Lean Six Sigma Quality Transformation Toolkit (LSSQTT)*
LSSQTT Tool #5 Courseware Content
“Lean, Six Sigma Tools: Assessing Technological Decision Making As The Engineering Economy”

1.  Infrastructural problem solving tools summarized: data and documentation
2.  Time study, work methods, work sampling
3.  Basic cost issues
4.  Safety, quality and productivity: basis for ergonomics
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*Updated summer, 2006 by John W. Sinn.

Infrastructural Problem Solving Tools Summarized: Data And Documentation

The current tool assumes that the reader has some orientation to various forms of data and documentation. The toolkit CD provides an overview and introduction to a broad array of data and documentation tools and approaches which are pivotal to problem solving and improvement. This tool represents both data and documentation, and their relationship can become increasingly clear as they are used. The tools are part of the broader technological change model, reinforced in the toolkit.

5.  Carefully document, evaluate, improvement.

The thorough understanding of problems, to a great extent a function of data and documentation, is pivotal to the process of ongoing improvement as an important part of the broader quality system. This assumes the problem is thoroughly understood by all concerned, acted upon and followed up on over time. The ability to ultimately solve the problem for improvement is a function of data collected over time, documented in ways which provide the basis for seeing clearly where, what and how to improve, ISO Foundations: 8-D, FMEA, OPCP and SOP. A key tool for documenting with data is disciplined corrective action. A common approach is "8-D", a process which uses several questions, or categories of response/reaction information necessary for action taken. The 8-D responses are:

1.  Team members/function.
2.  Source and description of concern.
3.  Immediate interim action, effective date and containment.
5.  Root causes/definition/corrective action.
6.  Permanent action, effective date, verification.
7.  Control for prevention.
8.  Congratulate and reward the team.

As with the OPCP, and any other corrective action situation, the 8-D may be a rather short report and documentation, simply filling in blanks on the form. Or, depending on complexity and significance of the issue under investigation for improvement, it may be a more detailed and lengthy report.
8-D, or eight disciplines, is a problem solving tool for corrective action which, by design, emphasizes our disciplined team effort in the broadest sense. Virtually all facets of our system can be called upon to help solve, document, and/or control a process or product situation requiring attention. Even where the root cause of the problem may be known, it may be useful to place the issue in the 8-D reporting format and process, to help systematically follow through for improvement.

The 8-D is a systematic communication tool for resolving problems and doing change. This is a fact based tool which helps provide a standard reporting and disciplined approach, followed in all functions and applications, and driven by teams. The fact-driven 8-D relies on various data as a prime element within the documentation for corrective action and problem solving. Like many other documentation forms for corrective action, the 8-D is a living document, intended to be updated and followed through on over time as change occurs.

By contrast, Failure Mode and Effects Analysis or FMEA is a formalized technique and process whereby cross functional teams of technical persons can assess product and process systems to assure that failure in components or elements have been addressed, and hopefully, prevented. This involves identification, analysis and prioritization for ongoing improvement, consistent with all Kaizen and documentation approaches for lean environments.

FMEA is used to analyze failures after they have occurred or to prevent their occurrence. Frequently called potential failure mode and effects analysis, the opportunity for identifying a problem before it becomes a reality is advantageous to all concerned. The extent to which FMEA tools can be used prior to a failure to enhance the design function, the better. FMEA tends to be used either as a design tool, a process analysis tool, or a product improvement tool. The earlier FMEA systems are used, the better, raising applications opportunities for new product introduction and launch.

FMEA seeks root causes of a problem, or potential problem, and rates or prioritizes the likelihood of its occurrence. Since there are typically numerous roots involved in any problem, it is important to identify them all, and then to rate them in terms of severity and or likelihood of occurrence. Most FMEA systems actually result in a systemic identification of likely causes of failure, and a numeric weighting related to its occurrence, called RPN or risk priority number. FMEA tools help flush out likely effects of the cause, again providing numeric rankings for effects. This is different from cause and effect analysis in that cause and effect is more interested in identifying the root causes for action and follow through while FMEA documents and delineates actions categorically as a follow through mechanism. Follow through also addresses recommended actions and effects over time.

FMEA information is generally fed back to engineering and quality groups or others for enhanced design work or for other changes/improvements. It should be recognized that the design FMEA is likely aimed at engineering design changes. The process FMEA results in identification of root causes, based on noted or suspected effects in processing. Based on these causes and effects being identified, changes and improvements can and should be pursued through an applications engineering group or team in the traditional organization or through quality engineering groups or teams of various persons in the less traditional organization. There is an obvious relationship between failures or problems in processing and possible problems in the end product.

It is particularly important that the FMEA process and application view be presented within the context of the broader systems approach to quality functions. Problem solving at the shop floor or job site level today (and more importantly in the future) must be within the context of technological impacts and implications throughout the organization--all aimed at enhanced competitiveness based on ongoing improvements. This requires enhanced documentation based on data and people, all targeted at lean kaizen.

A myopic view of the product and its operations will simply not be satisfactory for competitive problem solving. The FMEA process and application also includes hands-on orientation, knowledge and experiences, as well as abilities in materials, processing and mechanical aspects of technology. Typical FMEA broader issues and relationships could include:

1. **Root cause, effect**. Analyzing quality problems or concerns related to processing or design issues or circumstances. This is an obvious relationship to cause and effect roots, and wanting to "know more".
2. **Value analysis**. Conducting value and/or cost analysis on a new process being considered for production. While it is not the intent of FMEA to conduct value or cost analysis, it is a logical by-product for good design and planning.
3. **Innovation**. Analyzing various materials or processes for a redesigned product. The
FMEA process, if used systematically, can assist us in "looking inside" our product and process for new and innovative ways.

4. **Layout improvement.** Determining plant layout and materials handling in new or existing processing facilities--looking for implications in the final product--and at all stages of production.

5. **Up front planning.** New product or process development--implications for quality. The FMEA makes an excellent analytical tool to determine "up front" the impact of change.

6. **Understanding the customer.** Market analysis as related to technical aspects of product or process development--customer input--both internal and external.

7. **Teaching and learning.** Training or evaluation related to redesigned products or processes can and should occur. As we improve, the RPN numbers should be reduced over time. As we share information and knowledge in the process of conducting FMEA, we all have an opportunity and challenge to teach and learn.

8. **Documenting process.** Simply to document the process, creating an important record and paper trail of our overall effort. This must include both the macro process as well as sub-processes within the broader process.

9. **Ongoing improvement, measurement.** To identify ways to improve the product or process, prior to or after a problem has been realized. FMEA serves as a point of reference, and context, to gage our improvement, with everyone being on the same sheet of music.

10. **Prevention.** The interest in FMEA is prevention wherever possible. When a failure or other problem occurs, we will want to prevent future occurrences.

11. **Reaction and enhancement.** Systematic immediate reaction and enhancement method for upgrading products and processes, based on potential concerns which surface from internal and external sources knowledgeable. If the FMEA is being pursued in a disciplined and well managed manner we can anticipate problems rather than merely "put out fires".

12. **Team process.** The FMEA provides an excellent team "learning environment", mentoring new or existing persons for growth in the broader organization. In fact, it should be recognized and underscored that the FMEA should be conducted from a team approach, drawing upon various elements of expertise in suppliers and customers, internal and external.

13. **Robust improvement.** The FMEA is probably second only to the OPCP in its robustness as a planning and improvement tool--just by following the steps in the process it will likely lead to enhanced product performance. This requires us to place the FMEA in the OPCP as a standard operating procedure, not done by chance or when customers are yelling loudly.

14. **Regular review systems.** Ideally, systematically, and on a semi-regular basis, we should exercise the discipline required to review each design, product or process for improvements--the FMEA may prove useful for this. FMEA review process can "trigger" ongoing questioning for improvement.

15. **Broad communication.** The FMEA, like other documentation tools and systems, provides an excellent communication tool both internally and externally, to keep all parties and individuals concerned apprised of the situation, upstream and downstream, internal and external. And once again, this assumes that a cross functional team is doing the FMEA--at minimum representing quality, engineering and production (operators and supervisors). Maintenance personnel are involved for reasons related to reliability.

Each of the above areas represent applications, circumstances and relationships which can bring about improvements in quality and productivity, leading to overall enhanced competitiveness.

Operators, supervisors and others will be involved in teams in the FMEA process, since they will often be collecting much of the original data which will lead to further understanding and possibly the solution or completion for the FMEA. Knowledge about process or product is resident with operators--it is incumbent upon the teams to listen carefully to what the operators have to say. It is also important that we structure our teams carefully at the outset of a technical problem to fully and appropriately use our internal and external expertise, as well as others', as a team function.

**Design, Product And Process FMEA.** It is important to understand the importance of the design process in the overall quality system, and process of bringing product to fruition in production. This has been summarized in the previous section, generally to result in prints or drawings which capture the important specifications for production. While the prints may capture important specifications from design and engineering, still we must translate this into workable information and value adding potential
for the organization. This becomes the role of the quality manager, engineer, technician or services person, all part of the broader quality professional team needed to do the work described. FMEA becomes one of the critical tools needed as a mechanism to translate and move data and documentation forward for communicating broadly with suppliers and customers, internal and external.

Relationships among FMEA types. Throughout product life cycle FMEA is useful for preventing, detecting or resolving failures. This can be done in the design FMEA early on in the product life, in product as it matures, and at the process where product is produced. There may be various FMEA’s in motion at different stages of the product life cycle, depending on failures presumed or actual, and depending on other customer needs and requests. Various FMEA’s may relate to one another, depending on focus and intent. The product life cycle, also related to quality function deployment, is shown below as related to FMEA. Product life cycle provides additional insights into relationships inherent in product development and deployment.

Three stages are commonly identified as important parts of product life cycle related to potential failures. These are early life, useful life and wear out. During early life, the failure rate is high because we do not have all the bugs out., people are being trained, new processes are being introduced, and so on. During useful life the failure rate goes down and levels off for a period of time because we have gotten the design and engineering side of the product, as well as production (process) under control. In the wear out phase, due to maintenance issues, length of service life, changes occurring around the product in other technologies, and other factors, we see an increase in failures.

FMEA can be useful at any phase of the product life cycle, and the life cycle may be impacted by the use of FMEA at various points. Assuming various products are being introduced, matured, and gradually phased in and out, as a function of a broader organizational plan, FMEA, systematically used, will be pivotal for planning. FMEA should be used with other documentation tools—particularly the OPCP discussed elsewhere.

An additional measure or step which is sometimes added to the FMEA, is the recalculation of the RPN based on the actions taken, changes in key characteristics, and other variables identified and acted on in the FMEA process. While this is not shown on the form provided in the toolkit, it should be given careful consideration since it does recognize and allow for ongoing improvement as a function of the process. It is also true that generally the total FMEA process would be redone or repeated over time, allowing for a more robust approach to the recalculation of the RPN over time. We anticipate that this value would come down over time.

Ongoing Process Control Plans And SOP

Identifying problems requires a thorough and detailed analysis of processes which go into our products. Gaining this understanding has traditionally been difficult, disjointed and often not a top priority. It is increasingly clear that we cannot improve upon that which we do not understand. Regardless of who completes/uses this information now, teams will need this information, in as accurate and complete a form as possible, in the future to solve problems for ongoing improvement. Much, if not all of it, is information based—and much of the information is numerical data. A major part of the discipline referred to earlier is related to building and maintaining systems accurately, methodically, and in a timely manner. This means gathering and documenting information and data to be used at later times and places for analyzing and solving problems.

Various organizations will call these devices/forms by various titles, but generally they are titled manufacturing data sheets, manufacturing information sheets, or as with the approach shown, "ongoing process control plan". The idea is to provide basic information about building product. More specifically, the OPCP is designed to document key methods, techniques and other general information used in the processing applications for the product under discussion. This includes process name, tools for production, process parameters, product characteristics, and possibly other specific process oriented information particular to this product, the emphasis being placed on better understanding the processes involved in producing the product. Secondly, the OPCP is designed to identify and document key customer information and expectations in the form of specifications, evaluation method, sample and inspection, analysis and reaction methods, and perhaps other information vital to controlling and improving the processes involved.

Some of the information is largely the responsibility of Quality personnel while other information may come from customer sources, supplier sources, standards in the industry, and so on. Particularly important in these regards are product characteristics, specifications, evaluation, inspection and analysis approaches and systems. These areas
are particularly important because their determination relate to internal data collection and analysis systems by various persons, fundamental to ongoing improvement--with a firm basis--particularly documentation and data. Also, cost savings can result by re-establishing levels and methods based on documented changes--improvements in product and process. But, if, due to un-disciplined approaches in processing or systems in general, we do not make improvements--or cannot demonstrate improvements in quality--we may be losing dollars. Assuming we are actually making progress--improvements are being made--the OPCP should be changing. The OPCP must be regarded as a dynamic document, an important enhancement for lean. Systems used to maintain the information must be built to respond in a timely manner for enhancements to the system--including all involved both internal and external.

The OPCP is important for procedural reasons:

1. The OPCP must represent general information related to the "best" and "correct" way to do our processing for this particular product.
2. How can we improve on our process if we do not know what the process is? The OPCP sets fundamental benchmarks in the total process--benchmarks that can help us reduce "moving targets"--and help us know when we have improved, and why.
3. The OPCP should be based on other more detailed information and documentation such as engineering drawings, customer feedback, test results, statistical process control information, gauge analysis results, among others. This represents much detailed procedural work which can be reduced or redirected over time, as we make improvements--or increased if needed.
4. Depending on maturity of the product, amount of resources directed toward a given product program, and others, it is assumed that the OPCP will become a processing summary supported by various persons, teams, departments, corporate, and others internal and external. This "total document" or report about processing and procedural issues for a particular product will be our best defense for broad customer negotiations and ongoing relationships--doing business in the future.

But all of the above assumes that we can continue building around the OPCP system to document our procedures for improvement. It also assumes strong "team" and "cooperative" attitudes throughout the organization, a willingness to continue teaching and learning from one another.

**Documentation functions, kaizen relationships.** It is important that we recognize the importance of the OPCP as a documentation and communication device. While this may appear to be self-evident, it is also true that many persons, depending on function, have not had a great deal of involvement in building and using the OPCP. As teamwork and cooperation become increasingly prevalent for all persons organizationally, particularly for supervisors and operators, the use of this device will become more useful and necessary. The OPCP represents and summarizes many other inputs and sources of information.

The importance of the OPCP as a documentation device cannot be over stated. This is true in various ways related to Kaizen processes:

1. When customers want to know how we are processing product, OPCP provides the basis.
2. If internally we wish to determine how something is being done, with processing a product, the OPCP provides a basis.
3. When suppliers wish to better understand what is happening to their raw material or component in our process, the OPCP is the starting point.
4. When we wish to perform a detailed analysis, for whatever reason, and regardless of application, the comprehensive OPCP in summary and report form over time, should provide at least part of the information.
5. When we are being considered for a new customer program or project, the OPCP can provide a demonstrated basis for processing in similar situations and applications.
6. The OPCP provides necessary "paper trail" information for certification and verification of process, if questions arise in the future.
7. The OPCP provides an excellent system for evaluating ourselves over time, based on strong and accurate documentation of our process at various points along the way--in the evolution of a given product. This is generally referred to as a "measure of success".
8. The OPCP document provides a rather straightforward method for teams, individuals, departments and others to see and understand their involvement and role in building the product--and their responsibility and accountability are increasingly apparent.
9. The OPCP is the fundamental mechanism for communication, internal and external,
upstream and downstream, with customers and suppliers. The OPCP serves as a primary method for "leveling the playing field" for all concerned, taking guesswork out of issues to "nail down" how we do what we do.

10. If we are planning a new product introduction, OPCP forms a detailed description of how the plan should be accomplished.

11. OPCP’s provide important training and education tools we can assemble and use, particularly for helping various groups see how their process or role in production relates to others in the organization.

The OPCP is a substantial document, one that forms the basis for much that is important to the future of the organization. The OPCP relies upon accurate and timely information gathered and compiled throughout a broad and complex network involving many persons and organizations. The OPCP can only be as good as the information upon which it is based--and the people which are providing the data.

**OPCP-Basis For Ongoing Improvement.**

The OPCP is key to continuous improvement processes which must occur on an ongoing basis if we wish to remain competitive. The basis for continuous improvement with the OPCP follows.

**Define the customers and suppliers of our products or services.** Traditionally we think of customers as persons or groups who buy our product or service. But we must remember that anyone who depends upon us for assistance, information, components, or service in general, downstream internal or external, is a customer. Only when we thoroughly know and understand our customers can we begin to fully meet their needs. Similarly, we must also understand our suppliers, and our role as a supplier, for our customers. Both functions require substantial effort ongoing. This requires defining and detailing the characteristics and specifications of our product or service in detailed and specific ways.

**Detail and document the process.** It is imperative that we thoroughly understand the processes we use in our production operations and functions. If we do not regularly evaluate the processes, broadly and at specific operations, we simply will not know where improvement opportunities exist. This should occur as process flow using the traditional engineering analysis symbols and time study tools. But it should also be accomplished in detailed ways to include standard operating procedures at specific and detailed locations in production.

**Drive stakes in the ground upon which to gage improvements.** At some point it will be imperative that we know clearly and precisely the extent to which we have made improvements. It is important to have clearly established and understandable measures of success for evaluation. This could be cycle times, products produced over time, defects or defectives, downtimes, maintenance schedules, and so on. This is the basis to set goals for improvements, moving forward for enhanced competitiveness, and general context of lean.

**Make the improvement happen.** Working through the team or other appropriate mechanisms, implement the improvement over a pre-determined schedule of events, using a project managed approach in a disciplined manner. Although it may be unrealistic to believe that all teams will be productive at all tasks, or that all projects will go smoothly, it should be recognized that we must move forward with planned improvements, ongoing, if we are going to remain competitive. We can, and must, learn as teams and individuals from our mistakes and failures as well as from our successes. It is essential that we take well calculated risks and learn together with them as we go forward in the learning organization.

**Carefully document and evaluate the improvement.** All processes or operations must be documented for comparative analysis and evaluation over time. This will often require benchmarking the best improvements for duplication and replication of systems for accomplishment, setting proper examples throughout the organization. We do not need to reinvent the wheel each time we set out to conduct improvements, but can use relevant information in various applications for enhanced competitiveness. This requires emphasis on audits and verification of systems through tracking and data driven measurements. It is simply not acceptable to propose and implement improvements without regular follow-ups to show our continuous improvements.

**Pursue/evaluate additional related improvements.** Similar to the previous statements, other improvements may/should be underway simultaneously. As we have multiple improvements in motion simultaneously, it will be vitally important that documentation in a systematic manner be part of our strategy. This is part of the design of the OPCP, providing the broader format for ongoing improvement. Competitive organizations would have multiple ongoing elements of the OPCP dynamically in motion for broad improvement.

**Involve internal and external customers and suppliers.** Although it may seem obvious to involve those closest to the problem or circumstance for
improvement, it is likely not always occurring. We can all gain in building the better relationship by working with our customers and suppliers, using the OPCP as the base from which we improve, collectively. This baseline, if used properly, can also provide the necessary foundation for demonstrating our potentials to current customers, for remaining and building a continuous relationship.

**Repeat the process, ongoing.** This process, and the document titled the OPCP, is designed to be an ongoing process. The dynamic is part of the broader improvement system, using our information and communication to solve problems and document for future circumstances. Based on the stakes driven in the ground at any point along the evolutionary journey, we can be better positioned to improve.

Related to control plans as "macro" tools, the SOP, provides one of the best "micro" kingpins for continuous improvement. SOP's, identifying and detailing standard procedures, or methods, provide much needed continuity. However, standards we place in force, through teams and leadership, are not the end themselves. Standards must be ever evolving, changing for continuous improvement in work. These cannot be changed or built in a frivolous or light-hearted manner. There should be an SOP for how we change and control SOP's for several reasons:

1. To prevent unwarranted changes which have not come through appropriate team methods.
2. To assure methods and procedures reflecting operator views--vital to actual use of SOP's.
3. To assure all individuals, customers and suppliers are involved in changes being made.
4. To facilitate upgrades provided through broader improvement systems.

The concept of standard methods has its basis in the need to separate the person's work from the machine. The SOP serves to provide the counterpart to the machine's repetitive and consistent motion, providing the maximum capacity available, if used properly. Through SOP, and control plans, we standardize sufficiently to provide necessary discipline required to synchronize overall process and production.

The basic SOP should contain basic necessary steps, in terms written and conceived by operators, for running and interacting with equipment to get product out the door. Multiple SOP's, articulated with a broader activity plan, in effect, are the most important documents, as the actual point of contact for operators and others to facilitate:

1. Manpower redeployment since we see a leveling effect via idle time opportunities.
2. Process reduction since leveling standardizes functions, and inefficiencies are easier to see.
3. Quality is more readily built in since work is done with greater consistency.
4. Maximizing on capacity due to more readily predicted production and synchronization.
5. Layout will be improved via disciplined work methods as we do standard work over time.
6. Via repetitive work, visual management by work sampling and methods analysis occurs.
7. Data-based issues surface since we "see" them via work in process and material handling wastes being "flushed out" and documented.

Waste becomes increasingly apparent as we use SOP's. This occurs by continually improving methods and procedures, and reflecting the change in the SOP.

**Time Study, Work Methods, Work Sampling, Flow Charting**

Time study is a stop watch technique for documenting and analyzing time involved in a given process or work. This is used for process planning and other positive purposes--rather than only punitive (analysis to find out if people are doing as much as they should be) purposes. Several steps should be observed when conducting a time study. First, it is important to learn about the job to be studied. Obtain process sheets, drawings, plant layouts, and any existing standard data. Persons conducting studies must know as much history of the job as is possible prior to conducting the study. The analyst should go to the work area and study how the job is done. If not previously available, list steps and procedures necessary to complete the task under study.

After individual times are recorded, specific areas appearing to be inefficient are determined and analyzed for ways to improve upon. If this is the first time a task is being analyzed, it may be timed for several trials, and averaged. If standards already exist, times gathered may be compared to standards arrived at over many trials of the same task. If no standard exists, the analyst can time enough trials of the task to permit a similar value to occur from the average worker. Although standards are costly to develop, due to the extensive number of trials required, they do provide a baseline.

Work methods are used to improve methods involved in completing the task. Many of the same principles apply as discussed in time study. The
primary objective is to improve and standardize methods. Time study forms usually have a column for description of the task being performed. While the prime purpose is time study, it also provides the basic requirement for work methods analysis, listing current methods for performing a task. When combined, this is called time and motion study.

Work methods analysis determines details involved in the task, or work. The task is identified in terms of all human and mechanical movements to determine if movements are necessary and productive. Human inputs are significant for methods analysis since wasted movements mean direct added cost due to non-productive time spent on unnecessary outputs. Wasted motions and movements by equipment may also be costly since the machine is costing some number of dollars as a capital expense. General work methods principles are:

1. Consider safe work methods top priority.
2. SOP's identify tool and material locations.
3. Avoid "dead-head" empty-handed trips.
4. Use the shortest path between two points.
5. Sequence tasks logically, not backtracking to something unrelated, combating waste.
6. Use machinery compatible with people. Machines fit people, not persons to machines.
7. Consider difficult and easy steps co-mingled to allow people to work with less fatigue.
8. Avoid combining potentially hazardous circumstances with fatiguing methods.
9. Make work accessible. People struggling to do work requires additional effort.
10. Eliminate, combine, simplify for value added.
11. Use curved motions, point-to-point, for worker comfort and less fatigue, versus straight line.
12. Hand motions work in unison for "balance".
13. Use consistent tool, material, people locations.
14. Worker hands are not work holding fixtures.

Work areas are analyzed for cost and time savings, quality enhancements, and other improvements.

Work sampling is a technique that can provide answers in a relatively short time--based on the form nearby. Work sampling, or activity sampling, was a technique originally called the snap-reading method after the snap-shot concept of photography. Work sampling is generally limited to the investigation of time when a worker is working, to provide categories for identifying activities, particularly non-productive types. Identification occurs by various persons and can be done spontaneously, observing talking, idling, location concerns, and other non-productives.

Related to time and motion studies, and work methods, other tools useful for addressing productivity are facility layout and process flow charting. Process flow charting uses symbols placed in a condensed format. The typical flow symbols, shown in the flow chart example provided, are usually placed in a progressive line format, connected, and numbers are placed in or near the symbol to correspond to a chart with all procedures for producing the product listed. The advantage of process flow charting is that the entire system (or a sub-component) can be analyzed graphically. Times and costs can be placed alongside each process on the chart, permitting further comparison and analysis. We observe processes or tasks where the greatest time and/or cost is incurred and then troubleshoot these for greater efficiency and productivity. By placing the plant layout in schematic diagram form, analysts can identify trouble spots. Studying a layout may disclose that space is not fully used, and we can attempt to better maximize on the space.

Relationships of people, machinery, and materials movement should be carefully analyzed to determine lengthy (costly) movements and potential bottlenecks or other costly down-time possibilities. Time studies, flow charts, and plant layout diagrams can help remove potential hazards, avoiding costly down-time, retraining personnel, health and hazard insurance payment increases, and so on.
Basic Cost Issues

Key cost analysis and implementation costs relate to break even analysis, return on investment, value analysis, determining actual costs in production, costs of work in process, and so on. The implication is that by documenting and using Kaizen methods we can reduce these costs and improve.

Product cost analysis is the act of identifying and tracking costs in the product being produced. A form is provided showing one approach which includes cost categories for information. These include part name, materials, operation or function, specifications and direct and indirect costs. This provides cost details easily organized and readily understood (particularly for more complicated functions or activities), and the ability to condense information into a manageable form, including sub-cost totals for each itemized category.

Break even analysis. Another cost enhancing tool is break even analysis. This shows relationships between various cost factors, production levels, profit and loss, sales income, and other cost factors. Break even analysis is particularly helpful to get a handle on the big picture in production. However, it can also help in looking at very specific production circumstances such as a given work area, operation, or machinery/process comparison. Break even analysis is either a graphical representation or a mathematical model. Break even analysis is:

\[
\text{Profit or loss} = I - (FC + VC)
\]

Where \( I \) = income, the number of units produced and sold times the selling price per unit. \( FC \), or fixed cost, and \( VC \) or variable cost, summed, represent the total cost of production. When costs are subtracted from income, the \( P \) or \( L \) is provided. Then:

\[
\text{Breakeven point} = \frac{FC}{SIU - VCU}
\]

Sales income per unit = \( SIU \), variable cost per unit = \( VCU \), and fixed cost = \( FC \). Fixed costs do not change with volume, at least short term. Examples include taxes, depreciation, administrative costs, rents, and clerical costs. Variable costs include raw materials and direct labor involved directly in the production of the product. Fixed costs are also sometimes referred to as burden costs directly associated with a given technological function. It is quite common to allow some percentage of a work center cost as fixed or burden cost. Gray areas might be maintenance costs since it is often not clearly associated with only one product, or even one product line. Maintenance costs rise with increased output since machinery is used up more quickly.

Using an example where fixed costs are $100.00 and variable cost per unit is $0.50, and sales income per unit is $1.00, break even point (BEP) can be calculated as follows:

\[
\text{BEP} = \frac{FC}{SIU - VCU}
\]

\[
\text{BEP} = \frac{100}{1} - 0.50
\]

\[
\text{BEP} = 200 \text{ units or $200.00}
\]

Based on values given in the example, the break even point is 200 units or $200.00. Profit or loss (\( P/L \)) for a production quantity of 300 units under the conditions already given is found by:

\[
P/L = I - (FC + VC)
\]

\[
P/L = 300 - (100 + 150)
\]

\[
P/L = 300 - 250
\]

\[
P = 50.00
\]

The production quantity of 300 units provides profit of $50.00. Explaining the break even graphical analysis, the fixed cost line is always shown as a horizontal line which is struck at the point in dollars off of the vertical side. Regarding both the vertical and the horizontal portions of the graph, it is
important to always have equal graduations determined and laid out. This enables a 45 degree angled line to be struck, always going through the break even point. If the variable cost line is struck from the point where the fixed cost and the vertical line meet, and run through the break even point, the graph will be properly shown. This provides a quick and efficient analysis, a useful presentation device and a method for communication among various groups within an organization, as shown above.

**Capital investment analysis.** Another cost analysis tool is related to capital investment. This is important since monies for investment and expansion must be used very prudently. Capital investment approaches focused on return on investment (ROI). ROI includes a technical description of the new process, cost justification statement, shipping and installation costs, depreciation and the ROI table. This includes information about the equipment's specifications and capabilities while cash inflow relates proposed equipment to the current process and provides cost and time comparison in labor and scrap cost savings. Cash inflow is a cost gain of old equipment versus new. A new fixturing system, for a construction or manufacturing site is an example.

Technical description includes the automatic fixturing system attached directly to the existing press brake, as a manual system. Total cost is $1,050.00 including shipping, setup and training. The vendor will supply in 30 days of order placement. The fixture will be bolted in position to enhance quality and productivity by enabling the operator to more quickly and precisely position work within the press. Users researched indicated lost time accidents were reduced with use of the fixture.

Cash inflow is based on a new fixture to reduce time in positioning parts by the operator by approximately 2 seconds per part loaded X an estimated 1800 parts per week providing 3600 seconds saved per week, or 60 minutes. This is one hour of labor @ $10.00 per hour X the 35 weeks estimated to use the press. Total labor savings provides $350.00. It is also estimated that the new fixture will reduce the current scrap and reject rate of 200 parts to a lower level of 100 parts per week. Since each part has an actual value of .10 at this point in production, it is estimated that 100 parts X .10 will result in savings of $10.00 per week or $350.00 over the 35 weeks of the program. Summarizing:

1. Labor savings = $350.00
2. Scrap and reject savings = $350.00
3. Total estimated cash inflow = $700.00

The basis for the projected/estimated cash inflow savings were (1) demonstrations on site at the vendor's location; (2) actual installed applications of a demonstrator on our site for a trial period of one month; and, (3) discussions with three current customers/users of the fixture provided by the vendor. All estimates provided are conservative, and the basis was one part program which remains firm and possibly even expands beyond 35 weeks per year. Assuming greater savings are realized beyond current projections, and additional product or programs can be realized beyond the 35 weeks, the cash inflow projection can be enhanced.

A quick method for potential cost and payback relationships is to divide cash inflow for one year by initial total costs. Called simple payback, this is:

\[
\text{CI} / \text{ITC} = \text{PB}
\]

where ITC is initial total cost, CI is cash inflow and PB is payback in percent. Given values used earlier:

\[
\frac{$700.00}{$1050.00} = 61\%
\]

When this program is run under the conditions noted, it would result in this type of cost savings and payback, paying for itself in less than two full years.

**Safety, Quality And Productivity**

People and technology in combination will eventually result in some form of safety related issues. Safety is a primary concern since safe people will be productive people. People who do not feel safe in the workplace are preoccupied with hazards and become less productive. The triangulated relationship between safety, quality and productivity is not to be dismissed or taken lightly. Quality in a product cannot be sufficiently addressed if we are moving so quickly to be productive that we do not slow down long enough to build good product. If we are moving so fast that we become unsafe, our efforts will become counter-productive. Safe workers are productive workers, and a safe environment is a quality environment.

**Safety objectives.** Four safety objectives are generally important. *Accident reduction* is a major objective since the fundamental interest is in reducing lost time accidents. These are accidents which result in people losing time from work, or accidents which result in death or dismemberment. *Cost reductions* due to replacing what was lost in accidents is also a safety objective. Losses may
include workers, products, and equipment. Morale, productivity and quality is related to improving intangibles for workers. If workers feel safe, they will likely have better morale, productivity and quality. Frequency and severity relates to reducing both the frequency and severity of accidents. While the major objective is to reduce accidents, it is also true that accidents will occur. The objective is to reduce both frequency and severity of accidents.

Safety management. Safety, like quality and productivity, is a concern of all. Safety requires top management support if it is to be successful. It is only through visible and financial support from the top that safety will be taken seriously.

Clear responsibility. We must understand responsibilities. Who will document hazards? Request repairs? Report unsafe practices?

Absolute accountability. People need clear safety responsibilities relating to safety, and they must be held accountable for actions in their responsibility areas. If people know they will be evaluated on, and held accountable for, their responsibilities, they will increasingly assist in facilitating safe working conditions.

Develop goals and objectives. Safety goals and objectives can be requested from people. Done on a regular basis, this helps ensure safety from people since they will be 'thinking safety.'

Safety dollars savings. Safety programs require showing cost savings. Documentation must disclose effects of training, teams, and other efforts for improving safety. This includes training costs; workers compensation payments; costs of injured workers; costs of damaged machinery; and others.

Safe procedures. Safety must be part of all procedures. Safety should be standard working and operating procedure. No matter what the job, there are safe methods which can be identified, documented, trained for, and accounted for.

Design/build-in safety. When the opportunity presents itself, either for original design or in a redesign, plant layouts, work areas and machinery should be considered with an attitude toward safety.

Front line supervision. One of the most important people for safety is the front line supervisor. If this person is effective, many safety problems will be eliminated or reduced.

Be persistent. Safety must be continually repeated. Via posters, newsletters, team meetings, safety fairs, family safety outings, and in other ways, safety must be continually reinforced.

Do it right the first time. One way to create a safer environment is via new employees with "new employee indoctrination". Many accidents involve new employees, and the opportunity is significant, getting people off to a good start.

Use job safety analysis. A clear safety method is job safety analysis (JSA.) The JSA shows procedures to complete a job in one column and possible accident concerns to be avoided in an adjacent column. JSA also is an excellent training tool, a standard procedure for task analysis.

Keep effective records. Manage record keeping to track accidents. This is important for many reasons, but fundamentally baseline data must be documented as proof of improvement.

Accident investigation. Investigation includes all details and costs on forms for collecting data about accidents.

Conduct inspections. Inspections are conducted in various ways, but intent remains the same. The inspection helps discover safety issues and unsafe practices before they become problems. This documents that we are taking proper steps and precautions.

Build off the job safety programs. Many accidents occur away from the workplace, raising concerns 'off the job safety.' Recognizing the investment made in people, and costs required to replace them, we know it pays to worry about health and safety off the job as well as on the job.

OSHA compliance. Another area of concern is related to the Occupational Safety and Health Act (OSHA.) OSHA provides inspection and general record keeping procedures. OSHA, used properly, is a positive influence in the technological environment.

Productivity Improvement. Productivity is output per hour of work. Various inputs are used to produce the outputs measured as productivity. Typical inputs include materials, human effort, energy sources, capital for investment, plant and machinery, among others. Many industries are not using these inputs to gain productivity at satisfactory rates, and some foreign industries are better producers. It is projected by some that if our productivity does not improve more rapidly, the US could lose its world-wide leadership position. Although American organizations are beginning to recognize the problem, the issue for American producers remains one of improving productivity.

Explanations of why American productivity has been slipping are fairly complex. One possibility includes low levels of business investment, caused by increased uncertainty in the economy and volatile interest rates. Low investment rates are disconcerting since old equipment continues in use even though it should be updated. Older equipment requires increased maintenance,
has lower output than newer models, causes down
time due to breakdowns, can create unsafe and
reduced work rates, requires more effort to obtain
precision tolerances, leading to more
rejected/reworked pieces. All of these can create
additional labor inputs and lowered outputs.

Part of the explanation may also lie with our
government. More pervasive government
regulation and requirements (e.g., air, water, safety),
have taken huge 'nonproductive' capital outlays for
equipment and programs. Also, paperwork required
to administer regulations and requirements is time
consuming without necessarily adding value.

Shifts in employment have gone away from
agricultural and manufacturing toward service and
government sectors. Service and government work
activities are particularly troublesome since
standards are often nonexistent or not well
established, and without a means for measuring
increases or decreases. These areas are also difficult
to measure or enforce standards for efficiency.

There is often a reluctance to lay off workers
in organizations when business turns down.
Individuals may be carried even though there is
insufficient productive work for them to be involved
in. This may represent dollars which could have
been invested in more productive expenditures.

A decline has occurred in the willingness
some to work hard, caused by numerous factors.
This may include cultural shifts and individual
attitudes. Some people (labor and management)
may be primarily interested in getting their pay
check. There may be an attitude among some
people which in effect says, "Who cares how things
are going as long as I get my pay check"? It is also
possible that the 'protection' offered some workers
by unions, federal and state discrimination, workers'
compensation and general equality laws, encourage
output rates which are lower than their capability.

A demographic shift is occurring toward
younger, less skilled workers. Productivity is
compounded due to loss of older experienced
workers, and their valuable knowledge and
expertise. This, coupled with fewer people entering
skilled trades, creates voids in basic work needs,
and serious productivity issues surface. As well, in
many industries new, younger people are simply not
being hired to build infrastructure for the future.

Complexities involved in tracking costs often
make it quite difficult to know precisely what is
going on in an organization. When decisions and
changes are made, through time results can begin to
show in dollars, it is often a long span of time.
Time lag makes it difficult to have cost effective
decisions related to productivity improvements.

As demand rises for commodities and other
goods and services, world-wide, costs rise. General
democratization occurring in many countries, along
with capitalism and free enterprise in various forms,
aids in driving world prices upward. This places
additional pressure on producers to compete, from
obtaining resources to marketing products.

Educational institutions are having great
difficulty keeping pace in their efforts to prepare
individuals. Increasing numbers of people may be
inadequately prepared for technological culture and
various roles, translating into reduced work output.
We provide various forms of education within the
organization for all employees, taking dollars away
from much needed capital outlays.

Research and development has been reduced
during recent years. Profit margins have been
weakened and monies have been channeled into
capital investment or for maintenance rather than
into researching and developing for the future. The
implication is that new/better technologies which
might have been used to increase productivity have
not been fully realized due to decreased research
and development. New product development--real
innovation--perhaps has not received the attention
required to help keep us competitive.

Many industries have provided the market
with every model and option conceivable. This
reduces productivity since so many different
components, styles and types often means we do not
know as much about each model as we should. We
stylize and change product lines rather frequently to
stay competitive. Not staying with one model long
enough to test, develop, perfect, and upgrade it can
be counter productive. If we try to do too much,
offer too many options, we may be hurting
ourselves. Inventory required to carry the variety of
components is a cost that cuts into productivity.

Lack of communication and coordination
contributes to lack of productivity. Although some
claim this is a problem due to largeness, it appears
to be common to many. Through better
communication and coordination perhaps the same
solution to a problem can be applied (perhaps with
some modification) elsewhere. Reducing
duplication of effort where possible can improve
productivity. Many individuals (managers/laborers
alike) really do not know what their assignment/role
is in industry. Without purpose, people may lack
motivation, and again, productivity may suffer.

Productivity With A Human Face. We can
not overlook investments in people and productivity
gains which can be recognized through this
resource. Key points for improving productivity through people are provided in this section.

People at all levels should be encouraged to take pride in their work. Generally, work does have value and is a contribution to the productive output of an organization regardless of who is doing it or level in the organization. People who are proud of what they accomplish will tend to do more than individuals who are not proud of their work, leading to improved productivity.

People should be encouraged to continuously improve themselves and their organization. Suggestion boxes, cash incentives, a day off, increased promotions and so on, should be provided to individuals who show improvement in themselves or their work areas. The attitude should be engendered for all people to attempt to do better in whatever they are responsible for. It is important for the organization to follow-up on ideas individuals provide and do something about possible improvements. If nothing is done, credibility will be questioned and other possible improvement ideas will be less likely to emerge.

Change is part of all organizations. Change which is necessary, however, can also be a disruptive force in the organization and therefore be less than desirable. People should be encouraged to view change in technological functions as a positive means to staying competitive and viable for improved productivity. The notion that once the system is on line it can stay the way it is forever, is simply a falsehood. Technological functions, by their very nature, must change. It is most likely that people who can remain positive and optimistic in the change oriented environment, even to the point of thriving on the changes, will most likely be the more productive individual. If the individual views change as bad, they may feel threatened and be less productive. We must view change as necessary, useful and generally, good.

People should be encouraged to learn to question the current approach and method in a diplomatic manner. If questions are not conducted in a diplomatic manner others may become upset, leading to a less productive situation. If questioning is approached with diplomacy and tact, with the overall goal of involving others in a cooperative manner, perhaps a productivity increase will occur.

People should be encouraged to grow with criticism. Criticism given in a professional manner, and in good faith, should be accepted. While some self evaluation and criticism can occur by the individual, some guidance and feedback/input could come from one's peers and others in the workplace.

This process must be undertaken with great sensitivity if true productivity gains are go be made.

We should use incentives to improve productivity in technological functions. Various incentive plans include (1) piece-rate plan; (2) standard-hour wage plan; and, (3) group profit sharing plans. Piece rate rewards based on total numbers of units produced over time, while the standard hour wage plan guarantees a minimum amount of pay regardless of number completed. Group plans reward a dividend on a regular basis, determined by total productivity levels in a group.

Industrial managers must possess skills which enable them to effectively communicate with all individuals, including line workers as well as top management. Communication skills are particularly important since they may be involved in technical circumstances where human relations, motivation, supervision and training will be part of their responsibilities. While technical knowledge and functions should continue to receive a top priority, we should also be encouraged to perfect our public speaking, business presentation, technical writing, human relations, and other skills.

**Statistical Quality, Basis For Data**

The use of statistical methods enables us to make quantitative statements about data that often could not be communicated as readily by other means. Statistics refers to data, the collection of numbers that represent raw materials, products or systems we work with. These may be test scores, reaction times, frequency of rejects, numbers of product produced, or other similar numerical measures or indicators of items or behaviors. Statistics also means methods reflected in formulas, derived and developed to treat data.

The task of statistics is to reduce groups of data to meaningful and useful information. These values, or information, can assist us in several ways. This includes planning, policy changes and general decision making, setting standards, and others. Based on numerical indicators and measures from production, we can take some of the guess work out of making decisions--and become increasingly competitive in the process. Without data we are less certain, less definitive, and more oriented to making "seat of the pants" types of decisions. Statistics provide a more solid, formal, base for decisions.

Based on data generated, policy can be configured or altered. If existing modes of organizing and operating prove to be problematic, changes can
be made. Changes may be based on statistical indicators, and after changes, new data generated could be used for comparative analysis. Over time and with training, persons will be exposed to data which can help make decisions and changes in managerial issues which are confronted. This is what data based decision making is--using data to improve.

Statistical feedback provides opportunities for standards to either be altered or created. Equally as useful, based on statistical feedback, control in processes can be pursued. Statistical analysis of the process can be pursued by gathering information which is documented/stored. This provides a data base, invaluable for comparative and analytical purposes, enabling better decisions and improvement.

Assuming a data base is built-up over time, much useful productivity information can be derived. Has productivity or quality actually been improved? By observing results based on statistical feedback, employees can gain insights and understanding about when they have mastered a task at a sufficient quality level. This takes a disciplined, well trained, "comfortable with numbers" work force--not quickly or easily achieved. Statistical information, as data, can provide an excellent communication and documentation system for internal and external purposes. Not using data properly increases chances that customers will go elsewhere to do business.

One of the key reasons for using data is to actually "know" what we are talking about. It is one thing to say "oh about half" versus saying 50%. Or if we say "well, quite a few of the products were defective", rather than saying "20% of the products were defective", it is different. If we say "10 of the products had 3 defects each, yet none of them were actually defective", it can make a significant difference. The difference is that we are being more precise when we place a proper numerical indicator into the discussion. This relates to wanting to make improved decisions, rather than "seat of the pants" decision-making. This difference is precision of communication--knowing better what and when we say something--the root of the need to use data.

Descriptive statistics seek to accurately describe a situation through data. This deals with the present, limited to describing present conditions for numbers actually studied. Inferential statistics deals with inferences, implications, and generalizations from the sample to a larger population. Inferential statistics are concerned with the future, broadening conclusions to include other groups beyond those studied, such as probability for occurrences of events.

Central tendency is three measures, including mean or average; median or positional value; and, mode or most frequent. Uses of central tendency occur in several ways. The average or mean is the one used most often. It is used to report average size, average yield, average percent defective, and so on. The median is used in special situations such as data that can be ranked but not easily measured including color, softness, or smoothness of a surface. The mode is the most frequent or representative value, used to eliminate effects of extreme values in a distribution.

Range shows extremes in a given group of data. The range of data listed below is 3 (top) to 21 (bottom). Rank ordered data in the range follows:

<table>
<thead>
<tr>
<th>Rank</th>
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<tbody>
<tr>
<td>21</td>
</tr>
<tr>
<td>15</td>
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<tr>
<td>14</td>
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<td>12</td>
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<td>12</td>
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<tr>
<td>10</td>
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<tr>
<td>7</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

We determine the mode to be number 12, appearing twice, and the average, \( \frac{84}{8} = 10.5 \). This is a sum of 84 divided by a total number of values, 8.

What started out as raw numbers has become a rather useful set of descriptive data. If this was the temperature for the first eight days in the month of January, it gives even more meaning to the data and those days. This is essentially what descriptive data is about. Inferential data would reflect behavior over time in another way--still using our example. Studying the ten year average of the same set of eight days in January we find that each of the averages is:

<table>
<thead>
<tr>
<th>Year</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>11</td>
</tr>
<tr>
<td>1986</td>
<td>12</td>
</tr>
<tr>
<td>1987</td>
<td>12.5</td>
</tr>
<tr>
<td>1988</td>
<td>13</td>
</tr>
<tr>
<td>1989</td>
<td>11.5</td>
</tr>
<tr>
<td>1990</td>
<td>14</td>
</tr>
<tr>
<td>1991</td>
<td>15</td>
</tr>
<tr>
<td>1992</td>
<td>18</td>
</tr>
<tr>
<td>1993</td>
<td>20</td>
</tr>
<tr>
<td>1994</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Summing these would be 137.5, and when divided by 10, it would be 13.75. We say that the mean, or \( \bar{X} \) bar, of all of the 10 means is a grand mean, or \( \bar{X} \) double bar. Thus 13.75 is the grand mean of the ten year average. The inference drawn from this data is that the temperature for the first eight days of January in most years will be in the range of 10.5 to 20 degrees, and on average will be 13.75 degrees.
Dispersion is represented by three measures including range; variance; and standard deviation. Range is the minimum value subtracted from the maximum value in a set of numbers, and as a measure of variability is useful when the number of values is small. Standard deviation, as an indicator of total variation, reflects central tendency in data. Variance is the square of standard deviation, a broader look at behavior around the mean. As a function of descriptive data, these fall under the broad rubric of normal curve. The "normal curve" is illustrated nearby for further description.

Standard deviation is a calculation of dispersion among the mean, or sample total variation around the mean. Use of standard deviation allows total population to be predicted as being within + or -1 standard deviation 68% of the sample resides, within + or - 2 standard deviation 95.5% of the population resides, and within + or -3 standard deviation 99.7% of the population resides. Standard deviation is the most valuable and used measure of a frequency distribution. It expresses dispersion in a single number and important relationships between "standard deviation" and normal curve.

Variation in product is the basic issue. When summed and a calculated, the value for the mean is a basis for further analysis. Presented graphically, it is commonly shown as a normal curve. The normal curve represents all of our sampled data--all else is directly related back to the normal curve.

Generally +3 sigma is three standard deviations on the high side of the mean or average. Three standard deviations on the low side of the mean is -3 sigma. Approximately 99.7% of all values will fall within + 3 sigma and -3 sigma, of the mean, if under statistical control (plus or minus three sigma). A statistical limit set three standard deviations on the high side of the mean, or +3 sigma, is termed upper control limit. Lower control limit is a statistical limit that is set three standard deviations on the low side of the mean, or -3 sigma. Approximately 95.5% of all values will commonly fall within the range of +2 sigma on the high side of the mean to -2 sigma on the low side. The remaining +1 to -1 sigma on either side of the grand mean represent approximately 68% of all data.

**Sampling--Defining The Source Of Information.** Sampling is the act of deriving sufficient numbers of product to be studied and inspected, based on quality characteristics previously determined. Samples must be representative of the population being produced, if it is to be valid. But sampling takes time and costs money to perform, and thus cannot be done any more than is absolutely necessary. Sampling is important for several reasons:

1. Sampling some, not all units, reduces costs.
2. Complete and accurate data since a good "picture" of production is gained.
3. Less damage, fewer products are inspected.

Sampling can occur in various ways, ranging from random and with very little structure, to a highly structured procedurally oriented act. Factors governing sampling are cost and quality required:

1. Consistency must be observed.
2. If some items are more likely to be selected, or less than a full range of characteristics can be observed, it requires changing the plan.
3. The only good sample is a representative and accurate picture of the population.
4. Samples must come from the entire lot and all population conditions must be represented.
5. Every item must have an equal chance of being selected for the sample.
6. Personnel gathering data and samples must be trained in documentation and reporting.
7. Adequate time must be allowed for sampling to occur. Pushing too hard may damage data.
8. Proper measuring tools must be provided to enable a proper sample to be taken.

Consistent with other quality systems' design and functioning, it is important for sampling to occur at the point of production, and to be a standard part of the production procedure for workers.

**Attribute Charting Systems.** The need to track and chart various attributes, under different types of circumstances, has lead to the development of several types of attribute control charting systems. P charting is generally regarded as the most used attribute chart. The general steps associated with attribute p charting include collecting data, calculating fraction defective, and the upper and lower control limits. Based on the calculations we will plot the results for analysis, over time, and complete appropriate analysis and
corrective actions if needed—depending on the findings at the operator workstation.

**Attribute Step 1: Collect Data.** Data are collected on the number inspected, generally identified as n, and the number found to be defective in the total sample (n) inspected. Data would typically be divided into subgroups according to some predetermined logic system, per the customers request, or based on some inspection SOP, consistent with the type product or process under study. Subgroup size is consistent with attributes being studied, typically no less than 50 to facilitate generalizations to larger populations.

**Attribute Step 2: Collect/Calculate Each Fraction Defective.** The second major attribute step is to calculate the fraction defective or non conforming for each subgroup. This information should be entered on the chart or some type of collection form for tracking and further analysis purposes. Fraction defective is determined by dividing number of defectives (np) by subgroup size (n), expressed as np/n mathematically.

**Attribute Step 3: Calculate Average Fraction Defective.** The average fraction defective is a function of summing pn and dividing by the total n for an average or mean value, commonly expressed as p bar. This step converts individual subgroups to grouped data, reflecting normal curve behavior.

**Attribute Step 4: Computing The Control Limits And Central Line Values.** Upper and lower control limits are calculated based on the p bar value converted to a percentage, or times 100. The p bar converted by percentage is used as the central line in the chart, centrally located between the upper and lower controls (UCL and LCL). UCL and LCL are calculated based on standard deviation logic as:

$$UCL / LCL = p \pm 3 \sqrt{\frac{p(1-p)}{n}}$$

The UCL is +3 sigma, the LCL is -3 sigma, p is a function of np divided by n, and the p bar value represents sums of the total sample population.

**Attribute Step 5: Plotting The Points.** After all calculations are performed, information is plotted on a form similar to what is provided nearby. Note that "ups and downs" may be observed in the step 5 charting graph as a function of varied subgroup sizes, sometimes unavoidable. This requires considering consistent subgroup (n) sample sizes wherever possible to provide consistency in charting (50, minimum, is recommended sample size).

**Attribute Step 6: Analysis Of The Chart.** As data is tracked and plotted, the chart will provide a quick and generally easy-to-use tool for determining if the attribute being studied is sufficiently conforming. Actions appropriate to the circumstances should be taken to adjust and improve over time. Many of the same decisions made during X bar and R charting for variable data must be dealt with for attributes. Similar steps for calculating control limits, plotting the points of inspection, and interpreting this information, are applicable in principle and practice:

--what is the purpose of the chart?
--where should inspection occur?
--which characteristics should be charted?
--what should the size of the sample be?
--should the sample size be constant?
--frequency of samples?
--information include on the chart?
--how does the p chart relate to Pareto?

Issues regarding startup of the chart include:

--judgments about defects and defectives
--recording accurate data--how, who, etc.?
--calculation of the p, completing forms
--plotting the points

Continuing control chart--issues could include:

--calculation of the control limits
--plotting the control limits
--plotting the sampled data points
--interpretation of control/lack of control
--comparison of current charts to past
--discipline for follow through

Possible actions based on p charting include:

--keeping process in control
--review of specifications, characteristics
--providing information to various teams
--ongoing improvements based on charts

Given constant improvement, we know that incremental "tightening" of control limits will be sufficient for gaining constant improvement. This may be inconsistent with use of calculated controls, but as systems mature, we know we are under control (or out of control) and that improvement is incremental. This is consistent with the "start-up" nature of attribute charting and data, often aimed broadly at longer-term variable systems.

**Attributes, Checklists And Charting**

Defects and defectives can be tracked via a simple check sheet or checklist. Whether attribute or variable, the check sheet can be used to begin the
charting process, and also serve as the start of
decision making. Not only is the immediate
judgment on defect and defective being provided, but
the broader corrective action for improvement should
(and can) be noted. Checklists can be pivotal for
obvious reasons relating to doing all of the things we
have been trying to reinforce. They:

1. Provide indicators of defects or defectives at
   the point of production.
2. Are operator friendly, a good transitional
   mechanism on data collection.
3. Tie into basic work instruction or standard
   operating procedure (SOP).
4. Can be pivotal in Kaizen analysis, reinforcing
data and documentation.

Examples include housekeeping and safety
checklists, process flow and charting analysis, and
various scheduling and balancing tools.

Another, possibly less complex charting
technique in the attribute judgment method is the
simple histogram, sometimes called bar charts. These simple charts are bars, lines or other symbol
which represent a corresponding number of values or
observations tracked in production--attributes
identified and logged--converted in to summaries
which help identify key areas needing improvement.
The bars can either be horizontal or vertical and are
generally proportionally constructed relative to the
information they represent.

Histograms are constructed by first
determining the number of classes (cells) to use. The
number of cells in a histogram of data should be
determined based on the number of values in the
sample. Cells or blocks of information may also be
influenced by other "common sense" information
based on what we know about the situation. For
example, it may be obvious that the data generally falls into groupings based on the nature of process,
characteristics or others. Histogram steps include:

1. Organize by determining class (cell) intervals,
based on total group of actual data.
2. Construct a tally with classes in rank order--a
category for each type observation or attribute.
3. Tally data observations into appropriate class
and list the total frequency for each cell.
4. Prepare the vertical and horizontal axis.
Vertical axes are frequencies of classes and
horizontals are classes of the frequency tally.
5. Fill bars to height of total frequency for class.
6. Analyze and interpret data to determine
appropriate steps for ongoing improvement.

An example uses frequencies ranging from 4 through
20, and judgments of attributes from A through H.

<table>
<thead>
<tr>
<th>freq</th>
<th>16 xx xx xx</th>
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<tbody>
<tr>
<td></td>
<td>12 xx xx xx xx</td>
</tr>
<tr>
<td></td>
<td>8 xx xx xx xx xx xx xx</td>
</tr>
<tr>
<td></td>
<td>4 xx xx xx xx xx xx xx</td>
</tr>
</tbody>
</table>

```
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

One Type Histogram.

Some inaccuracies exist based on groupings and
cells. This could be "tightened" in subsequent
analysis based on actual measurements taken.

A variation on the histogram is the bar graph.
While similar, the bar graph can sometimes be
constructed and used more readily. Bar graphs may
also use horizontal groupings as shown below where
TA, TB, and TC are frequencies of judgments given
in more detail and sub grouping in cells. Judgments
shown below reflect a simple distribution of
attributes observed ranging from A to H, and could
be color, sheen, surface quality, or virtually any other
common attribute or judgment, regardless of product.

<table>
<thead>
<tr>
<th>Attribute/ Judgement</th>
<th>TA</th>
<th>TB</th>
<th>TC</th>
<th>Tally A</th>
<th>Tally B</th>
<th>Tally C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>*</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>**</td>
<td>***</td>
<td>**</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>****</td>
<td>*****</td>
<td>***</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>*****</td>
<td>********</td>
<td>****</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>*****</td>
<td>********</td>
<td>*****</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>*********</td>
<td>*********</td>
<td>*****</td>
</tr>
<tr>
<td>G</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>***</td>
<td>*****</td>
<td>***</td>
</tr>
<tr>
<td>H</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>**</td>
<td>***</td>
<td>**</td>
</tr>
</tbody>
</table>

Attributes Organized Into Bar Chart Form.

Some general considerations for these types of bar
graphs include their usefulness for viewing groups of
information and for comparing and analyzing similar
groups of data. The groupings of information also
approximate a normal curve, defined earlier.
Behaviors studied as attributes should occur
randomly and represent the broader population.

A slightly modified version of the histogram,
increasingly popular over the last several years is the
Pareto chart. Pareto is a bar chart in histogram form,
which also organizes the data according to highest to
lowest percentages of behaviors. Another useful
graphical chart is the pie chart illustrated nearby.
The graphic shows 100 product defects by categories,
sorted and organized within the pie chart--by count
and %. This analytical tool is a simple "slice out of
the pie" for each area represented. The power in this approach is "seen" clearly by comparing larger versus smaller areas, where we need to make improvements.

An additional bar type graph, related to histograms, is the Pareto chart. The reason for the Pareto popularity, similar to many of these tools, is its quick graphical analytical focus for quality improvement. The Pareto orders data, based on defects, ranks the occurrences by percentage, and gives a graphical pictorial for quick reference and ease of use. An example Pareto application is shown nearby. General procedures to use are as follows:

1. Identify the problem or attribute to study.
2. Collect data supporting frequency by attribute.
3. Focus on categorical or individual attribute.
4. Identify the maximum level among all attributes, placing most from left to right.
5. Individual behavior associated with the problem is generally shown as 100%.
7. Right vertical matrix is up to 100% downward.
8. Horizontal matrix is categories of attributes.
9. Construct vertical bars for percentages.
10. Interpret information and improve, repeat.

Occurrences are given their numerical value with "x's" in the vertical bar columns. It may be helpful to place the greatest to least column (item) of from left to right on the chart. The % value on the right is not always 100%—in fact it is unlikely that any one set of occurrences would ever equal 100%.

**Matrices and data bases.** An additional data driven form of documentation discussed as part of improvement and problem solving is matrices and data bases. The basic configuration is provided as numerous examples throughout the tool and toolkit. Most documentation and data forms for collection and analysis of information rely upon organizing matrices for better seeing relationships. Similar to all tools, the concept is to determine what information is to be organized and collected. Based on what must be done, various tables and spreadsheets are available to assist, within various software formats.

Two examples are provided at the conclusion of the applications section of the current tool. These are both done in Microsoft Word, one as a table and the other as an Excel spreadsheet. The advantage of the spreadsheet over the table is that calculations can be performed in the spreadsheet. After determining what must be done and how it should look, the spreadsheet can be designed to calculate various basic mathematical functions. By contrast, if all we wish to do is display information, a simple table in the Word pull down may be sufficient.

**SPC, X-bar And R, Variable Charting**

SPC, or statistical process control, is a technique used during processing, a statistical technique used to help operators and others make decisions. A charting process is implemented to allow operators to (a) determine when to make adjustments to process parameters, and (b) to describe how much variation exists in any particular process. In short, SPC, based on the X bar (or mean) and R (or range), has the potential to help shift the responsibility for reducing product variation from a quality control department to the operator/processor.

The fundamental cost savings in SPC and X bar and R charts are a by-product of consistency and accuracy of production output. There are at least two situations where SPC can be implemented. The first situation involves the analysis of existing processes. In this case, SPC can be used to (1) determine how consistent and accurate a process is, (2) provide a basis for making adjustments during production to maintain control, and, (3) to establish proper production procedures. The second situation involves the introduction of a new product. In this case, SPC can be used to determine whether a process is capable of meeting predetermined design specifications. SPC can provide base line data at the onset of production, forming the basis for continuous improvement. There is an economic advantage to SPC, although typically not short term gains noted quickly. Rather, SPC cost savings must be observed over time, often years.

X-bar and R charts can help define the amount of variation due solely to chance causes. If the process is operating within limits determined through charting methods, the process is generally considered stable and predictable. It represents the best that people operating the machine are able to do given existing process. If this is unacceptable, then the basic system should be changed, including the type of
An important reason for use of control charts is to provide documentation. Documentation can be used to help know when to rebuild, adjust or replace machinery; when, where and how to change procedures; or for general comparative analysis between methods. Documentation serves as "baseline" data used in analyzing changes/upgrades for improvement. After additional charts are put together, based on improvements, new charts should be compared to base line data. Charts can be shared among workers, shifts, departments, plants as a fundamental communication mechanism.

Control charts take some of the guess work out of process decision making. Once data are collected and tabulated we have some basis for decision making, rather than "gut feelings" only. One key reason for using X-bar and R charts is to provide a systematic approach to managing production. Charting assists people in rational decision making.

X-bar and R charting methods work best in continuous production where characteristics can be identified for measurement. Continuous production, with similar characteristics provided over time, have repeated values indicative of the process. The greater the variation in conditions under which data are gathered, the greater the likelihood of incorrect process conclusions being drawn and acted upon. Continuity and repeatability in production, from measurement to measurement, are an important condition. A knowledgeable operator is required, since, if a new operator were to begin charting, error in operator control would be noted. The error would be caused by the lack of repeatability and continuity on the part of the operator. After the operator has gained experience, repeatability and continuity will improve and charting will reflect "under control" conditions. Also related to repeatability and continuity, reliability in material and machinery are required and assumed to be at a level sufficient to provide "in control charting conditions". Not only managers, but perhaps more importantly, the line worker must be disciplined and capable of performing routine calculations, computer applications, and analytical reasoning.

Standard procedures for X-bar and R charting are necessary. Reliability of charting technique is affected by the extent that procedures are known and followed in SOP form. General guidelines are:

1. Decisions prior to beginning charting.
2. Starting the control charts.
3. Drawing conclusions from the charts.

Decisions and issues include determining objectives of the charts, and knowing why they are being used by all involved. Another decision is the choice of the characteristic to be charted. This is usually a specification or variable measure which can be gaged. Decisions on sub grouping, sampling strategy, sizing and frequency, including setting up the forms for recording data, must be made.

Starting control charts requires accurate measurements on a repeatable basis using a systematic approach (i.e., all measurements are completed following the same procedures). Operators must record the measurements and other relevant data such as time of day, name of operator, machine used, and any circumstances to explain unusual findings.

Drawing conclusions from the charts includes getting an indication of control or lack of control based on points falling outside of the control limits/lines. The apparent relationship between what the process is doing and what it is supposed to do is of interest in the charts? Actions suggested by control chart data include changes in the process, operator, specifications, material, etc. Issues about sufficient charting information, use of the charts for acceptance or rejection, and even whether to stop or continue, should be standard procedure.

Based on SPC analysis it can be determined if a machine is in control or out of control. If it is out of control, some part of the process may be modified. Regardless, new data will be collected and whether the process is in control or not, charts are a tool for decision making. The operator, with help from others team members, determines when a process is running normally or is in need of adjustment. Prior to commencing with charting over the longer term, the process should be capable and under control as proven through actual start up procedures in charting.

An example process involves drilling a hole .500 inch deep in a block of aluminum. While the average hole will be very close to .500 inch deep, variation up and down will occur.

**Step 1: Sampling.** Remember this is a continuous and ongoing operation. We repeat this procedure every 10 minutes for at least 16 subgroups.

**Step 2: Calculating Values.** This first involves calculating the average of the subgroup depths. Secondly the range (maximum depth - minimum depth of each subgroup) are calculated. Next, the mean of all average depths (X bar) is calculated (sum of average depths divided by 16). In this example the X double bar was calculated to be .501 inches. Last,
the mean range is calculated (sum of ranges divided by 16). A mean range of .006 inches was calculated.

**Step 3: Plotting X Bar Chart.** On the form provided, values have been plotted, and mean values for each subgroup are shown. The center of the graph is shown as the grand mean or X double bar (.501), with the vertical axis representing depth values and the horizontal axis representing time.

**Step 4: Plotting R Bar Chart.** Ranges for each subgroup are shown on the form. The center of the graph for R is .006, with the vertical axis representing ranges and the horizontal axis representing time.

**Step 5: Calculating Control Limits.** Control limits represent boundaries for acceptable variation within a process. The calculations for these are based on simple formulas. The upper control limit (UCL) and the lower control limit (LCL) are calculated by:

\[
\text{UCL} = X + A2R \\
\text{LCL} = X - A2R
\]

A2 is a constant statistical value based on subgroup size. The example was sampled 5 times in each subgroup and a factor .58 was used. Other statistical values for different subgroup sizes vary (five is the norm). Substituting values, the calculations are:

\[
\text{ULC} = .501 + .004 = .505 \\
\text{LCL} = .501 - .004 = .497
\]

Control limits for range use only the upper control limit since we are not concerned with minimum variation in a process range, and hence there is no lower control limit. The formula for the range UCL multiplies the mean range times a constant statistical value, D4. In this case D4 is equal to 2.11 based on subgroup sizes of 5, and UCL is calculated as .012.

**Step 6. Plotting the Control Limits.** The last step is to plot the control limits.

**Step 7. Interpretation of Charts.** As the ongoing process is charted and repeated, an operator determines if a machine is in control (within the boundary of the control limits). If the process is outside the limits corrective action should be taken.