Breakthrough Improvement for Your Inspection Process

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Introduction

At final inspection, each manufactured part is often visually evaluated for defects and a decision is made to pass or fail the part. These pass/fail decisions are extremely important to manufacturing operations because they have a strong impact on select rates as well as process control decisions. In fact, because Six Sigma projects focus on defect reduction, these pass/fail decisions are often the basis for determining project success. Yet the same company that demands precision for continuous measurements to less than 1% of the specification range often fails to assess—and thus may never improve—their visual inspection processes.

This article presents a process to increase the accuracy of pass/fail decisions made on visual defects and reduce these defects, advancing your quality objectives in an area that is commonly overlooked. The Six Step Method for Inspection Improvement is illustrated using a case study from Hitchiner Manufacturing Company, Inc., a manufacturer of precision metal parts that successfully implemented this method.

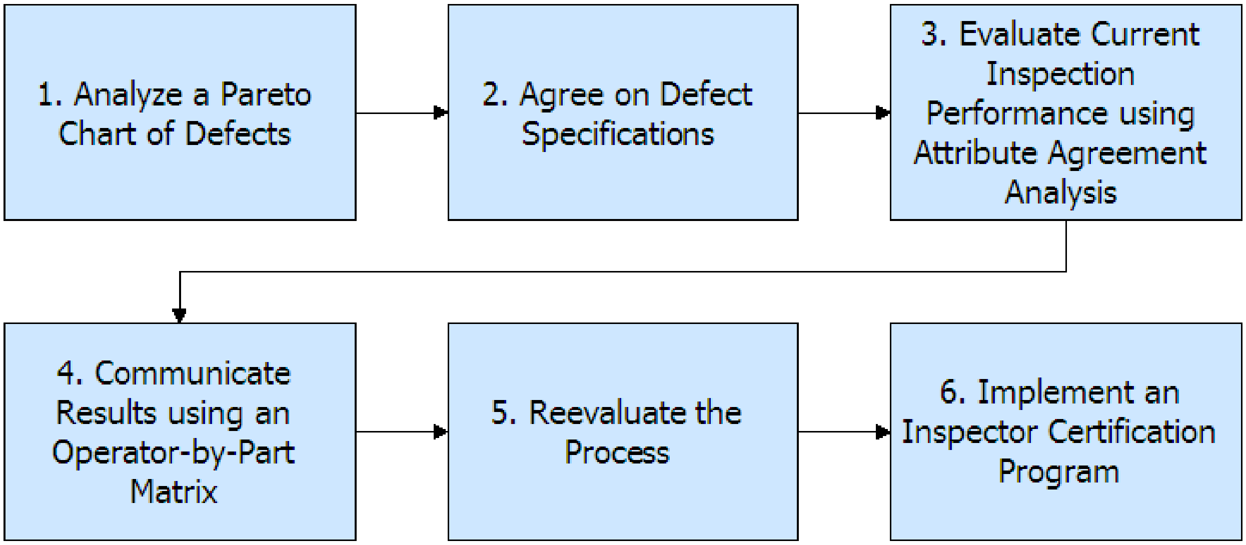
The Six Step Method

The Six Step Method for Inspection Improvement applies established quality tools, such as Pareto charts, attribute agreement analysis, inspector certification, and operator-by-part matrix, to:

- Identify the area of greatest return
- Assess the performance of your inspection process
- Fix the issues affecting the accuracy of pass/fail decisions
- Ensure process improvements are permanent

An outline of the Six Step method is shown in Figure 1. The method is not designed to address factors affecting the detection of defects, such as time allowed for inspection, skill and experience of the inspector, or visibility of the defect. Instead, the primary goal is to optimize the accuracy of pass/fail decisions made during visual inspection.

Figure 1. Six Step Method for Inspection Improvement



Six Step in Action: Case Study and Process Description

Hitchiner Manufacturing produces precision metal parts for automotive, gas turbine, and aerospace industries. Its manufacturing operation involves melting metal alloys, casting individual ceramic molds, vacuum-forging metal parts in the molds, peening to remove the mold, machining to dimensions, inspecting, and packaging parts for shipment. Before initiating Six Sigma, Hitchiner realized that defect reduction projects would rely on data from the inspection process. Therefore, ensuring the accuracy of the inspection data was a critical prerequisite for implementing Six Sigma. Hitchiner accomplished this by applying the process outlined in the Six Step Method for Inspection Improvement.

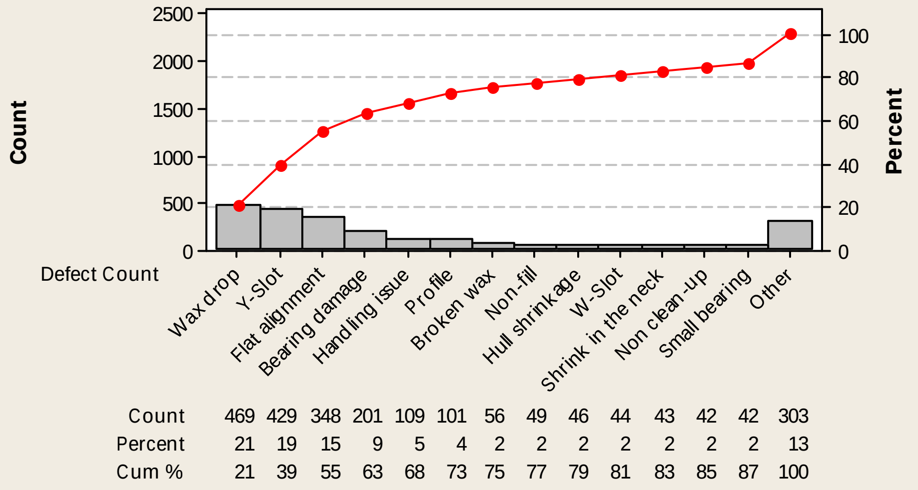
Laying the Foundation for Improvement

Step 1: Analyze a Pareto Chart of Defects

The first step to improve your inspection process is to identify the visual defects that will net the greatest return for your quality improvement efforts. Most inspection processes involve far too many defects and potential areas for improvement to adequately address them all. The key to your project success is to quickly hone in on the most significant ones. To order the defects by frequency and assess their cumulative percentages and counts, create a Pareto chart of defects. If the impact is based not only on defect counts, but is also related to cost, time to repair, importance to the customer, or other issues, use a weighted Pareto chart to evaluate the true cost of quality. Another option is to conduct a simple survey of inspectors to determine which defects are the most difficult to evaluate and therefore require the most attention. No matter which approach you use, your key first step of the project is to identify the significant few defects on which to focus your efforts.

Hitchiner used a Pareto analysis to compare the number of defective units for each type of defect (Figure 2). The chart allowed them to prioritize the defects by their frequency and select six key inspection defects. As shown by the cumulative percentages in the Pareto chart, these six defects comprise nearly three-fourths (73%) of their total inspection decisions. In contrast, the other 26 defects represent only about one-quarter (27%) of the visual defects. Allocating resources and time to improve the decision-making process for these 26 defects would not produce nearly as high a payback for their investment.

Figure 2. Pareto of Inspection Defects by Defect Type

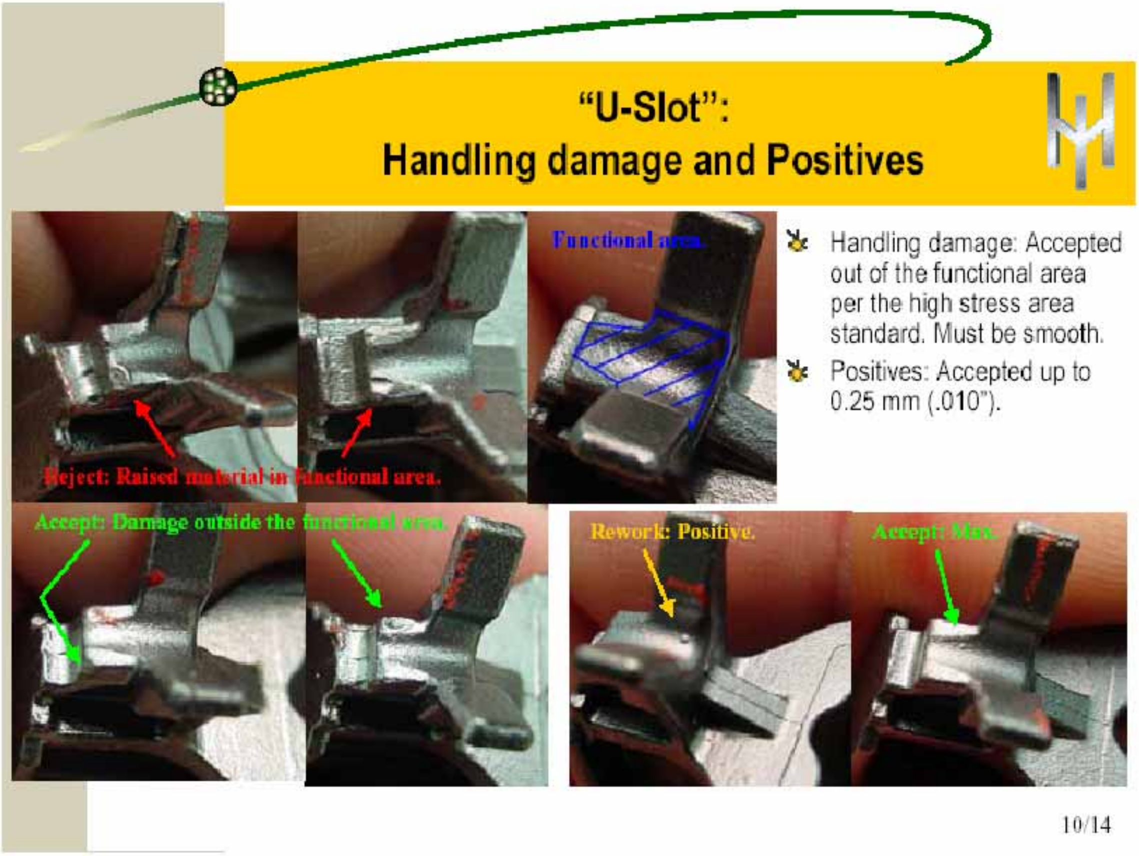


Step 2: Agree on Defect Specifications

In the second step, have key stakeholders—Quality, Production, and your customers—agree on definitions and specifications for the selected defects. Base the specifications on the ability to use the part in your customer's process or on your end-user's quality requirements. When successfully implemented, this step aligns your rejection criteria with your customer needs so that "failed" parts translate into added value for your customers. Collecting inputs from all stakeholders is important to understand the defect's characteristics and their impact on your customers. Ultimately, all the major players must reach consensus on the defect definition and limits before inspectors can work to those specifications.

At Hitchiner, the end product of step 2 was a set of visual inspection standards for defining acceptable and unacceptable defect levels for its metal parts. Figure 3 shows an example of one of these standards for indent marks. By documenting the defects with example photographs and technical descriptions, Hitchiner established clear and consistent criteria for inspectors to make pass/fail decisions. For daily use on the plant floor, actual parts may provide more useful models than photographs, but paper documentation may be more practical when establishing standards across a large organization.

Figure 3. Defect Definition and Specification



"U-Slot":
Handling damage and Positives

- Handling damage: Accepted out of the functional area per the high stress area standard. Must be smooth.
- Positives: Accepted up to 0.25 mm (.010").

10/14

Step 3: Evaluate Current Inspection Performance using Attribute Agreement Analysis

After defining the defect specifications, you're ready to assess the performance of the current inspection process using an attribute agreement analysis. An attribute agreement study provides information on the consistency of inspectors' pass/fail decisions. To perform the study, have a representative group of inspectors evaluate about 30 to 40 visual defects and then repeat their evaluations at least once. From this study, you can assess the consistency of decisions both within and between inspectors and determine how well the inspectors' decisions match the known standard or correct response for each part.

Table 1 summarizes the results of an attribute agreement study from Hitchiner. Five inspectors evaluated 28 parts twice. Ideally, each inspector should give consistent readings for the same part every time. Evaluate this by looking at the column # Matched within Inspector. In Table 1, you can see that inspector 27-3 matched results on the first and second assessments for 19 of 28 parts (68% agreement). Inspectors 17-2 and 26-1 had the highest self-agreement rates, at 85% and 100%, respectively.

Table 1. Assessment of Inspection Process Performance

Inspector	# Inspected	# Matched within Inspector / Percent*	Kappa within Inspector	# Matched Standard / Percent**	Kappa vs. Standard
Inspector 17-1	28	17 / 61%	0.475	14 / 50%	0.483
Inspector 17-2	28	24 / 85%	0.777	21 / 75%	0.615
Inspector 17-3	28	17 / 61%	0.475	13 / 46%	0.365
Inspector 26-1	28	28 / 100%	1.000	26 / 93%	0.825
Inspector 27-3	28	19 / 68%	0.526	16 / 57%	0.507
Sum of all Inspectors	140	105 / 75%	0.651	90 / 64%	0.559

* Matched within Inspector = both decisions on the same part matched across trials
** Matched Standard = both decisions on the same part matched the standard value

Inspector	# Inspected	# Matched All Inspectors / Percent	Kappa between Inspectors	# Matched to Standard /Percent	Overall Kappa
Overall Inspectors	28	7 / 25%	0.515	6 / 25%	0.559

In addition to matching their own evaluations, the inspectors should agree with each other. As seen in the column # Matched All Inspectors, the inspectors in this study agreed with each other on only 7 of 28 parts (25% agreement). If you have a known standard or correct response, you also want the inspectors' decisions to agree with the standard responses. In the case study, all assessments for all inspectors matched the standard response for only 6 of 28 parts (21% agreement).

The percent correct statistics provide useful information, but they shouldn't be your sole basis for evaluating the performance of the inspection process. Why? First, the percentage results may be misleading. The evaluation may resemble a test in high school where 18 out of 20 correct classifications feels pretty good, like a grade of "A-". But of course, a 10% misclassification rate in our inspection operations would not be desirable. Second, the analysis does not account for correct decisions that may be due to chance alone. With only two answers possible (pass or fail), random guessing results in, on average, a 50% agreement rate with a known standard!

An attribute agreement study avoids these potential pitfalls by utilizing kappa, a statistic that estimates the level of agreement (matching the correct answer) in the data beyond what one would expect by random chance. Kappa, as defined in Fleiss (1), is a measure of the proportion of beyond-chance agreement shown in the data.

Kappa ranges from -1 to +1, with 0 indicating a level of agreement expected by random chance, and 1 indicating perfect agreement. Negative kappa values are rare, and indicate less agreement than expected by random chance. The value of kappa is affected by the number of parts and inspectors, but if the sample size is large enough, the rule of thumb for relating kappa to the performance of your inspection process (2) is:

Kappa	**Inspection Process**
$\geq .9$	Excellent
$.7 - .9$	Good
$\leq .7$	Needs Improvement

In Table 1, the within Inspector kappa statistic evaluates each inspector’s ability to match his or her own assessments for the same part. The kappa value ranges from 0.475 to 1.00, indicating that the consistency of each inspector varies from poor to excellent. The Kappa vs. Standard column shows the ability of each inspector to match the standard. For operator 27-3, kappa is 0.507—about midway between perfect (1) and random chance (0) agreement, but still within the less-than-acceptable range. The kappa statistic between inspectors (.515) and the overall kappa statistic (.559) show poor agreement in decisions made by different inspectors and poor agreement with the standard response. Inspectors do not seem to completely understand the specifications or may disagree on their interpretation. By identifying the inconsistency, Hitchiner could now begin to address the issue.

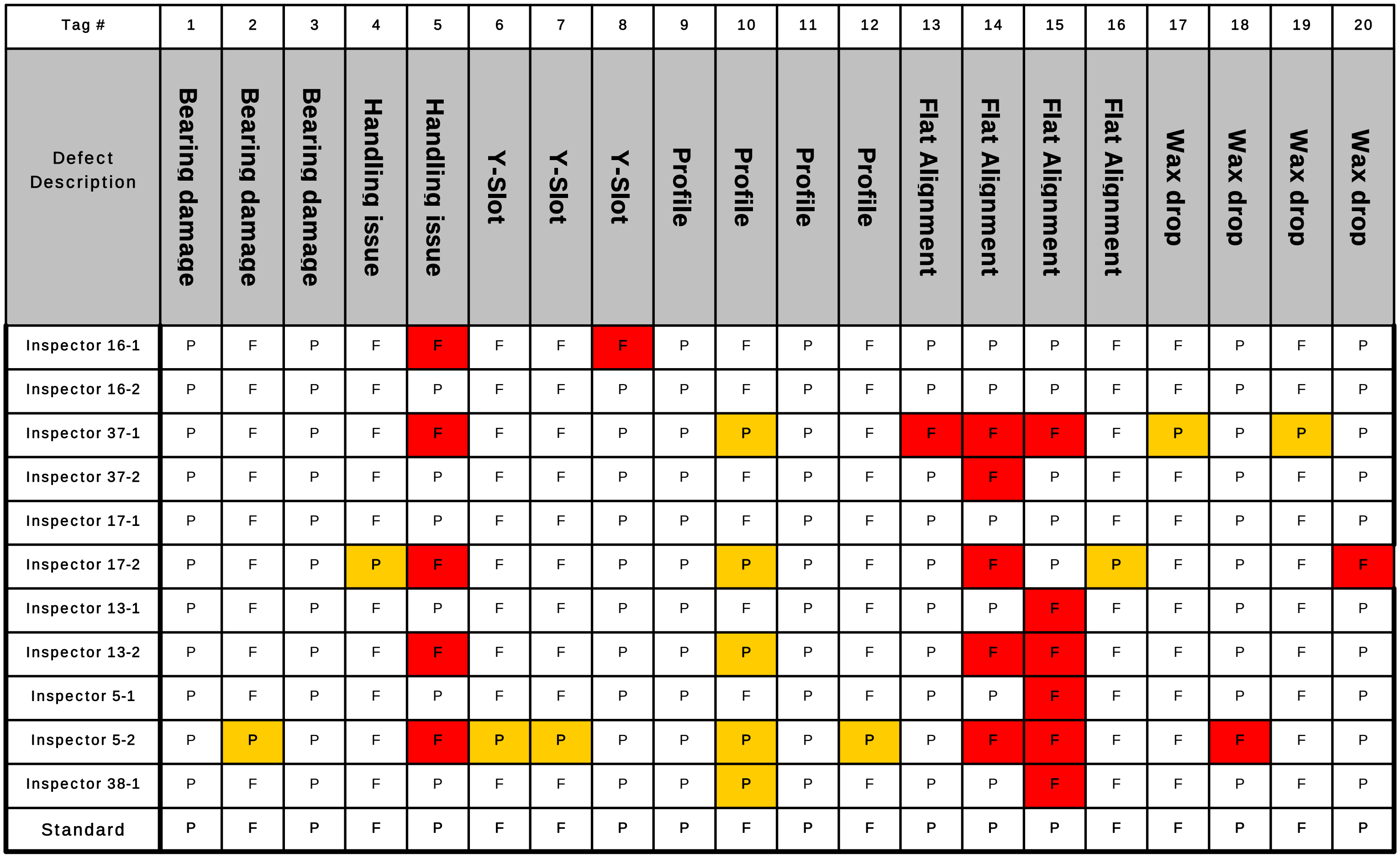
Step 4: Communicate Results using an Operator-by-Part Matrix

In step 4, convey the results of the attribute agreement study to your inspectors clearly and objectively, indicating what type of improvement is needed. An operator-by-part matrix works well for this.

The operator-by-part matrix for Hitchiner's inspection process is shown in Figure 4. The matrix shows inspectors' assessments for 20 parts, with color-coding to indicate correct and incorrect responses. If an inspector passed and failed the same part, an incorrect response is shown. The matrix also indicates the type of incorrect response: rejecting acceptable parts or passing unacceptable parts.

An operator-by-part matrix clearly communicates the overall performance of the inspection process. Each inspector can easily compare his or her responses with those of the other inspectors to assess relative performance. By also considering each inspector's ability to match assessments for the same part (the individual within-inspector kappa value), you can use the matrix to determine whether the incorrect responses are due to uncertainty about the defect (low self-agreement) or a consistent use of the wrong criteria (low agreement with others). If many incorrect responses occur in the same sample column, that defect or defect level may not have a clear standard response. Potentially, inspectors do not agree on a clear definition or specification for the defect and may require further training to agree on a severity level for rejection.

Figure 4. Operator-by-Part Matrix



Tag #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Defect Description	Bearing damage	Bearing damage	Bearing damage	Handling issue	Handling issue	Y-Slot	Y-Slot	Y-Slot	Profile	Profile	Profile	Profile	Flat Alignment	Flat Alignment	Flat Alignment	Flat Alignment	Wax drop	Wax drop	Wax drop	Wax drop
Inspector 16-1	P	F	P	F	F	F	F	F	P	F	P	F	P	P	P	F	F	P	F	P
Inspector 16-2	P	F	P	F	P	F	F	P	P	F	P	F	P	P	P	F	F	P	F	P
Inspector 37-1	P	F	P	F	F	F	F	P	P	P	P	F	F	F	F	F	P	P	P	P
Inspector 37-2	P	F	P	F	P	F	F	P	P	F	P	F	P	F	P	F	F	P	F	P
Inspector 17-1	P	F	P	F	P	F	F	P	P	F	P	F	P	P	P	F	F	P	F	P
Inspector 17-2	P	F	P	P	F	F	F	P	P	P	P	F	P	F	P	P	F	P	F	F
Inspector 13-1	P	F	P	F	P	F	F	P	P	F	P	F	P	P	F	F	F	P	F	P
Inspector 13-2	P	F	P	F	F	F	F	P	P	P	P	F	P	F	F	F	F	P	F	P
Inspector 5-1	P	F	P	F	P	F	F	P	P	F	P	F	P	P	F	F	F	P	F	P
Inspector 5-2	P	P	P	F	F	P	P	P	P	P	P	P	P	F	F	F	F	F	F	P
Inspector 38-1	P	F	P	F	P	F	F	P	P	P	P	F	P	P	F	F	F	P	F	P
Standard	**P**	**F**	**P**	**F**	**P**	**F**	**F**	**P**	**P**	**F**	**P**	**F**	**P**	**P**	**P**	**F**	**F**	**P**	**F**	**P**

🟥 F	Fail response for passing sample
🟨 P	Pass response for failing sample

For the Hitchiner study, Figure 4 shows that both types of incorrect decisions were made: passing an unacceptable part (13 occurrences) and failing an acceptable part (20 occurrences). Follow-up training with specific operators could reduce the number of these incorrect decisions. However, to fully improve the accuracy of pass/fail decisions, the defect specifications for parts

5, 10, 14 and 15 must also be more clearly defined. In this way, the operator-by-part matrix provides an excellent summary of the data and serves as a straightforward communication tool for indicating appropriate follow-up action.

Verifying and Maintaining Your Improved Performance

Step 5: Reevaluate the Process

Once you resolve issues for specific defects and provide new training and samples as needed, reevaluate your inspection process by repeating steps 3 and 4. The "bottom line" in gauging improvement to the inspection process is the kappa statistic that measures the overall agreement between the inspectors' assessments and the standard. This value tells you to what extent the inspectors are correctly passing or failing parts.

After completing steps 1-4, Hitchiner reassessed its inspection process in step 5 and discovered a dramatic improvement in the accuracy of pass/fail decisions. The overall kappa level for matching the standard increased from 0.559 to 0.967. In other words, inspection performance improved from less-than-acceptable to excellent. With an overall kappa value greater than 0.9, Hitchiner was confident that inspectors were correctly classifying visual defects.

The company experienced another unexpected benefit as well: by improving the accuracy of their pass/fail decisions on visual defects, they increased the overall throughput of good pieces by more than two-fold (Figure 5). Such an improvement is not at all uncommon. Just as a gage R&R study on a continuous measurement can reveal a surprising amount of measurement variation caused by the measurement process itself, attribute agreement analysis often uncovers a large percentage of the overall defect level due to variation in pass/fail decisions. More accurate pass/fail decisions eliminate the need to “err on the side of the customer” to ensure good quality. Also, more accurate data lead to more effective process control decisions. In this way, the improved accuracy of inspection decisions can reduce the defect rate itself.

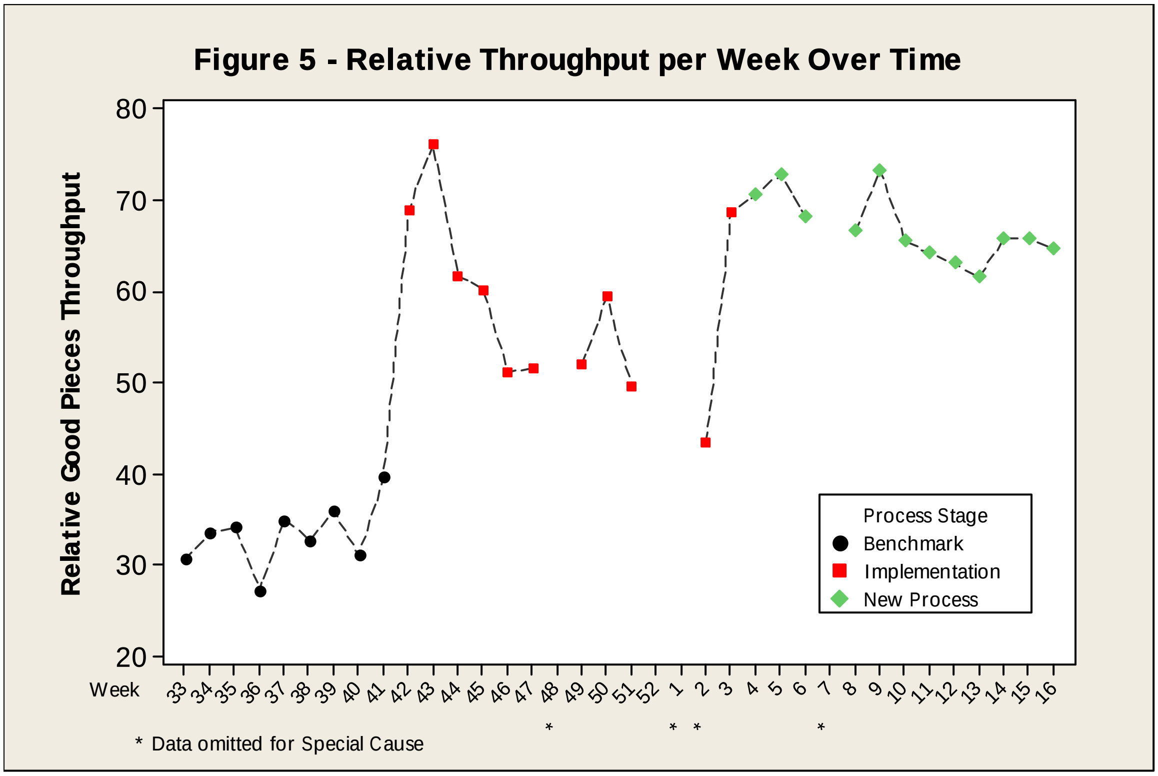


Figure 5 - Relative Throughput per Week Over Time

* Data omitted for Special Cause

Step 6: Implement an Inspector Certification Program

It's human nature to slip back into old habits. There's also a tendency to inspect to the current best-quality pieces as the standard, rather than adhering to fixed specifications. Therefore, to maintain a high level of inspection accuracy, the final step in improving visual inspections is to implement a certification and/or audit program. If no such program is implemented, inspection performance may drift back to its original level.

Hitchiner incorporated several smart features into its program. Inspectors are expected to review test samples every two weeks to stay on top of defect specifications. Each inspector anonymously reviews the samples and logs responses into a computer database for easy storage, analysis, and presentation of results. This process makes the computer the expert on the standard response rather than the program owner, thereby minimizing differences of opinion on the definition of the standard. Your test samples should include the key defects and all possible levels of severity. The ability to find the defect is not being tested, so clearly label the defect to be evaluated and include only one defect per sample. If inspectors memorize the characteristic of each defect with the appropriate pass/fail response, then the audit serves as a great training tool as well. However, memorizing the correct answer for a specific sample number defeats the purpose of the review. To prevent this, Hitchiner rotated through three different sets of review samples every six weeks.

Finally, offer recognition for successful completion of the audit. Reviewing the audit data at regularly scheduled meetings helps to underscore the importance of the inspection process and the accuracy of the pass/fail decisions as part of your organization's culture. The method you use will depend on your application, but regularly reviewing and monitoring the defect evaluation performance is crucial to maintain the improvements to your inspection process.

Conclusion

The decision to pass or fail a manufactured part based on visual inspection is extremely important to a production operation. In this decision, the full value of the part is often at stake, as well as the accuracy of the data used to make process engineering decisions. All parts of the Six Step Method for Inspection Improvement are necessary to increase the accuracy of these decisions and improve the performance of inspection processes, which are often neglected in manufacturing operations. When used as a critical step of this method, attribute agreement analysis will help determine where inconsistencies in the pass/fail decisions are occurring, within inspectors or between inspectors, and from which defects. With this knowledge, the project team can identify and fix the root causes of poor inspection performance.

References

1. Joseph L. Fleiss, *Statistical Methods for Rates and Proportions*, Wiley Series in Probability and Mathematical Statistics, John Wiley and Sons, 1981.
2. David Futrell, "When Quality Is a Matter of Taste, Use Reliability Indexes," *Quality Progress*, Vol. 28, No. 5, pp. 81-86.

About the Author

Louis Johnson is a technical training specialist for Minitab Inc. in State College, PA. He earned a master's degree in applied statistics from The Pennsylvania State University. He is a certified ASQ Black Belt and Master Black Belt.