with long faces. When asked, they said they'd just come from a meeting with the "new" senior management (a change that had occurred a few months back). The team had just been told that their project "wasn't on management's radar screen." Our team, unfortunately, had continued to work their project without checking in with an important group of **stakeholders**.

Although there may be many people interested in your project, we define a stakeholder as *somebody who can drive a stake through your project.* Throughout your project, ***you*** should keep the views and attitudes of your stakeholders "front and center." For example, when planning your changes, consider where the stakeholders fall on the adoption curve (below).

Consider how to leverage the stakeholders' attitudes. You may start the change with a group of innovators, then, once the change has shown evidence of working, move to the early adopters. Whatever you do, don't start by trying to influence the resistors!



Stakeholder Analysis

Many teams perform a "formal" analysis of their stakeholders (some talk this through; others are willing to commit it to paper!). The Stakeholder Analysis consists of three parts:

1. An assessment of the current "position" of each stakeholder relative to the change and a gap analysis of where they need to be for the change to be successful.

2. An analysis of why stakeholders who have large "gaps" are either against the change (or sometimes, too strongly for the change).

3. A plan to identify influence strategies to help close the stakeholder "gaps."

1. Stakeholder Assessment

Identify each important stakeholder. Discuss and note where they fall on the assessment matrix, using an "X" (below). Determine where the stakeholders should be in order for the change to be successful – note these with an "O."

You may also draw relationships between/among key stakeholders. For example, if stakeholder "A" is strongly against the change, but stakeholder "B" has an influence on "A," then draw a dotted arrow line from "B" to "A."

Stakeholder Assessment

Names	Strongly Against	Moderately Against	Neutral	Moderately Supportive	Strongly Supportive

2. TPCF Analysis (Technical-Political-Cultural-Financial)

Don't make the mistake of considering stakeholders who resist the change as either the "enemy" or as "dinosaurs." They are behaving rationally in their own minds. Try to understand *why* they are resisting the change.

Sources of resistance usually fall into one of four categories

- Technical (i.e. afraid to learn a new computer system because of potential to fail),
- Political (i.e. afraid since their power or prestige may suffer as a result of the change),
- Cultural (i.e. perhaps the change conflicts with their ethics, or other habits), and
- Financial (i.e. resistive due to the perceived cost of the change vs. perceived benefits).

If you can identify the source of resistance, then you will be in a much better position to identify influence strategies to address these sources.

3. Influence Strategy

Based on the analysis above, identify possible influence strategies to overcome resistance to your change. Use the matrix below to help you plan your actions.

Stakeholder	Issues/ Concerns	Identify "Wins"	Influence Strategy

8.13 CLOSING OUT THE TEAM

Once the team has achieved "victory," the only remaining task is to close out the team. This is usually not difficult, but a few pointers from experience:

Recognize their work and that the project is over - Humans need closure on things. A recognition ceremony can accomplish both. It's a chance to look back on the project, relive the "glory days," and recognize that it's time to face the future.

The ceremony is also a good way to promote the idea that teams can be a good way of accomplishing improvements.

Let them rest on their laurels, *at least a few days* - After a two year, intense project, a team that we led was faced with another arduous project. For about two weeks, though, we let the team members "putter around," cleaning up project files, their offices, and generally getting things in order. Not a lot of "productive" work was accomplished.

But the team needed to take a break, and gather their energy for the next project. There was no way we could have jumped into the next project the day after the first was complete.

Take time to evaluate the project - Every time we go through an improvement project, there's something we recognize that could have gone better. We also think about the things that went particularly well, so we can repeat them in the future when appropriate.

9. EXAMPLES

In this section, we'll show you a few examples of process-focused improvement at work. There are many different paths that improvement can take. We've identified two common categories that we see in our work with teams and improvement projects[28]:

Process-Known - Here, the process that produces the product or service (and the problem or quality issue) is apparent from the start. The process improvement effort starts generally by identifying the production process and then searching for one or more factors that are responsible for the quality "gap."

Process-Unknown - In this category, the product or service is not performing well, but the process responsible is not obvious. Much of the improvement effort is spent just trying to identify the responsible process. Changes are then planned to modify the appropriate *production process.* Equipment failures or other performance problems often fall into this category.

These examples come from a variety of industries. The tools and methods you'll see here apply to just about every industry and organization. Let's put it differently: we haven't found an industry yet that can't make very good use of these methods!!

[28]There is actually a *third* category - complete redesign. In these cases, changing one or two variables doesn't seem to produce the desired results. The entire product/service or its production process is redesigned. These projects tend to be complex and are often addressed by the *Design for Six Sigma* improvement methodology – see your friendly neighborhood Black Belt or Master Black Belt!

9.1 PROCESS-KNOWN EXAMPLES

These case studies are characterized by the “production process” being *known* at the start of the improvement effort. Simply speaking, we knew there was a repetitive problem, *and* we could begin to examine the responsible process immediately. A short summary of each example appears below:

Parking at the Airport - A quality circle-type improvement. A group of airport shuttle drivers determine how to improve the labeling of parking lots at a major airport.

Hiring Process Improvement - Feedback from supervisors indicated that the time to hire new employees was too long. Human Resources department staff work to improve the timeliness of this process.

Gentamicin Administration Process - A neonatologist thinks she’s been observing high gentamicin “trough” levels in newborns. She and a clinical pharmacy specialist work to improve the administration of this antibiotic.

Nuclear Plant Security - The security department at a nuclear power plant works to eliminate safety violations due to their *compensatory post* setup process.

Parking at the Tri-Cities Airport

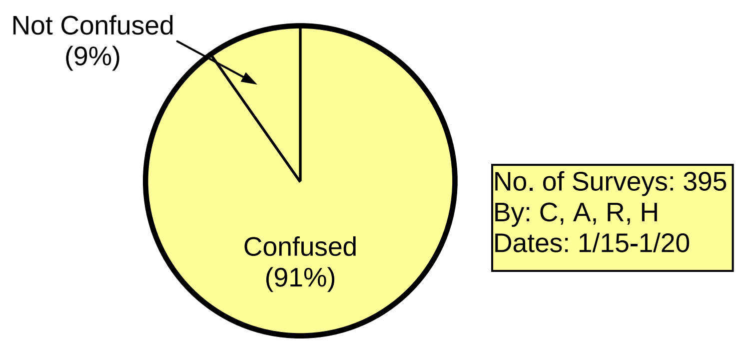
Define Reason for Improvement - Henry, Rich, Anna and Carmen are airport bus drivers who shuttle passengers back and forth from the terminal to the long-term parking lots. They see each other before and after each shift and talk on the radio to each other during the shift.

Since the new parking lot was constructed a few months ago, they have received a lot of complaints from passengers about the confusion in the parking lot names. The two lots on the south side of the airport terminal are called "Remote" and "Satellite," the north side lot is called "Overflow."

Although the passengers know "physically" where they left their cars, two shuttles go to the south side lots and the other two shuttles go to the north side lot. Passengers were saying that they couldn't remember which lot was which and which shuttle to take.

The drivers told the shuttle supervisor they'd like to work on improving this problem. He agreed and suggested that they collect some data to make sure that there really was a problem first. The team designed a simple survey card asking, *"Are you confused about which shuttle to take to long-term parking lots here at Tri-Cities Airport?"* and recorded the following data from returning passengers:

Passenger Survey - Confusion over Shuttle to Parking Lot
Tri-Cities Airport

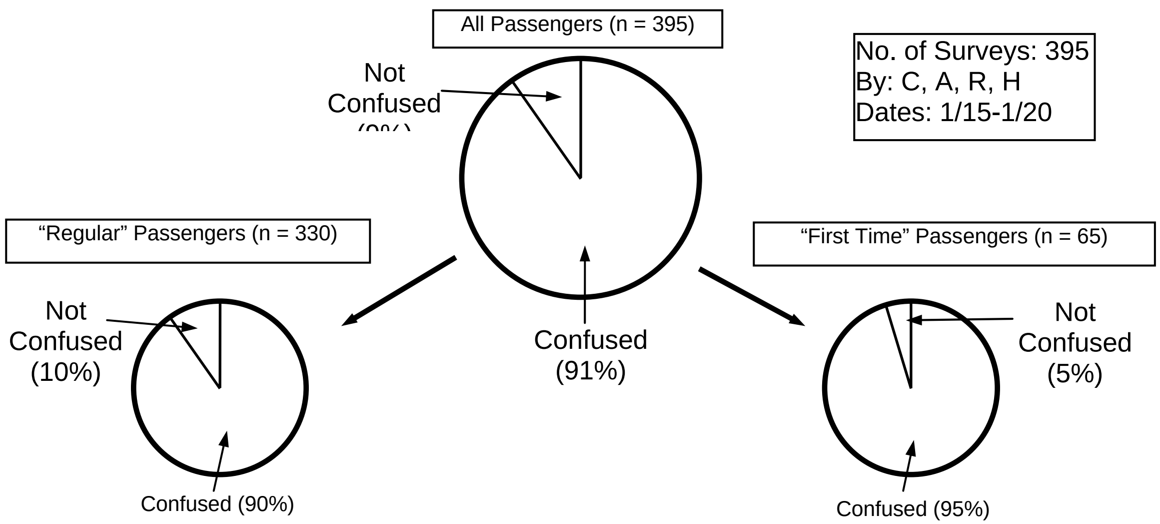


This data confirmed for them the need to work on this problem. They generated their theme statement:

"*Reduce shuttle/parking lot confusion for the airport passengers returning to Tri-Cities Airport."*

Measure the Current Situation - As part of their survey, they also determined whether the problem was unique to "first-time" passengers, or included "regular" passengers. On the survey card, they had included a check box for each of these categories. The stratified data appears below:

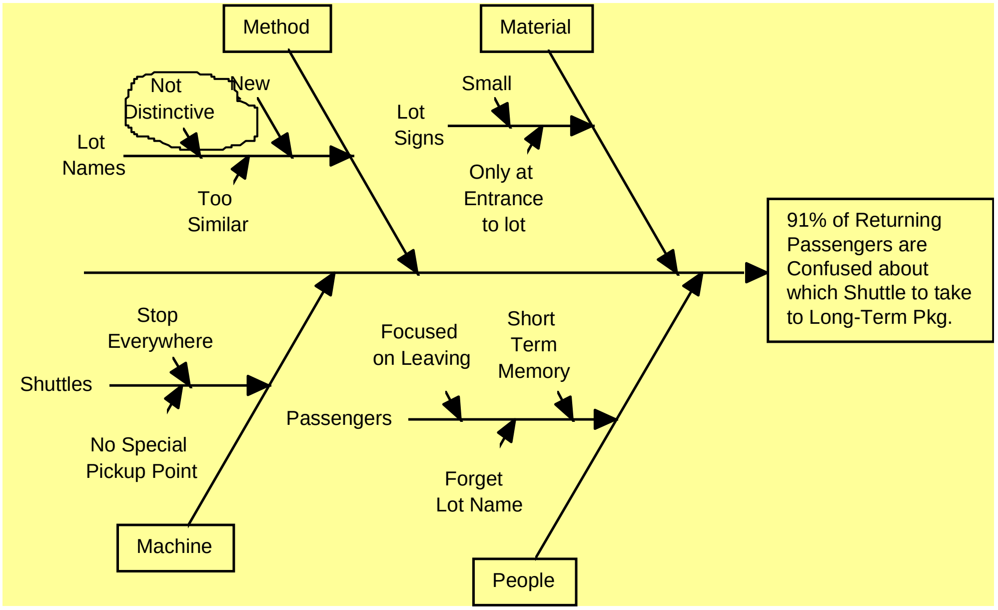
Stratification - Confusion over Shuttle to Parking Lot
Tri-Cities Airport



From this, the team concluded that there was really no difference in the type of passenger when it came to being confused. They generated their problem statement:

> *Ninety-one percent of Tri-Cities Airport returning passengers are confused about which shuttle to take to the long-term parking lots.*

Analyze the Process - The team then developed a Cause and Effect diagram to determine possible causes of this confusion. They used the "generic" categories of *method, machine, material* and *people* as major cause categories and then brainstormed the possible causes over their shuttle bus radios during one shift. Carmen took the ideas and prepared the Cause and Effect diagram:



The team "verified" the root cause by asking passengers why they were confused about which shuttle to take.

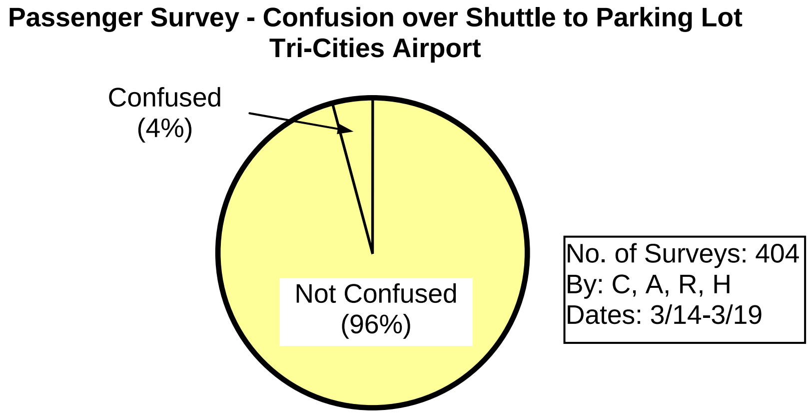
Identify and Evaluate the Countermeasures - After their shift one night, the team brainstormed how they could address the root causes. They came up with three ideas and then evaluated them for cost, benefit and feasibility:

Root Cause/Countermeasure Matrix

Root Cause	Countermeasures	Benefit	Cost	Feasibility	Total
Long Term Parking Lot Names not Distinctive	Provide Maps to Departing Passengers	3	2	4	24
	Change Parking Lot Names - Color Code	5	3	4	**60**
	Have Shuttle Buses go to all Long-Term Parking Lots	3	2	3	18

They presented their analysis to management, who approved the change after a few questions. The team then met with airport maintenance to plan the change. The lots were to be named ***Yellow, Green*** and ***Red***. An action plan was developed to create the new parking lot signs, shuttle bus signs and to paint posts, fences and other areas of the lots the new color. The team reasoned that it would be easy for the passengers to remember the color of the parking lot where they left their car.

Check the Results - The action plan was implemented and, following a week or so, the team again surveyed returning passengers to determine their reactions to the new parking lot names. The following results were obtained:



The drivers were proud of their results. The situation had been completely turned around.

Control the Process/Standardize the Improvement - After congratulating the team on their good work, airport management asked why the confusing names had been allowed to be used in the first place. The airport planning department said that the reason was because of the incremental growth of the parking needs; each time a new lot was added, nobody thought to look at the "big picture." Since the airport was continuing an expansion effort, their design checklist now included an "existing facilities name review."

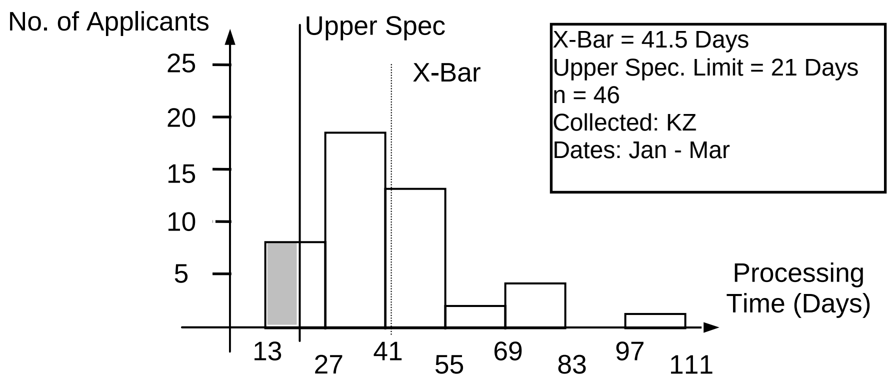
Plan the Next Steps - The team evaluated their improvement effort. They were pleased with the amount of time it took (about two months) to complete the PDCA cycle. Their use of the radio to conduct "team meetings" was beneficial and did not seem to disrupt normal operations. They started talking about their next improvement project.

Hiring Process Improvement

Define Reason for Improvement **-** The Human Resources (HR) department of a large multi-store grocery chain surveyed the managers of the stores to see what their opportunities to improve might be. The number one problem of the managers was the time required to hire an entry level employee.

The HR department researched their recent files and developed a histogram of the employment processing time:

Overall Employment Processing Time



The boundaries of the employment process time measured **start** with the *notification of the opening* and **end** with the *date an offer is extended.* The "Upper Specification Limit" of 21 days was obtained from discussions with managers. They would like to be able to offer an applicant a job within three weeks of the opening.

The shaded area of the histogram shows that very few of the employees were being hired within the desired time - clearly there is a need to improve this service.

The HR department manager formed a team to work on improving this process. They developed the theme:

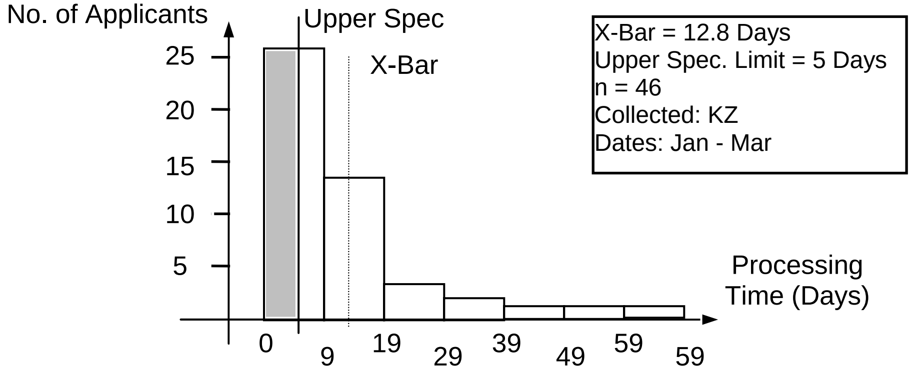
To reduce the Entry-Level Employment Processing Time.

Measure the Current Situation - Their first step was to understand where the delays were in the hiring process. They broke the process down into three major segments and, using the same data as above, determined the time required to complete these segments:

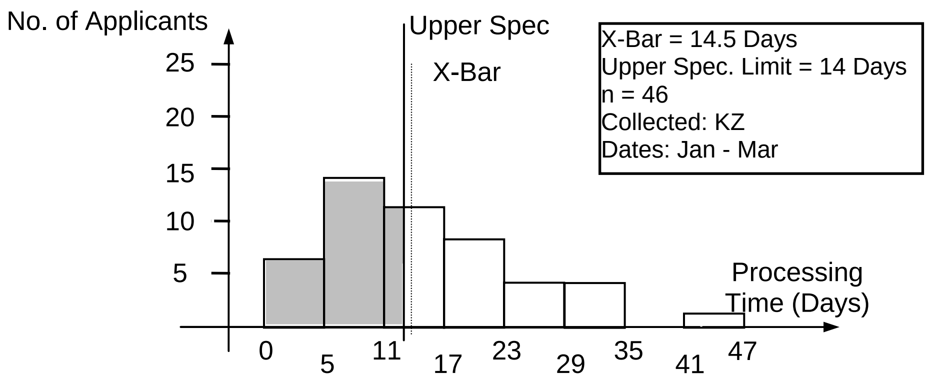
Process Segment

Segment Time Histograms

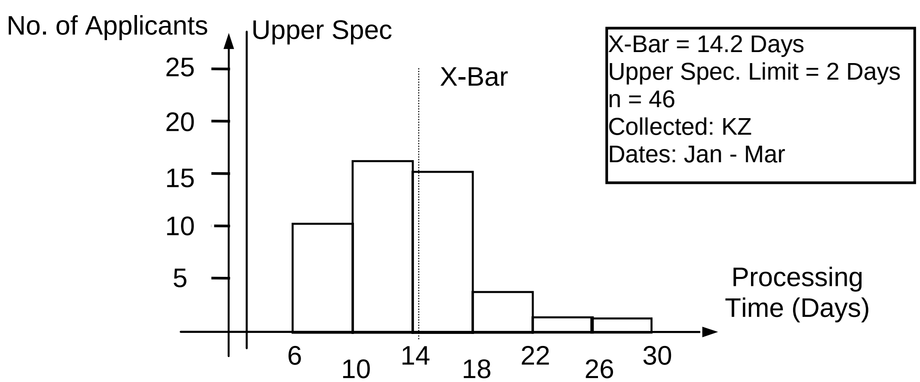
(P1) - *Supv. notifies Human Resources of a job opening to HR refers Applicant(s) to Supervisor*



(P2) - *HR refers Applicant(s) to* Supervisor to *Supervisor selects job candidate*



(P3) - *Supervisor Selects job candidate* to *Job offer extended by Human Resources to candidate*



There are significant delays in the first and second segments. On average, the second segment is OK and, since this time segment is controlled by the store supervisors, the HR team decided to focus on segments P1 and P3.

Analyze the Process **-** The team developed detailed flowcharts of the P1 and P3 process segments. They analyzed each of these segments for delays and wasted/non-value added steps. The results of their analysis are summarized below:

Segment P1 - Notification of Opening to HR Referral of Applicant(s) - When a notification was received, applicants "on-file" were called and scheduled for a pre-employment screening test. This test was given only once a week and introduced up to a seven day delay in this segment.

Segment P3 - Supervisor Selects Job Candidate to Job Offer Extended by Human Resources - After a candidate was selected, HR began the pre-employment processing. The candidates' driving record, past employer references and criminal/worker's comp checks were ordered. After these were cleared, the pre-employment physical was scheduled, and an offer was not made until after the physical's results were in. This contributed to about 9 days of "wait" time.

Identify and Evaluate the Countermeasures **-** The HR department staff identified two countermeasures, one for each segment:

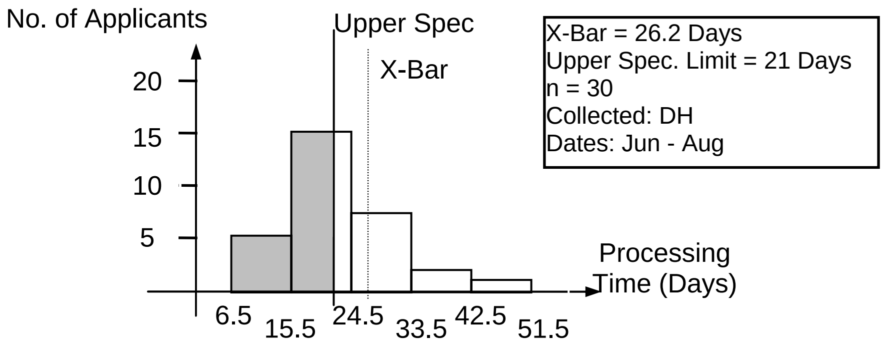
Segment	Countermeasure	Practical Method
P1	Create an "active" pool of applicants (Projected Savings = 6 days)	When applicants submit job application, HR reviews for appropriateness and "pre-qualifies" by scheduling pre-employment test and conducting personnel interview.
P3	Eliminate pre-employment physical wait time (Projected Savings = 10 days)	Schedule pre-employment physical at same time pre-employment processing begins.

Both countermeasures involved some increased cost; since the pre-employment tests were conducted on a larger number of "potential" applicants and the pre-employment physical would be "wasted" if the records checks didn't "pan out." Management approved both these changes, though, because the increased cost would be compensated for by the reduced processing time for the stores.

The HR team developed and implemented an action plan to incorporate these changes on a "trial" basis to their process. They collected data on the next 30 job notifications.

Check the Results - The overall results are shown below:

Overall Employment Processing Time



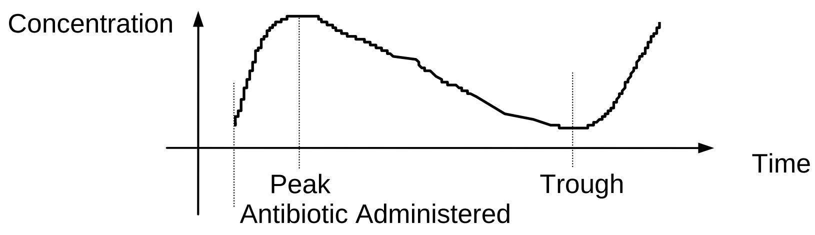
Human Resources conducted a telephone survey of supervisors who had hired employees during this time frame. The supervisors were all surprised that their job postings were being filled much quicker than before.

Standardize the Improvement - The changes to the process were incorporated into Human Resources' *Quality in Daily Work* process control system for this responsibility.

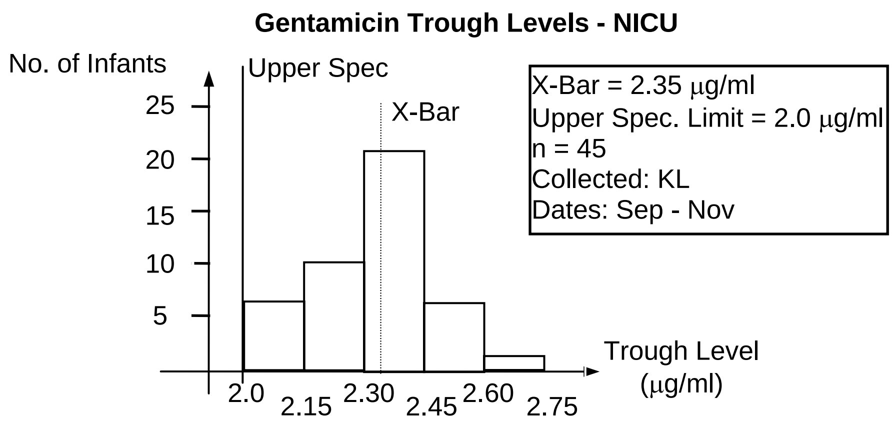
Plan the Next Steps - The team put data monitors in place for segments P1 and P3. They were also going to try and reduce the *variation* in the process segments and determine if there was anything HR could do to reduce the time associated with segment P2.

Gentamicin Administration Process

Define Reason for Improvement - A neonatologist at a large hospital has observed that several infants in the Neonatal Intensive Care Unit (NICU) had high "trough" levels of the antibiotic gentamicin. The "trough" level is the lowest observed level of a drug during the administration cycle:



If the trough levels of this antibiotic are too high (> 2.0 micrograms/milliliter (μg/ml)), kidney and ear problems can result in the newborn infants. The neonatologist asked a clinical pharmacy specialist to look into this potential problem. The specialist reviewed medical records for the past 45 infants in the NICU who were administered gentamicin. She plotted the data on a histogram:



The histogram confirmed that there is a problem in the administration process. The neonatologist and pharmacy specialist then began to work on understanding what was going on.

Measure & Observe the Current Situation - First, they checked to see if the gentamicin protocol was being followed and that there were no errors in the laboratory measurements of gentamicin levels in the infants. These both checked out OK.

The pharmacy specialist noted, though, a recent change in *when* the lab specimens were drawn. Previously, the specimen was scheduled after the *seventh* dose of the antibiotic. Now, specimens were drawn after the *third* dose. The specialist thought this to be significant, since many gentamicin prescriptions were discontinued before the seventh dose. She mentioned to the neonatologist that this might be why the high trough levels were not identified previously - no lab specimen was obtained.

Analyze the Process - With the background work done in the *Measure* step, there was only one hypothesis to investigate:

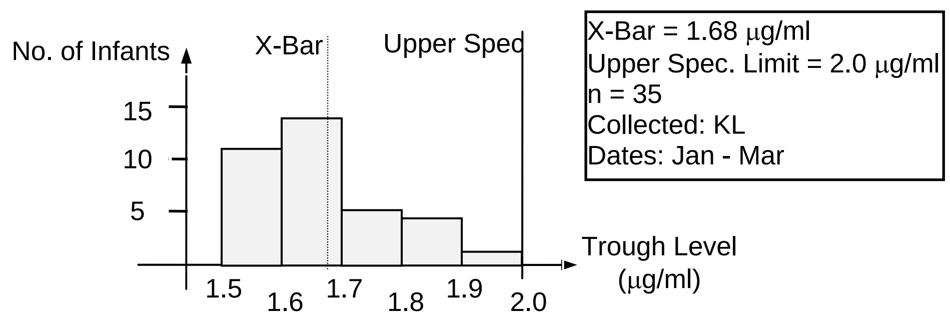
The gentamicin doses are given too frequently.

The pharmacy specialist performed the pharmacokinetic calculations for this drug and *verified* that, instead of administering the drug every 12 hours, it should be given every 18 hours. The calculations also showed that the required "peak" value for gentamicin would be reached with this dosage.

Identify and Evaluate the Countermeasures - This change was written up and presented to the physician's quality assurance committee and approved for trial implementation.

Check the Results - The next thirty-five infants were monitored for their gentamicin peak and trough levels. Peak levels were all found to be within therapeutic range; the trough levels were plotted on a histogram:

Gentamicin Trough Levels - NICU (After Dosage Change)



The results show that gentamicin administration is now within the therapeutic ranges and that the trough levels are "within spec." All babies are receiving the correct antibiotic dosages.

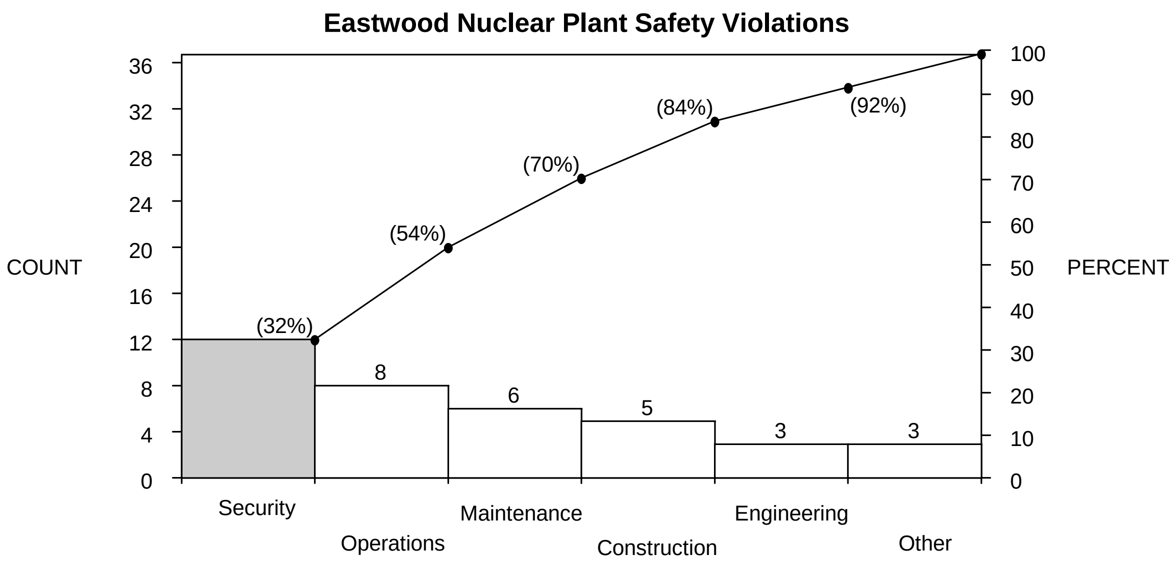
Standardize the Improvement - The neonatologist and pharmacy specialist took the results back to the Clinical Quality Improvement committee and presented their findings. The changes were made a permanent part of the gentamicin protocol.

Plan the Next Steps - Since the “standard” gentamicin dosage recommended in the literature was found to be incorrect, the team decided to write up their results for publication, so that their changes could be considered by other hospitals for replication.

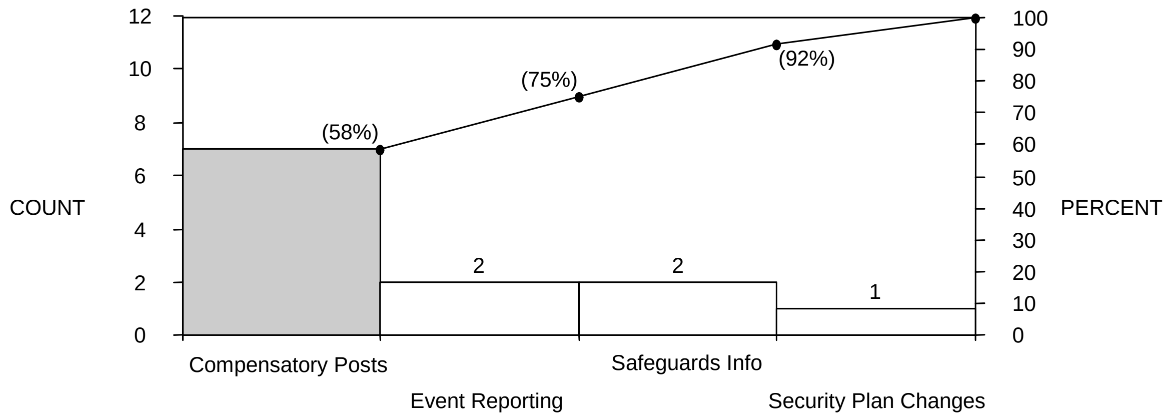
The pharmacy specialist continues to monitor gentamicin levels in newborns, plotting the data on a control chart each month.

Nuclear Plant Security

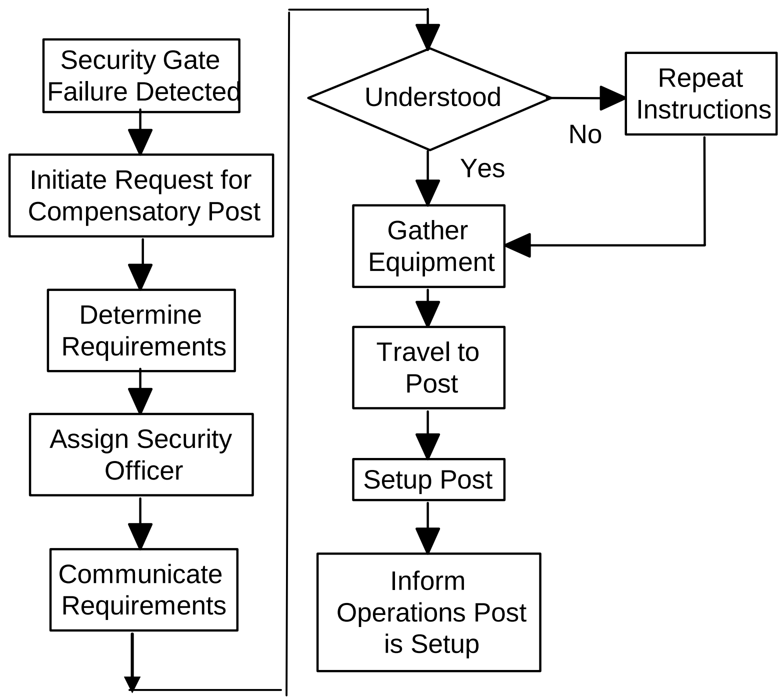
Define Reason for Improvement - Gary has recently been named manager of the security department at the Eastwood Nuclear Plant. Security has been troublesome at the plant. Twelve of 37 safety violations received by the plant in the last 15 months were charged to security:



Measure the Current Situation - Gary first stratifies the violations by type. He realizes that the largest source of security-related violations come from *compensatory posts.* Normally, gates to controlled access areas in the plant are controlled by automatic equipment. When the automatic equipment fails, a security officer is posted at the gate to *compensate* for the failure:



At this point, Gary decides to assemble a group of security supervisors and officers to work on understanding why these compensatory posts are causing problems. They start by reviewing the text of the safety violations and then flowcharting the process of setting a compensatory post. Virtually all of the violations were incurred because the *compensatory posts* were established late, incorrectly, or not at all:



Analyze the Process - Gary suggested to the team that they examine the entire process for possible errors, using an *Error Modes and Effects Analysis (EMEA).* They generated an initial EMEA in one meeting and then added to it during the week as they received requests for compensatory posts (next page)

Execute the Countermeasures - The security team took the actions identified on the EMEA and developed an action plan. They revised the process flowchart, created the security post checklist and trial implemented the countermeasures. They also collected data on the number of compensatory post errors detected at the field verification of the post and other process errors identified by the EMEA.

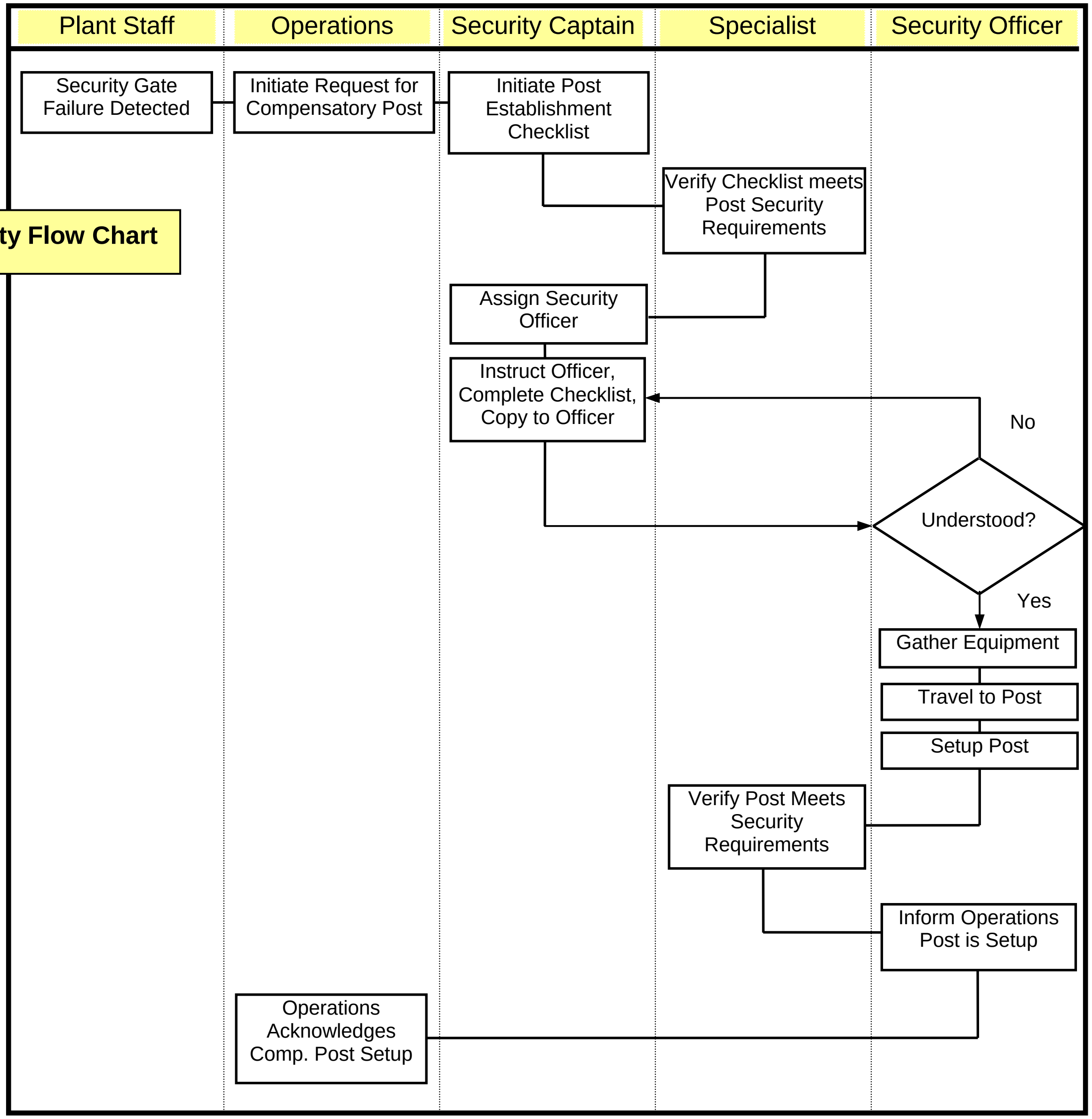
Check the Results - After six months, the team reconvened to examine the overall effects of their changes. During the six month trial, no errors occurred in setting up the posts and all posts were setup within the required time frame. Also, several safety inspections by the Nuclear Regulatory Commission site inspector did not identify any safety violations in the compensatory posts, despite increased surveillance by the inspectors in this area.

Standardize the Improvement - The revised process flowchart was used as the standard for future compensatory post requests. All security personnel were instructed in the revised process. The new process was also incorporated into the security training program:

Plan the Next Steps - Next, Gary and the team began discussions with the maintenance department to discover the causes of security gate failures, in an attempt to reduce the need for compensatory posts.

Error Modes and Effects Analysis - Compensatory Post Setup				
Process Step	**Potential Error**	**Effect of Error**	**Cause of Error**	**Action**
Security Gate Failure Detected	- Gate not detected - Wrong Gate reported	Gates fail closed, operators can't access area	- Low staff volume thru area - Unfamiliar with plant areas	None
Initiate Request for Comp. Post	- Delayed - Wrong Gate requested	Post not setup within time limits	- Staff unfamiliar with security process	None - signs in place at all gates already
Determine Requirements	- Wrong Post Classification	Wrong instructions provided to Security Officer	- Did not understand information	Develop Req'ments Checklist, Security Specialist approves completed chklist
Assign Security Officer	- Delayed	Post not setup within time requirements	- Security Officers on other duties	Include Time Requested on Checklist, develop work priority list
Communicate Requirements	- Requirements Misunderstood	Wrong equipment selected, travel to wrong gate	- Too much information to communicate verbally	Develop Req'ments Checklist
Gather Equipment	- Wrong Equipment	Can't setup post, have to return to security offices	- Forgot what was needed	Develop Req'ments Checklist
Travel to Post	- Delayed - Travel to wrong post	Post not setup within time requirements	- Distractions - Staff unfamiliar with plant area	Include plant map on back of checklist
Setup Post	- Delayed - Wrong Setup	Post not setup within time requirements	- Distractions - Forgot requirements	Field Verify Comp. Post, use Checklist
Inform Ops Post is Setup	- Operations not informed	Ops calls security	- Forget to call	Include on Checklist

Revised Security Flow Chart



9.2 PROCESS-UNKNOWN EXAMPLES

These case studies are characterized by the “production process” being *unknown* at the start of the improvement effort. The problems were occurring, but the teams had to “play detective” to discover the “guilty” process. A short summary of each example appears below:

Control Oil Trips - A nuclear power plant had experienced several automatic shutdowns due to problems in the turbine control system. A team of Instrumentation and Control technicians work to discover the causes and prevent future shutdowns.

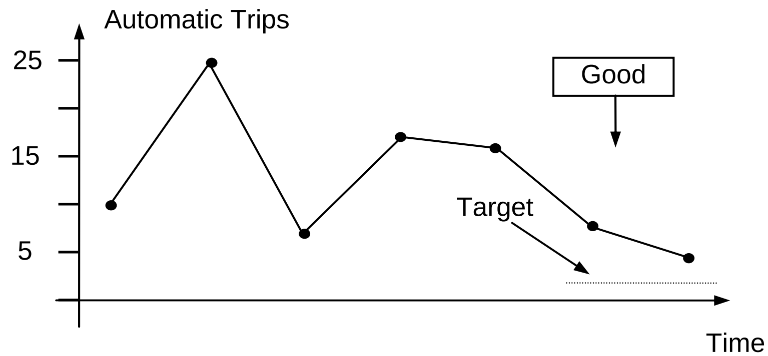
EDG Fuel Oil Unavailability - Two emergency diesel generators (EDGs) at a nuclear plant experienced significant unavailability due to problems with the fuel oil system. A system engineer works to discover the causes of these reliability problems.

Environmental Nonconformances - A large oil refinery has experienced too many environmental violations. A team of refinery personnel work to improve compliance with environmental regulations by reducing the number of environmental *nonconformances* due to late asbestos removal notifications.

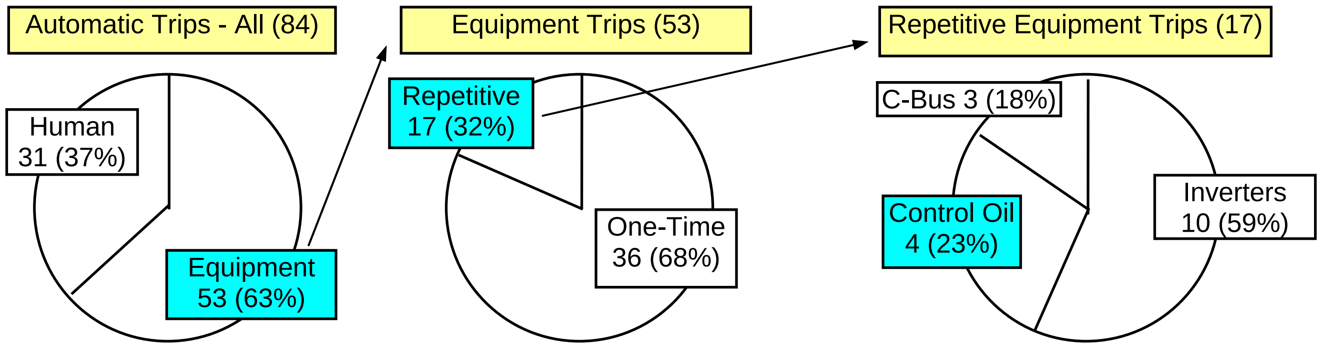
Control Oil Trips

Define Reason for Improvement - A nuclear plant began a program aimed at reducing the number of automatic reactor trips or plant shutdowns. A reactor trip is undesirable since it places demands on the plant safety systems in order to achieve "safe shutdown." The trip also challenges the utility's ability to supply electricity to the customer.

The plant's history of reactor trips for the past few years appears below. The last two years' trips are low, since the plant was shutdown much of the time due to design problems with the emergency power system:

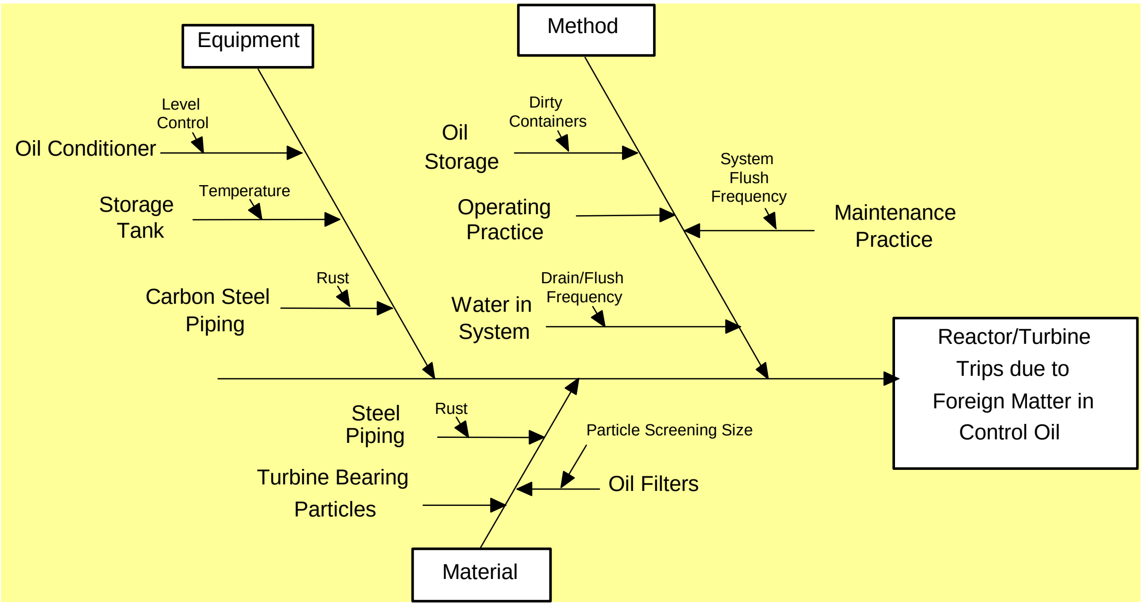


Measure the Current Situation - Plant management stratified the automatic trips and assigned teams to work on understanding their root causes. One of the repetitive trip sources was found to be from problems with the turbine control oil system:



The Instrumentation & Control (I&C) Department was assigned to work on the control oil trips and formed a team to solve this problem.

Analyze the Process - The team first reviewed the maintenance records relating to these trips. They discovered that the primary contributor to *all* control oil-related trips was *foreign matter in the control oil.* They studied the control oil system and its operation & maintenance. The following cause and effect diagram was prepared:



The team then investigated the potential root causes through a *Root Cause Evaluation Matrix:*

Potential Root Cause	**Verification Method**	**Impact on Effect**	**Evaluation/ Action**
Oil Storage/Dirty Containers	Observation	Medium	Examined storage drums Reviewed oil transfer procedure - OK
Operating Practice	Reviewed Procedures	Low	Revised procedure OP8570.1 - OK
Drain/Flush Frequency	Maintenance Records	High	Institute periodic drain/flush (refuelings)
Oil Level Control	Vendor Manuals/ Turbine Log Sheets	High	Reduced system efficiency, possible turbine damage
Storage Tank Temperature	Reviewed Transfer Procedure	Low	Xfer Procedure ensures clean transfers - OK
Rust in Steel Piping	Chemistry Analysis	High	Addressed thru system flush, improved filters
Turbine Bearing Particles	Chemistry Analysis	High	Addressed thru system flush, improved filters
Oil Filters not screening fine particulate	Chemistry Analysis	High	Particulate clogs control orifices, need finer particulate screening

Three root causes were determined to be the causes of the automatic trips. The team presented their findings to plant management and then began to select countermeasures for these causes.

Identify & Evaluate Countermeasures **-** The team then identified practical methods of addressing these root causes. One method required a design change to the oil level control system; this was submitted to engineering to work up as a plant design change. The remaining actions were the responsibility of the plant and they developed an action plan to implement their countermeasures:

Problem	Root Cause	Countermeasure	Practical Method
Foreign Matter in Turbine Control Oil Caused 4 Turbine/ Reactor Trips	Inadequate Filters	Install Upgraded Filters	Procure Filters, Schedule and Perform Maintenance
	Improper Oil Level Control	Install Automatic Oil Level Control	Request & Install Design Change
	Drain/Flush Frequency	Periodic Oil System Drain & Flush	Develop Maintenance Procedure, Schedule and Perform Drain & Flush

Check the Results **-** In this case, it took some time to see results. The filters were procured and installed during a “short notice outage.” The engineering department had a long backlog of design changes, so the automatic oil level control system wasn’t installed until the next refueling outage a year later. After these changes were implemented, no further control oil trips were experienced.

Standardize the Improvement **-** The revised oil filter specifications were incorporated into plant procedures. The maintenance department also developed a turbine oil sampling procedure to monitor the condition of the oil and efficiency of the filters.

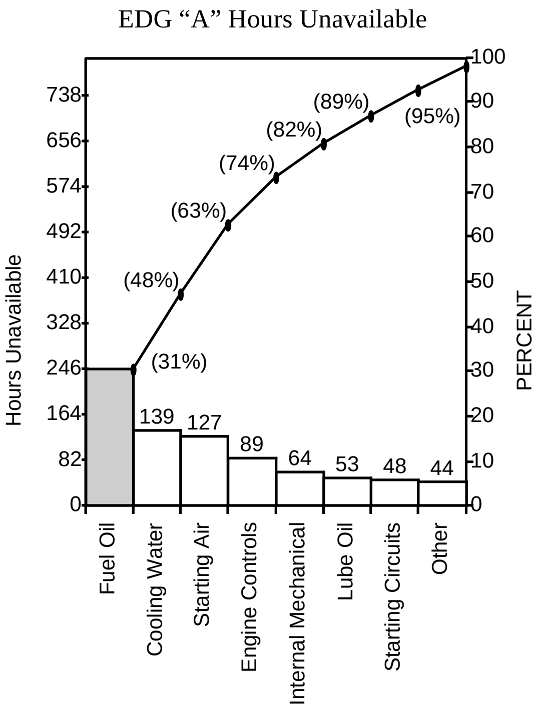
Plan the Next Steps **-** The team had come to understand the “intricacies” of the turbine control system during this effort. They decided to tackle some of the “one-time” automatic trips that involved the turbine control system.

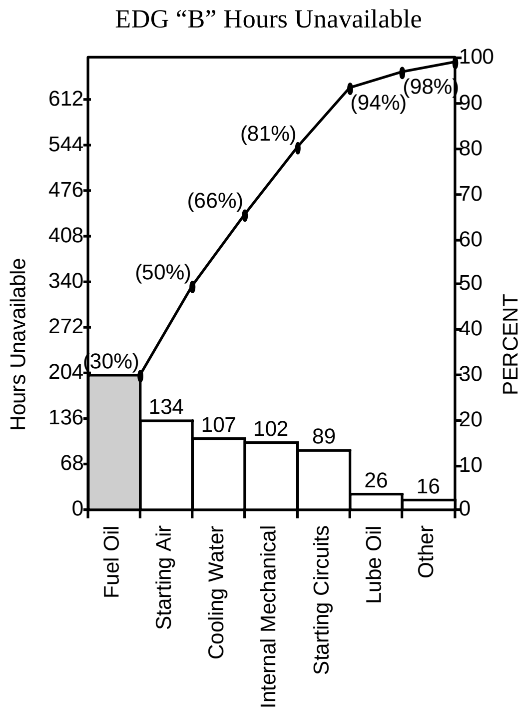
EDG Fuel Oil Unavailability

Define Reason for Improvement - All nuclear plants must have Emergency Diesel Generators (EDGs) to provide backup electric power for safety systems in case the normal power supply fails. As an older plant, the Anhinga Point Nuclear Plant was equipped with only two EDGs for two nuclear units. Reliability and availability of these EDGs is critical to plant safety.

A system engineer, Kathy Gilmore, was recently assigned responsibility for these machines by plant management, since their reliability history had not been very good. Kathy began by studying the unavailability history of the A and B EDGs, whom she nicknamed “Arnold” and “Brad.”

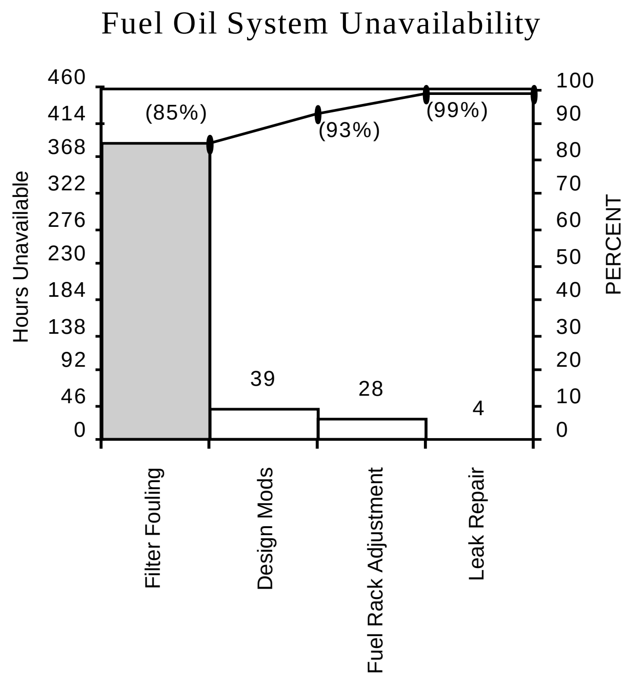
Measure the Current Situation - Kathy’s review led her to develop the following Pareto Charts for the EDGs. These covered the last fifteen months of plant operation:





Fuel Oil Problems were the biggest bar on her Pareto’s, so she chose to tackle these first. Since the EDGs were identical in design, she combined both fuel oil unavailability contributions stratified this data to discover why the fuel oil system was causing unavailability problems. The following “second” level Pareto shows the results of this study:

This Pareto clarified that Kathy needed to focus on fuel oil filter fouling to improve fuel oil system availability.



Analyze the Process - Kathy studied the fuel system, its operation and maintenance. With the help of some of the plant mechanics, she developed a cause and effect diagram for the filter fouling problem (see next page).

There were several root causes of the problem. Design, operation and maintenance issues plagued the fuel oil system.

Verification Activities - Kathy verified the causes as described below:

Fuel Oil Tank Cleanliness, Growth of Algae, etc. - The Main Fuel Oil Tank was sampled and determined to have a high level of algae. The southern location of the plant made rapid growth of the algae possible.

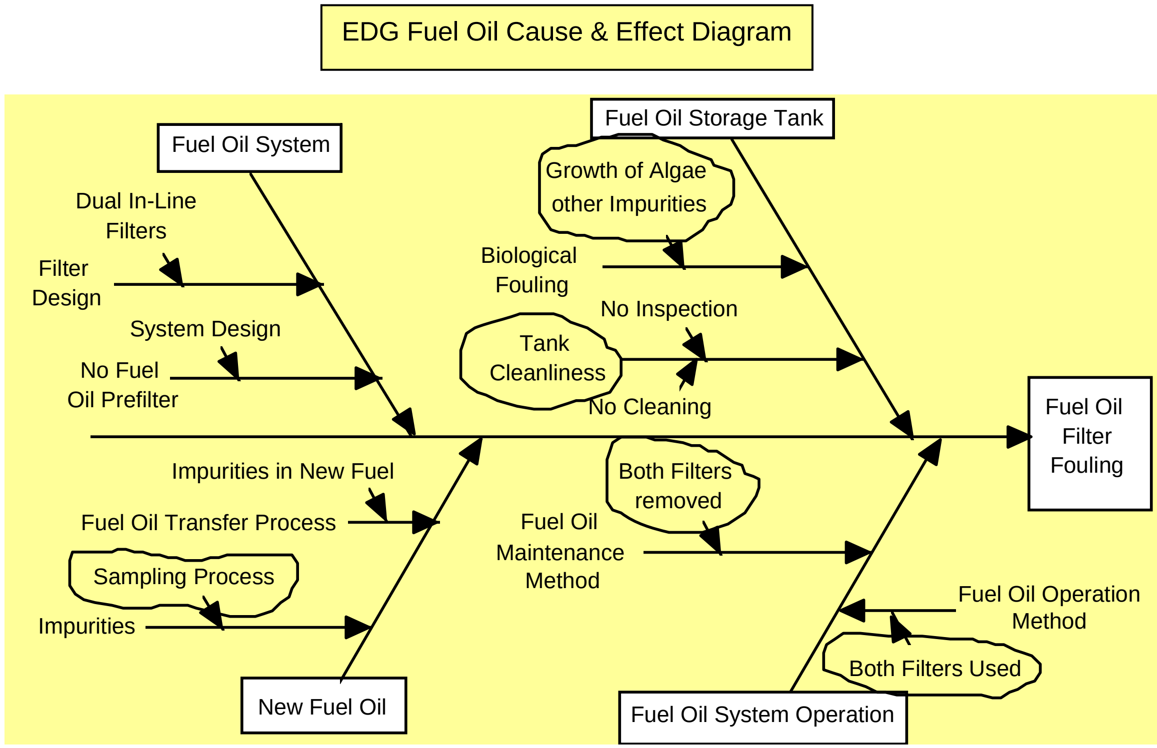
New Fuel Oil Sampling Process - New fuel oil was being pumped directly from the delivery truck into the fuel oil tank without sampling. Impurities in the new fuel oil were transferred directly to the tank.

Both Filters Used during Operation - The dual, in-line filters were both used during diesel operation. They fouled at the same rate.

Both Filters removed during Maintenance - Both filters were removed when they clogged. This necessitated declaring the EDG “out-of-service.”

Select and Implement the Countermeasures - Kathy developed countermeasures for the most important root causes identified:

Problem	Root Cause	Countermeasures
Fuel Oil Filter Fouling causes EDG Unavail.	Fuel Oil Tank Cleanliness, Growth of Algae, etc.	Develop Tank Sampling and Analysis Procedure. Purchase algae inhibiting chemical additives.
	New Fuel Oil Sampling Process	Develop Truck Sampling Procedure and criteria for rejecting new fuel oil with high impurity levels.
	Both Filters Used during Operation	Design is redundant. Use only one filter at a time. Change Operating Procedures.
	Both Filters removed during Maintenance	Replace one filter at a time; new operation method results in only one fouled filter at a time. Change Maintenance Procedures.



Kathy presented the countermeasures to plant management and obtained their approval to implement the countermeasures. She worked with Maintenance and Operations to develop and implement the new procedures. Plant Engineering and Purchasing revised the new fuel oil specifications and they discussed the new requirements with the fuel oil vendor.

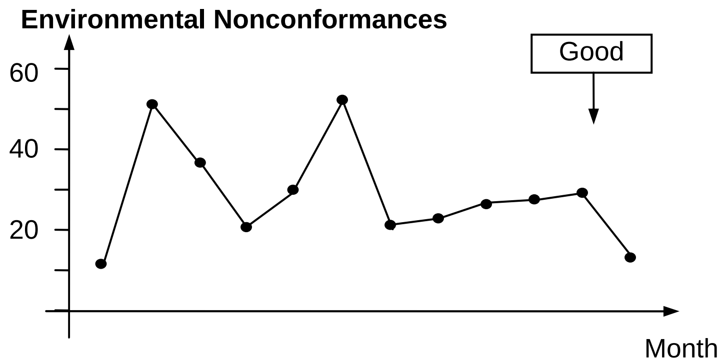
Check the Results - During the six months following the countermeasure implementation, the fuel oil system was unavailable for only 32 hours. This was equivalent to one month's unavailability prior to the countermeasures.

Standardize the Improvement - Plant procedures had been revised, so standardization was already complete.

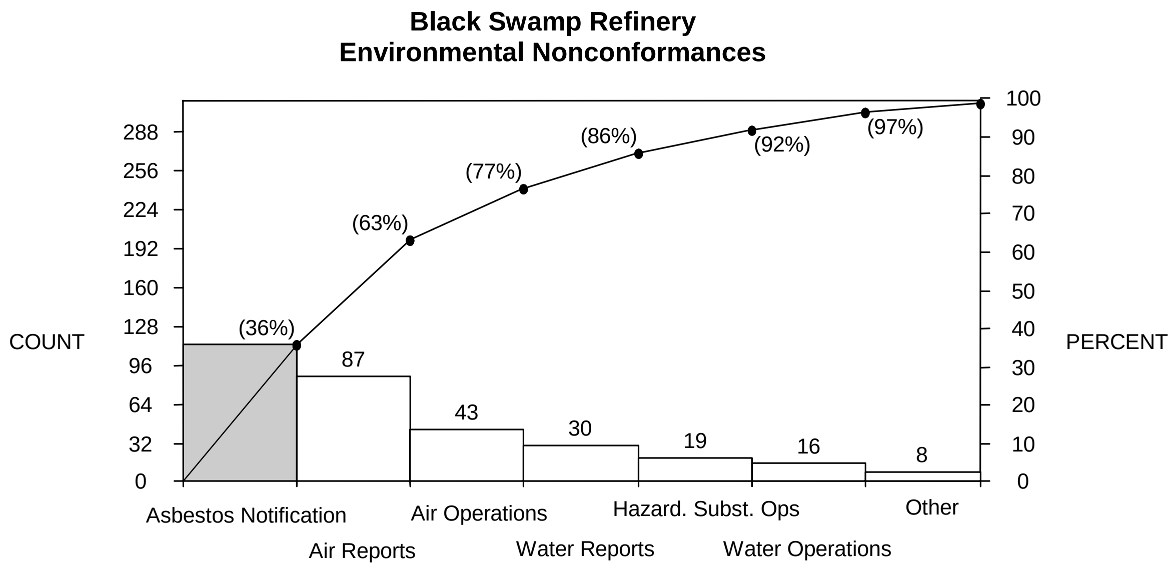
Plan the Next Steps - While the countermeasures were being implemented, Kathy then began to work on the next major sources of EDG unavailability: *Cooling Water System* problems for "Arnold" and *Starting Air System* problems for "Brad."

Environmental Non-Conformances

Define Reason for Improvement - The Black Swamp oil refinery had received a number of environmental violations from the Environmental Protection Agency and other state agencies. In response, management identified improvement in this area as a key strategic focus for the refinery. The Environmental Affairs (EA) department developed a graph showing all the environmental nonconformances identified in the refinery's operations for the last year:



Measure the Current Situation - The EA department then stratified the nonconformances by type:

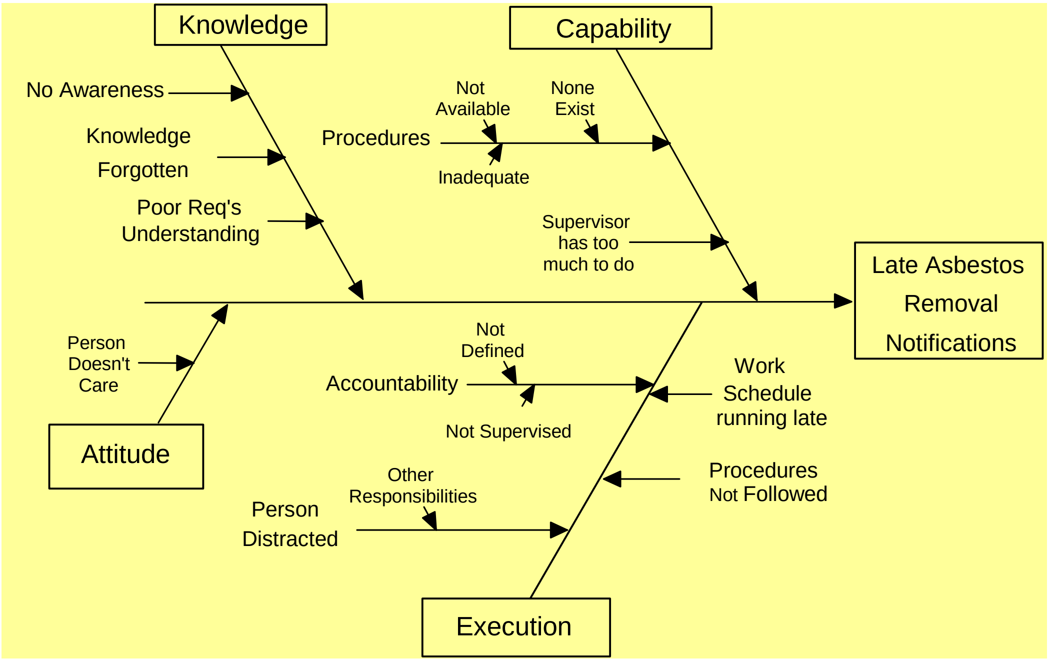


Late Asbestos Notifications were the number one category of non-conformances. These occur when asbestos has been identified in an area (by construction or maintenance) and management is not notified at all or within a certain time frame. Normally, when notification occurs, an asbestos team is called to safely remove the asbestos. If this doesn't occur, continued work in the area could risk workers to exposure to asbestos fibers.

Based on this information, management formed a cross-functional team composed of EA department and maintenance/construction department personnel. Their theme read:

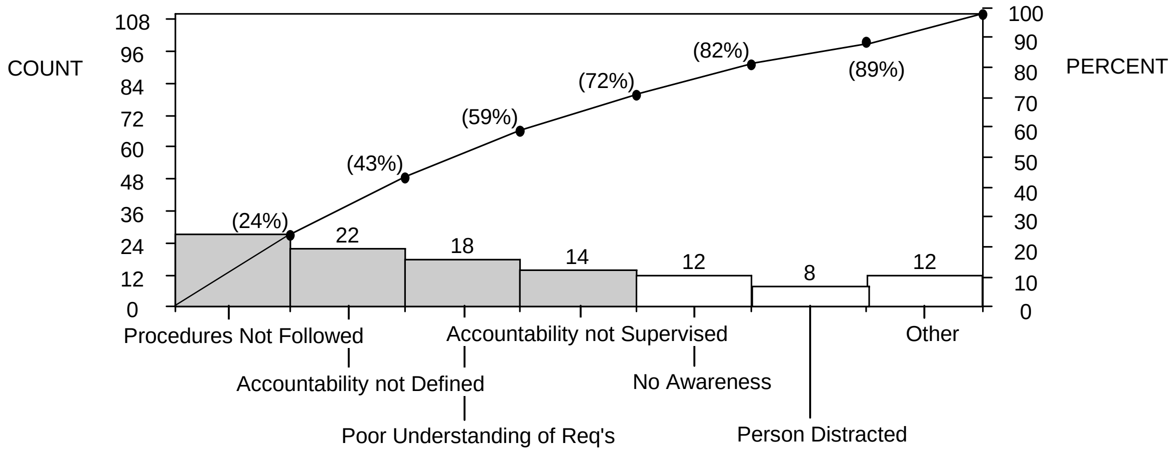
Reduce the number of late asbestos notifications by at least 50%.

Analyze the Process - The team then brainstormed possible causes of late asbestos notification:



They reviewed the non-conformance reports to determine which of these potential causes occurred most frequently. The Pareto Chart below shows the results of their *verification* effort:

Late Asbestos Notifications - Pareto of Causes



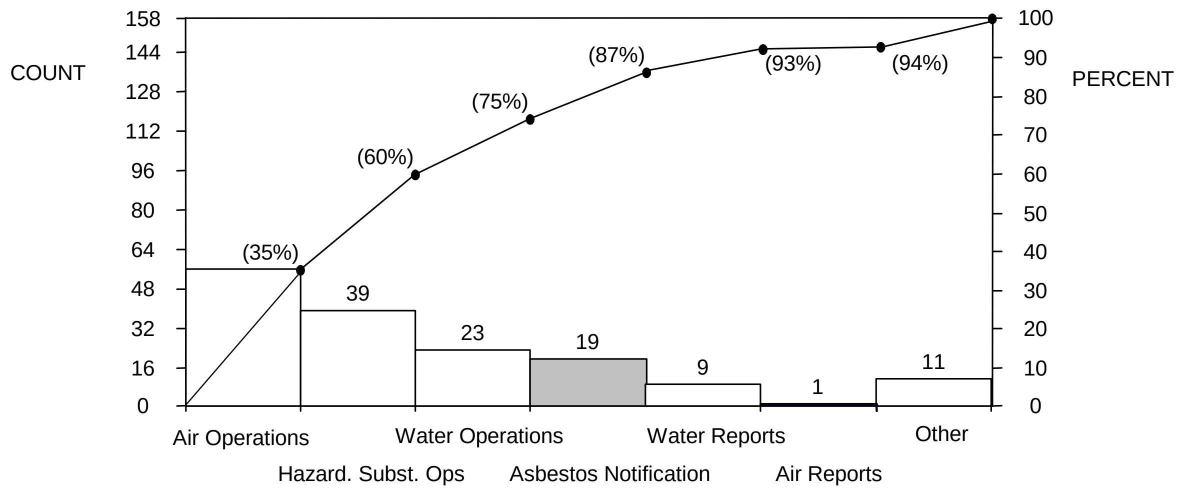
Four major causes contributed to 72% of the nonconformances. These were examined for possible countermeasures:

Identify & Evaluate Countermeasures - The team worked to identify practical methods of preventing these nonconformances:

Root Cause/Countermeasure Matrix

Problem	Root Cause	Countermeasure	Status
Late notification of asbestos	Procedures Not Followed	Establish Process Control System for Notification Process	To be Developed by 3/30
	Accountability Not Defined	Provide for Consistency in Assignments	Working to implement by 6/30
		Improve Accountability Description	To be implm'ted by 6/30
		Establish Process Control System for Notification Process	To be Developed by 3/30
	Poor Understanding of Requirements	Provide Training in Notification Requirements	Completed for current crews
		Clarify Requirements	Working to implement by 6/30
		Establish Process Control System for Notification Process	To be Developed by 3/30
	Accountability not Supervised	Discuss Problem with Maint/Constr.	Completed
		Establish Process Control System for Notification Process	To be Developed by 3/30

Check the Results - After implementing the countermeasures, the team monitored the reduction in asbestos nonconformances. The next year's Pareto Chart appears below:



The team had exceeded their goal of reducing the *asbestos notification* nonconformances by 50% (*Before* - 113, *After* – 19 – this category has also moved to the "Trivial Many").

Standardize the Improvement - The team standardized their improvement by ensuring that the process control system was incorporated into the construction and maintenance department procedures and that all new construction & maintenance supervisors were trained in the procedures.

Plan the Next Steps - Asbestos notifications are still the "big bar" on the Pareto of environmental nonconformances. The team planned to return to their cause and effect analysis and research additional problems with the process.

10. EXERCISES

Here are some exercises to help you practice the tools and techniques presented in this manual. Since one purpose of this manual is to support training in quality improvement methods, the exercises have been grouped by manual section.

Since each of these tools is a "sentence" or "paragraph" that is part of a quality improvement "story," we've tried to give you the context for use of the tool (i.e. why would a team or individual choose to use this tool *here*).

As you work through these exercises, try to think about the conclusions you might reach from the information. What would your next steps be if you were actually working on the problem?

Answers to odd-numbered questions appear in Appendix A.[29]

[29] Just kidding, they're *all* there! At least the ones we can answer.

10.1 IMPROVEMENT METHODS

1. Identify at least three “improvements” (not just problems solved) you’ve made or worked on. Using either the PDCA cycle or the steps of the improvement model, create a brief “story” of these improvements. Do your improvements “map” to these steps? What did you do differently? Was there an “analysis” step, or did you “jump to solution? (Note that this is not *always bad!*)

2. Take one or more of your current New Year’s resolutions and consider it as a process improvement effort. Is it losing weight, exercising, spending more time with the kids or your “significant other?” Think through how you would improve this “process.” Create a brief Storybook that shows how this resolution *could* result in personal improvement. Then do it!

3. Identify at least three problems your organization (this could be a department, plant, division, or entire company) currently faces. Clarify the reason for improvement for these problems. What data exists that tell you these are important problems?

4. Identify at least three problems your organization has addressed in the past that were *not* solved. Map the attempts your organization made to address these problems into the steps of PDCA or the improvement model. Can you see what went awry?

10.2 MEASURING PERFORMANCE *(Graphs and Charts)*

1. What performance measures does your department track? How are they tracked (i.e. spreadsheet once a month, graph, etc.)? Collect past data (at least 12 points, preferably 25 or more) and plot the data in sequence on a line graph. What does the graph tell you? What targets exist for these measures? How does the data compare to the targets?

2. Identify one product or service "produced" by your department. Who are the customers of this product or service? What is important to them about your product or service (consider the elements of *Quality - quality, cost, delivery, safety, corporate responsibility*)?

How do you know how well your product or service is performing? What data is collected? How is it tracked? What action is taken when the data (or the customer) indicates that the product or service is not doing well?

3. A hospital tracked the average Length of Stay (LOS) for patients receiving coronary bypass operations (with cardiac catheterization - DRG-106). Plot the following data on a line graph and interpret the results. Do you see any evidence of changes (apart from "normal" variation) in the process?

Average LOS/Month

1993		1994		1995	
Month	**Avg. LOS**	**Month**	**Avg. LOS**	**Month**	**Avg. LOS**
JAN	12.7	JAN	18.8	JAN	14.7
FEB	12.7	FEB	14.6	FEB	9.4
MAR	12.0	MAR	22.8	MAR	12.2
APR	16.3	APR	13.7	APR	10.1
MAY	11.2	MAY	12.9	MAY	8.1
JUN	16.2	JUN	12.3	JUN	12.0
JUL	10.0	JUL	14.5	JUL	12.1
AUG	13.4	AUG	12.5	AUG	12.2
SEP	18.1	SEP	18.2	SEP	14.5
OCT	14.9	OCT	14.0	OCT	9.8
NOV	12.2	NOV	10.0	NOV	13.4
DEC	9.5	DEC	11.6	DEC	9.6

4. A cable installation company tracks the number of jobs ordered each week and the number of jobs which cannot be completed the first attempt. Plot the number of jobs which cannot be completed on a line graph. What does this graph tell you?

Plot the fraction of jobs that cannot be completed. Does this graph tell a different story? Why?

Brenthaven Cable Service
Incomplete Job Log

Week	# Jobs/# Incomplete	Week	# Jobs/# Incomplete	Week	# Jobs/# Incomplete
1	52 14	7	11 0	13	73 12
2	192 25	8	23 5	14	5 1
3	171 10	9	30 7	15	67 10
4	137 21	10	7 0	16	81 4
5	80 21	11	12 1	17	18 4
6	195 32	12	34 3	18	91 15

(*Section 4 Topic*) Take the data from the first six weeks and perform a contingency table analysis. Are any of the weeks significantly different? Use 0.1 as the α-risk level.

5. Typically, customer satisfaction survey results are reported on a month-to-month basis. If this month's data is "up," people are happy; if it goes down, they try to figure out why. Here are the monthly average scores from a hotel chain's satisfaction survey, for the question, "*Would you recommend this hotel chain to a friend, family or co-worker?"* Plot the data on a line graph. What do you see? Are there *really* any trends, spikes or dips over which we should be concerned?

Customer Satisfaction Survey Results

Month	Score		Month	Score
JUL	6.25		JUN	6.34
AUG	6.31		JUL	6.21
SEP	6.30		AUG	6.26
OCT	6.21		SEP	6.22
NOV	6.22		OCT	6.25
DEC	6.28		NOV	6.28
JAN	6.33		DEC	6.40
FEB	6.35		JAN	6.28
MAR	6.28		FEB	6.22
APR	6.43		MAR	6.48
MAY	6.44		APR	6.30

6. A cardiac surgery unit implants pacemakers in patients. In the last six months, pacemakers from three manufacturers have failed while in service. As part of their investigation, they identified how many pacemakers were implanted by manufacturer and the number of failures experienced:

Pacemaker Failures

Manufacturer	# Implanted	# Failed
Electrolife	24	7
Heartaid	32	9
LifePulse	9	2

How would you display this data graphically? Do so. Do you think there is a difference in reliability by pacemaker manufacturer?

7. Gathering customer information can be interesting. A day surgery recovery unit had traditionally served post-surgical patients Jell-O if they felt hungry after recovering from surgery (and were allowed to eat!). They conducted a survey of patients to determine *their preferences.* Chart the survey results on a bar graph.

Patient Post-Surgery Food Preferences

Food Type	Frequency
Fruit	2
Jell-O	2
Juice	3
Mashed Potatoes	3
Nothing	2
Salads	5
Soup/Broth	14

8. Integrated Circuits (ICs) for critical medical and military applications are tested when received from the manufacturer. The following data are the number of defectives identified in recent batches of IC's received. Each batch consists of 10,000 ICs. Plot this data on a line graph. Has there been any improvement or degradation in quality?

Incoming Inspection - Defectives/10,000 ICs

Batch	# Defective	Batch	# Defective
1	10	7	11
2	8	8	8
3	14	9	12
4	6	10	13
5	23	11	17
6	15	12	14

9. The following data were obtained from a consumer survey of products and services. Consumers were asked to categorize the products and services according to the "value" they thought they received. Plot the data on a bar chart. What conclusions do you reach?

Product or Service	Percent Saying "Good Value"
Doctor's Fees	34.7
Health Insurance	29.0
Hospital Charges	21.0
Lawyer's Fees	34.7
Poultry	66.4
Videotape Rentals	65.7
Women's Apparel	50.8

10. An operating room schedule improvement team collected data on the time segments that contribute to *room turnover* after the preceding operation and before the next. Plot these time segments on a pie chart.

Operating Room Turnover Sub-Processes
(Average of 25 procedures)

Time Segment	Time (min.)
Clean Operating Room	3.96
Down Time	6.12
Setup	19.6
Patient Wakes	5.64

11. A large engineering firm conducted a survey of employees one year and two years after introduction of their Total Quality Management system. The questions were designed to determine how employees perceived progress made by management in transforming their style and practice of management. Prepare a radar chart and plot both of these survey results on the same chart. What changed from year one to year two? Where is management strongest, weakest in TQM?

Survey Question	**Average Score**	
	Year 1	**Year 2**
1. Company culture supports quality.	6.2	7.5
2. Company uses data in decision-making.	4.0	4.5
3. Quality led by senior management.	6.0	6.5
4. All company employees involved.	3.3	7.5
5. Practices quality principles.	5.2	5.4
6. Teams used to achieve important goals.	5.8	7.8
7. Engages suppliers in improvement.	3.0	3.2
8. Customer input used to support decisions.	4.6	6.5
9. PDCA practiced in daily management.	5.7	5.7
10. Supports quality in community.	4.3	4.4
11. Proactive with regulatory agencies.	8.0	8.2
12. Promotes quality education.	4.5	7.8
13. Quality objectives clearly defined in strategic plan.	5.0	4.2

12. Classify these variables by *type of data (measurement or count).* Don't do them all, pick some that you are familiar with and answer these until you get the idea of the difference between these data types:

Indicator/Variable	**Type (M or C)**
Concentration of a chemical solution	
Frequency of failure of an equipment	
Time to process expense account	
Number of hours an antibiotic is effective	
Percentage of Returns to Surgery	
Salary and Supply Expense	
Number of corroded tubes in a heat exchanger	
Daily fuel consumption of your car	
Dollar variance from budget	
Time to prepare a shift report	

Indicator/Variable	Type (M or C)
Number of employee Slips and Falls	
Number of Medical Record errors	
Dollars in Accounts Receivable	
Days in Accounts Receivable	
Number of linen stock outs	
Amount of linen supplied per day	
Interest Rate for Capital Loans	
Patient Length of Stay (in days)	
Customer Complaints	
Crack Length on aircraft wing structural member	
Customer Satisfaction (1 - 7 Likert Scale)	
Tire Pressure	
Length of wire between utility poles	
Number of thermal cycles for a pressure vessel	
Time between medication administrations	
Time between equipment failures	
Amount of drug administered	
Number of sutures	
Blood Pressure	
Potassium concentration in blood	
Time to process travel request	
Average monthly rainfall	
Barometric Pressure	
Number of copies per minute	
Computer central processor speed	
Computer hard drive memory capacity	
Infant birth weight	
Calories in a chocolate bar (with almonds)	
Percentage of burn area on a fire victim	
Light intensity of a fluorescent lamp	
Battery voltage	
Power output of a diesel engine	
Locomotive axle diameter	
Absorbed radiation (Roentgen Equivalent Man - REM)	
Size of a diamond in an engagement ring (carats)	
Pump flow rate (gallons per minute)	

Indicator/Variable	Type (M or C)
Acidity of gastric juices (pH)	
Patient care multiplier (hours of care/patient day)	

10.3 PICTURES OF THE PROCESS *(Flowcharts and Layout Diagrams)*

1. Question No. 2, of *Measuring Performance,* asked you to identify some product or service that your department produces. Develop an appropriate "picture" of the production process. This could be a flowchart, layout diagram, arrow diagram or "combined" chart. Your choice.

Next, examine this "picture." Thinking about what is important to the customer (i.e. timeliness, accuracy, quality, cost, etc.), are there any ideas that you get about how to improve this production process?

2. Flowchart one or more of the following processes. After flowcharting the process, try to analyze it to determine if there are ways the process might be improved. The most important quality characteristics are noted in parentheses. If "accuracy" is most important, try to determine where and what errors might be made (and what error-proofing measures might be taken). If timeliness is important, create a critical path diagram (estimate times to complete some of the steps) and look for ways to improve the critical path:

Travel Reservations (Accuracy, Time to Prepare) *Two weeks before traveling, a quality consultant checks the airline schedules on his on-line service. He copies down some likely flights and calls the airline reservations number. After making the airline reservations, he decides whether he'll need a hotel room and for how many nights. If a hotel is needed, he consults his list of favorite hotels for cities previously visited. If he has no "favorites," he calls the client and asks for some recommendations.*

Then he calls the hotel reservation number and makes his reservation. If they are booked, he tries the alternate hotel. Then, he calls the car rental agency to reserve a car. If they don't have anything available, he calls an alternate agency. After all the reservations are made, he prepares a travel folder for that trip, including typing and printing two copies of his itinerary. When he receives the airline tickets in the mail, these go in the folder.

Take-Out Pizza Ordering and Pickup (Accuracy, Timeliness - try this one as a responsibilities flowchart!) *A customer calls the pizza shop with a take-out order. The cashier takes the call and writes down the order on the order form. She then walks back to the kitchen area and tapes the order to the front of the shelf over the pizza "fixins" area.*

The pizza chef looks at the order and begins to make the pizza. The dough is first prepared, and then sauce and cheese applied. He glances at the order before putting the toppings on the pizza. Secret spices are the last to go on the pizza. If an oven is available, he'll pop the pizza in, if not, it waits until a previous order is removed. Occasionally, he'll check the pizza and turn it around in the oven. When the pizza is done, he removes it from the oven, checks it one last time and boxes it. He tapes the order to the pizza box and puts it on top of the oven to stay warm.

When the customer arrives, they tell the cashier their name and the cashier checks to see if the pizza is done. If it's not ready, she'll ask the chef how long and then tell the customer. If it's ready, she will bring it up to the cash register. She'll open the box for the customer to inspect the pizza. If everything's OK, the customer pays for the pizza and leaves. If not, she'll find out what and try to "disposition" the pizza (customer's willing to take it, but at a discount, customer not willing to take it, wants another, etc.).

Pam's Pack and Ship (Accuracy, Timeliness) *Pam takes orders for quality improvement videos. The customer will call to order. Pam takes the ordering information and inputs it to the computer. If the customer charges the order on a credit card, she takes the card number and calls to verify the card's validity. Then, she prints an invoice and shipping label.*

She takes these to the packing area and gathers the customer's videos from the inventory shelves. She packs these in a shipping box, inserts the invoice and tapes the box closed. Then, she tapes the shipping label to the box, weighs the box and puts it on the shipping shelf by the back door. Finally, she fills in the shipping log for the parcel service.

Operating Room Turnover (Cleanliness, Timeliness, and Accuracy) *After the surgeon or the assistant closes the incision and the patient is wheeled to recovery, the turnover process begins. First, the crew disposes of liquids and sharps (syringes, suture needles, etc.). If there are any specimens to be analyzed, these are prepared. Everything else is placed into a red disposal bag and on the operating table. The table is then moved to "Central" and the crew returns to the room.*

The room is then washed down (tables, lights, and kick panels) and the floor is mopped. A new suction canister is obtained for the next procedure. If one is not available, they call Materials Management to send one up "pronto." Linens are obtained and a new red disposal bag brought in. Anesthesia equipment is then obtained and readied. The bed is made up. The next surgical kit is obtained, opened and inspected. If there are items missing, these are obtained. The operating room tech then scrubs and performs the sterile setup of the surgical kit. The "counts" are done and meds are placed on the back table. Turnover concludes when the next patient is called.

Fast Valve-Open Power Plant Startup (timeliness, fuel costs, protection of turbine from overstress) *Power plants that are used in daily "start/stop" operation must be capable of quickly starting and shutting down to meet the needs of the utility's customers. At the same time, startup procedures must be mindful of equipment limits, such as occur when metal is heated too quickly and experiences thermal stresses. This procedure was developed to quickly start a turbine and minimize stresses.*

Initially, turbine metal temperature is at ambient temperature (90° - 100°F). The turbine control valves are opened. The operator applies steam to the turbine steam seals. Circulator and condensate pumps are started and a vacuum is pulled in the turbine condenser. Steam formed in the boiler passes through the superheater, increasing temperature, but decreasing pressure as it moves toward the condenser - it becomes superheated. Steam temperature is about 200°F when it reaches the control valves, with about 50-60°F of superheat (the condenser's saturation temperature at a vacuum of 22 inches of Mercury is about 150°F). The turbine experiences superheated steam before it rolls.

The turbine is accelerated at about 25-50 rpm/minute, while the boiler is fired at a 2°F/min. rate. Turbine oil temperature must be monitored during this process. Spec limits for oil temperature are as follows:

Startup Condition	***Oil Temp.***
Turning Gear Operation	*70°F*
Turbine Roll	*80°F*
Turbine Speed @ 1000 rpm	*90°F*

Turbine Speed @ 3000 rpm	*100°F*

If oil temperature doesn't track with the startup condition, the turbine control valves must be throttled to control turbine speed and the "open valve" procedure aborted for a "traditional" startup. When turbine speed increases above 3000 rpm, a "hold" occurs to allow the Intermediate Pressure turbine blade temperature to increase above 250°F. This also allows the turbine rotor bore temperature to increase above 175°F.

Between 3000-3300 rpm, control is transferred from manual to turbine computer. The computer then controls turbine speed and pressure during the final ramp up to synchronization and generator breaker closing. The plant is now "on-line."

Locomotive Dynamic Brake Testing (Accuracy) *This is a portion of a test designed to determine if a locomotive's dynamic brakes are functional. The dynamic brakes operate to slow the locomotive by turning the drive motors into electric generators. The electricity generated is dissipated through grids mounted on top of the locomotive with fans blowing air across the grids.*

At the start of the procedure, the locomotive's diesel engine is running. The tech connects a motor generator set to two leads on a terminal block. A voltmeter is then connected across the motor generator leads to read voltage (0 - 500 VDC). Another voltmeter (0 - 150 VDC) is connected across terminals of the rate control panel.

The motor generator voltage is increased until a voltage is indicated on the rate control panel voltmeter (when contact 8-2 opens). MG set voltage should be between 305 - 310 volts. If not, then, reduce MG set voltage to zero and adjust rheostat RH10. Repeat the test until the proper MG voltage conditions on contact 8-2 opening are achieved. Finally, reduce MG voltage to zero. Disconnect the rate control panel voltmeter. Proceed to the next test.

Diesel Engine Cylinder, Piston and Rod Inspection (accuracy) *This procedure inspects the condition of a locomotive diesel engine's piston and rod assembly. The inspection is performed periodically, or when trouble is suspected in the engine. Prior to the inspection, the engine is shut down and air box and oil pan inspection covers removed. All cylinder test valves are opened to allow rotation of the crank shaft.*

For the cylinder being inspected, the crankshaft is rotated (using the turning jack) until the piston is at bottom center. The technician inspects the top of the piston and the cylinder wall. If the piston crown is wet, the fuel injector may be leaking. Water leaks and cylinder scoring are noted. If these are present the entire power assembly may require replacement.

The crankshaft is then rotated toward "top dead center" until the piston compression rings are visible through the liner ports. The tech checks the following ring conditions: Side clearance of the Number 1 compression ring, condition of chrome grooves in ring (if little chrome is left, rings should be replaced), broken rings and ring blow-by (vertical brown streaks on the face of the ring - replace if condition is severe).

The piston skirt is inspected for scoring or buffing and the air box is inspected for foreign material and signs of water or oil leakage. The tech records the inspection results on the M-form and returns them to the scheduler's office.

Organ and Tissue Donation (timeliness, accuracy, family consent) *OK, we broke our earlier promise. You've probably seen the episode on "ER" anyway by now.*

The process starts with a potential donor. If the donor's heart is still beating (only this path will be followed here), the Organ Procurement Team (OPT) is called to the hospital. The nurse and team then ask the family for their donation approval.

If the family agrees, a "Release of Body" and forms NG212 and NG213 are completed. The nurse works with the OPT to save the organs and the unit nurse calls the Operating Room circulating nurse.

The "Release of Body" form is pinned to the body by the unit nurse and the OPT and body go to the Operating Room. Organs are retrieved, packed and shipped. The body is taken to the morgue. The transporter fills in the "Release of Body Log" in the morgue. Additional retrieval of tissues may occur in the morgue. The body is then sent to the funeral home.

The morgue signs the "Release of Body Log" to release the body to the funeral home and the funeral home representative signs the "Release of Body Form."

If the donation was not approved by the family, the nurse completes form NG212 and, after death, the body is transported to the morgue.

10.4 TOOLS FOR IMPROVEMENT *(Pareto, Histogram, Scatter Diagram)*

1. A hospital unit's nurse manager keeps a Patient Complaint Log, where every complaint by a patient or their family is dutifully noted. Over a six month period, here are the *recurring* complaint types and their frequencies. Prepare a Pareto Chart of these complaints. If you were the nurse manager "in search of" opportunities to improve service, which category would you address first?

Complaint Category	Frequency
Procedure Not Done	7
Wrong Procedure Done	5
Timeliness of Procedure	10
Personnel Response	2
Patient Event	2
Error in Chart/Orders	4

2. a) The senior management of a denim products factory set as a strategic objective the reduction of injuries to factory workers. They began by collecting data on the frequency and cost of injuries. Prepare Pareto Charts for this data by both of these measures. Which category(s) should management work on first?

Bludenim, Inc. - Employee Injuries - 1994

Injury Type	Frequency	Cost ($)
Cut	2	2742
Fiber in Eye	9	469
Lift	15	13,597
Pull	14	109,115
Puncture	1	1368
Slip/Fall	21	354,739
Struck Against	13	149,049
Struck By	12	2725

2. b) Slips and Falls were then examined to determine if there was a particular type that resulted in employee injuries.

Slips and Falls Category

Type of Slip/Fall	Frequency
Wet Floor/Object on Floor	14
Steps	4
Platform	2

Trailer	1

Develop a Pareto Chart of this data. If you were in this company's situation, what would be your next steps?

3. A payroll supervisor was working on reducing the number of "handwritten checks." These are employee payroll checks issued by hand, due to some error in the computer-generated check. She told us that each handwritten check was estimated to cost the company about $60.00. Develop a Pareto Chart of this data. Which category(s) would you work on first?

Handwritten Checks by Category (Jul - Dec '95)

Check Category	Frequency
Hours not Keyed	8
Hours not Paid/Left Off	46
Cash Plus not Paid	8
Cash Plus Sellback	48
Shift Bonus	0
Paid Wrong Rate	12
System Error	22
Badge Error	4
Refunds	8
Check Issued/Void or Lost	8

4. A Physical Therapy department in a hospital was being criticized by the Billing department for incorrect therapy bills. The therapists all had their own opinion why the bills were incorrect. They collected data over a one week period, with the following results. Develop a Pareto Chart of this data. What would your next steps be?

Physical Therapy Department
Incorrect Billing Categories

Category	Frequency
Attendance Sheet and Charge Ticket Differ	22
Inconsistent charging for Adaptive Aquatics/outings	4
Incorrect computer keying	3
Other	3

5. The hospital which tracked the Length of Stay data for the diagnosis, Coronary Bypass with Cardiac Catheterization, began an improvement effort to reduce the *unnecessary costs* of this diagnosis. They collected data on the charges associated with 13 patients who fell into this diagnosis. Prepare a Pareto Chart of this data.

Coronary Bypass with Cardiac Catheterization
DRG-106 (13 Patients)

Category	**Charges ($)**
Anesthesia	498
Cardiac Cath Lab	3170
Cardiac Diagnosis	546
ICU/CCU	3336
Lab & Blood	3183
Operating Room	6356
Other	347
Pharmacy	5182
Radiology	475
Regular Room	1602
Respiratory Therapy	2193
Step Down	438
Supplies	4863

Does this Pareto provide you with clues as to where to begin to reduce *unnecessary costs?* What's the problem with this Pareto? (Hint: what kind of "problem" is this?).

6. A nuclear industry "watchdog" group collected data on reports of failures occurring in nuclear plant safety systems. Prepare a Pareto Chart of these failures. What systems seem to need reliability improvement the most?

Nuclear Plant Safety System Failures
1989 - 1993

Safety System	No. of Failures
Reactor Coolant System	24
Control Rod Drive Mechanism	5
Steam Generators	2
Reactor Water Cleanup/Chemical Volume & Control System	5
Feedwater	12
Main Steam	19
Normal AC Power	13
Emergency AC Power	62

Other	11

7. An operating room scheduling team tracked the frequency of delays for the first case of the day. Plot their data on a Pareto Chart. What suggestions do you have for their next steps? Is there a different way they could have performed the Pareto Analysis that might reveal a different picture?

Delay Category	Frequency
Equipment	31
Staff	6
Sterilization	12
Anesthesia	97
Surgeon	67
Assistant Surgeon	1
Supplies	20
Patient Prep	121
Positioning Patient	113
X-Rays	4
Patient	5
Procedure Added	6
Other	35

8. A fiberglass boat manufacturer tracks the number of employee injuries occurring each month. They have recently begun an effort to reduce injuries. To help them identify their *current situation,* plot the following injury data on a frequency chart:

# Injuries	# Months with that # Injuries(1)
0	6
1	10
2	14
3	7
4	4
5	1

Note: 1) 6 months had 0 injuries each month, 10 months had 1 injury each month, etc.

9. As part of the manufacturing process for X-Ray film, a roll of film is periodically sampled from the production line. The film is inspected for defects and this data is recorded. Prepare a line graph of this data *and* a frequency chart (or histogram). What do these tell you about X-Ray film defects?

X-Ray Film Defects/Roll

Roll	Defects	Roll	Defects
1	8	13	9
2	16	14	25
3	14	15	15
4	19	16	9
5	11	17	9
6	15	18	14
7	8	19	11
8	11	20	9
9	21	21	10
10	12	22	22
11	23	23	7
12	16	24	28

10. A quality improvement team is investigating the number of errors on insurance claim forms. They have collected the following data on the number of errors on each claim form. Plot this data on a frequency chart:

# Errors/Form	Frequency
0	50
1	40
2	72
3	116
4	52
5	23
6	12
7	3

11. The following Histogram Table was included in an Obstetrics Department annual report. "Low Birth Weight" babies are those born with a weight less than 2500 grams. Create the histogram and determine the fraction of babies "outside the specification limit."

Glenwood Regional Medical Center - Obstetrics Department (1995)

Birth weight Range (gms)	# Babies
0 - 500	8
501 - 1000	34
1001 - 1500	62
1501 - 2000	101
2001 - 2500	219
2501 - 3000	693

3001 - 3500	1826
3501 - 4000	1747
4001 - 4500	681
4501 - 5000	150
5001 - 10000	16

12. A manager responsible for outpatient surgery services collected data on how many procedures of one type finished *over schedule.* The histogram table appears below. Graph this data as a histogram. What is wrong with the manager's approach to analyzing this problem?

Arthroscopic Surgery
Late Procedures (minutes)

Cell Boundaries	# Procedures
1.5 - 31.5	26
31.5 - 61.5	6
61.5 - 91.5	3
91.5 - 121.5	1
121.5 - 151.5	1

13. A manufacturer of replacement hip prostheses developed a new material to be used in the ball portion of the ball and socket joint. They tested a sample of the new hip prostheses and recorded the number of cycles to failure. Prepare and interpret a histogram of this data.

Suppose you were going to guarantee these hip replacements for a certain number of years (assuming use of 100,000 cycles/year). Your company is willing to accept no more than a 10% "return" rate. How many years would you recommend for the guarantee?

Ball and Socket Hip Joint - Cycles to Failure (x 100,000)

Sample #	Cycles	Sample #	Cycles	Sample #	Cycles
1	70.53423	15	45.85777	28	40.36265
2	57.66290	16	58.45372	29	55.52074
3	75.38743	17	39.09278	30	45.82043
4	53.37068	18	43.56339	31	71.76887
5	36.64118	19	59.04286	32	58.47448
6	66.78114	20	38.60609	33	52.44269
7	8.98866	21	57.17477	34	50.95448
8	49.16411	22	31.29472	35	18.69552
9	56.94399	23	23.03319	36	39.31841
10	35.00538	24	35.53958	37	43.65786
11	70.82054	25	62.38192	38	59.22478
12	58.79071	26	48.01895	39	26.88034

13 14	42.57816 53.15759	27	39.75132	40	51.37664

14. Piston Rings for Diesel Engines are measured for width (outside diameter - inside diameter). Four measurements are taken, at 90 degree angles around the piston ring. Create a histogram of the entire data set. What does this tell you? Create histograms for each of the measurement positions. Are there any differences?

Engine Piston Ring Widths - Model 8V645-TI (Millimeters)

	Position (degrees)			
Ring	**0**	**90**	**180**	**270**
1	6.447	6.432	6.442	6.435
2	6.419	6.437	6.429	6.425
3	6.419	6.411	6.414	6.411
4	6.429	6.429	6.441	6.459
5	6.428	6.412	6.443	6.436
6	6.440	6.435	6.409	6.438
7	6.415	6.430	6.410	6.433
8	6.435	6.444	6.430	6.411
9	6.427	6.437	6.424	6.420
10	6.423	6.445	6.424	6.437
11	6.428	6.444	6.438	6.431
12	6.431	6.425	6.422	6.432
13	6.422	6.437	6.417	6.447
14	6.437	6.432	6.410	6.438
15	6.425	6.440	6.422	6.450
16	6.407	6.431	6.421	6.418
17	6.438	6.400	6.439	6.440
18	6.435	6.412	6.427	6.448
19	6.431	6.420	6.433	6.424
20	6.412	6.427	6.436	6.440
21	6.452	6.442	6.450	6.424
22	6.420	6.431	6.413	6.403
23	6.429	6.447	6.439	6.432
24	6.428	6.427	6.420	6.432
25	6.442	6.434	6.413	6.429

15. The nursing units were complaining about the laboratory's responsiveness to requests for specimen analysis. Turnaround times for tests ordered from the clinical laboratory were collected for one day. Prepare a Line Graphs and a Histogram of this data. What do you suspect is occurring in this process?

Lab Turnaround Times (minutes)

24	66	40	14	41	11	47	15	34	23	30	46	49	30	53	41
51	13	14	31	11	25	15	35	23	55	70	27	43	20	12	15
13	30	32	16	25	5	35	25	51	30	19	53	29	45	50	32
29	17	27	36	20	13	18	55	9	62	42	15	32	17	42	14
15	38	60	6	45	18	42	22	21	15	6	42	11	40	26	32
33	33	8	29	27	42	22	55	28	35	27	21	50	18	49	15
30	75	17	21	62	30	50	21	63	17	22	46	15	41	7	17
67	25	27	49	22	65	15	43	20	38	50	16	44	19	21	38
21	55	61	8	50	17	32	18	45	17	11	51	14	44	48	20
48	21	14	17	18	38	28	42	8	41	53	22	41	8	41	45
12	48	32	13	42	7	64	24	37	20	17	50	19	36	23	18
28	18	11	30	12	15	13	51	11	55	31	14	41	17	50	51
29	41	24	28	27	23	31	18	52	21	20	22	47	20	17	18
	47		63		51		44		46		48		45		42

16. A power plant team had identified a problem during daily start-up operations. The high-pressure turbine has heat up rate limit of 100° F/Hour. This is intended to prevent excessive stresses on the turbine rotor metal. The team found that the operators were routinely heating the turbine an average of 175° F/Hour. As part of their improvement effort, they attempted to identify factors that the operator could control and that would limit the heat up rate of the turbine. The boiler's superheat temperature was one potential factor. Plot the following data on a scatter diagram and calculate the correlation coefficient. Is there evidence of a relationship between these variables?

Superheat Temperature (°F)	Turbine 1st Stage Metal Temperature (°F)		Superheat Temperature (°F)	Turbine 1st Stage Metal Temperature (°F)
690	540		720	600
700	549		730	590
725	550		720	600
770	530		730	590
700	500		730	610
775	560		740	587
810	590		740	590
850	640		750	590
890	639		750	589

850	675		760	610
710	590		770	580

17. A colonoscopy procedure consists of three time segments, *prep, procedure, and recovery/cleanup. Prep* and *recovery/cleanup* are dependent on a team of two nurses. The *procedure* time is dependent on the physician. How much time would you plan for the entire colonoscopy procedure for each physician?

Segment	Mean	Std. Dev.		Physician	Mean	Std. Dev.
Prep	22	7		Dr. Maynard	27	8
Rec./Cleanup	15	5		Dr. Rhew	42	11

18. This is from the *"We're not making this up, folks!"* category. An environmental studies company was testing an inexpensive field instrument to measure benzene levels in soils. They compared the results of this field instrument to that of the Environmental Protection Agency's (EPA's) standard method 8240. Their published conclusion: ". . . *the correlation of results indicates a linear relationship between the two sets of results."*

Here's the data published in their article. Plot the data on a scatter diagram and calculate the correlation coefficient. Do you agree with their conclusion?

Benzene Testing - Field vs. EPA Std 8240 Methods

Field Benzene Tester	EPA Std. Method 8240		Field Benzene Tester	EPA Std. Method 8240
0.05	2		0.15	15
0.10	2		0.10	16
0.18	2		0.20	16
0.10	3		0.10	17
0.25	3		0.10	19
0.05	4		0.05	24
0.08	4.5		0.50	24
0.05	6		0.40	28
0.09	7		0.75	29
0.28	8		1.35	46
0.10	9		1.50	49
0.05	9		0.20	57
0.20	10		1.25	70
0.40	10		1.30	70

0.07	13		0.40	88
0.20	13		1.70	116

19. Three surgical procedures are scheduled back-to-back for today in Operating Room #6. Past data indicates that each procedure takes about an hour, with a standard deviation of 15 minutes. What would be the earliest time you'd expect the procedures to be completed? What would be the latest time? The first procedure starts at 7:00 am.

20. A Medical Records director was trying to improve the performance of her department. Medical Records processes patients' bills. As long as the bill has not been sent it is recorded as "Accounts Receivable." The director suspected that one segment of the processing time was causing delays and increasing the Accounts Receivable amount. Plot this data on a Scatter Diagram. What are your conclusions?

Process Time (days)/Accts. Receivable ($)			**Process Time (days)/Accts. Receivable ($)**	
9.00	4033.00		12.00	4362.00
8.00	3661.00		12.00	3998.00
7.00	3952.00		11.00	3819.00
6.00	3793.00		7.00	3959.00
11.00	3562.00		10.00	3856.00
10.00	3572.00		9.00	3444.00
9.00	3910.00		9.00	3817.00
8.00	4117.00		8.00	4053.00
7.00	3909.00		7.00	3679.00
11.00	3978.00		9.00	3782.00
10.00	3567.00		10.00	3598.00
9.00	3443.00		8.00	3345.00
10.00	3724.00		8.00	3737.00
11.00	3870.00		9.00	4033.00
10.00	3649.00		8.00	3661.00

21. Three components of a valve stem/gate assembly are produced. What is the expected length and standard deviation of the assembly? The three components are welded together in series:

Component	**Mean**	**Std. Dev.**
Valve Stem	18.00"	0.03"
Valve Disk	8.00"	0.02"
Valve Guide	4.00"	0.02"

If the specification calls for the assembly to be no longer than 30.10 inches, is the current manufacturing process capable of meeting the spec? (Note: typically, if the average plus/minus ***3*** times the standard deviation is within the spec limits, the process is considered OK).

22. A pharmacy was trying to improve their staffing planning process. If they could predict the number of orders they would receive each day, then they could predict how many pharmacy techs were needed each day. They suspected that the census (number of patients) on the units served by each "satellite" pharmacy would influence the number of orders received.

The following daily data was collected for two different satellite pharmacies in the hospital. Is there a relationship? Can the pharmacy predict the number of orders based on the number of patients in the units?

2nd Floor Satellite			5th Floor Satellite	
Census/ Orders	Census/ Orders		Census/ Orders	Census/ Orders
55 323	50 301		52 269	35 224
61 191	48 157		63 281	41 224
52 353	52 276		71 247	42 285
58 316	51 291		66 235	37 290
54 312	60 277		70 228	44 261
61 321	54 315		66 277	46 225
65 368	60 351		71 258	43 252
54 308	64 375		67 258	49 282
52 260	55 338		63 259	39 255
50 369	53 230		57 187	41 227
55 346	62 343		65 255	39 191
52 234	58 281		78 232	45 283
52 267	52 251		69 218	52 273
49 263	65 412		60 248	54 281
48 218	53 255		66 344	52 308
46 245	53 228		73 316	48 245
47 167	56 274		80 308	41 295
40 137	51 404		60 255	47 250
41 245	63 356		34 93	48 199
52 329	65 322		46 234	48 228
57 385			41 295	41 131

23. Nuclear power plants must track the radiation exposure of each worker, including the workers' *skin dose* (measured in *millirads* (mrad)). This can be difficult to measure, especially for low energy *beta-emitters*, such as Xenon-133, or -135.

The worker's *whole body count* (WBC), though, is easy to measure. WBC indicates the amount of radioactive material absorbed by the body and is measured in *nanocuries* (nCi). A team at one plant tried to determine if there was a relationship between *whole body count* and a *calculated skin dose.* The following data were obtained:

Calculated Skin Doses vs. Whole Body Counts

Whole Body Count (nCi)	Calc'd Skin Dose (mrad)		Whole Body Count (nCi)	Calc'd Skin Dose (mrad)
200	2		6200	57
630	5		6200	57
1400	18		6300	63
2200	20		6600	80
2550	22		6700	82
2400	24		8800	83
2900	26		7800	87
3000	27		7800	87
2500	27		10100	88
2570	28		6300	93
2800	31		9300	99
3800	32		11300	100
2700	35		11200	101
5600	43		9300	103
5700	44		9800	104
4400	48		11800	109
6000	53		12500	110
6300	54		11000	112
5600	54		10400	120
5200	54		10900	120
4100	55		13500	120
5700	57		12500	125

Develop the scatter diagram, calculate the correlation coefficient and fit a line to the data using linear regression. For workers who have measured Whole Body Counts of 5000 and 10000 nCi, what skin dose did they receive?

10.5 CAUSE AND EFFECT *(The Fishbone Diagram)*

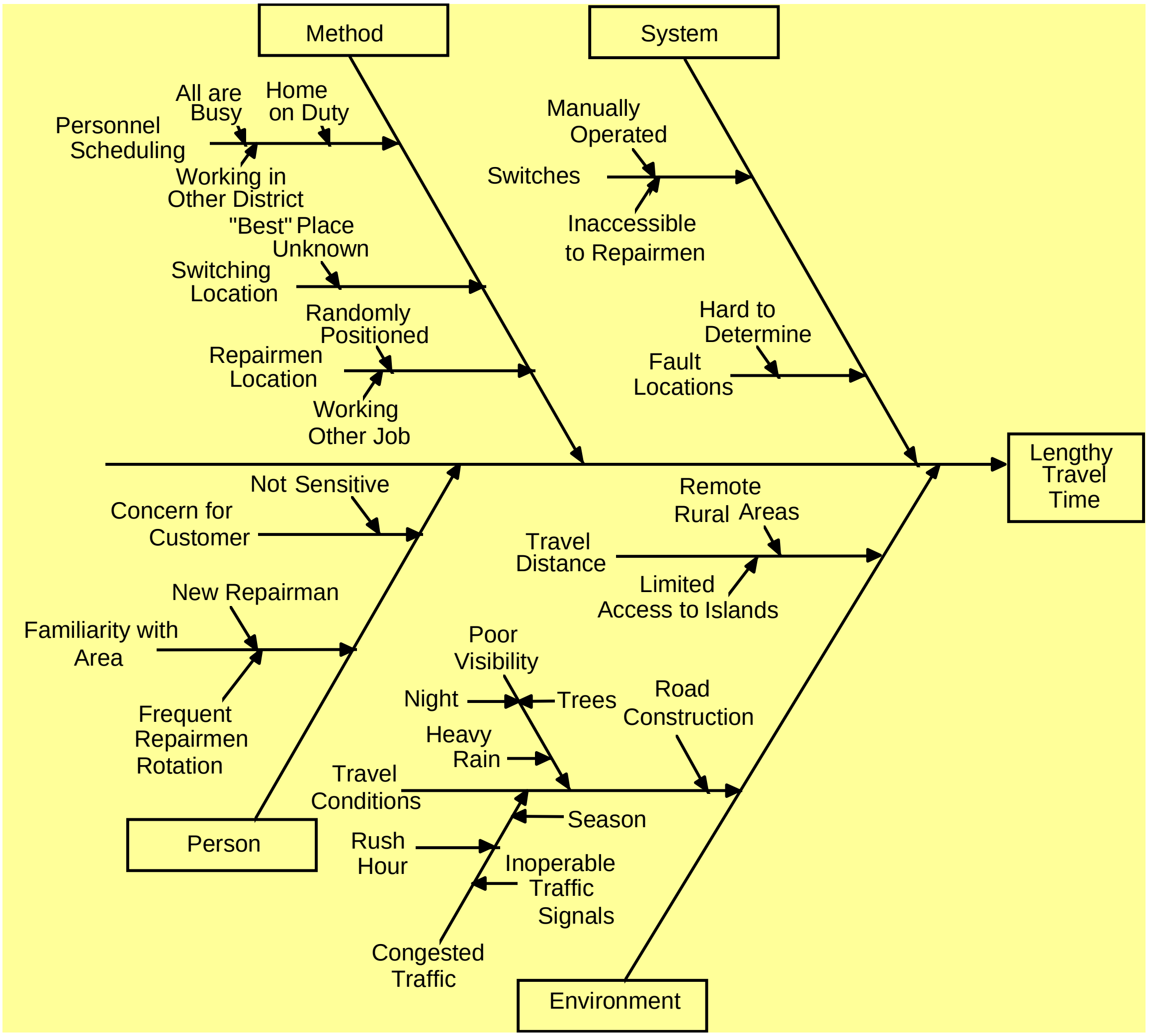
1. Here are some "simple" effects that you can use to practice developing cause and effect diagrams. Remember to focus on the *process* that produces these effects:

- Waiting time in a doctor's office averages 45 minutes.
- Teenager doesn't take garbage out 48% of required times.
- "Maintenance" backlog for house projects averages 10 items/month.
- VCR clock blinks "12:00" 80% of the time.
- Spouse snores on 75% of nights.
- Lights and TV left on in vacant "rec" room 63% of time.
- Employee late for work 22% of work days.
- Operating Room overtime averages 18% of payroll each pay period.
- Delay time of 15 minutes (average) between end of meal and receipt of check at a restaurant.
- Required surgical gowns not available for 10% of days.
- 15% of apartment rent checks received more than 10 days after due date.
- In the last four trips, only one bass was caught at Moore Lake.
- Hiring process takes 4 months from job posting to job filling.

2. For these examples, develop cause and effect diagrams “with” and “without” the problem. What factors are different?

- Pleasant car buying experience/unpleasant car buying experience.
- Children late for school/children not late for school.
- Pleasant discussion of family finances/argument during family finance discussion.
- Pleasant family vacation/”Clark Grizwald” family vacation (rent one of the “Vacation” tapes if you don’t know what we mean!).
- Successful installation of *Windows95™* (or other program)/ unsuccessful or difficult installation of *Windows95™*.
- Beneficial and Exciting Skills Training session/Boring, “Put you to Sleep” Skills Training session.

3. The following cause and effect diagram was developed by a team of utility repairmen, focusing on lengthy travel time to restore customers' electricity. Consider how you would go about *verifying* which of these potential causes were most important:

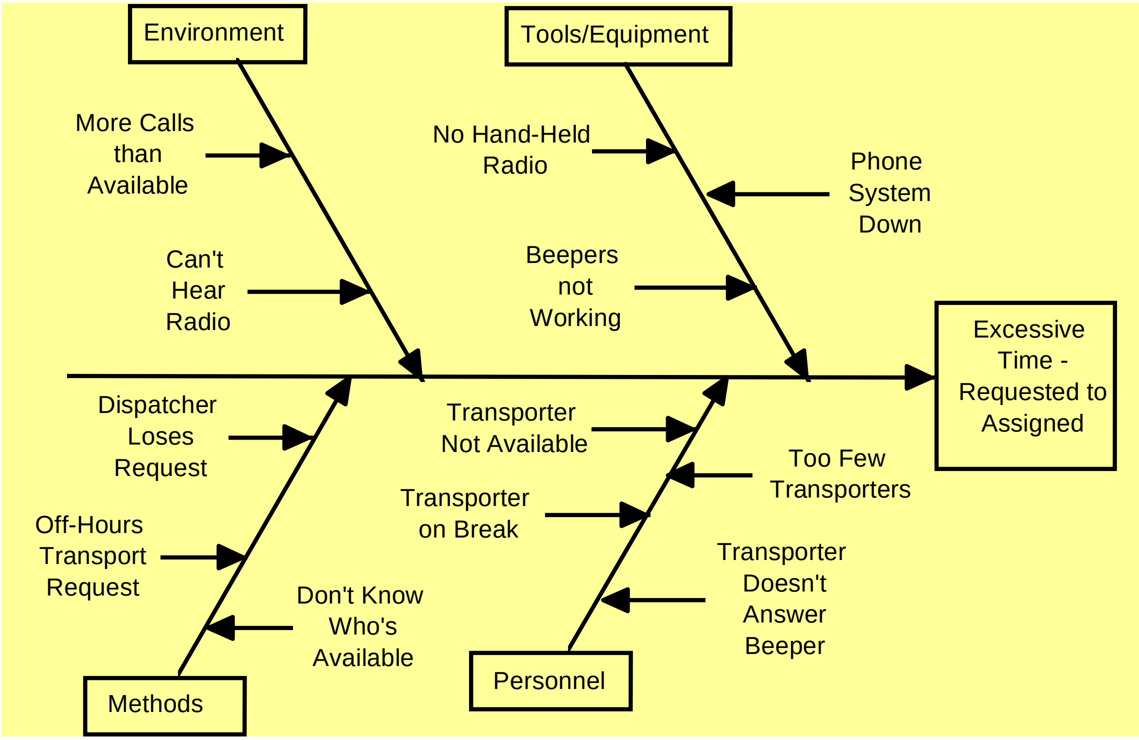


4. A team working on electrical splice failures analyzed 30 "pin and socket" splices that had failed in service. They developed the following Pareto Table and concluded that not meeting the clearance specification was the cause of the failures. They could only identify failed splices, as the remaining splices were buried underground. What could be wrong with their conclusion?

Pin and Socket Splice Failures
Pareto Table

Cause	Frequency	Cum. %
1/8" clearance specification not met	22	73.3
Unknown	3	83.3
Other	5	100.0

5. A hospital transporter team was working on improving the *timeliness* of their response to requests to transport patients within the facility. Calls for transporters came in to a central dispatcher, who then assigned them to available transporters. The team had identified one time segment, *transport requested* to *transporter assigned,* as being the source of most of the delays. Consider how you would *verify* which of the potential causes are most important:



10.6 SELECTING, PLANNING & MAKING IMPROVEMENTS

1. With a small group, *Brainstorm* a list of parties that you might like to throw (Valentine's Day, Clambake, Birthday, Toga, etc.). If the list is greater than 10, then *Multi-vote* the list. If necessary, then *Rank Order* the remaining list and reach *Consensus* on the one you will plan.

Develop a *Project Plan* to prepare for the party. Decide what needs to be done, who will do it, when it will be done, etc.

2. A team of Emergency Room (ER) staff and physicians were trying to improve their chest pain diagnostic & treatment process. Their goal was to reduce the time from when a patient with chest pains arrived at the ER to the time a thrombolytic ("clot-busting") agent is administered. The team made three changes to the process. Did they improve the timeliness?

Thrombolytic Administration Time
- ER Arrival to Drug Administered

Patient	Time	Patient	Time	Patient	Time	Patient	Time
1	180	*15*	58	*29*	80	*43*	75
2	115	*16*	29	*30*	77	*44*	70
3	50	*17*	38	*31*	100	*45*	61
4	38	*18*	38	*32*	65	*46*	36
5	60	*19*	50	*33*	39	*47*	39
6	42	*20*	82 **(2)**	*34*	60	*48*	45
7	90	*21*	55	*35*	63	*49*	35
8	100	*22*	64	*36*	60	*50*	55
9	35	*23*	50	*37*	50	*51*	45 **(3)**
10	28**(1)**	*24*	32	*38*	40	*52*	84
11	55	*25*	88	*39*	60	*53*	17
12	97	*26*	50	*40*	60	*54*	43
13	40	*27*	115	*41*	95	*55*	42
14	95	*28*	60	*42*	95	*56*	37

Changes: (1) - New Protocol, (2) - Revised Orders, (3) - Pole Added

3. The first quality improvement team chartered by a large hospital analyzed the problem of getting medical records from the nursing units to the Medical Records department after the patients were discharged. They made several process changes, measured their results and showed that a significant improvement had been made.

Four months after the change was made, the process was measured again. The team was surprised to note that the "gains" made through their work had evaporated and the process was performing as before. Comment on what you think may have happened.

4. A nuclear power plant team worked on improving the reliability of *Charging Pumps,* which were a major source of maintenance time and expense. The team found that the operators were using some manual valves to control flow from the pumps and that this resulted in premature wear of pump components. The operators were notified in a memo from maintenance about the problem and, for a while, the pumps were more reliable.

Two years later, the pumps began breaking down again. The same problem was found to be the cause. Comment on why you think the countermeasures didn't "stick."

5. Recall a few problems in your organization that have been "solved" more than once. Why haven't these problems been *prevented from recurring?*

6. We've worked with some large hospital groups. We'll guarantee that multiple hospitals will be working on improving essentially the same process (i.e. admitting, transport, surgery scheduling, nurse call, lab turnaround, etc.). Even within one hospital, several different nursing units or patient care units will be working on the same process. Comment on this issue.

10.7 MAINTAINING THE IMPROVEMENT *(Process Control, Control Charts)*

1. Develop a process control system for the following "production process." Consider how you might optimize the flow of the process to achieve both the quality and cycle time CTQs.

CTQs:	Ingredients:	Process Steps:
• Size (USL = 6") • Thickness (USL = 0.5") • Served Temperature (LSL = 130F) • Taste (Consumer Rating > 4.6/5) • Preparation Time < 10 minutes	• 1 ½ Cup Flour • 3 Tbl. Sugar • 1 ¾ Tsp. Baking Powder • 1 Tsp. Salt • 3 Tbl. Butter • 1 – 2 Eggs • 1 – 1 ¼ Cup Milk	1. Gather Ingredients 2. Mix Dry Ingredients 3. Melt Butter (30 Sec. in Microwave) 4. Mix Butter, Eggs, Milk 5. Mix Liquid and Dry Ingredients 6. Heat Griddle to 375 F 7. Pour Batter in 3" Circles 8. Flip after ~ 1 minute 9. Serve when brown on both sides

2. X-Bar, R control chart - **Compressor Stud Lengths –** A supplier fabricates studs for critical compressor applications. One key quality characteristic of the studs is their length. Their customer specifications call for a nominal value of 5.3750" with a tolerance of +/- 0.0005". The supplier pulls a subgroup of four studs each hour from the fabrication process and measures their length with a calibrated micrometer. In the table below, each row is a subgroup. Develop an X-Bar, R control chart.

Subgroup	Stud Length (in.)			
1	5.37526	5.37525	5.37454	5.37464
2	5.37478	5.37525	5.37495	5.37411
3	5.37446	5.37476	5.37482	5.37492
4	5.37525	5.37485	5.37527	5.37506
5	5.37463	5.37430	5.37502	5.37523
6	5.37511	5.37473	5.37486	5.37478
7	5.37473	5.37475	5.37510	5.37480
8	5.37484	5.37497	5.37480	5.37498
9	5.37520	5.37457	5.37432	5.37484
10	5.37534	5.37487	5.37511	5.37517
11	5.37472	5.37433	5.37526	5.37486
12	5.37502	5.37501	5.37532	5.37502
13	5.37475	5.37542	5.37462	5.37473

Subgroup	Stud Length (in.)			
14	5.37482	5.37529	5.37539	5.37475
15	5.37499	5.37504	5.37515	5.37515
16	5.37464	5.37509	5.37458	5.37476
17	5.37465	5.37487	5.37456	5.37472
18	5.37515	5.37492	5.37504	5.37519
19	5.37440	5.37531	5.37504	5.37525
20	5.37436	5.37475	5.37516	5.37474
21	5.37493	5.37514	5.37471	5.37481
22	5.37463	5.37467	5.37511	5.37510
23	5.37511	5.37510	5.37530	5.37477
24	5.37436	5.37401	5.37525	5.37493
25	5.37483	5.37493	5.37448	5.37518

3. X-Bar, R Control Chart: - Run your Card Drop Shop (using the standardized process) for 100 units. Develop an X-Bar, R control chart for this data with a subgroup size of 4.

4. X, mR Control Chart - **Butterfly Control Valve -** An air-operated butterfly control valve is used to control cooling water flow to heat exchangers in an air conditioning unit. The valve must close within ten seconds of receipt of the signal from the unit's protective circuitry. The valve is tested monthly and maintenance technical personnel record its closing time (in seconds). Develop an X, mR control chart.

2.87	3.67	4.36	4.58	4.52
1.96	2.62	4.16	5.81	3.62
2.22	4.61	4.08	4.27	2.86
1.51	4.46	4.2	2.22	3.81
5.04	3.95	4.82	2.65	3.91

5. X, mR Control Chart - The following data are the results of opinion polls taken in the three months prior to the 2000 US election. Each data is the percent favoring Governor Bush minus the percent favoring Vice President Gore. Are there assignable causes present (i.e. due to convention "lift", kissing a wife, etc.)?

Bush minus Gore – Polling Data

2	3
17	-3
-1 (August)	0
1	0
-3	-3
2	-13
-7	7 (October)
-6	8
-7.5	4
-7	0
-5.5 (September)	-1
-9	0
-11	4
4	5
3	3
0	

6. X, mR Control Chart - The following data were taken from the Raleigh News and Observer newspaper. The article implied that a high number of births were due to the Hurricane Floyd which occurred in October of the previous year (the middle column shows the nine month "lag" between the hurricane and the births). Is there evidence that Hurricane Floyd is an assignable cause of variation?

Births by Month - Wake County

Month	***9M Lag***	***Births***
Jan	Apr	44427
Feb	May	40821
Mar	Jun	44336
Apr	Jul	42101
May	Aug	43746
Jun	Sep	44076
Jul	Oct - Floyd	47085
Aug	Nov	47995
Sep	Dec	47050
Oct	Jan	45738
Nov	Feb	43087
Dec	Mar	45471

7. X, mR Control Chart - The following data were obtained at a company cafeteria in Osan, Republic of Korea. The cafeteria staff measured the quality of their food by how much was thrown away each day (average of food on the plates in grams). Develop and interpret an X, mR control chart for this data.

Day	Waste (gms)	Day	Waste (gms)
1	28	13	28
2	26	14	26
3	16	15	40
4	18	16	25
5	20	17	27
6	21	18	19
7	25	19	22
8	34	20	25
9	18	21	24
10	26	22	26
11	36	23	25
12	28	24	24

8. *np* control chart - Run the Card Drop Shop for 100 units in subgroups of size 10. Record the number of cards that fall outside of 20 inches from the target as *defectives.* Develop an *np* control chart for this data. Perform the calculations by hand; plot the points and limits on the control chart form. Open Mini-Tab on your PC. Create the *np* control chart. Compare results from Mini-Tab to your hand-drawn charts.

9. *np* control chart - **Motor Rejects -** A company that produces air conditioning units orders batches of the motors from a supplier. Due to past quality problems, the company inspects 20 motors from each batch. Each motor is accepted or rejected. Based on the number of motors rejected, a decision is made to either inspect the remaining motors or return the batch to the supplier for rework.

Number of Rejected Motors:

5	1	1	2	4
2	4	2	0	6
3	3	4	0	3
3	5	3	6	
3	2	1	4	

10. p control chart - Defective Full-Penetration Welds - A welding supervisor receives inspection reports by the Quality Control Department. The QC supervisor has recently called his attention to a seemingly high number of rejected full-penetration welds on critical high pressure piping systems. The welding supervisor begins his analysis of the situation by preparing a p-chart of rejected welds for the past six months.

Week	# Welds	# Defective		Week	# Welds	# Defective
1	476	41		14	352	36
2	379	40		15	415	39
3	412	42		16	557	60
4	424	48		17	581	51
5	483	44		18	466	57
6	415	48		19	584	54
7	541	55		20	573	66
8	544	50		21	471	51
9	466	39		22	305	49
10	439	37		23	383	44
11	428	40		24	379	47
12	363	31		25	526	59
13	463	57		26	543	66

11. c control chart - Ceramic Paint Pinholes - A paint manufacturing company, which produces special paints used by hobbyists on ceramics, tests samples of their paint daily. They apply the paint to unfired ceramic plates, fire the plates in a kiln and then inspect the finished plates. Among other defect categories, they count the number of pinholes in each sample. The test manager has recently begun to track the number of pinholes obtained from each sample on a c chart.

Number of Pinholes per Sample:

18	14
8	15
17	17
16	13
20	17
10	17
19	16
19	13
13	6
10	16
21	19
12	22
13	14

12. *u* control chart - **Design Change Requests (DCRs) -** Engineers are responsible for developing custom designs of air conditioning systems. As they are built, manufacturing discovers problems with the designs and requests changes from Engineering (Design Change Request). The Engineering Manager was curious to see if there were significant differences between the engineers.

# Units	# DCRs	Engineer
40	97	Maynard
90	69	Kinney
90	153	Gibbs
70	125	Nichols
30	45	Fritz
50	66	Stone
40	62	Fielding
10	25	Adams
70	82	Pelham

13. ***Pick-a-Chart (Control Chart Selection) -*** Often, one of the difficulties people face with control charts is the question of "Which is the right one?" This exercise is intended to give you some practice going through the logic of the Control Chart Selection Guide. As you develop your answer, note your assumptions. There is more than one way many of these scenarios could be charted.

Scenario	*Control Chart*
1. Each day, the number of units shipped is counted at 12:00 AM.	
2. The Sales department keeps track of the number of units sold each day, by type of unit.	
3. A laboratory gets a report, once a day, which provides the number of samples analyzed, the average processing time, and the standard deviation of the processing time.	
4. Each day, a technician measures the time she takes tubing a condenser on her shift.	
5. At a ballpark, a hot dog vendor counts the number of wieners sold each game day.	
6. A factory worker measures the diameter of valve stems after machining. She takes four stems at random from each hour's production.	
7. An engineer measures the cycle time for engineering change orders weekly.	
8. An administrative assistant tracks the number of days it takes customers to pay their bills. She keeps a chart for each of the company's top 6 customers.	
9. A quality consultant tracks the number of days she is on the road each month.	
10. A Sales supervisor has developed control charts for her clerks - they track the number of line items entered each day.	
11.The power of a motor is measured and is subject to a purchase specification.	
12. Coatings are purchased in tank car lots. The material is sampled and the chemical composition determined.	
13. The procedures group has noticed an increase in the number of comments made on their draft procedures being circulated for review. They are wondering if something unusual is going on in the procedure drafting/ review process.	
14. The LAN (Local Area Network) administrator has been trying to improve the reliability of the system. She is interested in seeing if the number of LAN "crashes" has decreased.	
15. This same LAN administrator has also been working on trying to reduce the time required to restore the LAN after it crashes.	
16. The Production Manager is interested in employee absenteeism, measured in days/employee. The corporate staff supplies her with a monthly report, which breaks down this measure into weekly increments.	
17. The Financial Officer is concerned about the utilization of company cars; he suspects that there are too many cars. He begins tracking the number of hours the cars are utilized for business purposes each week.	
18. A production facility wishes to improve the set-up time required when products being produced are changed. They usually make the same product for about two days and then switch over to another product.	
19. A bolt manufacturer must ensure that the tensile strength of stainless steel bolts meets the customers' specifications. About 5000 bolts are produced daily.	
20. You have been troubled by the number of times your production facility has been stopped due to power interruptions by the local utility. You have records of all production stoppages for the last two years.	

Scenario	*Control Chart*
21. A certain vendor provides you with bolts for your product. Before the bolts are used in your production process, you sample 50 from each box of 1000 and inspect them for defects.	
22. A large consulting firm prepares about 30 proposals per week for prospective clients. The Sales Department manager is interested in the number of proposals that are not accepted by clients.	
23. An engineering department prepares design changes to improve the performance of a chemical processing plant. They are interested in the number of **field change requests,** ***those changes that are requested by construction engineering because the design change cannot be implemented in the field.***	
24. A Sales Manager tracks weekly sales volumes by number of items sold, dollar amount of sales and items sold per salesperson.	
25. An Automotive Manager is concerned about the quality of a particular brand of tire used on company cars. His primary concern is the possibility of a tire blowout. If the size of the company car fleet stays constant, how should he track this process?	
26. A Records department director is concerned about the errors made by her staff. She asks for help in determining the best chart to use. She tells you that the number of records varies significantly from week to week.	
27. Each month you receive a departmental budget variance report that, among other things, provides the dollar amount you are over or under salary budget, supply expense budget and overtime hours.	
28. A physician thinks that the complications associated with a particular surgical procedure varies from surgeon to surgeon. Each surgeon does a different number of these procedures each year.	
29. A company is interested in using a new vendor to supply control circuits that emit a specified signal for a specified time. They wish to determine if the process used to produce the circuits is in control. They are particularly interested in the signal's duration.	

10.8 WORKING ON A TEAM (*Team Skills, Decision Making, Meetings)*

1. In which of these following situations do you think a team should be formed to improve quality? If a team is needed, what *type* should it be (see Section 7)? If you don't think a team is needed, how could or should the situation be addressed?

- A railroad has been experiencing water leaks on its locomotives' diesel engines. There are about 1000 locomotives in the railroad's fleet. The engineer's failure report includes where the leak is observed, but not why it occurred.

- An architectural firm has been receiving complaints from customers that "they are not responsive" to the customers' needs. The firm has four design groups, each acting as a design team for projects.

- A small manufacturing company wishes to improve its employee safety record. The company president wants to form a team, but the Safety Officer tells him that he can solve the problem with a new training program for proper lifting techniques.

- An unacceptably high defect rate of integrated circuits has plagued a small electronics firm for the last few weeks. The reliability engineer is working on a test plan, the design engineers are preparing changes to the IC design and manufacturing is changing their "clean room" procedures.

- A hospital's case managers have identified one physician as being "high" on both patient Length of Stay and Cost per Case for a certain diagnosis.

- Nurse Managers have been complaining to the chief nurse executive about delays in receiving laboratory "stat" specimen reports. The lab director says the orders are only being sent to the lab twice a shift.

- A physician called plant maintenance about dust blowing into one of her examining rooms from an air conditioning vent. The problem has existed for three days now.

- Two employees on the evening shift at a plastics plant are chronically late. The other shift members are angry at having to carry their "load" when they are late.

- A manufacturer of ceramics for hobbyists found that their product sales were declining. Projections indicated that the manufacturer would suffer a $10 million loss if the current trend continues.

- A regulatory agency has issued safety violations to a pharmaceuticals manufacturer. The violations cited "management inattention to safety requirements and plant conditions" as important causes.

2. Comment on the following "team" situations described below. Was the use of a team appropriate? What issues do you see that may lead (or did lead) to the success or failure of these efforts?

- A manager of an engineering division told a group of engineers to investigate computerizing a certain reference document. He told them to make sure and "prove" that the computerization was necessary so the necessary budget approvals could be obtained.

- A new chief engineer of a nuclear engineering department identified a "laundry list" of engineering practice problems. The chief assigned a group of engineering managers to form a team, prioritize the problems and start working on fixing them.

- The senior managers of a bank had just been through quality improvement training and were excited to begin improvement efforts. They assigned 10 projects to branch office and "back office" staff. The branch and "back" office managers were not consulted before these assignments were made.

- Factory management assigned a group of maintenance workers, purchasing and receiving personnel to work on reducing the time to obtain "non-stocked" spare parts for plant equipment. Three weeks after the team began; they realized a new parts inventory data base was being installed in the next month.

- A manager of a nursing unit assigned a group of nurses and nurse assistants to improve morale and communication in the unit. She thought that would help reduce turnover in the unit, which was running at 40% annually.

- A president of a small consulting firm had decided to expand the company office space. He assembled a team of clerical support staff to determine the best strategy to "handle the increased need for product inventory space." The team came back to him with the recommendation to let the consultants "telecommute" from their homes and use their office space for the product inventory. The president disagreed and proceeded to lease additional space.

- A hospital initiated a number of teams whose purpose was to improve the clinical quality of care for patients. Physicians were invited to participate on these teams. Although some were initially interested, the meetings were held during the day and, gradually, the doctors stopped coming to meetings.

- Nurses and quality assurance/utilization review staff were assigned to develop "Clinical Pathways," standardized methods of patient care. After reviewing the first five Pathways developed, the physicians told the chief nurse executive that the "Pathways were worthless, they weren't going to practice 'cookbook' medicine."

- Power plants were told by corporate management that they needed to have a certain number of teams "running" by years end. Over 80% of plant personnel work shifts that only allow for short breaks and lunch. By the end of the year, the only "functioning" teams were composed of administrative clerks.

- A new car dealer assigned members of his sales force to develop "best practices" for selling cars to customers. After three months of meeting, the team had not made any progress. The sales personnel are paid based on commission.

- A hospital's administration has decided to decentralize the respiratory therapy function to the patient care units. The leader of the team is the current department director. The patient care unit managers don't want the additional responsibility of respiratory therapy and the department director is reluctant to give up his "power."

3. Comment on the "dynamics" occurring in these team situations. What would you do to address the situation?

- Six members of a team are working on an improvement project. One of the members, although a solid contributor, is generally negative about the project, and is convinced that management will not adopt the team's recommendations. The other members of the team have taken to avoiding him, except one who vigorously "counterattacks" him every possible chance. You are the team leader.

- A team is working to reduce supply expenses in the surgical department. The team leader often comes to the meetings late and frequently has to develop the agenda in the first few minutes of the meeting. Team members have begun to avoid coming to meetings. You are a team member.

- A team assigned to design a new engineering scheduling process has a number of very strong personalities. One member frequently verbally attacks other members, another "acts out" and often leaves the meeting for a few minutes or wanders around the meeting room. One member heads the current scheduling department and is not happy about having others "meddle in her process." Although the team has designed a new process, planning to implement the changes is proceeding slowly. You are a team member.

- A team of secretaries has been formed and asked to select their own improvement project. The team leader is a young, shy secretary. One of the team members is an older, domineering secretary who thinks this "quality stuff" doesn't apply to her and that she doesn't need to be on the team. You are the young secretary's manager and she has come to you for advice.

- A development specialist has been assigned to lead a team that will design a quality improvement video on control charts. The company president has assigned members to the team, two of whom are consultants who are always joking around. Their language is sometimes "borderline crude" and they often make disparaging comments about the project. However, they have been the main two contributors to the ideas and work of the project. You are the team leader.

- You have been assigned to a team working on resolving a safety issue at a nuclear power plant. The team has frequent meetings with management. As the work continues, you start to suspect that management is not really willing to address the issue and that your team's real role is to justify the existing situation.

- A fossil power plant manager is assigned to lead a team of the company's "best" quality improvement people. Their assignment is to help the company's poorly performing nuclear plant "turn-around." The team members are all strong personalities, frequently disagreeing with the team leader. The team leader is good at developing a "vision" of where he wants to go, but not so good at the details. A small subgroup takes on the role of "translators," developing coherent, practical plans to implement the leader's vision.

- You have been brought in as the new Chief Operating Officer of a large, metropolitan hospital. You assess that each of the Vice Presidents has been running their own operations, with little communication between the departments. In fact, department directors have been told *not* to talk with those directors "belonging" to other VPs. All questions or problems have to come up through the "chain of command."

4. Here are some simple "decisions" that can be reached with the help of the Idea Generating and Group Decision Making methods of Section 7. Use these to practice before getting into a "real" situation. Don't forget to set criteria before you employ the decision making tools. (*Note: these can be conducted as meetings, using the meeting process of Section 7*):

- Where to have the department picnic.
- What to do for the pediatric cancer patients for Christmas.
- What to do for the nursing home patients for Christmas.
- What two-mile stretch of road your organization will "adopt."
- The "best" (you define "best") sitcom of all time (corollary - which episode is "best.").
- Why women love shopping (top 3 reasons) - except for tools and hardware.
- Why men hate shopping (top 3 reasons) - except for tools and hardware.
- Which are the top ten movies of all time.
- Who are the top ten baseball players of all time.
- Who has the "worse" (you define "worse") TV talk show.
- What to do for your secretary on Secretary's Day.
- What to do for your "boss" on Bosses' Day.
- What's the most important problem facing your department (Oops! Sorry, that's a real one!)

11. FORMS

Here are a few forms and “cheat sheets” you may find useful in your quality improvement work.

PROJECT PLAN

PROJECT:	

TEAM MEMBERS:		
T - TEAM LEADER		
F - FACILITATOR		

PROJECT TASKS	**WEEKS BEGINNING**											

MEETING AGENDA FORM

Date ____________ **Team** ____________

Time ____________ **Place** ____________

<u>Content</u>

1. Clarify Meeting Objective:

2. Review Roles:

____________ Team Leader

____________ Recorder

____________ Timekeeper

____________ Facilitator

3. Review Agenda Items

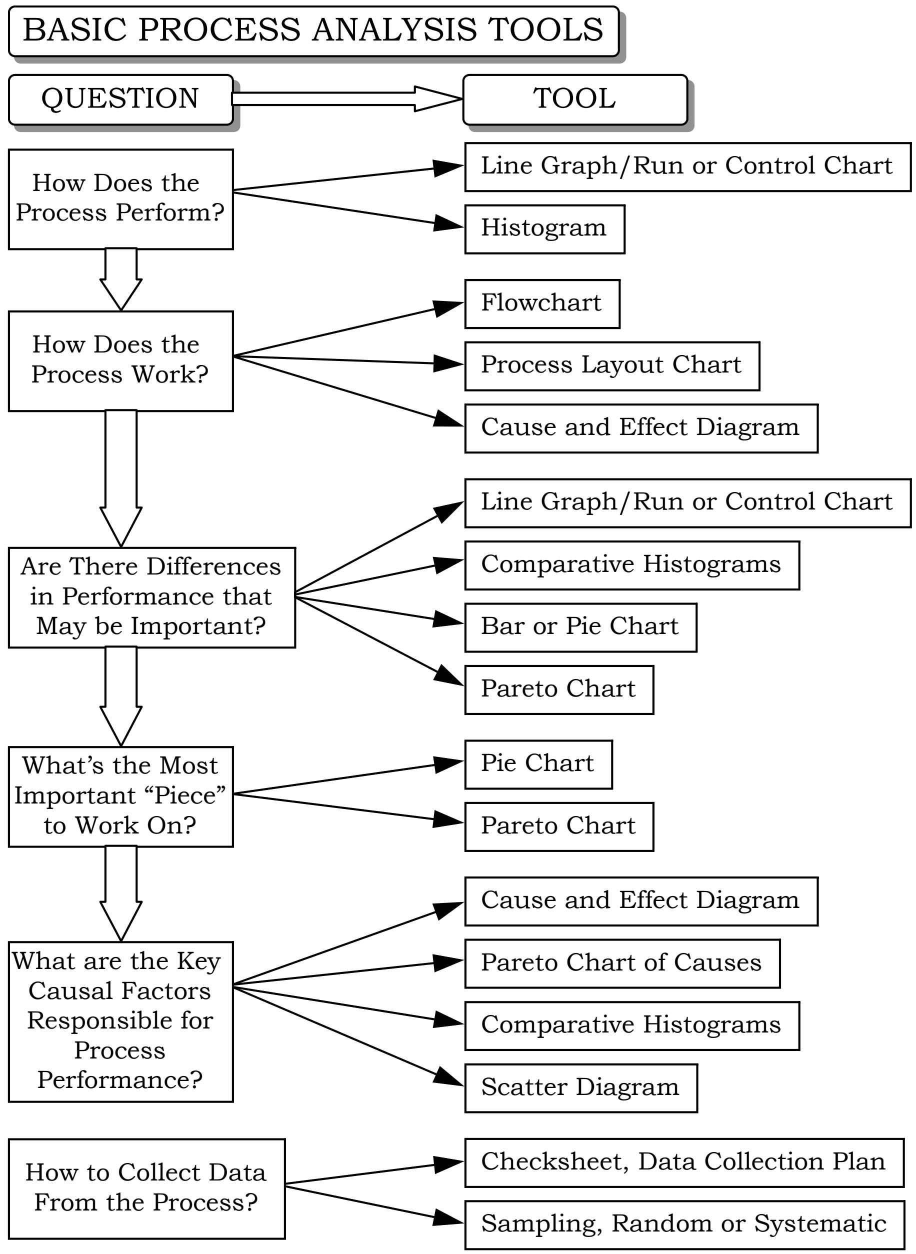
4. Agenda Items:

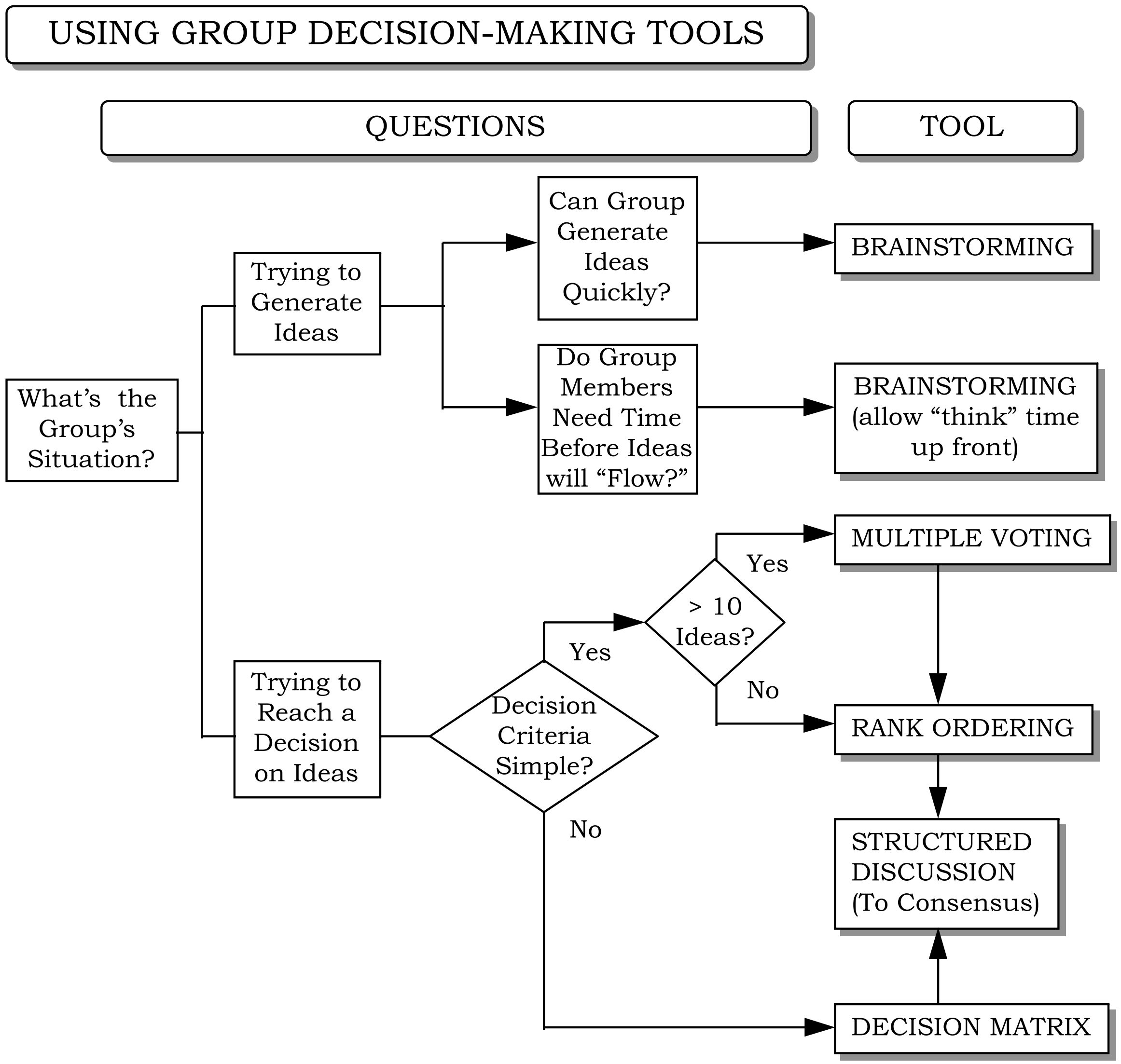
Topic	Time

5. Review Meeting Record

6. Plan Next Steps & Meeting Agenda

7. Evaluate Meeting


BASIC PROCESS ANALYSIS TOOLS
QUESTION
TOOL
How Does the Process Perform?
Line Graph/Run or Control Chart
Histogram
How Does the Process Work?
Flowchart
Process Layout Chart
Cause and Effect Diagram
Are There Differences in Performance that May be Important?
Line Graph/Run or Control Chart
Comparative Histograms
Bar or Pie Chart
Pareto Chart
What's the Most Important "Piece" to Work On?
Pie Chart
Pareto Chart
What are the Key Causal Factors Responsible for Process Performance?
Cause and Effect Diagram
Pareto Chart of Causes
Comparative Histograms
Scatter Diagram
How to Collect Data From the Process?
Checksheet, Data Collection Plan
Sampling, Random or Systematic



USING GROUP DECISION-MAKING TOOLS
QUESTIONS
TOOL
What's the Group's Situation?
Trying to Generate Ideas
Can Group Generate Ideas Quickly?
BRAINSTORMING
Do Group Members Need Time Before Ideas will "Flow?"
BRAINSTORMING (allow "think" time up front)
Trying to Reach a Decision on Ideas
Decision Criteria Simple?
Yes
> 10 Ideas?
Yes
MULTIPLE VOTING
No
RANK ORDERING
STRUCTURED DISCUSSION (To Consensus)
No
DECISION MATRIX

DMAIEC Improvement Story Review Form
Part 1 - The Search for Causes

DMAIEC Step	Objective/Questions	Comments
Define the Reason for Improvement	**Why is this an important problem to be addressed now?** • *Was the problem selected based on a customer-focus?* • *Was data used to confirm there is a problem?* • *Does the indicator reflect the problem theme?* • *Was a schedule developed to work the problem?* • *If a team was used, are the members appropriate?*	
Measure the Current Situation	**What is the current "production" process, are there important components of the problem?** • *Was the "production" process identified here (if possible)?* • *Was the problem stratified to a manageable "piece?"* • *Was a target established, based on customer needs?* • *Was a specific problem statement identified?*	
Analyze the Process	**Why is the problem occurring, what are the important process variables or root causes?** • *Was a Cause & Effect Analysis performed?* • *Were important process variables/root causes identified?* • *Were these verified with data?* • *Are the variables/causes actionable?*	

Notes:

DMAIEC Improvement Story Review Form
Part 2 - The Search for Solutions

DMAIEC Step	Objective/Questions	Comments
Identify and Evaluate the Countermeasures	**What can be done to improve the situation, practical methods?** • *Do the identified countermeasures address the important process variables/root causes?* • *Can the team implement the countermeasures?* • *Are the countermeasures cost-beneficial?* • *Will/Do the countermeasures achieve the desired target for improvement?* • *Was an Action Plan developed (5W1H)?* • *Were the barriers and aids to implementation considered?* • *When are results expected to be seen?*	
Execute Countermeasures & Check the Results	**Did the changes reduce the problem or improve the process?** • *Were the process variables/ root causes impacted "positively?"* • *Did the indicator selected in "reason for improvement" move in the desired direction?* • *Was the improvement target achieved?* • *If not, is there an understanding of why?*	
Control the Process	**Have the successful changes been made a part of the "production" process?** • *Has a means of standardizing the successful changes been identified (procedure, standard, protocol, specification, etc.)?* • *Has responsibility (and authority) to standardize the changes been delegated?* • *Have opportunities to replicate successful changes been identified?*	
Plan the Next Steps	**What's left of the problem, what are the future plans?** • *What could have gone better in the project?* • *What remains of the original problem?* • *What are the plans to address this?*	

Notes:

APPENDIX A. ANSWERS TO EXERCISES

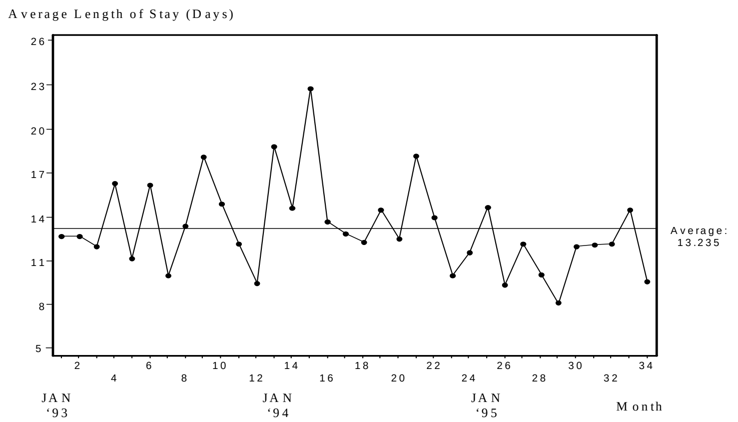
Here are our answers to some of the exercises presented in Section 10. For the discussion-type questions, we've given our "best" answer. You may have another answer that works.

A.1 IMPROVEMENT METHODS

These were all exercises that addressed your specific processes. Sorry, we can't answer any of these for you!

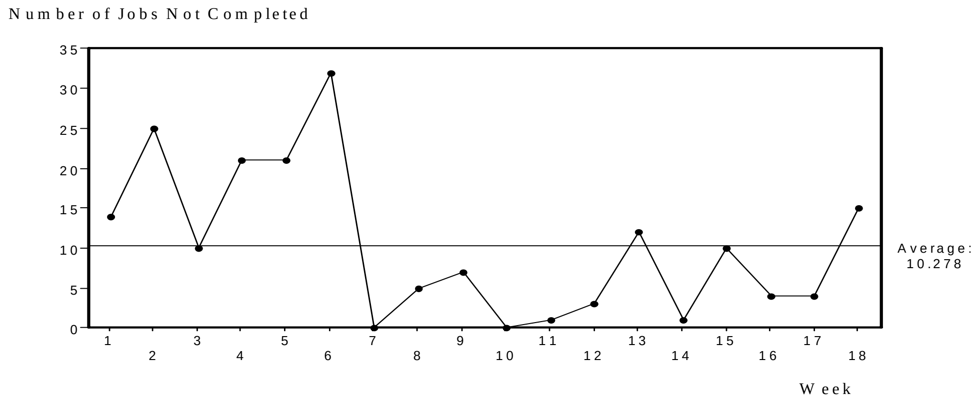
A.2 MEASURING PERFORMANCE *(Graphs and Charts)*

3. Average Length of Stay (LOS) for patients receiving coronary bypass operations (with cardiac catheterization - DRG-106):

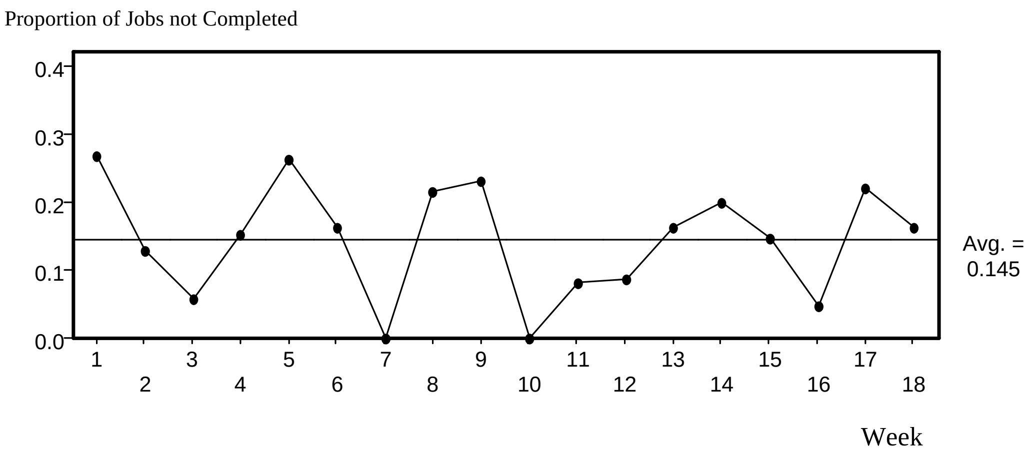


Interpretation: *After a peak in January, 1994, it appears that some process changes have been made that are causing improvement. Although there is month to month variation in the process, the 1995 data is significantly different than the previous process output.*

4. Cable installation company's number of jobs ordered each week and the number of jobs which cannot be completed the first attempt:



Interpretation: *From this graph, it appears that an improvement in the number of jobs not completed on the first attempt has occurred. Starting on week 7, there is a significant decrease in the number.*



Interpretation: *From this graph, though, there* ***does not*** *appear to be a decrease. The proportion of jobs not completed on first attempt has not changed, even though there is week to week variation. The point here is simple - whenever the value of an indicator depends on some* area of opportunity*, in this case the number of jobs attempted, we should plot the* rate *or* proportion, *rather than the individual number.*

(*Section 4 Topic*) *Contingency Table Analysis:*

Observed Counts

	Week						
	1	**2**	**3**	**4**	**5**	**6**	**Total**
Jobs not completed	14	25	10	21	21	32	123
Jobs completed	38	167	161	116	59	163	704
Totals	52	192	171	137	80	195	827

Step 1. State the Hypotheses:

- *Null Hypothesis (H_o)* **-** There is no relationship (i.e. independence exists) between the week and the proportion of jobs not completed.
- *Alternative Hypothesis (H_a)* **-** There is a relationship between the week and the proportion of jobs not completed.

Step 2. The Significance Level of the Test (α) is 0.10.

Step 3. The Rejection Region - The table is 6 rows by 2 columns. The degrees of freedom are then (6 - 1)(2 - 1) = 5. At the 0.10 risk level, the chi-squared (χ^2) critical value (from the table) is 10.24.

Step 4. The expected counts matrix is developed and the *test statistic* is calculated:

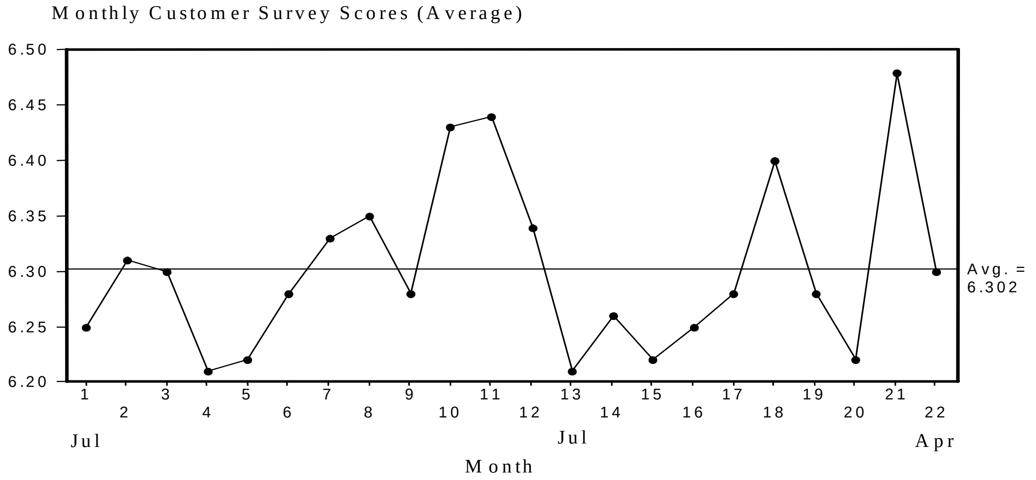
Expected Counts

	Week						
	1	**2**	**3**	**4**	**5**	**6**	**Total**
Jobs not completed	7.73	28.56	25.43	20.38	11.90	29.00	123
Jobs completed	44.27	163.44	145.57	116.62	68.10	166.00	704
Totals	52	192	171	137	80	195	827

χ_0^2 = 5.09 + 0.44 + 9.36 + 0.02 + 6.96 + 0.31 + 0.89 + 0.08 + 1.64 + 0.003 + 1.22 + 0.05 = 26.06

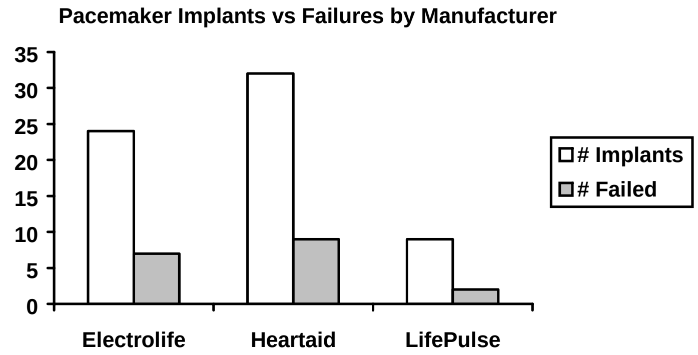
Step 5. The *test statistic (26.06)* is greater than the critical value of 10.24. Therefore, we would *reject the null hypothesis* in favor of the alternate, i.e. there *is* a difference in the proportion of jobs not completed by week.

5. ***Customer satisfaction survey results - Hotel Chain**:* Here's a line graph of the data.



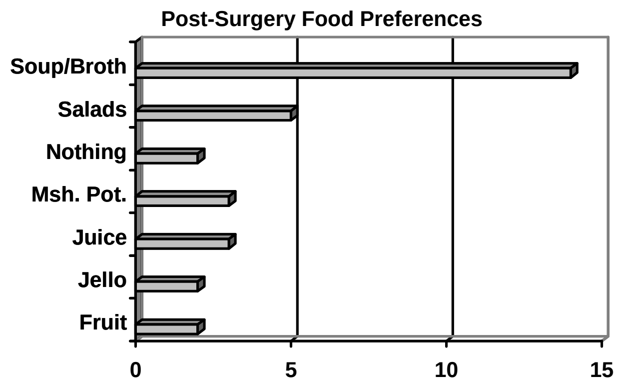
Interpretation: *It appears that there's a lot of variation in the customer's response to the "will you recommend this hotel?" question. During months 13 - 17 there appeared to be a "slump" in the hotel's rating. "What's going on here," management may ask. Extra Credit: ask one of your Black Belts to put this data on a control chart and help you interpret it.*

6. ***Pacemaker failures by manufacturer***: A simple bar chart is one way of displaying this data:

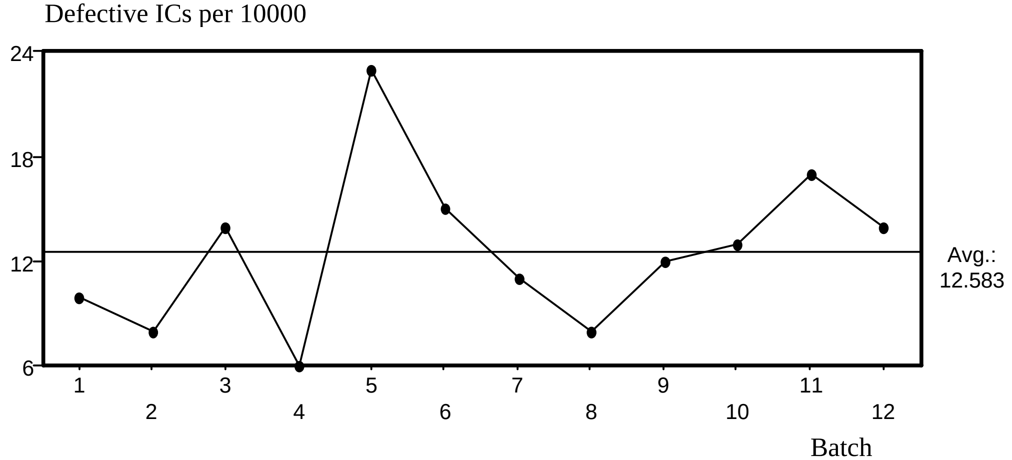


Interpretation: *From this graph, though, there* ***does not*** *appear to be much difference between manufacturers.*

7. ***Post-surgical patients - food preferences*****:**

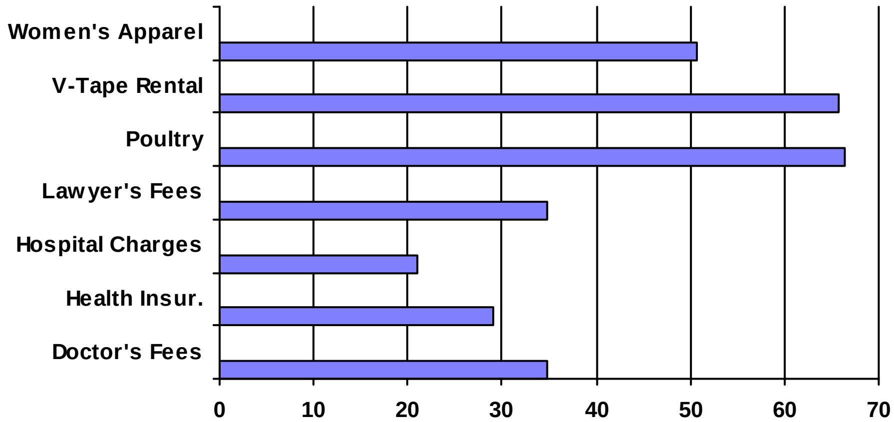


8. ***Defective Integrated Circuits (ICs) per 10,000 ICs:***



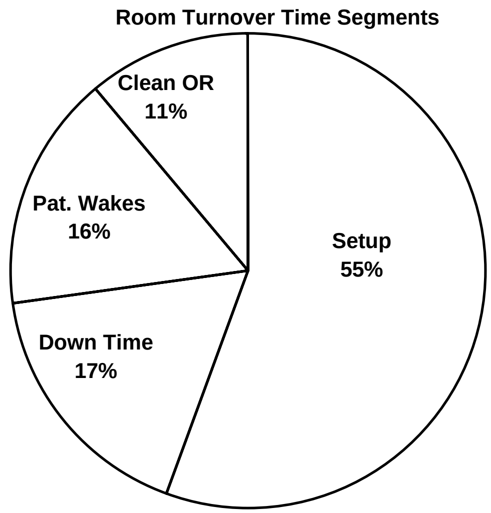
Interpretation: *Although there is batch to batch variation, we don't see any evidence of improved or degraded quality.*

9. ***Products/Services rated by "Value:"***

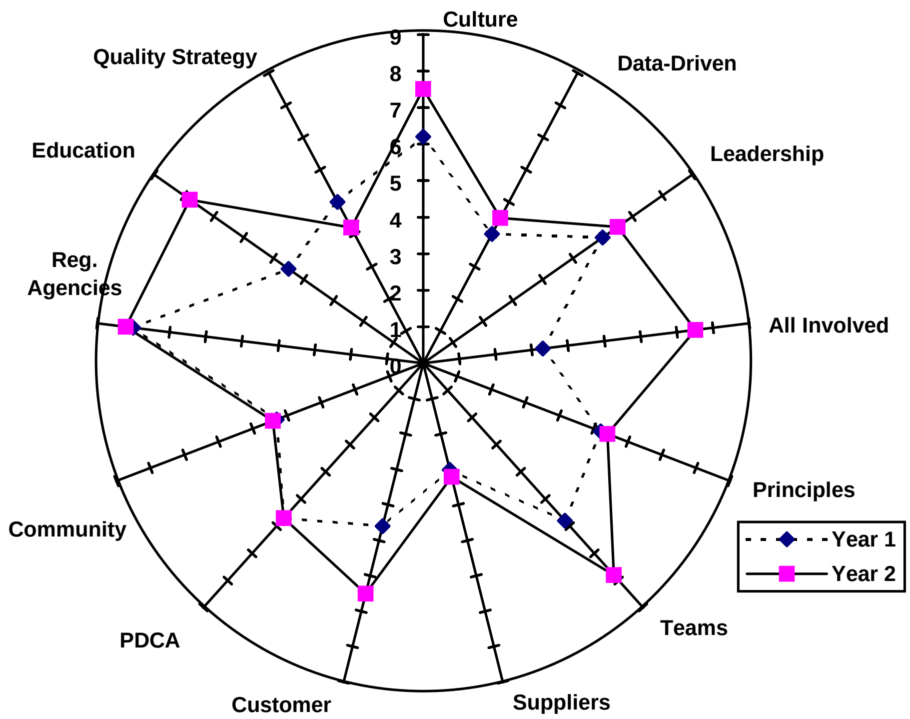


Interpretation: *Well, what can we say? Poultry and videotape rentals are perceived to be a better value than hospital charges, health insurance and doctor's fees!*

10. ***Room turnover time segments:***



11. ***Employee Survey - Engineering Firm Total Quality Management practices:***



12. ***Classification of variables by type of data (measurement or count):***

Indicator/Variable	Type (M or C)
Concentration of a chemical solution	Measurement
Frequency of failure of an equipment	Count
Time to process expense account	Measurement
Number of hours an antibiotic is effective	Measurement
Percentage of Returns to Surgery	Count
Salary and Supply Expense	Measurement
Number of corroded tubes in a heat exchanger	Count
Daily fuel consumption of your car	Measurement
Dollar variance from budget	Measurement

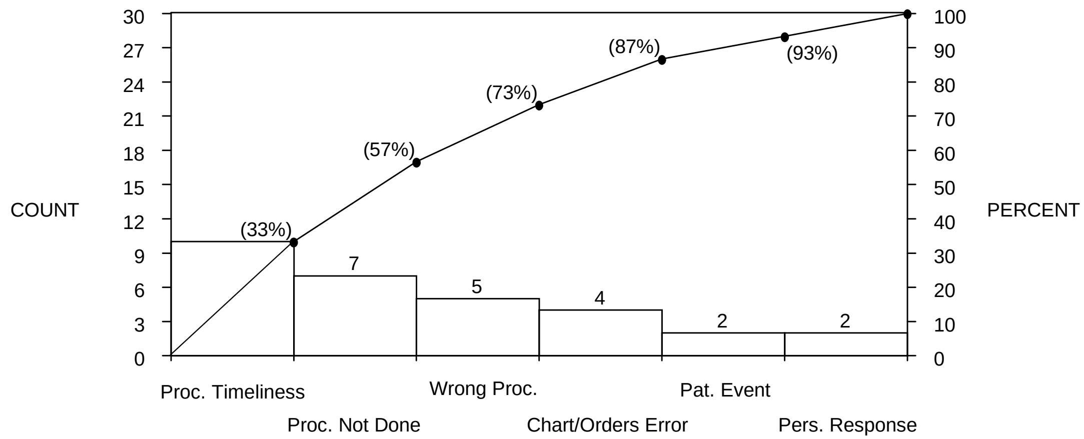
Indicator/Variable	Type (M or C)
Time to prepare a shift report	Measurement
Number of employee Slips and Falls	Count
Number of Medical Record errors	Count
Dollars in Accounts Receivable	Measurement
Days in Accounts Receivable	Measurement
Number of linen stock outs	Count
Amount of linen supplied per day	Measurement
Interest Rate for Capital Loans	Measurement
Patient Length of Stay (in days)	Measurement
Customer Complaints	Count
Crack Length on aircraft wing structural member	Measurement
Customer Satisfaction (1 - 7 Likert Scale)	Measurement
Tire Pressure	Measurement
Length of wire between utility poles	Measurement
Number of thermal cycles for a pressure vessel	Count
Time between medication administrations	Measurement
Time between equipment failures	Measurement
Amount of drug administered	Measurement
Number of sutures	Count
Blood Pressure	Measurement
Potassium concentration in blood	Measurement
Time to process travel request	Measurement
Average monthly rainfall	Measurement
Barometric Pressure	Measurement
Number of copies per minute	Count
Computer central processor speed	Measurement
Computer hard drive memory capacity	Measurement
Infant birth weight	Measurement
Calories in a chocolate bar (with almonds)	Measurement
Percentage of burn area on a fire victim	Measurement
Light intensity of a fluorescent lamp	Measurement
Battery voltage	Measurement
Power output of a diesel engine	Measurement
Locomotive axle diameter	Measurement
Absorbed radiation (Roentgen Equivalent Man - REM)	Measurement
Size of a diamond in an engagement ring (carats)	Measurement
Pump flow rate (gallons per minute)	Measurement
Acidity of gastric juices (pH)	Measurement
Patient care multiplier (hours of care/patient day)	Measurement

A.3 PICTURES OF THE PROCESS *(Flowcharts and Layout Diagrams)*

The flowcharts can appear in a lot of different forms. We'll trust you on these.

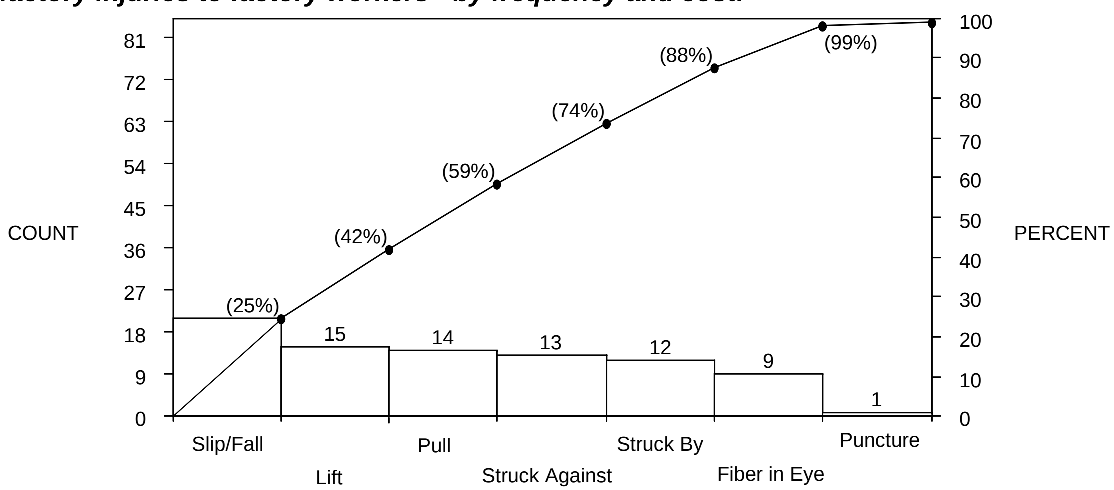
A.4 TOOLS FOR IMPROVEMENT *(Pareto, Histogram, Scatter Diagram)*

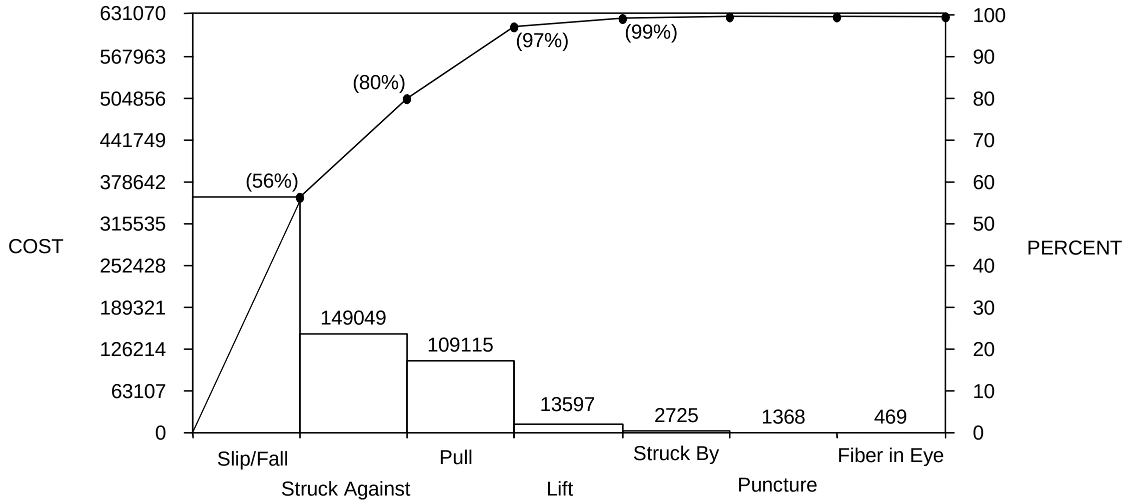
1. ***Patient Complaint Log - recurring complaint types:***



Interpretation: *Three categories - Procedure Timeliness, Procedure Not Done and Wrong Procedure contribute to 73% of the complaints. These should be addressed first in her improvement efforts.*

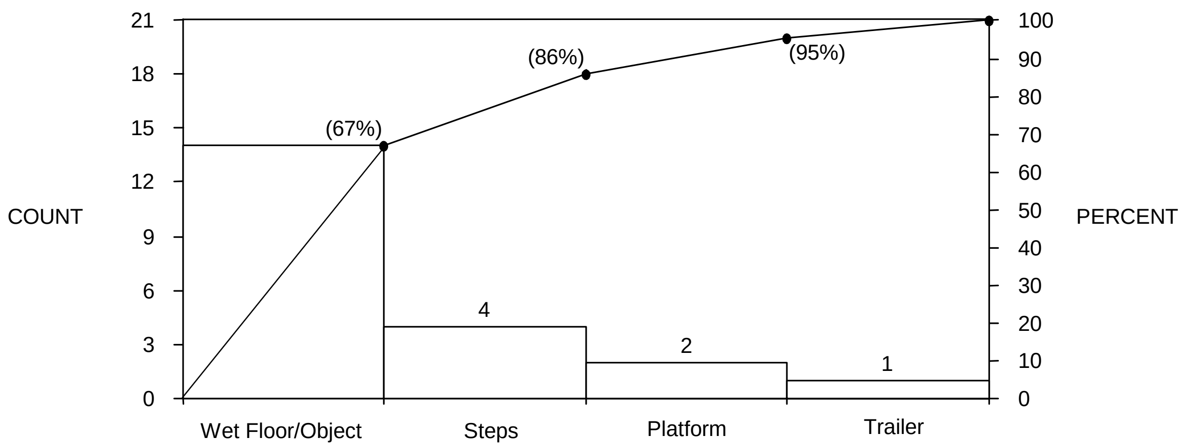
2. a) ***Denim products factory injuries to factory workers - by frequency and cost:***





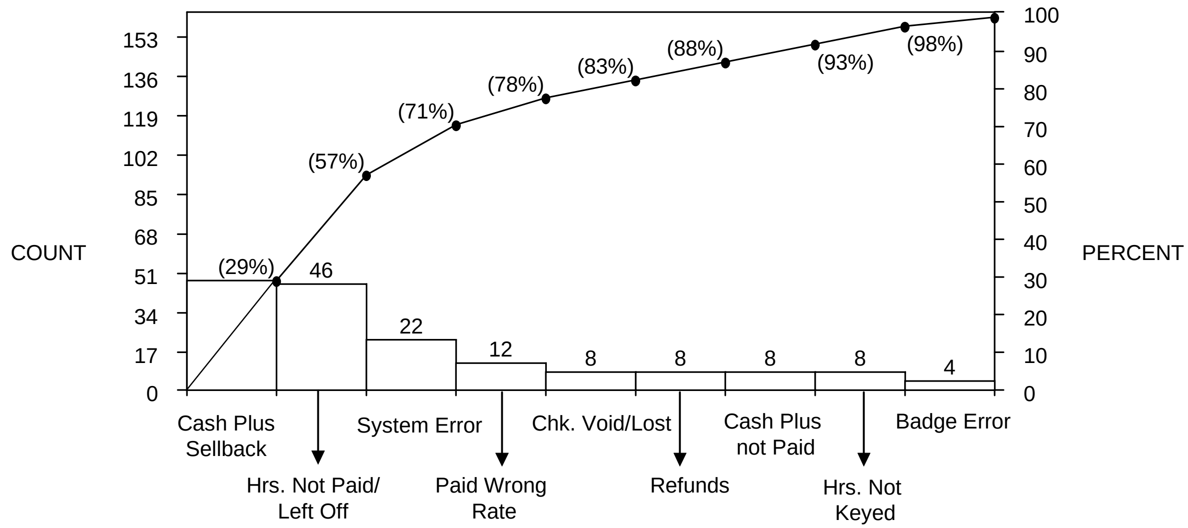
Interpretation: *Slips/Falls are the most important problem to address, both from a frequency and cost standpoint. Struck Against, Pull and Lift are the next three, although they differ in priority (frequency vs. cost). If cost is a good measure of the severity of the injury, management would want to address Struck Against next.*

2. b) ***Slips and Falls - Second Level Pareto:***



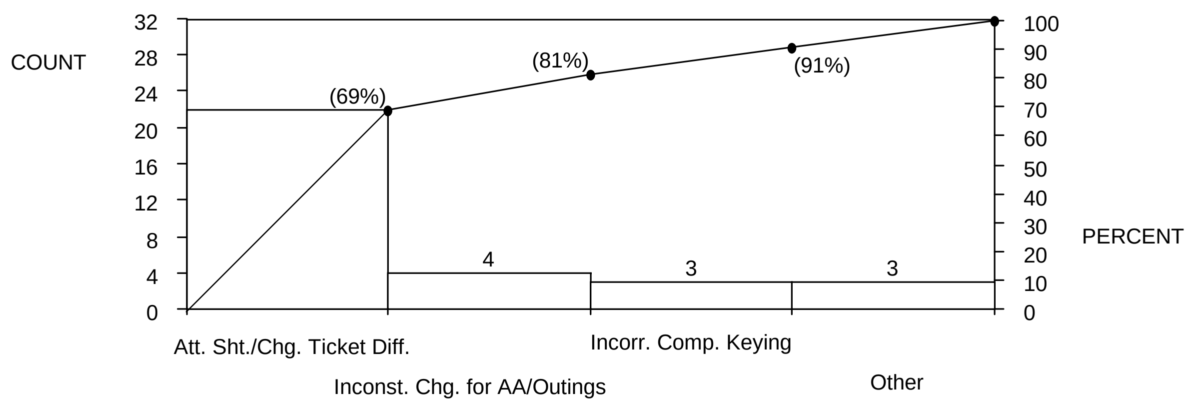
Interpretation: *Here, Wet Floor/Object on Floor is the most important source of slips and falls (by frequency). One question that should be raised regarding this Pareto: "Why was only frequency considered at this second level, why not also cost (as was done above)?"*

3. ***Payroll Department - number of "handwritten checks:"***



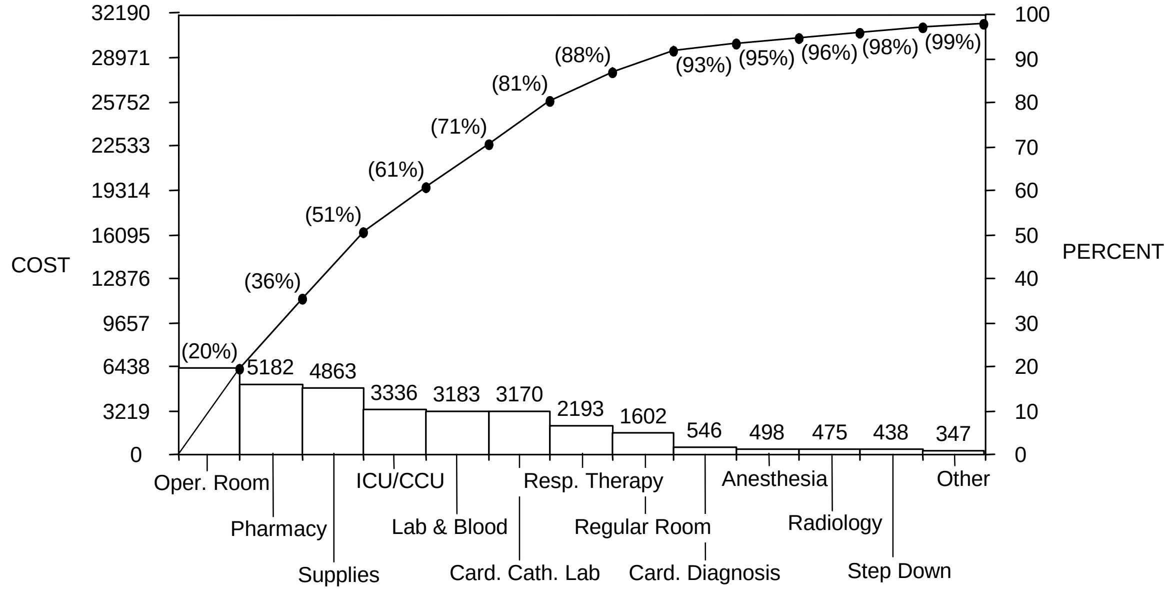
Interpretation: *Here, Cash Plus Sellback and Hrs. Not Paid/Left Off are the "big bars on the Pareto." Cash Plus is a program that converts "unused" sick leave into a dollar amount; employees often "sellback" their Cash Plus accounts when they need extra cash. These sellbacks are supposed to be planned in advance, not requested at the last minute, as was occurring here.*

4. ***Physical therapy department - incorrect therapy bills:***



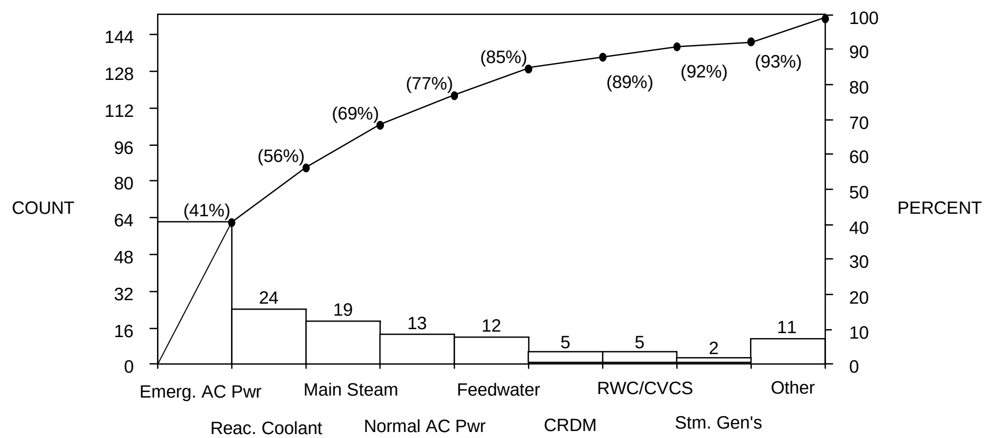
Interpretation: *Collecting this data gave the physical therapists a clear idea of the most frequent source of incorrect therapy bills: Attendance Sheet/Charge Ticket differences. Now they could move into Cause and Effect Analysis to discover why there were the differences.*

5. ***Charges for Coronary Bypass with Cardiac Catheterization:***

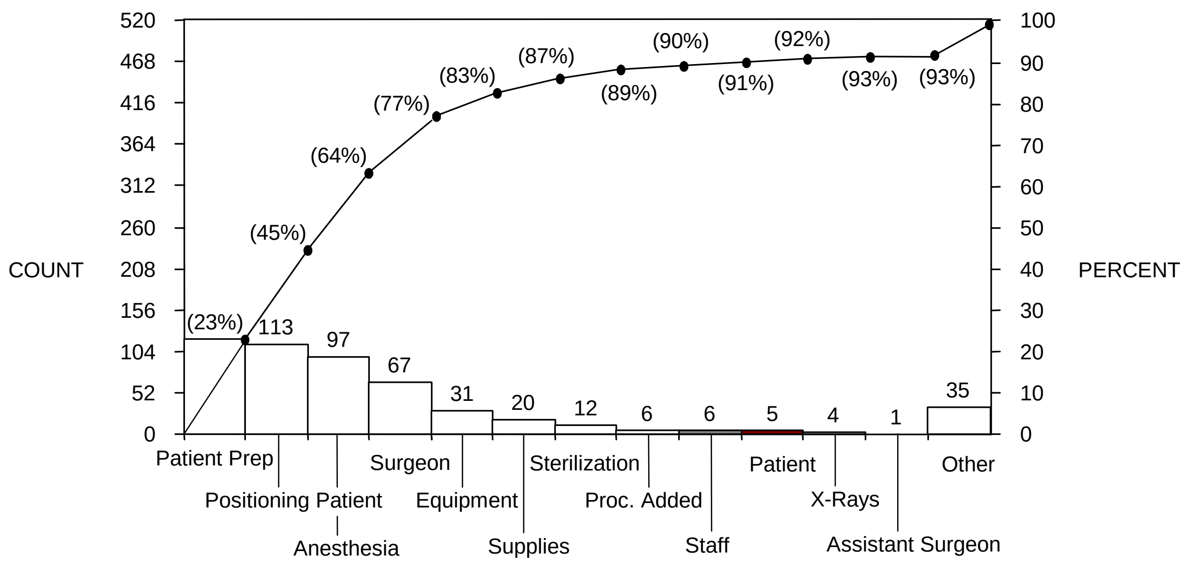


Interpretation: *This is not a good example of application of Pareto Analysis. The charges have been stratified well, but the "problem" has not been turned into a "zero problem." Although Operating Room, Pharmacy and Supplies are the "big bars on the Pareto," we don't know if they are the ones most in need of improvement.*

13. Failures occurring in nuclear plant safety systems:



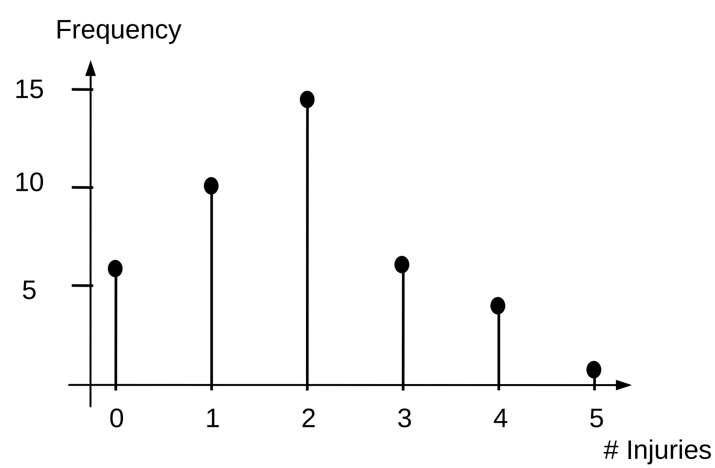
7. ***Operating Room Scheduling - First case of the day delays:***



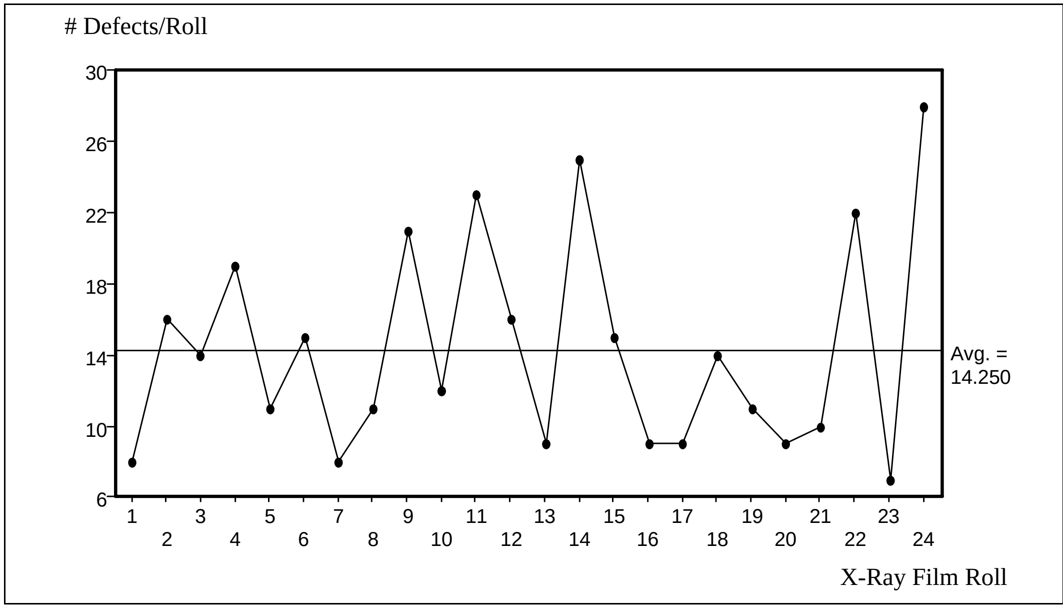
Interpretation: *This Pareto focuses on delays by frequency. If the OR team is working just to reduce the number of delays, that's fine. But if the team is working to start the procedures on-time, they should measure the time associated with each delay and perform a Pareto Analysis of the times.*

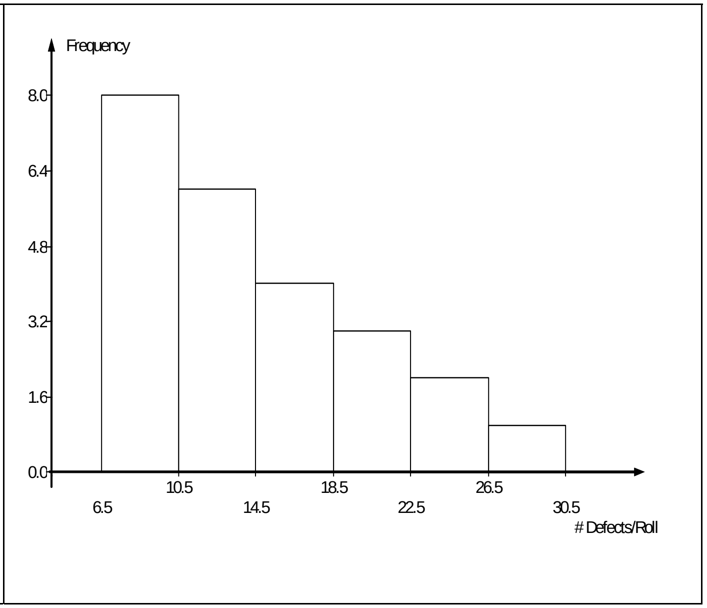
Another point regarding this Pareto is that the categories with less than six events should be grouped with the "Other" category. We thought we'd show you what a Pareto looks like with a lot of "teeny" categories included.

8. ***Fiberglass boat manufacturer - number of employee injuries per month:***



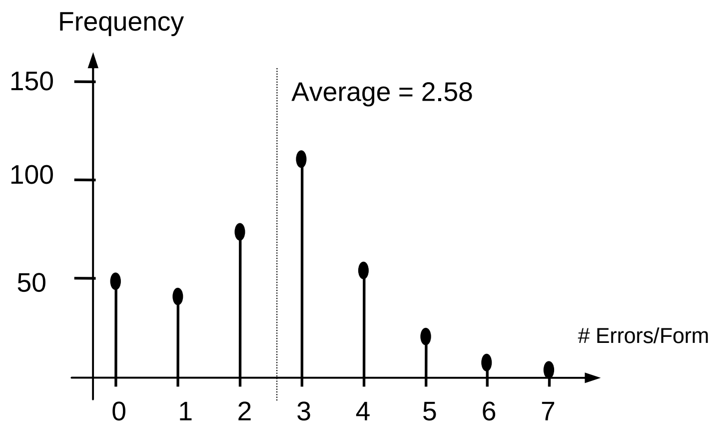
9. X-Ray film defects - line graph and histogram:



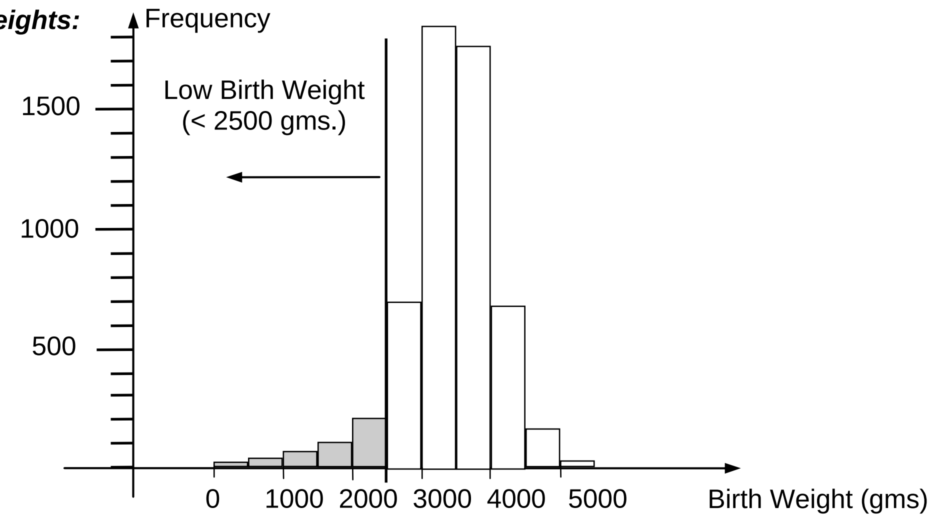


Interpretation: *First, we had to use a histogram to display this data, even though it is count-type. This is because there were about 20 data values, and the frequencies of these data values were not very large. The line graph shows roll to roll variation, and the histogram is skewed, or even truncated. This may indicate something odd with the process, or it may just mean that more data is needed to get a better picture of the variation.*

10. *Number of errors on insurance claim forms:*



11. ***Obstetrics Department annual report - Infant Birth Weights:***

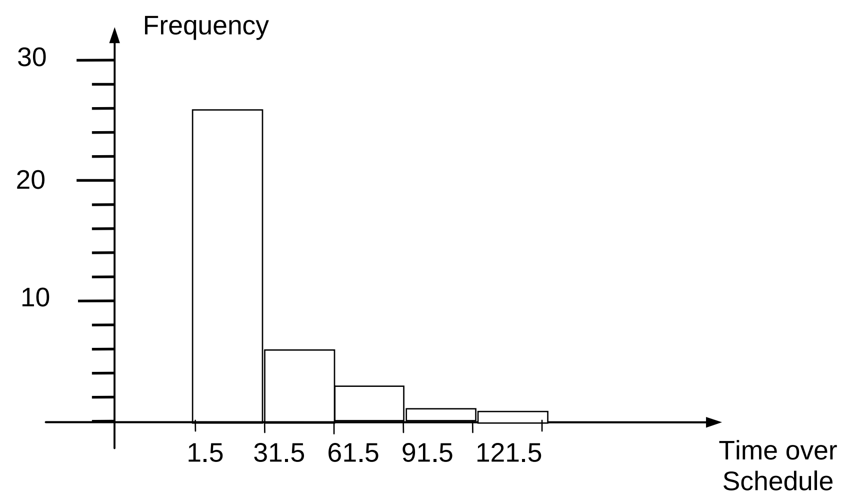


Fraction Less than 2500 gms = (8 + 34 + 62 + 101 + 219)/5537 = 0.08

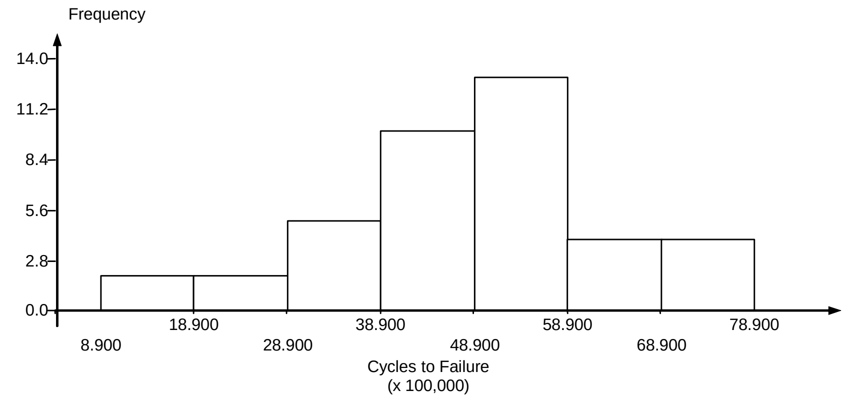
Note: *The last data cell extends from 5001 to 10000 gms. We included all these infants in one cell of width 500 gms. If we had all the data, we could have developed a better picture.*

12. ***Arthroscopic Outpatient surgery finished over schedule:***

Problem: *This is a common problem with data analysis. Here, the manager has taken* ***just*** *the procedures that weren't completed on time and plotted their delays on the histogram. This presumes that these procedures are "special," just because they didn't meet the "spec." Plot all of the data (preferably, first on a line graph or control chart) to see if there are trends, etc. Then take all the data and plot it on the histogram to get the "shape" of the process. This will help the manager see if the process is off-center, or if its variation is too large.*

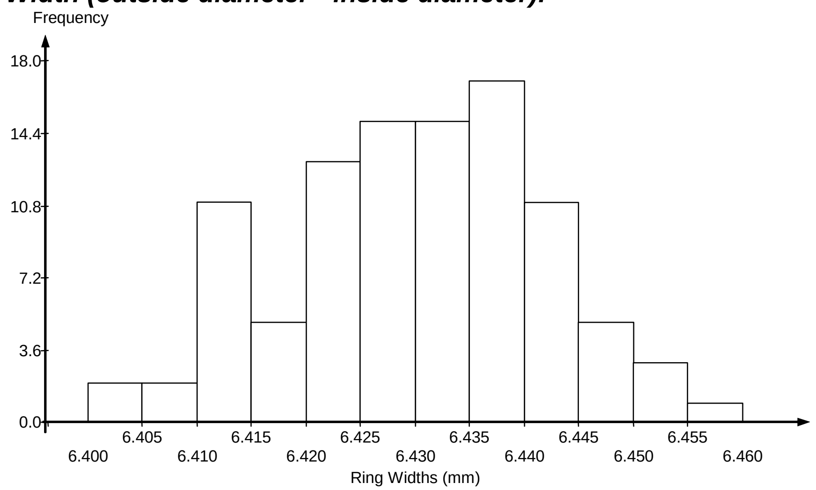


13. ***Replacement hip prostheses - number of cycles to failure:***



Warranty: *If the company wishes to keep the "return rate" below 10% of the hip replacements manufactured, then from this sample of 40, we want to know the time at which 4 (10% of 40) failed. From the histogram, this appears to be 2,890,000 cycles. At 100,000 cycles/year, the hips could be guaranteed for about 29 years. There is a lot of variation in the cycles to failure - the manufacturer may want to investigate why.*

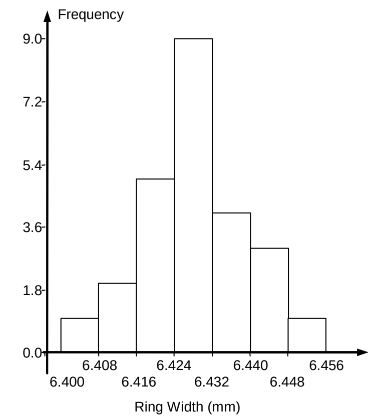
14. ***Diesel Engine Piston Rings - Width (outside diameter - inside diameter):***



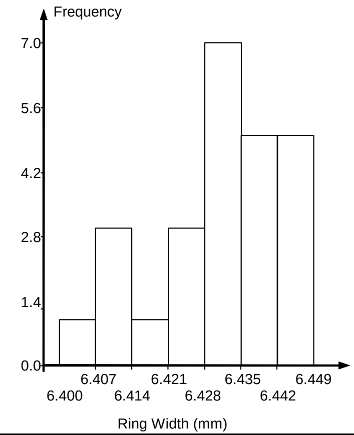
Interpretation: *There is wide variation in the overall ring widths. At this stage, we don't know whether it's due to ring to ring variation, or within-ring (positional) variation, or both. See the next page for histograms by ring position.*

The 0 Degree Position shows a symmetric distribution of ring widths. The variation of this position, though, is similar to the overall sample. The 90 Degree position is skewed and may even be a mixture of two processes. This position's skewness accounts for the "flatness" of the overall distribution on the right side. The 180 Degree Position is also "flat" and may also be a mixture of two or more processes. The 270 Degree Position is similar to the 0 Degree Position. It is symmetrical and its variation is the same as the overall distribution. Stratifying the data has identified at least one significant factor - the Piston Ring Position contributes to the overall variation. The analysis should next investigate why the 90 and 180 Degree Positions are different from the 0 and 270. There are other factors at work contributing to the overall ring variation.

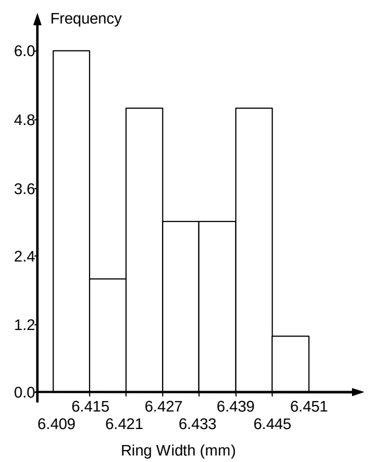
0 Degree Position



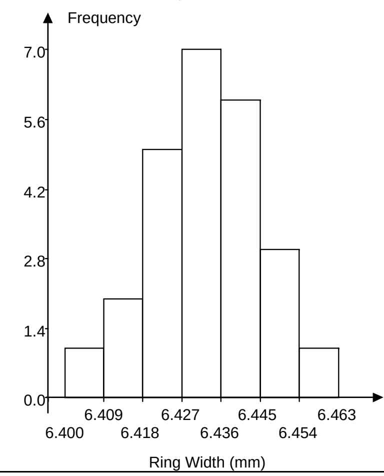
90 Degree Position



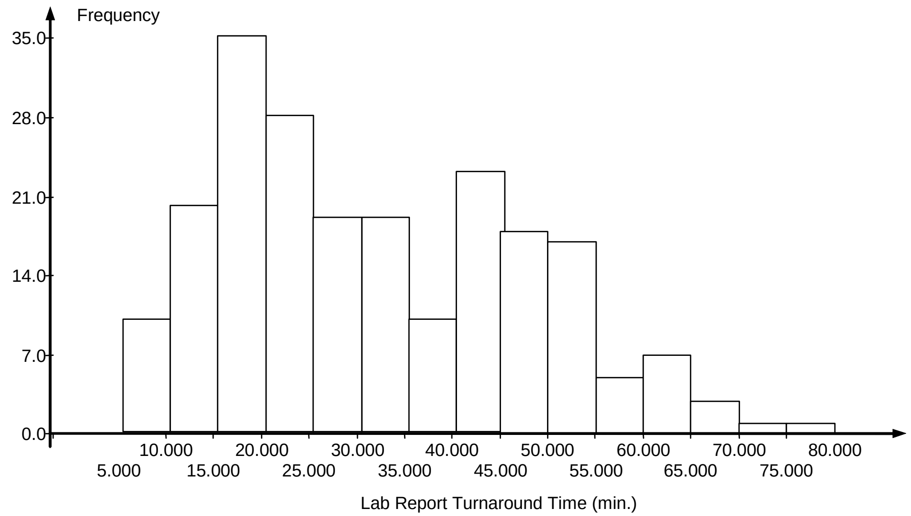
180 Degree Position



270 Degree Position

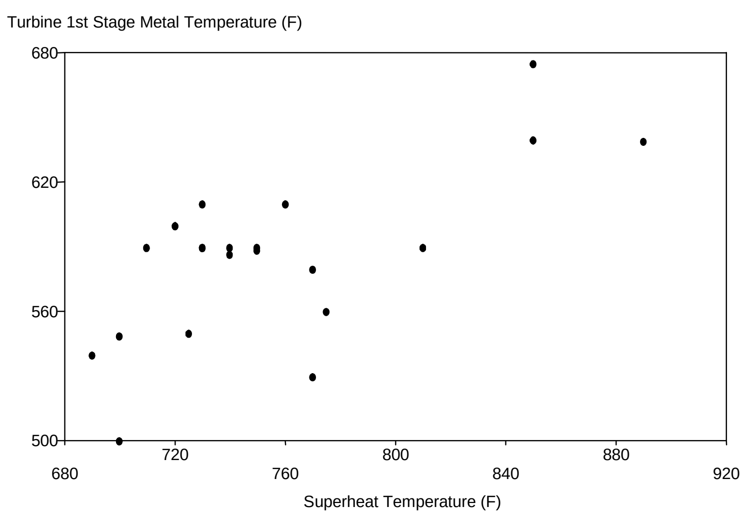


15. ***Turnaround times for tests ordered from the clinical laboratory***:



Interpretation: *At first glance, it appears as if there are two or more processes mixed together in this sample of data. Perhaps different types of laboratory analyses are mixed, or "stat" and "non-stat" requests are mixed. This data is crying out to be stratified.*

16. ***Power Plant Boiler Superheat Temperature vs. Turbine 1st Stage Metal Temperature:***



Interpretation: *There is a weak relationship between these two variables as shown by the scatter diagram. In this case, "theoretically" there is a lag between an increase in boiler superheat temperature and subsequent increase in the turbine metal temperature. We could ask how the data was collected to begin to see if perhaps there is a stronger than shown relationship between these variables.*

17. *Colonoscopy procedure scheduling - combining time segments:*

Maynard: Average Time: 22 + 27 + 15 = 64 minutes

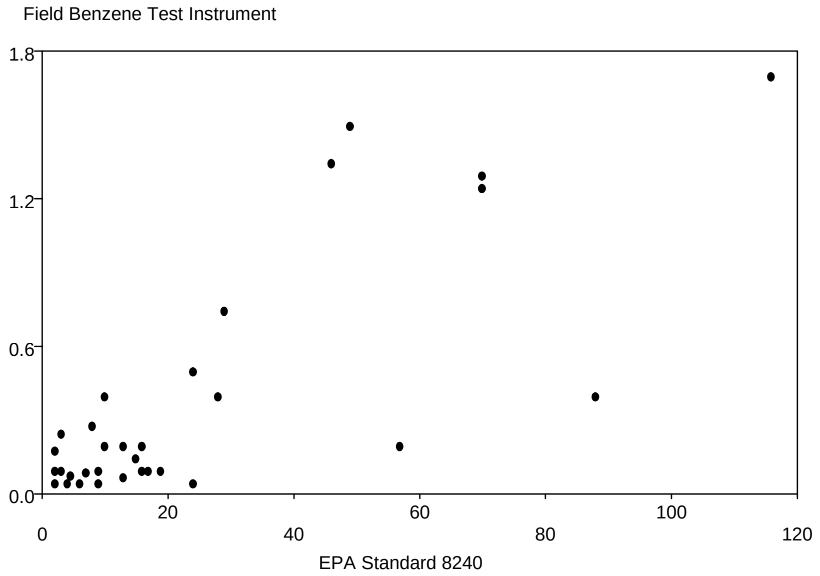
Standard Dev.: $\sqrt{7^2 + 8^2 + 5^2} = 11.75 \text{ minutes}$

Rhew: Average Time: 22 + 42 + 15 = 79 minutes

Standard Dev.: $\sqrt{7^2 + 11^2 + 5^2} = 13.96 \text{ minutes}$

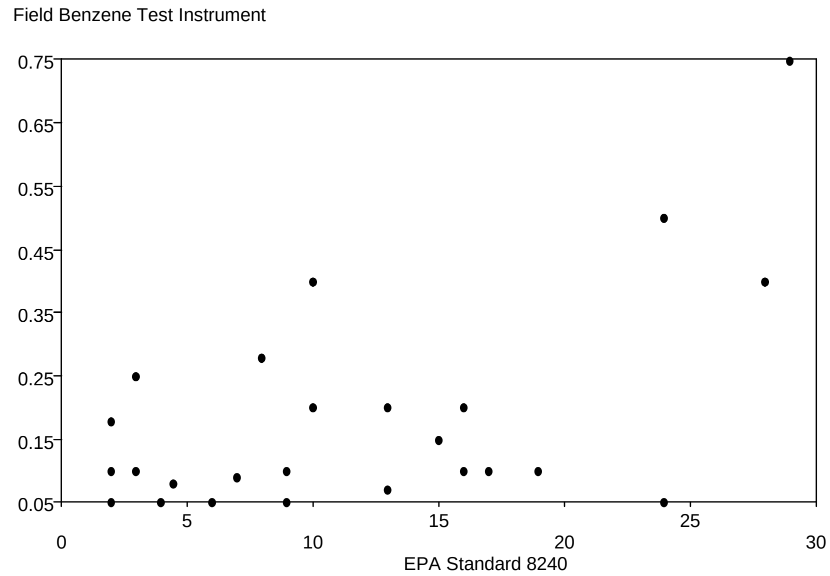
Scheduling Colonoscopies: *This is a "balancing act." If we set the schedule at the average time, then about half the time the schedule will run ahead, half the time behind. If we set the schedule at the average plus some multiple of the standard deviation (1 or 2), then we increase the probability that the procedure will be done within the allowed time. The downside to this, though, is that there will be "doctor down time" after many procedures.*

18. *Benzene levels in soils - field instrument vs. EPA standard method 8240.*



Correlation Coefficient: 0.780

Interpretation: *The Scatter Diagram does not seem to show good correlation between the standard method and the new field instrument. The correlation coefficient of 0.78 seems to indicate reasonable correlation. However, when the lower range of the data is plotted (below), this correlation decreases to 0.567, not very good.*



Correlation Coefficient: 0.567

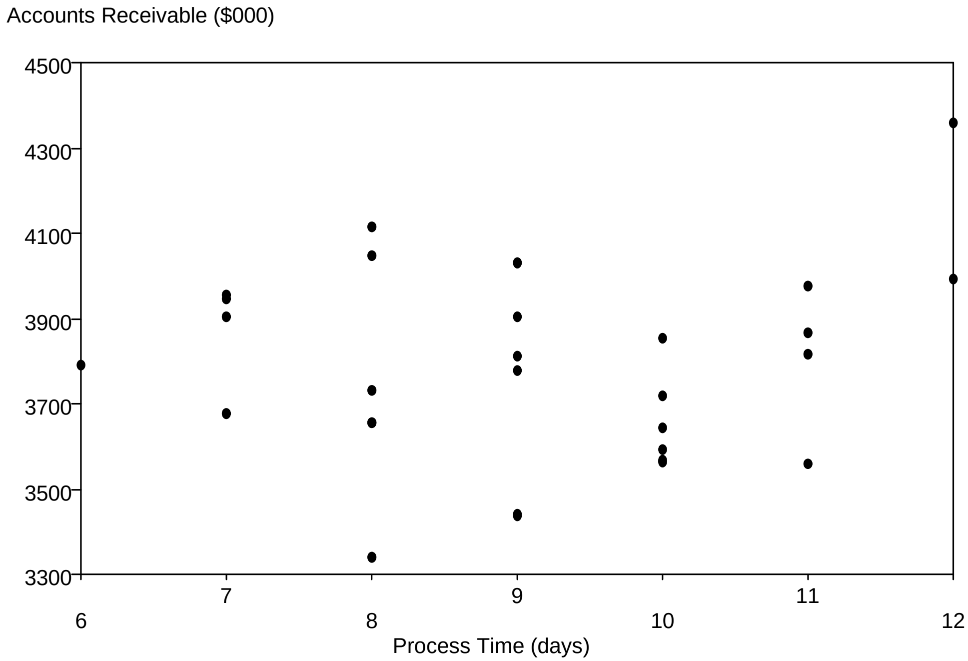
19. ***Surgical procedure completion times:***

Average Completion Time: 7:00 am + 3 x 1 hour = 10:00 am

Standard Deviation: $\sqrt{15^2 + 15^2 + 15^2} = 26 \text{ minutes}$

Adding and subtracting two standard deviations from the average completion time (2 x 26 minutes = 52 minutes) translates into a late completion time of about 10:50 am, and an early completion time of about 9:10 am.

20. ***Medical Records - Process Time vs. Accounts Receivable:***



Interpretation: *Not much correlation here. The Correlation Coefficient is 0.113, indicating that this variable explains only about 1.3% of the variation in Accounts Receivable dollars (the square of the Correlation Coefficient is used - the Coefficient of Determination).*

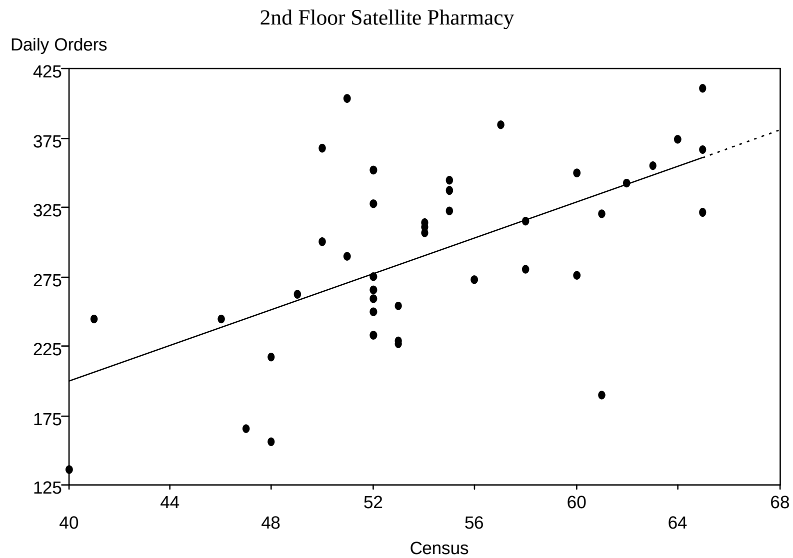
21. ***Valve stem/gate assembly:***

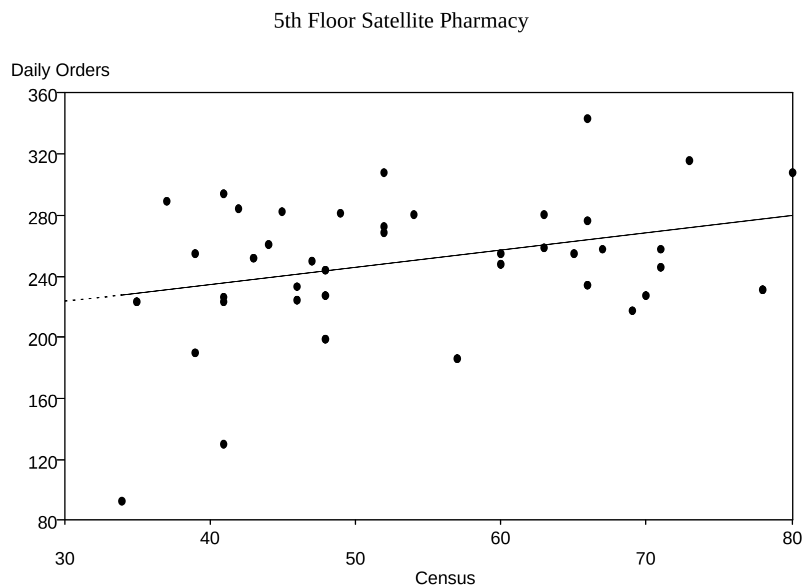
Expected (Average) Length: 18.00" + 8.00" + 4.00" = 30.00"

Standard Deviation: $\sqrt{0.03^2 + 0.02^2 + 0.02^2} = 0.041''$

Comparison to Specifications: *If the spec limit is 30.1", then the average assembly length plus three standard deviations is 30.00" + 3 x 0.041" = 30.123." The current process is not capable of consistently meeting the customer specification*.

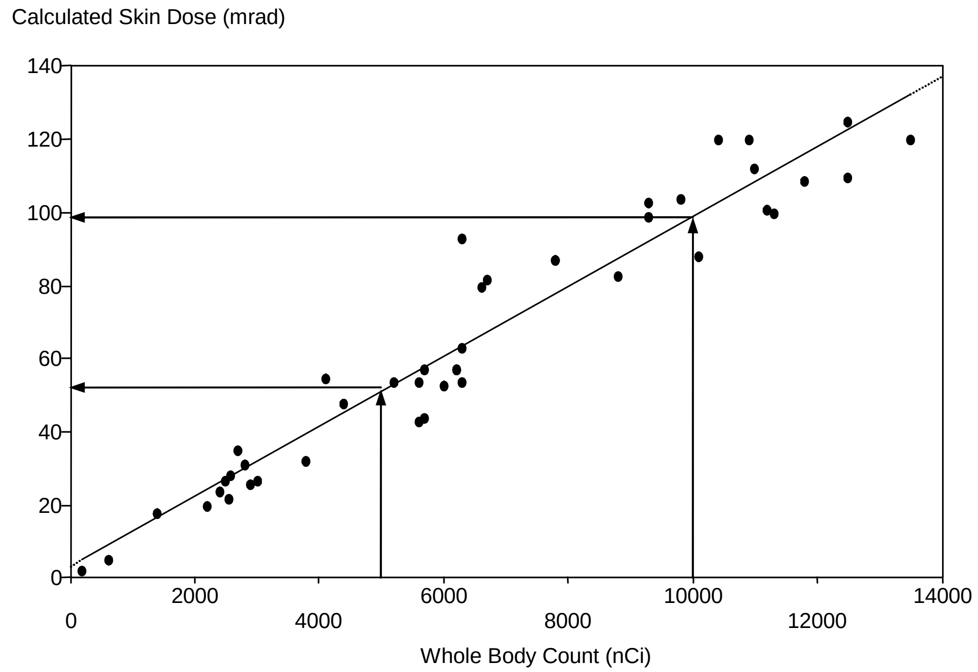
22. ***Satellite Pharmacy - Census vs. No. of Orders:***





Interpretation: *Neither Scatter Diagram shows much correlation between Census and Orders. Census explains about 35% of the variation in Daily Orders for the 2nd Floor Pharmacy, only about 10% of the variation in Daily Orders for the 5th Floor Satellite Pharmacy. The next avenue of attack was to investigate the number of patients admitted to the units served by these Pharmacies.*

23. *Nuclear plant personnel - whole body count vs. calculated skin dose.*



Correlation Coefficient: 0.964

Linear Regression Equation: CSD = 3.01 + 0.01 WBC
(CSD - Calculated Skin Dose, WBC - Whole Body Count)

Interpretation/Prediction: *Here, very good correlation has been established between the two variables. Whole Body Count explains 93% of the variation seen in the Calculated Skin Dose. For the workers who have measured Whole Body Counts of 5000 and 10000 nCi, their Skin Doses would be:*

$$CSD_{5000} = 3.01 + 0.01\ (5000) = 53.0 \text{ mrad}$$
$$CSD_{10000} = 3.01 + 0.01\ (10{,}000) = 103.0 \text{ mrad}$$

A.5 CAUSE AND EFFECT *(The Fishbone Diagram)*

3. ***Lengthy Travel Time - Verification of Potential Root Causes:*** For most cause and effect analyses, a few suspected causes will be identified and data gathered to verify if these suspected causes are important variables. For your "enlightenment," though, we've thought through how we would attempt to verify each of the causes on the fishbone of *Lengthy Travel Time.*

Most of the absence/presence type factors can be verified by collecting travel times when the factor is present and when it is not. But also, for many of these potential causes, we'd like to know *how often* they occur. For example, *how often* is travel time lengthened due to inoperable traffic signals? In fact, doing a Pareto Analysis of the *types of delays* may be a good first step before embarking on detailed time studies:

Potential Root Cause	**Type of Variable**	**Suggestions for how to Verify**
Scheduling - All are Busy	Absence/ Presence	Comparative Histograms of Travel Time when *all* repairmen are busy, 1-2 are available, 3-4 are available.
Scheduling - Home on Duty	Absence/ Presence	Comparative Histograms of Travel Time when repairmen are home on duty vs. in-the-field on duty.
Scheduling - Working in other district	Absence/ Presence	Comparative Histograms of Travel Time when repairmen are working in other districts, vs. working in the district.
Switching Location - Best Place Unknown	Variable	Histogram of times to determine switching location once fault location is determined.
Repairmen Location - Randomly Positioned	Variable	A Concentration Checksheet could be used here in the form of a map of the district where the failures were plotted and the "normal" location of the repairmen also plotted.
Repairmen Location - Working Other Job	Absence/ Presence	Comparative Histograms of Travel Time when repairmen are working other jobs when the failure occurs vs. stationed ready to respond to the failure.
Switches - Manually Operated	Absence/ Presence	Comparative Histograms of Travel Time (or a segment of TT) when switches must be manually operated vs. automatic switching.
Switches - Inaccessible to Repairmen	Variable	Survey of switch locations in the system, group by "access difficulty," time estimates of how long it takes to access each group.
Fault Locations - Hard to Determine	Variable	Histogram of time segment - arriving at area to fault location.
Concern for Customer - Not Sensitive	Variable	This is a "soft" measurement. Perhaps a "sensitivity" scale could be developed - 1 - "moseys" to the job, 5 - faster than a speeding bullet and an assessment of the repair crew done.
Familiarity - New Repairmen	Absence/ Presence	Comparative Histograms - Travel Time for new repairmen vs. experienced repairmen.
Familiarity - Frequent Repairmen Rotation	Absence/ Presence	This seems to be a cause of "new repairmen." If the *new repairmen* factor makes a difference, the rotation policy should be examined.

Potential Root Cause	Type of Variable	Suggestions for how to Verify
Travel Distance - Remote Rural Areas, Limited Access to Islands	Absence/ Presence	Comparative Histograms of Travel Time to Rural vs. Urban Area vs. Island Area failures.
Travel Conditions - Poor Visibility (Night, Trees, Heavy Rain)	Absence/ Presence	Comparative Histograms of Travel Time during “Ideal” conditions vs. “Degraded” conditions.
Travel Conditions - Road Construction	Absence/ Presence	Comparative Histograms of Travel Time through Road Construction areas vs. non-road construction areas.
Travel Conditions - Congested Traffic - Rush Hour	Absence/ Presence	Comparative Histograms of Travel Time during Rush Hour vs. non-rush hour times.
Travel Conditions - Congested Traffic - Inoperable Traffic Signals	Absence/ Presence	Comparative Histograms of Travel Time when Traffic Signals are inoperable vs. operable.
Travel Conditions - Congested Traffic - Season	Absence/ Presence	Comparative Histograms of Travel Time during Season vs. off-season.

4. ***Electrical Splice Team Verification:*** The *Absence/Presence* method of verification requires two conditions: the factor is present when the effect occurs *and* the factor is **not** present when the effect does not occur. The electrical splice team could only verify the former through their Pareto Table.

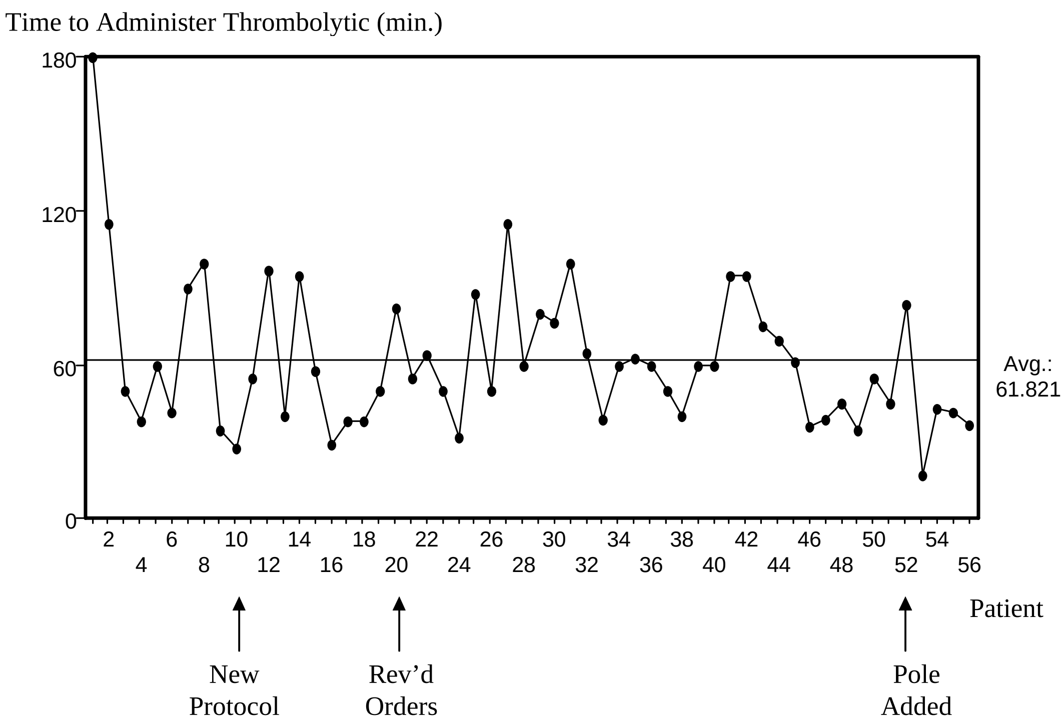
Although the 1/8” clearance specification was not met in 22 of the 30 failures, we don’t know how many splices are *operating* with the spec not met. They need additional evidence to conclude that the clearance problem is, in fact, the root cause of the failures.

5. ***Verifying causes of delay - transport requested to assigned to transporter****:* Similar to Exercise 3, a Pareto Analysis of the types of delays could be performed to identify the most frequent delays. Then, estimate times associated with the individual delay causes to determine the overall impact of these causes.

Potential Root Cause	**Type of Variable**	**Suggestions for how to Verify**
More Calls than Available	Variable	Record the volume of calls, compare to the number of transporters available to respond to the calls.
Can't Hear Radio	Absence/ Presence	Develop a Concentration Checksheet of hospital areas. Test where the radios can and can't be heard.
No Hand-held Radio	Absence/ Presence	We'd have to ask a question here. Are hand-held radios normally issued, or is this a suggested *countermeasure?* If they are normally issued, find out how often the radios aren't available for use by transporters.
Phone System Down	Absence/ Presence	Collect data on the percentage of time the phone system is down. If it's large, then establish the impact on transporter delay.
Beepers Not Working	Absence/ Presence	Collect data on the failure rate of beepers. If it's large, then establish the impact on transporter delay.
Dispatcher Loses Request	Absence/ Presence	Collect frequency data on this event.
Off-Hours Transport Request	Absence/ Presence	Collect frequency data on this event. Then establish its time impact.
Don't Know Who's Available	Absence/ Presence	Discuss with transporter dispatchers.
Transporter Not Available	Absence/ Presence	This one should be covered by "More Calls than Available."
Transporter on Break	Absence/ Presence	Collect frequency data on this event.
Too Few Transporters	Variable	Although this seems like a *countermeasure,* we could look at the demand for transporters against the number available to see if there is a large mismatch.
Transporter Doesn't Answer Beeper	Absence/ Presence	Collect frequency data on this event.

A.6 SELECTING, PLANNING & MAKING IMPROVEMENTS

2. ***Thrombolytic ("clot-busting") agent administration time:***



Interpretation: *Based on the process' performance, adopting the new protocol and the revised orders did* ***not*** *impact the overall administration time. Adding the Pole may be causing a decreased time, but more data is needed to confirm this.*

3. ***Medical Records "Evaporated" Improvement:*** The cycle of improvement must include a "hand-off" to standardization, or "daily management." In this case, the improvement was not standardized. The elements of standardization include a *method, training,* and a *follow-up* or *feedback system.* In this case, although a procedure had been revised and people trained initially, there was no *follow-up* on the improvement. People went back to their old habits and did not acquire the new habit.

4. ***Nuclear Plant - Charging Pump reliability****:* In this case, *standardization* was again the problem. The operators had been notified by memo, and changed their practice for a while, but the memo was not incorporated into plant procedures. Since it was more convenient for the operators to use the manual valves to control flow from the pumps, they went back to their “old habits.”

5. ***Multiple Identical Improvements:* There can be several reasons for this duplication of effort:**

Management not Aware of Improvement Work - When large organizations embark upon a quality improvement journey, each department is often encouraged to identify some product or service that needs improving. If the organization consists of “replicated” departments (i.e. a hospital has several nursing units, a utility has several power plants, and district offices, and a hotel chain has many different hotels.), these departments are bound to have similar problems and, hence, develop duplicate improvement efforts.

To avoid this duplication, it is easy to develop a data base of improvement efforts that are reviewed periodically by management for duplication.

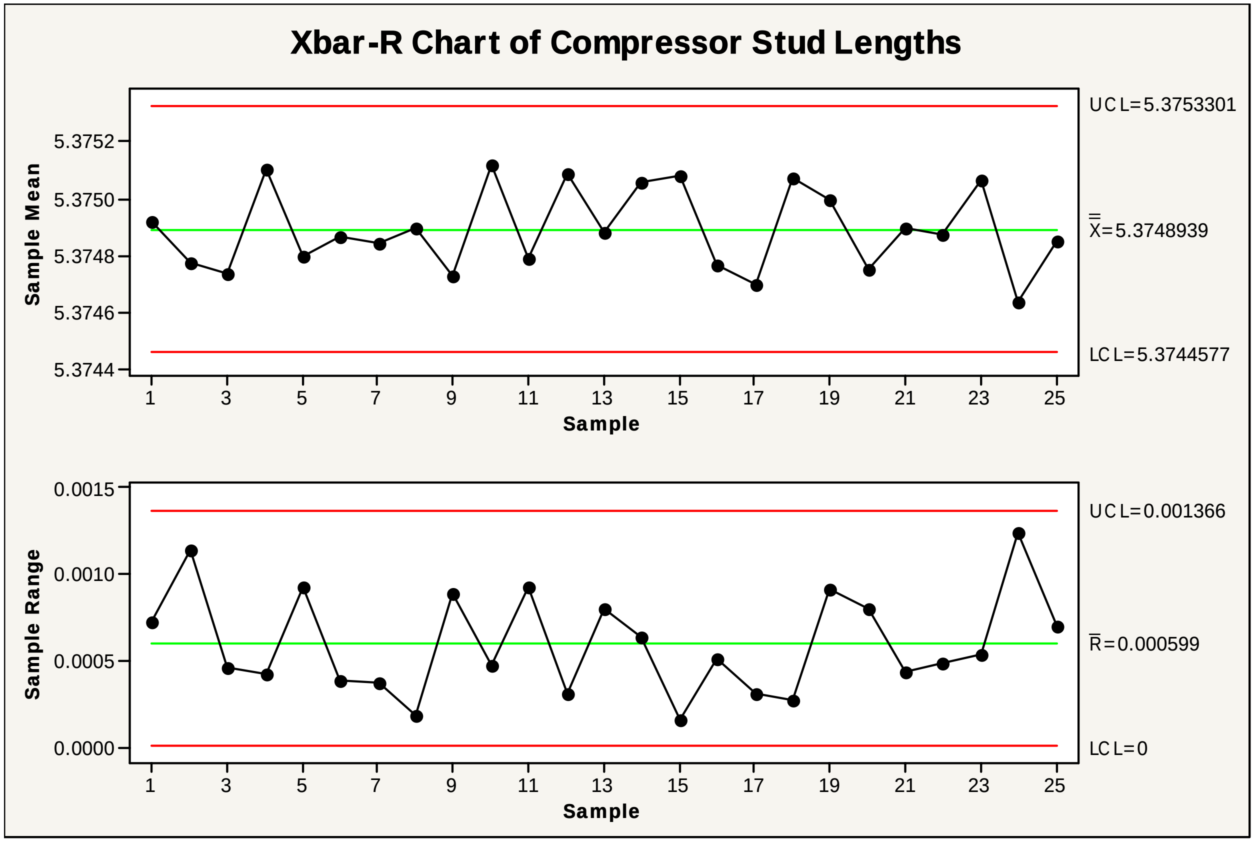
Standardization (or Lack of) - One new vice president of a utility quickly noticed that the company’s two nuclear plants had totally different alarm systems. The “whoop-whoop” sound signaled staff to evacuate the containment building at one plant, but signaled a fire at the other plant. People who traveled and worked at both plants had a hard time keeping them straight (not that the signals were *needed* that often, you understand!).

The new VP vowed that he would standardize these differences between plants. Well, five years later, the signals are *still* different. The point here is that it seems to be human nature to create different systems, even for essentially the same function. Multiple improvement efforts may be necessary simply because of the significant investment in the different “production” processes for the organization’s products and services.

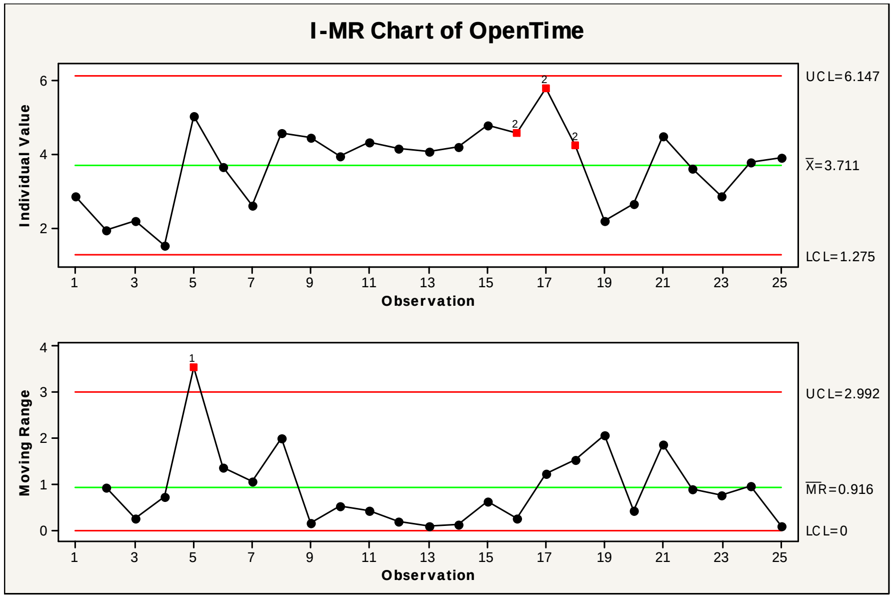
More and more organizations, though, are recognizing the advantages to standardization. A large power plant architect/engineering firm has advertised its “customized standard” power plants. They have realized the significant cost penalties of designing “one-of-a-kind” plants for each customer. Their strategy is to standardize the common systems of the plant, and then assemble these into a “custom” application for the customer.

A.7 MAINTAINING THE IMPROVEMENT (Process Control, Control Charts)

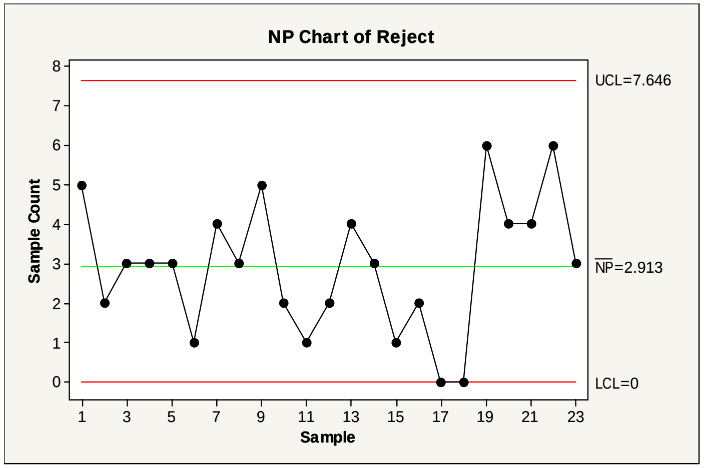
2. X-Bar, R control chart - **Compressor Stud Lengths –** The process does not display any assignable causes of variation – the process may be declared "in control."



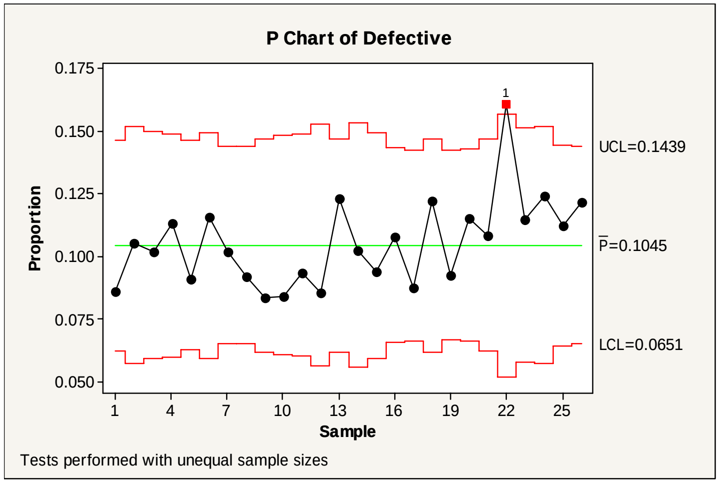
4. X, mR Control Chart **- Butterfly Control Valve -** The range chart shows one out of control point and the Individuals chart signals that 9 points are above the center line. The process is not in control.



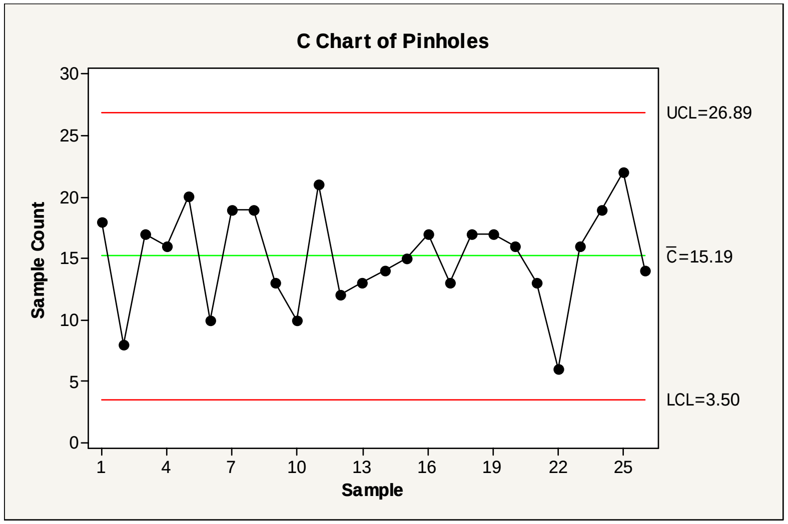
9. *np* control chart - **Motor Rejects -** The process is in control – no special causes of variation noted. However, the supplier's process can be relied on to produce about 3 out of 20 defective motors – around 15% defective!



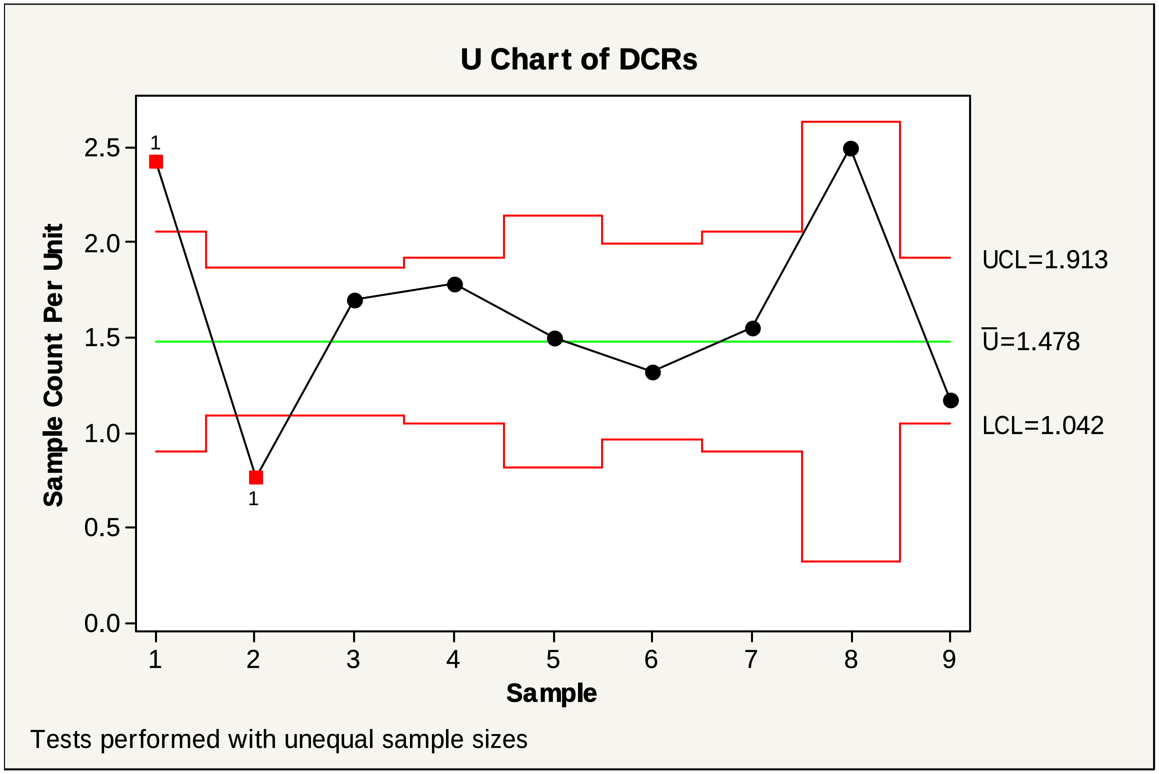
10. p control chart - **Defective Full-Penetration Welds** – The process shows one point outside the control limits – and it appears as though something has changed in the process starting around week 20.



11. c control chart - **Ceramic Paint Pinholes** – The process is under control – it can be expected to produce about 15 pinholes per subgroup.



12. *u* control chart - **Design Change Requests (DCRs) –** Engineer 1 (Maynard) and 2 (Kinney) are "out of control." It would be reasonable to ask why Maynard has a high number of DCRs and why Kinney has a low number of DCRs. Note that while Engineer 8 (Adams) and Maynard have the same rate of DCRs, Adams is part of the "system."



13. ***Pick-a-Chart (Control Chart Selection) -*** Often, one of the difficulties people face with control charts is the question of "Which is the right one?" This exercise is intended to give you some practice going through the logic of the Control Chart Selection Guide. As you develop your answer, note your assumptions. There is more than one way many of these scenarios could be charted.

Scenario	*Control Chart*
1. Each day, the number of units shipped is counted at 12:00 AM.	*Xmr or c*
2. The Sales department keeps track of the number of units sold each day, by type of unit.	*Xmr or c*
3. A laboratory gets a report, once a day, which provides the number of samples analyzed, the average processing time, and the standard deviation of the processing time.	*Number – Xmr, or c* Time – X-bar, S
4. Each day, a technician measures the time she takes tubing a condenser on her shift.	*Xmr*
5. At a ballpark, a hot dog vendor counts the number of wieners sold each game day.	*Xmr or c*
6. A factory worker measures the diameter of valve stems after machining. She takes four stems at random from each hour's production.	*X-bar, R*
7. An engineer measures the cycle time for engineering change orders weekly.	*Xmr*
8. An administrative assistant tracks the number of days it takes customers to pay their bills. She keeps a chart for each of the company's top 6 customers.	*Xmr (for each customer)*
9. A quality consultant tracks the number of days she is on the road each month.	*Xmr or p*
10. A Sales supervisor has developed control charts for her clerks - they track the number of line items entered each day.	*Xmr or c*
11.The power of a motor is measured and is subject to a purchase specification.	*X-bar, R or Xmr*
12. Coatings are purchased in tank car lots. The material is sampled and the chemical composition determined.	*X-bar, R or Xmr*
13. The procedures group has noticed an increase in the number of comments made on their draft procedures being circulated for review. They are wondering if something unusual is going on in the procedure drafting/ review process.	*U*
14. The LAN (Local Area Network) administrator has been trying to improve the reliability of the system. She is interested in seeing if the number of LAN "crashes" has decreased.	*C*
15. This same LAN administrator has also been working on trying to reduce the time required to restore the LAN after it crashes.	*Xmr*
16. The Production Manager is interested in employee absenteeism, measured in days/employee. The corporate staff supplies her with a monthly report, which breaks down this measure into weekly increments.	*Xmr*
17. The Financial Officer is concerned about the utilization of company cars; he suspects that there are too many cars. He begins tracking the number of hours the cars are utilized for business purposes each week.	*Xmr*
18. A production facility wishes to improve the set-up time required when products being produced are changed. They usually make the same product for about two days and then switch over to another product.	*Xmr, X-bar, R or S*
19. A bolt manufacturer must ensure that the tensile strength of stainless steel bolts meets the customers' specifications. About 5000 bolts are produced daily.	*X-bar, R or S*
20. You have been troubled by the number of times your production facility has been stopped due to power interruptions by the local utility. You have records of all production stoppages for the last two years.	*C*

Scenario	*Control Chart*
21. A certain vendor provides you with bolts for your product. Before the bolts are used in your production process, you sample 50 from each box of 1000 and inspect them for defects.	*Np*
22. A large consulting firm prepares about 30 proposals per week for prospective clients. The Sales Department manager is interested in the number of proposals that are not accepted by clients.	*Np or p*
23. An engineering department prepares design changes to improve the performance of a chemical processing plant. They are interested in the number of field change requests, *those changes that are requested by construction engineering because the design change cannot be implemented in the field.*	*U*
24. A Sales Manager tracks weekly sales volumes by number of items sold, dollar amount of sales and items sold per salesperson.	*Number – Xmr or c* $ Amount – Xmr Items – Xmr or c
25. An Automotive Manager is concerned about the quality of a particular brand of tire used on company cars. His primary concern is the possibility of a tire blowout. If the size of the company car fleet stays constant, how should he track this process?	*Np or c*
26. A Records department director is concerned about the errors made by her staff. She asks for help in determining the best chart to use. She tells you that the number of records varies significantly from week to week.	*U*
27. Each month you receive a departmental budget variance report that, among other things, provides the dollar amount you are over or under salary budget, supply expense budget and overtime hours.	*Xmr*
28. A physician thinks that the complications associated with a particular surgical procedure varies from surgeon to surgeon. Each surgeon does a different number of these procedures each year.	*P*
29. A company is interested in using a new vendor to supply control circuits that emit a specified signal for a specified time. They wish to determine if the process used to produce the circuits is in control. They are particularly interested in the signal's duration.	*X-bar, R*

A.8 WORKING ON A TEAM (*Team Skills, Decision Making, Meetings)*

1. *Team Appropriateness & Type:*

Situation	Appropriateness	Type
Diesel Engine Water Leaks	Yes - This is a significant reliability problem, the "why" is unknown, and several different processes could contribute to the leaks (design, operation & maintenance).	Cross-Functional
Architectural Firm - Customer Complaints	Yes - This is a significant customer satisfaction issue, and the designs are produced by different groups of architects.	Functional (include group members)
Employee Safety Record	Yes - The Safety Officer has "jumped to solution." A group of staff with the Safety Officer will have a better chance of getting to the root causes of safety issues.	Cross-Functional
IC Defect Rate	Yes - Here, the individuals are all going off in their own directions. Bring them together to work on the problem.	Cross-Functional
High Length of Stay/Cost for one Physician	Maybe - These personal performance issues are touchy. Perhaps one case manager could work with the doctor to examine which practice patterns are contributing to the stay and cost.	Cross-Functional
Lab Specimen Reporting Delays	Yes - This problem crosses department boundaries - no one department is going to be able to solve it. This is a good case to use to "break down the barriers" between departments.	Cross-Functional
AC Vent Dust	No - This one calls for immediate action. Now, maybe some effort is needed to determine why the *delay* occurred in completing the maintenance request.	N/A
Late Employees	No - This calls for a meeting between the shift supervisor and the employees. Now, some of the improvement techniques might be employed to discover why the employees are chronically late.	N/A
Declining Product Sales	Yes - This scenario calls for a strategic team - one that will understand the company's current situation and develop strategies to correct the situation. This strategy team may charter and manage several "sub-teams" working on individual improvements.	Cross-Functional
Pharmaceuticals Safety Violations	Yes - This should be a team composed of management, not staff. Similar to the above example, this strategy team may charter and manage other improvement projects.	Cross-Functional

2. *Team Appropriateness, Success/Failure Issues:*

Situation	Appropriateness/Success & Failure Issues
Reference Document Computerization	This could be a good improvement project, but the manager has already "jumped to solution." What's the problem that he's trying to address? Who's the customer and what's their "pain?" These issues should be addressed before chartering the team. This team could be headed for failure.
Engineering Practice Problems	This is a good cross-functional team opportunity. Many engineering problems are caused by "interfaces" between disciplines (mechanical, electrical, civil, etc.).
Banking Improvements	Senior management has "noble" objectives in mind, but they've apparently cut middle management out of the "loop." Staff will have a difficult time getting support to work on the improvements and an even harder time implementing changes to improve their processes - this one's headed for failure.
Non-Stocked Spare Parts	Choosing a team to work on this problem is a good idea, but the timing's a bit off. Since the new data base will be installed next month, the team should first investigate what potential impact it will have on their spare parts process. They may want to "hibernate" until after the new data base is up and running.
Reduce Turnover Rate	The nurse manager could be "jumping to solution." We'd recommend that she personally look into the reasons for turnover (sometimes, Human Resources will conduct exit interviews that can shed some light on this) before chartering a team.
Space Expansion Team	Here, the president had already decided what to do. He should just go ahead with this. Chartering a team to "ratify" his decision is not a productive use of teams and can actually be a negative influence on teams. He could also have made the charter clearer. He could have told the team that he wanted to expand the office and asked them to design the best use of the space in the expansion area.
Clinical Quality Teams	This is a difficult issue faced by many hospitals. The physicians' input is needed on improvement teams, but they often don't have time to spend working on these teams. Here, the timing of the meetings could be better, or the physicians could be invited to attend only when their input is critical.
Clinical Pathway Teams	This is a membership and buy-in issue. Since the physicians are one of the primary users of the Pathways, their initial buy-in is critical. This example is similar to the above; the issue of how to get the physicians to participate and accept the Pathways must be part of the improvement strategy.
Power Plant Teams	This commonly occurs when the "quality program" is run by a central corporate department. Corporate management hasn't considered the issue of *how* to encourage improvement teams.
Car Dealer's Sales Practice Team	Here, the salesperson's *incentive* is a key issue. No salesperson is going to share their "secrets" if they are in a competitive commission environment. The car dealer is going to have to address this issue first.
Respiratory Therapy Decentralization	This is a "lose-lose" situation. The patient care units don't want the function, the department head doesn't want to give it up. Administration *could* play "hard-ball," but that will likely lead to an unsuccessful outcome. Administration needs to consider how to make this a "win-win" for both groups. The team won't go anywhere until this happens.

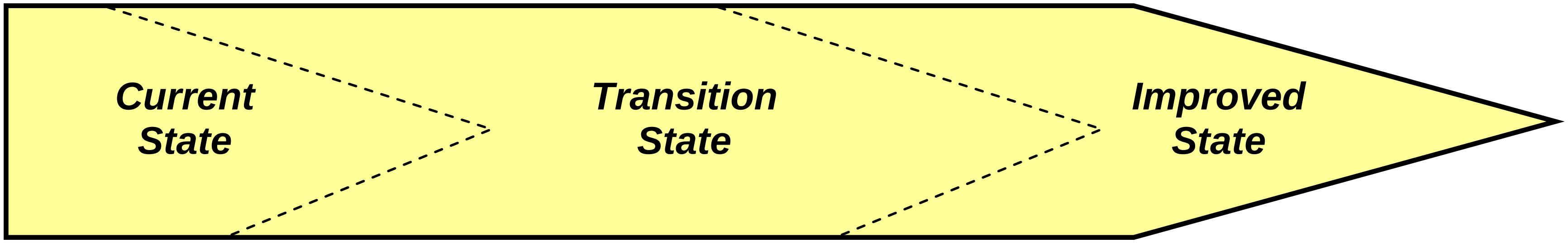
3. ***Team "dynamics:"***

Situation	Dynamics
"Solid but Negative"	You may want to avoid confronting the individual, especially if they are contributing to the work of the team. This person, though, will act as "slow poison" for the team; we'd predict a confrontation sooner or later. You should talk to him/her, explore the negative feelings and maybe try to work out some "personal" ground rules for their behavior.
Supply Expense - Late Team Leader	You could "let the leader fail." But the consequence of this strategy is that the team fails. You may feel comfortable addressing the issue with the team leader by yourself, or you may want to enlist the help of another member (avoid "ganging up" on the leader, though). Express your concerns as a member, try to identify the causes of the leader's lateness and develop a plan to improve their on-time performance.
Engineering Scheduling Process	Well, you're on a real "doozy" of a team. The Pareto Principle is going to have to apply here - what's the most important problem the team faces? What can you and others on the team do to address it? We suggest you meet with the team leader and express your concerns. If the leader shares your concerns, then plan how to address them.
Secretarial Team	We don't have a good answer for this one. This could be a growth opportunity for the team leader, or it could turn out to be an "engineered failure." The willingness of the team leader to take a firm hand with the "domineering" member will strongly influence the outcome. You could help the team get focused by facilitating their problem selection session and continuing to facilitate the team's progress. The support of the other members for the leader will be important. A frank discussion with the older secretary may be necessary, describing her behaviors and their impact on the team.
Video Development Team	This is an "iffy" situation. If the consultants' behaviors are offending other members of the team (i.e. if the "borderline crude" remarks could be construed as sexual harassment), then the consultants need to be counseled. If this is handled poorly, though, these members may react by shutting down their input and putting the project in jeopardy.
Nuclear Safety Issue Team	Unfortunately we've seen situations like this, where management has assigned teams to "resolve" issues with no real intention of doing anything with their recommendations. You should discuss your concerns with the team leader and not submerge them.
Nuclear Plant Turn-Around	This was the best team we ever participated on. Don't do anything!!
VP's On-Their-Own	This situation will not be resolved overnight. You're going to have to work hard and long to bring this team together. Develop a regular forum or meeting where the VP's have to get together to discuss hospital issues. You'll probably have to work on basic communication first. Identify some cross-functional improvement opportunities and charter teams to break down the barriers between departments.

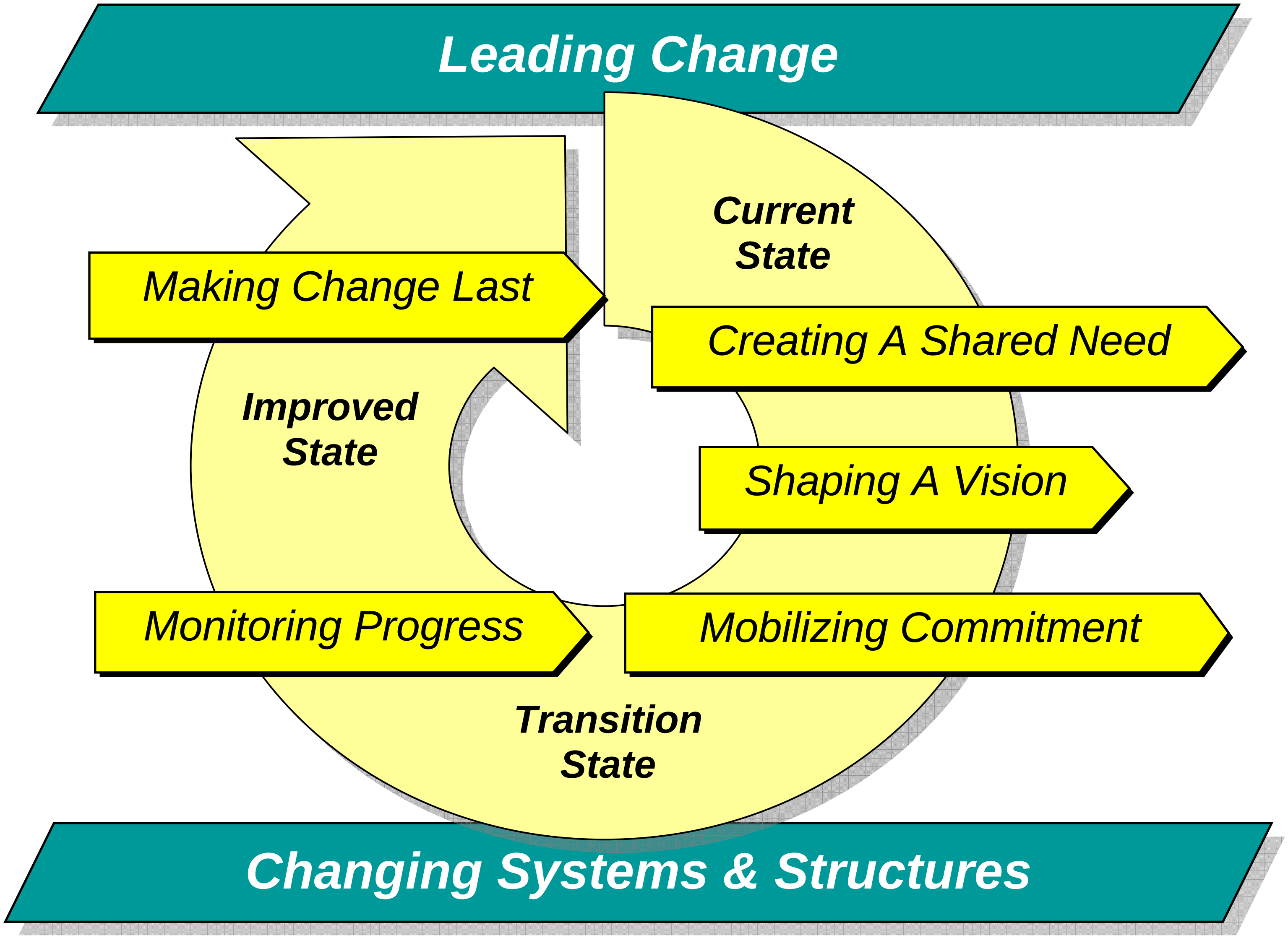
APPENDIX B – Accelerating Change

Change can be difficult – for people, departments, organizations. The techniques described in this appendix are covered in the Green Belt curriculum. Don't try these without "adult supervision!"

Change States

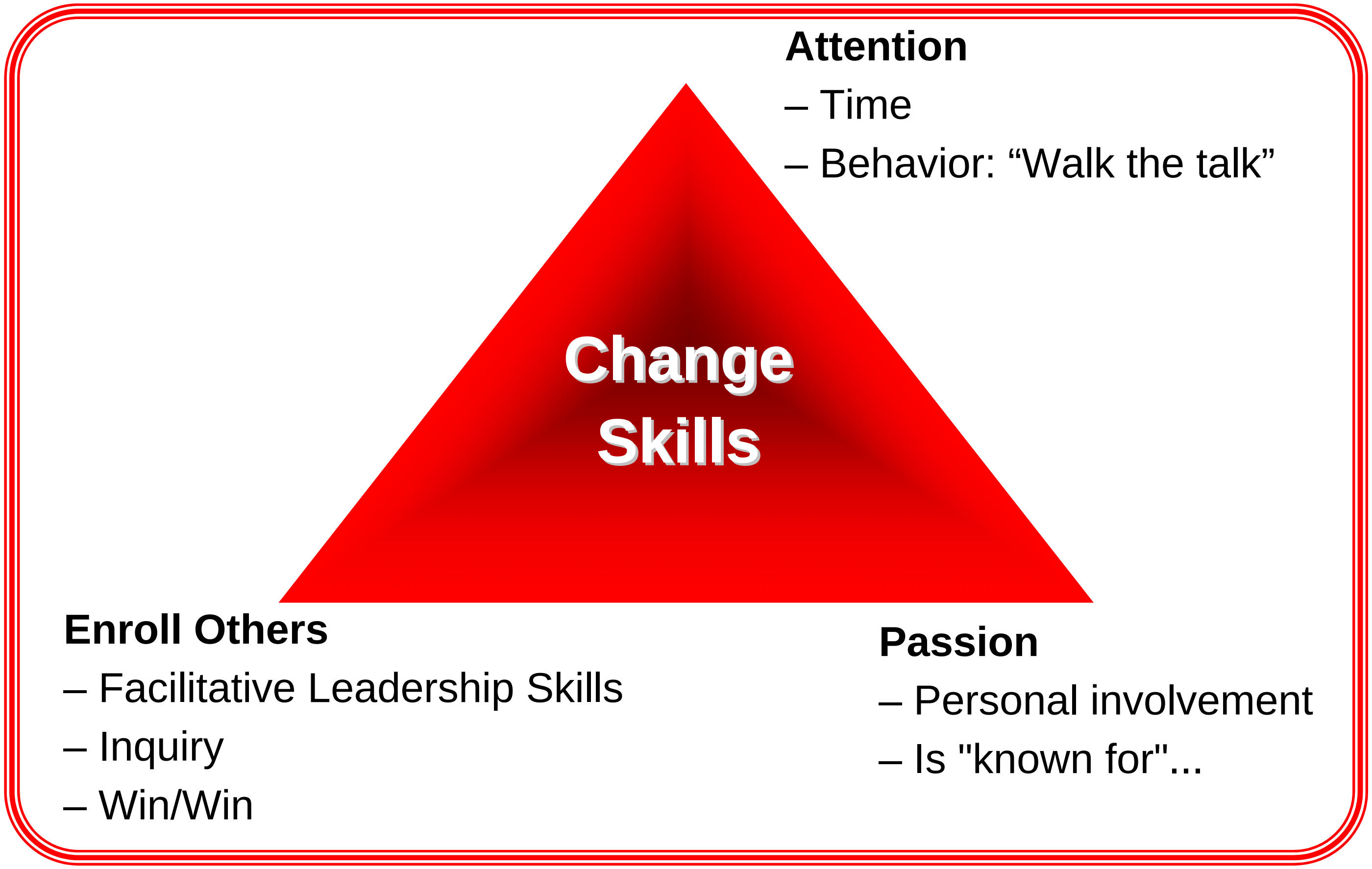


Change Management Model



Leading Change:

- **Key Principle: A Champion or Champions who sponsors the change**
- **Leadership Change Skills:**



Calendar Check:

1. **Identify 4-5 things you feel strongly about (at home or at work)**

2. **Check your calendar for the last 2-3 months to see what % of your time is spent on those things you say are important to you**

Creating a Shared Need

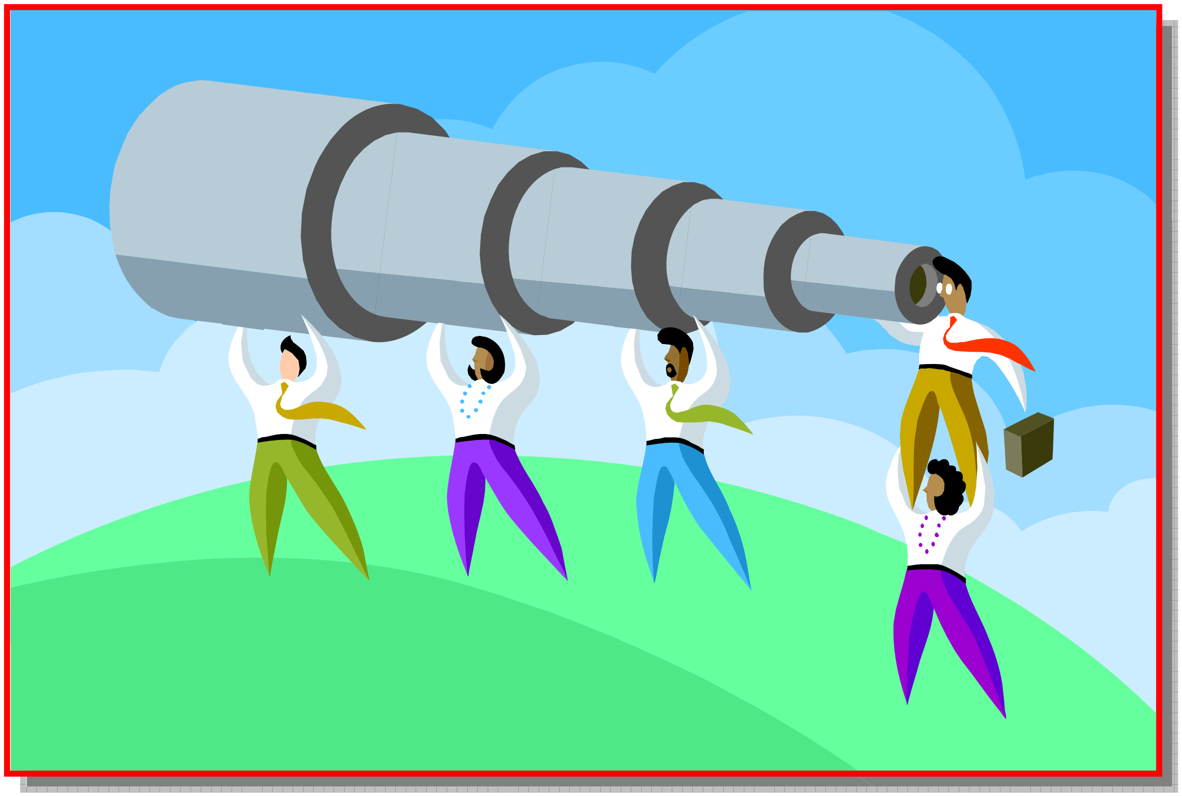
- **Key Principle: The reason to change whether driven by threat or opportunity is instilled within the organization and widely shared through data, demonstration, demand or diagnosis. The need for change must exceed its resistance**

SWOT Analysis:

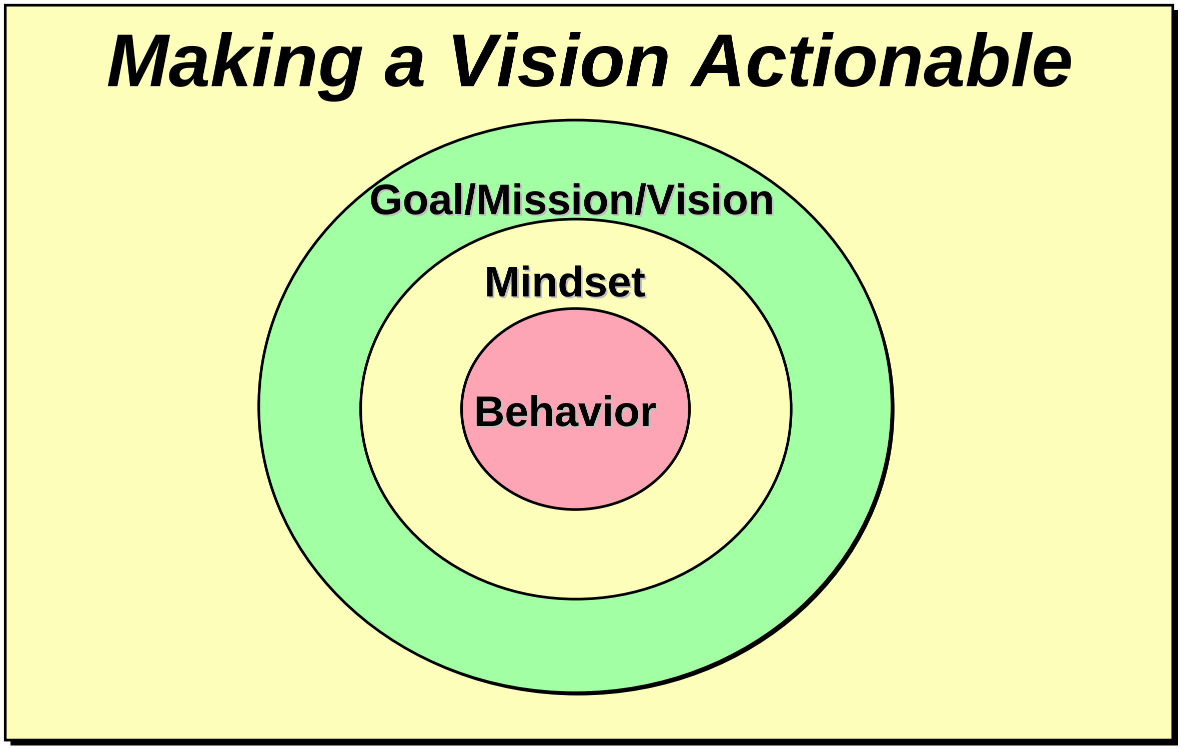
Strengths	**Opportunities**
Weaknesses	**Threats**

Shaping a Vision

- **Key Principle: The desired outcome of change is clear, legitimate, widely understood and shared**



Bull's Eye Charting

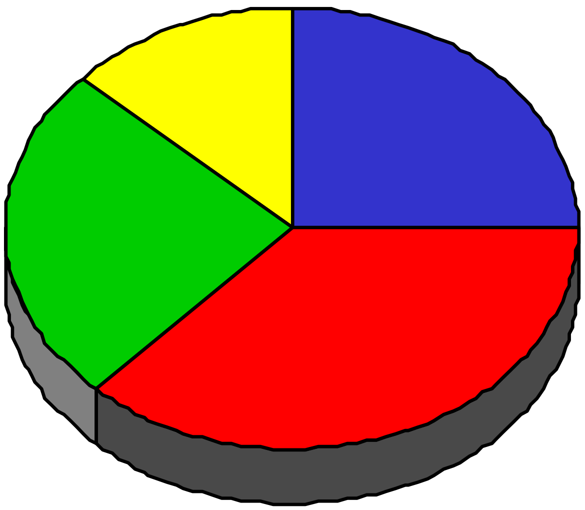


The Elevator Speech – ***You have just entered an elevator and someone asks about your project – what will you tell them in the ~ 30 seconds it takes to travel between floors? How will you get them excited about your project; maybe even willing to work on it with you?***

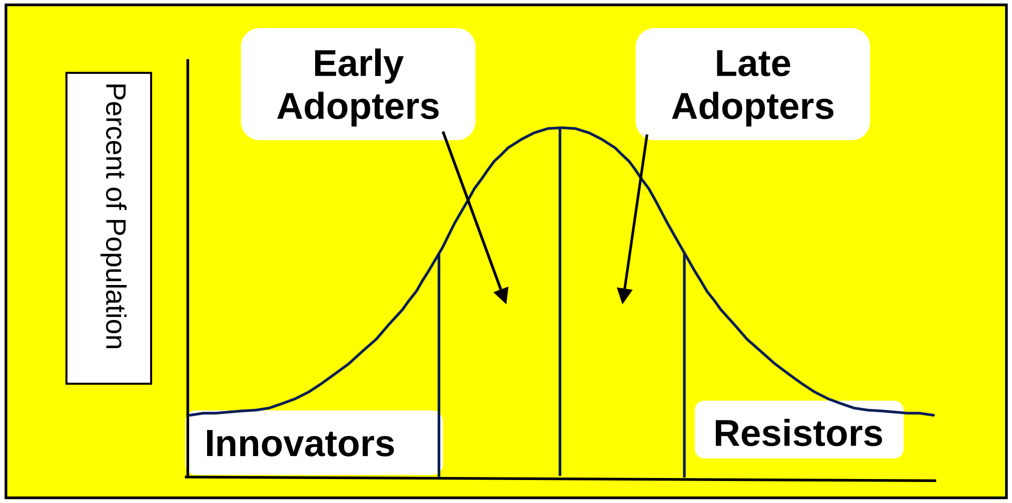
Mobilizing Commitment

- **Key Principle: There is a strong commitment from key constituents to invest in the change, make it work, and demand and receive management attention**

Key Stakeholder Map



Attitude Charting



Stakeholder Assessment

Stakeholder Assessment

Names	Strongly Against	Moderately Against	Neutral	Moderately Supportive	Strongly Supportive

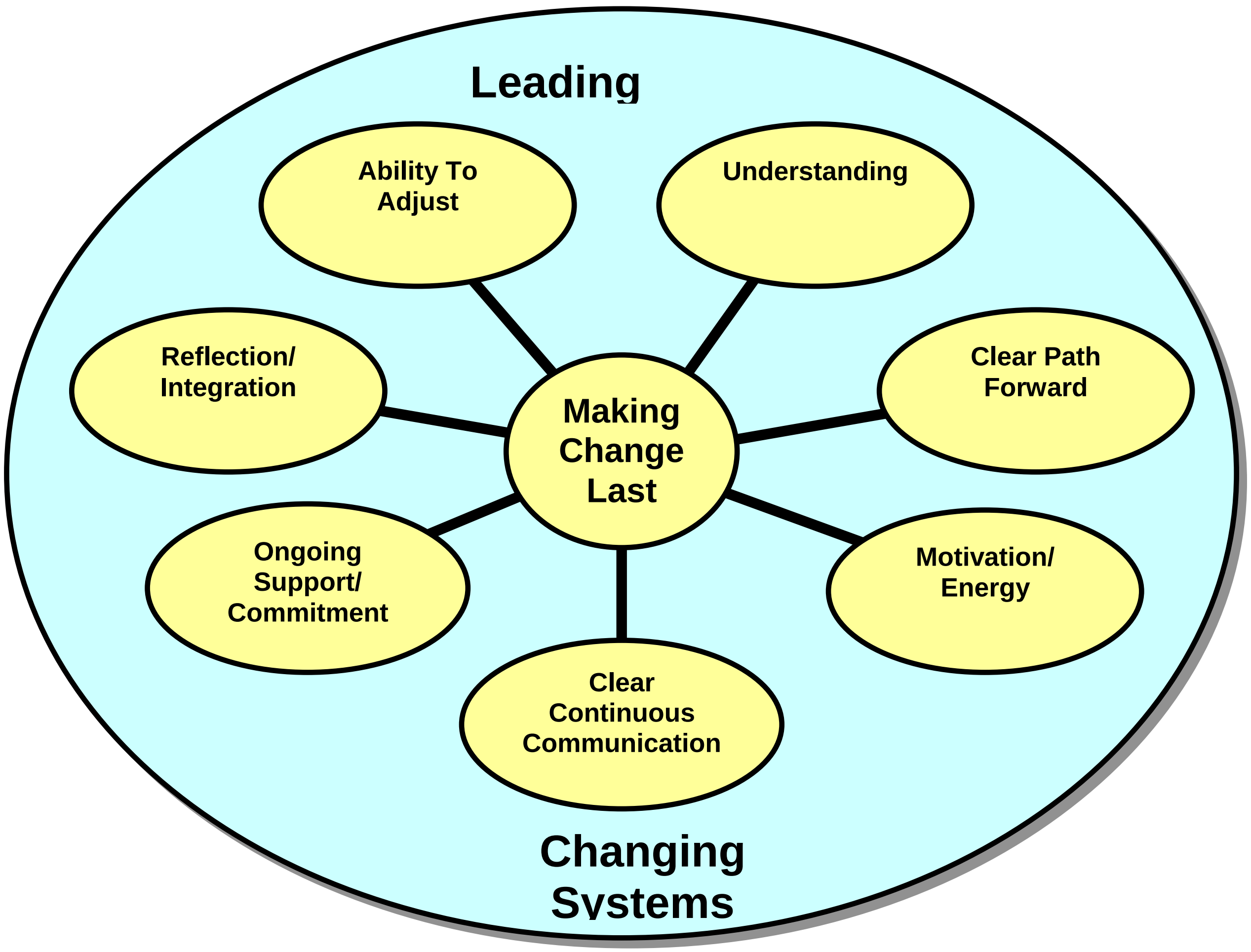
TCPF (Technical, Political, Cultural, Financial) Analysis

Influence Strategies

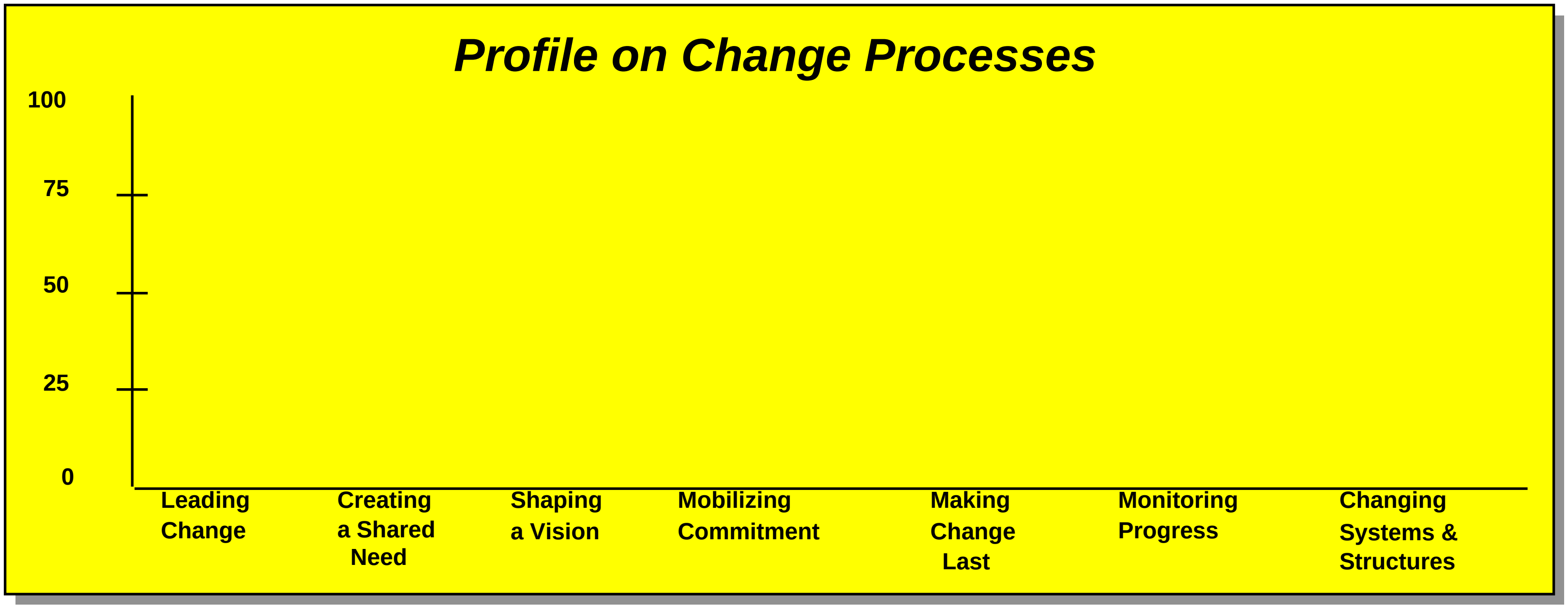
Stakeholder	Issues/ Concerns	Identify "Wins"	Influence Strategy

Making Change Last

- **Key Principle: Once change is started, it endures, flourishes and learnings are transferred throughout the organization**

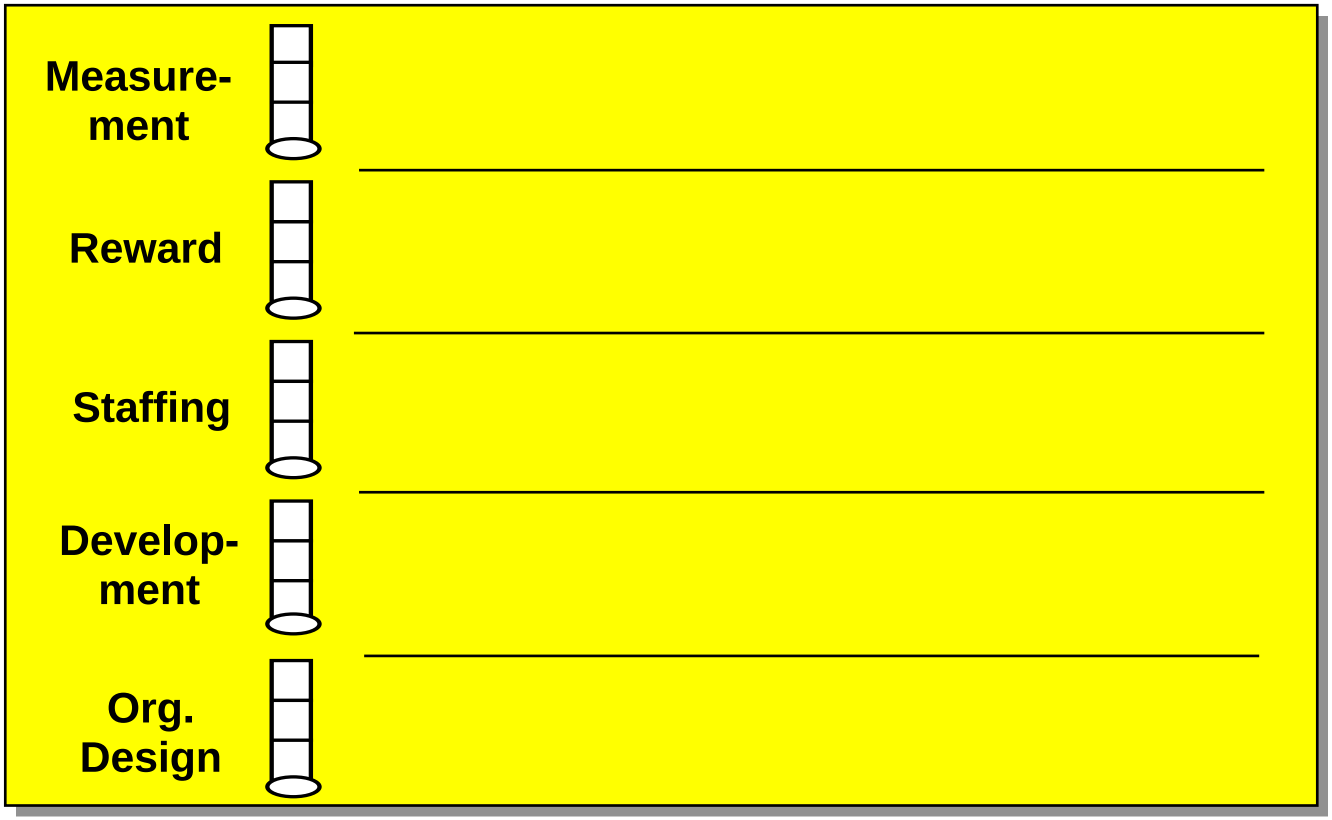


Change Profile



Change Management Self-Assessment

Systems & Structures Worksheet



Monitoring Progress

- **Key Principle: Progress is real; benchmarks set and realized; indicators established to guarantee accountability**

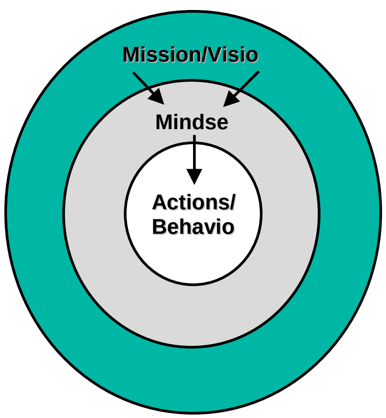
Changing Systems & Structures

- **Key Principle: Making sure that the management practices are used to compliment and reinforce change**

Changing Systems & Structures Involves Using/Modifying:

- **Staffing (How we acquire/place talent)**
- **Development (How we build competence/capability)**
- **Measures (How we track performance)**
- **Rewards (How we recognize/reward desired behavior)**
- **Communication (How we use information to build and sustain momentum)**
- **Designing Organizations (How we organize to support the change initiative)**

Measurement Assessment

Making a Vision	**3**	**4**	**5**	**6**	**7**	**8**
	Existing Measures 1. 2. 3. 4. 5. 6. 7. 8. 9. 10.	Which existing measures provide little or no information about any of the desired behaviors? 1. 2. 3. 4. 5. etc.	Which desired behaviors cannot be reliably measured by any existing measure? 1. 2. 3. 4. 5. etc.	If you achieve your desired changes, which existing measures will emit false signals indicating that performance is degrading? 1. 2. 3. 4. 5. etc.	If an employee carries out each of the desired behaviors, what is likely to be the organization's reaction? A = Reward or Approval B = Punishment or Disapproval C = No Reaction D = Impossible to Predict More of: 1. 2. etc. Less of: 1. 2. etc.	Existing Rewards Financial 1. 2. 3. etc. Non-financial 1. 2. 3. etc.
			5 How could we measure these desired behaviors?			**8** How could we reward the desired behaviors not now being rewarded?

APPENDIX C - BIBLIOGRAPHY

Here are a few of the quality improvement books that we always keep close at hand. Although 99% of quality improvement is practice (it just doesn't seem to happen if all you do is *read about it* or *talk about it!*), these references are good to review every once in a while. They always seem to contain a new tidbit or at least something we haven't thought about for a while.

1. STATISTICAL METHODS FOR QUALITY IMPROVEMENT, Hitoshi Kume, Association for Overseas Technical Scholarship, ISBN 4-906224-34-2 C0034, 1985 (1st published) - *Good basic book on the methods of quality improvement. We handed out thousands of these at FPL. Has one of the best descriptions of process improvement steps wrapped up into the QC Story (Chapter 10).*

2. OUT OF THE CRISIS, W. Edwards Deming, MIT Center for Advanced Engineering Study, ISBN 0-911379-01-0, 1991 (14th Printing) - S*till probably the best overall treatment of the late Dr. Deming's philosophy and practice. Get used to clipped sentences and other funny writing habits, though. It's best to warm up to Deming by reading the next reference first.*

3. DEMING MANAGEMENT AT WORK, Mary Walton, G. P. Putnam's Sons, ISBN 0-399-13557-X, 1990 - *Well, it's not all Deming management at work (FPL is listed as an example, but we didn't study under Deming), but it's still chock full of examples of how people apply process improvement and control, plus a gentle introduction into Dr. Deming's thinking. Very readable.*

4. INTRODUCTION TO QUALITY CONTROL, Kaoru Ishikawa, 3A Corporation, ISBN 4-906224-61-X C0034, 1990 - *This is our personal quality bible. It expands on his earlier work "What is TQC, the Japanese Way." This book is a must have, although you have to read it carefully. We find more in one paragraph of Ishikawa's book than we do in most American management gurus' entire books (you gurus know who you are!). We've seen companies that are 10 years into their quality transformations and have still not gone beyond this "Introduction. "*

5. THE BLACK BELT MANUAL, John J. O'Neill Jr., Sigma Quality Management, 2003 - *OK, we can't help but plug our own book. This tremendous tome, written over a 13 year journey (and continually updated) and includes "some" of our favorite tools (a number of which are described in this manual – see, you should have bought the Black Belt Manual first).*

6. COMPANY-WIDE TOTAL QUALITY CONTROL, Shigeru Mizuno, Asian Productivity Organization, ISBN 92-833-1100-0, 1989 - *Sometimes, when we can't quite figure out what Ishikawa is trying to say, Mizuno helps clear it up with a different, sometimes simpler approach. We keep them side by side on our bookshelf. Mizuno is also a smaller book, easier to pack in a briefcase for airplane reading.*

7. JURAN'S QUALITY CONTROL HANDBOOK, J. M. Juran, Editor-in-Chief, McGraw-Hill Publishing Company, ISBN 0-07-033176-6, 4th Edition, 1988 - *This is the sledgehammer of Quality books. Has just about every quality tool known to carbon-based life forms. Every organization needs to have at least one copy; if only to look like you're "doing quality." No, seriously, there's a lot of good stuff here. The only problem with this book is its lack of discrimination. For example, control charts and Pre-Control are presented as equal methods. No judgment or critique of the two methods is offered (and there should be!!).*