RISK-BASED DECISION-MAKING GUIDELINES

Volume 3
Procedures for Assessing Risks

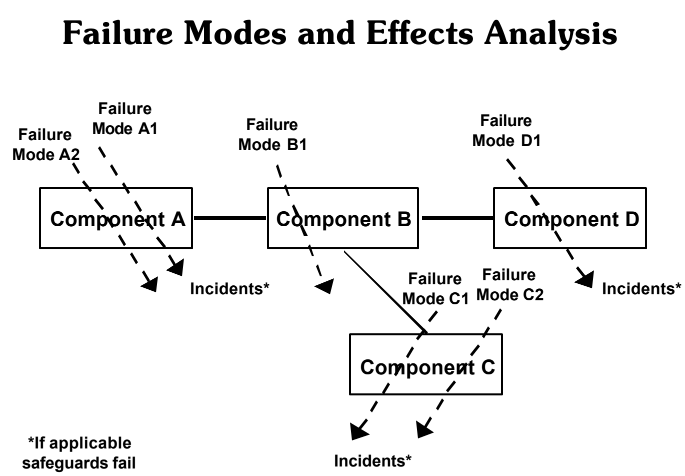
Applying Risk Assessment Tools

Chapter 9 — Failure Modes and Effects Analysis (FMEA)

Chapter Contents

This chapter provides a basic overview of the failure modes and effects analysis technique and includes fundamental step-by-step instructions for using this methodology to analyze various failure modes of system components. The following are the major topics in this chapter:

See examples of FMEAs in Volume 4 in the Failure Modes and Effects Analysis directory.



Summary of Failure Modes and Effects Analysis (FMEA)

FMEA is a qualitative reasoning approach best suited for reviews of mechanical and electrical hardware systems. The FMEA technique (1) considers how the failure modes of each system component can result in system performance problems and (2) ensures that appropriate safeguards against such problems are in place. A quantitative version of FMEA is known as failure modes, effects, and criticality analysis (FMECA).

Brief summary of characteristics

- A systematic, highly structured assessment relying on evaluation of component failure modes and team experience to generate a comprehensive review and ensure that appropriate safeguards against system performance problems are in place
- Used as a system-level and component-level risk assessment technique
- Applicable to any well-defined system
- Sometimes performed by an individual working with system experts through interviews and field inspections, but also can be performed by an interdisciplinary team with diverse backgrounds and experience participating in group review meetings of system documentation and field inspections
- A technique that generates qualitative descriptions of potential performance problems (failure modes, causes, effects, and safeguards) as well as lists of recommendations for reducing risks
- A technique that can provide quantitative failure frequency or consequence estimates

Most common uses

- Used primarily for reviews of mechanical and electrical systems, such as fire suppression systems and vessel steering and propulsion systems
- Used frequently as the basis for defining and optimizing planned equipment maintenance because the method systematically focuses directly and individually on equipment failure modes
- Effective for collecting the information needed to troubleshoot system problems

Example from a hardware-based FMEA

Machine/Process: Onboard compressed air system
Subject: 1.2.2 Compressor control loop
Description: Pressure-sensing control loop that automatically starts/stops the compressor based on system pressure (starts at 95 psig and stops at 105 psig)
Next higher level: 1.2 Compressor subsystem

Failure Mode	Effects			Causes	Indications	Safeguards	Recommendations/Remarks
	Local	Higher Level	End				
A. No start signal when the system pressure is low	Open control circuit	Low pressure and low air flow in the system	Interruption of the systems supported by compressed air	Sensor failure or miscalibration Controller failure or incorrect setting Wiring fault Control circuit relay failure Loss of power for the control circuit	Low pressure indicated on air receiver pressure gauge Compressor not operating (but has power and no other obvious failure)	Rapid detection because of quick interruption of the supported systems	Consider a redundant compressor with separate controls Calibrate sensors annually
B. No stop signal when the system pressure is high	• • •	• • •	• • •	• • •	• • •	• • •	• • •
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Limitations of FMEA

- **Examination of human error is limited**
- **Focus is on single-event initiators of problems**
- **Examination of external influences is limited**
- **Results are dependent on the mode of operation**

Limitations of FMEA

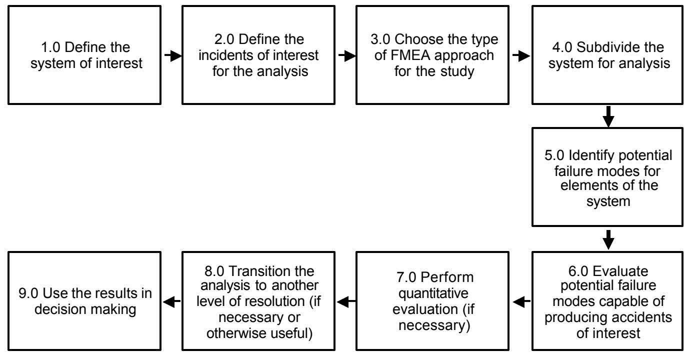
Although the FMEA methodology is highly effective in analyzing various system failure modes, this technique has four limitations:

Examination of human error is limited. A traditional FMEA uses potential equipment failures as the basis for the analysis. All of the questions focus on how equipment functional failures can occur. A typical FMEA addresses potential human errors only to the extent that human errors produce equipment failures of interest. Misoperations that do not cause equipment failures are often overlooked in an FMEA.

Focus is on single-event initiators of problems. A traditional FMEA tries to predict the potential effects of specific equipment failures. These equipment failures are generally analyzed one by one, which means that important combinations of equipment failures may be overlooked.

Examination of external influences is limited. A typical FMEA addresses potential external influences (environmental conditions, system contamination, external impacts, etc.) only to the extent that these events produce equipment failures of interest. External influences that directly affect vessel safety, port safety, and crew safety are often overlooked in an FMEA if they do not cause equipment failures.

Results are dependent on the mode of operation. The effects of certain equipment failure modes often vary widely, depending on the mode of system operation. For example, the steering system on a vessel is of little importance while the vessel is docked and is unloading cargo. A single FMEA generally accounts for possible effects of equipment failures only during one mode of operation or a few closely related modes of operation. More than one FMEA may, therefore, be necessary for a system that has multiple modes of operation.



Procedure for FMEA

The procedure for performing an FMEA consists of the following nine steps. Each step is further explained on the following pages.

1.0 Define the system of interest. Specify and clearly define the boundaries of the system for which risk-related information is needed.

2.0 Define the accidents of interest for the analysis. Specify the problems of interest that the analysis will address. These may include safety issues, failures in systems such as steering or propulsion, etc.

3.0 Choose the type of FMEA approach for the study. Select a hardware approach (bottom-up), functional approach (top-down), or hybrid approach for applying FMEA.

4.0 Subdivide the system for analysis. Section the system according to the type of FMEA approach selected.

5.0 Identify potential failure modes for elements of the system. Define the fundamental ways that each element of the system can fail to achieve its intended functions. Determine which failures can lead to accidents of interest for the analysis.

6.0 Evaluate potential failure modes capable of producing accidents of interest. For each potential failure that can lead to accidents of interest, evaluate the following:

- The range of possible effects
- Ways in which the failure mode can occur
- Ways in which the failure mode can be detected and isolated
- Safeguards that are in place to protect against accidents resulting from the failure mode

7.0 Perform quantitative evaluation (if necessary). Extend the analysis of potentially important failures by characterizing their likelihood, their severity, and the resulting levels of risk. FMEAs that incorporate this step are referred to as failure modes, effects, and criticality analyses (FMECAs).

8.0 Transition the analysis to another level of resolution (if necessary or otherwise useful). For top-down FMEAs, follow-on analyses at lower (i.e., more detailed) levels of analysis may be useful for finding more specific contributors to system problems. For bottom-up FMEAs, follow-on analyses at higher (i.e., less detailed) levels of analysis may be useful for characterizing performance problems in broader categories. Typically, this would involve system and subsystem characterizations based on previous component-level analyses.

9.0 Use the results in decision making. Evaluate recommendations from the analysis and implement those that will bring more benefits than they will cost over the life cycle of the system.

1.0 Define the system of interest

- **Intended functions**
- **Boundaries**

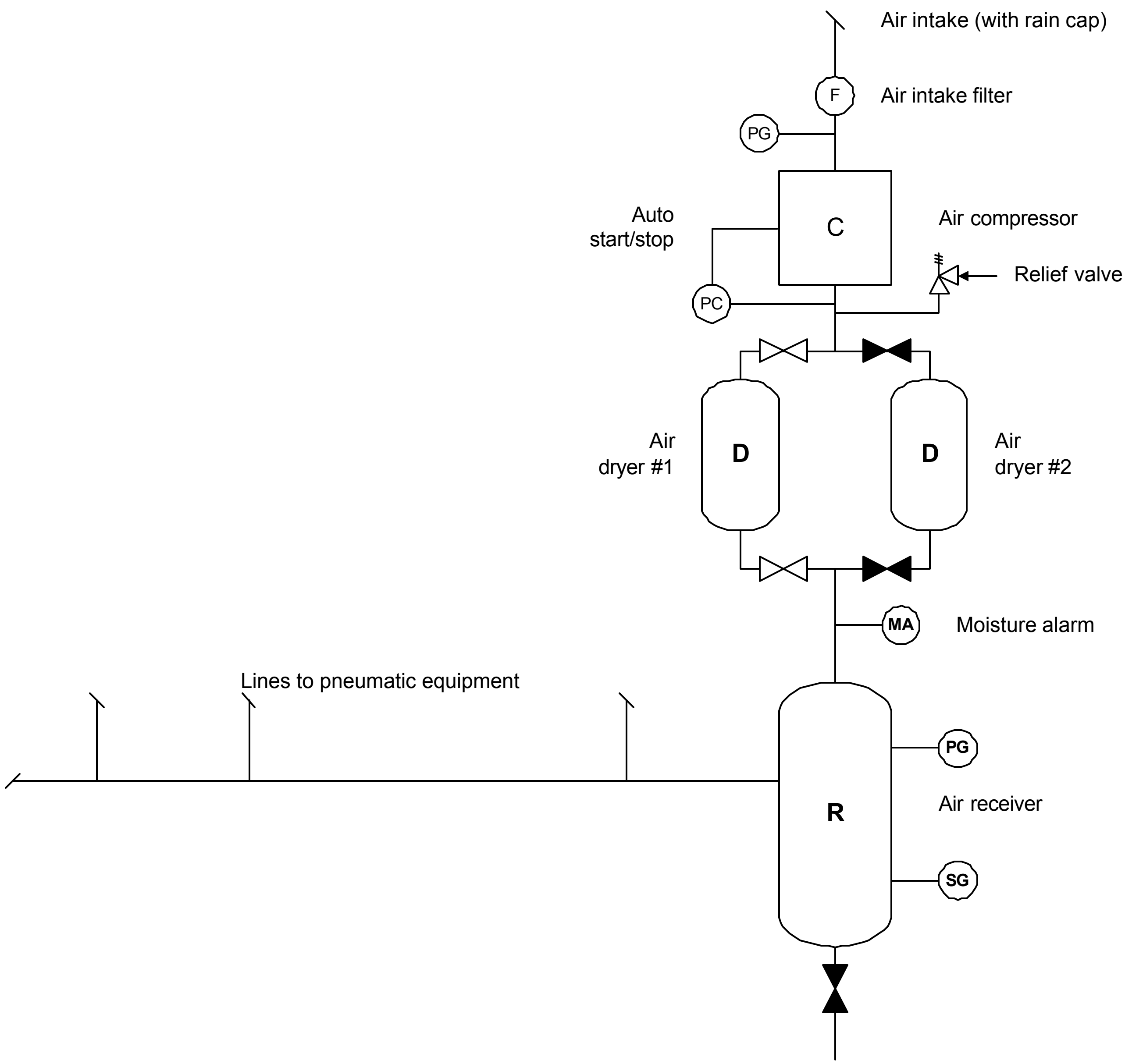
1.0 Define the system of interest

Intended functions. Because all risk assessments are concerned with ways in which a system can fail to perform an intended function, a clear definition of the intended functions for a system is an important first step.

Boundaries. Few systems operate in isolation. Most are connected to or interact with other systems. By clearly defining the boundaries of a system, especially boundaries with support systems such as electric power and compressed air, analysts can avoid (1) overlooking key elements of a system at interfaces and (2) penalizing a system by associating other equipment with the subject of the study. A diagram or schematic of the system is helpful for identifying boundaries.

Example

Compressed Air System		
	Boundaries of Analysis	
Intended Functions	Within Scope	Outside of Scope
• Provide compressed air at 100 psig • Remove moisture and contaminants from the air • Contain the compressed air	• Breaker supplying power to the compressor • Air hoses and piping at pneumatic equipment	• Power supply bus for the compressor • Air hose connections on pneumatic equipment



2.0 Define the accidents of interest for the analysis

- **Safety problems**
- **Environmental issues**
- **Economic impacts**

2.0 Define the accidents of interest for the analysis

Safety problems. The analysis team may be asked to look for ways in which failures in a hardware system may result in personnel injury. These injuries may be caused by many mechanisms, including the following:

- Steering or propulsion failures
- Hoist and rigging failures
- Exposure to high temperatures (e.g., through steam leaks)
- Fires and explosions

Environmental issues. The analysis team may be asked to look for ways in which the failure of a system can undesirably affect the environment. These environmental issues may be caused by many mechanisms, including the following:

- Equipment failures that result in an unplanned discharge of material into the water
- Equipment failures, such as seal failures, that result in a material spill

Economic impacts. The analysis team may be asked to look for ways in which the failure of a system may have adverse economic impacts. These economic risks may be categorized in many ways, including the following:

- Business risks, such as vessel detained at port, contractual penalties, lost revenue, etc.
- Environmental restoration costs
- Replacement costs, such as the cost of replacing damaged equipment

A particular analysis may focus only on events above a certain threshold of concern in one or more of these categories.

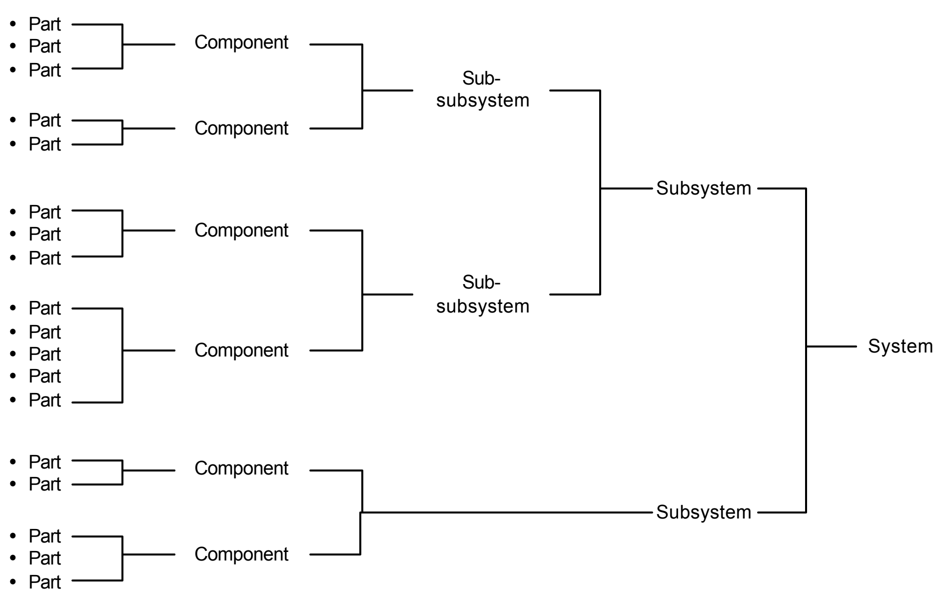
3.0 Choose the type of FMEA approach for the study

- Hardware approach (bottom-up)
- Functional approach (top-down)
- Hybrid of the two

3.0 Choose the type of FMEA approach for the study

Hardware approach (bottom-up). The hardware approach is normally used when hardware items can be uniquely identified from schematics, drawings, and other engineering and design data. The hardware approach typically focuses on the potential failure modes of basic components of the system. This is generally the lowest level of resolution that provides valuable information to decision makers. The hardware approach for defining an FMEA is a good choice when *every* component of a system must be reviewed (e.g., to make design or maintenance decisions). It can be difficult or inefficient, however, for use in analyzing (1) complex systems or (2) systems that are not well defined when the analysis must be performed.

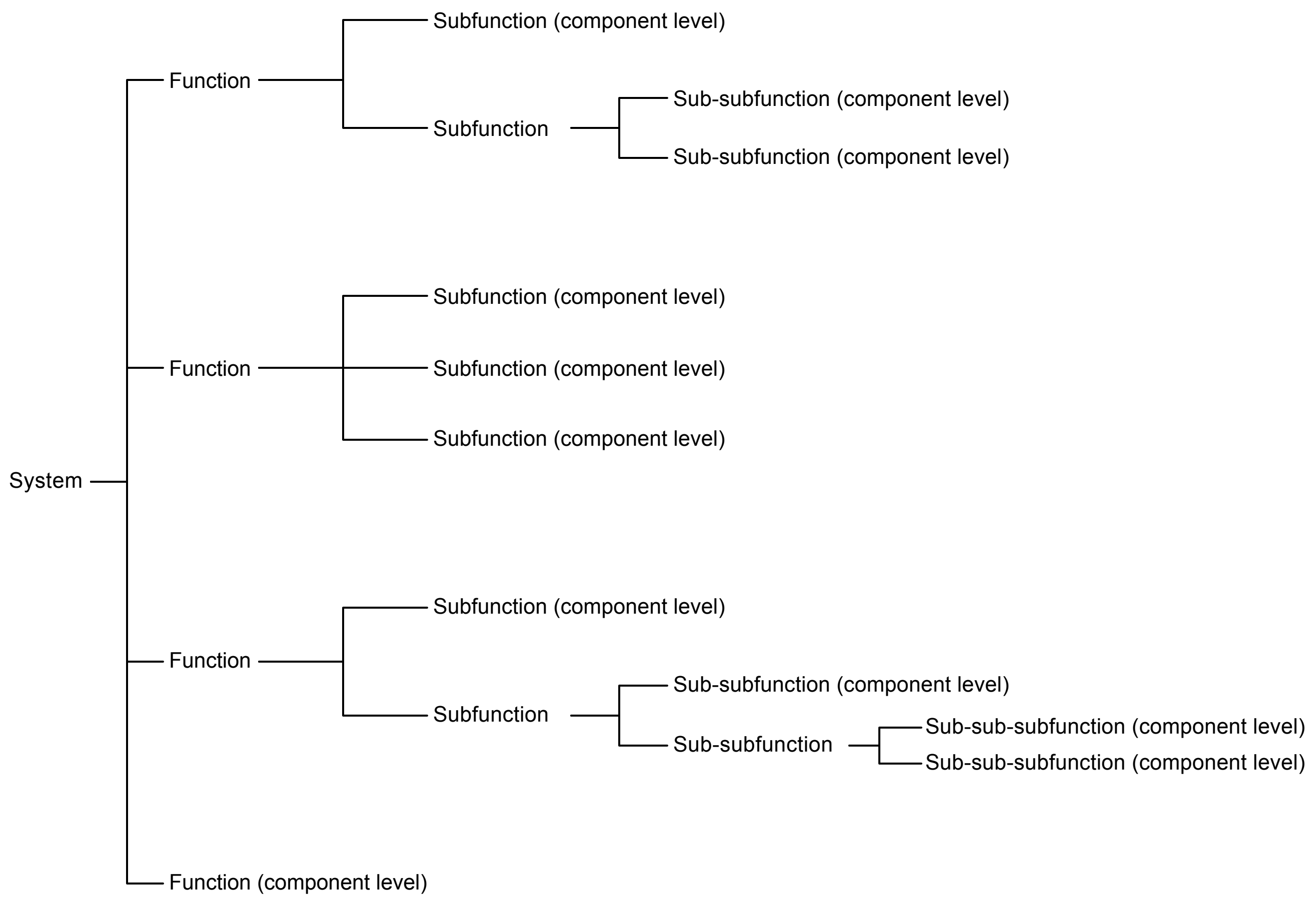
Hardware Focus
(Bottom-up Approach)



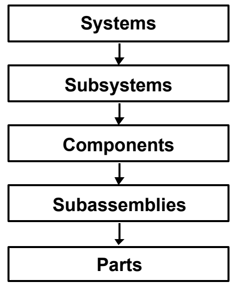
Functional approach (top-down). The functional approach is normally used when hardware items cannot be uniquely identified or when system complexity requires progressive analysis, with each successive level of analysis focusing in more detail on only the most important contributors. This approach focuses on ways in which functional intents of a system may go unsatisfied rather than on the specific failure modes of individual equipment items. The functional approach to an FMEA is particularly effective if the analysis focuses on only a limited set of accidents of interest, or if it must directly address only the most important contributors to potential problems rather than every individual component.

Hybrid of the two. An FMEA may begin with a functional approach and then transition to a focus on equipment, especially equipment that directly contributes to functional failures identified as important. Traditional reliability-centered maintenance analysis uses this hybrid approach, beginning with identification of important system functional failures and then identifying the specific equipment failure modes that produce those system functional failures.

Function Focus
(Top-down Approach)



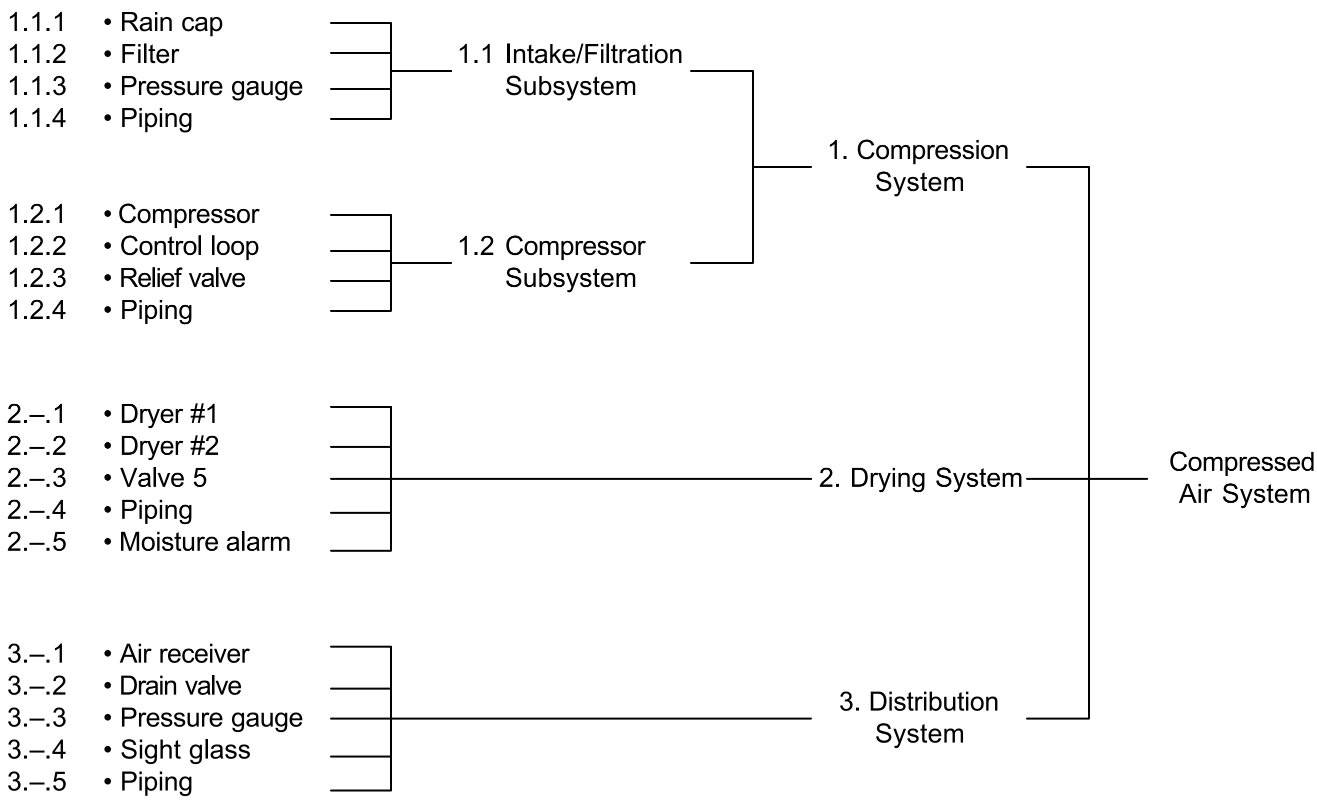
4.0 Subdivide the system by equipment or functions for analysis



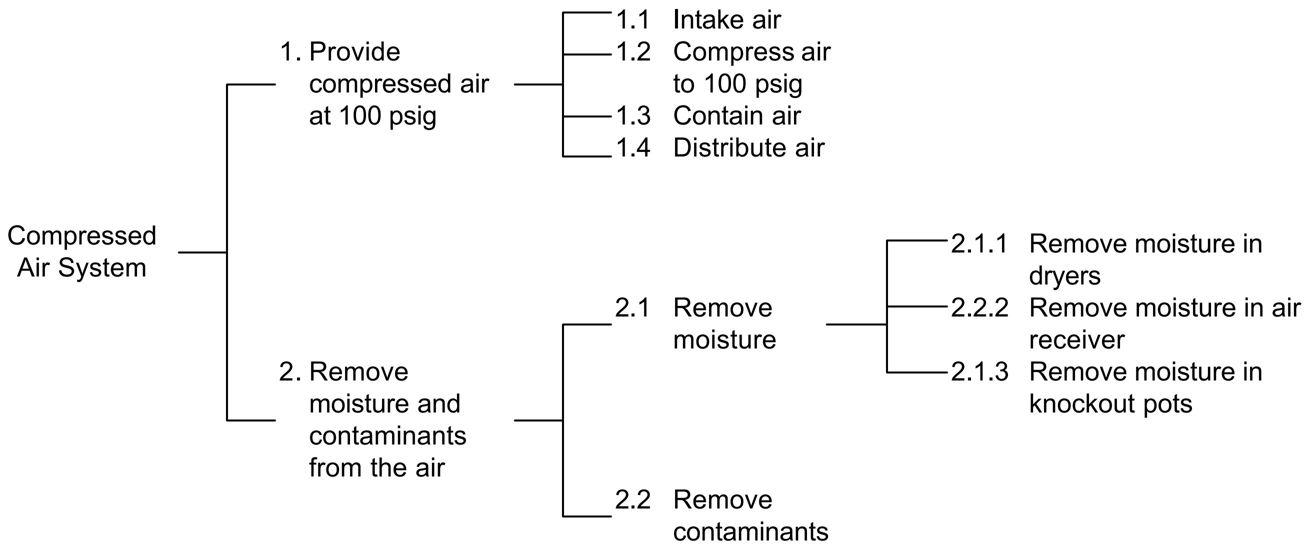
4.0 Subdivide the system by equipment or functions for analysis

This step defines the elements of a system that will provide the basic structure of the initial FMEA. These elements may be equipment items for a hardware approach or intended functions for a functional approach. Example structures for both approaches are illustrated on the next two pages.

Example of the hardware approach (bottom-up)



Example of the functional approach (top-down)



5.0 Identify potential failure modes for elements of the system

- **Premature operation**
- **Failure to operate at a prescribed time**
- **Intermittent operation**
- **Failure to cease operation at a prescribed time**
- **Accident of output or failure during operation**
- **Degraded output or operational capability**
- **Other unique failure conditions**

5.0 Identify potential failure modes for elements of the system

The list of typical failure conditions above applies to equipment items and functional statements. The next five pages provide examples of these conditions applied to a wide range of typical industrial equipment. Below is an example of the typical failure conditions applied to one functional statement.

Functional Failures of Interest

Function: Compress air to 100 psig

Typical Failure Condition		Specific Functional Failures to Consider
Premature operation	→	Compression starts prematurely – before the system is ready for operation – before the pressure decreases to the demand point for the compressor
Failure to operate at a prescribed time	→	Compression fails to start on demand
Intermittent operation	→	Compression does not always start on demand
Failure to cease operation at a prescribed time	→	Compression fails to stop when the required pressure is achieved
Loss of output or failure during operation	→	Compression does not produce compressed air
Degraded output or operational capability	→	Compression does not produce proper air pressure or volume
Other unique failure conditions	→	Someone is injured during compression operation Oil into the sewer during compression operation

Failure Modes for Common Types of Components

Component	Failure Mode
Pressure Vessel/Drum/Knockout pot	External leak External rupture Plugged Coil leak Coil rupture Coil fouled
Boiler (fired)	External leak External rupture Tube leak Tube rupture Tube plugged Tube fouled Overfired Underfired
Cooler	Tube leak Tube rupture Tube plugged Tube fouled
Pump	External leak External rupture Fails to start Fails off while running Starts prematurely Operates too long Operates at degraded head/flow performance (too fast, too slow, etc.)
Compressor/Blower/Fan	External leak External rupture Fails to start Fails off while running Starts prematurely Operates too long Operates at degraded head/flow performance (too fast, too slow, etc.)

Failure Modes for Common Types of Components (continued)

Component	Failure Mode
Mechanical power transmission assembly	Fails to start Fails off while running Structural member damaged
Cylinder/Piston assembly	External leak (cylinder) External rupture (cylinder) Internal leak (piston) Internal rupture (piston) Plugged Fails to start Fails off while running Starts prematurely Operates too long Operates too fast Operates too slow
Valves/Dampers	External leak External rupture Internal leak Plugged Fails to open Fails to close Fails to change position Spurious positioning Opens prematurely Closes prematurely
Pipe/Duct/Hose	External leak External rupture Plugged/Pinched/Kinked
Filter/Strainer	External leak External rupture Plugged Internal element rupture
Nozzle	Plugged Misdirected

Failure Modes for Common Types of Components (continued)

Component	Failure Mode
Fitting/Coupling	External leak External rupture
Relief device	External leak External rupture Plugged Fails to open on demand Fails to reseat Opens prematurely Closes prematurely
Flame arrester	External leak External rupture Mesh plugged Mesh ruptured
Sensor element	External leak External rupture Tap plugged Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal
Sensor switch	External leak External rupture Tap plugged Fails open Fails closed Activates at a lower setpoint Activates at a higher setpoint
Transmitter	External leak External rupture Tap plugged Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal
Controller	Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal

Failure Modes for Common Types of Components (continued)

Component	Failure Mode
Annunciator	Fails off Fails on Activates at a lower setpoint Activates at a higher setpoint
Gauges/Indicators/Recorders	Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal
Transducer	Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal
Programmable logic controller	Fails with no output signal Fails with a low output signal Fails with a high output signal Fails to respond to an input change Spurious output signal Calculation or interpretation error Sequencing error
Relay/Breaker/Fuse/Switch	Fails opened Fails closed Short circuit
Motor	Fails to start Fails off while running Starts prematurely Starts too late Operates too long Operates at degraded torque/rotational speed performance (runs backward, too fast, too slow, etc.)
Generator	High voltage Low voltage High current Low current Starts prematurely Operated too long
Conductor/Bus	Fails opened Shorts line to ground Shorts line to line

Failure Modes for Common Types of Components (continued)

Component	Failure Mode
Circuit board	Fails opened Shorts line to ground Shorts line to line Spurious output signal
Transformers	Fails with no output voltage/current Fails with a low output voltage/current Fails with a high output voltage/current
Uninterruptible power supply	Fails with no output voltage/current Fails to transfer correctly Fails with a low output voltage/current Starts prematurely Operates too long
Utility system	External leak External rupture Leak to/from process Rupture to/from process Fails with no supply from system Improper supply characteristics: • pressure • temperature • flow • composition • voltage • current
Human	Fails to perform a task Performs tasks in the wrong sequence Performs an additional task Performs the wrong task Performs a task improperly

6.0 Evaluate potential failure modes capable of producing problems of interest

- **Mission phase/operational mode**
- **Effects**
- **Causes**
- **Indications**
- **Safeguards**
- **Recommendations/remarks**

6.0 Evaluate potential failure modes capable of producing accidents of interest

Evaluating potential failure modes generally defines the following:

Mission phase/operational mode. A description of how the system is being used. This perspective is important for understanding the impacts of failure modes. More than one mission phase or operational mode may have to be considered for each potential failure mode.

Effects. The accidents that are expected if the failure mode occurs are often divided into the following categories:

Local effects	The initial changes in system conditions that will occur if the postulated failure mode occurs
Higher level effects	The change in condition of the next higher level of equipment or system function caused by the occurrence of the postulated failure mode
End effects	The overall effects on the system, typically related to one or more of the accidents of interest for the analysis. The end effect may be possible only if planned mitigating safeguards for the failure mode also fail

Causes. In a hardware-based FMEA, the causes are typically the failure modes of equipment at the next lower level of resolution for the system, as well as human errors and external events that cause equipment problems at this level of resolution. In a function-based FMEA, the causes are typically lower-level functional failures.

Indications. Indications are the identifiable characteristics that suggest to a crew member or some other inspector or troubleshooter that this failure mode has occurred. Indications can include visual, audible, physical, and odor clues.

Safeguards. Safeguards are the equipment, procedures, and administrative controls in place to help (1) prevent the postulated situation from occurring or (2) mitigate the effects if the situation does occur.

Recommendations/remarks. These are the suggestions for system improvements that the team believes are appropriate. Generally, they are suggestions for additional safeguards.

There are three basic levels of documentation possible for an FMEA analysis:

- **Complete.** Full descriptions for failure modes and a complete list of recommendations generated from the analysis
- **Streamlined.** Descriptions for failure modes that result in suggestions for improvement, along with the complete list of recommendations generated from the analysis
- **Minimal.** Complete list of recommendations generated from the analysis

Example from a Hardware-based FMEA

Machine/Process: Onboard compressed air system
Subject: 1.2.2 Compressor control loop
Description: Pressure-sensing control loop that automatically starts/stops the compressor based on system pressure (starts at 95 psig and stops at 105 psig)
Next higher level: 1.2 Compressor subsystem

Failure Mode	Effects			Causes	Indications	Safeguards	Recommendations/Remarks
	Local	Higher Level	End				
A. No start signal when the system pressure is low	Open control circuit	Low pressure and low air flow in the system	Interruption of the systems supported by compressed air	Sensor failure or miscalibration Controller failure or incorrect setting Wiring fault Control circuit relay failure Loss of power for the control circuit	Low pressure indicated on air receiver pressure gauge Compressor not operating (but has power and no other obvious failure)	Rapid detection because of quick interruption of the supported systems	Consider a redundant compressor with separate controls Calibrate sensors annually
B. No stop signal when the system pressure is high	• • •	• • •	• • •	• • •	• • •	• • •	• • •
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

Example from a Function-based FMEA

Machine/Process: Onboard compressed air system
Subject: 1. Provide compressed air at 100 psig
Description: Intake air, compress the air to 100 psig, and distribute the air (without loss) to the manufacturing tool stations or machine
Next higher level: Compressed air system

Failure Mode	Effects			Causes	Indications	Safeguards	Recommenda-tions/Remarks
	Local	Higher Level	End				
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
B. No/inadequate compressed air on demand	No air flow or pressure	No air flow to manufacturing	Interruption of the systems supported by compressed air	No/inadequate intake air No/inadequate air compression No/inadequate containment of compressed air No/inadequate air distribution flow path	Possibly no air pressure at the gauge on the air receiver or at the gauges for the tool stations (unless the flow path is blocked downstream of a gauge)	Rapid detection of quick interruption of the supported systems	Consider regular monitoring of the pressure differential across the intake air filter Consider checking the rain cap on the air intake annually Consider a redundant compressor
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

7.0 Perform quantitative evaluation (if necessary)

- Characterization of failure mode frequency
- Characterization of failure mode severity
- Characterization of failure mode risks

7.0 Perform quantitative evaluation (if necessary)

Quantifying the risks associated with potential failure modes of a system provides more precise results than qualitative analysis alone. Quantifying the risks of potential failure modes has many benefits, including the following:

- Overall levels of risk can be judged against risk acceptance guidelines, if such guidelines exist
- Risk-based prioritization of potential failure modes provides a highly cost-effective way of allocating resources (design, maintenance, etc.) to best manage the most significant risks
- Risk reductions can be estimated to help justify the cost of recommendations generated during the analysis

Volume 2, Chapter 2 of these *Guidelines* presents a wide range of approaches for quantifying the risks of potential system failure modes. The approaches range from very simple binning approaches to more complicated point estimates of frequencies and consequences. Regardless of the approach selected for a particular analysis, the information collected for each failure mode is generally included in the analysis table documentation, as shown in the following examples.

Example of Point Estimate Risk Calculations in an FMEA

Machine/Process: Onboard compressed air system

Subject: 1.2.2 Compressor control loop

Description: Pressure-sensing control loop that automatically starts/stops the compressor based on system pressure (starts at 95 psig and stops at 105 psig)

Next higher level: 1.2.2 Compressor subsystem

Failure Mode	Effects			Causes	Indications	Safeguards	Risk Prioritization			Recommendations/Remarks
	Local	Higher Level	End				Frequency	Cost	Risk	
A. No start signal when the system pressure is low	Open control circuit	Low pressure and low air flow in the system	Interruption of the systems supported by compressed air	Sensor failure or miscalibration Controller failure or incorrect setting Wiring fault Control circuit relay failure Loss of power for the control circuit	Low pressure indicated on air receiver pressure gauge Compressor not operating (but has power and no other obvious failure)	Rapid detection because of quick interruption of the supported systems	0.1/y	$500	$50/y	Consider a redundant compressor with separate controls Calibrate sensors annually
B. No stop signal when the system pressure is high	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

Example of Risk Categorizations in an FMEA

Machine/Process: Onboard compressed air system

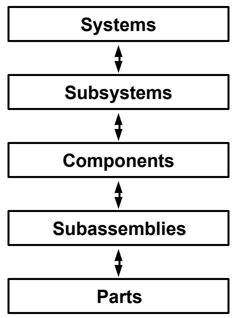
Subject: 1. Provide compressed air at 100 psig

Description: Intake air, compress the air to 100 psig, and distribute the air (without loss) to the manufacturing tool stations or machine

Next higher level: Compressed air system

Failure Mode	Effects			Causes	Indications	Safeguards	Risk Prioritization			Recommendations/Remarks
	Local	Higher Level	End				Frequency Category	Consequence Category	Risk Index Number	
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
B. No/inadequate compressed air on demand	No air flow or pressure	No air flow to air-operated valves	Interruption of the systems supported by compressed air	No/inadequate intake air No/inadequate air compression No/inadequate containment of compressed air No/inadequate air distribution flow path	Possibly no air pressure at the gauge on the air receiver or at the gauges for the tool stations (unless the flow path is blocked downstream of a gauge)	Rapid detection of quick interruption of the supported systems	4	2	6	Consider regular monitoring of the pressure differential across the intake air filter Consider checking the rain cap on the air intake annually Consider a redundant compressor
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

8.0 Transition the analysis to another level of resolution (if necessary or otherwise useful)



8.0 Transition the analysis to another level of resolution (if necessary or otherwise useful)

Hardware approach (bottom-up). Summaries of important issues at higher levels (systems and subsystems) are sometimes needed. When this type of information is needed, the results of lower-level analyses may be compiled into composite analyses for the higher levels. This includes composite risk characterizations.

Functional approach (top-down). Further subdivision and analysis of system functions occur only if decision makers need information at a more detailed level. Often, only a few areas must be expanded further.

Example of a Higher Level, Hardware-based FMEA

Machine/Process: Onboard compressed air system

Subject: 1.2 Compressor subsystem

Description: Equipment used to compress the intake air to 100 psig (including the compressor and its control loop, the discharge relief valve, and associated piping)

Next higher level: 1. Compression system

Failure Mode	Effects			Causes	Indications	Safeguards	Recommenda-tions/Remarks
	Local	Higher Level	End				
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •
B. Fails to provide air at 100 psig	No air pressure and the compressor not operating	No air flow/ pressure	Interruption of the systems supported by compressed air	Compressor control loop – no start signal when the system pressure is low Compressor – fails to operate Relief valve – spuriously opens Piping – leak/ rupture	Low pressure indicated on the air receiver pressure gauge	Rapid detection because of quick interruption of the supported systems	Consider a redundant compressor (diesel powered) with separate controls Calibrate sensors annually Replace the relief valve annually
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

Example of a Lower Level, Function-based FMEA

Machine/Process: Onboard compressed air system

Subject: 1.2 Compress air to 100 psig

Description: Compress intake air to 95 to 105 psig with enough volume to meet production tool/ machine needs

Next higher level: 1. Provide compressed air at 100 psig

Failure Mode	Effects			Causes	Indications	Safeguards	Recommenda-tions/Remarks
	Local	Higher Level	End				
A. Compressor starts prematurely	Unexpected compressor operation	Unexpected air pressure/flow Possible high pressure in the system	Possible injury (especially during maintenance work) Possible system damage from high pressure	Compressor control system sends false signal Manual override of compressor control system	Operating compressor when it is supposed to be stopped	Lockout/tagout of compressor during maintenance Pressure relief valve at the discharge of the compressor for preventing equipment damage	Consider removing the manual override button for the compressor Calibrate pressure sensing switch annually
B. Compressor fails to start on demand	• • •	• • •	• • •	• • •	• • •	• • •	• • •
• • •	• • •	• • •	• • •	• • •	• • •	• • •	• • •

9.0 Use the results in decision making

- System improvements
- Maintenance task planning
- Spare parts inventories
- Troubleshooting guidelines

9.0 Use the results in decision making

System improvements. FMEA results generally present a number of specific, practical suggestions for reducing accident exposure associated with a specific system. These suggestions often cover a range of issues from changes in design configuration and equipment specifications to better operating and maintenance practices. The qualitative and quantitative results from FMEAs also present the case for implementing the suggestions.

Maintenance task planning. One very prominent use of FMEAs is in maintenance task planning. Approaches like reliability-centered maintenance and other similar tools use the systematic analysis of FMEA as a basis for establishing effective maintenance plans.

Spare parts inventories. Another prominent use of FMEAs is in determining the types and numbers of spare parts to have on hand.

Troubleshooting guidelines. FMEAs that address indications and isolation of failures contain the information needed to develop highly effective troubleshooting guidelines.