

## **Failure Mode and Effect Analysis (FMEA) Packet**

This packet is intended for use in the fourth year mechanical engineering design sequence. The material in this packet should help design teams perform a Failure Mode and Effect Analysis (FMEA) or a Failure Mode, Effect, and Criticality Analysis (FMECA) on their design projects. This experience should increase the students' awareness of safety and reliability issues. The FMEA or FMECA should also help the design teams to improve the safety and reliability of their products while at the same time reducing design time and expenses. An example FMECA is included in the lecture. A homework assignment is included which involves completing an FMECA.

Time for presentation is estimated as 40-45 minutes.

### Objectives:

1. To develop an understanding of the procedure used to perform an FMEA or FMECA.
2. To understand the benefits of using an FMEA or FMECA.
3. To increase awareness of safety and reliability issues.
4. To help students improve the safety and reliability of their projects while reducing design time and expenses.

This packet includes the following items:

- Lecture material for the instructor
- Overheads for use during the lecture
- Handouts for the students
- Homework problem and instructor solution

## Failure Mode and Effect Analysis (FMEA) Lecture Outline

- I. Introduction to Failure Mode and Effect Analysis (**OVERHEAD 1**)
  - A. The Failure Mode and Effect Analysis (FMEA) is a “logical, structured analysis of a system, subsystem, device, or process” (Schubert, 1992). It is one of the most commonly used reliability and system safety analysis techniques.
    - 1. The FMEA is used to identify possible failure modes, their causes, and the effects of these failures.
    - 2. Proper identification of failures may lead to solutions that increase the overall reliability and safety of a product.
  - B. Timing (**OVERHEAD 2**)
    - 1. Initially, the FMEA should be performed while in the design stage, but it also may be used throughout the life cycle of a product to identify possible failures as the system ages.
    - 2. Failure mode and effect analyses may vary in the level of detail reported, depending upon the detail needed and the availability of information. As a development matures, assessment of criticality is added in what becomes a Failure Mode, Effects, and Criticality Analysis, or FMECA.
  - C. Benefits of FMEA (**OVERHEAD 3**)
    - 1. The final product must be “safe”, as defined by the application. FMEA helps designers to identify and eliminate or control dangerous failure modes, minimizing damage to the system and its users.
    - 2. An increasingly accurate estimate of probability of failure will be developed, especially if reliable probability data is generated with an FMECA.
    - 3. Reliability of the product will improve.
    - 4. The design time will be reduced due to timely identification and correction of problems.
  - D. Other possible uses of FMEA (**OVERHEAD 4**)
    - 1. FMEA can be used in the preparation of diagnostic procedures.
    - 2. FMEA can be used to set appropriate maintenance procedures and intervals.
    - 3. In legal proceedings, FMEA may be used as documentation of the safety considerations that were involved in the design.
    - 4. As listed in MIL-STD-1629A, additional applications for FMEA include “maintainability, safety analysis, survivability and vulnerability, logistics support analysis, maintenance plan analysis, and for failure detection and isolation subsystem design.” Failure mode and effect analyses can be used for many applications in which reliability and safety are a concern.
- II. Types of FMEA (**OVERHEAD 5**)
  - A. Two main types of failure mode and effect analyses are used.
    - 1. Functional
      - a. This type of FMEA assumes a failure, and then identifies how that failure could occur.
      - b. The functional approach is typically used when individual items cannot be identified or a complex system exists.

- c. The functional approach generally involves a top-down analysis in which a specific failure mode for the entire system is traced back to the initiating subsystem failure mode(s).
    - 2. Hardware
      - a. The hardware approach investigates smaller portions of the system, such as subassemblies and individual components.
      - b. The hardware approach generally involves a bottom-up analysis in which the effects of possible failure modes of a subsystem, assembly, component, part, etc. on the entire system are identified.
  - B. This lecture will cover the hardware approach to FMEA since it is more commonly used than the functional approach.
- III. FMECA (Failure Mode, Effects, and Criticality Analysis) (**OVERHEAD 6**)
- A. An FMECA is essentially an FMEA, with an added criticality analysis. Another section should be added to the tabular format for criticality.
  - B. A failure mode, effects, and criticality analysis (FMECA) is performed to evaluate reliability and safety by identifying critical failure modes and their effects on the system.
  - C. The FMECA is performed on parts that are especially critical to the operation and well being of operators. A thorough knowledge of the system is required to complete an FMECA.
  - D. FMECAs can also be used to analyze processes, with the focus on process functions and operations and how failure may occur.
  - E. Failure data is necessary to complete the criticality portion of an FMECA.
  - F. (**OVERHEAD 7**) Failure modes may be ranked by the assigned criticality to determine which failure mode should be reduced in criticality by redesign or other abatement methods. System users should specify acceptable criticality levels.
  - G. Three ways to complete FMECA:
    - 1. Use criticality indices.
    - 2. The severity and probability indices are added together to yield the criticality index. It represents a measure of the overall risk associated with each combination of severity and probability. This method is commonly used in preliminary design when the failure probabilities are not known.
    - 3. Another method, which will only be mentioned here, involves determining the criticality using failure probability.
  - H. (**OVERHEAD 8**) A failure mode, effects, and criticality analysis can be a starting point for many other types of analyses, including:
    - 1. System Safety Analysis
    - 2. Production Planning
    - 3. Test Planning and Validation
    - 4. Repair Level Analysis
    - 5. Logistics Support Analysis
    - 6. Maintenance Planning Analysis.
 These additional analyses may also be used to update and improve the FMECA as new information evolves.
- IV. Performing an FMEA (**OVERHEAD 9**)
- A. The scope of an FMEA should be determined while information is being collected to perform the analysis.

B. The following information may be helpful when preparing an FMEA:

1. Design drawings
2. System schematics
3. Functional diagrams
4. Previous analytical data (if available)
5. System descriptions
6. Data gained from past experience
7. Manufacturer's component data/specifications
8. Preliminary hazard list (if available)
9. Preliminary hazard analysis
10. Other system analyses previously performed (Vincoli, 1997.)

C. Many documents exist that provide guidance on how to perform an FMEA.

1. MIL-STD-1629A was the standard for the U.S. military until 1998.
2. On August 4, 1998, the military standard, MIL-STD-1629A dated 24 November 1980, was rescinded, with instructions for users to "consult various national and international documents for information regarding failure mode, effects, and criticality analysis."
3. Because no better reference exists than the rescinded MIL-STD-1629A, it is used as a primary reference for this module.

V. Steps in FMEA (**OVERHEAD 10**)

A. The following is a procedure for performing an FMEA.

1. Define the scope of the analysis.
  - a. Resolution
    - i. Decide on an appropriate system level at which to perform the FMEA (subsystem, assembly, subassembly, component, part, etc.)
    - ii. Generally, the resolution of the FMEA should be increased as the design progresses.
  - b. Focus
    - i. The FMEA may be intended to determine the effects of failure modes on individual areas such as safety, mission success, or repair cost.
    - ii. For example, a safety-focused FMEA might indicate that a particular failure mode is not very critical, even though the failure may result in significant repair costs or downtime.
2. (**OVERHEAD 11**) Prepare a block diagram of the system - A block diagram graphically shows the relationship between the system's components.
3. Identify possible failure modes for each component.
  - a. What is the failure mode?
    - i. Failure modes are ways the system or component might fail. They might include yielding, ductile rupture, brittle fracture, fatigue, corrosion, wear, impact failure, fretting, thermal shock, radiation, buckling, and corrosion fatigue.
    - ii. An example of a failure mode would be corrosion, which might cause a metal pipe underneath a kitchen sink to develop a leak.
  - b. How does the failure occur?
    - i. Example: Corrosion is a time-based failure mode that would attack the metal

pipe over time. Water and other particulate material are a requirement for corrosion to occur.

4. **(OVERHEAD 12)** Identify possible causes for each failure mode.
  - a. What is the root cause?
    - i. Example: An uncoated metal pipe that has water running through it regularly.
5. Analyze the effects of the failure modes.
  - a. What are the effects of the failure?
    - i. Local effects.
      - (i) Example: A hole would develop in the pipe causing a water leak. Water damage to the surrounding environment may occur.
    - ii. System effects.
      - (i) Example: The system is defined as a house. Further water damage could result and possibly major flooding if corrective action is not taken in a reasonable amount of time.
6. **(OVERHEAD 13)** Classify the severity of the effects of each failure mode using the following four categories:
  - a. 4. Catastrophic (Death or system loss)
  - b. 3. Critical (Severe injury, occupational illness, or system damage)
  - c. 2. Marginal (Minor injury, occupational illness, or system damage)
  - d. 1. Negligible (Less than minor injury, occupational illness, or system damage)(Bloswick, NIOSH P.O. #939341 and MIL-STD-882B)
7. **(OVERHEAD 14)** Estimate the probability of each failure mode. Failure mode probabilities may be classified as follows:
  - a. 4. Probable (Likely to occur immediately or within a short period of time)
  - b. 3. Reasonably Probable (Probably will occur in time)
  - c. 2. Remote (Possible to occur in time)
  - d. 1. Extremely Remote (Unlikely to occur)

Note: **(OVERHEAD 15)** Severity and probability rankings will help the designer(s) to identify the criticality of the potential failure and the areas of the design that need the most attention. When a criticality index is included, the analysis is called a Failure Modes, Effects, and Criticality Analysis, or FMECA.

(Bloswick, NIOSH P.O. #939341)

8. For each failure mode, either propose modifications to prevent or control the failure mode or justify the acceptance of the failure mode and its potential effects.
  9. The criticality index is often defined as the sum or product of the severity and probability indices. The higher the criticality index, the higher the priority for change. The actual categorization of criticality indices into specific change priorities is generally a management decision.
- VI. Example (pressure cooker) **(OVERHEAD 16)**
- A. FMECA are generally presented in a tabular form.
  - B. Discuss the example FMECA.
    - Overhead 17: Defined scope**
    - Overhead 18: Block diagram**
    - Overhead 19-20: Completed FMECA**
- VII. FMECA Output **(OVERHEAD 21)**

A. Information gained from FMECA includes:

1. Listing of potential failure modes and failure causes. These could help guide the system testing and inspection techniques.
2. Further designation (criticality) of potential failures that could affect overall system performance.
3. Detection and control measures for each failure mode.
4. Management information.
5. Input for further analysis.

VIII. Limitations of FMECA (**OVERHEAD 22**)

- A. Critical failure modes, causes, or effects that are not recognized by the designer(s) will not be addressed by the FMECA.
- B. FMECA does not account for multiple-failure interactions, meaning that each failure is considered individually and the effect of several failures is not accounted for.
- C. FMECA does not analyze dangers or problems that may occur when the system is operating properly.
- D. Human factors are not considered.

IX. Lecture Summary (**OVERHEAD 23**)

- A. The overall safety of a design can be improved by using FMECA during the design process.
- B. The quality of the final product will be improved.
- C. The design process will be faster and progress more smoothly.

# **OVERHEADS**

# Failure Mode and Effect Analysis

The Failure Mode and Effect Analysis (FMEA) is a “logical, structured analysis of a system, subsystem, device, or process.”

It is one of the most commonly used reliability and system safety analysis techniques.

- The FMEA is used to identify possible failure modes, their causes, and the effects of these failures.
- Proper identification of failures may lead to solutions that increase the overall reliability and safety of a product.

## Timing

Initially, the FMEA should be performed while in the design stage, but it also may be used throughout the life cycle of a product to identify possible failures as the system ages.

Failure mode and effect analyses may vary in the level of detail reported, depending upon the detail needed and the availability of information. As a development matures, assessment of criticality is added in what becomes a Failure Mode, Effects, and Criticality Analysis, or FMECA.

## Benefits of FMEA

- The final product must be “safe”, as defined by the application. FMEA helps designers to identify and eliminate or control dangerous failure modes, minimizing damage to the system and its users.
- An increasingly accurate estimate of probability of failure will be developed, especially if reliable probability data is generated with an FMECA.
- Reliability of the product will improve.
- The design time will be reduced due to timely identification and correction of problems.

## Other Possible Uses of FMEA

- FMEA can be used in the preparation of diagnostic procedures.
- FMEA can be used to set appropriate maintenance procedures and intervals.
- In legal proceedings, FMEA may be used as documentation of the safety considerations that were involved in the design.
- As listed in MIL-STD-1629A, additional applications for FMEA include “maintainability, safety analysis, survivability and vulnerability, logistics support analysis, maintenance plan analysis, and for failure detection and isolation subsystem design.”

## Types of FMEA

Two main types of failure mode and effect analyses are used.

- Functional
  - This type of FMEA assumes a failure, and then identifies how that failure could occur.
  - The functional approach is typically used when individual items cannot be identified or a complex system exists.
  - The functional approach generally involves a top-down analysis in which a specific failure mode for the entire system is traced back to the initiating subsystem failure mode(s).
- Hardware
  - The hardware approach investigates smaller portions of the system, such as subassemblies and individual components.
  - The hardware approach generally involves a bottom-up analysis in which the effects of possible failure modes of a subsystem, assembly, component, part, etc. on the entire system are identified.

## **Failure Mode, Effects, and Criticality Analysis**

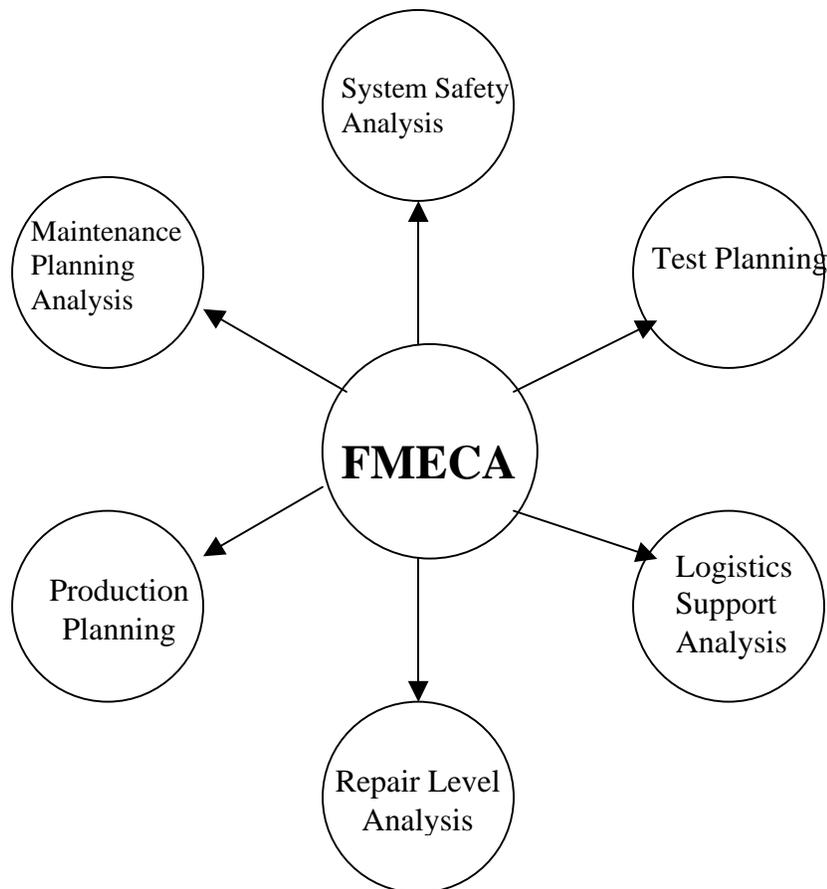
An FMECA is essentially an FMEA, with an added criticality analysis. An additional section should be added to the tabular format for criticality.

- A FMECA is performed to evaluate reliability and safety by identifying critical failure modes and their effects on the system.
- The FMECA is performed on parts that are especially critical to the operation and well being of operators. A thorough knowledge of the system is required to complete an FMECA.
- Failure data is necessary to complete the criticality portion of an FMECA.

## FMECA

- Failure modes may be ranked by the assigned criticality to determine which failure mode should be reduced in criticality by redesign or other abatement methods. System users should specify acceptable criticality levels.
- Three ways to complete FMECA:
  - Use criticality indices.
  - The severity and probability indices are added together to yield the criticality index. It represents a measure of the overall risk associated with each combination of severity and probability. This method is commonly used in preliminary design when the failure probabilities are not known.
  - Another method, which will only be mentioned here, involves determining the criticality using failure probability.

A failure mode, effects, and criticality analysis can be a starting point for many other types of analyses, including:



These additional analyses may also be used to update and improve the FMECA as new information evolves.

## **Performing an FMEA**

The scope of an FMEA should be determined while information is being collected to perform the analysis.

The following information may be helpful when preparing an FMEA:

- Design drawings
- System schematics
- Functional diagrams
- Previous analytical data (if available)
- System descriptions
- Data gained from past experience
- Manufacturer's component data/specifications
- Preliminary hazard list (if available)
- Preliminary hazard analysis
- Other system analyses previously performed

## Steps in FMEA

The following is a procedure for performing an FMEA.

- Define the scope of the analysis.
  - Resolution
    - Decide on an appropriate system level at which to perform the FMEA (subsystem, assembly, subassembly, component, part, etc.)
    - Generally, the resolution of the FMEA should be increased as the design progresses.
  - Focus
    - The FMEA may be intended to determine the effects of failure modes on individual areas such as safety, mission success, or repair cost.
    - For example, a safety-focused FMEA might indicate that a particular failure mode is not very critical, even though the failure may result in significant repair costs or downtime.

- Prepare a block diagram of the system - A block diagram graphically shows the relationship between the system's components.
- Identify possible failure modes for each component.
  - What is the failure mode?
    - Failure modes are ways the system or component might fail. They might include yielding, ductile rupture, brittle fracture, fatigue, corrosion, wear, impact failure, fretting, thermal shock, radiation, buckling, and corrosion fatigue.
    - An example of a failure mode would be corrosion, which might cause a metal pipe underneath a kitchen sink to develop a leak.
  - How does the failure occur?
    - Example: Corrosion is a time-based failure mode that would attack the metal pipe over time. Water and other particulate material are a requirement for corrosion to occur.

Identify possible causes for each failure mode.

- What is the root cause?
  - Example: An uncoated metal pipe that has water running through it regularly.

Analyze the effects of the failure modes.

- What are the effects of the failure?
  - Local effects.
    - Example: A hole would develop in the pipe causing a water leak. Water damage to the surrounding environment may occur.
  - System effects.
    - Example: The system is defined as a house. Further water damage could result and possibly major flooding if corrective action is not taken in a reasonable amount of time.

Classify the severity of the effects of each failure mode using the following four categories:

4. Catastrophic (Death or system loss)
3. Critical (Severe injury, occupational illness, or system damage)
2. Marginal (Minor injury, occupational illness, or system damage)
1. Negligible (Less than minor injury, occupational illness, or system damage)

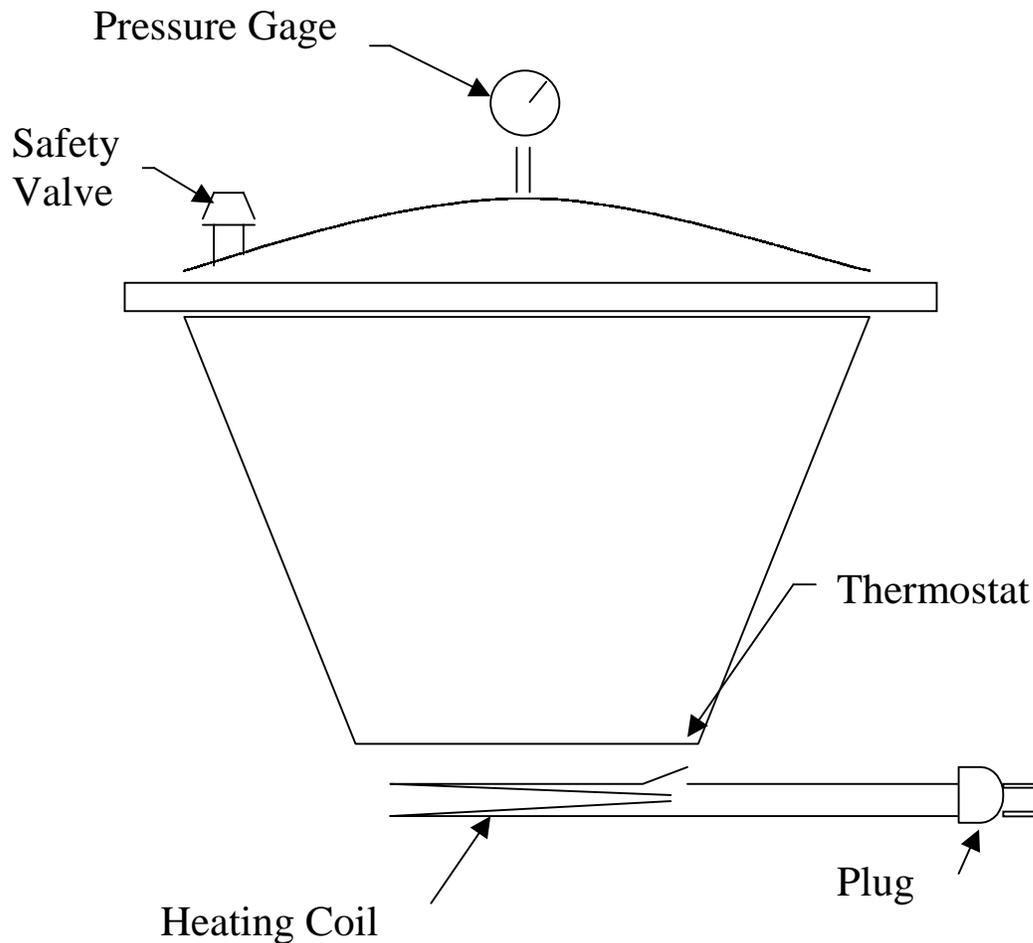
Estimate the probability of each failure mode.  
Failure mode probabilities may be classified as follows:

4. Probable (Likely to occur immediately or within a short period of time)
3. Reasonably Probable (Probably will occur in time)
2. Remote (Possible to occur in time)
1. Extremely Remote (Unlikely to occur)

Note: Severity and probability rankings will help the designer(s) to identify the criticality of the potential failure and the areas of the design that need the most attention. When a criticality index is included, the analysis is called a Failure Modes, Effects, and Criticality Analysis, or FMECA.

For each failure mode, either propose modifications to prevent or control the failure mode or justify the acceptance of the failure mode and its effects.

The criticality index is often defined as the sum or product of the severity and probability indices. The higher the criticality index, the higher the priority for change. The actual categorization of criticality indices into specific change priorities is generally a management decision.



### **Pressure Cooker Safety Features**

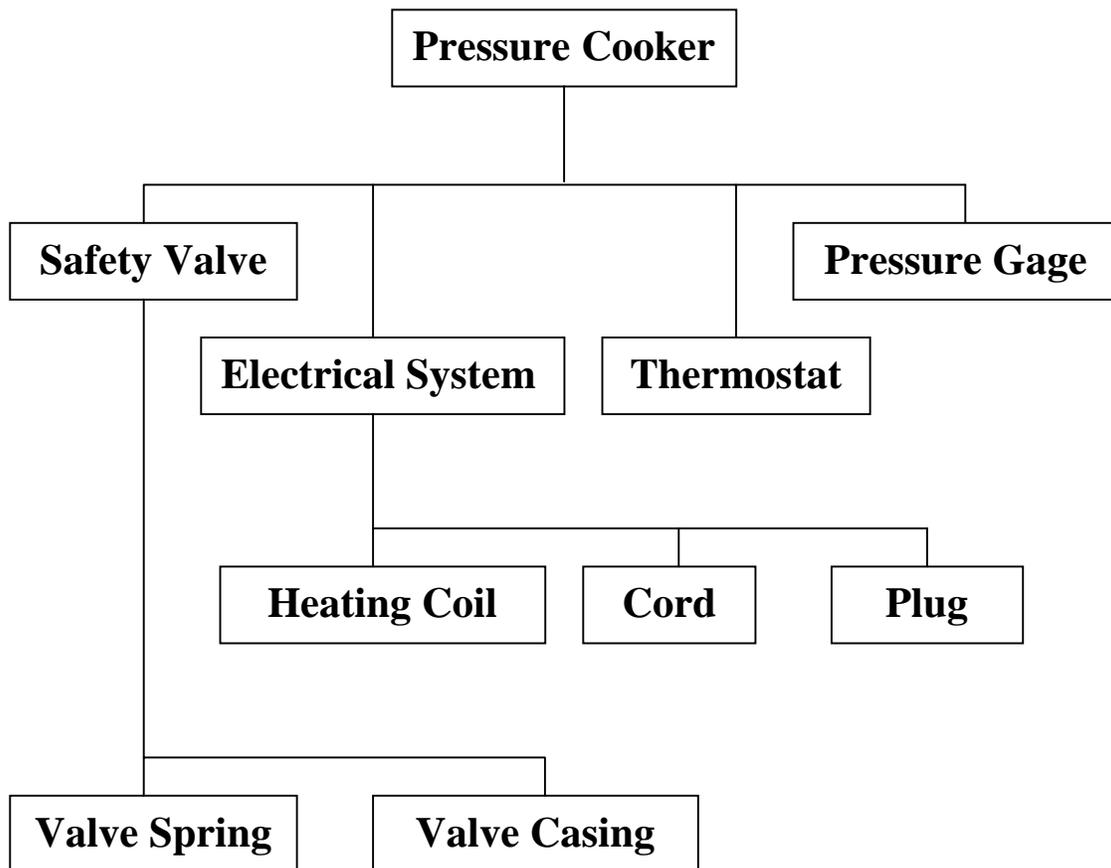
1. Safety valve relieves pressure before it reaches dangerous levels.
2. Thermostat opens circuit through heating coil when the temperature rises above  $250^{\circ}\text{C}$ .
3. Pressure gage is divided into green and red sections. "Danger" is indicated when the pointer is in the red section.

## **Pressure Cooker FMECA**

Define Scope:

1. Resolution - The analysis will be restricted to the four major subsystems (electrical system, safety valve, thermostat, and pressure gage).
2. Focus - Safety

## Pressure Cooker Block Diagram



**Failure Modes, Effects and Criticality Analysis for a Pressure Cooker (hardware approach with a focus on safety)**

Item	Failure Mode	Failure Causes	Failure Effects	Severity	Probability	Criticality	Control Measures/Remarks
Electrical System	No current	<ul style="list-style-type: none"> <li>Defective cord</li> <li>Defective plug</li> <li>Defective heating coil</li> </ul>	Cooking interruption (mission failure)	1	2	2	<ul style="list-style-type: none"> <li>Use high-quality components.</li> <li>Periodically inspect cord and plug.</li> </ul>
	Current flows to ground by an alternate route	Faulty insulation	<ul style="list-style-type: none"> <li>Shock</li> <li>Cooking interruption</li> </ul>	2	1	2	<ul style="list-style-type: none"> <li>Use a grounded (3-prong) plug.</li> <li>Only plug into outlets controlled by ground-fault circuit interrupters.</li> </ul>
Safety Valve	Open	Broken valve spring	<ul style="list-style-type: none"> <li>Steam could burn operator</li> <li>Increased cooking time</li> </ul>	2	2	4	Design spring to handle the fatigue and corrosion that it will be subjected to.
	Closed	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Potential overpressurization	1	2	2	<ul style="list-style-type: none"> <li>Use corrosion-resistant materials.</li> <li>Test the safety valve.</li> </ul>
Thermostat	Open	Defective thermostat	Cooking interruption	1	2	2	Use a high-quality thermostat.
	Closed	Defective thermostat	Overpressurization eventually opens valve	1	2	2	Use a high-quality thermostat.
Pressure Gage	Falsely indicates safe conditions	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Operator is not alerted of unsafe pressure build-up (explosion)	4	2	8	<ul style="list-style-type: none"> <li>Use corrosion-resistant materials.</li> <li>Test the safety valve.</li> </ul>

	Falsely indicates unsafe conditions	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Operator might assume system will not operate correctly	1	2	2	
Safety Valve and Thermostat	Both open	Broken valve spring and defective thermostat	Increased cooking time or cooking interruption	1	2	2	<ul style="list-style-type: none"> <li>Design spring to handle the fatigue and corrosion that it will be subjected to.</li> <li>Use corrosion-resistant materials.</li> <li>Test the safety valve.</li> <li>Use a high-quality thermostat</li> </ul>
	Both closed	Corroded or otherwise faulty valve and defective thermostat	<ul style="list-style-type: none"> <li>Loss of system</li> <li>Severe injuries or fatalities</li> </ul>	4	2	8	

## **Information gained from FMECA**

Information gained from FMECA includes:

1. Listing of potential failure modes and failure causes. These could help guide the system testing and inspection techniques.
2. Further designation (criticality) of potential failures that could affect overall system performance.
3. Detection and control measures for each failure mode.
4. Management information.
5. Input for further analysis.

## **Limitations of FMECA**

1. Failure modes must be foreseen by the designer(s).
2. FMECA does not account for multiple-failure interactions.
3. FMECA does not analyze dangers or problems that may occur when the system is operating properly.
4. Human factors are not considered.

## Lecture Summary

- The overall safety of a design can be improved by using FMEA/FMECA during the design process.
- The quality of the final product will be improved.
- The design process will be faster and progress more smoothly.

## **Failure Mode and Effect Analysis (FMEA) Lecture Handout**

- I. Introduction to Failure Mode and Effect Analysis
  - A. The Failure Mode and Effect Analysis (FMEA) is a “logical, structured analysis of a system, subsystem, device, or process” (Schubert, 1992). It is one of the most commonly used reliability and system safety analysis techniques.
    - 1. The FMEA is used to identify possible failure modes, their causes, and the effects of these failures.
    - 2. Proper identification of failures may lead to solutions that increase the overall reliability and safety of a product.
  - B. Timing
    - 1. Initially, the FMEA should be performed while in the design stage, but it also may be used throughout the life cycle of a product to identify possible failures as the system ages.
    - 2. Failure mode and effect analyses may vary in the level of detail reported, depending upon the detail needed and the availability of information. As a development matures, assessment of criticality is added in what becomes a Failure Mode, Effects, and Criticality Analysis, or FMECA.
  - C. Benefits of FMEA
    - 1. The final product must be “safe”, as defined by the application. FMEA helps designers to identify and eliminate or control dangerous failure modes, minimizing damage to the system and its users.
    - 2. An increasingly accurate estimate of probability of failure will be developed, especially if reliable probability data is generated with an FMECA.
    - 3. Reliability of the product will improve.
    - 4. The design time will be reduced due to timely identification and correction of problems.
  - D. Other possible uses of FMEA
    - 1. FMEA can be used in the preparation of diagnostic procedures.
    - 2. FMEA can be used to set appropriate maintenance procedures and intervals.
    - 3. In legal proceedings, FMEA may be used as documentation of the safety considerations that were involved in the design.
    - 4. As listed in MIL-STD-1629A, additional applications for FMEA include “maintainability, safety analysis, survivability and vulnerability, logistics support analysis, maintenance plan analysis, and for failure detection and isolation subsystem design.” Failure mode and effect analyses can be used for many applications in which reliability and safety are a concern.
- II. Types of FMEA
  - A. Two main types of failure mode and effect analyses are used.
    - 1. Functional
      - a. This type of FMEA assumes a failure, and then identifies how that failure could occur.
      - b. The functional approach is typically used when individual items cannot be identified or a complex system exists.
      - c. The functional approach generally involves a top-down analysis in which a specific failure mode for the entire system is traced back to the initiating subsystem failure mode(s).

2. Hardware

- a. The hardware approach investigates smaller portions of the system, such as subassemblies and individual components.
- b. The hardware approach generally involves a bottom-up analysis in which the effects of possible failure modes of a subsystem, assembly, component, part, etc. on the entire system are identified.

B. This lecture will cover the hardware approach to FMEA since it is more commonly used than the functional approach.

III. FMECA (Failure Mode, Effects, and Criticality Analysis)

A. An FMECA is essentially an FMEA, with an added criticality analysis. Another section should be added to the tabular format for criticality.

B. A failure mode, effects, and criticality analysis (FMECA) is performed to evaluate reliability and safety by identifying critical failure modes and their effects on the system.

C. The FMECA is performed on parts that are especially critical to the operation and well being of operators. A thorough knowledge of the system is required to complete an FMECA.

D. FMECAs can also be used to analyze processes, with the focus on process functions and operations and how failure may occur.

E. Failure data is necessary to complete the criticality portion of an FMECA.

F. Failure modes may be ranked by the assigned criticality to determine which failure mode should be reduced in criticality by redesign or other abatement methods. System users should specify acceptable criticality levels.

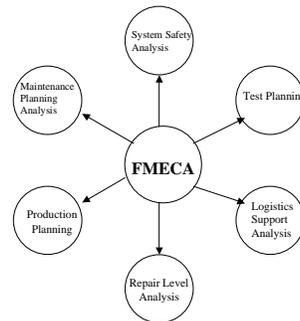
G. Three ways to complete FMECA:

- 1. Use criticality indices.
- 2. The severity and probability indices are added together to yield the criticality index. It represents a measure of the overall risk associated with each combination of severity and probability. This method is commonly used in preliminary design when the failure probabilities are not known.
- 3. Another method, which will only be mentioned here, involves determining the criticality using failure probability.

H. A failure mode, effects, and criticality analysis can be a starting point for many other types of analyses, including:

- 1. System Safety Analysis
- 2. Production Planning
- 3. Test Planning and Validation
- 4. Repair Level Analysis
- 5. Logistics Support Analysis
- 6. Maintenance Planning Analysis.

These additional analyses may also be used to and improve the FMECA as new information evolves.



update

IV. Performing an FMEA

A. The scope of an FMEA should be determined while information is being collected to perform the analysis.

B. The following information may be helpful when preparing an FMEA:

- 1. Design drawings

2. System schematics
3. Functional diagrams
4. Previous analytical data (if available)
5. System descriptions
6. Data gained from past experience
7. Manufacturer's component data/specifications
8. Preliminary hazard list (if available)
9. Preliminary hazard analysis
10. Other system analyses previously performed  
(Vincoli, 1997.)

C. Many documents exist that provide guidance on how to perform an FMEA.

1. MIL-STD-1629A was the standard for the U.S. military until 1998.
2. On August 4, 1998, the military standard, MIL-STD-1629A dated 24 November 1980, was rescinded, with instructions for users to "consult various national and international documents for information regarding failure mode, effects, and criticality analysis."
3. Because no better reference exists than the rescinded MIL-STD-1629A, it is used as a primary reference for this module.

V. Steps in FMEA

A. The following is a procedure for performing an FMEA.

1. Define the scope of the analysis.
  - a. Resolution
    - i. Decide on an appropriate system level at which to perform the FMEA (subsystem, assembly, subassembly, component, part, etc.)
    - ii. Generally, the resolution of the FMEA should be increased as the design progresses.
  - b. Focus
    - i. The FMEA may be intended to determine the effects of failure modes on individual areas such as safety, mission success, or repair cost.
    - ii. For example, a safety-focused FMEA might indicate that a particular failure mode is not very critical, even though the failure may result in significant repair costs or downtime.
2. Prepare a block diagram of the system - A block diagram graphically shows the relationship between the system's components.
3. Identify possible failure modes for each component.
  - a. What is the failure mode?
    - i. Failure modes are ways the system or component might fail. They might include yielding, ductile rupture, brittle fracture, fatigue, corrosion, wear, impact failure, fretting, thermal shock, radiation, buckling, and corrosion fatigue.
    - ii. An example of a failure mode would be corrosion, which might cause a metal pipe underneath a kitchen sink to develop a leak.
  - b. How does the failure occur?
    - i. Example: Corrosion is a time-based failure mode that would attack the metal pipe over time. Water and other particulate material are a requirement for corrosion to occur.

4. Identify possible causes for each failure mode.
  - a. What is the root cause?
    - i. Example: An uncoated metal pipe that has water running through it regularly.
5. Analyze the effects of the failure modes.
  - a. What are the effects of the failure?
    - i. Local effects.
      - (i) Example: A hole would develop in the pipe causing a water leak. Water damage to the surrounding environment may occur.
    - ii. System effects.
      - (i) Example: The system is defined as a house. Further water damage could result and possibly major flooding if corrective action is not taken in a reasonable amount of time.
6. Classify the severity of the effects of each failure mode using the following four categories:
  - a. 4. Catastrophic (Death or system loss)
  - b. 3. Critical (Severe injury, occupational illness, or system damage)
  - c. 2. Marginal (Minor injury, occupational illness, or system damage)
  - d. 1. Negligible (Less than minor injury, occupational illness, or system damage)

(Bloswick, NIOSH P.O. #939341 and MIL-STD-882B)
7. Estimate the probability of each failure mode. Failure mode probabilities may be classified as follows:
  - a. 4. Probable (Likely to occur immediately or within a short period of time)
  - b. 3. Reasonably Probable (Probably will occur in time)
  - c. 2. Remote (Possible to occur in time)
  - d. 1. Extremely Remote (Unlikely to occur)

Note: Severity and probability rankings will help the designer(s) to identify the criticality of the potential failure and the areas of the design that need the most attention. When a criticality index is included, the analysis is called a Failure Modes, Effects, and Criticality Analysis, or FMECA.

(Bloswick, NIOSH P.O. #939341)

8. For each failure mode, either propose modifications to prevent or control the failure mode or justify the acceptance of the failure mode and its potential effects.
  9. The criticality index is often defined as the sum or product of the severity and probability indices. The higher the criticality index, the higher the priority for change. The actual categorization of criticality indices into specific change priorities is generally a management decision.
- VI. Example (pressure cooker)
- A. FMECA are generally presented in a tabular form.
  - B. Discuss the example FMECA.
    - Defined scope**
    - Block diagram**
    - Completed FMECA**
- VII. FMECA Output
- A. Information gained from FMECA includes:
    1. Listing of potential failure modes and failure causes. These could help guide the system testing and inspection techniques.

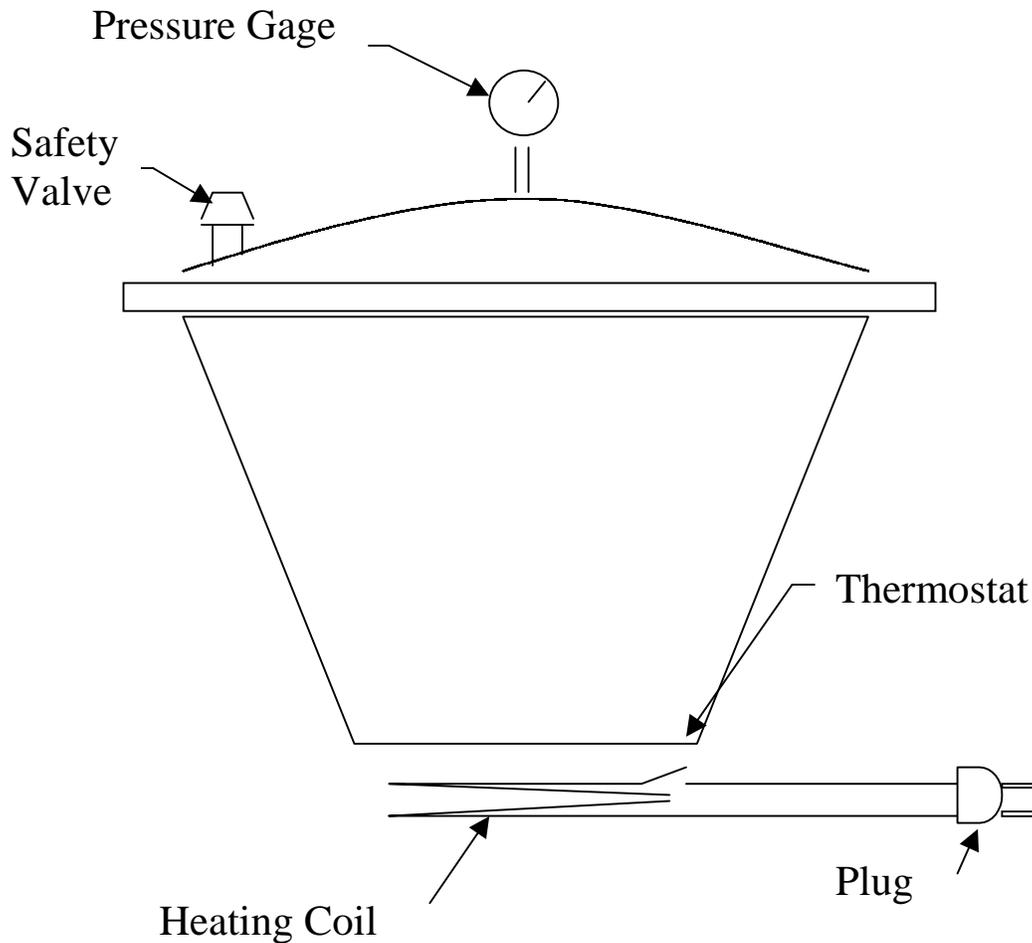
2. Further designation (criticality) of potential failures that could affect overall system performance.
3. Detection and control measures for each failure mode.
4. Management information.
5. Input for further analysis.

VIII. Limitations of FMECA

- A. Critical failure modes, causes, or effects that are not recognized by the designer(s) will not be addressed by the FMECA.
- B. FMECA does not account for multiple-failure interactions, meaning that each failure is considered individually and the effect of several failures is not accounted for.
- C. FMECA does not analyze dangers or problems that may occur when the system is operating properly.
- D. Human factors are not considered.

IX. Lecture Summary

- A. The overall safety of a design can be improved by using FMECA during the design process.
- B. The quality of the final product will be improved.
- C. The design process will be faster and progress more smoothly.



### **Pressure Cooker Safety Features**

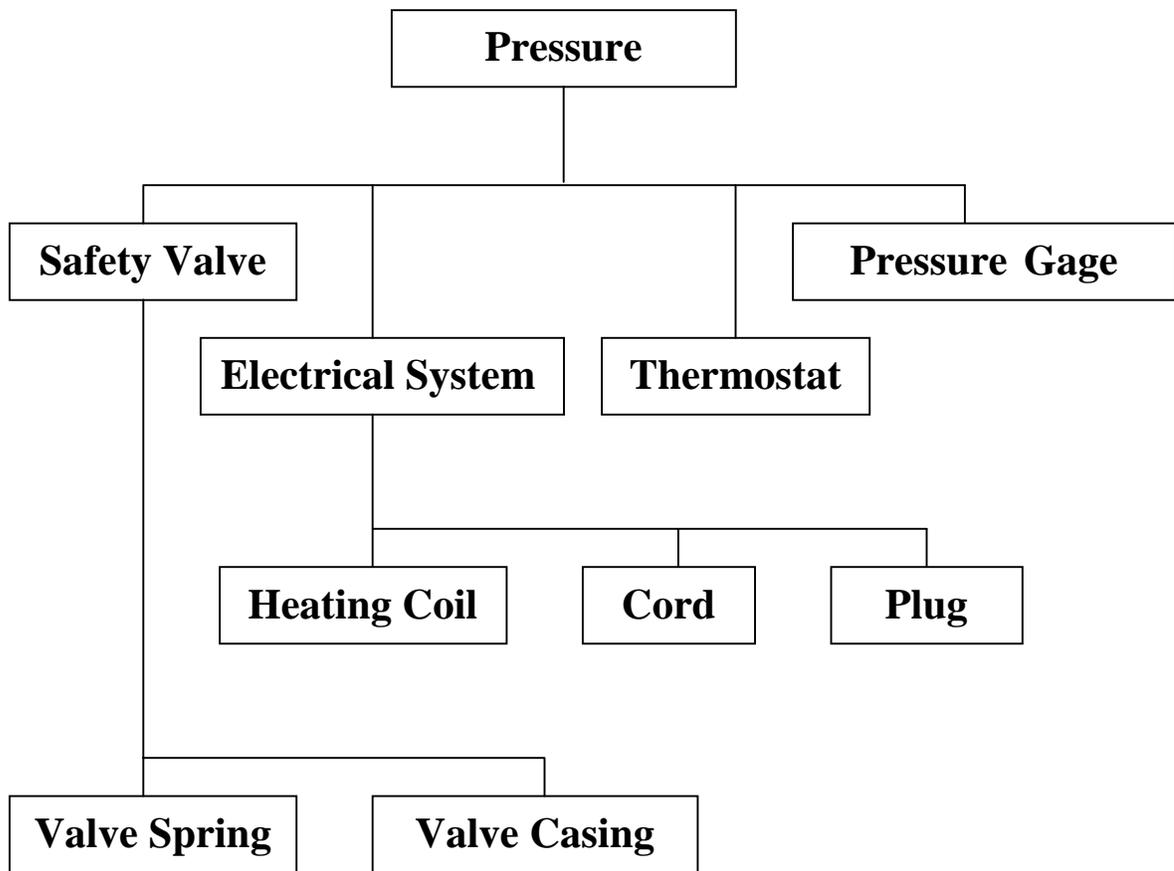
1. Safety valve relieves pressure before it reaches dangerous levels.
2. Thermostat opens circuit through heating coil when the temperature rises above 250° C.
3. Pressure gage is divided into green and red sections. "Danger" is indicated when the pointer is in the red section.

## **Pressure Cooker FMECA**

Define Scope:

1. Resolution - The analysis will be restricted to the four major subsystems (electrical system, safety valve, thermostat, and pressure gage).
2. Focus - Safety

# Pressure Cooker Block Diagram



### Failure Modes, Effects and Criticality Analysis for a Pressure Cooker (hardware approach with a focus on safety)

Item	Failure Mode	Failure Causes	Failure Effects	Severity	Probability	Criticality	Control Measures/Remarks
Electrical System	No current	<ul style="list-style-type: none"> <li>Defective cord</li> <li>Defective plug</li> <li>Defective heating coil</li> </ul>	Cooking interruption (mission failure)	1	2	2	<ul style="list-style-type: none"> <li>Use high-quality components.</li> <li>Periodically inspect cord and plug.</li> </ul>
	Current flows to ground by an alternate route	Faulty insulation	<ul style="list-style-type: none"> <li>Shock</li> <li>Cooking interruption</li> </ul>	2	1	2	<ul style="list-style-type: none"> <li>Use a grounded (3-prong) plug.</li> <li>Only plug into outlets controlled by ground-fault circuit interrupters.</li> </ul>
Safety Valve	Open	Broken valve spring	<ul style="list-style-type: none"> <li>Steam could burn operator</li> <li>Increased cooking time</li> </ul>	2	2	4	Design spring to handle the fatigue and corrosion that it will be subjected to.
	Closed	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Potential overpressurization	1	2	2	<ul style="list-style-type: none"> <li>Use corrosion-resistant materials.</li> <li>Test the safety valve.</li> </ul>
Thermostat	Open	Defective thermostat	Cooking interruption	1	2	2	Use a high-quality thermostat.
	Closed	Defective thermostat	Overpressurization eventually opens valve	1	2	2	Use a high-quality thermostat.
Pressure Gage	Falsely indicates safe conditions	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Operator is not alerted of unsafe pressure build-up (explosion)	4	2	8	<ul style="list-style-type: none"> <li>Use corrosion-resistant materials.</li> <li>Test the safety valve.</li> </ul>
	Falsely indicates unsafe conditions	<ul style="list-style-type: none"> <li>Corrosion</li> <li>Faulty manufacture</li> </ul>	Operator might assume system will not operate correctly	1	2	2	

Safety Valve and Thermostat	Both open	Broken valve spring and defective thermostat	Increased cooking time or cooking interruption	1	2	2	<ul style="list-style-type: none"> <li>• Design spring to handle the fatigue and corrosion that it will be subjected to.</li> <li>• Use corrosion-resistant materials.</li> <li>• Test the safety valve.</li> <li>• Use a high-quality thermostat</li> </ul>
	Both closed	Corroded or otherwise faulty valve and defective thermostat	<ul style="list-style-type: none"> <li>• Loss of system</li> <li>• Severe injuries or fatalities</li> </ul>	4	2	8	

## **FMECA Homework Assignment**

Complete a hardware FMECA for a standard pair of inline skates. Use the lecture handout to help you complete the FMECA. An FMECA worksheet has been included. It may be necessary to make additional copies. Include a short cover memorandum discussing your FMECA and the assumptions you made.

Learning objectives:

1. To develop an improved understanding of the need to consider all potential failure modes of engineering components in the earliest phases of design concurrent with other critical issues.
2. To develop an understanding of the procedure used to develop an FMECA.
3. To develop an increased understanding of the interaction of failure modes of engineering components in design.
4. To develop improved understanding of the failure mechanisms of fatigue and wear (with emphasis on fretting) in engineering components.
5. To develop an improved understanding of the critical issue of manufacturing as related to its role on failure modes.
6. To develop an improved understanding of the critical role of material specifications in relation to the control of failure.
7. To develop an improved understanding of the role of interfaces on failure modes in design.
8. To develop an improved understanding of the role of dimensioning and tolerances in failure processes and design.
9. To improve skills in preparing written technical reports.
10. To develop an increased understanding of the role of the FMEA and reliability issues in the design process.



**FMECA Homework Assignment Solution (Example only; answers will vary)**

<b>Hardware Item</b>	<b>Failure Modes</b>	<b>Causes of Failure</b>	<b>Failure Effects</b>	<b>Severity</b>	<b>Probability of Occurrence</b>	<b>Criticality</b>	<b>Failure Detection Methods</b>	<b>Immediate Intervention</b>	<b>Long Term Intervention</b>	<b>Comments</b>
Rubber wheels	Abrasive wear	Abrasive wear with road	Increased friction, reduced rolling "smoothness"	2	4	8	Visual inspection/user feeling	Rotating or replacing worn wheels	Scheduled inspection and wheel maintenance	Difficult to prevent, easy to fix
	Deformation wear	Deformation wear with wheel and road surface	Increased friction, reduced rolling "smoothness"	2	3	6	Visual inspection/user feeling	Rotating or replacing worn wheels	Scheduled inspection and wheel maintenance	Difficult to prevent, easy to fix
Metal sleeves in wheels	Yielding	Yielding due to load on wheels	Wheels not free to roll as easily	3	2	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
	Fatigue	Crack in the sleeve caused by surface fatigue	Wheel may fall out of sleeve	3	2	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
	Crevice corrosion	Crevice corrosion; solution becomes trapped during manufacture	Wheel not free to roll in sleeve, may lead to failure of sleeve	3	2	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
	Crevice corrosion	Corrosion between metal and plastic	Wheel not free to roll in sleeve, may lead to failure of sleeve	3	2	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
	Stress corrosion	Stress corrosion of sleeves	Wheel not free to roll in sleeve, may lead to failure of sleeve	2	3	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
	Deformation wear	Wear between metal sleeves and wheels	Wheel not free to roll in sleeve, may lead to failure of sleeve	3	2	6	Annual inspection/user feeling extra friction	Replacement of part	Routine inspection and lubrication	Requires taking apart the wheel assembly of blade
Plastic Brake Block	Abrasive wear	Abrasive wear with road	Reduced stopping ability	2	4	8	Visual inspection by user	Replacement of block	Routine inspection and replacement	Has safety impact on user
Bolt/screw assembly for brake block	Direct chemical attack	Direct chemical attack occurs due to contact with water, salt, etc.	May lose break block, inability to stop/slow	2	4	8	Visual inspection by user	Removal of old assembly; replacement	Inspection, use of another material with less corrosive tendencies	Seals bolt to screw and is difficult to remove

## **References**

Bloswick, Donald S., *Systems Safety Analysis*, NIOSH P.O. #939341

Goldberg, B.E., et al., *System Engineering "Toolbox" for Design-Oriented Engineers*, NASA Reference Publication 1358, Marshall Space Flight Center, Alabama, 1994.

Hammer, W., *Occupational Safety Management and Engineering, Fourth Edition*, Prentice Hall, Englewood Cliffs, New Jersey, 1989.

MIL-STD-882B, 1984.

MIL-STD-1629A, *Procedures for Performing a Failure Mode, Effects, and Criticality Analysis*, 24 Nov. 1980.

MIL-STD-1629A NOTICE 3.

<http://astimage.daps.dla.mil/docimages/0001/12/92/1629CAN.PD6>

O'Conner, *Practical Reliability Engineering, 3<sup>rd</sup> edition, Revised*, John Wiley & Sons, Chichester, England, 1996.

*Readings in System Safety Analysis*, 5<sup>th</sup> Ed., Safety Sciences Dept., IUP.

Schubert, Michael. SAE G-11: Reliability, Maintainability, and Supportability Guidebook. April 1992.

Vincoli, Jeffrey W., *Basic Guide to System Safety*, Van Nostrand Reinhold, New York, New York, 1997.