

Process Approach to Determining Quality Inspection Deployment

June 8, 2015

Eric S. Richter and Arthur L. McClellan
Systems and Operations Assurance Department
Mission Assurance Subdivision

Prepared for:

National Reconnaissance Office
14675 Lee Road
Chantilly, VA 20151-1715

Contract No. FA8802-14-C-0001

Authorized by: Engineering and Technology Group

**Developed in conjunction with Government and Industry contributions as part of the U.S. Space Programs
Mission Assurance Improvement Workshop.**

Distribution Statement A: Approved for public release; distribution unlimited.

Acknowledgments

This document was created by multiple authors throughout the government and the aerospace industry. For their content contributions, we thank the following authors for making this collaborative effort possible:

Jack Harrington – The Boeing Company
Jeanne Kerr – Lockheed Martin Corporation
Dan Gresham – Orbital Sciences
Dave Martin – Raytheon Space and Airborne Systems
Art McClellan – The Aerospace Corporation
Brian Reilly – Defense Contract Management Agency

A special thank you for co-leading this team and efforts to ensure completeness and quality of this document goes to:

Eli Minson – Ball Aerospace and Technologies Corporation
Frank Pastizzo – SSL
Eric Richter – The Aerospace Corporation

The Topic Team would like to acknowledge the contributions and feedback from the following organizations:

The Aerospace Corporation
Ball Aerospace and Technologies Corporation
The Boeing Company
Defense Contract Management Agency (DCMA)
Lockheed Martin Corporation
Northrop Grumman Aerospace Systems
Orbital Sciences
Raytheon
SSL

The authors deeply appreciate the contributions of the subject matter experts who reviewed the document:

Kathy Augason – Lockheed Martin Corporation
Kevin Craig – SSL
Ken Dodson – SSL
Ed Gaitley – The Aerospace Corporation
Neil Limpanukorn – SSL
David Newton – Northrop Grumman
Ethan Nguyen – Raytheon
Michael Phelan – DCMA
Robert Pollard – Ball Aerospace and Technologies Corporation
Thomas Reinsel – Raytheon

Executive Summary

As new technologies are implemented in manufacturing areas, inspection processes will be affected. Often because product quality has increased or automated inspection equipment has been introduced, the inspection activity may be reduced or eliminated. In many cases a disciplined process is needed to evaluate performance data against risk to determine if this change is warranted. A tool has been developed using an Excel® spreadsheet with an imbedded checklist, which will guide users through a series of decision points to make a determination if a change is warranted. The approach attempts to answer the question: How can inspection practices be identified, reviewed, and updated to keep up with technological changes, trend results, facility changes, etc.? This tool uses relevant manufacturing data to assist the users in making practical decision for reducing inspection.

Contents

1.	Introduction	1
1.1	Background	1
1.2	Application	2
1.3	Assumptions	2
1.4	Scope	2
2.	Inspection Evaluation Rationale and Tool Definition	3
2.1	Inspection Process	3
2.2	Tool Output	4
2.3	Flowchart for Evaluating a Change	4
2.4	Tool Description	9
2.5	Required Attributes and Skill Sets When Applying this Tool	13
3.	Summary and Conclusion	14
4.	Definitions and Acronyms	15
5.	References	17
Appendix A.	Sample Tool Applications	18
A.1	Application: Technology Introduction Into Manufacturing Process	18
A.1.1	Process Weighted More Heavily Than Inspection	18
A.1.2	Example: Paste Printer Upgrade to Surface Mount Technology (SMT) Process	18
A.2	Application: Technology Introduction Into the Inspection Process	21
A.2.1	Inspection Weighted More Heavily Than the Manufacturing Process	21
A.2.2	Example: Torque Process	21
A.3	Data Driven Inspection Change	23
A.3.1	Management or Stakeholder Request	23
A.3.2	Example: Reduced Inspection for Mate/Demate Process Based on Data Analysis	23
A.4	Example: Enlarging the Scope of Applicability	25
Appendix B.	Deming's Rule Explanation	27
B.1	The Deming Rule	27
B.2	Severity of Defects	27
Appendix C.	Frequently Asked Questions	28
Appendix D.	Imbedded Excel® Tool	30

Figures

Figure 1.	Inspection system and inspector interaction.	3
Figure 2.	Return on investment (change in inspection resources) vs. investment (effort to perform analyses and capital expenditures) [Pick chart].	5
Figure 3.	Process for identifying the potential for reduced inspection using evaluation gates.	6
Figure 4.	Tool example for a manufacturing process change.	12
Figure 5.	Tool example for a manufacturing process change.	20
Figure 6.	Tool example for inspection process change.	22
Figure 7.	Tool example for management directed change.	24
Figure 8.	Tool example for modification of an application scope change.	26

Tables

Table 1.	Study Weights as a Function of Type of Process Change	13
----------	---	----

1. Introduction

1.1 Background

It has been fifty-five years since Department of Defense inspection requirements were given in MIL Q 9858 *Quality Program Requirements* [1] and MIL I 45208 *Inspection System Requirements* [2]. During the intervening years product quality and complexity as well as inspection capabilities have increased primarily through technological improvements. Government and commercial customers as well as contractors would benefit from a process to determine if the current level of inspection is appropriate given the technological advances. Decreased inspection, where appropriate, not only reduces handling risk to hardware but has the potential to increase efficiency of operations. For these reasons a task team of government and industry representatives was established to identify a process by which manufacturing and inspection processes could be analyzed to determine the most appropriate inspection methods and tools to use.

Industry representatives provided a list of their “top 10” processes that warranted investigation for change. The methods used to generate these lists varied, but typically included elements addressing the following issues:

- Process on a program or manufacturing critical path
- Results from nonconformity data analysis
- Process adequately monitored and capable
- Measurement accuracy required
- Redundant inspections in place
- Detection capabilities
- Expert opinion
- Severity of nonconformities found in inspection

Lists provided from the industry team members were combined, sorted, and evaluated by the team to identify the following twelve primary processes which should be evaluated for reduced inspection:

- Electrical connector mate/de-mate (class II mates)
- Non-flight and non-critical torques
- Kit inspection prior to release to factory floor
- Witness of test set-up
- Material verification by inspection of bonding/staking/potting
- Inspection of bonding/staking/potting in non-hidden applications
- Inspection of wire stripping and crimps on flight harnesses
- Witness of a critical move or lift
- Inspection of surface mounted components
- Fastener inspection per GSFC requirements
- Printed wiring assembly damage inspection
- Paint or surface coating inspection

This document presents a tool and its associated guidance for applying a consistent method to determine the value of reducing inspection for any process. It is particularly useful when a program, customer, or manufacturing operations group in a company introduces a new inspection technology or changes an existing inspection technology.

1.2 Application

The primary audience involves those directly concerned with assessing the impact and benefits of using a new inspection technology or a modification of an existing inspection technology. The analyses required as input to the evaluation tool should reside in the user organization's command media and should be performed by personnel skilled in their use. If the tool is used to evaluate a supplier's processes their input should be obtained to ensure they are capable of supporting any changes. The tool is applicable to stakeholder requirements because it should be used to provide objective evidence on the impact on the ability to verify requirements. The provided tool and its output is not intended to be the final decision but a basis for an organization to decide which of the many potential modifications are most appropriate for its stakeholders and business environment.

1.3 Assumptions

It is assumed that the users of this information are adequately proficient in quality, reliability, and other associated disciplines to apply these tools effectively. This guide is not intended to provide an overall summary of disciplines required to make an informed and appropriately risk-adjusted application of its content. It is left to the implementing organization or user to appropriately address and include customer, company, or other stakeholder input when using this guide or implementing its recommendations.

1.4 Scope

The purpose of this guide is to present a process to determine if the level of inspection is appropriate given that product quality has increased or automated inspection equipment has been introduced. The study presents a spreadsheet with an embedded checklist and a user's guide. The intent is to provide a structured process approach for decision making regarding the modification of inspection levels.

The reasons that inspection processes may be altered are many, but the following are a few:

- Introduction of new inspection technologies
- Introduction of new manufacturing technologies
- Significant process change or facility change
- Observed lack of findings during historical inspections
- Cost or schedule drivers
- Change in management or customer requirements
- Reduction in manufacturing mishaps
- Observed lack of failures

Each of these changes requires a re-evaluation of the inspection process approach. The guidance and tool included in this document are intended to provide a data and process driven approach to making decisions on quality deployment when processes change or when external factors require an alternative approach to requirement verification.

2. Inspection Evaluation Rationale and Tool Definition

2.1 Inspection Process

Inspection is often considered a non-value added expense and therefore subject to budget constraints that are usually trying to reduce the inspection footprint. Comments such as “inspection is a bottleneck” or “inspection is too expensive” are representative of this viewpoint. If these arguments lead to a reduction in inspection without proper analysis, the organization may be faced with significant risk that will materialize in the future. The inadequacies of inspection can be traced to either improperly applying an inspection system or the problems with the individual inspection process as shown in Figure 1. Aside from inexperience in designing an inspection system, external forces such as cost and schedule constraints or lack of funding to implement proper inspection processes and tools can increase risks.

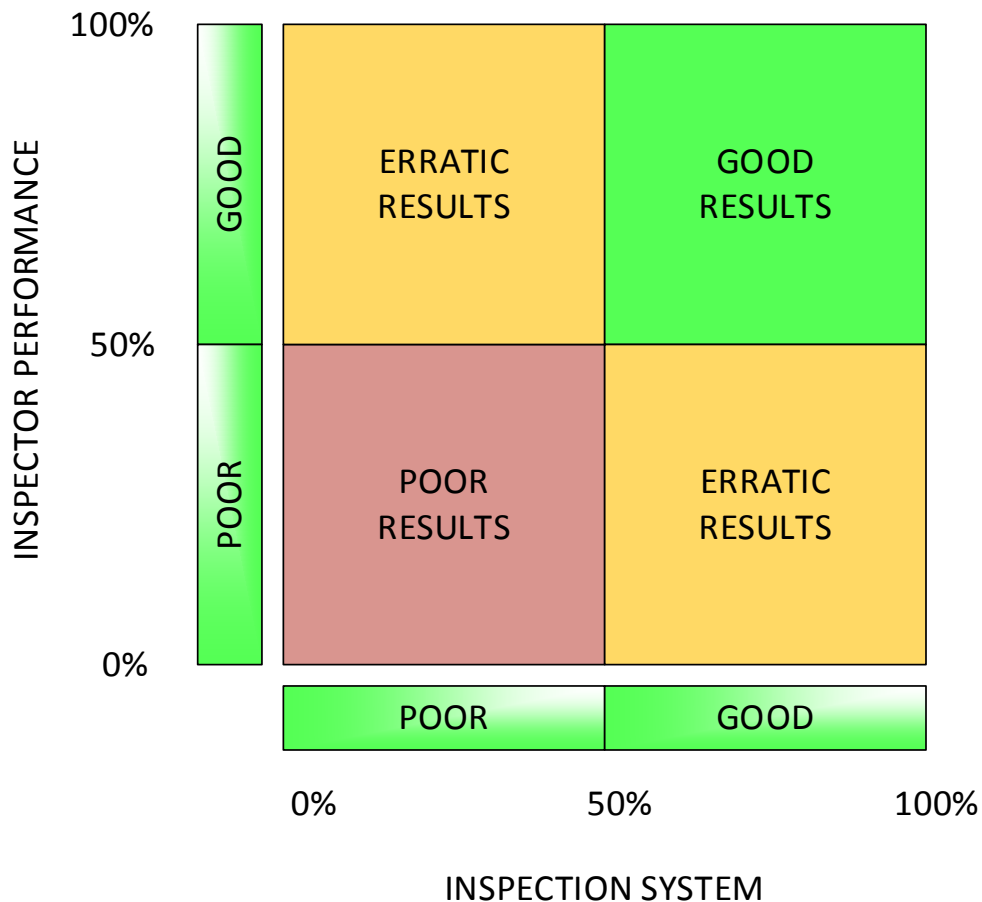


Figure 1. Inspection system and inspector interaction.

The inspection system is the approach for deploying inspectors and the assignment of tasks to these inspectors. Depending on the nature of the process to be inspected and the quality level of the particular process, the inspection system may choose to use 100% inspection, sampled inspection, operator inspection, patrol inspection (inspector moves from station to station), automated inspection, or a combination of multiple types. Inspector capability is dependent upon training to standards, the capability of the inspection tools in use, the time allowed for inspection, and the record keeping provided.

The inspection result is dependent upon the interaction of the inspection system and the capability of the individual inspector. When either the inspector or the inspection system is poor, then inspection results are erratic as shown in Figure 1. Only when both are good, will the inspection result be good. In general the evaluation of the inspectors or the inspection system involves an auditing approach which gathers the results of the auditing effort over time.

Before significant and potentially expensive changes are made to the manufacturing or inspection processes, the contractor should make sure that the ineffective inspection process isn't simply the result of a mismatch between inspection system and inspector deployment.

2.2 Tool Output

The level of inspection is dependent upon the capability of the underlying manufacturing process which in turn can be affected by design tolerances and key characteristics. In general process variability should be independent of the people performing the process. The process should have business or product requirement goals which are met. Ancillary controls should be in place such as adequate worker training, use of calibrated equipment, and appropriate raw materials presented to the process.

When the manufacturing process changes, the inspection approach should be re-evaluated. These changes include introduction of new manufacturing technologies, significant process changes or changes in facilities, and design changes. On the other hand, inspection techniques may improve because of the introduction of inspection technologies or improved inspection techniques. Finally, inspection may be affected by changes in specifications and customer requirements, cost and schedule drivers noted by management, or defect analysis and other anomaly investigations.

Each of these conditions requires an appropriate analysis of the relevant manufacturing, inspection, or stakeholder requirements changes. The tools presented here evaluate the return on investment of an inspection change vs. the investment to implement the change. Investment includes both the effort to conduct the analyses if they haven't been performed as well as the effort to modify inspection. As shown in Figure 2, if the return on investment is high and the investment is low, then it is a natural inspection change to make (Just do it). On the other hand if the return is low and the investment is high, then it's best to avoid the change (Forget it). When the return on investment is low and the investment is low, most likely these are second in line to tackle and there may be many of these changes to make (Backlog). Finally when the return on investment is high and the investment is also high, a strategy must be chosen to determine which inspection approach to change (Strategic).

Each tool asks the reviewer to evaluate the investment and the return on investment of an inspection change using ten analyses. The tool then locates the coordinates of the analysis onto Figure 2 giving the reviewer guidance on whether a change in the inspection process is warranted commensurate with the effort required to bring about the change.

2.3 Flowchart for Evaluating a Change

The process for identifying when an inspection process is a candidate for modification follows the process flow indicated in Figure 3. The process is generic in nature and requires the user to perform multiple evaluations incorporating internal corporate processes. These evaluations provide management a risk assessment of the change. Various steps of the process (described below) will list the studies required by the tool to be described in Section 4.4 so that a clear link between the flow diagram and the tool is made.

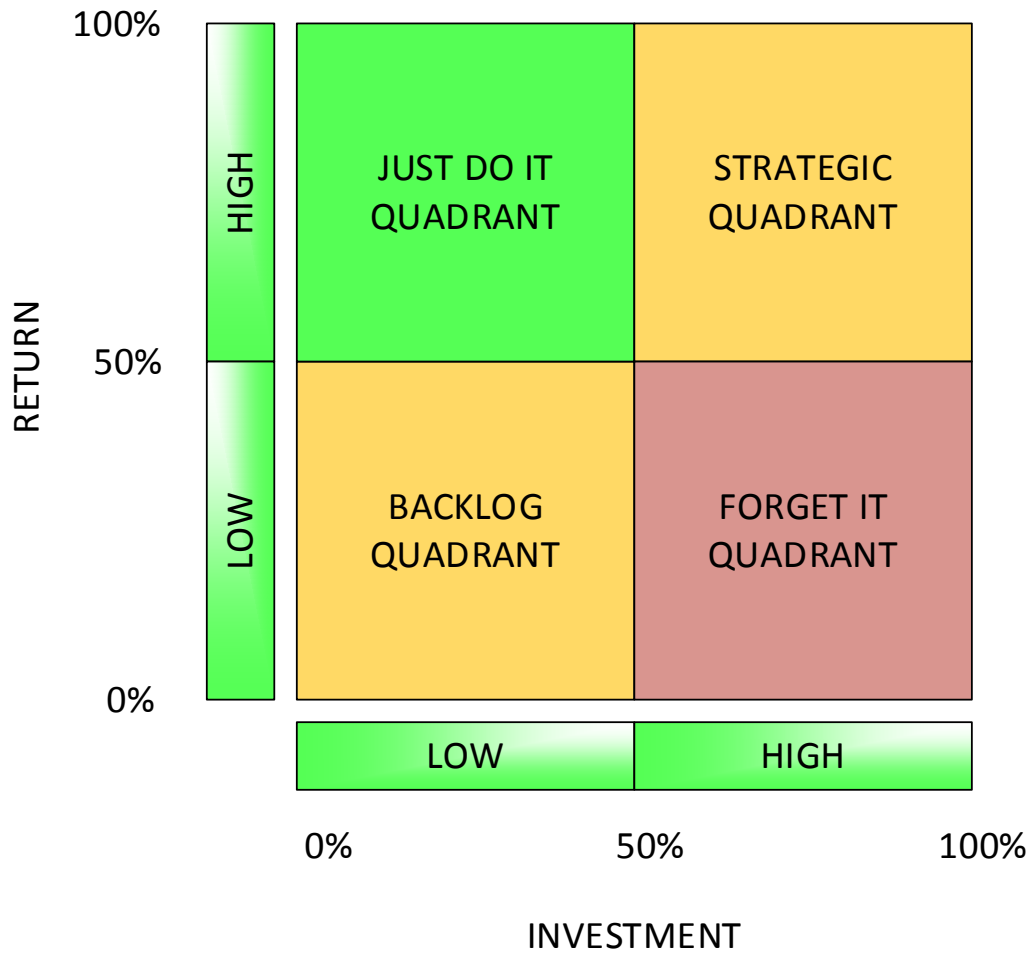


Figure 2. Return on investment (change in inspection resources) vs. investment (effort to perform analyses and capital expenditures) [Pick chart].

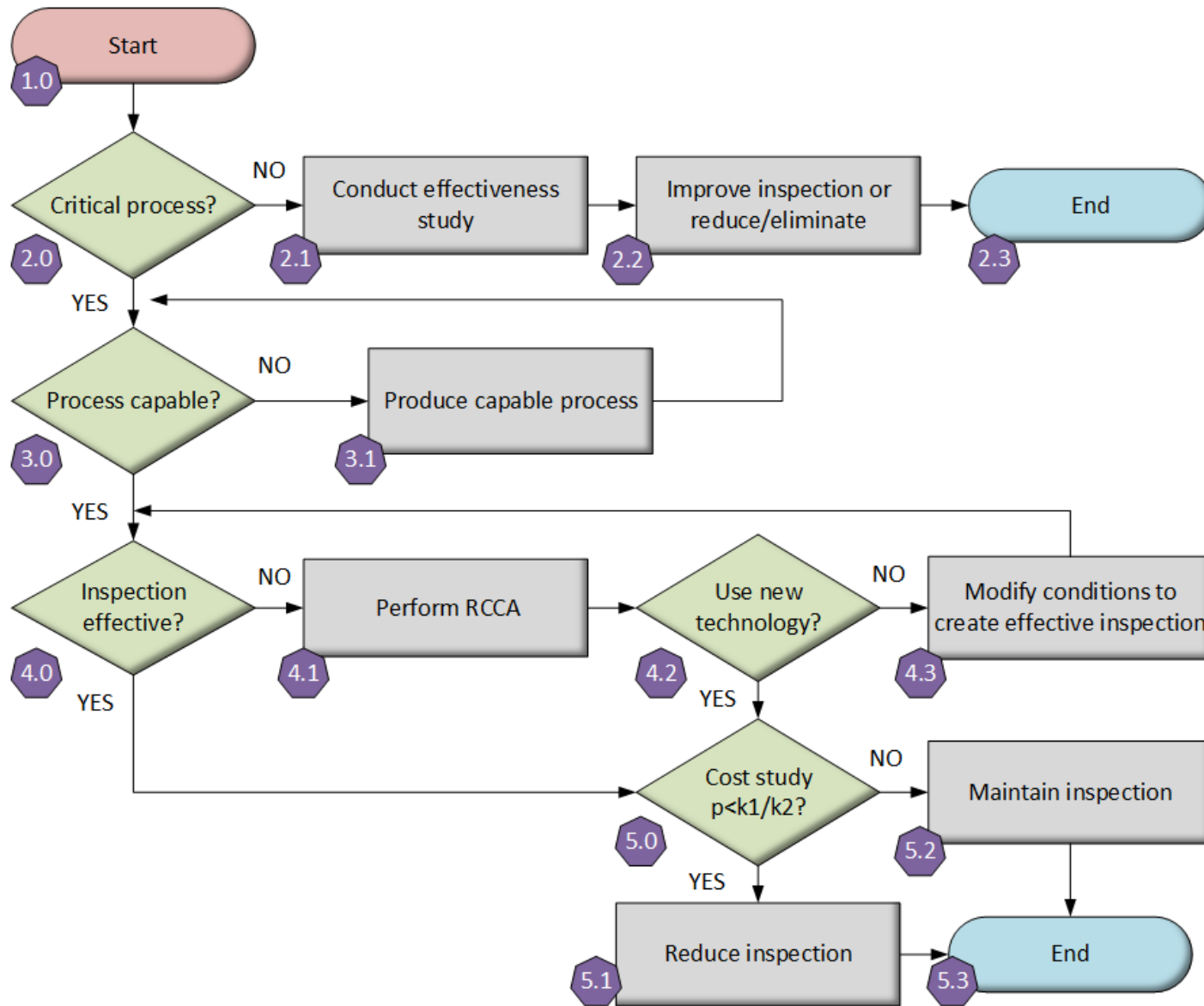


Figure 3. Process for identifying the potential for reduced inspection using evaluation gates.

#	Step	Description
1.0	Start	<p>The decision to review the inspection function with the expectation of reducing inspection may result from various changes to the production line: introduction of manufacturing equipment which increased the quality of the product; introduction of new inspection equipment, perhaps automated; or directives from management or the stakeholder resulting from data analysis or change in requirements.</p> <p>It is assumed that before changes occur, the original manufacturing and inspection processes are well understood. In other words, a baseline should be established before embarking on a change.</p> <p>Seminal military documentation [1] [2] suggested that inspection should be placed at the earliest available point in the build process so that defects would be discovered well before they were extremely costly to correct. This document reinforces the same idea through a cost analysis.</p> <p>The approach to evaluating the inspection process presented here includes the analysis of nonconformity data. It should be noted that attribute data is after-the-fact and therefore inferior to variables data. When monitoring any process, the goal should be to monitor process shifts before defects occur. Contractors should strive to determine the appropriate variables data to detect small process shifts.</p>
2.0	Critical process?	<p>Critical processes are those where failure or likelihood of failure would seriously endanger the safety of personnel or alternatively, produce product that could seriously degrade the mission or result in mission failure. Critical processes require more study before changing their inspection functions. Critical processes are often identified by the contractor in conjunction with the customer.</p>
2.1	Conduct effectiveness study	<p>For this step, the process is not a critical one. Less scrutiny is required in this case and so the use of the tool described in Section 4.4 is not as important. Through the use of data and observation, the inspection function is evaluated for effectiveness. This evaluation can include a review of inspector efficiency, escapes, differences between inspectors, and so on.</p>
2.2	Improve inspection or reduce/eliminate	<p>With this non-critical process, simple modifications to the inspection process may be undertaken to reduce inspection, perhaps through sampling, or elimination if it is obvious that inspection is no longer needed.</p>
2.3	End	<p>Having conducted this simple study, any changes should be monitored with data collection to assure the proper decision was made.</p>
3.0	Process capable?	<p>The assumption for this step is that a new manufacturing process has been introduced and that this process is a critical one. Before considering any changes to the inspection function, the process must be demonstrated to be capable.</p>

#	Step	Description
3.1	Produce capable process	A capable process is repeatable and produces the desired product. Before considering the reduction of inspection, the process must be capable. Typical activities pursued include conducting a PFMEA, monitoring the process for stability, and conducting a pilot study. Furthermore, it's necessary to monitor the process for changes in the nonconformity rates and any impact to the inspection function. The tool analyses that address this step are one through five. Once the process is demonstrated to be capable, then the process flow returns to step 3.0.
4.0	Inspection effective?	An inspection function is effective if it is successful in finding manufacturing errors. Often this is determined by reviewing nonconformity and inspector escape data. If a manufacturing process has been changed then it should be determined that the inspection function is still effective. Changes in the manufacturing process may require new inspection tools or techniques. Alternatively the manufacturing process may not have been changed, but new technology has been introduced into the inspection function. Again with the introduction of inspection change, it is necessary to ensure that inspection is still effective.
4.1	Perform RCCA	If it has been determined that the inspection function is not effective, then a root cause corrective action must be conducted. A review of the inspection system and the inspector capabilities must be conducted as discussed in Section 4.1. Variation between inspectors is determined with a gage repeatability and reproducibility (gage R&R) study. The tool analyses that address this step are six through eight.
4.2	Use new technology?	This step asks whether new technology will be introduced to make inspection more effective. If not, then a more routine method of inspection improvement is required. If technology is to be introduced, then a longer term cost, or equivalently risk, study must be performed and evaluated in step 5.0.
4.3	Modify conditions to create effective inspection	In this step the assumption is that no significant technology changes have been made to the inspection function. As a result, better training, inspection system improvement, sharing of best practices, and reviews of requirements may be sufficient to make inspection effective. As always, data analysis is required to ensure inspection is effective. The process flow then returns to step 4.0.
5.0	Cost study $p < k_1/k_2$? [5]	At this stage it is assumed that the manufacturing process is capable and that inspection is effective. The Deming rule is explained in more detail in Appendix B. Basically the probability of error is compared to the cost of inspecting a part divided by the cost to remove, repair, reassemble, and retest the part if it is found later to be defective. As can be seen from the rule, if it is very expensive to fix hardware at a later stage (which is often the case for space hardware), then the probability of error should be very small. Otherwise inspection is required because errors found downstream are more expensive to correct than the cost of inspection. This step is addressed by analysis nine in the tool.
5.1	Reduce inspection	In this case the probability of error is sufficiently low, possibly because of the introduction of technology, that inspection may be reduced. Usually when a significant reduction of inspection is proposed, the stakeholder should be involved in the decision. This is addressed by analysis ten in the tool.

#	Step	Description
5.2	Maintain inspection	When the cost or risk study does not pass the test, then an inspection reduction is not advised. Plans should be made to maintain the same level of inspection.
5.3	End	Steps 5.1 and 5.2 both lead to this final step which is the conclusion of the inspection evaluation.

2.4 Tool Description

The tool shown in Figure 4 requires the user to evaluate each listed study for a return on investment (ROI) as well as the investment to complete the study. As mentioned earlier, investment includes the effort to conduct the study as well as the investment to change the inspection approach. Referring to study #1, for impact the user must estimate that when the study is completed, on a scale of inspector reduction (100% reduction being the highest ROI), what is the likely ROI? Referring to the first study question in Figure 4 (Do the results of a PFMEA show potential for reducing inspectors?) the rating is given as a 75% reduction. Apparently the PFMEA indicated that the number of defects would reduce significantly and that the inspection process could be modified. However, the study did not go so far as to say inspection could be eliminated.

Each of the ten studies to be conducted are briefly discussed below.

#	Study	Discussion
1.	PFMEA	<p><i>Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.</i></p> <p>Often this analysis is either skipped or done as an afterthought. A PFMEA assigns a risk priority number (RPN) to each manufacturing process step. (RPN is explained in the definition of PFMEA.) It identifies potential risks in the process to prevent future nonconformities. Its value is that it in part identifies high risk areas in the process and quantitatively measures the increase or reduction of risks based on deliberate improvements. It should be noted that a contractor may have an equivalent investigation process that identifies potential faults in a manufacturing process and sensitivities in inspection. It may be appropriate to substitute a contractor's approach for PFMEA. A PFMEA should take into account the differences between defects which affect the intended use of the product and nonconformities which may be a simple non-fulfilment of a requirement. Alternatively expressed, a PFMEA, or equivalent tool, should take into account the severity of nonconformities. This is discussed further in Appendix B. Finally it is advisable to verify that past issues requiring inspection are still addressed or are no longer present because of technology advances.</p>
2.	Process qualification & capability	<p><i>Is the new process qualified and capable? Based on what is known about the new process, can inspectors be reduced? Conclusions should be based on data.</i></p> <p>Qualification is a process specified by internal procedures as well as stakeholder requirements and assures the process produces an acceptable product or output. This analysis becomes important if the manufacturing or inspection process is being altered or upgraded significantly. Capability refers to the ability of a process to fulfill requirements for a product. [3]</p>

#	Study	Discussion
3.	Pilot	<i>Does the pilot or proof of concept indicate inspectors can be reduced?</i> Prior to full implementation of the manufacturing process, a pilot should be conducted to determine the manufacturing change's effect on inspection.
4.	Nonconformity rate	<i>Will the new process significantly reduced nonconformities and thus reduce the number of inspectors needed?</i> If the rate of nonconformities is low (high quality) a longer evaluation period may be required. It is a key indicator on whether or not inspection may be modified. Nonconformities may be found by either production or inspection. This analysis should take into account the differences between defects and nonconformities, possibly by weighting nonconformities on the basis of severity. If a process has a low nonconformance level but defects are noted having critical severity, a case can be made to not reduce inspection.
5.	Production rate	<i>Will the new process total output rate or output variability affect the number of inspectors needed? Are any inspector bottlenecks predicted?</i> If a change in production alters the rate of production, it could cause inspection bottlenecks. If the rate is increased, possibly more inspection resources will be needed to maintain the required throughput, cycle time, etc. And if enough time is not given to inspection then escapes may occur.
6.	Gage R&R	<i>Will the process change inspector reproducibility and repeatability or equipment precision to tolerance ratio cause a change in inspector numbers? (See GageR&R definition)</i> Often bypassed, a gage repeatability and reproducibility study is essential for determining the two components of measurement error: repeatability and reproducibility of the gage. It verifies that the training and performance of inspectors as well as the gage are both appropriate for the measurement being made.
7.	Lessons learned	<i>Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?</i> Usually inspection techniques were developed based on particular nonconformities that were noted in the past. Does the new manufacturing process eliminate the need to inspect for any items?
8.	Inspection escapes	<i>Will the new process help reduce inspector escapes and alter the number of inspectors required?</i> This may take some time to determine as an escape may be found months after the product first went through inspection.
9.	Deming's cost analysis [5]	<i>Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)</i> Three quantities must be determined: p, the probability of a nonconformity occurring; k1, the cost to inspect one part; and k2, the cost to fix a nonconformity when it is discovered downstream which involves dismantling, repair, reassemble, and retest. Many contractors will say they simply do not have these numbers, but upon further thought they may well have them or be able to estimate them based on similar processes for which there are numbers. For example, p is commonly reported. k1 involves dividing the total inspection time by the number of inspections. k2 may be the most difficult quantity to obtain, but often the cost of an equivalent failure investigation or root cause corrective action is known: perhaps not precisely, but we may only need approximate values. A contractor may

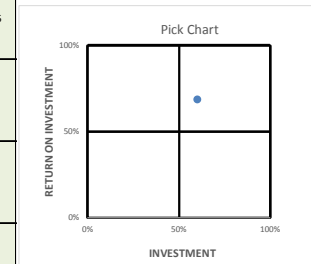
#	Study	Discussion
		<p>have an equivalent method for assessing risk and it is appropriate to substitute such a process for the Deming approach. It should be noted that Deming's approach in its simplest form does not take into account the severity of nonconformities which is why a PFMEA stressed in the first analysis is so important. An example of this analysis is given in Appendix B.</p>
10.	Stakeholder's reaction to change	<p><i>Will the stakeholder allow the change? Take into account any stakeholder-mandated inspections.</i></p> <p>The results can range anywhere from no changes are allowed, to allowing change with evidence, to full agreement with the change. Obviously it's best to determine the stakeholder opinion before embarking on a major process change and that's why, in part, the tools were developed.</p>

Process Being Reviewed	Printed wiring board, paste application process
Scope	Flight hardware
Nature of change	Stencil approach replaced by solder paste printing machine
Process Revision	
Lead Reviewer	
Date	
Analysis Revision	
Quadrant	STRATEGIC
Conclusion	Upgrading stencil process improves quality and inspection could be reduced. Implementation is expensive though.

If a analysis is not to be done, the suggested ranks are ROI=Do not reduce inspectors and I=High cost/effort.
Weight cells shaded in red indicate a change from the pre-set weight and may indicate results could be incorrect.

Change due to introduction of new manufacturing equipment.	Justification	Weight (0-100%)	Click cell below to see pull-down	Return on Investment (ROI) Rank (Savings)			ROI Value	Click cell below to see pull-down	Investment or Effort Rank (Cost)				Effort Value
				\$	\$	\$			\$	\$	\$	\$	
1	Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	No cost/effort					0
2	Is the new process qualified and capable? Based on what is known about the new process, can inspectors be reduced? Conclusions should be based on data.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
3	Does the pilot or proof of concept indicate inspectors can be reduced?	5%	Reduce inspectors 75%	\$	\$	\$	0.15	Medium-high cost/effort	\$	\$	\$		0.15
4	Will the new process significantly reduce nonconformities and thus reduce the number of inspectors needed?	10%	Reduce inspectors 75%	\$	\$	\$	0.3	Low cost/effort	\$				0.1
5	Will the new process total output rate or output variability affect the number of inspectors needed? Are any inspector bottlenecks predicted?	5%	Do not reduce inspectors				0	Medium-high cost/effort	\$	\$	\$		0.15
6	Will the process change inspector reproducibility and repeatability or equipment precision to tolerance ratio causing a change in inspector numbers? (See GageR&R definition)	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
7	Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?	10%	Remove inspectors	\$	\$	\$	0.4	High cost/effort	\$	\$	\$	\$	0.4
8	Will the new process help reduce inspector escapes and alter the number of inspectors required?	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
9	Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)	20%	Reduce inspectors 50%	\$	\$		0.4	Medium cost/effort	\$	\$			0.4
10	Will the stakeholder allow the change? Take into account any stakeholder mandated inspections.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	No cost/effort					0
Total Weighting Sum		100%											

ROI Score	2.75	Investment Score	2.4
Weighted Return	69%	Weighted Investment	60%



Weighted score falls in the following quadrant:
STRATEGIC

Figure 4. Tool example for a manufacturing process change.

The tool is dependent upon the weights assigned to each study. It was recognized that the values could change depending on what was causing inspection to be re-evaluated. The three possibilities include the following:

- Manufacturing process change
- Inspection process change
- Data driven process change

The suggested weights are included in Table 1 below.

Table 1. Study Weights as a Function of Type of Process Change

Study Line Number	Manufacturing Process Change	Inspection Process Change	Management or Stakeholder Input Change
1 Manufacturing	10%	10%	10%
2 Manufacturing	10%	3%	3%
3 Manufacturing	5%	3%	3%
4 Manufacturing	10%	3%	3%
5 Manufacturing	5%	3%	3%
6 Inspection	10%	15%	8%
7 Inspection	10%	10%	10%
8 Inspection	10%	20%	20%
9 Cost or Risk	20%	30%	30%
10 Stakeholder Input	10%	3%	10%

Notice that for the manufacturing process change, the manufacturing study lines are weighted more heavily. Similarly for the inspection process change, inspection study lines are more heavily weighted. Finally for management or stakeholder input, study lines 9 and 10 are more strongly weighted. The tools presented have these weights built in. They may be changed to fit a user's particular need; however, the spreadsheet will warn the user that the weights have been changed.

2.5 Required Attributes and Skill Sets When Applying this Tool

The skill sets required for this tool are basic Excel® skills expected of any quality engineer. However, the inputs to the tool require significant analysis and judgment and require multiple other processes and tools to be used to generate them. Therefore, it is recommended that while quality engineering may own the tool and the implementation of its output, there should be a management or steering organization driving the analyses required to generate the inputs to the tool. This may come from multiple organizations or a single organization, but in all cases this organization should provide the subjective review of analysis outputs from PFMEAs, risk analyses, personnel reviews, *etc.* that provide an input to the tool. The management organization should also be able to provide input into the weighting of the inputs and how those weights reflect the completeness, risk, and opportunities available within each analysis.

3. Summary and Conclusion

A cross-industry team was tasked with evaluating the inspection process in light of modern manufacturing methods. This team developed generic evaluation methodologies for a wide range of inspection processes then compiled an Excel®-based tool to aid in systematic evaluation and comparison across the industry. The tool is tailored by modifying weights to certain suggested studies to three different scenarios: change in the manufacturing process, the inspection process, and data driven decisions. Each tool weights specific analyses thought to be important for each situation and allows the user to input the investment and return on investment required for each analysis. The tools then produce scores which guide the user into assessing whether or not it is of value to institute the anticipated inspection modification. In the end, after the analyses are completed and used to determine acceptability of the inspection modification, then an additional analysis may be required to make the final decision.

Examples which illuminate the application of the tool are provided in Appendix A. Ultimately the tools are aids only and are not a substitute for management experience and business decision making.

Instructions and insights for the use of this electronic tool are provided herein for use by industry. The tool may be launched from the document and is found in Appendix D.

4. Definitions and Acronyms

Audit	A systematic, independent, and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which audit criteria are fulfilled. [3]
Capable	A process is capable when it is repeatable and produces the desired output within the expected cost constraints. Capability refers to the ability of a process to fulfill requirements for a product. [3] In addition, this term as used herein includes the throughput required to prevent gridlock at the inspection process.
Critical process	A process whose failure or likelihood of failure would seriously endanger the safety of personnel or alternatively, produce product that could seriously degrade the mission or result in mission failure.
Defect	Non-fulfilment of a requirement related to an intended or specified use. [3]
Escape	An inspection error as evidenced by an issue found at a higher level when it should have been caught at the first opportunity presented to inspection.
Gage R&R	Gage R&R is used to determine the inherent precision of the gage (repeatability) and the variation of measurement between operators using the gage (reproducibility). [4] It also provides a precision to tolerance ratio for the inspection system which is used to determine if the system is capable of measuring the specified tolerance.
Inspection	Evaluation by observation and judgment accompanied as appropriate by measurement, testing, or gaging to assess the conformance of supplies and services to contract requirements.
Inspector	A person authorized to perform a detailed examination of a product with the goal of determining if the product meets established requirements.
Investment	The labor and capital equipment needed to evaluate and potentially change an inspection process. It can include conducting studies and analyses, purchasing capital equipment, and changing planning and processes to accommodate the changes.
Likelihood	Likelihood is the chance that something might happen. Likelihood can be defined, determined, or measured objectively or subjectively and can be expressed either qualitatively or quantitatively.
Method	Practice, procedure, method, and work instruction are named in accordance with the nomenclature of business command media and share the following definition: A document that defines what processes must be performed, what products must be produced, when and how often it must be done, and who is responsible. It may also include the "How to" instructions that implement the process.
Nonconformity	Non-fulfilment of a requirement. [3]
PFMEA	Process Failure Modes and Effects Analysis is a structured approach to preventive action that assigns a risk priority number (RPN) to each process step based anticipated failures. The RPN is the product of frequency of occurrence, severity, and detection.
Process	A series of logically related activities comprised of value added tasks that transforms an input into a specific end result or output (i.e., product or information) required by a stakeholder.
Process control	A process is under control if it is repeatable, stable, and operating at its designed target with normal variation.

Quality engineer	i) A person responsible for evaluating overall process performance on a regular basis to provide confidence that processes will satisfy the relevant quality requirements and recommends process changes when evidence indicates poor quality. ii) A person who objectively evaluates products or processes. Quality engineers provide stakeholder advocacy and ensure that the design, development, and production of all products satisfy stakeholder requirements and expectations.
Requirement	Need or expectation that is stated, generally implied, or obligatory. [3]
Return on Investment (ROI)	The earning power for the resources invested to implement a change (<i>e.g.</i> project cost) by the organization. This term is used herein to indicate the savings incurred from changes made to the inspection process.
RCCA	Root Cause Corrective Action. Root cause is the identification of the failure from which a chain of effects or other failures originates. Corrective action is the activity undertaken to eliminate the cause of a detected nonconformity. RCCA efforts are usually deployed on situations of a serious nature.
Surveillance	Frequent observation of an area or process with the intent to gather data on the proper functioning of processes.
Testing	A measurement used as a means of determining if functional requirements of a product are met.
Tool	Hardware or software that automates some portion of product or process implementation.
Verification	Confirmation through the provision of objective evidence that the requirements for a specific intended use or application have been fulfilled. [3]

5. References

1. MIL Q 9858A, *Quality Program Requirements*. Department of Defense, 9 April 1959.
2. MIL I 45208A, *Inspection System Requirements*. Department of Defense, 26 February 1960.
3. ISO 9000:2005(E), *Quality management systems – Fundamentals and vocabulary*. International Organization for Standardization, Switzerland, 2005.
4. Montgomery, D.C., *Statistical Quality Control*. John Wiley and Sons, Hoboken, New Jersey, 2013.
5. Deming, W.E., *Out of the Crisis*, Chapter 15. The MIT Press, Cambridge, Massachusetts, 2000.
6. *Aviation Critical Safety Item Management Handbook*. NAVAIR 11-515, Joint Aeronautical Commanders' Group, 16 March 2011.

Appendix A. Sample Tool Applications

Three examples are given below on the application of the tool which correspond to the three tabs on the Excel® spreadsheet. The first example addresses a change in the manufacturing process while the second involves a change in the inspection process. The third example involves a data driven example and demonstrates how the use of the tool could prevent a costly event.

A.1 Application: Technology Introduction Into Manufacturing Process

A.1.1 Process Weighted More Heavily Than Inspection

The first application involves the situation in which the manufacturing process undergoes a significant upgrade. This may be the result of the introduction of a new manufacturing technology. Assuming the quality of the product is significantly improved, the level of inspection may be reduced or eliminated. The tool in this case emphasizes the analyses that pertain to the capability and stability of the new process. (40% of the weights are devoted to the manufacturing process.) The inspection analyses explore whether or not the fidelity of the inspection process must be modified or if inspection can be eliminated.

A.1.2 Example: Paste Printer Upgrade to Surface Mount Technology (SMT) Process

The tool shown in Figure 5 requires the user to evaluate each listed study for a ROI as a result of the investment or effort to complete the study. ROI is a measure of the impact on the inspection process: a high ROI would mean the study has made a good case for reducing inspection. Note that the weights are set, yet they can be changed by the user. However, if they are changed, the tool will flag this change as a risk to the correctness of the conclusion.

For ROI, the user must estimate using a pull down menu of choices ranging from no reduction to full reduction of inspectors, what is the ROI when the analysis is completed? Referring to the first study question in Figure 5 (Do the results of a PFMEA show potential for improved quality?) the rating a 75% reduction in inspection. Apparently the PFMEA indicated that the number of defects would reduce significantly and that the inspection process could be modified. However, the study did not go so far as to say inspection could be eliminated.

For this same PFMEA study, the investment to complete the study is rated the lowest rank of no cost/effort. This is because as the justification column indicates, the study is completed and no further work is required. Note that some analyses will ultimately require the purchase of capital equipment to make a proper assessment. For example, #2 asks if the process is qualified. This can't be done until the capital equipment is installed. However, the cost is indicated as high cost/effort and the ROI is estimated as a 75% reduction in inspection personnel. In this case investment includes not only the expense of conducting the analysis but also of acquiring the equipment. Until the capital equipment is operational, ROI will have to be estimated.

Reviewer responses at times may appear to be contradictory. Consider the responses to analyses #4, #7, and #8. The response to #4 indicates the process will improve significantly, but #7 and #8 indicate a long study is still needed. The justification indicates the response to #4 is based on manufacturer's data and applies to the paste printing process which is a manufacturing change. However, #7 and #8 refer to nonconformities found by inspectors and escapes respectively. The effort to determine these metrics will take time and involve all SMT process errors, not just paste printing. So for example, if the paste were perfect, but the oven profile was incorrect, many nonconformities could still result.

The tool indicates that there is a significant case to be made for modification to the inspection process as indicated by the high ROI score of 69%. However, the tool also indicates there is a significant amount of work and capital expense required to bring about the manufacturing process changes as indicated by the investment

score of 60%. This is understandable as the paste printing equipment is purchased, the process must be qualified, a pilot conducted, and the process must be monitored to determine if the number of nonconformities is reduced. All of this activity takes time and expense which justifies the high score.

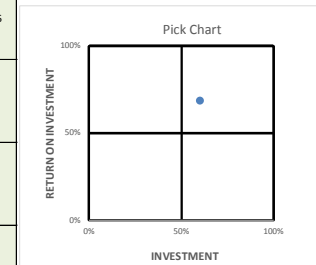
Referring to Figure 2, this places the process change in the strategic quadrant which means management has chosen to undertake this effort because of the improvement to the manufacturing process. Reduction of inspection is of secondary concern. One might ask, if the quality of the product has improved, why would inspection not be reduced or even eliminated? The answer is that while placement of paste is important, there are other issues that can cause nonconformities, such as the use of incorrect parts, part placement, or even oven zone temperatures used in the SMT process. Essentially the tool indicates the jury is still out as to whether or not this manufacturing change will be sufficient to reduce or change the inspection approach. However, the tool indicates that there is a good possibility that the inspection time per unit may be reduced. Note that the fifth study indicates that the rate of production may go up which may require more inspectors albeit a similar or reduced inspection time per unit.

Process Being Reviewed	Printed wiring board, paste application process
Scope	Flight hardware
Nature of change	Stencil approach replaced by solder paste printing machine
Process Revision	
Lead Reviewer	
Date	
Analysis Revision	
Quadrant	STRATEGIC
Conclusion	Upgrading stencil process improves quality and inspection could be reduced. Implementation is expensive though.

If an analysis is not to be done, the suggested ranks are ROI=Do not reduce inspectors and I=High cost/effort.
 Weight cells shaded in red indicate a change from the pre-set weight and may indicate results could be incorrect.

Change due to introduction of new manufacturing equipment.	Justification	Weight (0-100%)	Click cell below to see pulldown	Return on Investment (ROI) Rank (Savings)			ROI Value	Click cell below to see pulldown	Investment or Effort Rank (Cost)				Effort Value
				\$	\$	\$			\$	\$	\$	\$	
1	Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	No cost/effort					0
2	Is the new process qualified and capable? Based on what is known about the new process, can inspectors be reduced? Conclusions should be based on data.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
3	Does the pilot or proof of concept indicate inspectors can be reduced?	5%	Reduce inspectors 75%	\$	\$	\$	0.15	Medium-high cost/effort	\$	\$	\$		0.15
4	Will the new process significantly reduce nonconformities and thus reduce the number of inspectors needed?	10%	Reduce inspectors 75%	\$	\$	\$	0.3	Low cost/effort	\$				0.1
5	Will the new process total output rate or output variability affect the number of inspectors needed? Are any inspector bottlenecks predicted?	5%	Do not reduce inspectors				0	Medium-high cost/effort	\$	\$	\$		0.15
6	Will the process change inspector reproducibility and repeatability or equipment precision to tolerance ratio causing a change in inspector numbers? (See Gage&R definition)	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
7	Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?	10%	Remove inspectors	\$	\$	\$	0.4	High cost/effort	\$	\$	\$	\$	0.4
8	Will the new process help reduce inspector escapes and alter the number of inspectors required?	10%	Reduce inspectors 75%	\$	\$	\$	0.3	High cost/effort	\$	\$	\$	\$	0.4
9	Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)	20%	Reduce inspectors 50%	\$	\$		0.4	Medium cost/effort	\$	\$			0.4
10	Will the stakeholder allow the change? Take into account any stakeholder mandated inspections.	10%	Reduce inspectors 75%	\$	\$	\$	0.3	No cost/effort					0
Total Weighting Sum		100%											

ROI Score	2.75		Investment Score	2.4
Weighted Return	69%		Weighted Investment	60%



Weighted score falls in the following quadrant:

STRATEGIC

Figure 5. Tool example for a manufacturing process change.

A.2 Application: Technology Introduction Into the Inspection Process

A.2.1 Inspection Weighted More Heavily Than the Manufacturing Process

The second application assumes the manufacturing process has not significantly changed, but new inspection equipment may be able to eliminate inspection and allow inspection to be performed by the technician. In this case it is assumed the manufacturing analyses are well understood and up-to-date. The emphasis of the tool is on the inspection process in this case. (45% of the weights are devoted to the inspection process.) Often when inspection is replaced, some sort of technician self-check is implemented.

A.2.2 Example: Torque Process

In this particular example (Figure 6), production management has decided to purchase wireless data transfer torque wrenches for use in the integration and test area. These wrenches will transmit the torque value to the planning software which will check the torque value with respect to the specification and give a pass or fail notice to the operator. It is believed that the quality inspection can be eliminated in favor of operator inspection. Training of the operators will have to take place to assure quality standards are maintained.

Notice that some of the questions in the tool have been modified slightly over the previous example; however, the tool maintains the same structure of having the first five analyses address manufacturing, the next three address inspection, and the last two address cost and stakeholder input.

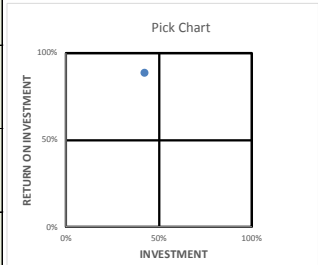
In this example the weighted ROI value is 89% while the weighted investment is 42%. Because there is already a low error rate, the reviewer indicates that for question #8 it will take some time to gather sufficient data to notice if escapes occur. The justification cell states that there were no errors in a sample size of 1000 torques, although possibly three escapes were discovered in unrelated investigations. Although this torque process is about a four sigma process, one would want to have at least a five sigma process which would require sample size of at least ten times the current sample size, or 10,000 torques, with no additional errors. Management may choose to replace quality inspection with operator inspection, accept the risk, and not wait until data could demonstrate the change was appropriate.

Process Being Reviewed	Torque process
Scope	Integration and test torque process
Nature of change	Install wireless data transfer torque wrenches
Process Revision	
Lead Reviewer	
Date	
Analysis Revision	
Quadrant	JUST DO IT
Conclusion	Tool suggests the change to replace inspection by technician self check is warranted.

If an analysis is not to be done, the suggested ranks are ROI=Do not reduce inspectors and I=High cost/effort.
 Weight cells shaded in red indicate a change from the pre-set weight and may indicate results could be incorrect.

Change due to introduction of new inspection equipment.	Justification	Weight (0-100%)	Click cell below to see pulldown	Return on Investment (ROI) Rank (Savings)	ROI Value	Click cell below to see pulldown	Investment or Effort Rank (Cost)	Effort Value
1 Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.	A PFMEA doesn't show any new failures, yet would allow automatic feedback to technician.	10%	Remove inspectors	\$ \$ \$ \$	0.4	No cost/effort		0
2 Is the new inspection process qualified and capable? Conclusions should be based on data.	Process has been qualified for years.	3%	Remove inspectors	\$ \$ \$ \$	0.12	No cost/effort		0
3 Does the pilot or proof of concept indicate inspectors can be reduced?	Conducted pilot indicates technician self inspection is acceptable. No inspection needed as long as the data are recorded.	3%	Remove inspectors	\$ \$ \$ \$	0.12	No cost/effort		0
4 Are there any changes in requirements which could affect identification of defects? Do these changes affect the number of inspectors required?	There are no changes in requirements.	3%	Remove inspectors	\$ \$ \$ \$	0.12	No cost/effort		0
5 Will the new inspection process total output rate or output variability affect the number of inspectors needed? Are any bottlenecks predicted?	Having technicians perform self check would speed process up significantly. However if inspectors were eliminated no bottlenecks would occur. However an adequate number of torque wrenches would have to be purchased.	3%	Remove inspectors	\$ \$ \$ \$	0.12	Low cost/effort	\$	0.03
6 Will the process change inspector reproducibility and repeatability or equipment precision to tolerance ratio causing a change in inspector numbers? (See GageR&R definition)	This effort was never done on technicians that would be using the special torque wrenches.	15%	Reduce inspectors 75%	\$ \$ \$	0.45	Medium-high cost/effort	\$ \$ \$	0.45
7 Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?	Historical reasons include verifying technician torqued to the correct value and record the value properly. These actions would be verified by the new torque wrenches and automated planning.	10%	Remove inspectors	\$ \$ \$ \$	0.4	No cost/effort		0
8 Will the new process help reduce inspector escapes and alter the number of inspectors required?	Escapes are expected to go to zero. However previous data indicated zero errors in 1000 torques, although 3 escapes were discovered in unrelated root cause investigations.	20%	Remove inspectors	\$ \$ \$ \$	0.8	Medium-high cost/effort	\$ \$ \$	0.6
9 Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)	Predictions are escapes would approach zero. Some inspection of the planning software would be required to make sure the computer is checking for the correct values.	30%	Reduce inspectors 75%	\$ \$ \$ \$	0.9	Medium cost/effort	\$ \$	0.6
10 Will the stakeholder allow the change? Take into account any stakeholder mandated inspections.	Customer supports the introduction of the new tool wrenches.	3%	Remove inspectors	\$ \$ \$ \$	0.12	No cost/effort		0
Total Weighting Sum		100%						

ROI Score	3.55	Investment Score	1.68
Weighted Return	89%	Weighted Investment	42%



Weighted score falls in the following quadrant:
JUST DO IT

Figure 6. Tool example for inspection process change.

A.3 Data Driven Inspection Change

A.3.1 Management or Stakeholder Request

The final tool tab is used when a management or stakeholder change is requested in response to an analysis or review of feedback from design or process related data. A change may result from data analysis, such as a reduction in nonconformities. The inspection process may need to be re-evaluated if it is found to be a significant bottleneck. Or inspection may be re-evaluated if design or customer requirements change based on an analysis such as recurring use-as-is dispositions for nonconformities. This situation also includes the evaluation of impediments to any changes, such as operator concerns that jobs may be eliminated. The tool in this case emphasizes inspection studies (weighted as 38%) as well as cost and stakeholder studies (30% and 10% respectively). It is assumed the manufacturing process has been operating some time as a qualified process with a low level of nonconformities. But since there is a desire to change inspection, it is important to ensure the necessary inspection studies have been completed before a change is made to the production line.

A.3.2 Example: Reduced Inspection for Mate/Demate Process Based on Data Analysis

The tool requires the user to evaluate each study listed for the ROI for reduced inspection as well as the investment to complete the study. Note that the weights are set, yet can be changed by the user. However, if they are changed, the tool will flag this change as a risk to the correctness of the conclusion. In this example (Figure 7) a management decision resulted in changes to several weights.

For investment, the user must estimate the effort to complete the study. Using a pull down menu the user chooses an investment rank ranging from no cost/effort to high cost/effort. Note the user will have to match their financial system to the scale. For some contractors, \$300,000 may not be high cost while for a supplier, \$10,000 could be viewed as high cost.

Referring to the first study question in Figure 8 (Do the results of a PFMEA show potential for reducing inspectors?) the investment rank is given as high cost. The justification comment states the study has not been done but it is believed that the effort would take about six months to complete. Since there are no plans to do a PFMEA, the rules suggest that the ranks be indicated as no reduction in inspectors and high cost for the analyses. (This is indicated in red instructions near the top of the tool matrix.) Although the management may believe that it is not important to conduct a PFMEA, the designers of the tool believe it is a necessary step in minimizing the risk of a faulty conclusion.

Notice that in this example, management decided to also change the weights of the manufacturing analyses. Since the PFMEA was weighted as zero, the remaining weights of the four manufacturing analyses were changed so that the total sum of weights remained 100%. The tool indicates these weight changes by shading the weights for the first five analyses in red.

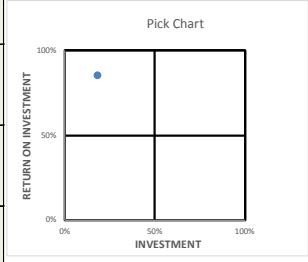
The tool indicates that there is a significant case to be made for modifying the inspection process as indicated by the high ROI score of 86%. The investment score is low at 18%. Referring to Figure 2, this places the process change in the “just do it” quadrant. These scores imply there is little risk to embarking on a modification of the inspection process, possibly eliminating it. However, the red shaded weights for the manufacturing studies indicate the weightings have been changed and may affect the accuracy of the tool output. The change in weight was the result of management not requiring a PFMEA. This study would identify any particular failure mechanisms in the process which might be important if inspection were eliminated. This becomes evident as shown in the next section.

Process Being Reviewed	Mate demate
Scope	Test to flight harness DC mates
Nature of change	Review the current process for possible schedule and cost savings through the reduction of inspection.
Process Revision	
Lead Reviewer	
Date	
Analysis Revision	
Quadrant	JUST DO IT
Conclusion	For a low effort, significant ROI can be achieved. However there are warnings based on changes in the standard weights (as indicated by the red cells).

If a analysis is not to be done, the suggested ranks are ROI=Do not reduce inspectors and I=High cost/effort.
 Weight cells shaded in red indicate a change from the pre-set weight and may indicate results could be incorrect.

Change due to favorable data results.	Justification	Weight (0-100%)	Click cell below to see pulldown	Return on Investment (ROI) Rank (Savings)	ROI Value	Click cell below to see pulldown	Investment or Effort Rank (Cost)	Effort Value
1 Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.	Management will not require a PFMEA. Weight for this is changed from 10 to 0%. Other weights of manufacturing studies were adjusted accordingly.	0%	Do not reduce inspectors		0	High cost/effort		0
2 Is the manufacturing process qualified and capable? Based on manufacturing process data, can the number of inspectors be reduced?	Process has been qualified for years.	6%	Remove inspectors		0.24	No cost/effort		0
3 Does the proof of concept for the data driven inspection change indicate inspectors can be reduced?	Since inspectors don't find many errors, the proof of concept is obvious.	6%	Remove inspectors		0.24	No cost/effort		0
4 Are there any changes in requirements which could affect identification of defects? Do these changes affect the number of inspectors required?	There are no changes in requirements. Some effort must be expended to train the operators.	6%	Remove inspectors		0.24	Low cost/effort		0.06
5 Will the total output rate or output variability affect the number of inspectors needed? Are any inspector bottlenecks predicted?	Elimination of inspection would speed up the process, but no bottlenecks are expected.	4%	Remove inspectors		0.16	No cost/effort		0
6 Do the inspector reproducibility and repeatability measurements or equipment precision to tolerance ratio support a change in inspector numbers? (See GageR&R definition)	This effort has never been done on inspectors, let alone on operators who would act as inspectors.	8%	Reduce inspectors 75%		0.24	Medium cost/effort		0.16
7 Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?	There are no lessons learned that the operators would not already be aware of.	10%	Reduce inspectors 75%		0.3	No cost/effort		0
8 Will a change in inspector numbers affect escapes? How does this impact the number of inspectors needed?	Escapes are expected to be low. Data for the last year showed 14 defects for 47,019 test mates.	20%	Reduce inspectors 75%		0.6	Medium cost/effort		0.4
9 Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)	For test mates nonconformities can be caught at the next level with little cost to repair.	30%	Remove inspectors		1.2	No cost/effort		0
10 Will the stakeholder allow the change? Take into account any stakeholder mandated inspections.	Customer has expressed some concerns but given a tentative go-ahead.	10%	Reduce inspectors 50%		0.2	Low cost/effort		0.1
Total Weighting Sum		100%						

ROI Score	3.42	Investment Score	0.72
Weighted Return	86%	Weighted Investment	18%



Weighted score falls in the following quadrant:
JUST DO IT

Figure 7. Tool example for management directed change.

A.4 Example: Enlarging the Scope of Applicability

The change was made to the inspection process described in A3.0 with a successful implementation in spite of the weighting warning. But management was so happy with the result that they decided to eliminate inspection on flight mates without applying the tool. Results were not so good. A costly mistake resulted in the need to break a thermal vacuum test. Since the scope was expanded from test to flight, the tool would have to be applied again. In this case several changes in the tool would result in a different conclusion. Most likely the tool would have looked similar to Figure 8 and changes in ranks occurred for lines #4, #9, and #10. The affected ranks are indicated with a red font. The weights were restored to their original values.

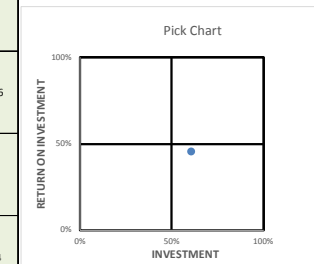
Note that the tool now indicates a 46% weighted ROI score and a 61% weighted investment score. This places the result in the “FORGET IT” quadrant. The reason the ROI score changed so significantly is that the impact for reducing inspection dropped because of the PFMEA and cost analyses. These analyses also increased the investment metric as significant resources would have to be devoted to completing these analyses. Finally, note the entries for the PFMEA study. Since management decided not to conduct this study, the user followed the template suggestion of leaving the entries in the ROI columns blank because there is no study to provide a ROI. In addition, the investment rank is listed as high cost because management believed the investment was excessive.

Process Being Reviewed	Mate demate
Scope	Flight to flight mates prior to thermal vac
Nature of change	Review the current process for possible schedule and cost savings through the reduction of inspection.
Process Revision	
Lead Reviewer	
Date	
Analysis Revision	
Quadrant	FORGET IT
Conclusion	Because mates cannot be inspected before thermal vac, there is a risk of high cost if mate problem happens while under test.

If a analysis is not to be done, the suggested ranks are ROI=Do not reduce inspectors and I=High cost/effort.
 Weight cells shaded in red indicate a change from the pre-set weight and may indicate results could be incorrect.

Change due to favorable data results.		Weight (0-100%)	Click cell below to see pulldown	Return on Investment (ROI) Rank (Savings)				ROI Value	Click cell below to see pulldown	Investment or Effort Rank (Cost)				Effort Value
Studies to be conducted	Justification													
1	Do the results of a PFMEA show potential for reducing inspectors? Decision making should be based on risk priority numbers or an equivalent approach.	10%	Do not reduce inspectors					0	High cost/effort	\$	\$	\$	\$	0.4
2	Is the manufacturing process qualified and capable? Based on manufacturing process data, can the number of inspectors be reduced?	3%	Remove inspectors	\$	\$	\$	\$	0.12	No cost/effort					0
3	Does the proof of concept for the data driven inspection change indicate inspectors can be reduced?	3%	Remove inspectors	\$	\$	\$	\$	0.12	No cost/effort					0
4	Are there any changes in requirements which could affect identification of defects? Do these changes affect the number of inspectors required?	3%	Remove inspectors	\$	\$	\$	\$	0.12	Medium cost/effort	\$	\$			0.06
5	Will the total output rate or output variability affect the number of inspectors needed? Are any inspector bottlenecks predicted?	3%	Remove inspectors	\$	\$	\$	\$	0.12	No cost/effort					0
6	Do the inspector reproducibility and repeatability measurements or equipment precision to tolerance ratio support a change in inspector numbers? (See GageR&R definition)	8%	Reduce inspectors 75%	\$	\$	\$		0.24	Medium cost/effort	\$	\$			0.16
7	Are the historical reasons for the inspector staffing levels still valid? Do lessons learned indicate a change in inspector levels is warranted?	10%	Reduce inspectors 75%	\$	\$	\$		0.3	No cost/effort					0
8	Will a change in inspector numbers affect escapes? How does this impact the number of inspectors needed?	20%	Reduce inspectors 75%	\$	\$	\$		0.6	Medium cost/effort	\$	\$			0.4
9	Does the cost or risk to repair defects escaped from inspection justify reducing inspectors. (See Appendix B for Deming rule discussion.)	30%	Do not reduce inspectors					0	High cost/effort	\$	\$	\$	\$	1.2
10	Will the stakeholder allow the change? Take into account any stakeholder mandated inspections.	10%	Reduce inspectors 50%	\$	\$			0.2	Medium cost/effort	\$	\$			0.2
Total Weighting Sum		100%												

ROI Score	1.82		Investment Score	2.42
Weighted Return	46%		Weighted Investment	61%



Weighted score falls in the following quadrant:
FORGET IT

Figure 8. Tool example for modification of an application scope change.

Appendix B. Deming's Rule Explanation

B.1 The Deming Rule

The reason hardware for space involves so much inspection can be easily explained by the Deming rule. To understand the method consider the following definitions:

p = average percentage of nonconformities taken over a period of time. For example, a printed wiring board facility estimates that they have 10,000 opportunities for error in any month. If 30 nonconformities were noted in a month, then $p = 30/10,000 = 0.3\%$

k_1 = cost to inspect one printed wiring board. For example, an inspector spends four hours to review all the solder joints, parts, and connectors on a board. If the inspector's time to the company is \$50/hour, then the cost to inspect the board is \$200.

k_2 = cost to remove the board from its unit, repair it, reassemble it, and retest the unit if the board failed. In this example, estimating the cost is challenging. But let's say if components are not mounted on the board properly, their leads can fail in vibration testing. By the time the board reaches vibration testing it most likely has been tested by itself, placed in a unit and given a functional test, then placed into a vibration test setup. Failure at this level would mean all of the previous costs mentioned would have been wasted as well as a schedule hit and the need to remove, repair, reassemble, and retest. Let's say total cost for this is \$100,000.

To apply Deming's rule, we simply ask the question is $p < k_1/k_2$? In this case $p=0.3\%$ and $k_1/k_2 = 200/100,000 = 0.2\%$. Since $p > k_1/k_2$ as in this case, then 100% inspection is in order.

For space hardware, the cost of finding a nonconformity downstream can be very costly which usually makes k_1/k_2 a small number. According to the rule, 100% inspection is the appropriate way to proceed. This is one reason why space hardware is inspected so frequently and at all phases of the build. A missed nonconformity can be very costly to fix. Space hardware must be built with low error rate processes. And as hardware moves into the integration phase, processes must be even more controlled to offset the increase in the complexity of operations.

B.2 Severity of Defects

The space industry does not maintain a consistent definition set for major, minor, and critical elements of a system or product. The definition of each of these is left up to the business or program to define as they see fit. The lack of a standard definition set for defining severity levels limits the ability for nonconformities to be standardized across an array of programs thus leading to confusion on when a process is in control or not. See the Joint Aeronautical Commanders Group (JACG) handbook for the approach used by the aviation industry. [6]

Deming's rule was originally applied to incoming inspection instead of production. However, when applying the rule to the building of hardware, it's advised to take into account the severity of nonconformities. For example, loose fiber on a printed wiring board is less costly to correct than removal and replacement of a ball grid array package. In addition, distinguishing between nonconformities and defects (see definitions) requires attention to severity. To account for this difference, defects may be categorized as critical, major, minor, or some similar scale. Then a weight, or demerit, is assigned to each category and the total number of demerits are calculated as a replacement for the simple concept of nonconformity count given in section B1.0. [4]

This is why a PFMEA is so important because it can take into account the severity of nonconformities and defects as well as the likelihood of their occurrence.

Appendix C. Frequently Asked Questions

My management has directed us not to perform one of the analyses. How do I fill in the investment and ROI entries for this line item?

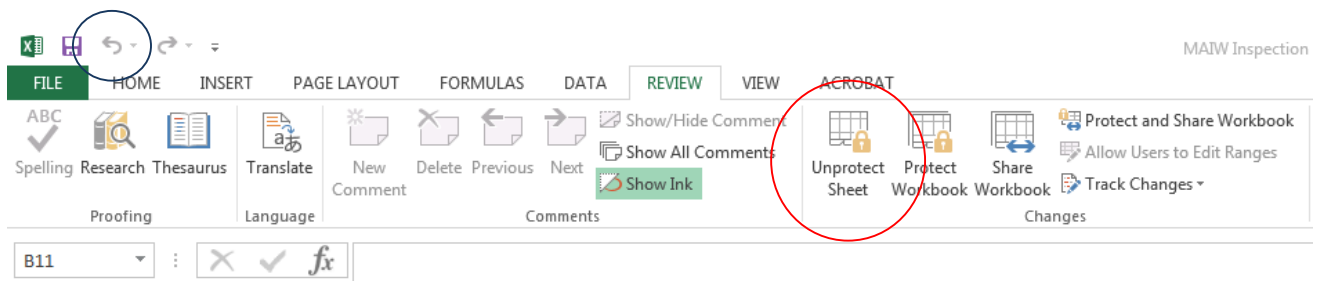
The argument used is that the cost of the analysis is considered by management to not be worth the investment. This is equivalent to setting the investment rank to high cost/effort. Since the analysis has not been done, there is no ROI, therefore leave all entries in the ROI rank columns blank for this line item. These entries have the effect of moving the point on the pick chart closer to the “Forget It” quadrant. Note instructions for this issue are given on the template.

I don't believe the weights are appropriate for the process I'm working on. What do I do?

The tool allows the weights to be changed as necessary. Just make sure the weights all add up to 100%. When weights are changed, they will be indicated by a red background. This simply reminds the user that a deviation from the suggested weights has been taken. All calculations will be accordingly adjusted to the weights you enter.

I want to print a portion of the spreadsheet but I can't set the print area. How do I do that?

The tool is protected so that cells that contain formulas do not inadvertently get overwritten. To remove protection choose Review and then select Unprotect Sheet as shown below.



Once protection has been removed, select your print area (under Page Layout) and print. After printing you might want to protect the sheet again. Go to Review and click on Protect Sheet. A pop-up window will appear. Make sure the boxes labeled *Protect worksheet* and contents of locked cells and *Select unlocked cells* are checked. Then click on OK.

The Pick Chart has moved from its original location. What do I do about this?

Usually this is caused by comments in the justification column being of different lengths. Simply adjust each line item to be three to five lines each.

The point on the pick chart doesn't agree with my intuition of where it should be. What does this mean?

First check your ranks to make sure they are correct. Investment rank ranges from no cost/effort to high cost/effort using the pulldown menus. Similarly for ROI do not reduce inspections means there's little payback for the effort expended to do the analyses, while remove inspectors means there's a significant return of investment. If your entries appear to be correct, the tool may require you to assess the situation further. In general the weights have been established to yield reasonable but conservative results. Of course if you have changed the weights, then review the weights to make sure they are reasonable.

Our group cannot seem to agree upon rank values or even the weights. Can you help?

A common way to resolve these issues is through voting. For example let's say you want to determine the value of a rank. You might give each person two votes. They can place each vote on separate ranks or they can place two votes on any one rank. The rank with the largest number of votes wins. There are all sorts of variations to the voting rules that can be created. For instance you might allow people to explain why they believe their vote is correct (in an effort to encourage others), or the voting might be silent or anonymous (to make sure each person contributes equally). Find out what method works best for the group and stick with the rule.

I want to remove an inspection. Of course there's always the possibility that a mistake will get through that the inspection would have caught can get through. But the likelihood of that occurring is very small. Can I eliminate the inspection?

Of course we suggest you complete all the entries for the tool. The line item that most likely will cause you trouble is line 9 (Deming's $p < k1/k2$ rule). What is the expected expense should the defect be missed? Where might it be discovered? Is it in integration and test or on the launch pad? Would inspection always catch this error, or could there be an escape? You, or better yet, management in conjunction with the stakeholder input must decide whether they are willing to accept the risk given the low probability of occurrence. Remember the conservative approach is to conduct 100% inspection if there is a likelihood of an expensive effort to remove, repair, reassemble, and retest.

I don't understand, is investment the effort used to change inspection or the effort to conduct the analyses?

It can be both. Many organizations have not done the analyses, so it might be expensive (large investment) to conduct the analyses. Sometimes reducing inspection may be as simple as re-assigning the inspector. Other times there are other costs such as modifying planning, perhaps training production personnel, etc. However, the main emphasis of the tool is to determine if it is worth pursuing the change to inspection; and therefore, most of the cost is tied up in the analyses. If the tool suggests a reduction in inspection is reasonable, management has the obligation to review any addition costs prior to making the change.

Is there a subset of analyses that are more important than others? I really want to get a quick estimate as to whether or not I should proceed with potentially reducing inspection.


The weights are intended to guide the user into understanding the relative importance of certain analyses. Some users may initially put in best estimates for certain analyses. For example you might not want to go into a full study of whether or not inspector escapes will be reduced by proposed changes, so you might use engineering judgement to make your first pass through the tool. Obviously it is important to identify any roadblocks before completing all analyses. For example if the stakeholder simply will not allow a change, clearly it might be better to complete initially only those studies that will be useful in convincing the stakeholder to change their position.

The tool plotted my point right between two quadrants of the pick chart. Which quadrant do I choose?

The division between quadrants should not be thought of as a sharp line but rather a fuzzy band. When the point is plotted near the vertical 50% line question whether the investment is too great to proceed. When the point is near the horizontal 50% line, question whether the ROI is sufficient. In either case discussion and engineering judgement is in order to make a final determination on whether or not to proceed.

Appendix D. Imbedded Excel® Tool

Double click on the paper clip to use the imbedded Excel® tool. Choose the appropriate tab for your application (manufacturing process change, inspection process change, or data driven process change) and complete the required information.

Double click on the paper clip to see the embedded Excel spreadsheet. 

Process Approach to Determining Quality Inspection Deployment

Approved Electronically by:

Todd M. Nygren, GENERAL
MANAGER
SYSTEMS ENGINEERING
DIVISION
ENGINEERING &
TECHNOLOGY GROUP

Jacqueline M. Wyrwitzke,
PRINC DIRECTOR
MISSION ASSURANCE
SUBDIVISION
SYSTEMS ENGINEERING
DIVISION
ENGINEERING &
TECHNOLOGY GROUP

Jackie M. Webb-Larkin,
SECURITY SPECIALIST III
GOVERNMENT SECURITY
SECURITY OPERATIONS
OPERATIONS & SUPPORT
GROUP

Technical Peer Review Performed by:

Jacqueline M. Wyrwitzke,
PRINC DIRECTOR
MISSION ASSURANCE
SUBDIVISION
SYSTEMS ENGINEERING
DIVISION
ENGINEERING &
TECHNOLOGY GROUP

Cheryl L. Sakaizawa,
ADMINISTRATIVE SPEC III
MISSION ASSURANCE
SUBDIVISION
SYSTEMS ENGINEERING
DIVISION
ENGINEERING &
TECHNOLOGY GROUP

Eric S. Richter, ENGRG
SPCLST SR
SYSTEMS AND
OPERATIONS ASSURANCE
DEPT
MISSION ASSURANCE
SUBDIVISION
ENGINEERING &
TECHNOLOGY GROUP