Appendix – Summary of PWWEAM Methodology

Plant Wellness Way EAM System-of-Reliability Summary

The Plant Wellness Way is an enterprise asset management methodology based on reliability engineering and risk elimination principles to achieve high-reliability operating equipment.

The PWWEAM produces highly reliable plant and machinery because it identifies how to create individual equipment component health and ensures that the required means and actions are done. When machine parts work at least material-of-construction stresses, they reach their highest reliability, and the equipment is reliable for its entire service life. The board room decision to use the Plant Wellness Way as a company's asset management methodology ensures that its business processes and reliability practices will create and sustain operational and maintenance success. The Plant Wellness Way identifies and removes operational risk to get the utmost equipment reliability, plant availability, and asset utilization while safely minimizing production unit cost. The proprietary six-step IONICS methodology used in the Plant Wellness Way eliminates risks and puts reliability success into life-cycle processes. The best solutions become standard operating practice, and your people are trained to use and implement them correctly.

Overview of the Six IONICS Processes

IONICS is a set of six processes: **I**dentify risks, **O**rder risks by criticality, **N**egate component risk solutions, **I**nstall risk controls, **C**ultivate chance of process success, and **S**ynthesize new ideas. Each step has a custom logic tree to follow. The IONICS processes combine into the PWWEAM methodology sequence shown in Figure A.1. IONICS is used to develop the life-cycle asset management, operational, and maintenance management strategies and activities needed for world-class operating plant and business process reliability.

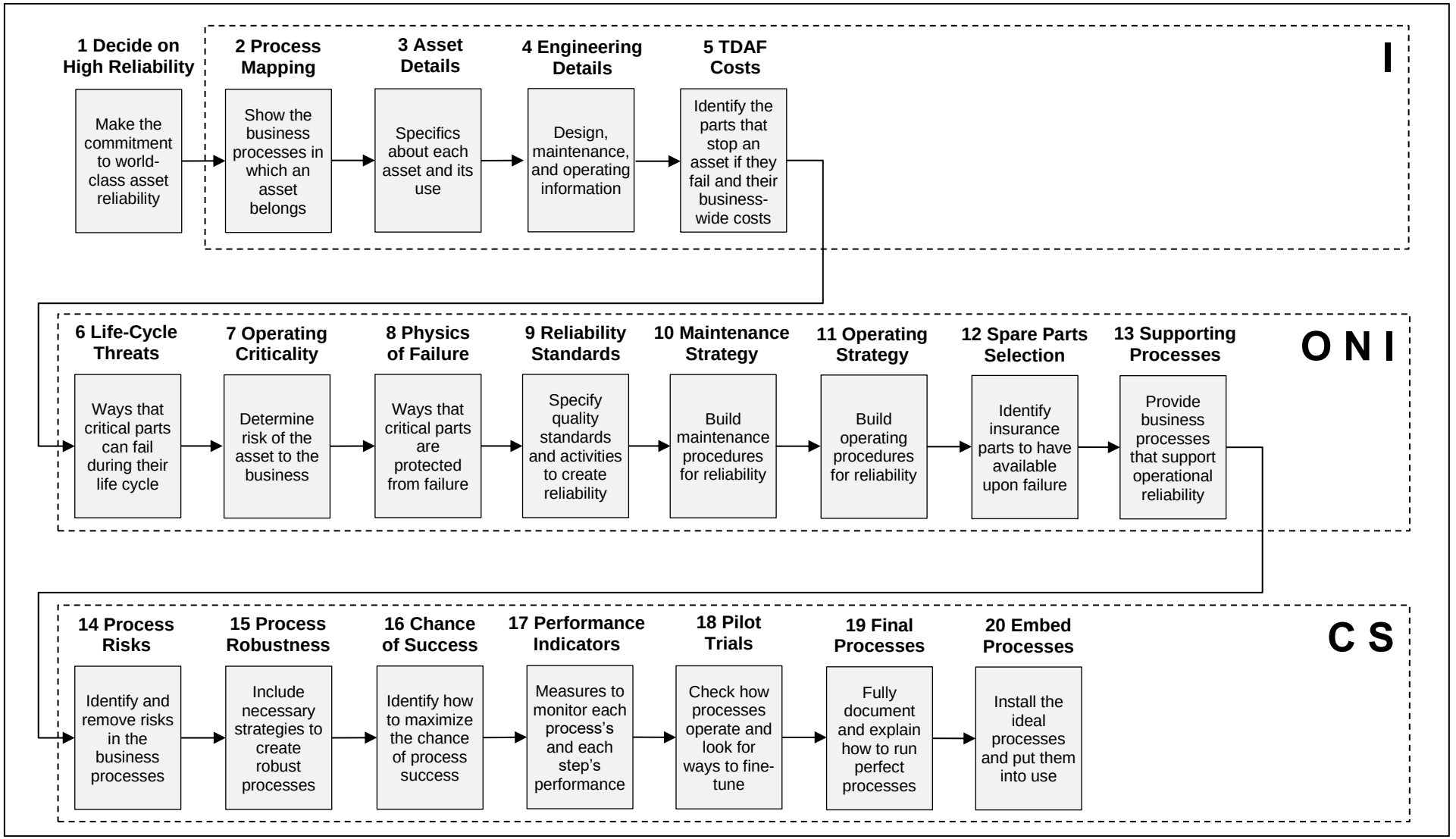

Figure A.1—The Plant Wellness Way Methodology Six Step IONICS Process Map

The IONICS process steps detailed in the book are summarized next to provide a quick reference for users of the Plant Wellness Way system of reliability methodology.

1. Decide That You Want World-Class Reliability

The board and senior executives of an organization publicly state their personal commitment to achieving world-class reliability and allocate sufficient funds and resources to achieve it.

2. Process Map of Business Process to Work Levels

Map the company as it is today from high-level business operations right down to the procedures performed in the workplace. Draw workflows across the page, adding summary procedures below a step and noting all its required outputs above the step. For each output specify its ideal range of quality values.

3. Asset Lifetime Details

Describe each operating asset and understand its required duty and service life.

- Tag or equipment number
- Asset description
- Asset criticality (highest rating from asset criticality step)
- Asset location
- Asset purpose and required operational output(s)
- Installed new or second-hand? If second-hand, where was it used prior to this operation?
- Date installed in the operation

- Frequency of use during current service life
- Subassemblies (children)
- Subassemblies' tag or equipment numbers (if used)
- Subassemblies' descriptions
- History of failures for this asset
    - At the operating site (list failures by date in a spreadsheet)
    - Types of failures that similar assets experience in the industry (list in a separate spreadsheet)

Asset Failure Frequency Distribution

- Create a failure run chart for the asset over its entire service life to date. Whenever possible, identify the cause(s) of each failure event. You may need to look at the operating history in logbooks and shift logs or the maintenance history in the CMMS and even conduct interviews with knowledgeable operations and maintenance personnel.
- Develop the asset failure event frequency distribution curve from failure history timeline.
- Identify which failure types and/or causes occur too often.

4. Asset Engineering Design, Drawings, Manuals, and Parts Lists

It is necessary to fully understand the construction, use, and correct performance of equipment at tits design engineering level. Gather all the technical, maintenance, and operational information about the asset, such as equipment manufacturer's information, manuals, drawings, and so on.

Collect these details for each asset:

- Service duty when in use
- Design data (e.g., maximum/minimum pressures(s), maximum/minimum flow(s), maximum/minimum temperature(s), maximum/minimum hours of operation)
- Operating and maintenance manuals
- General assembly drawings
- All subassemblies
- All parts
- All parts' materials of construction

5. Identify All Critical Parts and Their TDAF Costs

Identify the parts in an asset whose failure would stop a critical assembly from operating—these are called *critical parts.* They are often the working parts, or the moving parts, in the asset. They can also be the structural components and/or the fastening components.

When critical parts fail, there can be catastrophic consequences to the business. Determine the business wide TDAF costs of their failure to see how disastrous a breakdown would be to the organization. Record this information in the Operating Criticality Analysis spreadsheet.

- Identify on the bill of materials parts whose failure would cause adverse production impacts.
- Estimate the TDAF costs for each part's failure.

6. Critical Part Life-Cycle Threats

When a part can fail, it is necessary to explore what events across its life cycle could happen and become the root causes of a failure.

Answer the Eight Life-Cycle Questions

In the Physics of Failure Factors Analysis spreadsheet (see Chapter 11), answer the eight Life-Cycle Questions for each critical part.

You want to gain a solid understanding of the opportunities and situations in which critical parts can fail and the circumstances that lead to a component's failure.

For each critical part, identify if it can be failed from the following:

- Early-life failures occurring from situations such as
  - Manufacturing error and failure-inducing manufacturing methods
  - Human error during assembly or rebuild
  - Human error during installation
  - Human error during commissioning
- Random events, including
  - Failure inducing manufacturing process methods
  - Extreme stress events
  - Cumulative stress events
  - Acts of God or natural events
- Failures from asset use (e.g., filters blocked, brake pads worn out, etc.)
  - Causes of a part's failure during operation

  - Hours of operation, number of times used, and/or production throughput between failure events
- Potential and extent of material-of-construction fatigue
- Potential and extent of material-of-construction wear-out (aging)
- Degradation by damaging substances in the contacting environment

Do a Physics of Failure Factors Analysis to identify all the failures that could happen to each critical part, along with each of its cause mechanisms. In a POFFA, you identify all the failure mechanisms from throughout a critical part's life cycle that cause risk of stress or structural harm.

- Use the Physics of Failure Factors guideword list (see Chapter 11) to identify events that could fail microstructures from deformation, fatigue, degradation, or damaging environments.
- Indicate all life-cycle phases during which each failure event cause could happen.

The POFFA is done at this point to prove that there truly are risks throughout your business that can cause your plant and equipment to fail. If a company is to achieve world-class reliability, it must remove all dangers and risks to the reliability of its plant and equipment.

7. Asset Operating Criticality

Conduct an Operational Criticality Analysis to identify the severity of business risk from a failure of each critical part in an asset. Determine Criticality 1 and Criticality 2 values for all critical parts. Use a separate spreadsheet for each production process used.

- Do risk analysis based on ISO 31000 Risk Management Guidelines or equivalent.

- Calibrate the risk matrix and clarify the location of the low risk level and other levels, including a region of "accepted" risk.
- Ensure that the company's risk matrix consequence categories are financially equivalent for the various risk event types and properly applies $\log_{10}$-$\log_{10}$ math.
- Expand the risk matrix into at least a 16 x 13 $\log_{10}$-$\log_{10}$ layout. It is preferable to use a fine scale for the axes so that movements in risk can be seen clearly.
- Make an estimate of the frequency of POFFA events occurring using the likelihood scale of the risk matrix.
- Develop an "operating risk window" on the risk matrix from worst possible impact event to least impact event. Consider the range of business impacts from its failure, including safety, financial, environmental, operational, and so on.
    - Use TDAF costs of each event in the criticality analysis.
    - Include downtime from each event (least to maximum duration).
    - Include "acts of God" when such are possible (e.g., lightening, flood, earthquake, tornado, etc.)
- Take into consideration the consequential impacts of an asset's failure
    - What else stops when the asset fails?
    - Would subsequent harm also occur to personnel, environment, next-door sites, etc?
    - What redundancy exists for the asset?
    - What is the time needed to supply failed parts once an order is placed?

Subassembly Criticality

Because of the size and complexity of an asset, it may be necessary to investigate its subassemblies separately.

- Repeat the costing for each of the subassemblies (children) when a failure could stop an asset's operation.

8. Physics of Failure Reliability Strategy Analysis

Complete a Physics of Failure Reliability Strategy Analysis for those parts that carry unacceptable operating risk from failure. The aim is to prevent all risk and defect creation events from occurring throughout a component's lifetime. Select effective risk controls and mitigations for each failure mechanism using the Physics of Failure Reliability Strategy selection spreadsheet (included in the spreadsheets accompanying this book).

- Complete the asset details in the Physics of Failure Reliability Strategy spreadsheet.
- Transfer all POFFA critical parts and their cause mechanisms into the spreadsheet.
- Determine suitable life-cycle strategies to eliminate or prevent each mechanism from arising.
- Indicate all the life-cycle phases during which the risk mitigations are to be used.

9. Specify Reliability Standards by Equipment Part

Identifying what can be done to achieve maximum reliability for a machinery part's operating life requires defining precision zones of outstandingly reliable operation for each critical component using the precision maintenance criteria listed in Table A.1. To tailor probability in your favour set 3T (target, tolerance, test) quality values for each criterion listed. Extend the list to include all engineering, maintenance, and operating criteria needed to address the POFFA mechanisms. Although this list applies to mechanical equipment, the setting of quality requirements is a

universal principle that applies to all other types of physical assets and their components, including structural, civil, electrical, and electronic items. For all assets you need to set and determine all the quality values that bring them long, trouble-free service lives

Item	Description	3T Quality Criteria
1	Accurate fit and tolerance at operating temperature	Target: Tolerance: Test:
2	Impeccably clean, contaminant-free lubricant for the entire lifetime	Target: Tolerance: Test:
3	Distortion-free equipment for the entire lifetime	Target: Tolerance: Test:
4	Shafts, couplings, and bearings running true to centre	Target: Tolerance: Test:
5	Forces and loads into rigid mounts and supports	Target: Tolerance: Test:
6	Collinear alignment of shafts at operating temperature	Target: Tolerance: Test:
7	High-quality balancing of rotating parts	Target: Tolerance: Test:
8	Low total machine vibration	Target: Tolerance: Test:
9	Correct torques and tensions in all components	Target: Tolerance: Test:
10	Correct tools in the condition to do the task precisely	Target:

		Tolerance: Test:
11	Only in-specification parts	Target: Tolerance: Test:

Table A.1—Necessary Health Conditions for Mechanical Parts

You want a critical part to always remain within its reliability precision zone by selecting the appropriate quality standards for engineering, maintenance, and operating activities and practices. The standards let you monitor actual behaviour during equipment manufacture, installation and use to ensure that a component suffers the least stress possible in every situation across its lifetime.

- A target value (ideally, this is world-class performance, or at least a magnitude better performance than average performance).
- A tolerance range (for physical assets the minimum value is that specified by the original equipment manufacturer in its manuals).
- A challenging “stretch” value set between minimum and world-class performance dividing the tolerance range into three clearly identifiable zones.

In the case of dimensions, instead of specifying each part’s specific tolerance values, you can use International Tolerance Grades, which automatically allow for changes in component size and distance.

The activities needed to achieve and sustain the quality standards that maximize the reliability of a critical part become the operating, maintenance, and reliability strategies adopted

for the component during its lifetime. The sum of an equipment's parts reliability strategies become the asset's life-cycle management strategy. All strategies and how they are to be achieved will be fully explained in the asset's engineering, operating, maintenance, and reliability procedures and relevant documents.

Reliability Growth Cause Analysis

The RGCA technique is a detailed reliability strategy selection, analysis, and cost–benefit justification for the tasks used to make a part survive to maximum service life.

10. Maintenance and Installation Parts Deformation Management

The requirements are to have all equipment parts in their least-stress, full-health condition during operation and to sustain those conditions throughout the equipment's service life. The life-cycle microstructure risks for each critical part identified in the Physics of Failure Reliability Strategy spreadsheet are now addressed with truly useful maintenance activities. Where statutory laws and regulations apply to an asset, such as cranes, pressure vessels, lifts, and so on, include the necessary maintenance requirements in an additional column in the spreadsheet.

- For each critical part, identify
  - Necessary health conditions for the part (e.g., precision tolerance range, temperature range, moisture/humidity range, etc.); the information identified in response to the list of 3T quality parameters required in Table A.1 will satisfy this requirement
  - Necessary health conditions of neighbouring parts in contact (e.g., surface finish, temperature range, etc.)
  - Likelihood that the health conditions will be achieved during installation

  - Likelihood that the health conditions will be sustained during operation
  - Installation and maintenance opportunities that could arise to cause deformation (e.g., installation during construction, overhaul during service life, major failure requiring rebuild, etc.)
  - Frequency with which the identified installation and maintenance opportunities for deformation will arise
- Check the Physics of Failure guidewords to confirm that all situations are identified and covered by a suitable and effective strategy for the part and for its neighbours.

Develop Maintenance Procedures

For each critical part, put the required controls for every cause of deformation into a written ACE 3T maintenance procedure to create a component with low stress in a healthy environment.

In time, a library of procedures for component health will accumulate that can be used repeatedly in future for assets where critical parts suffer the same situations and threats of failure.

Identify Work-Around upon Failure

When there are means to minimize production impact of an asset's failure, like redundancy, hiring of mobile equipment, transfer of production to another line, etc., list and explain the option(s).

11. Operating Strategy Parts Degradation Management

The requirement is to have all equipment critical parts in their least-stress condition during operation and to sustain those conditions throughout the equipment's service life. Develop

standards for operation of plant and equipment to ensure workplace safety and the long service life of parts in the Physics of Failure Reliability Strategy spreadsheet.

- For each critical part, address
  - Necessary operating conditions for the part (e.g., operating pressure range, operating temperature range, operating moisture/humidity range, etc.)
  - Likelihood that the operating conditions will always be achieved
  - Likelihood that the operating conditions will be sustained during service life
  - Operating opportunities that could rise to cause degradation (e.g., change-overs, process disruptions, poor raw material, contamination, etc.)
  - Frequency with which the identified operating opportunities for degradation will arise

- Check the Physics of Failure guidewords to confirm that all situations are identified and covered by a suitable and effective strategy.

Develop ACE 3T Standard Operating Procedures

For each critical part, put the required controls needed for each cause of degradation into a written ACE 3T operating procedure to create a component with low stress in a healthy environment.

Identify Work-Around upon Failure

When there are means to minimize the production impact of an asset's failure, list and explain the options(s), such as redundancy, hiring of mobile equipment, transfer of production to another line, and so on.

12. Spares Selection by Part

The spare parts that must be speedily available are chosen based on the operational risk from a part's failure. Develop answers for each critical part in the Physics of Failure Reliability Strategy spreadsheet.

- Determine the TDAF cost consequence of a critical part's failure, allowing for any work-around available to the organization
- Determine the frequency of a critical part's failure:
  - In the operation
  - In the industry
- Allow time for the supplier to deliver replacement parts when ordered
- Determine the resulting risk reduction if a part is available in a timely manner.

13. Supporting Business Processes

Use the Stress-to-Process Model to identify who must be involved throughout the organization to ensure the integrity and security of the asset and its critical parts for both degradation management and deformation management during the following:

1) Design selection
2) Manufacturing
3) Procurement and delivery
4) Initial installation
5) Throughout its service life
6) Decommissioning and disposal

Set the responsibilities for doing all Physics of Failure Reliability Strategy actions. This requires identifying who will do the work of delivering the reliability strategy. For each critical part's reliability strategy, specify the following:

- Skill set and minimum competence required
- Role(s) or function(s) that will do the work
- Organizational department owning the work

Identify all the documents that contain each of the life-cycle strategies, actions, and monitoring (e.g., procedure, work instruction, duty statement, etc.) so that ownership of responsibilities is clearly allocated. The same reliability creation information can be required to reside in more than one document.

Design and Operations Costs Totally Optimized Risk (DOCTOR)

The DOCTOR business risk assessment is to be immediately introduced into all capital projects and plant change projects.

14. Risk Analysis of Supporting Business Processes

Check to see what risk situations, scenarios, and events could arise in all business processes that impact the life cycle to cause the failure of any critical parts in an asset.

Put the process steps across the top of a spreadsheet, and for each step, do a risk analysis focused on how a step could cause plant and equipment parts to fail. In the analysis, address the risks in each business process and its individual steps affecting the following:

- A complete asset
- Subassemblies
- Parts and components
- Work procedures

15. Build Process Robustness

Once potential problems are identified, Three-Factor Risk Analysis strategies are selected to substantially reduce the risks and mapped onto a risk matrix to confirm that the risk reduction will occur. All means to make processes antifragile and robust are developed and incorporated into business process and procedures.

Consider applying the following techniques:

- Consequence reduction strategies
- Opportunity reduction strategies
- Uncertainty reduction strategies
- Improvement of component robustness and reliability
- Parallel tasks (application of the Carpenter's Creed, "measure twice, cut once")
- 3T (Target-Tolerance-Test) error-proof activities
- Mistake-proof techniques included in the process design

16. Chance of Success Analysis for Processes

Once a process is designed, you can simulate and test how well it will work. A business process has risks of failure in each process step. Identify what can prevent a process step from being completed correctly. Possible problems that arise in each process step are recorded, and a value of the chance of a problem's occurrence is determined from historical data. Processes that have an unacceptable chance of not working well are weak processes and must be redesigned to be much more effective.

For each process develop a flowchart showing all its steps across the top of a spreadsheet. For the process,

- Explain and define the purpose of each step
  - Describe the procedure for doing the step
  - Specify the correct step inputs using 3T format
  - Specify the correct step output using 3T format
- Identify problems and weaknesses in each process step through the use of risk analysis
- Make probability estimates of each existing process step's low and high chance of success
- Calculate the whole current process's low and high chance of success
- Propose how to resolve unacceptably weak process steps
  - Introduce 3T controls
  - Introduce redundancies
  - Introduce effective technology
  - Redesign the step with a more effective procedure

- Make low and high probability estimates of each redesigned process step's chance of success
- Calculate the redesigned process's low and high chance of success
- Continue developing solutions for weak processes until the low chance of success for the whole process is adequately high

17. Performance Indicators

The effectiveness of a process is seen in its results. Develop measures to monitor your processes and workplace activities. Embed the data collection and report generation into relevant procedures.

- Establish process step Performance Indicators for self-monitoring by the step "owner"
  - Monitor inputs
  - Monitor outputs
  - Establish frequency distribution curves of step monitoring PIs
- Establish process outcome KPIs for regular senior management monitoring
- Establish frequency distribution curves of senior management KPIs
- Monitor performance with a useful mix of
  - Leading indicators
  - Lagging indicators
  - Process distribution curves
- Cascade measures across departments and roles if necessary to understand the process behaviour

Continuous Improvement

To keep moving a company forward, keep moving the required performance ever higher toward the pinnacle of excellence by making the ACE 3T standards ever more demanding.

18. Pilot Test Trials

A new process is designed to what seems like a suitable degree of outcome certainty. Before changing an entire business to the new process, it needs to be tested in the workplace to be sure that it is effective. A Change to Win project can be used to involve the users of the new process and get their input and buy-in. The learning from the trial is put back into the process design to make changes and refinements that improve its chance of success when implemented in the company.

19. Document the Final Process Designs

Specify and define the complete process and all its procedures in total detail to ensure process control and capability.

For each process,

- Map each level, from top overview down to the shop floor, in the detail needed to get the desired success rate.
- Establish procedures, including detailed instructions when risks in process steps justify the need to be meticulous.
- Incorporate 3T quality assurance.
- Identify each process step “owner” who has ultimate responsibility to do the step correctly.

- Identify each process step “buddy” when people are put in parallel for better process reliability.

20. Embed the Final Processes

Prior to putting the final process design into use, everyone impacted by the new process needs appropriate levels of training and practice. The people working in the new process need to be competent to do their new roles before the process is implemented. Becoming proficient requires both the education and understanding of what is to be done, as well as the practical skills to ably do the role.

The final action is to run the process in its entirety and monitor whether individual steps are delivering the required performance results. When problems arise, look at the step distributions to identify the causes of excessive variation and fix the process design.

Physics of Failure Deformation–Degradation Analysis

An alternative way to use the Physics of Failure Factors to identify how component microstructures fail is shown in Table A.2: Deformation–Degradation Analysis (Def-Deg Analysis). In this approach, the event and condition guidewords are used to answer questions about how stress, fatigue, and degradation can occur for a part. The solutions to prevent the causes and create exceptional equipment reliability are your reliability strategy, after which you make plans to put them into use at the right points in the life cycle.

The aim of a Physics of Failure Deformation–Degradation Analysis is to identify the physical reasons that a critical equipment part can fail and, for each cause, determine what actions and practices will prevent the failure. For each critical part, ask three Physics of Failure questions to find the incidents that destroy the atomic structure:

1. How can the part's microstructure be overstressed?
2. How can the part's microstructure be fatigued?
3. How can the part's microstructure be degraded?

Physics of Failure Deformation–Degredation Analysis for a Gearbox Drive Pinion																	
			Part Identification			Physics of Failure Causes (See Guidewords List)											
Item	Equipment No.	Equipment Description	Equipment Assembly Description	Part No.	Part Description	How Can the Part's Atomic Structure Be Overstressed?	POF Causes of Each Atomic Overstress	Methods to Prevent POF Overstresses		What Human and Business Factors Can Cause the Overstress?		How Can the Part's Atomic Structure Be Fatigued?	What Can Cause the Fatigue?	Methods to Prevent Fatigue	How Can the Part's Atomic Structure Be Degraded?	What Can Cause the Degradation?	Methods to Prevent Degradation
								In Manufacture	*In Operation*	*Human Factors*	*Business Processes*						
1	GBX001	Conveyor drive gear-motor	Gearbox	301	Pinion	Load in extremely small area	Bent shaft	Prove shaft straightness		Install out-of-spec part, part installed wrongly	Make no QA checks	Excess fluctuating force	Fluctuating operating load		Attack metallurgical elements	Corrosion	
							Bent teeth	Prove teeth form		Install out-of-spec part	Make no QA checks		Bent shaft			Water in lubricant	
							Chipped teeth	Replace with new		Install out-of-spec part	Make no QA checks		Bent teeth			Corrosive chemical	
							Jammed solid	Remove solids			Allow contaminated lube		Misshapen tooth form				
							Running metal to metal	Lubricant separation			Allow degraded lube		Jammed solid				
							Expansion from high temperature		Keep within design envelope	Run equipment above design	No operating standards		Flexing of neighboring components		Wear material away	Running metal to metal	
							Misshapen tooth	Prove teeth form		Install out-of-spec part	Make no QA checks		Flexing housing			Solids in lubricant	
													Flexing mounting				
						Crack in surface	Forging residue	Prove manufacturing QA			Make no QA checks		Soft foot distortion				
							Casting inclusion	Prove manufacturing QA			Make no QA checks						
							Casting cavity	Prove manufacturing QA			Make no QA checks	Rubbing contact	Bent shaft				
							Machining mark	Prove manufacturing QA		Install out-of-spec part	Make no QA checks		Bent teeth				
							Jammed solid	Remove solids			Allow contaminated lube		Misshapen tooth form				
							Weak metallurgical structure	Prove material selection			Make no QA checks		Low lubricant viscosity				
							Corrosion pit		Replace with new	Install out-of-spec part	Make no QA checks						
						High-impact force on area	Jammed solid	Remove solids									
							Excessive start-up		Limit start-up load	Start-up under full load	No operating standards						
							Cumulative forces (misalignment, out-of-balance, soft foot)	Prove precision assembly and installation engineering standards are achieved		Install outside precision standards	Make no QA checks						
							Induced vibration	Remove causes of induced vibration		Install outside precision standards							
							Soft foot distortion	Prove equipment bases and base plates are flat to the manufacturer's standard		Install outside precision standards	Make no QA checks						
							Hammered		Replace with new pinion	Hit with hard object, dropped a distance	Make no QA checks						
				305	Helical gear wheel												

Table A.2—Physics of Failure Deformation–Degradation Analysis for a Gearbox Drive Pinion