Lean Six Sigma Quality Transformation Toolkit (LSSQTT)*
LSSQTT Tool #12 Courseware Content
“Gauge Repeatability And Reproducibility (R & R):
Inspection And Measurement As Critical Services”

1. Using gauges and instruments, lean, six sigma opportunities
2. Sampling issues further explored
3. Quality characteristics, important features and certification
4. Evaluating gauges, measurement error
5. Gauge R & R, traceability and the broader quality system
6. Traditional versus new approaches--supervisors, operators and others
7. 100% inspection and sampling influences on quality characteristics
8. Evaluation of quality characteristics--startup thoughts, six sigma, ISO/QS
9. Data and documentation for lean, six sigma, kaizen

*Updated fall, 2007 by John W. Sinn.

Using Gauges And Instruments, Lean, Six Sigma Opportunities

Most gauges and instruments for data gathering, like all other technology have a correct method of use. This should be documented, demonstrated, and mastered by all concerned with their use. Procedures for proper use should be built by teams of operators, supervisors, quality and engineering personnel, and perhaps others such as gauge vendors. But the key point is that if we expect certain individuals to have integrity with and within the system, we must rely upon them from the start--giving them full support and all the tools they need to get the job done.

Recognize that procedures identified above are pivotal to doing business in the future. Documented procedures not only provide one of the key training vehicles, but importantly, this also forms the basis for supplier relations--most suppliers will want evidence that you are actually gathering the data--gauge use procedures form a key part of this. When it becomes evident that a problem requires attention, one of the keys to improvement is knowing how we actually use gauges to gather data. How can we improve if we do not know how we are currently doing it?

Mastery of gauges and instruments for data gathering starts with proper procedures for use, with full documentation built with strong operator input and guided by supervisors and others. But mastery of the gauge will be a function of discipline and practice of using the gauge or instrument. Much gauging of the future will be of a "high tech" orientation, requiring precise procedures, basic understanding of digital electronics, and confidence by and of, the operators and others in the system. All of this can be best handled through team functions with all concerned to properly demonstrate and train for the system. Ultimately, as with most other functions, "best operators" will emerge within the system, providing pivotal support persons for troubleshooting and improving the data collection system at a gauge level.

Specific inspection procedures, systems. Specific inspection procedures are essential to providing optimum quality. These procedures typically rely on general information such as that provided earlier in this section. Inspection is usually organized around specific phases such as receiving, in-process, final and shipping inspection procedures, but incorporated into the overall production plan and quality system. As indicated earlier, it is important that people perform these inspections as part of their routine work rather than being done by roving inspectors. The bottom line here is that inspection, as part of the quality system, is not a separate added on function. Rather, it is integral to the act of producing the product, virtually a part of the standard operating procedure (SOP).

But inspection must also be regarded as "adding value" wherever possible. Inspection must not be a simple added on activity, taking more time and adding possible opportunities for damaging product. As with any other task in production, we wish to do inspection in the least intrusive and most productive manner possible. Examples of this could include such simple acts as:

1. Waiting to close the package until final ship functions, allowing one more quick observance of the shipping labels and contents,
original order and scheduling/routing slips, among other important functions.

2. Use of poke yoka fixtures to only allow setups and preparatory assembly and "next step" functions in the right way—causing inspection and production to occur in simultaneous ways.

3. Continued development of SOP's to seek better ways to accommodate inspections by operators at the point of production with charting functions and other disciplined and empowered steps, without taking away from getting product out the door. This should occur particularly where flow charts demonstrate bottlenecks, WIP buildups, non-conformities or other problems/opportunities.

4. Simple use of checklists and sheets which require individuals such as operators and supervisors to study important parts of a work site or project, prior to moving forward, signing off and in effect certifying compliance to a standard or norm.

Much of the above can best be accomplished by determining capacity as a function of SOP's in the broader context of flow and layout of the total production analysis. This is at the core of kaizen, or quality improvement, and is covered in much detail in the various lean and six sigma relationships inherent in data and documentation tools within the toolkit. It is suggested that broad-based inspection and data gathering activities at the point of production provide many opportunities to do kaizen for lean based on six sigma principles and methods.

Organizations and products will require varying levels and types of inspection for quality. For example, aviation, nuclear-related, and many government programs will require 100% inspection. A typical rule of thumb for many other products and organizations, however, is 10% inspection of appropriate pre-determined characteristics. A minimal number of inspections should occur, but without reducing or jeopardizing quality. It is also worth pointing out that given statistical process control and other on-going improvement techniques, it should be true that inspection can occur less over time, and be justified and defended through documentation and charts.

The typical inspection system will involve, at minimum, receiving, in-process, and final/shipping elements or steps. As part of this the component which we are generally most concerned with, due to the production relationship overall, is the in-process component. The charting, tracking and measuring components are oriented primarily to in-process functions. Even so, attributes can and should be tracked and logged in final ship inspection where packaging, labeling, and overall quality are observed as a function of the last steps in production. As raw materials and parts are received for production, we can inspect attributes and variables as important start up characteristics. Receiving inspection provides that all subcontracted materials, parts and assemblies should be subjected to a receiving inspection prior to acceptance from vendors. Purchased material should be inspected by an appropriate sample plan using standard organizational procedures unless otherwise mandated by the customer. If necessary, vendor supplies should be verified by statistical process charts where feasible to prove control within specific limits. It may also be necessary for material or assembled components to be verified by an independent lab on a random basis periodically depending on the nature of the product or service being produced. If any of the above are non-conforming, the material should be tagged and sent to an area for non-conformance. The supplier must be notified and a request for disposition, corrective action, and date of corrective action provided. If an organization can not meet production schedules without rework, the cost of the same should be at the expense of the vendor. Statistical process control is a requirement for all suppliers and they must insure their process is in control and provide charts and records for customer examination.

In-process inspection procedures should be conducted on all products, processes and production phases and equipment to insure quality. To verify proper operations, the first part can be verified 100 percent to establish conformance to specifications. All inspections must be documented and should be available upon customer request. Records should be maintained for an appropriate period of time, per the nature of the product and organization. In-process inspection, other than first piece will be performed by the operator, whenever possible, although others involved in the quality system may need to supplement this. It may be necessary to shut down the process, with primary responsibility remaining with the operator when the process is graphically shown as being out of control. Others would likely become involved to assist in the analysis for corrective action, perhaps focusing through an improvement team.

Final processing inspection should be conducted per either customer instruction or general organizational standards and procedures, but focused on characteristics previously identified. Proper final documentation for certification should include all
pertinent test data, sampling plans and final inspection results. If the product is approved by the operator, all documentation will be completed and a final tag attached authorizing a move to shipping. Final audits before shipment may be necessary with spot audits performed and recorded by individuals (dock audits) in the shipping function. Shipping personnel focus on likelihood that all parts for shipping have been prepared to insure the best commercial means of packaging in order to preclude any damage.

Packaging should be reviewed on a timely basis to insure customer specifications are being met or exceeded. Components, assemblies and parts should randomly be inspected for cleanliness, any visible damage, part number, marking and packaging compliance per instructions furnished by the customer or as specified in general standards, including labeling. Noncompliance of packaging requirements may be cause for follow-up with operators and others, perhaps providing impetus for an improvement project.

Inspection systems and the inspection function may be expensive. It is for this (and others) reason that many organizations are conducting only first piece last piece (FPLP) inspections. This is where first and last pieces produced are inspected and compared within an entire lot, on an as needed basis. Generally speaking, if the first and last piece in a production run, or lot, are satisfactory, then it seems safe to assume that the entire group is satisfactory. Since this does not give a "total" picture by any means, it may prove totally inadequate depending on the product, lot size, and so on. But FPLP inspection may be a good place to begin. Regardless, what is inspected must be properly documented and charted.

**Sampling Issues Further Explored**

Sampling is the act of deriving sufficient numbers of product to be studied and inspected based on quality characteristics previously determined. The sample must be representative of the total population being produced, if the sample is going to be valid. But sampling takes time and costs money to perform, and thus cannot be done any more than is absolutely necessary. Yet sampling is important and essential in the quality system for several reasons. This has to do with costs, productivity, gaining an accurate picture, and reducing inspection and damage to product.

Sampling can occur in various ways, ranging from random and with very little structure, to a highly structured procedurally oriented act within the quality system. Generally, the factors governing amount of structure in the sampling procedure relate to cost in production and inspection and degree of quality required in the product. Considerations and guidelines for sampling presented earlier, and summarized now in graphical form are shown nearby.

Consistent with other quality systems' design and functioning, as presented earlier, it is important for sampling to occur at the point of production, and to be a standard part of the production procedure for line workers. Assuming quality and production systems are working correctly, individuals who should want the best sample are persons responsible for maximum quality and productivity, persons on the line. Sampling can occur in various ways, ranging from random and with very little structure, to a highly structured procedurally oriented act within the quality system. Factors governing amount of structure in sampling procedure relate to cost in production inspection and degree of quality required in product.

Some specific considerations and guidelines for sampling relative to lot size and numbers for samples are provided in a graphical table nearby. Note that the table provides various levels of sample based on other important considerations.

<table>
<thead>
<tr>
<th>Lot Size</th>
<th>Normal</th>
<th>Tightened</th>
<th>Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 50</td>
<td>5</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>51 to 90</td>
<td>7</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>91 to 150</td>
<td>11</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>151 to 280</td>
<td>13</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>281 to 500</td>
<td>16</td>
<td>29</td>
<td>8</td>
</tr>
<tr>
<td>501 to 1200</td>
<td>19</td>
<td>34</td>
<td>9</td>
</tr>
<tr>
<td>1201 to 3200</td>
<td>23</td>
<td>42</td>
<td>9</td>
</tr>
<tr>
<td>3201 to 10000</td>
<td>29</td>
<td>50</td>
<td>9</td>
</tr>
<tr>
<td>10001 to 35000</td>
<td>35</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>35000 to 150000</td>
<td>40</td>
<td>74</td>
<td>9</td>
</tr>
<tr>
<td>150001 to 500000</td>
<td>40</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>500001 and over</td>
<td>40</td>
<td>102</td>
<td>9</td>
</tr>
</tbody>
</table>

Sample Sizes Of Normal, Tightened Or Reduced As A Function Of Lot Size.
Picking up on the previous information about level of sampling relative to lot size in production, it is obvious that the part history and records from inspection tracking are important considerations. The form provided nearby provides a key element in the overall quality system, and while generic, can be used at the point of production or elsewhere in incoming, in-process, or ship/final stages. But it should also be noted that various levels of robustness can be built into the sampling plan based on other variables. These are noted in a graphical summary nearby.

One additional point is rather important in the overall sampling mix. This relates to the characteristics for sampling and measuring over time. On the one hand this appears to be rather straightforward and simple. But the fact is that this is not only important, but it can also be rather costly. This is true since much time and general resource will be aimed at measuring that particular characteristic, once identified. Thus, it is important to make sure that they are carefully identified and justified through the customer, suppliers, engineering and quality personnel, operators, supervisors and others. Certainly, as improvement is noted over time in production, based on statistical process control, it is important to continuously re-evaluate the quality characteristics. It may be possible over time to discontinue tracking a given characteristic, as it comes under control, thus enabling the charting process to move on to another characteristic for study and analysis.

**Quality Characteristics, Important Features And Certification**

But what is a quality characteristic? Quality characteristics are important dimensions, features or parts of a component. This involves the classification of numerous important areas of a product, such as dimensions, speed, hardness, weight, finish, each according to their relative importance in contributing to the quality of the product. This enables the quality effort to be directed to the matters of greatest importance, through the use of priorities. It also simplifies selection of sampling plans, and it increases inspection accuracy on important characteristics by providing a clearer focus.

Quality characteristics impress on the designer the need to carefully consider the importance of each characteristic in establishing tolerances and general relationships in quality terms. It also helps to assure minimum quality cost by decreasing chances of error and aiding in general quality of communication. Establishment of characteristics to be inspected may occur simply based on the key problems identified. Quality characteristics' determination occurs based on input from the customer, engineering functions, and perhaps others.

Attributes are quality characteristics either possessed or not possessed by an item being inspected. Piece attributes may be evaluated after being produced and could include (but not be limited to) under, to, or over size, or the number of clearly identified flaws in the piece. Quality attributes are generally identified as observations and judgment calls as opposed to measurable characteristics, and are either viewed as acceptable or unacceptable in conformance quality terms. The process charts generally associated with attribute data are p charts, np charts, c charts, and u charts, with each of these having been discussed in an earlier tool.

A quality variable is any product characteristic measurable on a continuous basis or scale. Shaft diameters, strength in materials, density in photography, are all variables related to quality. Variables, then, are used as measures of quality, and are often the basis for statistical quality control and analysis. Variable data are commonly associated with X bar and R charts. These concepts were further explored in earlier tools and are summarized here in graphical form from the previous tool.

The characteristic relationship to inspection also relates to certification, both becoming and maintaining. Vendor certification is an attempt to determine the quality of a vendor and certify (for legal purposes, ultimately) that what was specified is actually provided from a vendor to the user of a product or component in production. This represents a contractual agreement which provides a basis for the user to hold the vendor accountable (liable) if in fact the specifications were contracted for but not delivered as per the certification.
Vendor certification can help organizations realize they will be held accountable as vendors, and therefore they will make certain that their product or service is actually delivered as per specifications and certification. When products, materials, services, components and so on, are actually delivered the way they were supposed to be, it reduces transport costs (to return), rejects in production, scrap rates, and so on. This all improves the overall competitive edge of the user of the certified item. Selection of the vendor becomes more a systematic and empirical activity, and less a "who do you know -- political" situation. Vendors are chosen, then, on their true basis for ability to deliver according to certification.

Connecting this all to the current section and set of tools, it should be noted that certification is increasingly being specified in terms of inspection system, SPC charts and capability measures, all which, if used correctly, may be useful to assist in proving or disproving that certification was or was not met. And in as much as we are essentially certified, if not contracted to deliver according to specified limits and tolerances, it is important for us all to measure and record correctly--not only for ongoing improvement--but also just to get good quality product out the door on schedule and at or above the specified quality levels according to our customer's needs.

Evaluating Gauges, Measurement Error

The following procedures are intended to assist in the analysis of gage repeatability and reproducibility (R & R), sometimes called measurement analysis. This tool is particularly appropriate and helpful for analyzing shop floor (and other) gauges and instruments, and their operators, for usefulness in the broader inspection system. It is also true, however, that these R & R values will increasingly be required for documentation as suppliers and vendors--to be shipped with product and/or provided in other ways to demonstrate general capability in the inspection and quality system.

The fundamental reason for the R & R analysis is to assure as best we can that our gauges are in fact accurate, and that our operators are using them correctly. Gauge analysis would be a logical area of pursuit if we are seeing unexplainable variation in our X bar and R charts, or if we have eliminated virtually all other possibilities--the gages simply should be evaluated on a regular basis. This is shown graphically in summary form nearby. Other relationships include obvious connections to maintenance, indicating that when the gages do not check out as repeatable it is likely they are needing repair or calibration, or both.

Measurement error is one of the pivotal areas to focus on for variation reduction. By determining gage R & R, as baseline data, and gradually tweaking the system, significant improvement can occur. But, as has been shown earlier, the cost of inspection is such that we cannot make frivolous changes to the system. This is precisely where the measurement analysis fits in: by better knowing the error, in real percentages, or as hard data, documented over time for improvement, we can better be positioned to continue the improvement process. It is also an opportune time to place the technological change model in perspective. While measurement error is not called out as an individual entity, it must be recognized, like other data driven opportunities, that this is a key issue in the broader mix.

As the model reminds us, the overall team effort requires leadership in a synchronized manner. We must draw upon all of our talent, trusting one another to provide solid data and documentation which can be used to make better decisions and solve the technical problems, seizing the opportunities for improvement. And we should also remember the role that technology--as in gauges--can and does play in the change and improvement process. The possible change should only be made after thorough analysis with gauge R & R, and other data driven tools.

Recording data--forms/systems. Although eventually data collection may occur semi-automatically via computer terminals at workstations, currently most data will be manually measured at the gage and manually recorded on forms. This establishes the basis for the system, in conjunction with the gage and procedure for use--manually collected data. It is important that all operators and others understand the importance of taking good measures and recording this data accurately. Much
analysis time will be spent—and decisions made on the basis of this data, and thus, it is vitally important that it be done carefully.

Similarly, the forms are only as good as the people make them. Through use, and based on team inputs, the forms should continue to evolve toward a satisfactory collection, organization and analysis tool. Part of the point is, as we use the forms, as a key part of the system, we should be jotting down notes, talking to our supervisor about them, observing how others use them, and so on. Perhaps most important, we should be listening to what our customers are saying about the forms as well as the rest of the system. This includes people up and down the line, in quality functions, engineering personnel, other team members, and so on—all internal and external customers. This also includes the broader sampling and inspection methods as part of the quality system.

Performing the gauge R & R analysis. By way of definition, repeatability looks at equipment variation, based on ranges produced. Reproducibility looks at operator or appraisor variation, based on means produced. When combined the two values (means and ranges) provide a value indicative of overall measurement ability in gages. The steps in the gage R & R procedure are focused in seven major areas, or steps, all summarized in several forms and procedures shown later in the tool application area as an example. The steps must be followed carefully to achieve accurate data and analysis for improvement.

Step 1. Gather data. Work with 2 or 3 knowledgeable operators using variable measures, consistent with general X bar and R charting methods. Each operator (A, B, or C) should provide 2 or 3 trials, measuring the same characteristic 10 times, using the same gage and measuring system, consistent with other operators. When all operators are completed there should be 2 or 3 trials for each operator, consisting of 10 measures in each trial. This should provide 20 or 30 measures for each operator and 40 to 90 measures for the total gage analysis. Note that in the example, there were two operators, each completing three trials.

Step 2. Determine Operator Trial Averages. First sum all values in each trial. Determine operator averages by summing all measures and dividing by 20 or 30 depending on number of trials (3 in this case). When completed you should have two or three averages, A, B, and C. These should be recorded and a value shown for the difference in maximum and minimum operator. The value entered is .0021 for differences in the two averages of operator A and B in our example.

Step 3. Determine ranges. This is completed for each operator by summing each set of ranges and then dividing by 10 to find RA, B or C. Sum RA, RB and RC, and divide by 2 or 3 (2 operators in this case) to determine a grand range, or R average. This is shown as follows in our example:

RA = .0009
RB = .001
R average = .00095

Step 4. Calculate Range Upper Control Limit (UCL R). UCL R is a statistical value used as one indication of control in the gage R & R study. UCL R is found by multiplying the R average times the D4 constant value. D4 is 2.58, shown in a constants table based on three trials. When all values are integrated the UCL R is calculated as .0024. This value provides a statistical indication of numbers of range values which are outside the UCL R. In this case one R value is found to be outside the UCL, .0003, indicating a fairly stable control measure. However, this would be tracked over time and an effort made to reduce the measures outside the UCL to 0.

Step 5. Determine Equipment Variation (EV). Equipment variation is also called repeatability and is found in equipment by multiplying R average times the constant K1 value of 4.56 for 2 trials or 3.05 for 3 trials. Recall that in our example R average was .00095. The value 3.05 is used since we have three trials for each of two operators. Thus,

EV = (R Avg) (K1)
EV = (.00095) (3.05)
and EV = .0029

Step 6. Determine Appraiser Variation (AV). Also called reproducibility, appraiser variation or AV focuses on the operator variance. AV is found by multiplying the difference in minimum and maximum averages for operators times a K2 constant of 3.65 for 2 operators or 2.70 for 3 operators, and squaring this value. This value then has the EV squared and divided by the quantity of parts (n) times operators (r) subtracted, and the total value is then reduced to a square root. Referring back to the example form to view the mathematical calculation:

AV = √[(Diff Max-Min)(K2)]² - [(EV)² / (n x r)]
AV = √[(.0021)(3.65)]² - [(0.0029)²/(10 x 2)]
and \( AV = 0.087 \)

**Step 7. Determine \( \% AV \).** This is done using a mathematical calculation requiring the \( AV \) previously determined, divided by the tolerance. Once determined the square root is found and taken times 100. This is expressed mathematically as:

\[
\% AV = 100 \sqrt{\frac{AV}{Tolerance}}
\]

and when the numbers are applied from our example,

\[
\% AV = 100 \sqrt{\frac{0.087}{0.032}}
\]

and \( \% AV = 2.70 \% \)

**Step 8. Determine \( \% EV \).** Similar to \( AV \), this is done by first dividing \( EV \) by the tolerance, and multiplying times 100. As shown in the example tolerance is provided as \( 0.032 \) and \( EV \) is \( 0.0029 \). When the values are placed in the formula, it appears as:

\[
\% EV = 100\left( \frac{EV}{Tolerance} \right)
\]

\[
\% EV = 100\left( \frac{0.0029}{0.032} \right)
\]

and \( \% EV = 9.05 \% \)

**Step 9. Determine \( R \& R \).** \( R \& R \) is found by taking the square root of \( EV \) squared summed with the \( AV \) squared. Mathematically this is expressed as:

\[
R&R = \sqrt{EV^2 + AV^2}
\]

\[
R&R = \sqrt{(0.0029)^2 + (0.087)^2}
\]

and \( R&R = 0.087 \)

**Step 10. Determine \( \% R \& R \).** \( \% R \& R \) is found by taking the square root of \( \% EV \) squared summed with the \( \% AV \) squared. Mathematically this is expressed as:

\[
\% R&R = \sqrt{(\% EV)^2 + (\% AV)^2}
\]

\[
\% R&R = \sqrt{(9.05)^2 + (2.70)^2}
\]

and \( \% R&R = 10 \% \)

Each \% should not exceed a range of 10-30\% to be acceptable. It should be noted that \( EV \) \( AV \), and \( R \& R \) are near or below 10-30\%, maximum. If they were 10\% to 30\% we would pursue improvements in our systems to assure reliable data. This would include calibration of our gages, assuring that we are in fact using the proper gages, our operators are well trained in their use, among others. If we would exceed 30\% we would likely declare that a complete redesign of the system is in order.

Our example would appear to be well under control from a gauging standpoint. Further explanation would that our gages are repeatable in performance and our operators’ performances are reproducible. We are probably using proper gages, well calibrated, and our operators are properly trained in their use and application. Also our data being collected for the \( R \& R \) analysis was collected under well designed circumstances, and with good controls, and samples, among other variables. Note that this will not always be the case, and we will sometimes need to analyze around less desirable circumstances for improvement.

**Using the gauge analysis information.** Part of knowing whether gages and the broader quality system is capable and under control requires determining, as precisely as possible, what the quality problems are. This may include simply knowing where to look for information about process quality. This could also be traced to specific factors and includes people, materials, methods, and environment--each consisting of several sub-categories within their own areas, contingent upon specific conditions.

There are various relationships to be taken into account. If gages are not repeatable, clearly, data which will be collected for various analysis and documentation applications will not only be suspicious, but wrongful conclusions could likely be arrived at. Additionally, several sources of information could prove useful in determining and prioritizing product quality problems, and associated process capability problems. These sources could include inspection data, material reviews and scrap and rework data, and warranty review information. Each of these will be briefly presented and discussed in various sections, realizing this all must be built into the quality system. The results of gauge \( R \& R \) analyses, and other inspection related information, by machine operators and line inspectors, when properly documented, can provide early signals of quality problems. Various other related personnel in the quality system can also provide useful statistical analysis information for quality performance over time. This could include quality engineers, applications and process engineers, and others.

Material reviews (MR’s), documenting materials and parts which exceed tolerance, can be
useful in tracing historical quality issues and in evaluating potential corrective actions. This, of course, assumes proper documentation as part of the quality system. Similar to MR's, information on vendor scrap (scrap tickets, scrap cost reports, etc.) and rework (salvage costs, salvage requirements, etc.) can be useful in tracing and prioritizing quality problems based on quality costs. Also, information on warranty claims and associated costs can be useful in ensuring that prioritization of quality problems is consistent with customer requirements. This could also relate to reliability engineering information and service life data being readily available and being tracked over time. The proper quality system would provide this information routinely, or on some minimum schedule, if requested.

Gage R & R, Traceability And The Broader Quality System

Quality systems, and in particular metrology and inspection functions such as gage R & R, must assure form, fit, finish and function of the product. These will be further addressed in terms of surface quality considerations, tolerances and allowances, and dimensions and shape in a different tool. This relates to design and engineering functions, as well as manufacturing, not to mention function after a product is in service, or reliability. As has been demonstrated throughout the seminar, the above information and sources for potential quality problems and capability issues can be excellent opportunities for problem solving teams. While very challenging to organize and maintain, the team atmosphere and attitude is part of the necessary total quality approach so essential for competitiveness in technological organizations in the future. All of the above, particularly in conjunction with problem solving teams, represent excellent opportunities for using the statistical process control tools overviewed here. X bar and R charting, capability analysis, and gage R & R evaluation tools are useful methods for helping gain competitiveness necessary for the future.

Specific inspection procedures in SOP form are essential to providing optimum quality. These procedures typically rely on general information such as that provided earlier in this section. Inspection is usually organized around specific phases such as receiving, in-process, final and shipping inspection procedures, but incorporated into the overall production plan and quality system. As indicated earlier, it is important that people perform these inspections as part of their routine work rather than being done by roving inspectors. The bottom line here is that inspection and gauging, as part of the quality system, is not a separate added on function. It is integral to the act of producing the product.

Specific products will require varying levels and types of inspection for quality. A typical rule of thumb for many other products and organizations, however, is 10% inspection of appropriate predetermined characteristics. Certainly, a minimal number of inspections should occur, but without reducing or jeopardizing quality. Note that, given statistical process control and other on-going improvement techniques, it should be true that inspection can occur less over time, and be justified and defended through documentation and charts.

In-process inspection procedures should be conducted on all products, processes and production phases and equipment to insure quality. To verify proper operations, the first part can be verified 100 percent to establish conformance to specifications. All inspections must be documented and should be available upon customer request. Certain key inspection points must be maintained to establish that operations can provide a means to produce a fully acceptable final part, including the implementation of statistical process control and selected parts. Instruction and check sheets should be provided at each operation which must include characteristic(s) observed, number of observations, number and type of deficiencies, final disposition, corrective action, operator identification, date of inspection and/or test, method or equipment used, and other information depending on the situation.

Records should be maintained for an appropriate period of time, allowing full traceability potential should the need arise. All material or operations must be identified regarding quality status, dated, and prepared for subsequent operations. In-process inspection, other than first piece will be performed by the operator, whenever possible, although others involved in the quality system may need to supplement this. For example it may be necessary to shut down the process, with primary responsibility remaining with the operator when the process is graphically shown as being out of control. But then others would likely become involved to assist in the analysis for corrective action, perhaps being the focus of an improvement team.

Final processing inspection and audits should be conducted per either customer instruction or general organizational standards and procedures, but focused on characteristics previously identified. Proper final documentation for certification should include all pertinent test data, sampling plans and
final inspection results. If the product is approved by the operator, all documentation will be completed and a final tag attached authorizing a move to shipping. Certifications for conformance may be completed and remain with the records, by part number, and possibly a copy with the lot. Audits before shipment may be necessary with spot audits performed and recorded by individuals in shipping functions.

A rigorous inspection and measurement system must be built to provide optimum quality. But we must also remember that inspection and gauging does cost, and thus, it must not be overdone. Pointers for simplification are presented to help guard against overbuilding the inspection system. These are in the form of questions.

1. Can gauging be accomplished by use of standard inspection equipment, and does it minimize the need for special training?
2. Does gauging equipment required minimize set-up time, operating time, and operator fatigue?
3. Does the equipment require standard maintenance/service contracts, procedures and readily available components and how do operators relate to the maintenance function?
4. Is automatic data recording afforded through the use of the gauging equipment?
5. Can gauging be accomplished with unaided eye, or with less than ten times magnification?
6. Will gauging require standard techniques and equipment, or will special devices or services be needed?
7. Do tolerances permit adequate ratios of accuracy from standard measuring equipment?
8. Can inspection and gauging be readily accomplished during fabrication or processing at the job site, by workers on the line? If not, what must be done?
9. Do our records and documentation provide clear and detailed information about when, where, how and by whom all inspection are accomplished with traceability of product in the total system?

Wherever possible, processes selected for production should not require formal certification or special licenses for operation, and required processing equipment should be standard within the organization. Likewise, gauging and inspection procedures should be standard with plants and vendors, organization-wide. The required processing equipment should be readily calibrated or adjusted by people who are available and using calibration equipment which is on hand--primarily operators. Calibration should occur by operators, wherever possible, and they should be given adequate and consistent procedures and training.

The gauging process should minimize quality checks and inspections of in-process components or product by permitting readouts, automatic gauging, vision systems, and perhaps through product or process redesign. The process should minimize the need for special training and certification of operators and inspectors as well as minimize scrap. As pointed out later, scrap is often a function of maintenance-related issues. It is pivotal that the maintenance of processing equipment be handled in a manner consistent with total productive maintenance for total quality. Major work may be by a division-wide, centralized operation, and competent professionals. But all maintenance must be done in a systematic fashion involving operators, and not simply repairing when breakdowns occur. Quality occurs best where records have been kept on maintenance and repairs, wear checks, operator comments, and so on, for preventive maintenance, leading to quality improvements.

**Traditional Versus New Approaches--Supervisors, Operators And Others**

Traditional metrology functions revolve around providing sufficient inspections per standards and procedures determined over time. More specifically, this includes calibration systems, reviewing audit and certification procedures, analyzing and assisting with test equipment issues, monitoring measurement standards, among others associated with satisfactory quality systems through metrology.

Inspection is shifting from the traditional concept of a "roving inspector" to operators performing the inspection function for quality as a part of the production function. This is a fundamental point in the quest for competitiveness and the quest for world class and total quality status. It is simply inappropriate for additional persons to be looking over the shoulders of good quality workers, double-checking their work, as was the case with traditional inspection functions just a few short years ago. Most of what is being described below is intended to be done out on the shop floor by operators--putting the responsibility for quality systems deployment under their control. It is still true that some inspection functions must be done in
climate controlled laboratories by highly skilled metrologists. But part of the fundamental goal, if we are to become and remain competitive, is to place responsibility for quality at the point of production.

Several types of information must be available for adequate inspection to occur. These include the customers' order and product specifications. What did the customer ask for? How do we know what the limits/tolerances are for acceptability? We must know the desired quality characteristics by work station. What is expected at each station? Related to this, are there industry-wide specifications or other peculiarities we should be aware of? If yes, are these being adequately communicated to all personnel, as needed? Are the results of previous inspections available, and is there good documentation? How do they perform inspections? Do we have other general information such as flow charts, usage information after distribution to customer, prior complaints, troubles and customer feedback? How do we--and should we--organize all of this for our internal and external use? Might it be best placed in an SOP format at the workstation?

Effective inspection occurs in part through several systems' components, primarily emphasizing the operator. Establishment of quality standards must occur and be evaluated periodically. A system for inspection planning must be put together. How does this occur? What is the organizational structure to encourage good planning and interaction, both for inspection as well as other elements related to quality? Development and use of inspection instructions must be accounted for, as a part of production, certainly to include training for the same. How does this relate to standard operating procedure--can we build the inspection procedure right in as part of the standard? Again, this is the SOP.

The system, regardless of who does it, must include internal audits for quality and methods to handle reporting media, with documentation and feedback for improving the system? Once reported, how does analysis of data occur, and once analyzed, how does this information get used? Does the system account for good communication and feedback about what was found in inspection? The degree to which each element in the system is applied varies with the product line, customer requirements, manufacturing phases, cost, ability of workers, time available, and perhaps others. However, the design and use of the elements and their system is a key factor contributing to top rate inspection functions and quality overall.

Related to the above system for inspection, again regardless of whether traditional or non-traditional, the details of test or inspection procedure are key elements in the inspection system. This includes tests to be conducted, with step by step procedures on-line. Measurements to be taken and equipment to be used must be identified, with appropriate training and procedures accounted for. Further, it is important to identify data to be recorded and symbols to be used. Sample sizes must be determined, along with procedures for selecting samples, frequency of collection, and so on. Who should do this--what is the team role--the operator role?

Another key detail in inspection is the required accuracy of test equipment. Are we too accurate or are we accurate enough? As the process and product are improved, what might the implications for gauging and inspection be, particularly relating to automation upgrades. Likewise, environmental conditions during tests are important, and will need to be addressed on an on-going basis. If the quality system and overall production system, within a cultural environment of change, is dynamic and improving on-going, the quality of work life should be improving in very real ways. The shop floor should be getting cleaner, certainly including air quality, climate, lighting, general housekeeping and so on. And along with all else, clear criteria for acceptance or rejection on the line, must be identified and communicated, as well as how decisions are made for shutting down production, who files what reports and to whom, and so on, all designed to help improve the system.

Clearly, it must be reiterated that the data collection system will only be as good as the people gathering and recording the data. Assuming we wish to build integrity into our system, it is vital that we place the basic responsibility of inspection with the operators, revolving around data collection, recording, and ultimately, analysis for correction. But if we are to be successful with this approach, we must be certain that operators have been equipped with the tools, and that they are ready, able, and willing to use the tools.

Prior to moving forward, it is worth taking a few moments to reflect on the role of the supervisor in the inspection system. First, the supervisor must be able to actually use the instruments and gages which operators are expected to use--just like all other technology in their areas of responsibility. Second, the supervisor must be capable of training, supporting and monitoring all data gathering functions, particularly emphasizing the recording and use of forms for data. At the current time much analysis of data is being done off line, by personnel in quality and engineering. It is quite likely that this
must change and these functions will need to be brought out to the point of production--increasingly as a function of a computer terminal.

Eventually, as the system matures, increasing analysis and problem solving for continuous improvement will be controlled at the shop floor by operators, under the guidance and direction of the supervisor. It should also be recognized that as this occurs, engineering and quality personnel will be called upon to serve on teams to assist in solving problems, and to support in other ways, all leading to on-going improvements in products. But the system is led by strong foundations at the plant floor level, requiring effective operators and supervisory support to gather reliable data, reflective of actual production conditions.

**100% Inspection And Sampling Influences On Quality Characteristics**

Sampling can occur in various ways, ranging from random and with very little structure, to a highly structured procedurally oriented act within the quality system. Generally, the factors governing amount of structure in the sampling procedure relate to cost in production and inspection and degree of quality required in the product. Considerations and guidelines for sampling were presented earlier.

Consistent with other quality systems' design and functioning, as presented earlier, it is important for sampling to occur at the point of production, and to be a standard part of the production procedure for line workers. Assuming quality and production systems are working correctly, individuals who should want the best sample are persons responsible for maximum quality and productivity, persons on the line. Sampling can occur in various ways, ranging from random and with very little structure, to a highly structured procedurally oriented act within the quality system. Generally, the factors governing amount of structure in the sampling procedure relate to cost in production and inspection and degree of quality required in the product.

Quality systems, and in particular metrology and inspection, must assure form, fit, finish and function. These will be further addressed in terms of surface quality considerations, tolerances and allowances, and dimensions and shape. It must be understood that this relates considerably to design and engineering functions, as well as production functions throughout the organization, not to mention function after a product is in service, or reliability. More to the point, these all provide excellent examples of quality characteristics, primarily from a manufacturing vantage point. But the principles are very similar for all industrial applications.

The example of surface quality considerations include roughness, and finer irregularities in surface texture, usually resulting from processing but not necessarily limited to processing. Surface quality could also be a function of corrosion or other physical impact beyond processing. Roughness height/width waviness and other errors of form are all typical concerns when considering surface quality. Measuring surface quality is generally accomplished by moving a fine stylus or probe across the surface of the component being examined. However, a more precise method is interferometry, a quality/metrology method involving putting light on the objects' surface and measuring the interference in light waves.

When parts are designed to go together, some tolerance is typically allowed, identified as a characteristic. Tolerance says how much deviation from standard can be allowed, above or below, positive or negative. These are generally given in bilateral, unilateral or limiting tolerances. Bilateral is where the part can vary $\pm .003$, but is $\pm$ in either direction from the specification. Unilateral allows only deviation in one direction, such as $+.003$ or $-.003$. Limiting simply says the range of dimension, as with $.003$, but is not directional relating to the specification. These tolerances also relate to specification (or "spec") limits in a separate section during the discussion of control charting.

Allowances indicate contact/space between mating components. Clearance is free space allowed and interference is when negative clearance is required, as in the case of press fits. Allowances also relate to specifying quality in the design function, and function in mechanical applications. These all represent characteristics in quality.

Base line dimensioning is useful in specification of quality characteristics. It is where all dimensions and measures are given from a common reference point. This eliminates tolerance build up and provides all measures to a common reference point. This is a spin off of computer numerical control, absolute programming, where all dimensions come from X and Y coordinate intersection in machining operations. Geometric dimensioning and tolerancing also relates here since all forms/shapes are treated similar to base line dimensioning. The quality system must help assure that proper information is specified in design and engineering functions, and built into the product. This all relates to the discussion about quality characteristics.
Part of knowing conclusively whether a process is capable requires determining, as precisely as possible, what the quality problems are. This may include simply knowing where to look for information about process quality. Several sources of information could prove useful in determining and prioritizing product quality problems, and associated process capability problems. These sources could include inspection data, material reviews and scrap and rework data, and warranty review information. These were thoroughly presented and reviewed in the tool on capability and will not be presented here. But quality characteristics must be viewed within the context of capability and the broader quality system.

No two mass produced products are exactly alike, since processes contain many sources of variability. Differences in similar products may be large, or they may be insignificant but they are always present. Production components and parts are particularly susceptible to potential variation from the machine, material, operator, methods, environment, and perhaps other factors. To reduce variation in a process, the variation must be traced back to its sources. The first step is to make the distinction between common and special causes of variation. Common causes refer to the many sources of variation within a process that is in statistical control. They behave like a constant system of chance causes. While individual measured values are different, as a group they form a predictable pattern that can be described as a distribution. Special causes (often called assignable causes) refer to any factors causing variation that cannot be adequately explained by any single distribution of the process output, as would be the case if the process were in statistical control. After identification and analysis, we can improve.

Part of knowing conclusively whether a process is capable requires determining, as precisely as possible, what the quality problems are. This may include simply knowing where to look for information about process quality. This could also be traced to specific factors, classified as follows:

1. People—Variations among operators and others.
2. Material—Work piece material variations, and variations in tooling, coolant, bushings, etc.
4. Environment—Variation in ambient temperature, power supply, dust particulates, etc.

Additionally, several sources of information could prove useful in determining and prioritizing product quality problems, and associated process capability problems. These sources could include inspection data, material reviews and scrap and rework data, and warranty review information. This, of course, is at the core of the toolkit. Documentation and data are the keys to moving forward for improvement, all based on characteristics being known, understood and analyzed over time within the broader perspective of quality. Once again, it should be pointed out that the above information and sources for potential quality problems and capability issues can be excellent opportunities for problem solving teams. While very challenging to organize and maintain, the team atmosphere and attitude is part of the necessary total quality approach so essential for competitiveness in technological organizations in the future.

As we make subtle and incremental changes in our gauging system, or change the tolerance in our specifications, or upgrade our SOP at the work station, conduct various brainstorming and cause and effect sessions, and so on, we should begin to see gradual improvements in the capability. This is the nature of the process, and it will only occur through disciplined and systematic efforts over time—generally many months. It is also true that the team environment is thought to be the most effective vehicle for communicating and moving these types of issues forward for improvement, as has been alluded to in various tools and ways.

**Evaluation Of Quality Characteristics--Startup Thoughts, Six Sigma, ISO/QS**

One important thrust of this tool is the focus on a clearer understanding of what characteristics are, and their relationship to other important parts of the quality system. But part of the tool is also suggesting that characteristics must be evaluated over time, for upgrades in various ways. Characteristics can only be assessed based on solid data, as in six sigma. These upgrades could include:

1. **Redefinition of the characteristic.** Perhaps some critical dimension or other specification-related information has changed over time, resulting in the need to redefine the characteristic. This may be a function of a customer driven engineering change.
2. **Elimination of the characteristic.** Perhaps over time it has been demonstrated that the characteristic simply does not need to be
tracked any longer. This would most likely be as a result of our ability to demonstrate that it remains under control over time.

3. **Expansion of a characteristic.** As design and engineering changes occur, it is likely that the characteristics being tracked andcharted over time will at first be expanded, and ultimately evaluated for phasing out.

While the above may begin to describe some of the various conditions under which changes in characteristics can occur, it must be remembered that the primary reason for evaluating the characteristics have to do with making ongoing improvements in product, and reducing costs due to reduced tracking and monitoring. Related forms for analyzing and auditing characteristics are provided as applications.

A general approach for beginning to systematically evaluate characteristics must be based on a strong data driven charting system. The primary evaluative criteria would be questions such as:

1. Is the characteristic, demonstrated in a numerical manner, preferably variable data, increasingly coming, remaining under control? Is the chart showing a trend over time, reflecting data in calculated control limits?

2. Have there been customer complaints, internal or external, during recent times related to the characteristic in question?

3. Has this characteristic been referenced in any corrective actions recently? If yes, in what ways and why? If no, are there any internal corrective actions which we may need to do as preventive functions?

4. Does gage R & R, Cpk and other data driven information support the characteristic by showing strong repeatability and reproducibility measures and improved capability overall?

5. Do we have routine reviews of characteristics in our quality system, supporting the possibility of its elimination for tracking, or reduction in sampling, or changes in the way we inspect—to a more cost effective method?

6. Are there customer review inputs, or issues, which support or refute our findings?

7. Has the tolerance been questioned and/or adjusted recently, and why yes or no?

8. Have there been engineering design changes on this characteristic recently, and why?

9. Has this characteristic been audited recently and why?

While there certainly may be other inputs, dependent on the product, organization, suppliers and customers, among others, this is likely a reasonable place to begin our evaluation process. It should be noted that this should be a regular, ongoing, and systematic process, perhaps done on a monthly routine basis. The primary goal here, similar to some of our global competition, should be the entire elimination of the SPC tracking system, based solely on our ability to demonstrate through data, that we have the process and its individual characteristics under control.

We would be wise to review our records and documentation to determine how the characteristics under review became significant to begin with. We may discover that some of the original reasons are no longer applicable, or perhaps are less important. This is a pivotal part of the broader ISO/QS documentation process—being able to demonstrate over time that changes may be called for. It is important to be able to substantiate any changes in characteristics based on data and documentation.

**Data And Documentation For Lean, Six Sigma, Kaizen**

Part of what should be starting to become obvious, based on various previous tools, is that organizations must have processing information and communication devices and systems. These must be based securely on data and documentation. The data and documentation must then also be derived from knowledge and understanding of characteristics which we all collectively acknowledge and communicate about for improvement. This the essence of teams working to improve, or kaizen, for lean using six sigma tools.

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 "ongoing process control plan". These types of documents are often called, or related to, "standard operating procedures" or SOP's. The SOP will be briefly discussed following the OPCP, and both are discussed in more detail in subsequent tools under the set of tools in the toolkit as documentation. Regardless of what these forms and approaches are titled, the idea is to provide basic information about how we build product. More specifically, the "ongoing process control plan" (OPCP), is designed to:
1. Document key methods, techniques and other general information used in the processing applications for this product. This includes process name, tools for manufacturing, process parameters, product characteristics, and possibly other specific process oriented information particular to this product.

2. Identify key customer information and expectations in the form of specifications, evaluation method, sample and inspection, analysis and reaction methods, and perhaps other vital information.

It should be noted that some of the information is largely the responsibility of internal 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. The reason these areas are particularly important is because:

1. Their determination relate to internal data collection and analysis systems by internal employees.
2. These are key areas for ongoing improvement--with a firm basis--particularly documentation and data.
3. Cost savings can result by re-establishing levels and methods based on documented changes--improvements in product and process.
4. But similar to cost savings in item 3 above, if, due to un-disciplined approaches in processing or our manufacturing systems in general, we do not make improvements--or can not demonstrate our improvements in quality--we can/may be losing dollars.

It is vitally important that all involved begin to recognize that assuming we are actually making progress--improvements are being made--quality characteristics should be addressed, and changing. The OPCP must be regarded as a dynamic as opposed to a static document. And the systems which are 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. At a quick glance, the characteristic may appear to be somewhat "buried" in the nearby graphic. But it should be underscored that much of this is founded upon a detailed identification and analysis, over time, of the quality characteristics.

The OPCP is important for procedural reasons related to quality characteristics. Some of these are identified below:

1. The OPCP must represent general information related to the "best" and "correct" way to process our 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, gage analysis results, among others. All of this information represents much detailed procedural work which can be reduced or redirected over time, as we make improvements--or increased if improvements do not come.
4. But at some point, 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 will be our best defense for broad customer negotiations and ongoing relationships in the future.

The OPCP is a substantial document forming the basis for much that is important to the future, relying upon accurate and timely information which is gathered and compiled throughout a broad and complex network involving many persons and teams. Obviously, the OPCP can only be as good as the information upon which it is based--and the people which are providing the data. But it should also be apparent that one of the key components in the OPCP and the broader organization and system, is the establishment and maintenance of quality characteristics. Virtually all of the information provided through the OPCP is related to, and supported by, the quality characteristics within the broader quality system.

Related to the OPCP as a "macro" tool, standard operating procedures, or SOP, provides one of the best "micro" kingpins for continuous improvement. This is true since the basis of being
able to plan and conduct production in any rational manner must assume that we all perform the same work similarly, or even the same. SOP's, with their identification and detailing of standard procedures, or methods, provide much of this need for continuity. It will become apparent, however, that the standards which we place in force, through teams and other leadership methods, are not the end in and of themselves. Rather, the standards must be ever evolving, changing for continuous improvement in our work and the overall quality system.

SOP's provide the best methods, the correct approaches, and certainly what the customer demands--and documented for all to follow and improve. While they are not fixed or permanent, the SOP must not be changed in a frivolous or light-hearted manner. In fact there should likely be an SOP in the organization for how we change our SOP's. Control systems must be in place:

1. To prevent unwarranted changes which have not been made through appropriate team methods.
2. To assure methods and procedures which reflect the operator view point--this is vital to the success of SOP's.
3. To assure that all individuals and departments, customers and suppliers are involved in any changes which are made.
4. To facilitate all upgrades which are in fact provided through broader improvement systems--when others make improvements, we want to assure that we are using the best procedures.

The concept of standard methods has its basis in the need to separate the person's work from the machine. In the earlier form used to determine operation capacity, from a previous tool, this was identified as manual work and processing work. The SOP serves to provide the counter part to the machine's repetitive and consistent motion, providing the maximum capacity available, if used properly. Through the use of the SOP, operators can become standardized sufficiently to provide the necessary discipline required to synchronize the overall process and production system. This is reflected in a nearby graphic, including visual inspection in the broader quality system:

SOP's are dynamic as opposed to static, bringing an element of very real opportunity for change to the workplace. The operator and team dynamic, where knowledge and experience combine with innovative thinking and a desire to improve, are facilitated in a necessary way with the SOP. Also, the machine, with autonamation, or automatic controls and various types of mechanization, provides a consistent dynamic which operators and others can base their other operations on, bringing the dynamic better under control for competitiveness and profitability. The point is, even where automation is prevalent in various ways, SOP's will be required, and certainly helpful—in fact in many cases, given the cost and complexity involved, the SOP which is actually used and adhered to, will be vital.

It should be obvious from the above that this process analysis technique, while still macro from the previous topic, OPCP, is now also facilitating a micro technique. Shown in graphical form, the SOP building process is provided nearby. The specific application being discussed as a micro analysis technique for Kaizen and documentation purposes is being provided as a tool for building the SOP. It should be remembered that the operation capacity study is based on the assumption that we can detail out our operation processes and functions, all which will be studied further for improvement later as we build the SOP's and use all in the broader Kaizen process. It should also be apparent that the capacity determination and SOP building processes, while quite useful as independent techniques for improvement in any isolated circumstance, are necessities for improvement through synchronous and JIT techniques in the broader Kaizen and improvement sense.

The most functional or immediately useful, particularly to the operator, is likely the basic SOP form. This form should contain the basic necessary information, in terms written and conceived by operators, for running equipment and interacting with equipment in other ways, to get product out the door. This form, in effect, becomes the most important standard procedure, since it is the actual point of contact for operators and others, in gemba or the workplace. The basic work area SOP is important since it is can facilitate the following:

1. Manpower redeployment occurs since through the SOP we can begin to see a leveling effect in all persons. This will lead to idle time by some, and their opportunity for redeployment.
2. WIP reduction will tend to occur naturally since the procedural leveling will tend to standardize the total production function, leading to inefficiencies and quality characteristics being more difficult to hide.
3. Quality is more readily built in since it is identified in the SOP, and the work is done
with greater consistency, person to person--all easier to see and manage.

4. Maximizing on capacity, since we can more readily predict all aspects of production and leveling for synchronization.

5. Layout will be improved due to the disciplined work method which emerges for persons through the SOP. As we conduct standard work over time we are increasingly likely to observe and act on this area of improvement.

6. Based on the workers repetitive work, visual management techniques will be more readily facilitated. This could include work sampling, kanban, or others.

7. Quality problems associated with data will tend to surface and be more obvious since we can now see them. This is based on the WIP and material handling wastes being "flushed out" and cleaned up.

Waste, or muda, in general will become increasingly apparent as we use SOP's. This occurs by continually improving methods and procedures, and reflecting these changes in the SOP.