CHAPTER 2

Solution 2.1

Which of the following statements are true about why Failure Mode and Effects Analyses (FMEAs) need to be supported by well-understood and communicated principles? (Select all that apply.)

1. The entire FMEA process needs to be driven by correct philosophy, meaning that the approach is based on proven principles that support achieving high safety and reliability. (True)

2. The essence of "guiding principles" is the specific procedures that the FMEA team follows once the FMEA has begun. (False. The FMEA guiding principles are the foundation for excellent FMEAs. The procedures are the detailed steps of how to implement FMEAs.)

3. If one's approach to doing FMEAs is based on incorrect objectives or wrong principles, then the results will be less than desired. (True)

4. Having the right philosophical approach to doing FMEAs applies to System and Design FMEAs, but not to Process FMEAs. (False. Having the right philosophical approach to doing FMEAs applies to all types of FMEAs.)

Solution 2.2

Which of the following statements about "guiding principles" is correct and why? (Select the correct one.)

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1. “Select FMEA projects based on preliminary risk assessment” means that once the project has been selected, every item in the bill of material must receive an FMEA. (False. “Select FMEA projects based on preliminary risk assessment” means to use risk criteria to identify which items in a bill of materials warrants the rigorous FMEA procedure.)

2. “Keep the focus on areas of concern and risk” means that if the FMEA team has the correct membership and is led by a skilled facilitator, it is a good practice to limit FMEA entries to areas of genuine concern to one or more of the team members. (True. Limiting the FMEA discussion to areas of concern to at least one team member keeps the team from going off track and wasting time.)

3. “Fully execute all actions to ensure risk is reduced to an acceptable level” means that all recommended actions must be reevaluated after execution and the assessed risk is zero. (False. In most cases it is not possible to bring risk to zero. The objective is to reduce risk to an acceptable level.)

4. “Management plays a key role in establishing and supporting an effective FMEA process” means that management must attend all FMEA meetings to ensure they are done properly. (False. The FMEA team needs to be comprised of the correct team members. Having management present at all FMEA team meetings can stifle important dialog and reduce overall effectiveness.)

Solution 2.3

FMEAs should align with and support “Design for Reliability.” Which of the following statements embody this relationship? (Select all that are correct.)

1. Knowing how to calculate reliability is important, but knowing how to achieve reliability is more important. (True)

2. FMEA is a key tool in calculating reliability. (False. Calculating reliability is not a primary objective of FMEA.)

3. Design for Reliability practices must begin early in the design process and be well integrated into the overall product development cycle. (True)

4. Design for Reliability tools precede FMEAs. (False. FMEA is one of the key tools of Design for Reliability.)

CHAPTER 3

Solution 3.1

Which of the following are true statements about FMEA? (Select all that apply.)

1. An FMEA is an engineering analysis done by the most knowledgeable person on the engineering team. (False. An FMEA is an engineering analysis done by a cross-functional team of subject-matter experts.)

2. Part of the FMEA is to identify and carry out corrective actions to address the most serious concerns. (True)
3. The primary objective of an FMEA is to understand the design. (False. The primary objective of an FMEA is to improve the design.)

4. Risk assessment is not part of the FMEA procedure. (False. Risk assessment is an integral part of the FMEA procedure.)

Solution 3.2

Hypothetical Scenario: A hydraulic pump company is developing a new line of hydraulic pumps that has a new material for the pump piston never before used in hydraulic pumps. (Answer True or False each of the following.)

1. The current hydraulic test procedures should be used. The FMEA should not be used to recommend modifications to pump or piston test procedures. (False. One of the uses of FMEA is to improve the test procedures, and this would be especially important given the new piston material.)

2. The correct sequence is to first test the new pump with the new piston material, and then perform an FMEA to verify the design. (False. FMEAs should be done before testing begins in order to make design improvements as early as possible and to make improvements to the test procedures.)

3. A Pump System FMEA would include system safety, system integration, and interfaces between the pump subsystems. (True)

4. A Piston Design FMEA should be done early in the product development process before the piston design is frozen. (True)

Solution 3.3

Indicate whether each statement about the application of FMEA is true or false.

1. One of the uses of FMEA is to improve the reliability of the product. (True)

2. One of the uses of FMEA is to improve the safety of the product. (True)

3. FMEAs can be used to improve the quality of the manufacturing process. (True)

4. One of the primary applications of FMEA is to fix field problems. (False)

Solution 3.4

In an FMEA, which of the following is true about a “function”? (Select all that apply.)

1. A “function” is what the item is intended to do, without respect to any standard of performance. (False. A function description needs to include the standard of performance.)

2. A “function” is what the item is intended to do, usually to a given standard of performance. (True)

3. There is one function for each item in an FMEA. (False. There can be many functions for an item.)
4. The function description in an FMEA must include the consequence or impact on the end user. (False. An effect must include the consequence or impact on the end user, not a function.)

Solution 3.5
In an FMEA, which of the following is true about a “failure mode”? (Select all that apply.)

1. A “failure mode” is the specific reason for the failure. (False. A “failure mode” is the manner in which the item or assembly could fail to meet the intended function and its requirements.)
2. A “failure mode” is the manner in which the item or assembly could fail to meet the intended function and its requirements. (True)
3. In an FMEA, there is one failure mode for each function. (False. There can be many failure modes for each function.)
4. The failure mode description in an FMEA must include the consequence or impact on the end user. (False. An effect must include the consequence or impact on the end user, not a failure mode.)

Solution 3.6
In an FMEA, which of the following is true about an “effect”? (Select all that apply.)

1. An “effect” is the specific reason for the failure. (False. An “effect” is the potential consequence or impact of the failure to the system or end user.)
2. An “effect” is the potential consequence or impact of the failure to the system or end user. (True)
3. An “effect” is the manner in which an item does not accomplish its intended functions. (False. This describes a failure mode, not an effect.)
4. None of the above. (False)

Solution 3.7
In an FMEA, which of the following is true about a “control”? (Select all that apply.)

1. A “control” is the specific recommendation by the FMEA team to control the risk associated with the cause of failure. (False. Controls are the methods or actions that are planned or currently in place to reduce or eliminate the design-related risk associated with the cause of failure. Recommendations need to be in the Recommended Actions column of the FMEA.)
2. A “control” needs to be taken to the level of root cause of the failure. (False. Causes in the FMEA need to be taken to the level of root cause, not controls.)
3. There are often two types of controls identified in an FMEA: prevention-type controls and detection-type controls. (True)
4. “Controls” are the methods or actions that are not currently planned, but need to be done to reduce or eliminate the design-related risk associated with the cause of failure. (False. Controls are methods or actions that are planned or currently in place.)

5. “Controls” are the methods or actions that are planned or currently in place to reduce or eliminate the design-related risk associated with the cause of failure. (True)

**Solution 3.8**

In an FMEA, which of the following is true about “Risk Priority Number (RPN)”?
(Select the best answer.)

1. An “RPN” is the sum of Severity, Occurrence, and Detection rankings. (False. An “RPN” is the product of Severity, Occurrence, and Detection rankings, not the sum.)

2. An “RPN” is the product of Severity and Occurrence rankings. (False. An “RPN” is the product of Severity, Occurrence, and Detection rankings.)

3. An “RPN” is the product of Severity, Occurrence, and Detection rankings. (True)

4. None of the above. (False)

**Solution 3.9**

Using the Automotive Industry Action Group (AIAG, 4th edition, 2008) severity scales (reference Figures 3.2 and 3.3), select an appropriate severity ranking for the following examples of effects:

1. Item: Power steering pump
   Function: Delivers hydraulic power for steering by transforming oil pressure at inlet [xx psi] into higher oil pressure at outlet [yy psi] during engine idle speed
   Failure Mode: Inadequate outlet pressure less than [yy psi]
   Effect (Local: Pump): Low pressure fluid goes to steering gear
   Effect (Next level: Steering Subsystem): Increased friction at steering gear
   Effect (End user): Increased steering effort with potential accident during steering maneuvers
   **Answer:** Severity ranking 10

2. Item: Shaft (part of rock grinding equipment)
   Function: Provide mechanical transfer of [xx] rotational force while maintaining linear and angular stability
   Failure Mode: Shaft fractured
   Effect (Local: Shaft): No torque output (does not transport energy)
   Effect (Next level: Grinder Subsystem): Rock grinder teeth do not move
   Effect (End user): No rocks are pulverized, and product order is not filled
   **Answer:** Severity ranking 8
   Function: Induction harden shafts using induction hardening machine, with  
   hardness to specification #123, and case depth [xx] inches  
   Failure Mode: Shaft hardness too soft  
   Effect (In plant): 100% scrap  
   Effect (End user): Potential shaft fracture with complete loss of  
   performance  
Answer: Severity ranking 8  
4. Process Step: Clamp bicycle upper frame tube in weld fixture  
   Function: Securely clamp upper tube in weld fixture, without damaging part  
   and without looseness or movement of part in fixture  
   Failure Mode: Tube not clamped securely (loose)  
   Effect (In plant): Tube position incorrect, with possible defective welds  
   from tube shifting, and potential for 100% scrap  
   Effect (End user): If upper tubes get out of plant with defective welds,  
   the bicycle frame could collapse, with potential rider injury  
Answer: Severity ranking 10  

Solution 3.10  
Perform the following steps as part of a hypothetical Design FMEA on an inexpensive wooden pencil:  

1. Assuming “pencil system” is the highest level of the system hierarchy, identify  
   and write down two additional items from the wooden pencil system  
   hierarchy.  
   Possible answers for pencil system hierarchy:  
   Wooden shaft  
   Lead shaft  
   Eraser  
   Ferrule  
   Compare answers to the above and see if similar. Review Chapter 3 definitions  
   and examples as needed.  
2. For the item “Pencil system”, identify and write down two functions of a  
   wooden pencil.  
   Possible answers for pencil system functions:  
   To provide a safe and easy-to-use tool to write on paper, according to usages  
   defined in technical requirements  
   To provide an easy way to completely erase mistakes  
   The pencil wood and lead must be easily sharpened using a normal pencil  
   sharpener, bringing the pencil back to full operation
Compare student answers to the training answers and see if similar. Ensure function descriptions include a standard of performance. Review Chapter 3 definitions and examples as needed.

3. Identify and write down two potential failure modes of the first function.

**Answer:** Refer to the “Failure Mode” column in Figure 1, “Example of partial design FMEA on pencil system for training purposes.” Find in the spreadsheet the example failure modes for the identified function. Compare student answers to the training answers and see if similar. Ensure failure modes describe the **manner in which** the item could fail to meet the function and its requirements. Review Chapter 3 definitions and examples as needed.

4. Identify and write down the potential effect of the first failure mode.

**Answer:** Refer to the “Effect” column in Figure 1. Find in the spreadsheet the example effect for the identified failure mode. Compare student answers to the training answers and see if similar. Ensure the effect is taken to the system or end user. Review Chapter 3 definitions and examples as needed.

5. Rank the severity of the effect, using the AIAG 4th edition severity scale. Note that in this scale, “vehicle” can be replaced by “item.”

**Answer:** Refer to the “Severity” column in Figure 1. Find in the spreadsheet the severity for the identified effect. Compare student answers to the training answers and see if similar. Review Chapter 3 definitions and examples as needed.

6. Identify and write down two potential causes of the first failure mode.

**Answer:** Refer to the “Cause” column in Figure 1. Find in the spreadsheet the example causes for the identified failure mode. Compare student answers to the training answers and see if similar. Ensure the cause description is a root cause. Review Chapter 3 definitions and examples as needed.

7. Identify and write down one prevention-type design control for the first cause.

**Answer:** Refer to the “Design Controls (Prevention)” column in Figure 1. Find in the spreadsheet the example prevention-type design control for the identified cause. Compare student answers to the training answers and see if similar. Review Chapter 3 definitions and examples as needed.

8. Identify and write down one detection-type design control for the first cause.

**Answer:** Refer to the “Design Controls (Detection)” column in Figure 1. Find in the spreadsheet the example detection-type design control for the identified cause. Compare student answers to the training answers and see if similar. Review Chapter 3 definitions and examples as needed.

9. Assuming either the severity or the RPN is high enough to require action, identify and write down two potential recommended actions to address the risk from the first failure mode/cause.

**Answer:** Refer to the “Recommended Action” column in Figure 1. Find in the spreadsheet the example recommended actions for the identified failure mode/cause. Compare student answers to the training answers and see if similar. Review Chapter 3 definitions and examples as needed.
<table>
<thead>
<tr>
<th>Function(s)</th>
<th>Failure Mode(s)</th>
<th>Effect(s)</th>
<th>Cause(s)</th>
<th>Design Controls (Prevention)</th>
<th>Design Controls (Detection)</th>
<th>Design Action(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pencil wood</td>
<td>To provide a</td>
<td>User unable</td>
<td>Type of wood too soft for</td>
<td>Pencil system design guide</td>
<td>Pencil shaft strength test</td>
<td>1. Review supplier process to control hardness of supplied wood to meet...</td>
</tr>
<tr>
<td>shaft breaks during normal usage</td>
<td>safe and easy-</td>
<td>to write on paper</td>
<td>high-force users</td>
<td>#123</td>
<td>#105</td>
<td>2. Add pencil hardness agents to pencil system design guide #123.</td>
</tr>
<tr>
<td></td>
<td>to provide a</td>
<td></td>
<td>Wood shaft diameter too small</td>
<td>Pencil system FEA</td>
<td></td>
<td>3. Develop wood hardness test regimen and add to pencil test plans.</td>
</tr>
<tr>
<td>Pencil lead</td>
<td>To provide an</td>
<td>User unable to write</td>
<td>Type of lead material too brittle</td>
<td>Graphite material spec</td>
<td>User writing test #A0c</td>
<td>1. Modify pencil shaft finish spec #1334 to include wood smoothness agent.</td>
</tr>
<tr>
<td>breaks during normal usage</td>
<td>easy way to</td>
<td></td>
<td>Wood lead extends too far from wood enclosure due to improper sharpening</td>
<td>#789</td>
<td></td>
<td>2. Perform Process FMEA on pencil exterior paint and finish processes.</td>
</tr>
<tr>
<td>Pencil is not easy to use by an average writer</td>
<td>To provide an</td>
<td>User able to write, with reduced performance and comfort</td>
<td>Wood exterior finish too rough due to improper finish specification</td>
<td>Pencil lead finish spec #1234</td>
<td>User writing test #A0c</td>
<td>3. Conduct customer clinic with typical pencils to verify ergonomics.</td>
</tr>
<tr>
<td>Eraser does not erase graphite inscriptions on writing surface</td>
<td>To provide an</td>
<td>User cannot erase, resulting in customer dissatisfaction</td>
<td>Excessive eraser wear due to insufficient (dry-based) composition in eraser material</td>
<td>Pencil eraser design guide</td>
<td>User writing test #A0c</td>
<td>1. Perform DOE eraser composition to optimize erasing performance.</td>
</tr>
<tr>
<td>Eraser falls off pencil during normal use</td>
<td>Easy way to</td>
<td>User cannot erase, resulting in customer dissatisfaction</td>
<td>Eraser ferrule too large for eraser size</td>
<td>GD&amp;T on eraser ferrule, pencil eraser</td>
<td></td>
<td>2. Add erasing evaluation to user writing test #A0c.</td>
</tr>
<tr>
<td>Eraser makes objectionable marks on paper</td>
<td></td>
<td></td>
<td>Eraser ferrule has insufficient strength due to inadequate crimp configuration</td>
<td>User writing test #A0c</td>
<td></td>
<td>3. Review eraser design guide #123 and modify based on DOE results.</td>
</tr>
<tr>
<td>Pencil wood/lead are easily sharpened using normal pencil sharpener bringing the pencil back to full operation</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Pencil wood does not sharpen</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load breaks off during sharpening</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**FIGURE 1.** Example Design FMEA on a Pencil System, for training purposes (incomplete). GD&T, Geometric Dimensioning and Tolerancing; FEA, Finite Element Analysis.
CHAPTER 4

Solution 4.1

Which of the following statements supports the rationale for FMEA selection? (Select all that apply.)

1. In order to reduce risk, FMEAs must be done on every subsystem, component, and part. (False. Doing FMEAs on every subsystem and component wastes resources and undermines the quality of FMEAs that are needed.)
2. FMEAs are time intensive and should be done on items that are selected based on defined risk criteria. (True)
3. Top management has the sole discretion of when to do FMEAs. (False. The decision to do FMEAs should be jointly shared by management and engineering.)
4. The design or process owner has the sole discretion of when to do FMEAs. (False. The decision to do FMEAs should be jointly shared by management and engineering.)

Solution 4.2

Which of the following risk criteria should be considered when deciding which FMEAs to do on a given project? (Select all that apply.)

1. The degree of new technology in the design. (True)
2. The cost of the piece part. (False. Although cost of potential failures is considered, piece part cost is not usually a risk criterion for FMEA selection.)
3. The degree of field failures on similar parts. (True)
4. The availability of potential FMEA team members to attend meetings. (False. FMEA projects should be selected based on risk criteria, and then the subject-matter expert team selected.)

Solution 4.3

Which of the following statements about the timing of Design FMEA projects are true? (Select all that apply.)

1. Design FMEAs should be started before a design concept has been identified and completed before product design has begun. (False. Starting FMEAs before the design concept has been determined is too early. The right tool would be a Concept FMEA. And completing FMEAs before design has begun is too early as the FMEA is best done coincident with product design.)
2. Design FMEAs should be started shortly after a design concept has been determined and completed before design freeze. (True)
3. Design FMEAs should be started shortly after a design concept has been determined and completed sometime after testing and before the product gets into the hands of the consumer. (False. Completing FMEAs after testing is too
late. FMEAs need to be done before the design is frozen in order to improve the design, and before testing begins in order to impact the quality of tests.)

4. Design FMEAs should be started after the design has been completed and completed before launch of the new product. (False. Completing FMEAs after the design has been completed is too late. FMEAs need to be done before the design is frozen in order to improve the design.)

Solution 4.4

In the example of Preliminary Risk Assessment for the all-terrain bicycle project, one of the risk criteria columns is “Risk identified by System FMEA.” What does this mean?

**Answer:** A System FMEA can identify components whose failure will cause high risk to the system or end user, and where the risk is not reduced to an acceptable level through the System FMEA by itself. “Risk identified by System FMEA” refers to such subsystems or components. Refer also to “single-point failure,” as described in Chapter 7.

Solution 4.5

The Incredible Bike Company (IBC) has system design, system integration, and system assembly responsibilities for the new all-terrain bicycle. They decide to use FMEAs to ensure the safety and reliability of the next generation of all-terrain bicycles. The bicycle seat is made of a new material for comfort and durability, and the seat design is considered critical based on Preliminary Risk Assessment. Company X has responsibility for the seat and does the seat design; however, they outsourced the seat manufacturing to company Y. Company Y ships the seats to company X, who verifies they meet all requirements and ships to IBC for assembly as part of the new all-terrain bicycle. The question is, who has responsibility for the all-terrain System FMEA, all-terrain Process FMEA, seat Design FMEA, and seat Process FMEA, and why?

**Answer:** The IBC should perform and execute the all-terrain System FMEA and all-terrain Process FMEA. Providing the original equipment manufacturer (OEM) has responsibility for system design and integration, they should be performing and executing the System FMEA. And provided the OEM has system manufacturing and assembly responsibilities, they should be performing and executing the system Process FMEA. Company X should perform and execute the Design FMEA for the seat. Since they have responsibility for the design of the new seat, they have the subject-matter experts in seat design and are in the best position to do the Design FMEA. Company Y performs and executes the Process FMEA for the seat. Since they manufacture the seat, they have the resources and expertise regarding seat manufacturing and should do the Process FMEA.

CHAPTER 5

Solution 5.1

In an FMEA, which of the following are true statements about the severity, occurrence, and detection scales? (Select all that apply.)
1. The scales from the selected FMEA standard must be used exactly as is, without any modification. (False. Companies are encouraged to tailor the FMEA scales to their unique needs.)

2. In using the detection scale, the higher the rating on the scale, the lower the detection-related risk. (False. The higher the rating on the detection scale means the higher the detection-related risk.)

3. In using the severity scale, severity should be thought of as the severity of the failure mode. (False. Severity should be thought of as the severity of the effect of the failure mode.)

4. In using the occurrence scale, the FMEA team should use objective data, if available, to establish the occurrence rating. (True)

Solution 5.2

Which of the following are true statements about FMEA preparations? (Select all that apply.)

1. Past FMEAs should be easily accessible to the FMEA team. (True)

2. Warranty, recalls, and other field history are part of Failure Review and Corrective Action System (FRACAS) but not needed in preparation for FMEAs. (False. Information about product warranty, recalls, and other field failure data are key elements of FMEA preparation.)

3. Test procedures are needed to provide the functional requirements. (False. Test procedures are needed as part of evaluation of design controls, not to provide functional requirements. The engineering technical specifications are the best source for functional requirements.)

4. An FMEA interface matrix is a chart showing which interfaces must be considered in the analysis and the type of interface. (True)

5. FMEA team meetings with the subject-matter experts should begin as soon as the FMEA team is established, and the various preparation items gathered in between meetings. (False. FMEA preparation should be completed before the FMEA team meetings with subject-matter experts in order to ensure that the meetings are effective and valuable time is not wasted.)

Solution 5.3

Reference Figure 5.7, "System FMEA block diagram example—all-terrain bicycle.” Name three missing elements from the System FMEA Block Diagram.

1. The Rider interfaces with the Sprocket-Pedal Subsystem, both physically and with energy transfer.

2. The Suspension Subsystem connects to the Front Wheel Subsystem (through the front forks) with both physical and energy transfer interfaces.

3. The Front Wheel Subsystem physically connects to the frame (through the front forks)
Solution 5.4

Which of the following would usually be part of a System FMEA team? (Select all that apply.)

1. Design engineer (True. However, the individual design engineers for the various subsystems can be rotated at specific times into the System FMEA meetings in order to avoid the FMEA team getting too large.)
2. System engineer (True)
3. Manufacturing engineer (True)
4. Reliability or quality representative (True)
5. Director over department of items being analyzed (False. Unless the director is a subject-matter expert that is essential to the System FMEA team, it is not a good practice to have a director in the meetings, as the team may lose its objectivity and creativity.)
6. System test engineer (True)
7. Service or field representative (True)

Solution 5.5

The purpose of an FMEA Block Diagram is (select all that are true):

1. To document the primary functions of the item. (False. The purpose of an FMEA Block Diagram is to visually show the scope of the FMEA including interfaces. Visually showing primary functions is one of the purposes of the Functional Block Diagram.)
2. To document the primary failure modes of the item. (False. The purpose is to visually show the scope of the FMEA including interfaces.)
3. To visually show the scope of the FMEA including interfaces. (True)
4. To visually show the timing of the FMEA. (False. Timing of the FMEA is not part of the purpose of the FMEA Block Diagram.)

Solution 5.6

The FMEA facilitator is trying to determine when to begin holding the FMEA meetings with the subject-matter expert team. (Select all that are true.)

1. Begin holding FMEA meetings as soon as the decision to do the FMEA has been made. (False. This would not allow time to do proper preparation.)
2. Begin holding FMEA meetings as soon as all the preparation steps have been completed. (True)
3. Begin holding FMEA meetings after the FMEA facilitator has met with each team member separately and received their input. (False. This would miss important FMEA preparation steps and would also miss the FMEA team synergy and dialog.)
4. Begin holding FMEA meetings after the FMEA facilitator has filled out the FMEA worksheet. (False. This would miss important FMEA preparation steps and would also miss the FMEA team synergy and dialog. FMEAs should be supported by a properly selected team.)

Solution 5.7

Which of the following are important elements of good FMEA preparation? (Select all that apply.)

1. The company organization structure (False. This is not typically part of FMEA preparation.)
2. Technical specifications of the item being analyzed with FMEA (True)
3. Schematics of all subsystems outside the scope of the FMEA (False. Although understanding adjacent subsystems that are interfaced with the item being analyzed can be useful, schematics of all subsystems are not relevant to the scope of the FMEA.)
4. Field history of similar items to the scope of the FMEA (True)
5. A visual representation of the scope of the FMEA (True)
6. Past FMEAs of similar items to the scope of the FMEA (True)
7. All FMEAs in the company archive (False. This would be unnecessary to the scope of the FMEA project.)

Solution 5.8

A Design FMEA will be done on the design of a flashlight. List six examples of information that should be gathered prior to the first meeting with the FMEA team. Answer: The student answers should be similar to the following “gather information” for a flashlight Design FMEA.

- Flashlight Bill of Materials (System hierarchy)
- Past flashlight Design FMEAs
- Flashlight field history
- Flashlight engineering requirements (functional, performance, operating environments, etc.)
- Flashlight drawings and schematics
- Government or safety regulations that apply to flashlights
- Flashlight test procedures
- Preliminary Design Verification Plan for the flashlight
- Preliminary test data for flashlight (if available)
- FMEA Block Diagram, Parameter Diagram (P-Diagram), FMEA interface matrix, and Functional Block Diagram for flashlight
- Results of flashlight design concept selection or trade-off studies, if applicable
- Actual flashlight (similar to design intent)
List of specific design changes for new flashlight project
Other documents and information that highlight the nature of the flashlight design concept

Solution 5.9

Draw an FMEA Block Diagram for the flashlight. Be sure to include physical connections and energy transfers as well as the interfaces.

Answer: The drawing should be similar to Figure 2, "FMEA Block Diagram example of a flashlight." Ensure that physical connections and energy transfers are clearly identified as well as interfaces.

Solution 5.10

A Process FMEA will be done on the assembly of a flashlight. List six examples of information that should be gathered prior to the first meeting with the FMEA team.

Answer: The student answers should be similar to the following "gather information" for a flashlight Process FMEA.

Flashlight Bill of Materials
Flashlight Bill of Process
Solution 5.11

Scenario: You are preparing to lead a System FMEA on the all-terrain bicycle. Review the section titled “All-Terrain Bicycle Functional/Technical Specifications” in Appendix C, “All-Terrain Bicycle Documents.” Answer these questions:

The Front suspension has a requirement: “Should withstand g-force acceleration to 3g, above which it is considered abusive.” Should this requirement be part of the all-terrain System FMEA, and if so, how would it be used?

Answer: During the ground rules and assumptions portion of FMEA preparation, the team will need to consider whether abuse of the all-terrain bicycle will be within the scope of the analysis. The specification clearly says that g-forces above 3g are considered abusive. The team may wish to ignore any g-forces above 3g. The 3g limit would carry over to the function column of the System FMEA as one of the primary functions, such as “the bicycle must be able to safely and reliably withstand g-forces up to 3g while riding on all surfaces, environments, and maneuvers, according to the customer usage document.”

The Gears have a requirement: “Ease of pedaling—should be able to move bicycle with 5 Nm torque on first gear.” Should this requirement be part of the all-terrain System FMEA, and if so, how would it be used?

Answer: The ease of pedaling requirement should be used in the function column of the System FMEA as one of the primary functions. For example, one of the all-terrain bicycle functions might be “The rider should be able to easily pedal the bicycle forward in first gear applying 5 Nm of torque.”

What type of requirement seems to be missing from the section titled “All-Terrain Bicycle Functional/Technical Specifications” of the “All-Terrain Bicycle Documents” in Appendix C?

Answer: The requirements in the document cover subsystem usage, subsystem-to-user interface, and subsystem-to-environment interface. Missing are requirements
related to subsystem-to-subsystem interfaces. Example might be steering while braking maneuvers to avoid loss of control of bicycle by rider.

**Solution 5.12**

Refer to the “Operating Conditions” table in Appendix C, “All-Terrain Bicycle Documents.” How should information like this be used in FMEA applications?

**Answer:** The Operating Conditions table of the bicycle performance requirements document describes the operating and environmental profile that is expected for the all-terrain bicycle. This information is important when defining the “standard of performance” of primary FMEA functions. If a “Requirements” column is used, the operation conditions may define the requirements associated with corresponding functions. Failures often result from usages that occur outside the operating conditions envelope. This is why it is important for the FMEA team to agree on the failure definition and how the team will deal with usages outside of normal operating conditions.

**CHAPTER 6**

**Solution 6.1**

**Hypothetical Scenario:** A System FMEA is planned for the all-terrain bicycle. Which of the following should be included within the scope of the all-terrain System FMEA? (Select all that apply.)

1. The interfaces between the bicycle subsystems (True)
2. The interactions between the bicycle and the rider (True)
3. The components of the bicycle (False. The individual components of the bicycle would be part of component Design FMEAs.)
4. The all-terrain bicycle assembly process (False. The bicycle assembly process would be taken up in the all-terrain Process FMEA.)

**Solution 6.2**

Which of the following is an example of an effect in the Hand Brake Subsystem Design FMEA? (Select all that apply.)

1. Bicycle wheel does not slow down when the brake lever is pulled, potentially resulting in accident. (True)
2. Cable binds due to inadequate lubrication or poor routing. (False. This would be an example of a Cause.)
3. Provide the correct level of friction between brake pad assembly and wheel rim to safely stop bicycle in the required distance, under all operating conditions. (False. This would be an example of a Function.)
4. Insufficient friction delivered by hand brake subsystem between brake pads and wheels during heavy rain conditions. (False. This would be an example of a Failure Mode.)
Solution 6.3

FMEA teams sometimes get confused between failure mode, effect, and cause in an FMEA. Which of the following are true statements about a failure mode, effect, and cause in an FMEA? (Select all that apply.)

1. The "cause" is the cause of the effect. (False. The "cause" is the cause of the failure mode, not the cause of the effect.)
2. The "cause" is the cause of the failure mode. (True)
3. The "effect" is related to the cause. (False. The "effect" is related to the failure mode, not the cause.)
4. The "effect" is related to the failure mode. (True)

Solution 6.4

Which of the following apply to prevention-type design controls? (Select all that apply.)

1. Prevention-type design controls are part of the basis for determining the detection ranking. (False. Prevention-type design controls are part of the basis for determining the occurrence ranking, not the detection ranking.)
2. Prevention-type design controls describe how a cause or failure mode can be prevented based on newly recommended actions. (False. Prevention-type design controls describe how a cause or failure mode can be prevented based on current or planned actions, not on newly recommended actions.)
3. Prevention-type design controls describe how a cause or failure mode can be prevented based on current or planned actions. (True)
4. Prevention-type design controls are part of the basis for determining the occurrence ranking. (True)

Solution 6.5

Which of the following statements are true about failure mechanisms? (Select all that apply.)

1. Understanding the underlying failure mechanism will help to generate effective recommendations to resolve the problem and improve the design. (True)
2. Understanding the underlying failure mechanism does not help to ensure proper tests are developed to detect the failure mode and its cause. (False. Understanding the underlying failure mechanism is critical to ensuring proper tests are developed to detect the failure mode and its cause.)
3. Failure mechanisms are the physical, chemical, thermodynamic, or other processes that result in failure. (True)
4. An example of a failure mechanism is electrical wiring. (False. Electrical wiring is a component and by itself does not describe the physical, chemical, thermodynamic, or other processes that result in failure.)
5. An example of a failure mechanism is metal fatigue. (True)
Solution 6.6

It is important to identify the primary functions in the Function column of an FMEA. There are a number of different types of functions. List three function types.

Answer: The three types of functions should be similar to the list of functions directly below:

- Basic functions (the primary purpose of a product, usually obtained from requirements or specification documents)
- Interface functions (from the FMEA Block Diagram or FMEA interface matrix)
- Reliability functions (life of the product)
- Product appeal functions
- Ergonomic functions
- Human interaction functions
- Legal and regulatory functions
- Functions relating to installation of a product to mating components
- Packaging and shipping functions
- Fluid retention functions
- Service functions
- Storage functions
- Injury prevention functions (prevent a product from causing problems to the user, such as excess vibration, noise, odor, particle contamination, etc.)
- Self-protection functions (protect people from harm during manufacture, assembly, or use)
- Design for manufacturing or assembly functions

Solution 6.7

Interfaces must be covered in the scope of an FMEA. One way to do this is to include interfaces in the FMEA Function column. Chapter 6 includes an example of an interface-type function for the interface between the all-terrain handlebar subsystem and hand brake subsystem.

What document contains the interface information?

Identify two other subsystem interfaces for the all-terrain bicycle that should be included in the scope of the all-terrain System FMEA.

Answer: There are three possible locations for system interface information. If an FMEA Interface Matrix was done, that is the best location. Reference Chapter 5, Section 5.3.2, and Figure 5.9, “FMEA Interface Matrix example.” If an FMEA Interface Matrix was not done, the system hierarchy will provide the listing of the subsystems, which is input to identifying subsystem interfaces. Additionally, some companies generate an Interface Control Document, which typically specifies the primary interfaces for the system.

Check to see if the two all-terrain subsystem interfaces identified in Problem 6.7 are in the FMEA Interface Matrix example from Figure 5.9.
Solution 6.8

An FMEA is being done on a projector lamp, with a function “Provide reliable light for image transfer at a minimum of 1000 lumens for 2000 hours of operation.”

One possible failure mode is “lamp burns out prematurely.” Brainstorm one other possible failure mode.

For the failure mode “lamp burns out prematurely,” brainstorm two possible causes. Try to include at least one underlying failure mechanism.

Answer: Reference Figure 8.17, “Excerpt from Projector Lamp Design FMEA,” in Chapter 8, Section 8.7. Compare answers to this FMEA excerpt.

Solution 6.9

Hypothetical Scenario: A manufacturer of air conditioning (AC) systems is concerned about potential failures introduced during installation of the AC system at commercial or residential sites. From an FMEA standpoint, how should this concern be addressed?

Answer: As part of the System FMEA, well-defined installation functions should be added, with appropriate failure modes, effects, causes, and controls, so that the risk from installation can be assessed and necessary corrective actions identified and executed.

Solution 6.10

A Process FMEA is being done on a pump assembly station. Widget “A” is a supplier part that is assembled into the pump. One of the operations being analyzed is “inspect the length of widget ‘A’ to print dimension 123.” The Process FMEA team has identified the primary function of this operation as “verify the length of widget ‘A’ meets the print dimension 123, using measuring device #456.” One of the failure modes identified by the team is “length of widget ‘A’ is less than dimension 123.” Describe what is wrong with that failure mode.

Answer: As written, the failure mode “length of widget ‘A’ is less than dimension 123” is a deficiency in the supplier part widget “A,” and is not the manner in which the pump assembly inspection operation does not meet or deliver the function of the operation. A failure mode of the function of the inspection operation might be “widget ‘A’ parts erroneously passed with dimension 123 exceeding print.”

Solution 6.11

Scenario: In 2011, a vehicle manufacturer announced a recall of certain models for improper routing of the vehicle’s power steering hose, which could lead to melting of the hose due to its close proximity to the catalytic converter. The safety concern was that the melted hose could drip power steering fluid onto the vehicle’s catalytic converter and potentially ignite the flammable hydraulic steering fluid. From an FMEA viewpoint, which type of FMEA should address this issue within the scope of the FMEA and why?
Answer: This is an interface issue between two subsystems: the power steering hose, which is part of the power steering subsystem, and the catalytic converter, part of the exhaust subsystem. Interfaces between subsystems is one of the objectives of System FMEA. A properly done System FMEA should address subsystem interfaces within its scope.

Solution 6.12

An example of a function from the System FMEA of the all-terrain bicycle stated, “The bicycle must provide safe and reliable transportation, including safe stopping distances and safe operation under all customer usage conditions as defined in the all-terrain technical specification.” As noted in Section 6.2.2, this example of function is worded quite generally, and in practice, it may be advisable to break it down to more discrete functions, which aid in defining failure modes.

Refer to Appendix C, “All-Terrain Bicycle Documents,” and the “Checklist of function types” in Section 6.2.2 of this chapter. Brainstorm three primary functions of the all-terrain bicycle.

Answer: Each of the requirements defined in Appendix C of the technical specifications document can be considered as input to the function descriptions in the System FMEA or Subsystem FMEAs. The “Checklist of function types” can be used to be sure none is missed. Some of the requirements may translate to the System FMEA and others may translate to Subsystem FMEAs.

Here are a few examples of possible additional functions for the System FMEA:

The bicycle must be able to safely and reliably withstand g-forces up to 3g while riding on all surfaces, environments, and maneuvers, according to the customer usage document.

The bicycle should be able to safely withstand two times the 95th percentile rider (in terms of weight) on the top part, plus 2000 N of force on points of contact with rear and front wheel, and 1500 N on point of contact with handlebars.

The rider should be able to easily pedal the bicycle forward in first gear applying 5 Nm of torque.

The bicycle should be able to safely come to a full stop within 5 meters when the 95th percentile rider (size and weight) travels on a horizontal asphalt road at a speed of 35 miles per hour.

The bicycle should be able to safely come to a full stop within 10 meters when 95th percentile rider (size and weight) travels on a 20-degree decline at a speed of 25 miles per hour, on a combination gravel and leaf surface. (Note that this requirement would have to be either added to the requirements document or otherwise bought into by the all-terrain bicycle team.)

The bicycle should be able to safely come to a full stop within 5 meters when 95th percentile rider (size and weight) travels on a horizontal asphalt road at a speed of 15 miles per hour, during steering maneuvers defined in steering requirements document #ABC. (Note that this requirement would have to be either added to the requirements document or otherwise bought into by the all-terrain bicycle team.)

(Similarly, each of the requirements from Appendix C and the “Checklist of function types” can be reviewed for applicability at the System FMEA level,
and added to the function column of the System FMEA, with team concurrence. Care should be taken to only include what the team believes to be the primary functions of the all-terrain bicycle, and not include requirements that are too detailed and outside the objectives of the System FMEA. For example, one of the requirements in the technical specifications document is an offering of “grey-black or silver-red” color. The team may choose to exclude this color requirement in the function column of the System FMEA.

CHAPTER 7

Solution 7.1

Figure 7.7 is an excerpt from the Brake Cable Design FMEA, with the recommended actions omitted. Study the FMEA, including severities and RPNs, and prioritize issues for corrective action. Use the Causes numbers (1, 2, 3, 4) to identify the priority sequence.

**Answer:** The sequence should be:

1. Cause 1. (High severity, high RPN)
2. Cause 2. (High severity, regardless of RPN)
3. Cause 4. (High RPN)

Solution 7.2

Which of the following is important input to prioritization of corrective actions? (Select all that apply.)

1. All high RPN issues, regardless of whether severity is high or low (True)
2. All high severity issues, regardless of whether RPN is high or low (True)
3. All low severity issues (False. Low severity does not rise by itself to priority for corrective action.)
4. All low RPN issues (False. Low RPN does not rise by itself to priority for corrective action.)

Solution 7.3

Which of the following are action strategies to reduce the severity risk? (Select all that apply.)

1. Make the design fault tolerant. (True)
2. Introduce redundancy to the design. (True. Depending on the system configuration, it is possible to reduce system-level severity with redundant design.)
3. Reduce stress–strength interference. (False. This will reduce likelihood of the cause of failure.)
4. Increase the design margin. (False. This will reduce likelihood of the cause of failure.)
Solution 7.4

Which of the following are action strategies to reduce the occurrence risk? (Select all that apply.)

1. Make the design fault tolerant. (False. This will reduce the severity.)
2. Introduce redundancy to the design. (True. Depending on the system configuration, it is possible to reduce the occurrence of system failure with redundant design.)
3. Reduce stress–strength interference. (True)
4. Increase the design margin. (True)

Solution 7.5

Which of the following are characteristics of well-written FMEA recommended actions? (Select all that apply)

1. The name of the person on the FMEA team who recommended the action. (False. This is not useful information, as all FMEA recommendations are team approved.)
2. The name of the person who is responsible for execution of the recommended action. (True)
3. A brief description (no longer than three or four words in length) of what action is to be done. (False. FMEA recommended actions should be described in sufficient detail to be fully understood even by someone who is not part of the FMEA team.)
4. The date the recommended action was first established. (False. This is not useful information.)
5. The date the recommended action needs to be completed. (True)

Solution 7.6

Which of the following are true statements about management's role in ensuring the execution of FMEA recommended actions? (Select all that apply)

1. Management needs to stay directly involved in the approval, status, and execution of all FMEA recommended actions for high severity and high RPN issues. (True)
2. The responsibility for execution of FMEA recommended actions should be delegated to the quality or reliability engineer. (False. Management needs to be directly involved with the execution of all FMEA recommended actions for high severity and high RPN issues.)
3. The primary role of management in FMEA execution is to ensure financial budgets are maintained. (False. There are many roles for management in FMEA execution and maintaining budgets is only one of the roles.)
4. One of the primary roles of management in FMEAs is to help to eliminate roadblocks to execution of FMEA action items. (True)
Solution 7.7

An FMEA team is considering how to address a high severity and high occurrence issue. Some of the team members want to reduce the severity risk with action strategies such as fail-safe and early warning. Other team members want to significantly reduce the occurrence risk using a robust design strategy. What is the best approach for this team?

Answer: It is always a good idea to reduce risk due to high severity, if possible. In addition, risk due to high occurrence should be addressed. The best approach is both of these strategies.

Solution 7.8

What are “single-point failures”? How can an FMEA team identify and address single-point failures?

Answer: A “single-point failure” occurs where failure of a single component results in complete failure of the entire system. Single-point failures can be identified from a System or Design FMEA where a component failure results in complete loss of performance of the system. One of the best ways to address single-point failures is through redundant design. If redundancy is not possible, the potential failure frequency needs to be reduced to a very low level.

Solution 7.9

Refer to the following example of a Process FMEA recommended action from Chapter 3:

Process Step: Apply lubrication to O-ring using lubricant gun
Function: Lube O-ring with ABC lubricant, using XYZ specification
Failure Mode: Insufficient lubrication
Effect: Gas leak at fitting, with potential for operator injury; system inoperable in field use
Cause: Lubrication gun calibration incorrect due to calibration procedure not followed
Prevention Control: In-plant lube gun calibration procedures
Detection Control: End-of-line pressure testing

Recommended Action: Use modified lubrication gun calibration procedure #12345 and update maintenance plan to calibrate every 1000 parts.

The effect of the example failure mode says, “Gas leak at fitting, with potential for operator injury; system inoperable in field use.” Since there is potential for operator injury, the severity would be a 10, on a scale of 1–10. Which of the three types of risk (severity, occurrence, and detection) does the example recommended action address? What might be a recommended action to reduce the severity of the effect?
Is it possible to eliminate the failure mode due to the cause (Lubrication gun calibration incorrect)?

**Answer:** The example recommended action would lower the occurrence risk, as it affects the frequency of the cause, “Lubrication gun calibration incorrect due to calibration procedure not followed.”

Some possible suggestions to reduce the severity ranking include:

1. Require the operator to wear a gas mask during O-ring lubrication operation. This would be an application of the action strategy called fail-safe, because if the failure occurs (insufficient lubrication) with the effect (gas leak at fitting), the operator is prevented from injury.
2. Install a gas sensor at the lube O-ring operation to alert the operator if there is gas leaking. This could potentially reduce the severity ranking to a 9 (with warning).

It might be possible to eliminate the failure mode due to the cause of “Lubrication gun calibration incorrect” by the following action:

- Recommend a lubrication gun that will not operate if miscalibrated. The feasibility of this idea would need to be researched, and would require either a change to the lubrication gun design or purchasing a different lubrication gun.

**CHAPTER 8**

**Solution 8.1**

Review the Shock Absorber case study in Section 8.1 and the Process FMEA in Figure 8.2. Suggest three improvements that can be made to this PFMEA.

**Answer:** The following are potential improvements that can be made to the Shock Absorber Process FMEA.

1. Evaluation of the Shock Absorber Process FMEA shows 13 failure modes/causes with initial RPN values greater than 100, yet six of these RPNs are still above 100 even after action taken. There are five failure modes/causes with severity 9 or 10 and initial RPN greater than 100, yet all five of them have RPNs still above 100 after action taken. Each of these high severity and high RPN issues could have more effective actions to further reduce risk.
2. Many of the causes are “operator fault.” This is not a root cause. Each of these causes can be taken further to a root cause that will help define more effective corrective actions.
3. Most of the functions do not include a standard of performance or requirement. Defining the functions using verbiage such as “Do this, to this, with this” and including a standard of performance will result in more meaningful failure modes.
4. Many of the causes have high RPNs. Yet actions such as “Job enrichment by relocating the operators” could be more specific and comprehensive in resolving these causes. There are no multiple actions, which are often needed with high severity and high RPN issues.
Solution 8.2

Review the Strudel Pastry Manufacturing case study in Section 8.2 and the FMEA/Hazard Analysis table in Figure 8.7. Suggest two improvements that can be made to this FMEA/Hazard Analysis.

**Answer:** The following are potential improvements that can be made to the Strudel Pastry Manufacturing FMEA/Hazard Analysis:

1. In this case study, RPNs under 130 do not require corrective actions, regardless of severity. RPN thresholds are not advisable, as they are often misused and counterproductive. Suggest addressing all of the high severity issues, and high RPNs with effective actions to reduce risk.
2. Corrective actions such as “check supplier” could be more specific.
3. Causes such as “improper sanitation” are not root causes. The corresponding corrective action (proper sanitation) could be more specific.

Solution 8.3

Review the Motorola Solutions “Press-to-Talk” case study in Section 8.3 and the FMEA single-line excerpt in Figure 8.10. For teaching purposes, brainstorm two other hypothetical failure modes for the press-to-talk (PTT) functionality.

**Answer:** Other hypothetical failure modes for teaching purposes might be:

1. Button jams closed
2. Button jams open
3. Button closes, but no signal is transmitted
4. Button has soft tactility (easy to press)

Solution 8.4

Review the Flashlight case study in Section 8.4 and the flow of information from Fault Tree Analysis (FTA) to FMEA in Figure 8.16. Although this FMEA is a truncated excerpt to show the transfer of information from FTA to FMEA, it can be used as a teaching example. Suggest two improvements that can be made to the FMEA in Figure 8.16.

**Answer:** The following are potential improvements regarding the Flashlight FMEA in Figure 8.16:

1. This FMEA has no functions. Beginning the FMEA with well-written functions will facilitate the identification of properly worded failure modes.
2. The FMEA combines design-related failure modes such as “corroded switch” with process-related failure modes such as “incorrectly installed.” Best practice is to use separate analyses for design and process.
3. The “Fault Detection” column probably corresponds to the “Design Controls” column in a Design FMEA. However, the entries are entirely “Final Inspection.” More specificity in identifying design controls will aid in the accuracy of the corresponding detection rating.
4. There are no recommended actions. However, these may have been truncated by the author for the purposes of illustrating the flow of information between FTA and FMEA.

Solution 8.5

Review the DC-10 Cargo Door Failure case study in Section 8.5. Use the door latch pin failure on the DC cargo door latching subsystem as an example to practice identifying function, failure mode, effect, cause, and controls based on the cargo door latch pin failure history. Try answering the following questions.

**Identify a function**

Write down on a memo pad a possible function of the door latch pin of the DC-10 cargo door.

**Solution to identify a function**

Check if your answer is something like “The function of the door latch pin is to fully secure the cargo door in the closed position during all operating loads and environmental conditions without allowing the door to close unless fully latched.”

**Identify a failure mode**

Write down on a memo pad a possible failure mode of door latch pin of the DC-10 cargo door.

**Solution to identify a failure mode**

Check if your answer is something like “Door latch pin bends under maximum stress loading.”

**Identify an effect**

Write down on a memo pad a possible effect of the door latch pin failure mode.

**Solution to identify an effect**

Check if your answer is something like “Bent latch pin allows the door to appear to be closed when it is not fully secure, thus failing to abort airplane takeoff, potentially creating a pressure differential between inside and outside air, with the possibility of catastrophic cargo door blowout during flight.”

**Identify a severity**

Write down on a memo pad the severity of the effect of the door latch pin failure mode. Refer to Chapter 3, Section 3.5.5 for an example of a severity scale.

**Solution to identify a severity**

Check if your answer is severity 10 (Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.)

**Identify a cause**

Write down on a memo pad a possible cause of the door latch pin failure mode.

Solution to identify a cause

Check if your answer is something like “Door latch pin bends under extreme loads due to inadequate pin diameter” or “Specification of pin material has inadequate hardness.”
Identify a control (prevention type)
Write down on a memo pad a possible prevention-type control for the cause of the door latch pin failure mode.

Solution to identify a control (prevention type)
Check if your answer is something like “Latchung material selection based on American National Standards Institute (ANSI) standard #XYZ” or “Taguchi project on latching system to optimize the door latch geometry.”

Identify a control (detection-type)
Write down on a memo pad a possible detection-type control for the cause of the door latch pin failure mode.

Solution to identify a control (detection type)
Check if your answer is something like “Cargo door slam test #123” or “Door latch pin bending load test.”

Identify a recommended action
Write down on a memo pad a possible recommended action for the cause of the door latch pin failure mode.

Solution to identify a recommended action
Check if your answer is similar to the following:

For a possible cause “Door latch pin bends under extreme loads due to inadequate pin diameter”:
- Increase diameter of door latch pin, based on Taguchi study of optimum door latch geometry.
- Revise cargo door testing to include extreme loads during door closing and inspection of door latch pin after testing complete.

For a possible cause “Specification of pin material has inadequate hardness”:
- Select stronger material for door latch pin based on analysis of extreme loads during door operation.

Figure 3 places the practice answers for the door latch pin exercise in FMEA spreadsheet format.

Solution 8.6
Review the Space Shuttle Challenger O-ring Failure case study in Section 8.6. Use the O-ring failure on the space shuttle Challenger as an example to practice identifying function, failure mode, effect, cause, and controls based on the O-ring failure history. Try the following exercises.

Identify a function
Write down on a memo pad a possible function of the O-ring in solid rocket booster (SRB) of the space shuttle Challenger.

Solution to identify a function
Check if your answer is something like “The function of the O-ring is to provide a flexible seal that conforms to the varying shape of the
<table>
<thead>
<tr>
<th>Item/Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>S E V</th>
<th>Potential Cause(s) of Failure</th>
<th>O C C</th>
<th>Current Design Controls (Prevention)</th>
<th>Current Design Controls (Detection)</th>
<th>D E T</th>
<th>R P N</th>
<th>Recommended Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door latch pin: fully secure the cargo door in the closed position during all operating loads and environmental conditions without allowing the door to close unless fully latched.</td>
<td>Door latch pin bends under maximum stress loading</td>
<td>Bent latch pin allows the door to appear to be closed when it is not fully secure, thus failing to abort airplane take off, potentially creating a pressure differential between inside and outside air, with the possibility of catastrophic cargo door blowout during flight.</td>
<td>10</td>
<td>Door latch pin bends under extreme loads due to inadequate pin diameter.</td>
<td>TBD</td>
<td>Taguchi project on latching system to optimize the door latch geometry</td>
<td>TBD</td>
<td>TBD</td>
<td>1. Increase diameter of door latch pin, based on Taguchi study of optimum door latch geometry. 2. Revise cargo door testing to include extreme loads during door closing and inspection of door latch pin after testing complete.</td>
<td></td>
</tr>
<tr>
<td>Specification of pin material has inadequate hardness.</td>
<td>TBD</td>
<td>Latching material selection based on ANSI standard #XYZ</td>
<td>TBD</td>
<td>TBD</td>
<td>1. Cargo door slam test #123 2. Door latch pin bending load test</td>
<td>TBD</td>
<td>Select stronger material for door latch pin based on analysis of extreme loads during door operation.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.** Practice answers for door latch pin exercise in FMEA spreadsheet format.
SRB joint during system operation so that hot gases in the SRB do not escape.”

**Identify a failure mode**
Write down on a memo pad a possible failure mode of the O-ring.

**Solution to identify a failure mode**
Check if your answer is something like “O-ring seal becomes stiff and does not conform to the SRB joint during system operation.”

**Identify an effect**
Write down on a memo pad a possible effect of the O-ring failure mode on the SRB and the crew of the space shuttle Challenger.

**Solution to identify an effect**
Check if your answer is something like “Hot pressurized gases leak from SRB, resulting in potential structural failure of external tank and potential loss of shuttle and crew.”

**Identify a severity**
Write down on a memo pad the severity of the effect of the O-ring failure mode on the SRB and the crew of the space shuttle Challenger. Refer to Chapter 3, Section 3.5.5 for an example of a severity scale.

**Solution to identify a severity**
Check if your answer is severity 10 (Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.).

**Identify a cause**
Write down on a memo pad a possible cause of the O-ring failure mode.

**Solution to identify a cause**
Check if your answer is something like “O-ring elastomer material loses flexibility due to ambient temperature below specifications” or “O-ring insufficiently flexible for cold weather applications due to wrong material.”

**Identify a control (prevention type)**
Write down on a memo pad a possible prevention-type control for the cause of the O-ring failure mode.

**Solution to identify a control (prevention type)**
Check if your answer is something like “Elastomer material composition must meet standard #XYZ for cold weather applications.”

**Identify a control (detection type)**
Write down on a memo pad a possible detection-type control for the cause of the O-ring failure mode.

**Solution to identify a control (detection-type)**
Check if your answer is something like “O-ring test #ABC for durability and seal capability under cold weather conditions.”

**Identify a recommended action**
Write down on a memo pad a possible recommended action for the cause of the O-ring failure mode.

**Solution to identify a recommended action**
Check if your answer is similar to the following:
For a possible cause “O-ring elastomer material lost flexibility due to ambient temperature below specifications”:
- Change the elastomer material to a higher grade that maintains flexibility for the entire range of operating conditions, including adequate safety factors.

For a possible cause, “O-ring material insufficiently flexible for cold weather applications due to wrong material”:
- Conduct a Physics of Failure project on the O-ring to identify and model the precise failure mechanisms involved in cold weather applications.
- Based on results of project, make design or manufacturing changes to improve the performance of the elastomer material to ensure flexibility is maintained throughout the range of operating temperatures, including safety factors.

Figure 4 places the practice answers for the O-ring exercise in FMEA spreadsheet format.

Solution 8.7

Study the Projector Lamp FMEA in Figure 8.17 of Section 8.7. Analyze the FMEA in terms of quality, completeness, and adequacy. Note specific deficiencies and suggest improvements. Compare results to the teaching analysis.

Teaching Analysis

1. The function listed in the FMEA does not include the allowed degradation of brightness over its operating life. This needs revision. In addition, there are other functions, such as the “shock” loads.
2. The cause “slow gas leak due to customer abuse during installation” is not a root cause. What is it about the customer abuse that causes a slow gas leak? Additional verbiage, such as “customer abuse during installation causes slow gas leak due to lack of robust design in glass-to-base interface,” is needed.
3. Sneak Circuit Analysis is listed as a prevention control for the cause “inadequate voltage to lamp due to corrosion of base.” Sneak Circuit Analysis is designed to detect circuit problems and is therefore a detection-type control.
4. Each of the high severity or high RPN items have good design improvements recommended in the FMEA, with the exception of the last cause “customer abuse during installation causes slow gas leak due to lack of robustness in base-to-glass interface.” Consider adding additional recommended actions, such as “Conduct a Robust Design project to make glass-to-base interface more robust” and “Measure actual loads on the glass-to-base interface due to installation process. Recommend test or design changes based on measurements.”
5. The recommended test revisions are a plus and will help to ensure any future problems are detected.
6. The FMEA is incomplete and needs further development to ensure all functions and corresponding failure modes and causes are fully addressed.
<table>
<thead>
<tr>
<th>Item/Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>S E V</th>
<th>Potential Cause(s) of Failure</th>
<th>O C C</th>
<th>Current Design Controls (Prevention)</th>
<th>Current Design Controls (Detection)</th>
<th>D E T</th>
<th>R P N</th>
<th>Recommended Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-ring: provide a flexible seal that conforms to the varying shape of the SRB joint during system operation, so that hot gases in the SRB do not escape.</td>
<td>O-ring seal becomes stiff and does not conform to the SRB joint during system operation</td>
<td>Hot pressurized gases leak from SRB, resulting in potential structural failure of external tank and potential loss of shuttle and crew</td>
<td>10</td>
<td>O-ring elastomer material loses flexibility due to ambient temperature below specifications</td>
<td>TBD</td>
<td>Elastomer material composition must meet standard #XYZ for cold weather applications</td>
<td>O-ring test for durability and seal capability under cold weather conditions</td>
<td>TBD</td>
<td>TBD</td>
<td>Change the elastomer material to higher grade that maintains flexibility for entire range of operating conditions, including adequate safety factors.</td>
</tr>
<tr>
<td></td>
<td>O-ring insufficiently flexible for cold weather applications due to wrong material</td>
<td>TBD</td>
<td>Elastomer material composition must meet standard #XYZ for cold weather applications</td>
<td>TBD</td>
<td>O-ring test for durability and seal capability under cold weather conditions</td>
<td>TBD</td>
<td>Conduct a physics-of-failure project on the O-ring to identify and model the precise failure mechanisms involved in cold weather applications.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 4.** Practice answers for door latch pin exercise in FMEA spreadsheet format.
Solution 8.8

All-Terrain System FMEA

Study the all-terrain System FMEA in Figure 8.18. Analyze the FMEA in terms of quality, completeness, and adequacy. Since this is an excerpt of an FMEA, there will be missing functions, failure modes, and causes, so those topics are excluded from the analysis. Note specific deficiencies and suggest improvements. Compare results to the teaching analysis.

Teaching Analysis

1. The specific safe stopping distances and operating conditions can be included in the function description, either in the function column or in a separate column for Requirements.
2. The bicycle system performance testing in the detection controls column should have a specification.
3. Some of the actions are really two actions. It is better to place them in two rows for follow-up and to be reassessed individually.
4. "All weather" testing in the recommended actions column needs to be better defined.
5. The problem with brake misadjustment by the user could also be addressed by a redesign to make brake adjustment unnecessary under normal usage conditions. This is in addition to making the adjustment process itself more robust.

All-Terrain Hand Brake Design FMEA

Study the all-terrain Hand Brake Design FMEA in Figure 8.19. Analyze the FMEA in terms of quality, completeness, and adequacy. Since this is an excerpt of an FMEA, there will be missing functions, failure modes, and causes, so those topics are excluded from the analysis. Note specific deficiencies and suggest improvements. Compare results to the teaching analysis.

Teaching Analysis

1. As for System FMEA, this function could be better defined by identifying the specific stopping requirement.
2. Note that the failure mode at the subsystem level is linked to the cause at the system level.
3. The first cause is really two causes. The two causes should be analyzed separately.
4. Although the RPN for "External foreign material reduces friction" is only a value of 60, this is unacceptable due to the high severity. Specific recommended actions are needed to reduce both the occurrence and detection risk associated with this cause.
5. There is no detection control for the cause "Selected brake pad material does not apply required friction to wheel." The FMEA team cannot assess detection ranking at a value of 2 with no controls at all.
6. There is no detection control for the cause “External foreign material reduces friction.” The FMEA team cannot assess detection ranking at a value of 3 with no controls at all.

7. The cause “Selected brake pad material does not apply required friction to wheel” has no recommended actions. This issue must be rigorously addressed as it is rated high severity. Action is needed to reduce occurrence, and further action is needed to establish effective detection controls.

8. The second action for “Cable breaks” is really two actions. Arrange for these to be separated and tracked separately.

All-Terrain Brake Cable Design FMEA

Study the all-terrain Brake Cable Design FMEA in Figure 8.20. Analyze the FMEA in terms of quality, completeness, and adequacy. Since this is an excerpt of an FMEA, there will be missing functions, failure modes, and causes, so those topics are excluded from the analysis. Note specific deficiencies and suggest improvements. Compare results to the teaching analysis.

Teaching Analysis

1. Note that the failure mode at the component level (Cable breaks) is linked to the subsystem level cause.

2. The “Cable binds” failure mode has an effect that the team established as performance degradation (severity 7). This may well be the case, but the team needs to be sure that the effect of “Cable binds” does not elevate to “brakes do not work,” which is more serious than performance degradation.

3. Notice that at the component level, most of the cause descriptions include the phrase “due to.” This helps in getting to the root cause.

4. Note that the cause “Bend or kink in cable due to misrouting” is a design misrouting, not an assembly misrouting. This is a Design FMEA, and therefore assembly misrouting would usually be part of the Process FMEA.

5. Finite Element Analysis (FEA) is usually considered a detection-type control, as it is normally used to detect stress conditions that can lead to failure. However, since “FEA of all new cable material” may be part of the material selection process, it could be considered prevention-type control.

6. The first recommended action needs a follow-up action to evaluate the results of the material review and make needed changes.

7. The cause “Fatigue cracks in cable wiring due to inadequate cable thickness” needs recommended actions. Any time the severity is 9 or 10, the team should work toward getting both the occurrence and the detection rankings down to a value of 1. To list no recommended actions is unacceptable.

All-Terrain Wheel Spoke Installation Process FMEA

Study the all-terrain wheel spoke installation Process FMEA in Figure 8.21. Analyze the FMEA in terms of quality, completeness, and adequacy. Since this is an excerpt of an FMEA, there will be missing functions, failure modes, and causes, so those
topics are excluded from the analysis. Note specific deficiencies and suggest improvements. Compare results to the teaching analysis.

**Teaching Analysis**

1. The function should include the requirement for correct orientation. Then the failure mode “Wheel spokes not in correct orientation” would make more sense.

2. Notice the evaluation of both “Process Effect” and “Product Effect,” including the assessed severity of each. By evaluating both Process and Product effects, the team can be sure that the severity ranking denotes the most serious effect.

3. The recommended action “Kit the spokes into quantities of 36” could have been more specific. Notice the action taken was to purchase the spokes in kits of 36.

4. For the cause “Fixture is not error proofed to prevent incorrect orientation,” the detection control “In-station test for wheel alignment/truing” has a very high detection ranking. There could be an additional recommended action to improve the quality of the wheel alignment/truing.

5. As noted elsewhere, with high severity, the team should attempt to drive both occurrence and detection rankings to a value of 1.

**Solution 8.9**

Review the Resin Lever case study in Section 8.9 and the improved FMEA in Figure 8.23. Identify two positive attributes in this FMEA.

**Teaching Analysis**

Some of the positive attributes of this FMEA include:

1. Causes are taken to the root cause level.

2. Causes are associated with failure mechanism (column: Symptom as a factor).

3. Design recommended actions are multiple and specifically address the corresponding cause.

4. Design evaluations (column: Check method and result) are detailed and ensure the design improvement has been realized.

**Solution 8.10**

Review the three Design FMEA excerpts from Figure 8.25 of Section 8.10. Although these three FMEAs are example excerpts only, with sanitized data and recommendations, they can be used as teaching examples. Answer the questions below and compare to the teaching analysis.

Note there are many positive attributes of these three FMEA excerpts. For example, the causes in the driveshaft Design FMEA excerpt include the verbiage “due to” in both entries, which helps to ensure the root cause is established. Another example is the function descriptions in all three FMEA excerpts, which includes the “standard of performance” for each function. The analysis below selects content for teaching purposes only and is not meant to be critical of the general FMEA content.
1. Read the recommended actions for the three FMEA excerpts. Referring to the primary objective of an FMEA from Chapter 3, Section 3.2, what type of recommended action is not well represented in these excerpts and why is this important?

**Teaching Analysis:** Section 3.2 of Chapter 3 says, "The primary objective of an FMEA is to improve the design." A secondary purpose of an FMEA is to improve test and verification plans. Most of the recommended actions for all three of the FMEA excerpts are test based, and most of those do not actually improve the tests. The use of the FMEA recommended action tracking mechanism to implement already planned design controls or Design Verification Plans is not a recommended use of FMEA. This is covered in Chapter 7, Section 7.3.4, "Using the FMEA Recommended actions to Execute the Current Design Verification Plan," with one exception noted in that section. The type of recommended action that is not well represented in the three Design FMEA excerpts is *design improvement.*

2. Read the first line of the power steering pump FMEA excerpt. The failure mode is “excessive pressure (more than xx psi)” and the cause is “pressure relief incorrectly specified on drawing.” Does the recommended action address this cause? What other possible recommended actions might be considered?

**Teaching Analysis:** The recommended action to address the cause is “Review results of function test to confirm successful pressure and flow rates achieved.” Ideally a Design FMEA is used to improve the design or improve the test regimen. This recommended action only executes the current test to evaluate the design, which is fine to do, but is not the primary objective of an FMEA. The cause is, “pressure relief incorrectly specified on drawing”; therefore, the current recommended action does not directly address the cause. Since this is a high-risk issue (RPN = 280), with complete loss of performance (severity = 8), the team could consider multiple recommended actions to address this cause. One example might be an action to establish the correct relief pressure and ensure the design is capable of maintaining the correct pressure. And since the initial detection rating is 5, another action might be to develop an improved function test that reduces the detection rating to a lower value.

3. The first line of the driveshaft FMEA excerpt has “DR” in the Classification column, which stands for “documentation required.” Discuss how this special characteristic might be used in other analyses.

**Teaching Analysis:** This is a good example of the application of the Classification column. The “DR” symbol is informational and is meant to flag the failure mode/cause for follow-up in subsequent analyses. For example, based on the driveshaft Design FMEA, the driveshaft strength requires proper heat-treat specifications. The corresponding characteristics for heat treating the driveshaft can be carried over to the Process FMEA and controlled with the Process Control Plan. Appendix J of Society of Automotive Engineers (SAE) J1739 (2009) (not included) is an example of the driveshaft induction hardening Process FMEA, and the special characteristic information is properly transferred to the “shaft hardness too soft” failure mode and Classification column in the Process FMEA. From there, it can be transferred to the Process Control Plan and controlled in the manufacturing process.
CHAPTER 9

Practice Audit 9.1

Evaluating the Quality of the All-Terrain Brake Cable Case Study

Figure 9.1, showing the All-Terrain Brake Cable Design FMEA, includes errors that are specifically for instructional purposes. Study this FMEA and evaluate it against the first three FMEA Quality Objectives.

Student Exercise

**FMEA Quality Objective #1:** “The FMEA drives product or process design improvements as the primary objective.”

Student reviews the all-terrain Brake Cable Design FMEA against the first quality objective and determines how well it is met and why.

Teaching Analysis

1. The recommended action “Perform a thorough review of cable material alternatives including corrosion resistance” supports improving the cable design.
2. Conducting a Design of Experiments to optimize cable material is also in the direction of improving cable design.
3. A third recommended action should be added to implement the results of the analysis to ensure the design is improved and the high RPN (200) is significantly reduced.
4. Overall, this quality objective would get a medium score.

Student Exercise

**FMEA Quality Objective #2:** “The FMEA addresses all high severity and high RPN failure modes and their causes, as identified by the FMEA team, with executable action plans.”

Student reviews the all-terrain Brake Cable Design FMEA against the second quality objective and determines how well it is met and why.

Teaching Analysis

1. The severity 10 and RPN 200 corrosion issue is moderately addressed as covered in the first quality objective, with actions to implement the results of the studies missing. Also, there are no actions to reduce the detection risk.
2. The severity 10 and RPN 40 fatigue cracks issue is not addressed. Because this is a high severity item, there should be recommended actions to drive the occurrence and detection rankings both down to 1, if possible.
3. Overall, this quality objective would get a low score.

Student Exercise

**FMEA Quality Objective #3:** “The Test Plan or the Process Control Plan considers the failure modes from the FMEA.”

Student reviews the all-terrain Brake Cable Design FMEA against the third quality objective and determines how well it is met and why.
Teaching Analysis
1. There are no recommended actions to improve the test methods.
2. There are two severity 10 items, one with detection ranking 4 and the other with detection ranking 2. They should both have actions to improve the detection controls, preferably to a value of 1.
3. This quality objective is not achieved.

Practice Audit 9.2

Evaluating the Quality of the Bicycle Hand Brake Case Study
Figure 9.2 is a Design FMEA on a Bicycle Hand Brake Subsystem. It has been selectively modified with errors for evaluation of the 10 FMEA Quality Objectives. The FMEA team is made up of a bicycle design engineer and a bicycle test engineer, in support of a new all-terrain bicycle due to be launched soon. The FMEA was completed 4 weeks after design freeze, after testing had begun. For each of the 10 exercises, note how well the quality objective was achieved in the FMEA and why.

Student Exercise
FMEA Quality Objective #1: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #1: The FMEA drives product design or process improvements as the primary objective. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, there should be a number of effective design improvement actions in the Recommended Actions column. This FMEA has no design improvement actions and does not meet objective #1.

Student Exercise
FMEA Quality Objective #2: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #2: The FMEA addresses all high-risk failure modes with effective and executable action plans. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, every failure effect with high severity (9 or 10) and every failure cause with high RPN (based on FMEA team determination or company mandate) must be addressed with one or more effective actions in the Recommended Actions column. The team or reviewer should ask themselves if the recommendations will reduce the risk identified by high severity or high RPN to an acceptable level. This FMEA does not achieve this objective because the recommended actions only address detection risk and not severity or occurrence risk. For each of the high severity or high RPN line items, there need to be actions (as many as needed) that first attempt to reduce severity (if possible) and reduce occurrence to a very low rating, in addition to reducing detection ratings.
Student Exercise
FMEA Quality Objective #3: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #3: The Design Verification Plan (DVP) or the Process Control Plan (PCP) considers the failure modes from the FMEA. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, there needs to be effective actions in the recommended actions column to improve the detection controls for any line item with detection risk identified. Typically this means where the detection rating is not low, and either the severity or RPN is high. This FMEA has good actions in the recommended actions column for each line item where detection risk exists.

Student Exercise
FMEA Quality Objective #4: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #4: The FMEA scope includes integration and interface failure modes in both block diagram and analysis. Make note of how well this objective was achieved. Explain.

Teaching Analysis
Since the scope of this FMEA is at the subsystem level, to achieve this quality objective the component interfaces should be included in the Functions column and potential failure modes for these interfaces should be identified and analyzed. The interfaces and integration of the handbrake subsystem with the various other subsystems should be included in the System FMEA. The interaction of the brake lever, brake cable, brake pad, and brake caliper is not well described in the Functions column of this FMEA, and the one failure mode that attempts to deal with interfaces (the last failure mode in the FMEA) is not analyzed.

Student Exercise
FMEA Quality Objective #5: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #5: The FMEA considers all major “lessons learned” (such as high warranty and campaigns) as input to failure mode identification. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, all of the field failures for similar bicycle systems should be reviewed to ensure that there is no repeat of such failures within the scope of this FMEA. There is no indication in the problem introduction that this has taken place, and there is no indication in the body of the FMEA that “seen” failure modes have been included. Anyone reviewing this FMEA would have to satisfy themselves that all applicable field failures have been reviewed and will not reoccur.
Student Exercise

FMEA Quality Objective #6: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #6: The FMEA provides the correct level of detail in order to get to root causes and effective actions. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, the level of detail must be adequate to clearly identify risk, arrive at root causes, and clearly describe the line item being analyzed. This FMEA does a reasonably good job in level of detail: not too wordy and not missing clarity. Recall from the procedure chapter that each column in the FMEA needs to have the amount of detail necessary to arrive at the next column, as well as providing enough clarity so that someone who was not involved in the FMEA should be able to understand the concept that is being described.

Student Exercise

FMEA Quality Objective #7: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #7: The FMEA is completed during the “window of opportunity” from where it can most effectively impact the product or process design. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, the FMEA should begin shortly after the design concept has been identified and finished before design freeze. This FMEA was done late and does not meet this quality objective.

Student Exercise

FMEA Quality Objective #8: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #8: The right people are adequately trained in the procedure and participate on the FMEA team throughout the analysis. Make note of how well this objective was achieved. Explain.

Teaching Analysis
To achieve this quality objective, the Design FMEA team needs to be comprised of the right cross-functional team. In this case, there should minimally be representation from bicycle system engineering, hand brake design engineering, test engineering, manufacturing, quality or reliability, and field service. Since the FMEA team was made up of a design and test engineer, this quality objective was not met.

Student Exercise

FMEA Quality Objective #9: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #9: The FMEA document is completely filled out “by the book,” including “Action Taken” and final risk assessment. Make note of how well this objective was achieved. Explain.
Teaching Analysis
To achieve this quality objective, each of the columns of the FMEA needs to be procedurally accurate, technically correct, and all columns filled out. In addition to the issues identified above, the columns to the right of Recommended Actions are missing and therefore this quality objective is not met.

Student Exercise
FMEA Quality Objective #10: Review Figure 9.2 to assess how well it achieves the FMEA Quality Objective #10: The time spent by the FMEA team is an effective and efficient use of time with a value-added result. Make note of how this objective can be evaluated.

Teaching Analysis
To achieve this quality objective, all members of the FMEA team should agree that their time was well spent to a value-added result. This can only be assessed by interviewing the FMEA team.

As an additional note, evaluation of an FMEA for achieving the quality objectives by looking at the FMEA worksheet alone can only partially provide accurate evaluation. The best way to assess how well an FMEA meets quality objectives is to review both the FMEA worksheet and interview the FMEA team.

CHAPTER 10

Solution 10.1
A facilitator is one who . . . (Select all that apply.)

1. Contributes structure and process to groups. (True)
2. Effectively solves the problems brought forward by the group. (False. The facilitator brings the team to their best thinking, but the team solves the problem.)
3. Supports the group to achieve exceptional performance. (True)
4. Acts as a tiebreaker when the group cannot come to a decision. (False. This presupposes some kind of voting, and good facilitation involves bringing the team to consensus, not voting.)

Solution 10.2
Scenario: You are facilitating an FMEA meeting and two attendees are having a side conversation. You should . . . (Select all that apply.)

1. Out of courtesy, allow the side conversation to continue until the two attendees have finished their conversation. (False. Side conversations violate meeting "norms" and distract the team from their objectives.)
2. Interrupt the two people who are having a side conversation and tell them to leave the meeting. (False. There is no need to ask the team members to leave, only to redirect their energy to the team objectives.)
3. Refer the two attendees to the meeting “norms” and ask them to hold off any side conversations. (True)

4. Ask the two attendees if they are discussing something they want to share with the group that is consistent with the meeting agenda. (True)

Solution 10.3

Scenario: You are facilitating an FMEA meeting and the group is having trouble developing effective recommended actions for a known cause. The best facilitation tool to address this scenario is . . . (Select all that apply.)

1. Use conflict management techniques to find and address the obvious conflict that is holding up the group. (False. Conflict management should be used when there is visible conflict, not when the team has bogged down.)

2. Use active listening to try to understand better what the group is saying. (False. Good listening will not resolve the issue of solutions not easily forthcoming.)

3. Use brainstorming to open up the flow of ideas. (True)

4. Use probing questions to solicit more participation from everyone in the group. (True. Probing questions may be helpful, although the best solution is brainstorming.)

Solution 10.4

Scenario: Two people in the group you are facilitating begin shouting at one another and generally acting rude. You should . . . (Select all that apply.)

1. Use your active listening skills, as you know that conflict is good and there may be important ideas being communicated, even if rudely. (False. Unhealthy behavior must not be allowed to continue.)

2. Intervene in the conflict by telling the two people to stop shouting and refer them to the meeting “norms” that do not allow rude behavior. If they cannot cease, take a break from the meeting to allow things to cool down and ensure the two people can act with courtesy. (True)

3. Intervene in the conflict on the side of the person who you believe is correct. (False. The facilitator must not intervene by taking sides. The facilitator can express his/her point of view, but not to create a win/lose.)

4. Tell the two people to stop shouting and ask the group to vote on which of the two has the best ideas. (False. Voting is not the way to bring the team to consensus.)

Solution 10.5

Scenario: The FMEA team is having trouble understanding the difference between a failure mode and a cause. The meeting is dragging on and on. You should . . . (Select all that apply.)
42  END OF CHAPTER PROBLEMS: SOLUTIONS MANUAL

1. Refer to the FMEA training material and review the definitions of failure mode and cause with the team. Proceed when you are certain they understand the concepts. (True)

2. Move on to the next column so that the team can keep progressing. Come back to the issue later. (False. It is not helpful to have the team ignore a point of confusion.)

3. Have the team vote on which is the right definition and proceed. (False. Voting is not the way to resolve team confusions on basic definitions.)

4. End the meeting and reschedule for the next day. The break will probably refresh peoples' memory on the definitions. (False. It is best to address the problem when it is fresh on people's minds.)

Solution 10.6

The hallmarks of a good consensus process include ... (Select all answers that apply.)

1. One person who disagrees cannot hold up the team. (False. The one person who is overruled may have the most important input. Consensus takes time but is worth the effort.)

2. Many ideas are shared. (True)

3. No one pushes a predetermined solution. (True)

4. The team compromises to get agreement. (False. Compromise means finding middle ground, and often the middle ground is not the optimal solution. Remember, the team must be satisfied with and commit to the agreed-upon solution.)

Solution 10.7

The FMEA team has a few members who are not contributing during a discussion about potential recommended actions for a high-risk issue. What are three probing questions that the nonparticipating team members can be asked to solicit their input?

**Answer:** Any questions similar to the following:

"What can be done to reduce severity to a safe level by modifying the design?"

"Which of the ‘Action Strategies to Reduce Severity Risk’ should be recommended?"

"What can be done to reduce likelihood of occurrence to a very low level?"

"Which of the ‘Action Strategies to Reduce Occurrence Risk’ should be recommended?"

"What can be done to reduce likelihood of detection to a very low level?"

"Which of the ‘Action Strategies to Reduce Detection Risk’ should be recommended?"

"Are there any other actions that are needed to reduce risk to an acceptable level?"

"If the recommended actions are implemented, will that be sufficient to address all high severity and high RPN risk?"
Solution 10.8

Scenario: You are assigned to facilitate a Design FMEA; however, due to heavy workload and unavailability of subject-matter experts, you have been told to do the FMEA with the design engineer. What should you do?

Answer: One of the primary values of an FMEA is the discussion and synergy between the cross-functional subject-matter expert team, resulting in effective actions to reduce risk. There is limited value in an FMEA done entirely by a facilitator and one design engineer. Management needs to be made aware of the purpose of the Design FMEA, the minimum team requirements for success, and the consequences of doing an FMEA with improper expert participation.

Solution 10.9

When should brainstorming be used in an FMEA? List two examples showing which elements of an FMEA that could receive benefit from brainstorming and the circumstances that would generate the brainstorming technique for both examples.

Answer: Brainstorming is a technique for getting a flow of ideas on the table before making decisions. This technique is most useful when a decision or solution is not easily forthcoming. Although it can be used at any part of the FMEA that fits the above criteria, some specific examples of where brainstorming can be useful include:

1. Identification of Primary Functions To Be Sure None Are Missed. Brainstorming can help in the identification of primary functions if the flow of function identification is not forthcoming by the team. Engineering requirements documents usually include verbiage about functional requirements, but the team needs to be sure no important functions are missed, including interfaces and interactions, as well as the “standard of performance” for each function. Note, if the FMEA team identifies important functions that are not well described in the technical specs, they should recommend improvements to the requirements documents, in addition to any other recommendations they make.

2. Identification of Failure Modes. All failure modes of concern to the team need to be identified for each function. If the facilitator is observing that ideas for failure modes, either based on past failure information or new concerns, are incomplete or not forthcoming from the team, brainstorming can be a useful technique.

3. Identification of Causes. The team needs to be sure that all potential causes of concern are identified and taken to root cause for high-risk issues. Brainstorming can be helpful to be sure none are missed.

4. Identification of Recommended Actions. For both high severity and high RPN issues, effective recommended actions must be identified. Usually, multiple recommended actions are necessary for high-risk issues in order to reduce the different types of risk to an acceptable level. If the flow of ideas to resolve high-risk problems is not sufficient, brainstorming can be helpful.

There are potentially many places in the FMEA where brainstorming may be useful. The key is to use brainstorming wherever the team needs help in generating a flow of creative ideas. Care must be taken to end the brainstorming technique when the flow of ideas has been achieved, and shift to evaluating the ideas and determining which ones will be entered in the FMEA worksheet.
CHAPTER 11

Solution 11.1

Management has many important roles in the successful implementation of FMEAs in their company. Which of the following are key roles for management in implementing a successful FMEA process? (Select all that apply.)

1. Provides agreement on FMEA strategy and supports needed resources. (True)
2. Attends individual FMEA meetings to offer management input and support. (False. Managers should not attend individual FMEA meetings unless providing specific subject-matter input.)
3. Assists in integrating FMEA with other business processes. (True)
4. Personally gathers FMEA preliminary information (prework). (False. This is the job of the FMEA facilitator or as otherwise assigned.)
5. Provides effective reviews of high severity and high RPN failure modes, causes, and recommended actions. (True)
6. Personally facilitates FMEA meetings according to FMEA procedure. (False. This is not a management role.)
7. Supports the attendance of expert FMEA team members. (True)
8. Ensures that specific FMEA-related duties of employees are integrated into employee’s work instructions. (True)

Solution 11.2

The following are statements about management reviewing FMEA issues. (Select all that are true.)

1. It is important for management to review all failure modes, causes, and recommendations on a regular basis. (False. Management should review the high-risk FMEA issues. Reviewing all FMEA results will overburden the review process and dilute the needed emphasis on high-risk issues.)
2. Management should review the high-risk issues from FMEAs on a regular basis. (True)
3. When management reviews FMEAs they should offer feedback as to whether or not they support the recommendations from the FMEA team and why. (True)
4. It is only necessary to review the high-risk items from FMEAs once. (False. It is necessary to maintain a regular review of high-risk issues from FMEAs to be sure that all of the needed recommendations are implemented and risk reduced to an acceptable level.)

Solution 11.3

Scenario: An FMEA audit is underway. The FMEA team has omitted recommended actions for several high-risk issues in the FMEA. The FMEA auditor should . . . (Select all that apply.)
1. Make note of the omission, recommend the team develop effective actions for the high-risk issues, and recommend remedial FMEA training. (True)

2. Complete the FMEA properly as soon as the audit session is completed. (False. The FMEA team needs to complete the FMEA properly, not the FMEA auditor.)

3. Note the names of the offending FMEA team members and let their managers know that they are underperforming. (False. Any deficiencies noted from FMEA audits should be used to improve the FMEA process, not to report team members’ shortcomings. Improved FMEA training would be one appropriate outcome of the audit.)

4. Ignore this issue as it is not the auditors’ role to judge the quality of the FMEA. (False. It is definitely the role of the FMEA auditor to judge the quality of the FMEA.)

Solution 11.4

The following are statements relating to the question of how to deal with supplier parts. (Select all that are true.)

1. All supplier FMEAs should be reviewed and approved by the FMEA team according to the FMEA Quality Objectives. (False. Review and approval of FMEAs should be limited to critical parts.)

2. Suppliers of critical parts (deemed high risk by the project team) should be required to do FMEAs and warrant that they followed existing standards. (False. Suppliers of critical parts should be required to have their FMEAs reviewed and approved by the FMEA team or its representatives.)

3. Suppliers of critical parts (deemed high risk by the project team) should be required to do FMEAs, and the quality of these selected supplier FMEAs should be reviewed and approved by the FMEA team. (True)

4. If the FMEA team is reviewing a supplier FMEA and determines it does not meet the quality objectives, they should return the analysis to the supplier for corrections and resubmission. (True)

Solution 11.5

The Incredible Bike Company (IBC) has system design, system integration, and system assembly responsibilities for the new all-terrain bicycle. They decide to use FMEAs to ensure the safety and reliability of the next generation of all-terrain bicycles. The bicycle seat is made of a new material for comfort and durability, and the seat design is considered critical based on Preliminary Risk Assessment. Company X has responsibility for the seat and does the seat design; however, they outsourced the seat manufacturing to company Y. Company Y ships the seats to company X, who verifies they meet all requirements and ships to IBC for assembly as part of the new all-terrain bicycle. The question is who approves the seat Design and Process FMEAs and why?

Answer: The IBC should review and approve the seat Design FMEA from company X using the FMEA quality objectives described in Chapter 9. The seat design was considered critical based on Preliminary Risk Assessment, and IBC has
a vested interest in assuring the seat design meets all requirements and will integrate with the all-terrain bicycle. If the IBC considers the seat manufacturing process to be critical, they can also review and approve the seat Process FMEA. Otherwise, company X can review and approve the seat Process FMEA from company Y.

Solution 11.6

FMEAs can be linked to other quality and reliability tools to increase their value. Which of the following statements are true about the linkage of FMEAs to other tools? (Select all that apply.)

1. Design FMEAs may identify shortcomings in the manufacturing Process Control Plans. (False. That is outside the scope of a Design FMEA.)
3. Design FMEAs identify shortcomings in the Design Verification Plans. (True. Properly done, a Design FMEA can identify shortcomings in the Design Verification Plan.)
4. FMEA-related tasks should be integrated into the company's Product Development Process. (True. The tasks that relate to FMEA should be integrated into the Product Development Process as well as employee work instructions.)

CHAPTER 12

Solution 12.1

The following are statements about Failure Mode Effects and Criticality Analyses (FMECAs) (select all that are true):

1. FMECA adds a criticality analysis to FMEA, along with a different set of scales. (True)
2. There is no difference between an FMEA and an FMECA. (False. FMECA adds a criticality analysis to FMEA, along with a different set of scales.)
3. FMECA is no longer used by companies as the original standard has been canceled. (False. Although the original Military Standard [MIL-STD] 1629A has been canceled, some companies still choose to follow this standard, or use the SAE ARP5580 standard for doing FMECAs.)
4. The "C" in FMECA stands for "Cause" (False. The "C" stands for "Criticality.")

Solution 12.2

When doing a Criticality Analysis for an FMECA, keep in mind the following (select all that apply):
1. A Criticality Analysis is the same as an RPN calculation in an FMEA procedure. (False. Criticality analysis has its own procedure and calculation of criticality is not the same as RPN.)
2. Quantitative Criticality Analysis calculation uses the mode ratio of unreliability for each potential failure mode as part of its calculation. (True)
3. Qualitative Criticality Analysis uses severity and detection risk rankings. (False. Qualitative Criticality Analysis uses severity and occurrence.)
4. A criticality matrix can be used to graphically plot criticality versus severity. (True)

Solution 12.3

Mode Criticality is the product of which three factors? (Select the correct answer.)

1. Severity, probability of occurrence, and probability of loss (False)
2. Expected failures, mode ratio of unreliability, and item criticality (False)
3. Failure probability, mode ratio of unreliability, and expected failures (False)
4. Expected failures, mode ratio of unreliability, and probability of loss (True)

Solution 12.4

Perform quantitative criticality analysis on a bicycle brake lever.

Input Data:
The brake lever has an expected life of 5 years. The bicycle reliability engineer says the brake lever will have an estimated 0.5 failures in 5 years based on failure distributions, and so on.

There are two failure modes: cracking and bending. Cracking makes up 30% of the failures; bending makes up the other 70% of the failures. The probability of system loss for cracking is 60%, and for bending, is 10%.

Calculate the criticality for each potential failure mode and the overall criticality of the brake lever.

Answer:

\[
Mode \text{ Criticality} = \text{Expected Failures (for the item)} \times \\
\text{Mode Ratio of Unreliability (for the failure mode)} \times \\
\text{Probability of Loss (for the failure mode)}
\]

\[
Item \text{ Criticality} = \text{SUM of Mode Criticalities}
\]

For the failure mode: cracking

Expected failures for the brake lever = 0.5
Mode ratio of unreliability = 0.30
Probability of loss = 0.60
Mode criticality = 0.5 \times 0.30 \times 0.60 = 0.09
For the failure mode: bending
  Expected failures for the brake lever = 0.5
  Mode ratio of unreliability = 0.70
  Probability of loss = 0.10
  Mode criticality = 0.5 × 0.70 × 0.10 = 0.035
  Overall criticality of the brake lever = 0.09 + 0.035 = 0.125

CHAPTER 13

Solution 13.1

Which of the following statements are true about Design Review Based on Failure Mode (DRBFM)? (Select all that apply.)

1. DRBFM uses the same set of risk ranking scales as FMEA for severity, occurrence, and detection. (False. Most applications of DRBFM do not use the same set of risk ranking scales as FMEA.)
2. The DRBFM worksheet is identical to an FMEA worksheet, without the risk ranking scales. (False. The DRBFM worksheet has its own set of unique columns.)
3. After preparation for a DRBFM project, the responsible engineer completes the first portion of the DRBFM worksheet and provides a draft to the team prior to the review. (True)
4. The discussion portion of DRBFM is focused on the areas of the design that have not changed. (False. The discussion portion of DRBFM focuses on areas of change and interfaces.)

Solution 13.2

Which of the following are good practices when doing a DRBFM project? (Select all that apply.)

1. Ideally, the DRBFM project is based on a well-done FMEA, with the focus on changes and interfaces. (True)
2. The DRBFM should look at actual physical parts when discussing the changes to the parts. (True)
3. The discussion should be limited to areas of concern to the team. (True)
4. A DRBFM project should be done before beginning an FMEA. (False. DRBFM is done when there are changes to a design, and should be based on a well-done FMEA on the original design.)

Solution 13.3

In DRBFM, the essence of Good Design is . . . (Select one.)

1. To properly prepare for the DRBFM project. (False. Proper preparation is important for all FMEA and DRBFM projects, but is not the subject of Good Design.)
2. To examine the results of testing. (False. Examining the results of testing is part of Good Dissection.)
3. To begin with a proven and reliable design. (True)
4. To identify and eliminate risk due to changes in design. (False. Identifying and eliminating risk is part of Good Discussion.)

Solution 13.4

The following changes should be considered when doing Change Point Analysis. (Select all that apply.)

1. Changes to the supplier process (True)
2. Changes to the usage environment (True)
3. Changes to the DRBFM review team (False. Changes to the DRBFM team are not part of Change Point Analysis.)
4. Changes to component interfaces (True)

Solution 13.5

Intentional and incidental changes need to be considered when performing DRBFM. Which of the following are within the scope of incidental changes? (Select all that apply.)

1. The list of modifications that are being proposed to the current design (False. This would be within the scope of intentional changes.)
2. Differences in the usage environment conditions (True)
3. Changes in the shape of interfacing components (True)
4. Proposed changes to test regimens (False. Changes to test regimens are not part of incidental changes.)

Solution 13.6

The analysis portion of DRBFM procedure calls for two separate steps, with the first step being performed by the responsible engineer and the second step by the expert team. Which specific columns are filled out by the responsible engineer and which portion of the DRBFM procedure is done by the expert team?

**Answer:** The responsible engineer completes the first portion of the DRBFM worksheet, including intentional and incidental changes, functions, concerns, causes, and a description of how the current design avoids concerns, and provides a draft to the team prior to the review.

The expert team identifies additional points of concern, effects to customer, detailed causes, and recommended actions (design-related, evaluation-related, and manufacturing-/supplier-related) to eliminate the concerns.

Solution 13.7

The three elements of GD³ are Good Design, Good Discussion, and Good Dissection. What is Change Point Analysis and where does it fit into the GD³ process?
Answer: Change Point Analysis begins with the baseline design and focuses on the specific changes to the design. Change points can include changes in design, manufacturing, supplier, supplier design or process, usage environment, interfaces, specifications, performance requirements, or any other changes. It is the initial step in Good Discussion. See Figure 13.9 for an example of Change Point Analysis on a fictional catapult system.

Solution 13.8

Review Case Study 1 and Figure 13.8, “DRBFM worksheet of rack boot subassembly” in Section 13.6. One of the concerns being discussed by the DRBFM team was the hardness of the Rack Boot (with the thermoplastic elastomer) increasing from 50 to 95 HS. The authors said, “Participants noticed the problem of the increasing reciprocate resistance due to the change.” Discuss how the Recommended Actions address the concern relating to thermoplastic elastomer (TPO) hardness increase.

Answer: For “Items to reflect in Design,” the DRBFM team recommended, “Investigation for increasing resistance due to hardness change.” This investigation task will get closer to the root cause of the concern about increased reciprocating resistance, and open the door to a preventive action to resolve the problem.

For “Items to reflect in Evaluation,” the team recommended, “Measuring reciprocating resistance.” This task will improve the ability to detect the reciprocating resistance problem in current and future designs.

CHAPTER 14

Solution 14.1

In describing FTA, which of the following are true? (Select all that apply.)

1. FTA begins with an already identified unwanted event. (True)
2. An event is a logic symbol used in FTA that represents the relationship between fault inputs and outputs. (False. An Event is a graphical and mathematical representation of a fault or other unwanted occurrence.)
3. The top level of the FTA is the root cause of the unwanted event. (False. The top level of an FTA is an unwanted event.)
4. The best application for FTA is having all of the events connected by OR gates. (False. FTA is typically used when the team is analyzing a complex failure mode with many causes and would like a visual tool to graphically represent the complex set of causes.)
5. A gate is a logic symbol used in FTA that represents the relationship between fault inputs and outputs. (True)

Solution 14.2

FTA should be used . . . (Select all that apply.)

1. Instead of FMEA when the team has limited time. (False. FTA is time consuming and should be used when the right circumstances arise.)
2. When the FMEA team is analyzing a complex failure mode with many causes and would like a visual tool to graphically show the complex set of causes. (True)

3. When the FMEA team would like to understand the probability of a high-level unwanted event occurring. (True)

4. When failure data are not available. (False, FTA requires failure data in order to model the probability of the top level unwanted event.)

Solution 14.3

Review the FTA in Figure 14.4, “Bicycle does not stop in time,” and answer the following questions.

Question 1
On the left side of the FTA there is an intermediate event “Bicycle being ridden with misadjusted brake cable.” If the brake cable was misadjusted at factory and the user notices the problem (and takes the proper corrective action), what happens to the event “Bicycle being ridden with misadjusted brake cable”?

Answer: Since both of the input faults (“Brake misadjusted” and “User doesn’t notice”) are necessary to pass through the AND gate (“Bicycle being ridden with misadjusted brake cable”), the output fault does not occur.

Question 2
Based on the logic in the FTA, if the “Brake cable breaks” is a fault and the “Tires lose friction on riding surface” is not a fault, what happens to the top event “Bicycle doesn’t stop in required distance”?

Answer: The fault in the “Brake cable breaks” event is passed through the OR gate and creates a fault in the “Insufficient friction delivered by hand brake subsystem to wheel rims” event. This fault is passed through the OR gate to the top event “Bicycle doesn’t stop in required distance,” regardless of what happens with the event “Tires lose friction on riding surface.” The likelihood of the top event is determined by the failure distributions in each of the intermediate events and the logic of the FTA model.

Question 3
The intermediate event “Insufficient friction delivered by hand brake subsystem to wheel rims” event has four contributory events. Is this complete, or are there other possible contributory events? Where would one look in the Hand Brake Design FMEA for additional information?

Answer: There are other possible contributory events, such as brake pad failure or brake caliper failure. The Hand Brake Design FMEA should have many causes that are input to the identification of contributory events that potentially result in “Insufficient friction delivered by hand brake subsystem to wheel rims.”
CHAPTER 15

Solution 15.1

One of the primary purposes of Reliability-Centered Maintenance (RCM) is... (Select one.)

1. To determine the reliability of equipment. (False. Although equipment reliability may be part of the RCM analysis, this is not one of the primary purposes of RCM.)
2. To determine preventive maintenance (PM) requirements and other actions needed to ensure safe and cost-effective operations of a system. (True)
3. To improve the manufacturing process. (False. RCM can be applied to manufacturing equipment, but improving the manufacturing process is not the primary purpose of RCM.)
4. To develop highly reliable equipment that will not need any maintenance during the expected life. (False. RCM is used to determine PM requirements and other actions needed to ensure safe and cost-effective operations of a system. Developing highly reliable equipment that will not need any maintenance during the expected life is beyond the scope of RCM.)

Solution 15.2

Identify which of the following statements about RCM are true or false.

1. A well-done equipment FMEA or series of equipment FMEAs is at the core of an RCM analysis. (True)
2. The output of an RCM project is input to an FMEA project. (False. The output of an RCM project is PM requirements and other actions needed to ensure safe and cost-effective operations of a system)
3. Run to failure is a valid RCM strategy where equipment is allowed to run without any scheduled maintenance actions until it fails, at which point it is fixed or replaced. (True)
4. RCM uses the same Effect scale as FMEA. (False. RCM has a unique failure effect categorization logic based on the RCM standard being used.)

Solution 15.3

Review the gas insulated switchgear RCM project covered in Section 15.1.7. One of the concerns from the FMEA was SF₆ gas contamination. What failure effect consequence was identified from the decision diagram? What tasks were proposed in the PM program to address this concern?

Answer: The failure consequence was not “hidden,” and it was identified as “safety.” Therefore, the consequence was “Evident Safety.” The specific tasks identified in the PM plan were as follows:

Every year: Cleanliness and visual inspection for SF₆ gas pressure.
Every 5 years: SF₆ gas moisture and percent measurement.
Solution 15.4

A Hazard Analysis is . . . (Select one.)

1. In reality the same as a System FMEA. (False. Hazard Analysis is not the same as System FMEA)

2. A Design FMEA that focuses only on high severity and high occurrence. (False. This type of Design FMEA is not the same as a Hazard Analysis)

3. A type of FMEA that focuses on safety hazards and has its own set of scales. (True)

4. A type of FMEA that focuses on safety and uses the same scales as other types of FMEAs. (False. Hazard Analysis uses a different set of scales than typical FMEAs.)

Solution 15.5

Review Hazard Analysis example 1 on a pressure cooker (Section 15.2.3), including the Preliminary Hazard Analysis (PHA) worksheet. Answer the following questions.

What column is missing in the PHA worksheet?

**Answer:** The pressure cooker PHA example does not have a column for severity category. Even though all of the issues identified in a Hazard Analysis are safety related, there are gradations of severity that assist in prioritization of issues for corrective action. Refer to Figure 15.9, “Suggested Mishap Severity Categories” in Section 15.2.3.

What additional corrective or preventive measures might be considered to address the burn hazard, caused by “person touches hot pressure cooker surface or hot materials inside pressure cooker”?

**Answer:** The team correctly identified preventive measures such as using hot pads and keeping children away from the cooker. Since the probability of hazard due to the accident is considered “reasonably probable,” the team could also consider a design change to a cooker container material that has better insulation properties. A preliminary study of insulation material versus outside container temperature would provide data to help with the decision. The team could also consider a way to audibly or visually warn the user when outer container temperature rises to an unsafe range. Reference the action strategy order of precedence in step 4 of the Hazard Analysis procedure outlined in Section 15.2.2.

Solution 15.6

Review the all-terrain bicycle trade-off analysis in the section titled “All-Terrain Bicycle Performance Requirements” in Appendix C. What concept FMEAs could be done and how would these concept FMEAs help with the concept trade-off decision for the all-terrain bicycle?

**Answer:** Concept FMEA could be done on each of the three all-terrain bicycle concepts: design for speed, design for durability, and design for comfort. For each
of the concepts, the concept FMEA would provide an analysis of the risk due to failures and their causes, so the all-terrain team could consider that information when making their concept decision.

Solution 15.7

Some of the possible objectives for Software FMEA include . . . (Select all that apply.)

1. Identifying missing software requirements. (True)
2. Writing the software code. (False. Writing software code is not one of the objectives of Software FMEA.)
3. Analyzing a system’s behavior as it responds to a request that originates from outside of that system. (True)
4. Replacing the need to do Design or Process FMEAs. (False. Software FMEAs do not replace the need to do other types of FMEAs.)

Solution 15.8

Identify which of the following statements are true about Software FMEAs. (Select all that apply.)

1. Many of the preparation steps for Software FMEA are similar to regular FMEAs. (True)
2. As in traditional FMEAs, each function is analyzed for what can go wrong with the function. (True)
3. Software FMEAs should be done only at the function level, not at the logic or code level. (False. Software FMEAs can be done at the function, logic, and code levels.)
4. Unlike traditional FMEAs, Software FMEAs do not need to have recommended actions. (False. Software FMEAs, like every other type of FMEA, need effective recommended actions that are fully executed.)

Solution 15.9

When defining the functions in a Software FMEA, the procedure says the software should always go to the “desired state” no matter what causes the software to malfunction, and further says if a desired state is not identified in the specification, the software should always go into fail-safe state. From a software standpoint, what does it mean to “go into fail-safe state”? Give one example.

Answer: A fail-safe state is one that, in the event of failure, responds in a way that will cause minimal harm to other devices or danger to personnel. From a software standpoint, this means that if the software malfunctions, or if the software detects a hardware interface failure, it directs the system to a state that is not harmful to users or personnel. An example is an antilock brake system (ABS). If the ABS controller software malfunctions or if the controller software detects a failure of any part of the ABS system hardware, the primary vehicle brake system still functions safely, even if the ABS system is nonoperational. In other words, it fails safely.
Solution 15.10

Software FMEA procedure advises the use of precedence guidelines for solutions to software problems: (1) design out the failure mode, (2) use redundancy to achieve fault tolerance, (3) go into fail-safe mode (e.g., the ability to “limp home”), (4) implement early prognostic warning, and (5) implement training to reduce risk for human error. Refer to the example of software FMEA at the function level (Figure 15.16) in Section 15.4.2, specifically the “Robust Controls” column. Determine which precedence (1–5 above) was used for each of the four entries.

**Answer:**

Robust control: “Develop algorithm to reset to normal levels after imaging each patient” is an example of #3, “go into fail-safe mode.”

Robust control: “Include failure detection in software” is an example of #4, “implement early prognostic warning.”

Robust control: “Include visual/audio alarm in the code” is an example of #4, “implement early prognostic warning.”

Robust control: “Shut the system if radiation level does not match the inputs” is an example of #3, “go into fail-safe mode.”

Solution 15.11

Failure Modes, Mechanisms, and Effects Analysis (FMMEA) is different from traditional FMEA in the following ways. (Select all that apply.)

1. FMMEA requires each failure mode be analyzed for the underlying failure mechanism. **(True)**
2. FMMEA can be used to prioritize failure mechanisms for physics-of-failure models. **(True)**
3. FMMEA has the same output as a traditional FMEA. **(False. Unlike traditional FMEA, the output of FMMEA is a list of prioritized failure mechanisms for follow up.)**
4. FMMEA can use the same risk ranking scales as traditional FMEA. **(True. However, the FMMEA team may wish to modify the scales to better align to the FMMEA focus.)**

CHAPTER 16

Solution 16.1

A relational database is a type of database that (indicate true or false):

1. Is the same as Microsoft Excel®. **(False. An example of a relational database would be Microsoft Access®, not Microsoft Excel®.)**
2. Stores data in “relations,” which (to the end user) are in tables with rows and columns. **(True)**
3. Allows data to be easily accessed from other projects that are in the same database. (True)
4. Allows only single-user access at one time. (False. A relational database allows simultaneous access by multiple users.)

Solution 16.2
The reasons to move from spreadsheet-based FMEA software to a relational database include (select all that apply):

1. Comprehensive query functions across FMEAs. (True)
2. The FMEA team will save in-meeting and administrative time when doing multiple FMEAs. (True)
3. Multiuser environment with login security. (True)
4. Spreadsheet macros can accomplish the same functions as a relational database. (False. There are inherent limitations to spreadsheet macros and they are not able to accomplish the same functions as a relational database.)

Solution 16.3
When selecting software for doing FMEAs, it is important to consider (select all that apply):

1. Ease of performing basic FMEA functionality. (True)
2. Ability to access all FMEAs in the database. (True)
3. Linkage to other quality and reliability processes. (True)
4. Users’ familiarity with spreadsheet-based software. (False. Good FMEA software should be able to allow the user an option of interfacing with an FMEA worksheet that looks and feels like a spreadsheet, and still retain the features of a relational database.)