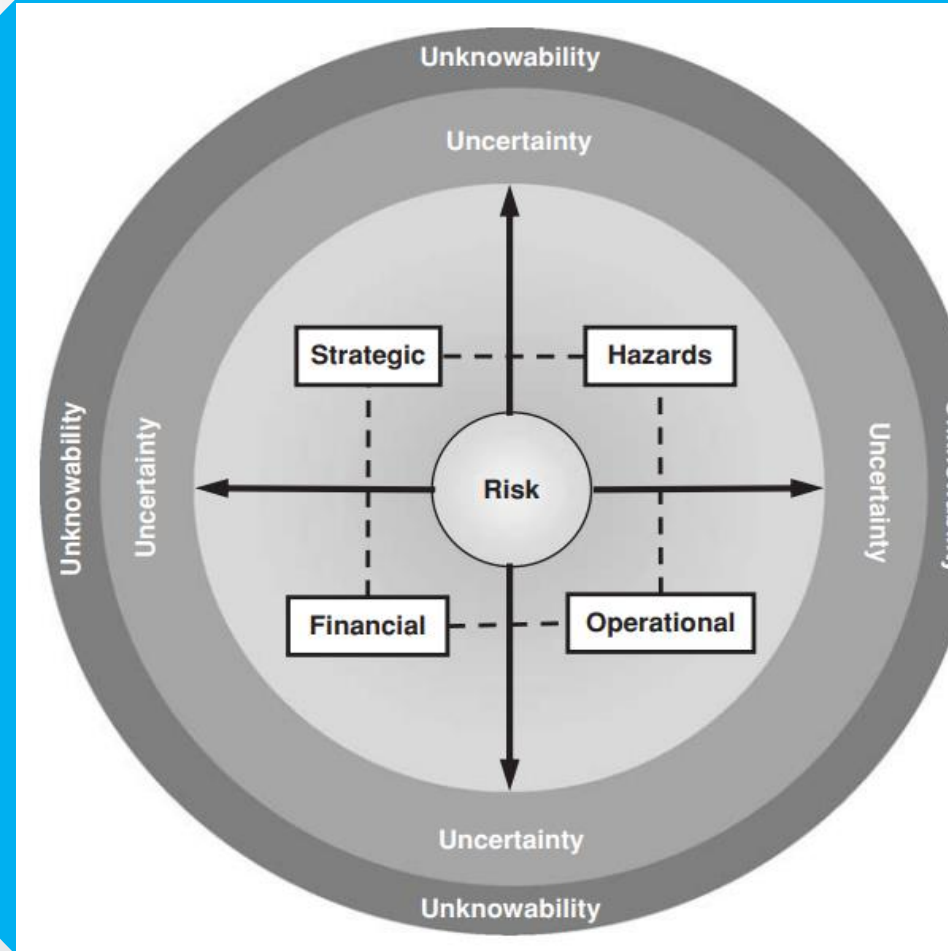


Strategic And Operational Risk Management

PMG630

Prepared by

Dr. Ayman Hassan



Lecture .5 “Tools and Techniques” **F**ailure **M**odes and **E**ffects **A**nalysis, **FMEA**

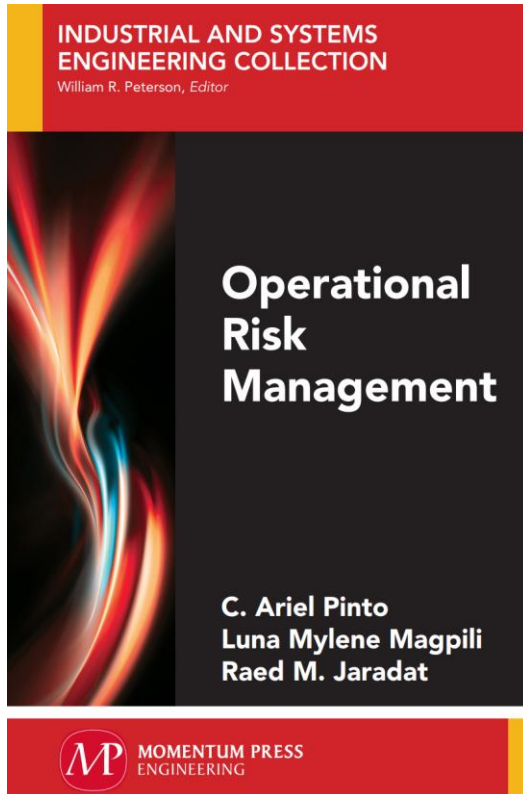
Chapter 3

Tools and Techniques

Failure Modes and Effects Analysis, FMEA

Prepared by

Dr. Ayman Hassan



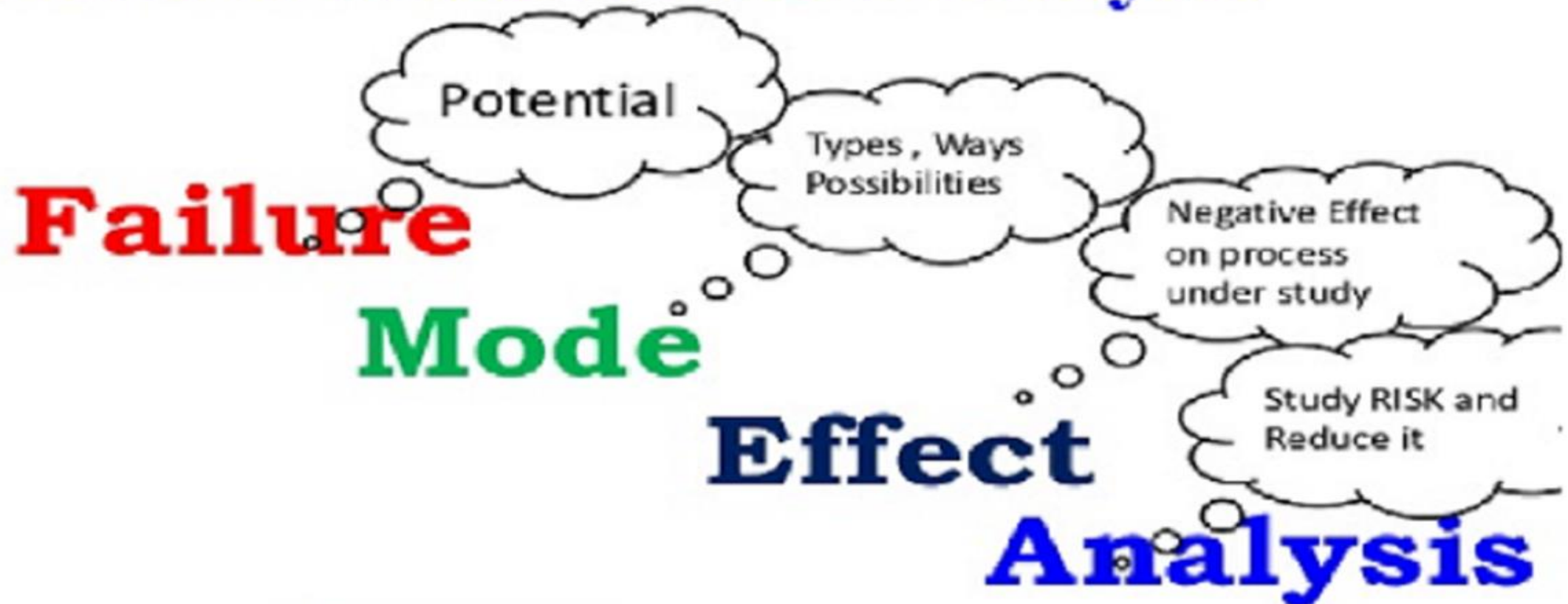
REF, 1



REF,2

1. Summary of the previous lecture “chapter.3 “
2. Introduction
3. **F**ailure **M**odes and **E**ffects **A**nalysis, **FMEA**
4. The Basics of – **FMEA**
5. Criteria for **FMEA** Analysis
6. Where and when to use **FMEA**?
7. The 5 steps of the **FMEA** process
8. Application to example
9. Conclusions
10. 10. References & Resources

Failure Mode Effect Analysis



What can go **WRONG** in your process or product

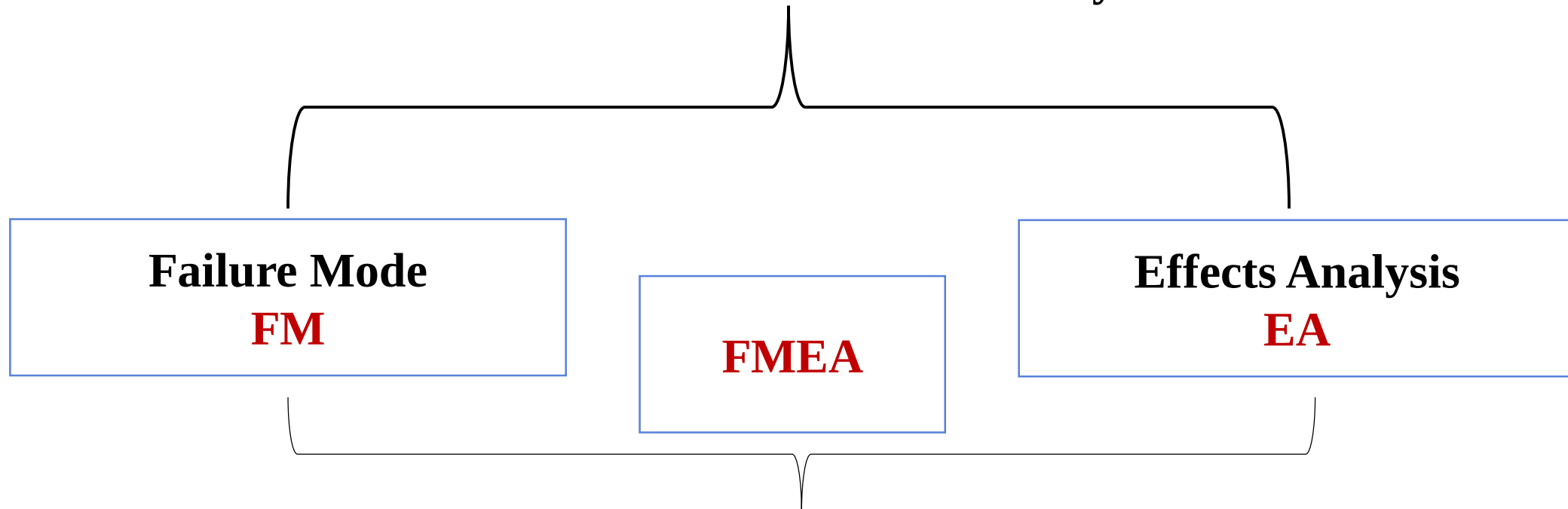
What is Failure Mode and Effects Analysis?

Failure **M**ode and **E**ffects **A**nalysis, **FMEA**

- Failure Modes and Effects Analysis (FMEA) is a systematic, proactive method for evaluating a process to identify where and how it might fail ?
- It is to assess the relative impact of different failures, in order to identify the parts of the process that are most in need of change.

We must pay attention at the beginning... We are studying a tool that identifies and analyses two important parts:

Failure Mode and Effects Analysis



- ✓ FMEA is a top-down quantitative technique applied to identify failures in a design, a process, a system, or an existing product, equipment, or service.
- ✓ FMEA is used to analyze elements or components of a system, their interactions and their effects on the operation of the system as a whole.
- The term failure modes pertains to ways in which functional elements may fail.
- The term effects analysis describes the consequences of those failures and any existing prevention or control measures to address them.

- Thus, FMEA similar to HAZOP also examines how existing system capabilities detect failures and manage such failures.
- Correspondingly, risks are ranked based on the likelihood and consequences of failure, as well as the current system's ability to detect and manage failure if they do occur.
- Similar to PHA and unlike HAZOP and JSA, FMEA further assesses the likelihoods of occurrence of these failures.

A Bottom-to-top FMEA approach...

- What are the effects of box failures on the **system**?
- What are the effects of board failures on the box?
- What are the effects of part failures on the board?

What if a part suffers Basic functional failure?



A Top-to-Bottom approach ...



- What system-level failures could occur, and what would cause them? How to mitigate effects?



- If assembly-level failures could cause the system problem, what would cause the assembly failure? How to mitigate effects?



- If board-level could cause sub-assembly problems, what could cause the board failure? How to mitigate effects?



- If component-level failures could cause the board-level problem, what in-turn would cause that failure? How to mitigate effects?

- FMEA is a qualitative and systematic tool, usually created within a spreadsheet, to help practitioners anticipate what might go wrong with a product or process. In addition to identifying how a product or process might fail and the effects of that failure, FMEA also helps find the possible causes of failures and the likelihood of failures being detected before occurrence.
- Used across many industries, FMEA is one of the best ways of analyzing potential reliability problems early in the development cycle, making it easier for manufacturers to take quick action and mitigate failure. The ability to anticipate issues early allows practitioners to design out failures and design in reliable, safe and customer-pleasing features.

An FMEA uses three criteria to assess a problem:

- 1- The severity of the effect on the customer,
 - 2- How frequently the problem is likely to occur and
 - 3- How easily the problem can be detected.
- ✓ Participants must set and agree on a ranking between 1 and 10 (1 = low, 10 = high) for the severity, occurrence and detection level for each of the failure modes.
 - ✓ Although FMEA is a qualitative process, it is important to use data (if available) to qualify the decisions the team makes regarding these ratings.

- FMEA is used to study a variety of systems and products that are more detailed and complex such as those in the aviation and electronics industry.
- More often, it is applied as periodic review throughout the life of the system to accommodate changes within the system and its environment.

- It is applicable in both the design and operation phases, particularly in the development of operational risk management strategies.
- It is useful for redesigning existing systems for a new application as well.
- FMEA is also used for risk and safety auditing and accident investigations.

The five most basic steps when conducting FMEA include identifying potential failures and effects, determining the severity of each, gauging the likelihood of each failure occurring, failure detection, and assigning a risk priority number.

Each step is described in greater detail as following.

The first FMEA step is to analyze functional requirements and their effects and identify all potential areas of failure.

It's important to consider that failure modes in one component can induce failure in others. List all failure modes per function and consider the ultimate effect(s) of each failure mode. Examples of failure effects include overheating, noise, abnormal shutdown, or user injury.

Severity refers to how serious the consequences and effects are of a failure.

A number of severity is assigned to each failure, with one being the lowest severity and 10 being the highest. Typical FMEA severity ratings are as follows:

- 1 - No effect, no danger
- 2 - Very minor – usually noticed only by very observant users
- 3 - Minor – only a minor part of the system is affected; the failure is noticed by average users
- 4-6 - Moderate – most users are merely inconvenienced and/or annoyed
- 7-9 - High – there is a loss of primary function; users are dissatisfied
- 10 - Very high – failure constitutes a safety hazard and can cause injury or death, or the product becomes inoperative, and customers become angry

Step 2: Determine severity, Table 1E

Effect	Rank	Criteria
No	1	No effect
Very slight	2	Customer not annoyed
Slight	3	Customer slight annoyed
Minor	4	Customer experiences minor nuisance
Moderate	5	Customer experiences some dissatisfaction
Significant	6	Customer experiences discomfort
Major	7	Customer dissatisfied
Extreme	8	Customer very dissatisfied
Serious	9	Potential hazardous effect
Hazardous	10	Hazardous effect

Step 2: Determine severity, Table 2 A

المعايير	الترتيب	التاثير
لا	١	لا تاثير
طفيف جدا	٢	العميل غير منزعج
طفيف حديا	٣	العميل منزعج حديا
بسيط متوسط	٤	العميل منزعج
متوسط	٥	العميل يشعر بعدم الرضا
ظاهر الخطورة	٦	العميل يشعر بعدم الراحة
خطورة كبير	٧	العميل غير راض بشكل كبير
خطورة كبيرة جدا	٨	العميل غير راض جدا " خطير "
خطورة توجب التدخل بجديه	٩	فقدان رضا العميل تماما
خطر للغاية	١٠	فقدان العميل نفسه تاثير خطير جدا

Step 3: Measure likelihood of occurrence

Examine and document the cause(s) of each failure mode and how often failure occurs. Look at similar processes or products and their documented failure modes. Examples of causes can include incorrect algorithms, insufficient or excess voltage, the temperature or humidity of the operating environment. Failure modes are also assigned a number based on occurrence, with 1 being the lowest and 10 being the highest.

1 - No documented failures on similar products or processes

2-3 - Low - relatively few failures occur

4-6 - Moderate - there are some occasional failures

7-8 - High - repeated failures are experienced

9-10 - Very high - failure is almost certain ,and the results in a hazard

Determine corrective actions and when they should be tested for effectiveness and efficiency.

Verify and inspect procedures within the design of the system or process. A detection value is assigned to each failure indicating how likely the failure will be detected, and ranks the ability of identified actions to remedy or remove defects or detect failures. The higher the value of D, the more likely the failure will not be detected.

- 1 - Fault is certain to be detected by testing
- 2 - Fault is almost certain to be detected by testing
- 3 - High probability that testing will detect the fault
- 4-6 - Moderate probability that tests will detect the fault
- 7-9 - Low probability that testing will detect the fault
- 10 - Fault will be passed undetected to the end-user/customer

Risk priority numbers (RPNs) influence which actions will be taken against failure modes.

RPN is calculated from the values of severity, occurrence, and detection as :

$$\text{RPN} = \text{Severity} * \text{Occurrence} * \text{Detection (or RPN} = S \times O \times D)$$

RPN should be calculated for the entire design and/or process and documented in the FMEA. The highest RPNs should get the highest priority for corrective measures. These measures can include a variety of actions including new inspections, tests or procedures, design changes, different components, added redundancy, modified limits, etc.

1. Define the system and the scope of the study.
2. Identify the key functional objectives.
3. For each objective, identify the ways failure can occur (the failure modes).
4. For each failure mode, identify the consequences (effects) if failure occurs.
5. Rate the consequences in terms of severity.
6. Identify the root causes for each failure mode.

7. Rate each root cause in terms of chance of occurrence.
8. Identify current preventive and control measures for each root cause.
9. For each root cause and failure, rate how well or early they can be detected and addressed.
10. Calculate the risk priority number (RPN) based on the consequences, occurrence, and detection.
11. Identify the failures that are considered critical.
12. Determine additional preventive or control measures as needed.

FMEA can be a comprehensive look at the total system as a whole, or it may focus on certain subsystems, elements, or components.

As an example, consider the bicycle as a system of interest.

An item analysis of the bicycle system is shown in Figure 3.5.

ITEM ANALYSIS—BICYCLE EXAMPLE

1.0 Bicycle System

← *System item*

- 1.1 Frame subsystem
- 1.2 Front wheel subsystem
- 1.3 Rear wheel subsystem
- 1.4 Sprocket–pedal subsystem
- 1.5 Chain–derailleur subsystem
- 1.6 Seat subsystem
- 1.7 Handle bar subsystem

1.8 Hand brake subsystem

← *Subsystem item*

- 1.8.1 Brake lever
- 1.8.2 Brake cable**
- 1.8.3 Brake pads
- 1.8.4 Brake caliper

← *Component item*

- 1.9 Suspension subsystem

Figure 3.5. Item analysis of bicycle.¹³

After completing the identification of the system of study, which the FMEA worksheet in Figure 3.6 will focus on the subsystem that has been identified, which is the handbrake subsystem, which is referred to as item 1.8 (shaded in grey) in the bicycle component analysis in Figure 3.5.

We begin preparing the FMEA working paper... as follows

FMEA Item No.: 1.8		Item description: Hand brake subsystem Date:								
(1) Function or process	(2) Potential failure modes	(3) Potential effect(s) of failure	(4) Severity (S)	(5) Potential cause(s) of failure	(6) Occurrence rating (L)	(7) Current design controls (prevent)	(7) Current design controls (detect)	(8) Detection rating (D)	(9) RPN $L \times S \times D$	(10) Recom- mended action(s)
<i>What should go right, what is supposed to happen</i>	<i>What are the ways that pre- vent the process or function to achieve its objective</i>	<i>What is the conse- quence of the failure</i>	<i>How sig- nificant is the impact</i>	<i>How can the failure occur</i>	<i>What is the likelihood of occur- rence</i>	<i>What are in place so that failure is prevented</i>	<i>What are in place so that failure is controlled</i>	<i>How effec- tive are the measures</i>	$L \times S \times D$	<i>What can be done</i>
Provide the correct level of friction between brake pad assembly and wheel rim	Insufficient fric- tion between brake pads and wheels during normal operat- ing conditions or extreme conditions	Bicycle wheel does not slow down when the brake lever is pulled potentially resulting in injury	5	Cable binds due to inadequate lubrication or poor routing	2	Make sure hand brake is consistent with design guide	Make sure testing satisfies established bicycle system durability tests	1	10	Review manual
				Foreign mate- rial reduces friction between brake pads and wheel rim	1					
				Cable breaks	3					

Figure 3.6. FMEA worksheet for bicycle brake component.¹⁴

FMEA
Item No.: 1.8

Item description: Hand brake subsystem
Date:

- **What should go right?**

{ Column 1: Functional objectives of the subsystem or component

- **What can go wrong?**

{ Column 2: Failure modes that prevent the achievement of objectives

- **What are the causes and consequences?**

The failure modes are described as risk events.

(1) Function or process	(2) Potential failure modes
<i>What should go right, what is supposed to happen</i>	<i>What are the ways that prevent the process or function to achieve its objective</i>
Provide the correct level of friction between brake pad assembly and wheel rim	Insufficient friction between brake pads and wheels during normal operating conditions or extreme conditions

{ Column 3: Consequences of failure (labeled effects in the FMEA worksheet)

{ Column 4: Severity (S) of the consequences

{ Column 5: Potential causes of failure

(3) Potential effect(s) of failure <i>What is the consequence of the failure</i>	(4) Severity (S) <i>How significant is the impact</i>	(5) Potential cause(s) of failure <i>How can the failure occur</i>
Bicycle wheel does not slow down when the brake lever is pulled potentially resulting in injury	5	Cable binds due to inadequate lubrication or poor routing Foreign material reduces friction between brake pads and wheel rim Cable breaks

- What are the likelihood or chances of occurrence?
{ Column 6: Likelihood (L) of each causes or failure (labeled occurrences in the FMEA worksheet)
- What can be done to detect, control, and manage them?
{ Column 7: Existing detection, prevention, and control measures
{ Column 8: Rating for existing detection (D), prevention, and control measures

(6) Occurrence rating (L) <i>What is the likelihood of occur- rence</i>	(7) Current design controls (prevent) <i>What are in place so that failure is prevented</i>	(7) Current design controls (detect) <i>What are in place so that failure is controlled</i>	(8) Detection rating (D) <i>How effec- tive are the measures</i>
2	Make sure hand brake is consistent with design guide	Make sure testing satisfies established bicycle system durability tests	1
1			
3			

{ Column 9: The risk score determined by the likelihood, severity, and effectiveness of existing detection, prevention, and control measures to address failure, evaluated as $L \times S \times D$

{ Column 10: Recommendations for additional prevention and control measures to address the failures, their causes, and consequences

(9) RPN	(10) Recom- mended action(s)
$L \times S$ $\times D$	<i>What can be done</i>
10	Review manual

Step1, identifies the system and the scope of the study.

FMEA can be a comprehensive look at the total system as a whole, or it may focus on certain subsystems, elements, or components.

As an example, consider the bicycles a system of interest.

An item analysis of the bicycle system is shown in Figure 3.5.

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← *Subsystem item*

- 1.8.1 Brake lever
- 1.8.2 Brake cable
- 1.8.3 Brake pads
- 1.8.4 Brake caliper

← *Component item*

- 1.9 Suspension subsystem

Figure 3.5 Item analysis of bicycle¹³

The FMEA worksheet focuses on a particular subsystem, the hand brake subsystem, and refers to Item 1.8 (shaded in gray) in the item analysis of the bicycle in Figure 3.5.

ITEM ANALYSIS—BICYCLE EXAMPLE

1.0 Bicycle System

← *System item*

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1.8.2 Brake cable

← *Component item*

- 1.8.3 Brake pads
- 1.8.4 Brake caliper

- 1.9 Suspension subsystem

Figure 3.5 Item analysis of bicycle ¹³

Step 2 identifies the key functional objectives of the system, subsystem, or component of interest.

It describes what the component is supposed to do to achieve the functional objective—description of what needs to go right.

Thus for the bicycle, one of its critical functions is the ability to stop safely within a required distance under all operating conditions.

This function is achieved through the hand brake by providing the correct level of friction between the brake pad assembly and the wheel rim when the brake lever is pulled.

This information is entered in Column 1 of the FMEA worksheet.

It describes what the hand brake subsystem is supposed to do to achieve the function of stopping or braking

(What should go right?).

Step 3 identifies the failure modes.

Column 1 defines what the component is supposed to do,

Column 2 describes what can happen (What can fail?) that will prevent the component from doing what it is supposed to do.

In other words, the failure modes are the different ways the component can fail to accomplish its functional objective.

For the bicycle, one potential failure mode is having insufficient friction between the brake pad and wheel rim during normal or extreme conditions such as heavy rains.

This information is entered in Column 2 of the FMEA worksheet. Note that it is important to describe in detail the conditions in which the failure mode can occur.

Step 4 identifies the consequences (effects) on the system as a whole, its elements, and the environment for each failure mode.

It helps to ask What happens when this failure occurs?

What does the user experience because of this failure? For the bicycle, insufficient friction means the bicycle wheel does not slow down when the brake lever is pulled, potentially resulting in collision, loss of control, and eventual injury.

This information is entered in Column 3 of the FMEA worksheet.

What does the user experience because of this failure? For the bicycle, insufficient friction means the bicycle wheel does not slow down when the brake lever is pulled, potentially resulting in collision, loss of control, and eventual injury.

This information is entered in Column 3 of the FMEA worksheet.

Step 5 provides a severity rating for each effect. Rating scales such as those used in Lecture 2 can be used. For the bicycle, the worse potential result of the identified failure mode is safety failure; the severity is evaluated as catastrophic (see Table 2.2).

A level 5 is entered in Column 4.

Step 6 identifies all potential root causes for each failure mode. What specifically causes this failure mode to occur? Here it is important to establish the causal chain of events to identify root causes. For the bicycle example, there are three potential causes for having insufficient friction between the brake pads and wheel rim

1) failure of cable binds due to inadequate lubrication or poor routing, (2) foreign material on brake pad or wheel rim that reduces friction, (3) cable itself breaks, and (4) brake lever misalignment. This information is entered in Column 5 in the FMEA worksheet.

Step 7 rates the root causes according to their likelihood of occurrence.

This rating evaluates the chance of failure because of a particular root cause. It follows that if a particular root cause is more likely to occur, then failure from this root cause is also more likely.

For the bicycle, the cable breaking is the most likely cause of insufficient friction among the causes. Using Table 2.3, its likelihood of occurrence is moderately possible and given a rating of 3. This information is entered in Column 6 in the FMEA worksheet.

Steps 8 and 9 describe and rate the effectiveness of preventive and control measures that currently exist. Each measure is evaluated according to how well or early the failure mode or its cause can be detected and addressed before the effects occur. Detection is rated on a scale from 1 to 5, where 1 means the control is absolutely certain to detect the cause or failure and 5 means the inability for detection.

For the bicycle example, detection of the cable binding due to inadequate lubrication or poor routing is given a rating of 2. This is due to the quality and testing process in the manufacturing of bicycles. Table 3.2 can be used to determine a detection rating. The information for steps 8 and 9 are entered in Column 7 and Column 8 of the FMEA worksheet, respectively.

Table 3.2. Example of detection scale¹⁵

Likelihood of detection	Criteria: likelihood of detection by design control	Rank
High to absolute uncertainty	No current design control or cannot be detected	5
Remote	Detection controls have a weak detection capability	4
Low	Product verification with pass or fail testing	3
Medium	Product verification with test to failure testing	2
High	Product verification with degradation testing	1

One can also evaluate reactive measures. Specifically, how the system is able to detect failure after the cause has already happened; and how the system is able to address the failure before the impact of the effects occurs. For example, if the bicycle had an indicator or an alarm that the hand brake subsystem has failed. This measure can inform the user to use alternative means for stopping or breaking.

In step 10, upon identifying the likelihood (L), consequences (S) of failure modes, and the current system's ability to address (D) the causes of failure, failure modes are then evaluated for criticality using a risk score similar to PHA. For FMEA, the risk score is known as the RPN and can be derived by multiplying $L \times S \times D$, corresponding to Columns 4, 6, and 8 respectively. The RPN score entered in Column 9 can provide guidance for ranking potential failures in the order they should be addressed.

Step 11 describes recommendations and proposed additional preventive control measures if necessary. Particular attention is given to proposals that will decrease the likelihood of occurrence, lower the severity of the consequences, or increase the capability or effectiveness to detect early and mitigate the causes of failure. Part of the recommendation should include the organizational functions responsible for these actions and target completion dates. This information is entered in Column 10 of the FMEA worksheet.

Failure case study:
2008 Formula SAE Car



Secondary Effects of Failure



Contributing Cause: NO significant testing prior to event

■ Photo: 2:30 AM on morning of race, California Hotel Parking Lot, Car still under construction



❑ [Causal Chain - Tool/Concept/Definition \(thwink.org\)](http://thwink.org)

[http://www.fmeainfocentre.com/examples/36VbatFMEA. pdf](http://www.fmeainfocentre.com/examples/36VbatFMEA.pdf)

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“ Product Design Hall, 2001

