Controlling the Human Factor

How to conquer the last frontier in equipment reliability, maintenance, and industrial engineering asset management

Let a Plant Wellness Way EAM System-of-Reliability End Your Business Risks Forever

Abstract

Controlling the Human Factor – How to conquer the last frontier in equipment reliability, maintenance, and industrial engineering asset management: Our machines and materials of construction do not cause our equipment problems and failures. The real problem for industry is the 'human factor' in stopping people making mistakes. You gain control over the 'human factor' by providing clear and comprehensive work procedures that explain exactly how to deliver the performance required and that give users the means to check and improve their performance. The Accuracy Controlled Enterprise 3T procedure layout and content lets you provide your people with the details of how to do their work with exceptional quality, and the means to correct and improve their efforts until they are that good.

Keywords: human factor, human element, human error, equipment reliability, failure prevention, defect elimination, standard operating procedures

The following extracts are from three sources investigating industrial plant and equipment failures.

"[1] Many managers and engineers believe most failures have a root cause in the equipment. Data from nuclear power plants (which maintain a culture of confessing failures and the roots of failures—this is in opposition to most industries were the culture is to hide the roots of failures) show the following roots for failures:

Early in the life of nuclear power plants -

Design error	35% [people induced problems - not calculation errors]
Random component failures	18% [process/procedure problems]
Operator error	12% [people/procedure problems]
Maintenance error	12% [people/procedure problems]
Unknown	12%
Procedure error & (procedure) unknowns	10%
Fabrication error	1% [people/procedure problems]
	100%

Mature nuclear power plants -

People	38%
Procedures & Processes	34%
Equipment	28%
	100%

[1] Barringer, H. Paul, P.E. 'Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures', www.barringer1.com

"[2] ASME (2002 report) shows a similar root for failures. For 10 years, from 1992-2001, 127 people died from boiler and pressure vessel accidents and 720 people were injured. In the 23,338 accident reports, 83% were a direct result of human oversight or lack of knowledge. The same reasons were listed for 69% of the injuries and 60% of recorded deaths. Data shows that if you concentrate only on the equipment, you miss the best opportunities for making improvements. Another point to seriously consider is little or no capital expenditures are required for improving people, procedures, and processes which can reduce failures. In case you believe that equipment is the biggest root of problems it will be instructive to download (http://www.bpresponse.com) the Final Report of BP's Texas City Refinery explosion and tick off the reasons behind the explosion which took the lives of 15 people and maimed more than 200 addition people—you will see objective evidence for people, procedures, and processes as the major roots for failures. The #1 problem was not equipment!"

"[3]… the major challenge to reliability theory was recognized when the theoretical probabilities of failure were compared with actual rates of failure [and the] actual rates exceed the theoretical values by a factor of 10 or 100 or even more. They identified the main reason for the discrepancy to be that the theory of reliability employed did not consider the effect of human error…. Human error in anticipating failure continues to be the single most important factor in keeping the reliability of engineering designs from achieving the theoretically high levels made possible by modern methods of analysis and materials…. nine out of ten recent failures [in dams] occurred not because of inadequacies in the state of the art, but because of oversights that could and should have been avoided…. the problems are essentially non-quantitative, and the solutions are essentially non-numerical."

The above quotes are evidence that the problems we have with our plant and equipment are not machine problems. Our machines are fine. The problems of poor equipment reliability, poor maintenance and poor production performance are in the minds and hearts of the people that control our companies, design and manage our business processes, and run and maintain our machines.

The reason you have so many equipment and production failures is that you, your people and your business processes cause them. That is what the evidence in the three extracts above proves. Human beings let happen all equipment failures that are not 'Acts of God'.

If you want to make serious improvements to your plant and equipment reliability you need to first focus all your efforts and resources on changing attitudes and beliefs. You need to change the way you and your people think about, and value, quality, and reliability.

To move from a repair-focused organization where failure is seen as inevitable, where maintenance is a servant giving fast response to failures, and reliability is the responsibility of an 'elite', to a reliability-focused organization with a culture of failure elimination which permeates staff at all levels requires a mindset change. It is driven by a passionate management over a long time[4].

You start by installing the right processes and systems into your business that the people can follow. Read this quote about causing change in organisations.

[2] Barringer, H. Paul, P.E. 'Use Crow-AMSAA Reliability Growth Plots To Forecast Future System Failures', www.barringer1.com
[3] Petroski, Henry, 'Design Paradigms: Case Histories of Error and Judgment in Engineering', Cambridge Press, New York, 1994. Remarks on Pages 7 and 8 about the role of humans in failures.
[4] Wardhaugh, Jim. Extract from 2004 Singapore IQPC Reliability and Maintenance Congress presentation 'Maintenance – the best practices'

“[5] Changing collective values of adult people in an intended direction is extremely difficult, if not impossible. Values do change, but not according to someone’s master plan. Collective practices, however, depend on organisational characteristics like structures and systems, and can be influenced in more or less predictable ways by changing these.”

You cannot change people’s internal values, but what you can change is the practices they must follow so that their cognitive dissonance brings about change in their values. Cognitive dissonance is the uncertainty and unhappiness that happens in your mind if you believe one thing but are forced to do something else.

For example, if you want people to do high quality work, provide a high-quality procedure they must follow and a report sheet to complete and hand-up at the end of every job so you can encourage and train them to do masterly work. If when the procedures are exactly followed users produce better results than they ever achieved without them, people start to change belief. Their old internal values change because the external evidence does not support them. This is cognitive dissonance in action. In this way the quality requirements built into the procedures brings about the necessary change in the value people put-on careful observation, quality workmanship and accurate recording. You use your standard operating procedures to describe and create the ‘role model’ you want your people to follow.

Creating Mind Changing Standard Operating Procedures

Take for example this 12-monthly procedure used by an organisation to look after a dust collector fan and its drive. It is at a typical level of quality and content used in many organisations. It is a disaster waiting to happen. On a scale of 1 to 10, with 10 being exceptional, this procedure would rate a zero.

Task Description:	**Dust Extractor PM.**		
Trade:	**Mechanical**	Machine Downtime Hrs *(if applicable)*	
Interval:	**Annual**	Total Job Time Hrs	

Safety: ***Has the “Job Safety Analysis” (JSA) been completed?*** ***Yes / No***

Is a “Clearance to Work” required for this task? ***Yes / No***

Complete the Condition Codes: A = Acceptable B = Corrective Action Performed C = Rectification Required

Equipment	**Task Instruction**	**Code**
Belt Drive,	Clean off any excess dust, oil or debris to original condition	
	Adjust Alignment of belt/pulleys	
	Measure belt/pulley alignment	
	Inspect Condition of Pulleys	
	Inspect bearings and regrease	
Piping-Valves,	Inspect for Physical damage, seal failure or corrosion	
Structure	Clean off any dust, oil or debris to original condition	
	Check for corrosion and physical damage	

[5] Hofstede, G. J., Cultures and Organisations – Software of the Mind, Second Edition, McGraw-Hill

Equipment	Task Instruction		Code
Describe Further Maintenance work Required. Has a Work Order Request been raised? Yes/No			
Work Completed By:		***Reviewed By:***	
Name/Signature		*Name/Signature*	
Date		*Date*	

On the surface the procedure looks passable. There are task instructions provided and it seems to cover the equipment that needs to be maintained. Unfortunately, this document will cause more equipment failures than it fixes.

The problem is that there is no indication of the quality of work required and the condition that the equipment must be in after the maintenance is done. In this procedure the people doing the work are totally ignorant of the quality of workmanship they must do. They are left to their own devices to decide how to do the job, and to the work quality they must achieve. If your machines are maintained using such 'zero-grade' procedures, you have a very serious problem to address very quickly, because your maintenance documents are making your machines breakdown. You have not controlled the 'human factors' that we now know are the real destroyers of equipment reliability.

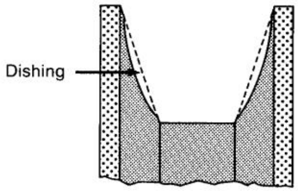
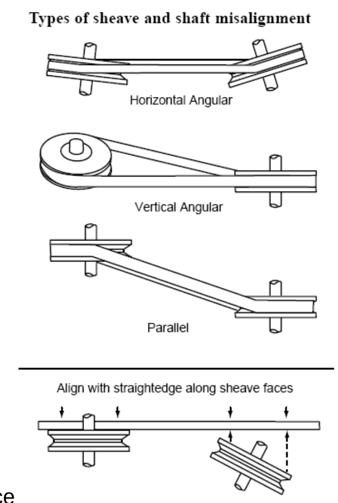
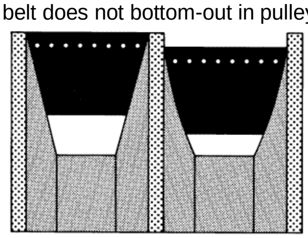
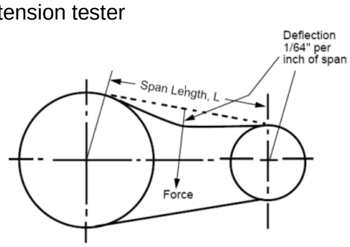
Below I've partially re-written the procedure with more effort made to specify the quality of the work to be performed and the condition in which the machine parts are to be left when the work is done. It took four hours of work to make the changes.

On the scale of 1 to 10, I would rate this procedure at a 3. It is a lot better than what it started as, but it will not deliver world-class equipment performance because it doesn't help people improve themselves. To achieve world-class work quality performance requires a different sort of procedure.

Task Description:	**Dust Extractor PM.**		
Trade:	**Mechanical**	Machine Downtime Hrs *(if applicable)*	
Interval:	**Annual**	Total Job Time Hrs	

Safety: ***Has the "Job Safety Analysis" (JSA) been completed? Yes / No***
Is a "Clearance to Work" required for this task? Yes / No

Equip	Task Instruction	Acceptable	Record What You Saw and Did at Each Step
	Do the 4 Monthly PM	**OFF-PM-M-04M-20035**	
Belt and Pulleys	Check the correct belts are fitted	The belt is a ?????????	
	Inspect belt for damage and evidence of slippage	Belt has no cracks, is not stretched, no frayed/damaged cords, no cuts or gouges. Belt has no evidence slippage such as shinny, hard contact surfaces	

Equip	Task Instruction	Acceptable	Record What You Saw and Did at Each Step
	Inspect pulleys and shaft - no evidence of structural problems - no evidence of belt slippage - no buckled /distorted / dished side wall  - no bent/damaged edge/lip on pulley - firmly held to shaft - measure run-out at outer edge for wobble - measure run-out of shaft at pulley for bent shaft	Pulley is in good structural condition. Pulley is running true and is square on shaft. Pulley vees are not polished Shaft is straight to within 0.0125mm run-out Run-out at outer edge within 0.025mm wobble.	
	Measure belt/pulley alignment and if necessary adjust motor position to bring within  tolerance	Drive pulley and driven pulley are within 0.5mm alignment per 300mm spacing of pulleys	
	Check belt does not bottom-out in pulley vee  Belt should ride like this Low riding belt indicates worn vee	Belt must clear bottom of vee by minimum of 1mm and run on pulley walls	
	Confirm belt tension is properly set to belt manufacturer's recommendation using a belt tension tester 	Belt tension is such that belt/pulleys do not slip under heaviest load condition, usually at full start-up load. For comparison, a typical belt movement on the tension side at midpoint between pulley centres is 1.5mm per 100mm spacing of pulley centres NOTE: Run a new Vee belt for 24-48 hours and then re-tension as the belt will have stretched	

Equip	Task Instruction	Acceptable	Record What You Saw and Did at Each Step
Piping-Valves	Replace passing valves identified on inspection history or causing operating problems		
	Replace damaged ducting based on inspection history and operating problems		
	Replace leaking compressed air piping and connections based on inspection history and operating problems		
Solenoid Valves and Pulse System	Bring in specialist subcontractor to do annual inspection and overhaul of pulse system and controls	Passes subcontractors checklist requirements	
Work Completed By:		***Reviewed By:***	
Name/Signature		*Name/Signature*	
Date		*Date*	

You could argue that this re-written procedure can be greatly improved. I would totally agree with that. I have left it as you see it because its purpose is to make clear that you need to make your procedures 'human factor' proof. And you do that by making sure every procedure contains every scrap of detail, and all the standards needed to do the work to the quality required to get the reliability you want.

If you do not want reliable equipment, simply do not tell your operators and maintainers how to deliver reliability. The 'human factor' will make sure you get a matching level of equipment performance.

Always remember what W. Edwards Deming said: "*Your system is perfectly design to give you the results that you get!"* His quote truthfully explains why you get the results that you do; you designed them into your business systems, because you neglected to design them out!

The Journey to World-Class needs Work Standardisation and Control of Work Quality

Now I do not want to leave you wondering what you need to do to get a 10 on my scale of job procedure quality. If you want world-class reliability you need to specify exactly what that is, and exactly how to get it. You cannot leave it to the guesswork of engineers, operators, and technicians. You must exactly state what world-class quality looks like and make clear to people exactly what they need to do to get it. You need to change the layout and content of your procedures to the Accuracy Controlled Enterprise 3T with tolerance banding style.

I've partially completed an ACE 3T (3T stands for Target, Tolerance, Test) procedure below for mating pipe flanges. I'd give it 5 out of 10. It is still not good enough because it has not yet been reviewed by two other experienced people and it has not yet been tested in the workplace to prove it produces the world-class performance it is meant to deliver. But it is already miles ahead of the quality and content value of flange installation procedures used by many companies.

A 10-score level ACE 3T procedure that controls work quality and delivers high work quality assurance takes a lot of research and time to write. It needs the research to bring all the facts together. It can only be written by people that understand the engineering of the equipment and how its parts work and can fail. They must make decisions on the standards your people will always meet and on the quality of work you will always demand of them.

You must change the mindsets and values of the people in your operation so that anything less than top-class is unacceptable. To make the journey to world-class you must seek, identify, and set world-class standards. You must make sure all your people have the intellectual capability, the quality of documentation, the depth of knowledge, the workmanship skills and precision tools to deliver those standards. In this way you control the 'human factors' that affect your plant and equipment, so they produce the right results.

Partially Complete Example of an ACE 3T Flange Bolting Procedure with Tolerance Banding

This is an example of an Accuracy Controlled Enterprise (ACE) 3T procedure with tolerance bands to bolt together 80 NB, ANSI B36.5, forged steel, Class 150 flanges. Each task has a target with the allowed limits banded into 'good, better, best'. It also provides instruction if the tolerance is not achieved.

NOTE: The example covers the method to use to create a 3T procedure and is not the actual procedure to use when bolting-up flanges. Each organisation must research, develop and approve their safe practices and procedures for bolting flanges. The use of turn-of-nut on pressure flanges may not comply with the applicable pressure piping design codes.

Flange Connection Procedure

Importance of correctly mating flanges: This procedure explains how to bolt-up correctly a pipe flange on 80mm (3") diameter pipe. Leaks of dangerous chemicals from pipe flanges create a safety and environmental hazard that can lead to death of workmates and the destruction of production plant and equipment. Even a water leak from a flange causes slip hazards and makes an unsightly mess. Pipe flanges must be bolted-up so they never leak.

This procedure is our current best practice and you should follow it exactly. It is the result of many people's efforts over many years. It is the quickest, best way yet found to do the job. You are encouraged to learn the job exactly as in this document. If after you master this procedure exactly, you believe that you know of improvements, please bring them forward for discussion. You can test your ideas and compare them to the procedure. If your suggestion proves to be better, it will become the new way of doing this job.

Necessary Equipment and Tools: Approved gasket, ring spanners, sockets (do not use adjustable shifters and pipe wrenches as they damage corners of bolt heads and nuts making their removal dangerous and unsafe), suitably load-rated studs and nuts, pencil, feeler gauges.

Task Summary

A summary of the process of installing gaskets and making flanges is below. A fully detailed procedure is beneath the list. If you have a problem that you cannot solve please see your supervisor.

1. Get work pack, tools, NEW fasteners and NEW gasket
2. Get safe handover isolated and pipe drained
3. Place personal danger tags, test if drained
4. Break and spread flange safely
5. Clean-up flange faces
6. Check unrestrained pipe alignment
7. Mount gasket and insert fasteners
8. Pull-up fasteners snug tight in sequence
9. Mark nut position and turn angle past snug
10. Turn nuts to position in sequence
11. Test flange for leakage at operating pressure
12. Safely clean-up, hand-back, complete job record and sign-off Work Order

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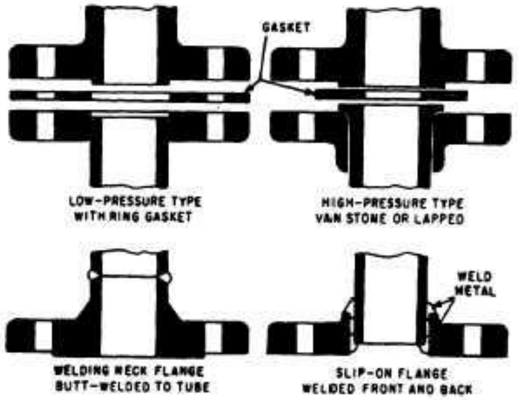
Bolt Size	Bolt Grade	Bolt Torque	Tolerance on Torque
5/8"	A193 B7 stud and nut	201 Nm (60% Yield)	+- 25% with Torque Wrench
		1/3 turn from snug tight	Between 1/3 to 1/2 turn
Gasket: Non-asbestos fibre, 1.5 mm thick, ring, approved grade for service as noted on work order			



Engineering Standards

Flange Squareness:
Good: Within 1mm for every 200mm diameter
Better: Within 0.75mm for every 200mm diameter
Best: Within 0.5mm for every 200mm diameter

Stress-free Flange Bolt Hole Alignment:
Good: Centres within 2mm
Better: Centres Within 1.5mm
Best: Centres within 1mm

Bolt Lubricant: Molybdenum disulphide

Step	Task Description	Mat'l - Tools	Tolerance Bands Good	Better	Best	Reading / Result	Action if Out of Tolerance	Sign off
1	Gather together NEW studs and nuts, washers gasket, thread paste, tools, job work order, danger tags, handover permit, special instructions, PPE	5/8" ring spanner or socket, podgy spike bar, screw driver, scraper	Request & collect issued items from store	Planner arranged all items ready for issue from Store	Planner has all items at job and job is ready to do		Only start work once all requirements are gathered together	
2	Contact Operations personnel responsible for plant isolations and handover		Contact Operator when ready to start job	Operator has plant off-line awaiting work	Operator has plant isolated, tagged and drained		Job can only start when Operations safely handover plant and piping	
3	Place personal danger tags at isolation points and accept plant handover after proving isolations and drainage	Danger Tags	Operator and repair man walk circuit and identify and tag isolations and open drains	Operator has isolated plant & tagged isolations out-of-service & drained piping	Operator provides isolation point drawing and walks circuit to show previous tagged isolations and open drains		Only start work when piping is fully drained and proven to be empty and possible gas build-up vented	
4	Release tension on exiting fasteners gradually in tightening sequence and then remove one fastener at a time but leaving the last fastener loosely in place if pipe springs unexpectedly, spring flanges with podgy bar	5/8" ring spanner or socket, anti-seize liquid	Back-off all nuts half a turn in sequence and then a full turn, removing all fasteners but last one. Spring flanges with podgy	Back-off all nuts half a turn in sequence and then a full turn, catch any drops of product from flange in suitable container, remove all fasteners but last one. Spring flanges with podgy	Cover fasteners with anti-seize, back-off nuts half a turn in sequence and then a full turn, catch any drops of product from flange in suitable container, remove every second fastener and finally all fasteners but last one. Spring flanges with podgy		If flange does not spread easily review the situation and consider use of hydraulic spreader or wedges without damaging flange faces	
5	Remove old gasket and clean flange faces, remove any burrs, check face is flat with straight metal ruler and 0.05mm shim in gaps, no draw marks, pits or scratches allowed across flange face	25 mm wide metal scraper, 80 grit emery cloth	Loose material removed, burr-free, flat face, no draw marks or pits deeper than 0.25mm	Grooves clean, face sanded, flat face, no draw marks or pits	Bright, smooth, flat face, no groove damage or pitting, as good as new		Replace or machine flange with identical rating and grade if pits are deep, or are in close clusters, or not flat *(pictures would be necessary)*	

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Step	Task Description	Mat'l - Tools	Tolerance Bands Good	Better	Best	Reading / Result	Action if Out of Tolerance	Sign off
6	Check unrestrained pipe alignment	5/8" ring spanner x 2, or socket and ring spanner	Flanges are unbolted and are in-line to within 2 mm	Flanges unbolted and are in-line to within 1.5 mm	Flanges unbolted and are in-line to within 1 mm		Cut pipe and remount flange to bring unrestrained flanges to within 1 mm alignment and 0.5 mm squareness to applicable procedure for the pipe material and grade	
7	Mount gasket and insert fasteners. Pre-cut studs to length and de-burr so that two full threads protrude out of each nut when fully tightened. Lightly lubricate the studs and the face of the nuts in contact with the flange.	Approved NEW gasket; NEW studs and nuts, bolt lubricant, podgy bar	Gasket slid between flanges and centred without damage and new studs/nuts fitted by hand	Gasket slid between flanges without and centred damage and studs/nuts lightly, pre-lubricated and fitted by hand within 2 minutes	Gasket slid between flanges and centred without damage and studs/nuts lightly, pre-lubricated and fitted by hand within 1 minute			
8	Pull-up fasteners snug tight in cross tightening sequence. Sung means flanges are in firm contact under about 20% of final bolt torque. It is obtained by the full effort of a well-built man pulling on a ring spanner until it can no longer be moved by hand. It can also be achieved by use of an impact wrench. When the spinning nut turns to blows, count three blows, and the bolt will be snug tight*. From HIGH STRENGTH BOLTING By ALAN T. (TED) SHEPPARD, The DuRoss Group, Inc.	5/8" ring spanner or socket, feeler gauges	Wind nuts onto studs by hand so studs extend equal distance either side of flange. Tighten nuts finger tight and check that flanges are parallel to an accuracy of 0.4mm with the feeler gauges. Pull all nuts on both flanges up sung tight in correct sequence.	Wind nuts onto studs by hand so studs extend equal distance either side of flange. Tighten nuts finger tight and check that flanges are parallel to an accuracy of 0.2mm with the feeler gauges. Pull all nuts on both flanges up sung tight in correct sequence within 5 minutes	Wind nuts onto studs by hand so studs extend equal distance either side of flange. Tighten nuts finger tight and check that flanges are parallel to an accuracy of 0.1mm with the feeler gauges. Number the studs in the sequence of tightening. Pull all nuts on both flanges up sung tight in correct sequence within 4 minute		If flanges are not parallel, directly 180° degrees opposite widest part of indicated gap, loosen nuts off one or more turns. Return to segment with gap and tighten until both flanges are in contact with gasket. This is necessary to prevent flange levering over the fulcrum formed by the outer edge of the two raised faces at points in contact with gasket. The restriction will cause exceptionally high flange to gasket clamp loading at this point, with possible damage to gasket, PLUS diverting necessary clamp loading bolt torque energy to correcting alignment on the opposite segment.	
9	Match-mark nut position **on one flange only** with a pencil when all nuts on both flanges are snug.	Pencil	Match-mark the nut and flange	Clearly match mark the nut and flange within 1 minute	Clearly match-mark the nut and flange within 45 seconds			
10	Turn each nut **on one flange only** an extra 1/3 of a turn to final position in cross tightening sequence. Re-tension continuously until all nuts are equally tight. No rotation of stud is permitted while tightening the nut.	5/8" ring spanner or socket, Impact wrench	Tighten nuts 1/4 of a turn in cross sequence and finally tighten nuts to 1/3 of a turn in cross sequence.	Tighten nuts 1/4 of a turn in cross sequence and finally tighten nuts to 1/3 of a turn in cross sequence in 5 minutes.	Tighten nuts 1/4 of a turn in cross sequence and finally tighten nuts to 1/3 of a turn in cross sequence in 4 minutes.		If a stud starts to rotate as the nut is tightened it indicates that the nuts were not snug to start with. Immediately stop and undo all studs and repeat nut snug tensioning procedure	
11	Test flange for leakage at operating pressure, release pressure and retighten nuts on same flange as originally tightened							
12	Safely clean-up, hand-back, complete job record and sign-off Work Order							

NOTE: The example covers the method to use to create a 3T procedure and is not the actual procedure to use when bolting-up flanges. Each organisation must research, develop and approve their safe practices and procedures for bolting flanges. The use of turn-of-nut on pressure flanges may not comply with the applicable pressure piping design codes.

Notice how the procedure specifies the standard and quality that must be achieved on the job. Nothing affecting quality is left to the discretion of the person doing the job. The 3T procedure clearly states the minimum acceptable outcome, called ‘good’, and it clearly states what top-class performance is in the ‘best’ column. Now every one knows what ‘good enough is’ and what ‘the best’ looks like.

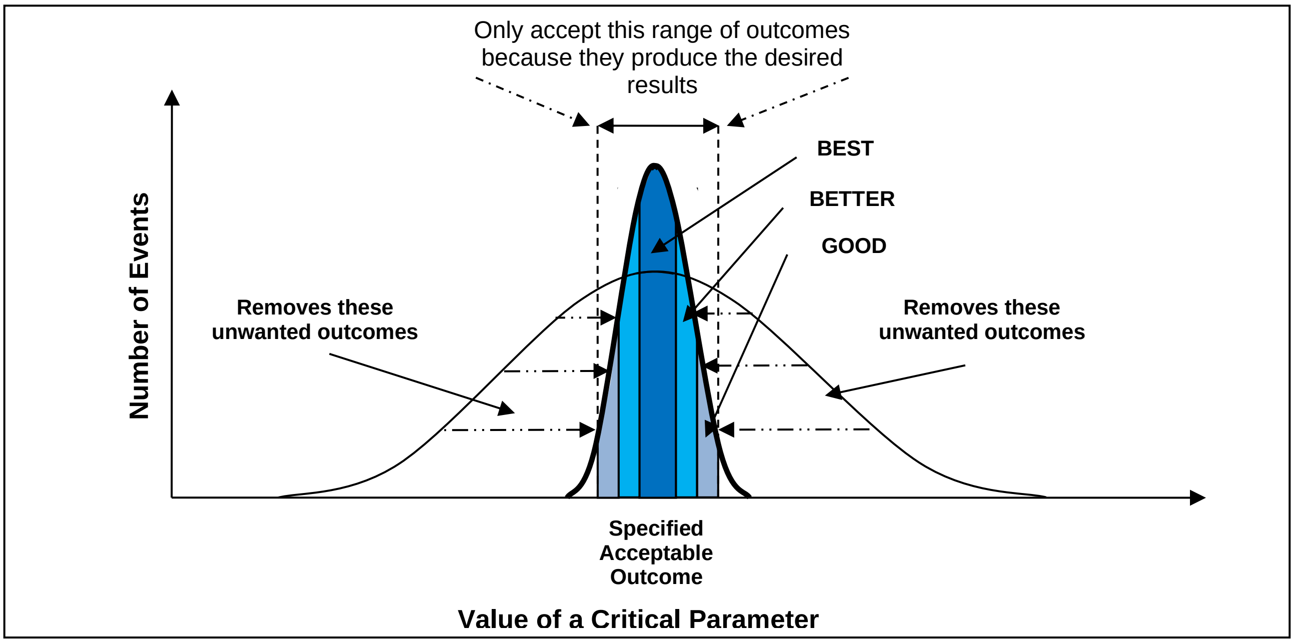

Figure 1 – Controlling Variability in Producing High Work Quality

The ACE 3T approach provides you with a practical and certain way to control work quality regardless of who does the job. Everyone now knows what quality work is and are encouraged to strive for it. A 3T procedure acts to remove variability. It creates statistical control over work processes involving human activity – it prevents human error. You know what a worker will try to do and what they will try to produce. 3T procedures standardize performance and deliver repeatable outcomes. This standardizing and repeatability effect on work quality is shown in Figure 1. Instead of having a wide range of possible results, the 3Ts limit the results to those you specify.

You can get more information on how to write ACE 3T procedures that prevent human error at our website.

My best regards to you,

Mike Sondalini
www.plant-wellness-way.com