Chapter 14: IONICS Process 3—Negate Component Risk Solutions

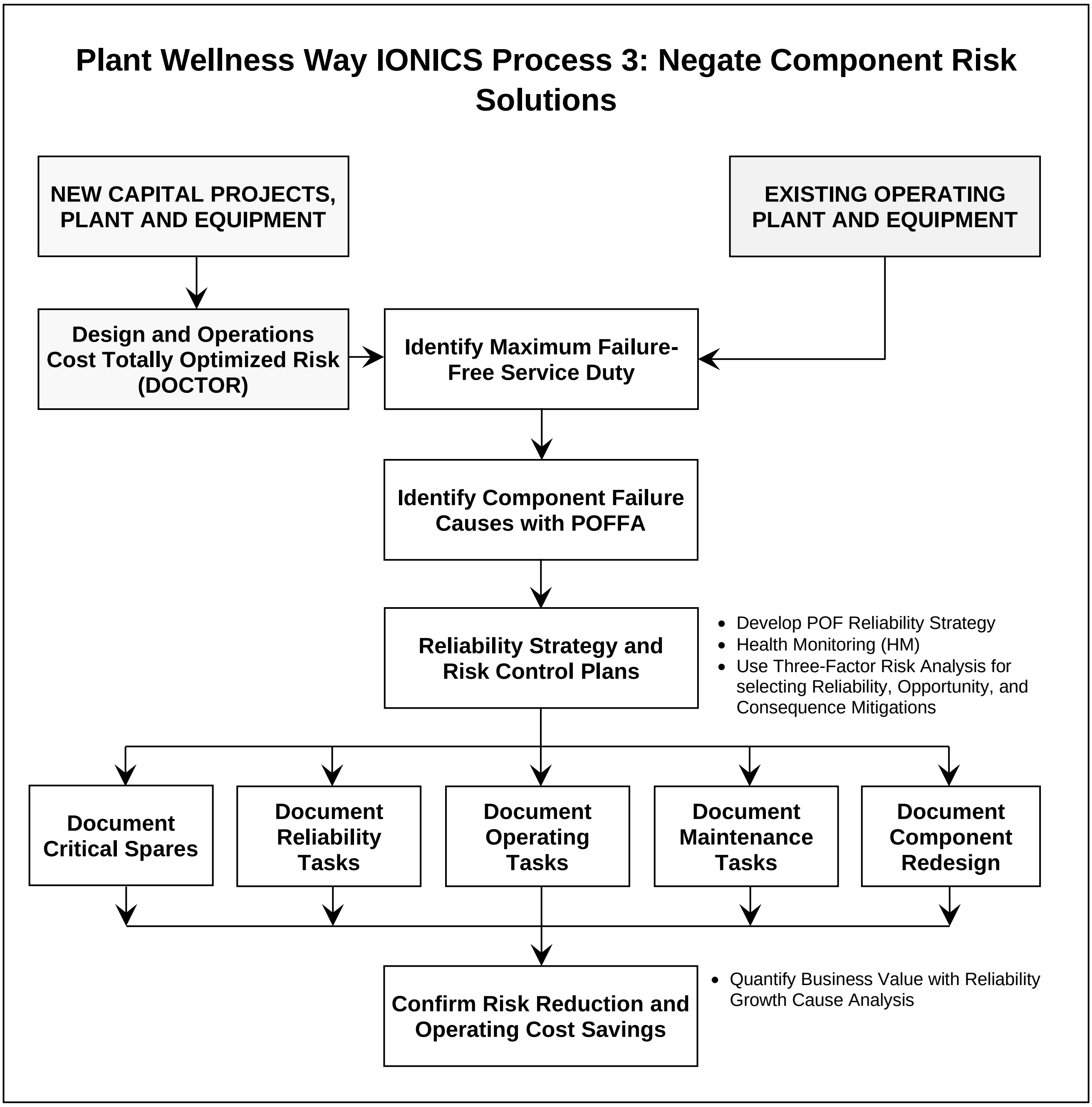


Figure 14.1—IONICS Process 3 Steps

Summary Description of Process 3: Select Risk Control Strategy

The operating risk control strategies you use or do not use directly impact your plant reliability and operating costs. Adding maintenance routines to control risks causes maintenance costs to rise. The added maintenance is beneficial only if it brings more operating profit. Burdening your company with extra maintenance because of poor capital project engineering selections adds still more operating costs. Running and maintaining plant and equipment in ways that destroy their reliability causes breakdowns and huge TDAF losses. To maximize operating profit, it is essential to apply a life-cycle asset management methodology that produces effective engineering, operations, and maintenance plans and actions that guarantee operating success. The Plant Wellness Way uses Physics of Failure Reliability Strategy selection and Reliability Growth Cause Analysis to design a reliability-creation strategy and prove that it will get world-class reliability and utmost operating profits.

Select Operating Risk Control Options in Projects

Design and Operations Cost Totally Optimized Risk (DOCTOR) analysis (see Chapter 7) is used for all capital projects or plant upgrades to maximize future operating profits. It slashes operating costs by letting project designers, managers and engineers eliminate and reduce operating risks when making equipment and design choices.

Set Equipment Lifetime Reliability Targets

Zero breakdowns during the service lifetime of your equipment is what you want. Determine and set the breakdown-free equipment service life you need. This does not mean there will be no maintenance—rather, your maintenance and operating strategies will change to ensure that parts' microstructures operate at least stress conditions and in healthy environments in which failures cannot happen. If an unwanted failure has initiated, it is identified and corrected so that equipment does not break down.

Identify Causes of Failure Using Physics of Failure Factors

You go deep into the detail of what causes equipment component failures in your operation to find and understand the failure cause mechanisms at play. Once you understand the events starting a failure, you're better able to select solutions to eliminate its root causes. You identify all possible microstructure destruction mechanisms and their causes using Physics of Failure Factors Analysis (POFFA) so that you know which situations that lead to a part's failure to remove or prevent.

Select Reliability Strategy for Operating Plant

Operating sites that want long reliability and low costs need to eliminate the reasons for poor reliability and high costs. Useful maintenance tasks are those that stop risks from becoming failures. The very best maintenance activities are those that remove the opportunity for failure—those that prevent the cause of failure so that events cannot arise, and consequences cannot occur. Once failure causes are identified using POFFA, you complete a Physics of Failure Reliability Strategy Analysis to select component design, manufacturing, supply chain, operating, maintenance, reengineering, and defect elimination strategies to use across the life cycle. To get a fuller appreciation of the reliability-creation choices, you can use a Three-Factor Risk Analysis to investigate and select the most effective opportunity elimination, reliability improvement, and consequence reduction strategies.

Document Your Plant and Equipment Risk Management Strategy and Plans

The entire Physics of Failure Reliability Strategy strategic asset management plan is written into the operation's processes, all applicable procedural documents company-wide, and work orders established in its computerized maintenance management system.

Confirm Extent of Risk Reduction Using Reliability Growth Cause Analysis

It can be 12 to 18 months before the effect of new reliability improvement strategies reduces the failure frequency so that savings show up in monthly reports. You need a way to check that your proposed strategies will remove—or at least substantially reduce—the risk of each failure. Reliability Growth Cause Analysis proves that your equipment reliability strategies will create reliability and deliver least operating costs before you implement them by using a risk matrix or financial calculation to show the expected reduction in risk.

Plant Wellness Way Risk Elimination and Reliability Methodology

Use the following approach to develop effective asset life cycle and operating risk reduction activities to create reliability.

How to Conduct a Physics of Failure Reliability Strategy Analysis

A Physics of Failure Reliability Strategy Analysis provides you with a structured methodology to select and place successful risk elimination and controls in the equipment life cycle. With it, you identify which parts fail, how they are failed, and where the chance of failure arises during their lifetimes.

For each part, a full range of engineering quality control standards are set for all Physics of Failure mechanisms that destroy its reliability—flatness, roundness, straightness, hardness, surface finish, porosity, cleanliness, fastener tension, fits and tolerances, lubricant condition, operating practices, installation requirements, and all other causes of Physics of Failure risk to the component—so they are within the range that brings a healthy, long-lived service life. The suite of quality standards defines the component precision operating zone for its entire lifetime. All Physics of Failure risks throughout the component life cycle are either eliminated or addressed and controlled to a level of risk that brings the parent equipment's total risk to within the "Accept" range on the risk matrix or represents no more than one failure of the parent equipment in a period equal to three times its service life.

Those parts with risks from wear-out and usage are put on preventive maintenance routines where the item is changed, or returned to its precision zone standards, when quality requirements exceed the allowed tolerance. Those parts that suffer risk from random failure events, typically because of high imposed stresses, go on a predictive maintenance condition monitoring plan to check for changed conditions away from the required precision standards. When an item's condition is beyond tolerance it is rectified back to its precision standards before failure initiation. For those parts that can suffer infant mortality and be destroyed by human error, error-proof engineering, operating, and maintenance procedures are written to achieve top-class results in all life cycle processes impacting the part's life. In the procedures, the applicable precision quality standards are specified, and the work quality controls, and proof tests needed to get components into their precision zones are set. Equipment overloads and process variables causing microstructure degradation are monitored when the plant operates, and every out of tolerance incident, along with its duration and the operating conditions at the time, are recorded for analysis to identify how to keep the equipment operating stably within its design envelope.

Identifying Critical Components

An Operating Criticality Analysis exposes the risks of equipment breakdown from component failure. Those parts for which the risk is too high are the equipment's critical parts—the components that must never fail during the service life. Later, you will develop strategies to prevent their failure. An example of an analysis to determine whether a part is critical follows. Figure 14.2 shows a roller bearing on a shaft. The item's components are identified using a "design logic" process map (also called a reliability block diagram) of the assembly. In Figure 14.3, a portion of the bearing assembly mounted on the shaft is drawn as a reliability block diagram mimicking its logical sequence of operation.

Figure 14.2—Ball Bearing and Shaft Assembly

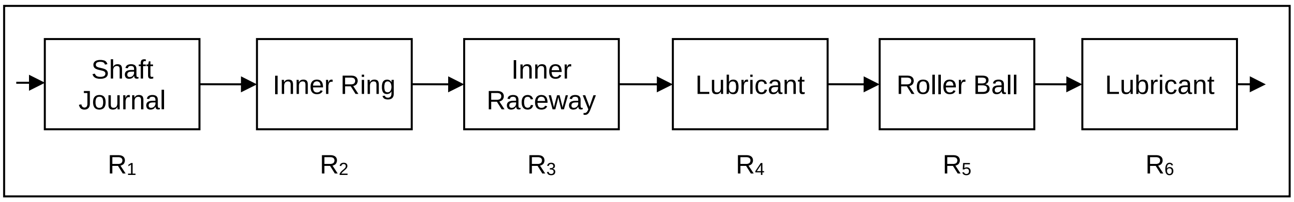


Figure 14.3—Process Map for Roller Bearing on Shaft

The flowchart shows that each part is critical because each item is part of a series arrangement. The loss of any part, such as the failed raceway in Figure 14.4, will cause the roller bearing to fail and the equipment to stop.

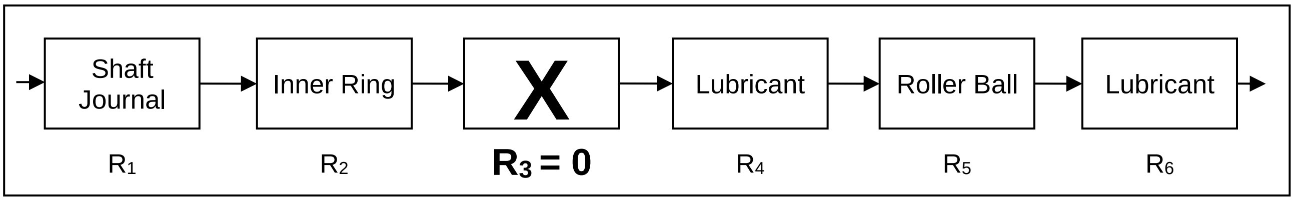


Figure 14.4—Process Map with Roller Bearing Raceway Failure

If you know the engineering of an equipment item, it may not be necessary to draw process maps for assemblies containing only a few parts, as the manufacturer's assembly drawings can be viewed directly and the critical parts identified by sight—the bearings, rubbing shaft seals, gears, and drive components taking start-up and operating loads are typical examples of critical parts. For more complex assemblies, the manufacturer’s drawings will not explain how the equipment works as an operating construction, and you will need to develop process maps. For example, it is impossible to be certain from the drawing how the parts in the gearbox shown on the exploded general assembly in Figure 14.5 interact when the gearbox is put together.

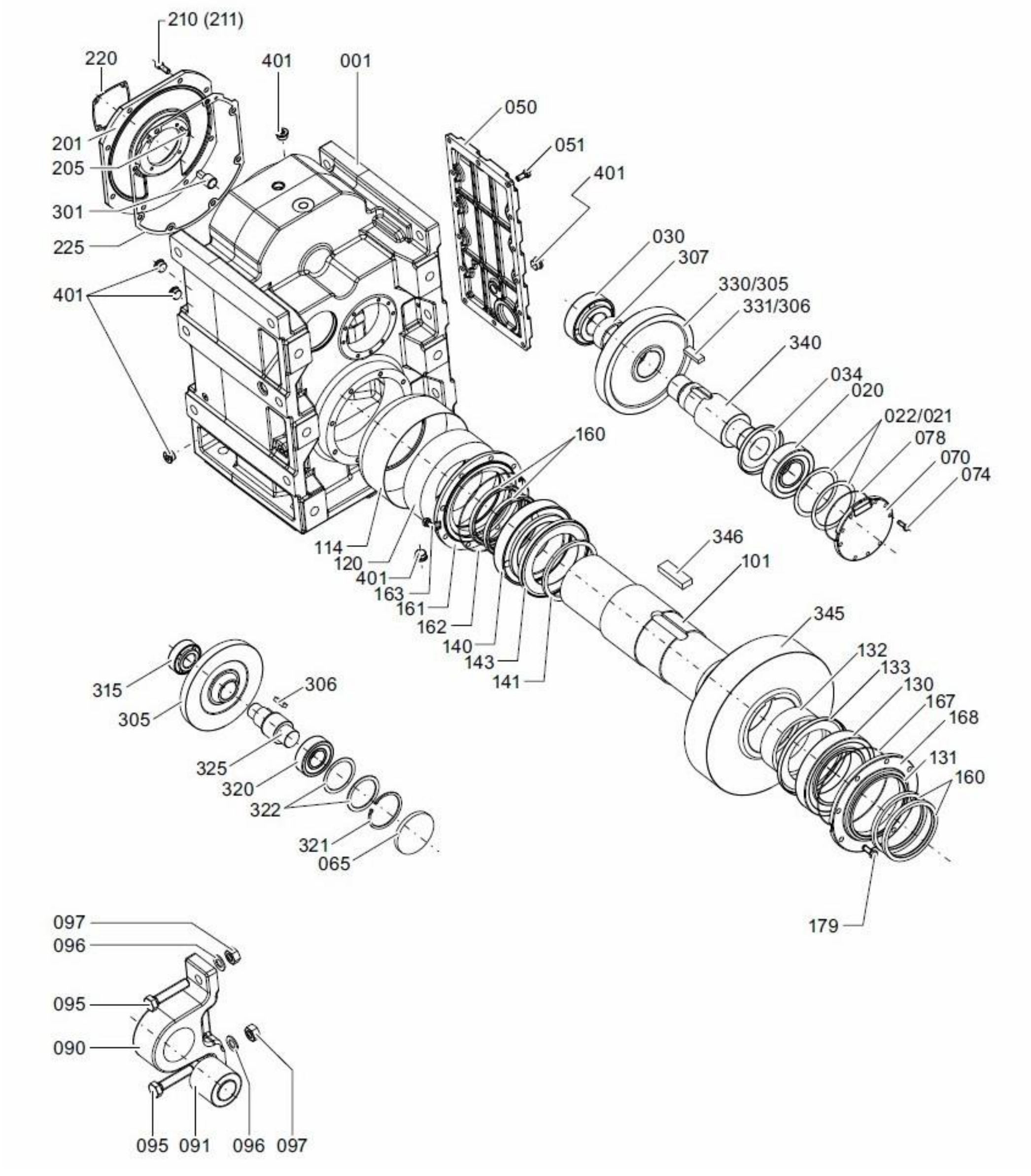
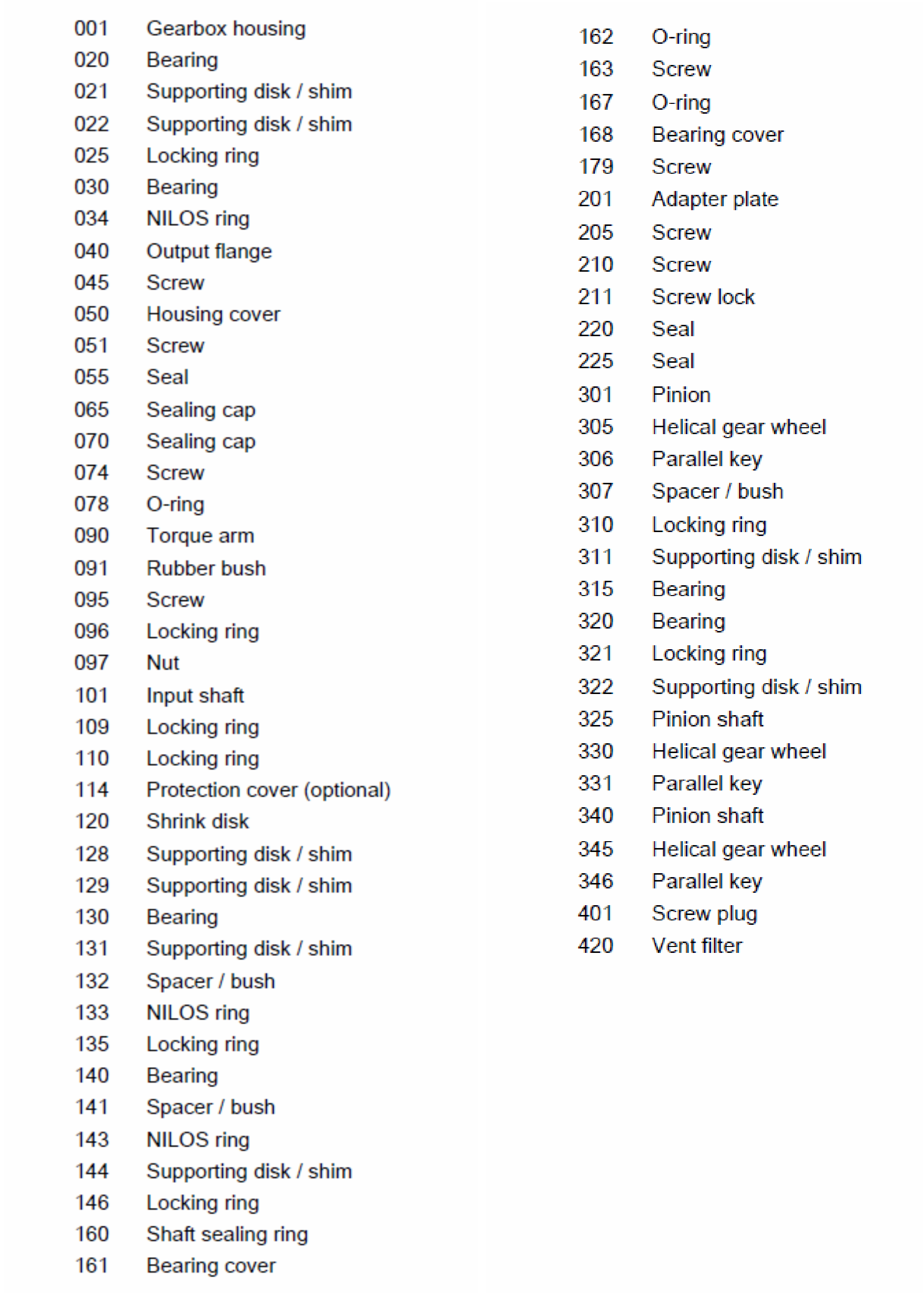


Figure 14.5—Exploded Parts Drawing of a Reduction Gearbox

When there is uncertainty about a part's nature and its use, you develop a design logic process map for the part and its neighbours to clarify the situation. You would not map the whole gearbox unless it is necessary. For straightforward engineering designs, a person experienced in the engineering and construction of the equipment would know how it operates and could identify its critical parts from the general assembly drawing and bill of materials, like that in Figure 14.6 for the gearbox.



001	Gearbox housing
020	Bearing
021	Supporting disk / shim
022	Supporting disk / shim
025	Locking ring
030	Bearing
034	NILOS ring
040	Output flange
045	Screw
050	Housing cover
051	Screw
055	Seal
065	Sealing cap
070	Sealing cap
074	Screw
078	O-ring
090	Torque arm
091	Rubber bush
095	Screw
096	Locking ring
097	Nut
101	Input shaft
109	Locking ring
110	Locking ring
114	Protection cover (optional)
120	Shrink disk
128	Supporting disk / shim
129	Supporting disk / shim
130	Bearing
131	Supporting disk / shim
132	Spacer / bush
133	NILOS ring
135	Locking ring
140	Bearing
141	Spacer / bush
143	NILOS ring
144	Supporting disk / shim
146	Locking ring
160	Shaft sealing ring
161	Bearing cover
162	O-ring
163	Screw
167	O-ring
168	Bearing cover
179	Screw
201	Adapter plate
205	Screw
210	Screw
211	Screw lock
220	Seal
225	Seal
301	Pinion
305	Helical gear wheel
306	Parallel key
307	Spacer / bush
310	Locking ring
311	Supporting disk / shim
315	Bearing
320	Bearing
321	Locking ring
322	Supporting disk / shim
325	Pinion shaft
330	Helical gear wheel
331	Parallel key
340	Pinion shaft
345	Helical gear wheel
346	Parallel key
401	Screw plug
420	Vent filter

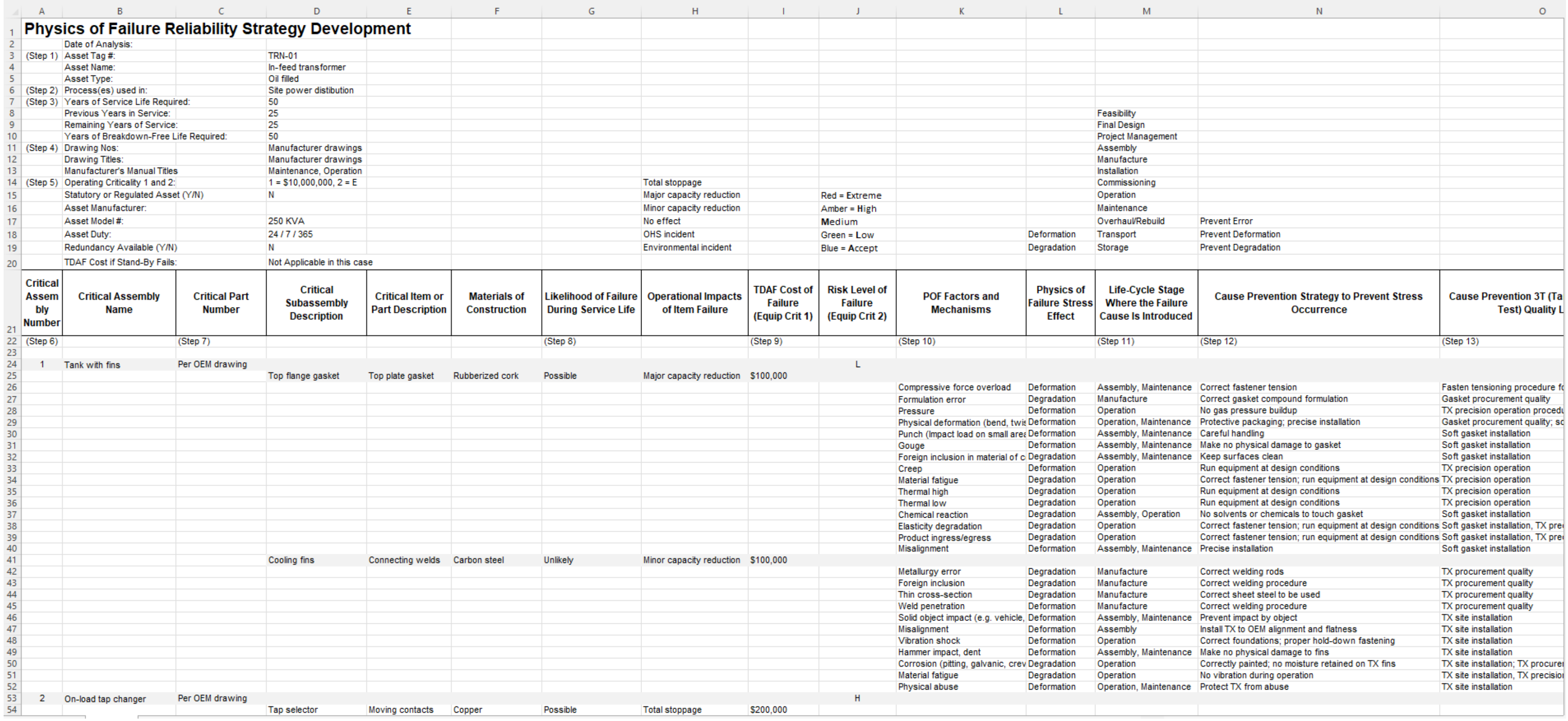
Figure 14.6—Bill of Materials for Reduction Gearbox

Rather than leave a critical part out of consideration, add parts you are not sure of to the spreadsheet and let the Physics of Failure Reliability Strategy Analysis resolve its criticality.

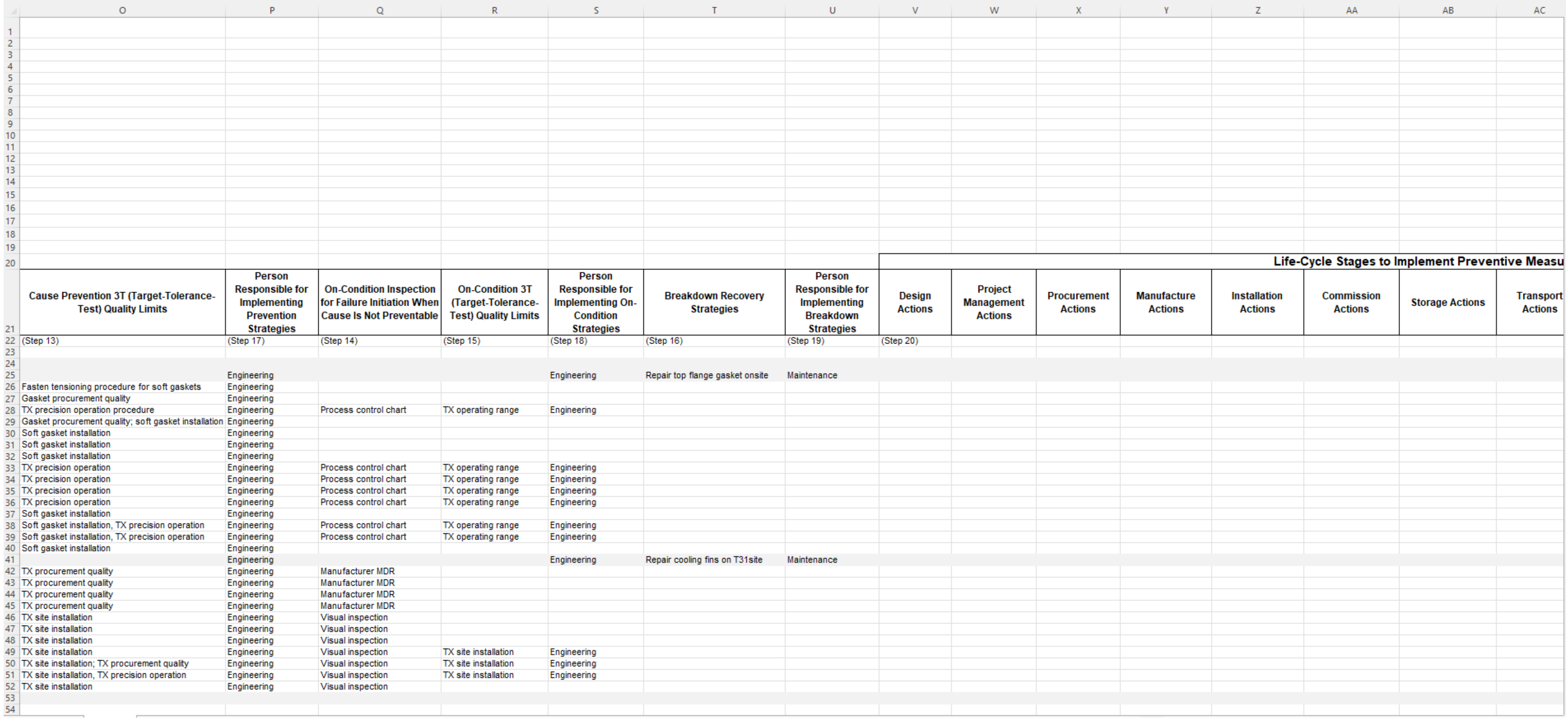
You don’t need to collect failure history to choose the right maintenance strategy for critical components. We can understand a lot about our equipment risks from the manufacturer’s general assembly or exploded parts drawings and from the bill of materials. Competent peoples’ past industrial experience, and good engineering design knowledge can be used to select sound maintenance and reliability strategy for critical components in the parts list.

Steps to Follow in a Physics of Failure Reliability Strategy Analysis

Using a Physics of Failure Reliability Strategy worksheet, systematically work through each requirement listed below. The numbers correspond to the steps noted in the Physics of Failure Reliability Strategy Analysis and Development worksheet in Table 14.1.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Physics of Failure Reliability Strategy Development**														
2		Date of Analysis:													
3	(Step 1)	Asset Tag #:		TRN-01											
4		Asset Name:		In-feed transformer											
5		Asset Type:		Oil filled											
6	(Step 2)	Process(es) used in:		Site power distibution											
7	(Step 3)	Years of Service Life Required:		50											
8		Previous Years in Service:		25									Feasibility		
9		Remaining Years of Service:		25									Final Design		
10		Years of Breakdown-Free Life Required:		50									Project Management		
11	(Step 4)	Drawing Nos:		Manufacturer drawings									Assembly		
12		Drawing Titles:		Manufacturer drawings									Manufacture		
13		Manufacturer's Manual Titles		Maintenance, Operation									Installation		
14	(Step 5)	Operating Criticality 1 and 2:		1 = $10,000,000, 2 = E				Total stoppage					Commissioning		
15		Statutory or Regulated Asset (Y/N)		N				Major capacity reduction		Red = Extreme			Operation		
16		Asset Manufacturer:						Minor capacity reduction		Amber = High			Maintenance		
17		Asset Model #:		250 KVA				No effect		Medium			Overhaul/Rebuild	Prevent Error	
18		Asset Duty:		24 / 7 / 365				OHS incident		Green = Low		Deformation	Transport	Prevent Deformation	
19		Redundancy Available (Y/N)		N				Environmental incident		Blue = Accept		Degradation	Storage	Prevent Degradation	
20		TDAF Cost if Stand-By Fails:		Not Applicable in this case											
21	**Critical Assembly Number**	**Critical Assembly Name**	**Critical Part Number**	**Critical Subassembly Description**	**Critical Item or Part Description**	**Materials of Construction**	**Likelihood of Failure During Service Life**	**Operational Impacts of Item Failure**	**TDAF Cost of Failure (Equip Crit 1)**	**Risk Level of Failure (Equip Crit 2)**	**POF Factors and Mechanisms**	**Physics of Failure Stress Effect**	**Life-Cycle Stage Where the Failure Cause Is Introduced**	**Cause Prevention Strategy to Prevent Stress Occurrence**	**Cause Prevention 3T (Ta Test) Quality L**
22	(Step 6)		(Step 7)				(Step 8)		(Step 9)		(Step 10)		(Step 11)	(Step 12)	(Step 13)
23															
24	1	Tank with fins	Per OEM drawing							L					
25				Top flange gasket	Top plate gasket	Rubberized cork	Possible	Major capacity reduction	$100,000						
26											Compressive force overload	Deformation	Assembly, Maintenance	Correct fastener tension	Fasten tensioning procedure fo
27											Formulation error	Degradation	Manufacture	Correct gasket compound formulation	Gasket procurement quality
28											Pressure	Deformation	Operation	No gas pressure buildup	TX precision operation procedu
29											Physical deformation (bend, twis	Deformation	Operation, Maintenance	Protective packaging; precise installation	Gasket procurement quality; so
30											Punch (Impact load on small area	Deformation	Assembly, Maintenance	Careful handling	Soft gasket installation
31											Gouge	Deformation	Assembly, Maintenance	Make no physical damage to gasket	Soft gasket installation
32											Foreign inclusion in material of c	Degradation	Assembly, Maintenance	Keep surfaces clean	Soft gasket installation
33											Creep	Deformation	Operation	Run equipment at design conditions	TX precision operation
34											Material fatigue	Degradation	Operation	Correct fastener tension; run equipment at design conditions	TX precision operation
35											Thermal high	Degradation	Operation	Run equipment at design conditions	TX precision operation
36											Thermal low	Degradation	Operation	Run equipment at design conditions	TX precision operation
37											Chemical reaction	Degradation	Assembly, Operation	No solvents or chemicals to touch gasket	Soft gasket installation
38											Elasticity degradation	Degradation	Operation	Correct fastener tension; run equipment at design conditions	Soft gasket installation, TX pre
39											Product ingress/egress	Degradation	Operation	Correct fastener tension; run equipment at design conditions	Soft gasket installation, TX pre
40											Misalignment	Deformation	Assembly, Maintenance	Precise installation	Soft gasket installation
41				Cooling fins	Connecting welds	Carbon steel	Unlikely	Minor capacity reduction	$100,000						
42											Metallurgy error	Degradation	Manufacture	Correct welding rods	TX procurement quality
43											Foreign inclusion	Degradation	Manufacture	Correct welding procedure	TX procurement quality
44											Thin cross-section	Degradation	Manufacture	Correct sheet steel to be used	TX procurement quality
45											Weld penetration	Deformation	Manufacture	Correct welding procedure	TX procurement quality
46											Solid object impact (e.g. vehicle,	Deformation	Assembly, Maintenance	Prevent impact by object	TX site installation
47											Misalignment	Deformation	Assembly	Install TX to OEM alignment and flatness	TX site installation
48											Vibration shock	Deformation	Operation	Correct foundations; proper hold-down fastening	TX site installation
49											Hammer impact, dent	Deformation	Assembly, Maintenance	Make no physical damage to fins	TX site installation
50											Corrosion (pitting, galvanic, crev	Degradation	Operation	Correctly painted; no moisture retained on TX fins	TX site installation; TX procure
51											Material fatigue	Degradation	Operation	No vibration during operation	TX site installation, TX precisio
52											Physical abuse	Deformation	Operation, Maintenance	Protect TX from abuse	TX site installation
53	2	On-load tap changer	Per OEM drawing							H					
54				Tap selector	Moving contacts	Copper	Possible	Total stoppage	$200,000						



	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
20								Life-Cycle Stages to Implement Preventive Measu							
21	Cause Prevention 3T (Target-Tolerance-Test) Quality Limits	Person Responsible for Implementing Prevention Strategies	On-Condition Inspection for Failure Initiation When Cause Is Not Preventable	On-Condition 3T (Target-Tolerance-Test) Quality Limits	Person Responsible for Implementing On-Condition Strategies	Breakdown Recovery Strategies	Person Responsible for Implementing Breakdown Strategies	Design Actions	Project Management Actions	Procurement Actions	Manufacture Actions	Installation Actions	Commission Actions	Storage Actions	Transport Actions
22	(Step 13)	(Step 17)	(Step 14)	(Step 15)	(Step 18)	(Step 16)	(Step 19)	(Step 20)							
23															
24															
25		Engineering			Engineering	Repair top flange gasket onsite	Maintenance								
26	Fasten tensioning procedure for soft gaskets	Engineering													
27	Gasket procurement quality	Engineering													
28	TX precision operation procedure	Engineering	Process control chart	TX operating range	Engineering										
29	Gasket procurement quality; soft gasket installation	Engineering													
30	Soft gasket installation	Engineering													
31	Soft gasket installation	Engineering													
32	Soft gasket installation	Engineering													
33	TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
34	TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
35	TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
36	TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
37	Soft gasket installation	Engineering													
38	Soft gasket installation, TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
39	Soft gasket installation, TX precision operation	Engineering	Process control chart	TX operating range	Engineering										
40	Soft gasket installation	Engineering													
41		Engineering			Engineering	Repair cooling fins on T31site	Maintenance								
42	TX procurement quality	Engineering	Manufacturer MDR												
43	TX procurement quality	Engineering	Manufacturer MDR												
44	TX procurement quality	Engineering	Manufacturer MDR												
45	TX procurement quality	Engineering	Manufacturer MDR												
46	TX site installation	Engineering	Visual inspection												
47	TX site installation	Engineering	Visual inspection												
48	TX site installation	Engineering	Visual inspection												
49	TX site installation	Engineering	Visual inspection	TX site installation	Engineering										
50	TX site installation; TX procurement quality	Engineering	Visual inspection	TX site installation	Engineering										
51	TX site installation, TX precision operation	Engineering	Visual inspection	TX site installation	Engineering										
52	TX site installation	Engineering	Visual inspection												
53															
54															

Table 14.1—Reliability Strategy Analysis and Development (Only partial of the spreadsheet is shown)

1. Select the asset to be investigated and number and name it.

2. Identify all operating processes to which the asset belongs. This information comes from plant drawings, process and instrument diagrams, electrical and control cabling drawings, and equipment asset lists. Draw process maps of the operation showing the equipment to be analysed. Ensure that every item used to run the asset is on the map. This includes power supplies, and ancillary items used only at start-up or shutdown. Specify the full range of necessary functions, their service duties, and required availability for the asset and each ancillary item.

3. Determine the prior and remaining years of service life required from the asset. Identify how long the parent equipment is required to run without unplanned downtime, safety issues, production slowdown, or product quality problems. This allows later measurement of the effectiveness of the risk control strategies and provides a means for prioritizing reliability improvements. Set the target for breakdown-free years of operation.

4. Get all the technical details, assembly drawings, and bill of materials covering all the asset's mechanical, electrical, and electronic items.

5. Conduct an Operating Criticality Analysis to determine whether the asset has components critical to the operation. Estimate the biggest TDAF cost for each assembly. If an asset is part of a duty-standby configuration, indicate that in the spreadsheet. For the analysis of operating risk, presume that the standby unit is available when determining criticality, however, also identify the full TDAF Cost if the duty unit failures when the standby is NOT available. From computerized maintenance management system records and

operating records, identify the failure frequency of each major assembly. You will need to use a representative period that reflects the effects of the operation's culture and management practices. At least five years is ideal. If the plant was upgraded or a process was changed, look at the extent of the change and records from the date of commissioning the change to determine its impact on failure frequencies.

6. List all critical major assemblies that make the asset operate.

7. Identify the vital subassemblies and parts in the bill of materials for each critical assembly item that make it work. When necessary, develop a reliability block diagram to understand the logic of the design and identify the influence of parts and interacting components.

8. Determine the likelihood frequency of failure for each vital subassembly or part from history data in operation and maintenance records. The likelihood scale of the risk matrix provides suitable frequency designations. For the analysis, presume that any standby unit is available when determining operational impact. If necessary, research the typical failure events that each component can suffer. When technical and failure information is not available in house, search the Internet for similar events, contact similar operating sites, or ask the original manufacturer for estimates.

9. Transfer Operating Criticality 1 and 2 values for the item from the Operating Criticality Analysis.

10. Do a Physics of Failure Factors Analysis for each vital assembly or part with a criticality above "Accept" to identify all possible human error, degradation, and deformation failure

mechanisms for all the material-of-construction factors. If a part has multiple materials of construction, do an analysis for each material (e.g., a flexible drive coupling connecting two shafts is made of steel and elastomeric parts and each material will fail from different mechanisms). Get a competent and experienced engineer who knows the equipment and its operation very well to do the POFFA (an electrical engineer for electrical equipment, a mechanical engineer for mechanical plant, and instrumentation and control engineer for control systems), or team with competent and career experienced operators and maintainers and do the POFFA together. Transfer the POFFA results to the Physics of Failure Reliability Strategy worksheet.

11. Identify all the life-cycle phases when each of failure cause mechanism can occur, including during the remaining service life of the asset.

12. Select error elimination, microstructure degradation and deformation prevention, opportunity elimination, material reliability improvement, or consequence reduction strategies for each mechanism to eliminate the possibility of failure or to minimize the chance of a failure starting. This will produce engineering, reliability, operational, and maintenance strategy and activities that reduce a critical component's operating risks. Choices include using life-cycle process changes, preventive maintenance, condition monitoring, renewal, or refurbishment. Set the frequency or a trigger for each activity. These plans and actions can apply to all issues related to the organization's design, engineering, supply chain, operational, and maintenance practices. You aim to drive a part's total operating risk so low that its contribution to the total parent asset risk provides no more than one chance of failure of the parent asset during three times the parent asset's

service life. Any mix of economically viable solutions across the life cycle that delivers that operational outcome is acceptable.

Confirm on a calibrated risk matrix or by calculation that the intended activities significantly reduce risk. The reliability improvement strategies chosen for a component must deliver substantial risk reductions to the equipment. At a minimum, the total effect of all mitigations used on a component must drop its risk to the “Accept” risk level. Perform a Three-Factor Risk Analysis to identify alternative or more viable asset life-cycle risk control strategies when known risk mitigations are ineffective. If no arrangement of mitigations achieves the required service life for a part, the remaining option is to reengineer the component so the microstructure of its new design can comfortably handle all service life stresses and contact conditions.

13. Set the ACE 3T (Target-Tolerance-Test) quality limits for each Physics of Failure mechanism. These are the quality standards established throughout the asset life cycle that, when achieved, prevent each cause of failure arising. A quality standard Tolerance value is the lowest value specified by either the parent asset’s manufacturer or by a component’s manufacturer. For example, the manufacture’s specification table for a flexible drive coupling used as a component by a pump-set maker to connect a motor to the pump will show the coupling can accommodate millimetres of misalignment, but the manufacturer of the pump-set permits no shaft misalignment more than a few microns. In this case, the Tolerance value to use for the shaft alignment quality standard is the maximum value for misalignment specified by the pump-set manufacturer. When setting the Target value

range, the quality standards to use are those that deliver world-class reliability from the part’s microstructure.

14. Select on-condition inspection tasks or do operating performance monitoring to detect changes in in the mechanisms affecting component health, when proactive failure cause prevention, or economic preventive maintenance are not viable to deliver failure-free service lifetimes. Proactive cause prevention is total removal of a failure mechanism so there is no cause that can generate a defect. Preventive maintenance is scheduled replacement of parts before failure. For the causes remaining, condition monitoring is used to look for evidence that a part’s health is within its Targets, or performance monitoring is done to monitor the stability of variables that raise the risk of failure. When operating variables stray out of control it is a trigger to rectify the problem before risks grow too great. Where possible use visual condition checks against the Target value, if simple observations cannot be safely and economically done, introduce suitable technological means to check component health conditions. You are not looking for evidence of failure initiation; rather, you want proof that the part is in fit condition and will remain so. If you detect adverse conditions, look for the cause(s) and remove them.

15. Set the operating and maintenance ACE 3T quality limits for each on-condition variable being monitored. Typically, the range of variables used are those that represent the stresses and health of the item being observed, e.g., operating loads, alignment, distortion, temperature, pressure, looseness, balance, lubricant chemistry, etc. Exceeding a Target value standard is a warning level alarm and exceeding the Tolerance value is the trigger for immediate rectification to return the component back to within all its Target values.

16. Determine the most economical breakdown operating and maintenance activities to be done to recover and return to operation if a vital part should fail during the asset's service life.

17. Assign a person to be responsible for implementing each chosen error elimination, degradation, and deformation strategy and training users. This includes developing new documents and updating existing documents with relevant tasks and ACE quality controls. Update process maps; develop error-proof procedures with relevant tasks and work assurance including the required quality standards; review and update or remove existing work orders; include new, fully detailed risk elimination work orders; train and educate all relevant personnel in the new procedures and explain why they are necessary for the operation's future success; update the CMMS planned work schedule with the latest work orders; develop the future maintenance resource demand into an overall maintenance resource schedule to understand the manpower load and the full range of skills needed in your crew.

Catalogue and cost the spares identified in the Physics of Failure Reliability Strategy Analysis and/or the Reliability Growth Cause Analysis as critical requirements for plant and equipment consequence reduction. Detail the spares required for planned maintenance activities each financial year for inclusion in the annual financial budget. Update the critical spares list and order any missing spares in a controlled and financially responsible manner.

Financially model the new strategy using Reliability Growth Cause Analysis and compare the new TDAF costs to the current TDAF costs to provide economic justification for changing strategies. (This analysis is optional if you are satisfied with the estimated risk reduction and financial gain shown in the risk matrix.)

18. Assign a person to be responsible for implementing each chosen on-condition maintenance and operating task. This includes developing new documents and updating existing documents with relevant tasks and ACE quality controls, and training users.

19. Assign a person to be responsible for implementing each vital part's chosen breakdown operating and maintenance activities (this is necessary to minimize the total consequential losses to the operation in case of failure).

20. Assign each Physics of Failure Reliability Strategy action to all relevant phases of the asset's life cycle and implement the actions.

Using the updated maintenance schedule, estimate the maintenance budget for the next two years, factoring in the reliability improvement effects on equipment as a result of the new reliability strategies. Submit the forecast maintenance budget for review by senior managers and answer their questions.

Monitor and track monthly each equipment's reliability performance measures and maintenance cost to ensure they are improving.

When there are multiple identical parts configurations for an asset—for example, each piston and cylinder of an internal combustion engine—you need only analyse one set of common components.

You will find that most equipment in industry is made of the same components using the same or similar materials of construction—about 100 types of parts make up nearly all industrial machines and equipment.[1] The results of a Physics of Failure Reliability Analysis will apply to many other items of equipment. Once you have a database of past analyses, you can mostly copy and paste an existing analysis into a new analysis. Be careful, however, to detect the exception to the rule. For example, in operations with multiples of the same bearing number in machines, you will be tempted to analyse one bearing and say the analysis represents all identical bearings across your operation. But if one bearing is inside a clean room and another is outside in full weather, the situations are not comparable, and each bearing will have different causes of failure.

Selecting and Implementing High Reliability Strategy

Keeping components in their precision zones is the universal purpose of the reliability, maintenance, operational, engineering, project, and asset management efforts applied in the Plant Wellness Way. With that aim in mind, you establish appropriate strategies, plans and activities throughout the organization and across the life cycle to maximize the chance of its success.

Each of the Physics of Failure Factors listed for a component are first addressed proactively to prevent all the failure mechanisms that cause the factors. The most effective solution is to select actions that will stop a cause mechanism from being present, thereby ensuring that no defects can be created, and no risks can exist. One by one, engineering, maintenance and operational decisions are made so that each mechanism is prevented with appropriate action or combination of actions to remove opportunities for the mechanism to occur during the life cycle.

Listed in Table 14.2 shows the maintenance and operating strategies used at a site that follows the Plant Wellness Way paradigm and practices.

Plant Wellness Way System of Reliability Strategy and Practices

Risk Level on Failure	**Maintenance Strategy**		**Lifetime Reliability Strategy**	**Operating Strategy**
Accept	• Do Breakdown Maintenance (BM) • Except, do Preventive Maintenance when the cycle cost is less than BM TDAF Cost		• For each failure cause mechanism select ACE 3T precision quality values and design manufacture, assemble, warehouse, install and operate so components live within their precision zones.	• Operate for degradation management so those factors and process conditions that initiate component failure cause mechanisms are kept within operating precision zones that maximize the component's reliability.
Low	• Do Preventive Maintenance (PM) where component useful life is confidently known e.g., filter, oil, brake pad, etc., coupled with defect-free Precision Maintenance, i.e., positional accuracy, no distortion, right fit and tolerance, right tightness, etc., (see Chapter 17) to insure components are in their precision zones. • Do early "economic" PM when cost of replacement is minor compared to the cost of a future failure, e.g., gear box, drive belt, separation screen, etc., coupled with defect-free Precision Maintenance	• If a failure by a cause mechanism is possible, e.g., from changed component quality parameters, component distortion, operating variable surges, etc., but when the failure occurs is a random event, then schedule component "health monitoring" (CHM) of failure cause mechanism to confirm compliance to its ACE 3T quality values (see Chapter 15), coupled with defect-free Precision Maintenance to return components to precision zone.		
Medium				
High				
Extreme				

Table 14.2—Summary of Plant Wellness Way Maintenance and Operating Strategies

Doing a Three-Factor Risk Analysis

Like all risk analyses, Three-Factor Risk Analysis starts by identifying what situations or events could arise in your operation to cause the failure of a critical part in an asset. Once potential problems are identified, strategies to eliminate or substantially reduce the risk are selected. In a Three-Factor Risk Analysis, potential risk controls are divided into three categories: consequence reduction, opportunity reduction, and reliability improvement. In each category, there are methodologies and techniques to reduce or eliminate the risk under consideration.

To confirm the effectiveness of the selected mitigations, they are either mapped onto a risk matrix, or the risk formula is used to calculate the new risk level and checked that the mitigations will reduce risk to the acceptable level.

Three-Factor Risk Analysis can be applied to address the risks in the following:

- A complete asset
- Subassemblies
- Parts and components
- Business processes and their individual steps
- Work procedures and work instructions

Table 14.3 provides a sample Three-Factor Risk Analysis worksheet for a machine component.

Three-Factor Risk Analysis

Event Risk = Consequence x [Opportunity x Probability (Chance of Event Happening at this Opportunity)]

Asset	Assembly	Part	Failure Event	Failure Cause	Opportunity to Fail	TDAF Cost Consequence ($)	Frequency of Opportunity (/yr)	Existing Mitigations / Controls	Likelihood (Chance) of Failure Cause	Existing Risk Level	Additional Mitigations/Controls	Chance Mitigations are Done Correct	New Likelihood	Potential Future Risk Level
Pump set	Motor	Shaft NDE bearing	Seized	Interference fit tight	Every time it is machined	$50,000	1 in 20 years	Standard machine shop work quality control	Possible	Low	Proof test journal and bore are to bearing OEM tolerance and form	High	Unlikely	Acceptable
				No Lube	Every time it is greased	$50,000	12 per year	Greaser selects own grease	Likely	Medium	Scheduled lube route, ultrasonic headset recording	High	Unlikely	Acceptable
				Wrong Lube	Every time it is greased	$50,000	12 per year	Greaser selects own grease	Likely	Medium	Separate grease guns for each lube type clearly marked and colour coded. Grease points color-coded, ultrasonic headset recording	High	Unlikely	Acceptable
			Spin in housing	Outer ring interference fit loose	Every time it is machined	$10,000	1 in 20 years	Standard machine shop work quality control	Possible	Low	Proof test journal and bore are to bearing OEM tolerance and form	High	Unlikely	Acceptable

Table 14.3—Sample Three-Factor Risk Analysis for a Bearing

Organizational Factors of Critical Parts Failure

It is well documented that around 80 percent of equipment failures can be traced to human error and unintended business process “traps” that cause calamity.[2] Notice how many human and business factors in the “Cause Prevention Strategy” column of Table 14.1 are related to human intervention. When you put parts through a Physic of Failure Reliability Analysis, you soon collect a list of the human and business process drivers of failure in your operation. You’ll see the same issues repeating. The analysis warns that there are systemic human-related causes that create equipment problems. You must confront the reality of the three organizational factors questions below to expose the business-caused failures that have worked their way into your company’s processes.

1. What human factors make an equipment part fail?
2. What business processes make an equipment part fail?
3. What engineering design issues make an equipment part fail?

Allocating Responsibility for Strategy Requirements

You are building the business-wide processes that will change your operation to deliver world-class equipment reliability. You are designing the future business and operational system that will take your company to reliability, maintenance, and operational excellence. The necessary engineering and precision standards to be met throughout the life cycle; the supporting documents needed in each department; the technical knowledge, skills, and competence needed by your people; the training of your workforce; the recording and reporting systems that confirm that strategies are being delivered correctly in your business units;[3] and so on throughout the organization need to be installed and put into use.

The Physics of Failure Reliability Analysis makes clear what needs to be done to get high reliability from your processes. All those tasks are assigned to the people most appropriate to do them. Those people have the competence to do the requirement correctly and do it well. Duties can be shared across groups if a requirement needs multiple disciplines and skills to complete it. A column of the spreadsheet is used to identify the people responsible for implementing a strategy. You could instead color-code a strategy to represent the people responsible for the associated work. A simple color-coded arrangement clearly differentiates the tasks assigned to engineering (yellow), operations (amber), maintenance (green), and so on.

Confirming the Economic Value of New Strategy

It is vital to prove that the risk controls you apply have a great chance of delivering the risk reduction needed. Be very suspicious of any maintenance strategy selection methodology that cannot prove that doing the maintenance strategy it suggests will bring real value to the company.

As part of the Physic of Failure Reliability Analysis, you compare the current risk level in the business for the asset under review to the risk that will result when the reliability improvement changes identified become standard operating practices. The proof of risk reduction can be done using a risk formula calculation in the Operating Criticality Analysis or shown on a risk matrix. For mitigations to be suitable, your selection must satisfy the criteria for an acceptable risk mitigation (see Chapter 5).

FOOTNOTES

1. A. A. Hattangadi, *Plant and Machinery Failure Prevention* (New York: McGraw Hill, 2005).

2. Federal Aviation Administration, “Aviation Maintenance Technician Handbook – General, Chapter 14 Addendum/Human Factors”, accessed at http://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/media/amt_handbook_addendum_human_factors.pdf, August 5, 2015.

3. Bruce McLaughlin, *Comprehensive Risk Abatement Methodology as a Lean Operations Strategy*, accessed at http://www.igi-global.com/article/comprehensive-risk-abatement-methodology-as-a-lean-operations-strategy/127540, August 24, 2015.