# Failure Modes Effects Analysis in MBSE


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# Introduction

- Failure Modes Effects Analysis is used in a number of industries to conduct an analysis of system, subsystem, and component design
- In some industries an FMEA is required by a regulatory body prior to receiving “authorization” to take a product to market

# FMEA Definition and Basics

- Failure Mode and Effects Analysis (FMEA) and Failure Modes, Effects and Criticality Analysis (FMECA) are methodologies designed to identify potential failure modes for a product or process, to assess the risk associated with those failure modes, to rank the issues in terms of importance and to identify corrective actions to address the most serious concerns.
- The purpose, terminology, and other details vary according to industry and type (e.g. Process FMEA, Design FMEA, etc.), the basic methodology is similar for all design efforts.
- Basics:
  - Identify Failure Modes
  - Assess Failure Modes
  - Rank the Failure Modes
  - Identify Corrective Actions

# Basic References

Failure Mode Effect Analysis: FMEA from Theory to Execution, 2 ed. by D.H. Stamatis, Quality Press

Procedures for Performing a Failure Mode, Effects and Criticality Analysis, MIL-STD-1629

FMEA and FMECA Webpage on Weibull.com (www.weibull.com/basics/fmea.htm), last accessed May 20, 2017

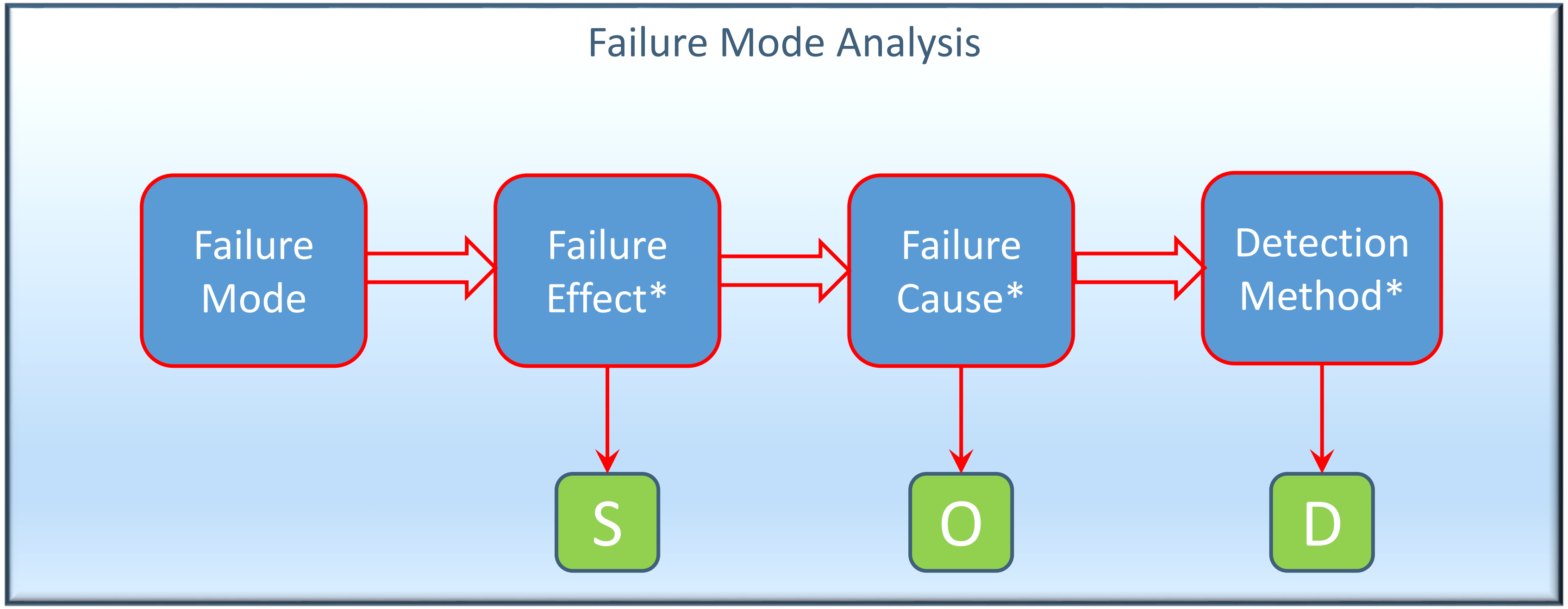
Potential Failure Mode and Effects Analysis (FMEA) Reference Manual (equivalent to SAE J-1739), 1995, (see www.lehigh.edu/~inrtibos/Resources/SAE_FMEA.pdf, last accessed May 20, 2017)

Q9 Quality Risk Management, Guidance for Industry, Annex I: Risk Management Methods and Tools (subsection I.2 and I.3), US FDA publication, June 2006 (specifically

Applying Human Factors and Usability Engineering to Medical Devices, US FDA publication, Feb 3, 2016

# Elements of a FMEA

# Expanding the basic FMEA Model…




S – Severity
O – Occurrence
D - Detectability

# Severity Rating

Severity (S) – a rating of the seriousness of the effect of a failure mode to the system, assembly, product, customer, or government regulation.

Severity is related to the Failure Effect.

Severity Guidance for system FMEA

| Effect | Rank | Criteria |
|---|---|---|
| **None** | 1 | No Effect |
| **Very Slight** | 2 | Customer not annoyed. Very slight effect on product or system performance. |
| **Slight** | 3 | Customer slightly annoyed. Slight effect on product or system performance. |
| **Minor** | 4 | Customer experiences minor nuisance. Minor effect on product or system performance. |
| **Moderate** | 5 | Customer experiences some dissatisfaction. Moderate effect on product or system performance. |
| **Significant** | 6 | Customer experiences discomfort. Product performance degraded, but operable and safe. Partial failure, but operable. |
| **Major** | 7 | Customer dissatisfied. Product performance severely affected but functional and safe. System impaired. |
| **Extreme** | 8 | Customer very dissatisfied. Product inoperable but safe. System inoperable. |
| **Serious** | 9 | Potential hazardous effect. Able to stop product without mishap – time dependent failures. Compliance with government regulation is in jeopardy. |
| **Hazardous** | 10 | Hazardous effect. Safety related – sudden failure. Noncompliance with government regulation. |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis

# Occurrence Rating

Occurrence (O) – a rating corresponding to the cumulative number of failures that could occur over the design life of a system or component.

Occurrence is related to the Failure Cause

CNF – Cumulative number of failures

Occurrence Guidance for system FMEA

| Effect | Rank | Criteria | CNF/1000 |
|---|---|---|---|
| **Almost Never** | 1 | Failure unlikely, history shows no failures | < .00058 |
| **Remote** | 2 | Rare number of failures likely | .0068 |
| **Very Slight** | 3 | Very few failures likely | .0063 |
| **Slight** | 4 | Few failures likely | .46 |
| **Low** | 5 | Occasional number of failures likely | 2.7 |
| **Medium** | 6 | Medium number of failures likely | 12.4 |
| **Moderately High** | 7 | Moderately high number of failures likely | 46 |
| **High** | 8 | High number of failures likely | 134 |
| **Very High** | 9 | Very High number of failures likely | 316 |
| **Almost Certain** | 10 | Failure almost certain. History of failures exists from previous or similar designs. | >316 |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis

# Detectability Rating

Detectability (D) – a rating of the ability of the proposed design control to detect a potential failure mode or occurrence.

Detectability is related to the Failure Control

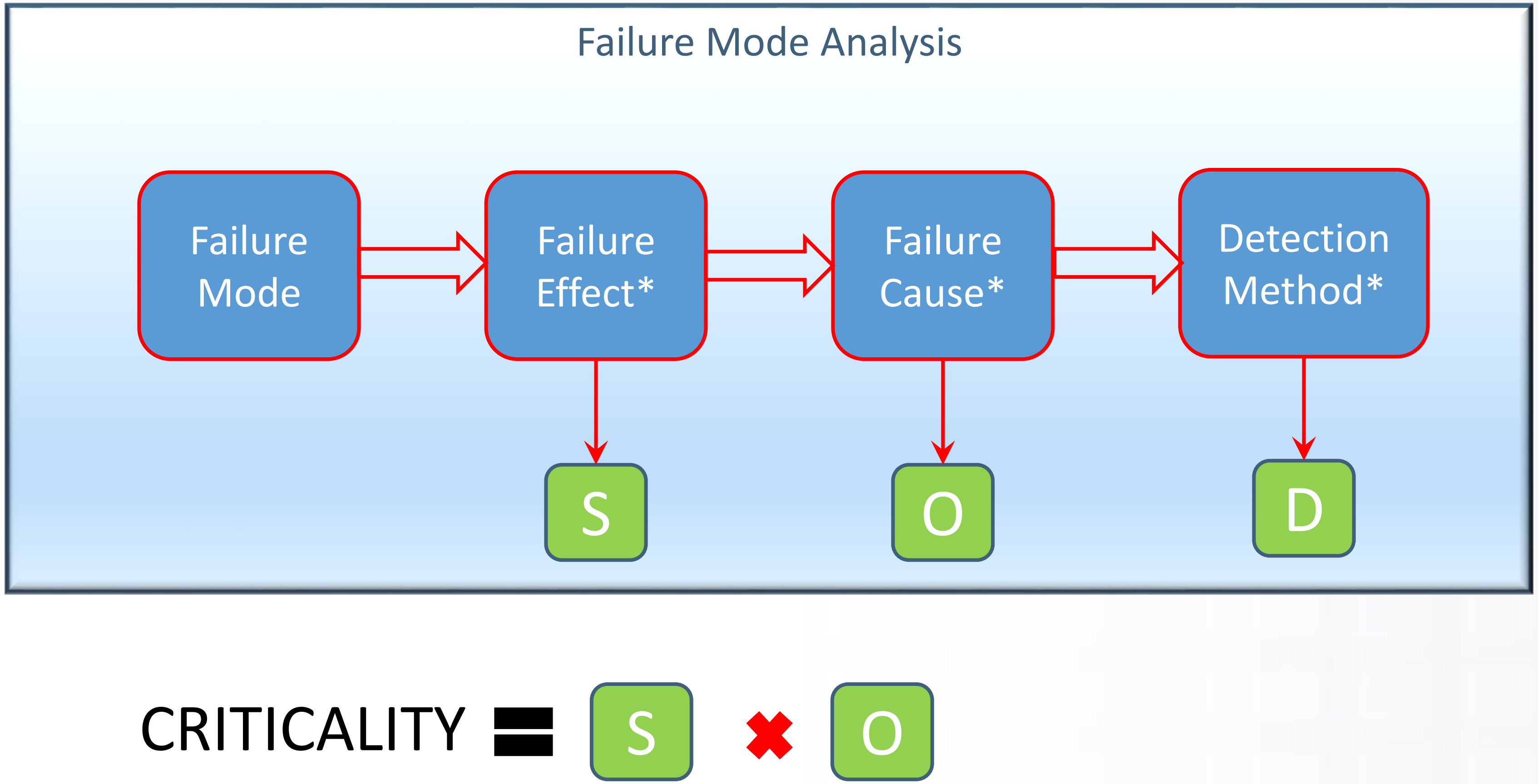
Detection Guidance for system FMEA

| Effect | Rank | Criteria |
|---|---|---|
| Almost certain | 1 | Proven detection methods available while in conceptual design |
| Very High | 2 | Has very high effectiveness |
| High | 3 | Has high effectiveness |
| Moderately High | 4 | Has moderately high effectiveness |
| Medium | 5 | Has medium effectiveness |
| Low | 6 | Has low effectiveness |
| Slight | 7 | Has very low effectiveness |
| Very Slight | 8 | Has lowest effectiveness in each applicable category |
| Remote | 9 | Unproven, or unreliable, or effectiveness is unknown |
| Almost Impossible | 10 | No technique is available or known, and/or none is planned |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis

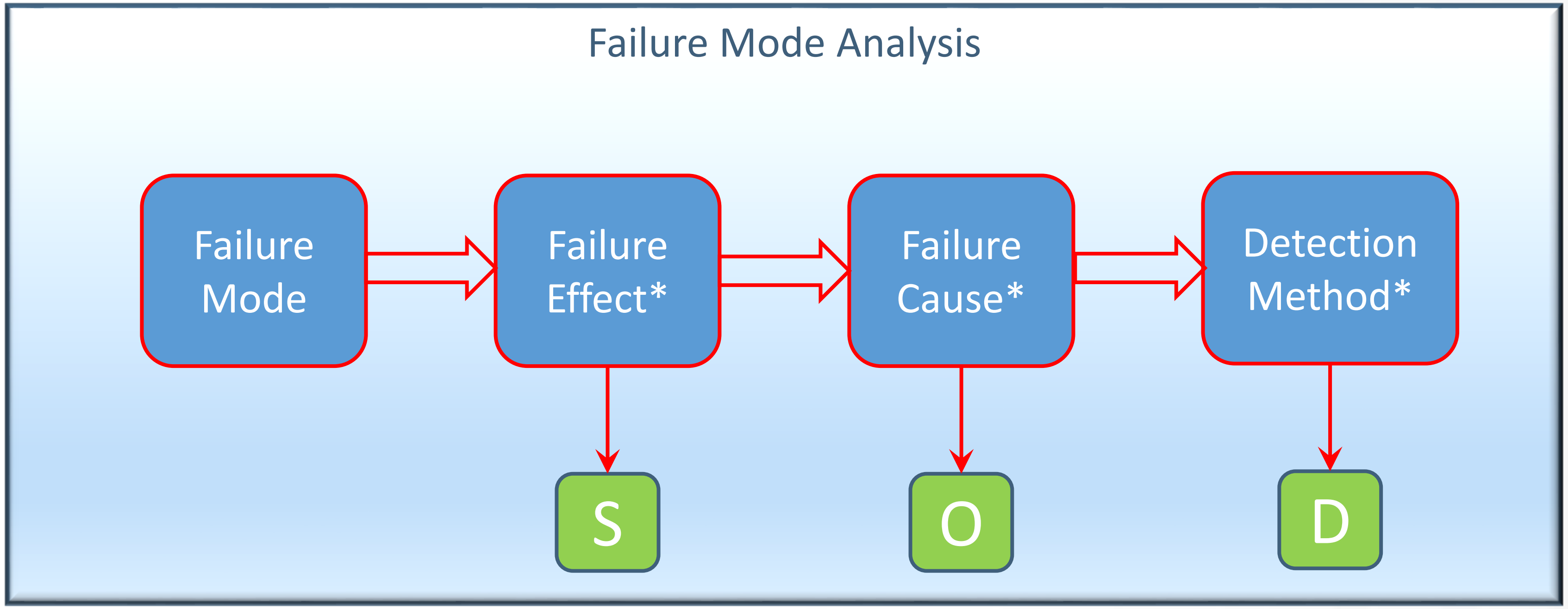
# Criticality of a Failure

Criticality – A relative measure of the combined influence of the consequences or a failure mode (severity or S) and its frequency (occurrence or O). The product of the severity times occurrence provides the relative criticality.



# Evaluating the Failure Relative to one another

Risk Priority Number (RPN) – A relative measure used to rank order potential system failures. The RPN defines the priority of the failure. The RPN is the product of the severity, occurrence, and detection ratings.




RPN = S × O × D

# Recommended Actions…

No FMEA should be done without a recommended action list to improve the system design.

Recommended Actions are taken to reduce severity, occurrence, detection, or all three of them. In essence to eliminate failures and thereby eliminate system deficiencies.

Using Criticality or RPN-

- Rank Order Failures and Causes
- Determine a subset of Failure (generally > RPN value)
- Develop Follow-up, Corrective Actions

# FMEA Example

# Automotive Industry Example

**POTENTIAL**
**FAILURE MODE AND EFFECTS ANALYSIS**
**Front Door L.H.**

FMEA Number 1450
Page 1 of 1
FMEA Type
Item 1.1.1 - Front Door L.H.
Process Responsibility Body Engineering
Prepared By J. Ford - X6521 - Assy Ops
Model Year(s)/Vehicle(s) 20XX/Lion 4dr/Wagon
Key Date 3/10/2015
FMEA Date (Orig.) 3/10/2015 (Rev) 3/21/2015
Core Team A. Tate Body Engrg, J. Smith - OC, R. James - Production, J. Jones - Maintenance

| Name / Function Requirements | Potential Failure Mode | Potential Effect(s) of Failure | SEVi | Classification | Potential Cause(s) of Failure | OCCi | Current Process Controls (Prevention) | Current Process Controls (Detection) | DETi | RPNi | Recommended Action(s) | Responsibility & Planned Completion Date | Action Results: Actions Taken & Actual Completion Date | SEVr | OCCr | DETr | RPNr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1.1 - Front Door L.H. | | | | | | | | | | | | | | | | | |
| Op. 70 Manual application of wax inside door/ cover inner door, lower surfaces with wax to specification thickness. | Insufficient wax coverage over specified surface | Allows integrity breach of inner door panel. Corroded interior lower door panels. Deteriorated life of door leading to: - Unsatisfactory appearance due to rust through paint over time - Impaired function of interior door hardware | 7 | | Manually inserted spray head not inserted far enough | 8 | | Visual check each hour - 1/shift for film thickness (depth meter) and coverage. | 5 | 280 | Add positive depth stop to sprayer. | Mfg Engrg - 3/10/2003 | Stop added, sprayer checked on line. | 7 | 2 | 5 | 70 |
| | | | | | | | | | | | Automate spraying. | Mfg Engrg - 3/10/2003 | Rejected due to complexity of different doors on same line. | | | | |
| | | | | | Spray head clogged- Viscosity too high- Temperature too low- Pressure too low. | 5 | Test spray pattern at start-up and after idle periods, and preventive maintenance program to clean heads. | Visual check each hour - 1/shift for film thickness (depth meter) and coverage. | 5 | 175 | Use Design of Experiments (DOE) on viscosity vs. temperature vs. pressure. | Mfg Engrg - 3/10/2003 | Temp and press limits were determined and limit controls have been installed - control charts show process is in control Cpk = 1.85. | | 1 | 5 | 35 |
| | | | | | Spray head deformed due to impact | 2 | Preventive maintenance program to maintain heads. | Visual check each hour - 1/shift for film thickness (depth meter) and coverage. | 5 | 70 | | | | | 2 | 5 | 70 |

**Figure 1:** Process FMEA (PFMEA) in the Automotive Industry Action Group (AIAG) FMEA-4 format.

Source: www.Weibull.com/hotwire/issue46/relbasics46.htm, last accessed 5/9/2017

# Integrating FMEA into an MBSE environment

# Objective

- Expand the “standard” MBSE schema used in Model Based System Engineering (MBSE) to provide for traceability to the FMEA
- Provide for the ability to produce a standard FMEA table
- Provide for Traceability from the system design to the FMEA

# Common Elements of any FMEA …

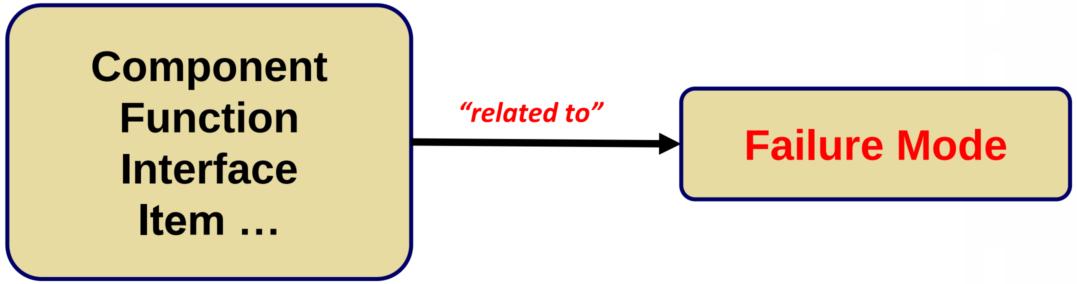
| Function | Potential Failure Mode | Potential Effects(s) of Failure | S | Potential Cause(s) of Failure | O | Current Process Controls | D | RPN | CRIT | Recommended Action(s) | Responsibility and Target Completion Date | Action Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Action Taken | S | O | D | RPN | CRIT |
| Dispense amount of cash requested by customer | Does not dispense cash | Customer very dissatisfied<br>Incorrect entry to demand deposit system<br>Discrepancy in cash balancing | 8 | Out of cash | 5 | Internal low-cash alert | 5 | 200 | **40** | | | | | | | | |
| | | | | Machine jams | 3 | Internal jam alert | 10 | 240 | 24 | | | | | | | | |
| | | | | Power failure during transaction | 2 | None | 10 | 160 | 16 | | | | | | | | |
| | Dispenses too much cash | Bank loses money<br>Discrepancy in cash balancing | 6 | Bills stuck together | 2 | Loading pro-cedure (riffle ends of stack) | 7 | 84 | 12 | | | | | | | | |
| | | | | Denominations in wrong trays | 3 | Two-person visual verification | 4 | 72 | 18 | | | | | | | | |
| | Takes too long to dispense cash | Customer somewhat annoyed | 3 | Heavy computer network traffic | 7 | None | 10 | 210 | 21 | | | | | | | | |
| | | | | Power interruption during transaction | 2 | None | 10 | 60 | 6 | | | | | | | | |

Failure Mode Identification

Cause Identification

# Failure Mode Class

Need a Class to capture the Failure Mode and the relation to the system entities




This arrangement allows for capturing a failure mode for any item in the system design.

# Failure Mode Entity Attributes

<u>Failure Mode</u>:
Name
Number
Description (Effect)
Severity
<u>Failure Cause</u>:
Name
Number
Description (Cause)
Occurrence
Control
Detection
RPN*
Criticality*

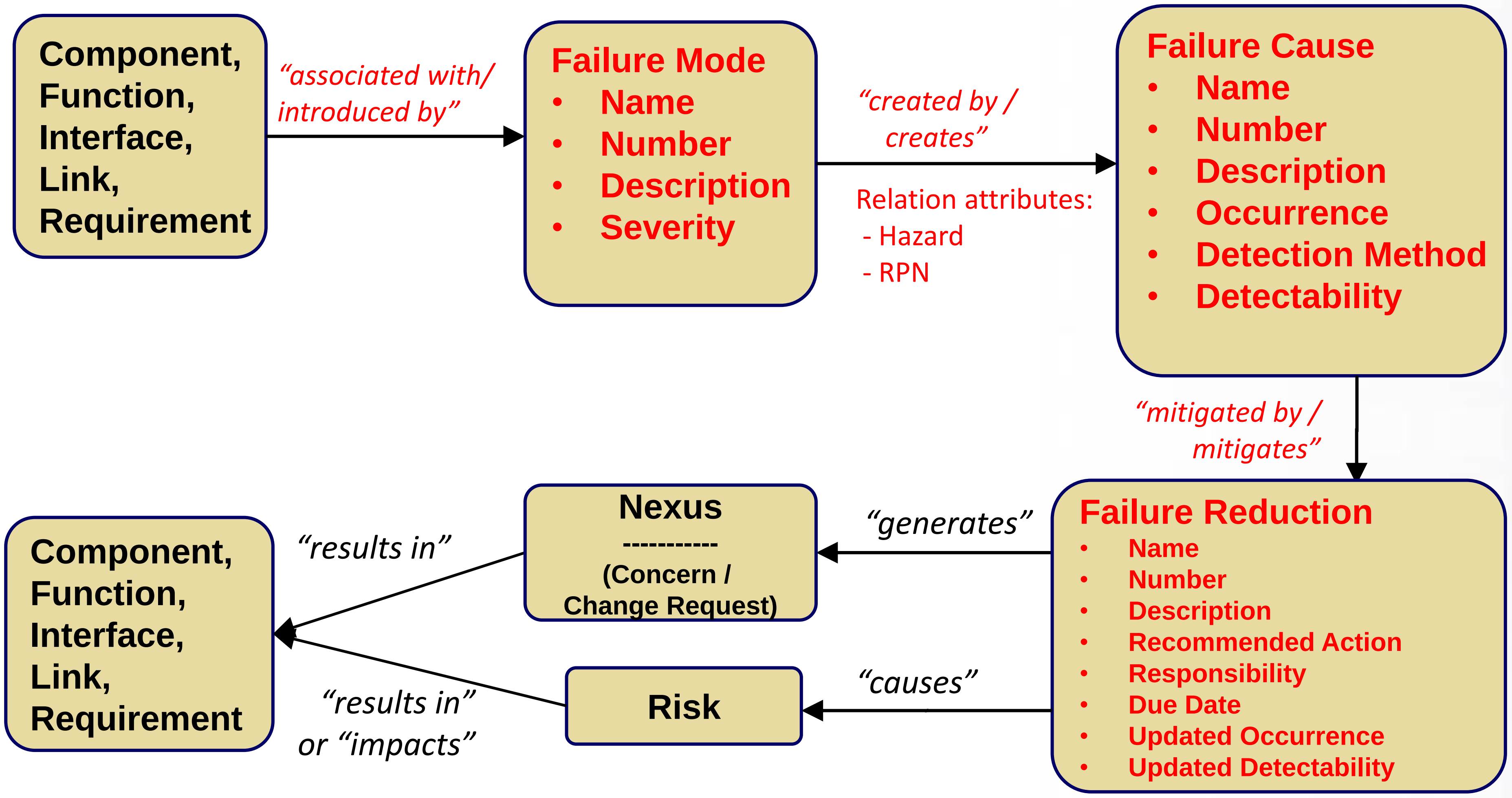
* Calculated Values

FMEA Analysis Features:

- One Failure Mode can have multiple causes
- Severity is associated with Failure Mode
- Probability of Occurrence associated with each Cause
- Detection associated with each Cause

| Function | Potential Failure Mode | Potential Effects(s) of Failure | S | Potential Cause(s) of Failure | O | Current Process Controls | D | RPN | CRIT | Recommended Action(s) | Responsibility and Target Completion Date | Action Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Action Taken | S | O | D | RPN | CRIT |
| Dispense amount of cash requested by customer | Does not dispense cash | Customer very dissatisfied | 8 | Out of cash | 5 | Internal low-cash alert | 5 | 200 | 40 | | | | | | | | |
| | | Incorrect entry to demand deposit system | | Machine jams | 3 | Internal jam alert | 10 | 240 | 24 | | | | | | | | |
| | | Discrepancy in cash balancing | | Power failure during transaction | 2 | None | 10 | 160 | 16 | | | | | | | | |
| | Dispenses too much cash | Bank loses money | 6 | Bills stuck together | 2 | Loading procedure (riffle ends of stack) | 7 | 84 | 12 | | | | | | | | |
| | | Discrepancy in cash balancing | | Denominations in wrong trays | 3 | Two-person visual verification | 4 | 72 | 18 | | | | | | | | |
| | Takes too long to dispense cash | Customer somewhat annoyed | 3 | Heavy computer network traffic | 7 | None | 10 | 210 | 21 | | | | | | | | |
| | | | | Power interruption during transaction | 2 | None | 10 | 60 | 6 | | | | | | | | |

# Schema Extension



# Reporting on the FMEA

# Example Generic FMEA Form

## Generally, the results of an FMEA are captured in a table similar to this.

| | | |
|---|---|---|
| ______ System | Design responsibility ______ | FMEA number ______ |
| ______ Subsystem | Key date ______ | Page ______ of ______ |
| ______ Component | | Prepared by ______ |
| Model year ______ | | FMEA date (Orig.) ______ Rev. ______ |
| Core team ______ | | |

| Item/ function | Potential failure mode | Potential effect(s) of failure | SEV | CRIT | Potential cause(s) mechanism(s) of failure | OCCUR | Current design controls | DETECT | RPN | Recommended action(s) | Responsibility and target completion date | Action results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Action taken | SEV | OCC | DET | RPN |
| | | | | | | | | | | | | | | | | |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, Appendix A, Figure E-10, D. H. Stamatis

# FMEA Basic Report

| System Element | Failure | Failure Description | Severity | Cause of Failure | Occurrence | Detection Method | Dectectabilty |
|---|---|---|---|---|---|---|---|
| Cooling Motor and Fan Assembly | Fan Vibration and Interference | Audible Noise, vibration; increased motor wear. | 5 | Fan Center of Gravity off axix of rotation causing 2-plan imbalance. | 5 | Design calls for lightweight fan with minimum band mass, part thickness. | 4 |
| Cooling Motor and Fan Assembly | Misalignment of Fan and Shroud | Fan and shroud mis-aligned cause reduction or complete loss of | 7 | Fan contacts shroud, noise or motor burnout. | 2 | Designed for easy assembly and alignment. | 3 |
| Cooling Motor and Fan Assembly | Motor Burnout | Motor Burnout causes loss of cooling to the system. | 5 | Overheating of motor assembly due to lack of air circulation around motor. | 2 | Vent holes in motor casing, fins in fan hub pull air throught motor body. | 5 |
| Cooling Motor and Fan Assembly | Reduced Fan Efficiency | Fan motor is assembled 120 degrees off nominal angle causes reduction of cooling effectiveness. | 6 | Symmetrical spacing of screw holes allows for non-unique mounting of fan motor. | 7 | Cuurent design requires visual verification of assembly. | 7 |
| | | | | Misassebly of Fan and Motor causes pinched wire. | 7 | Visual Inspection of Fan and Motor assembly. | 6 |

# FMEA with Criticality and RPN Calculations

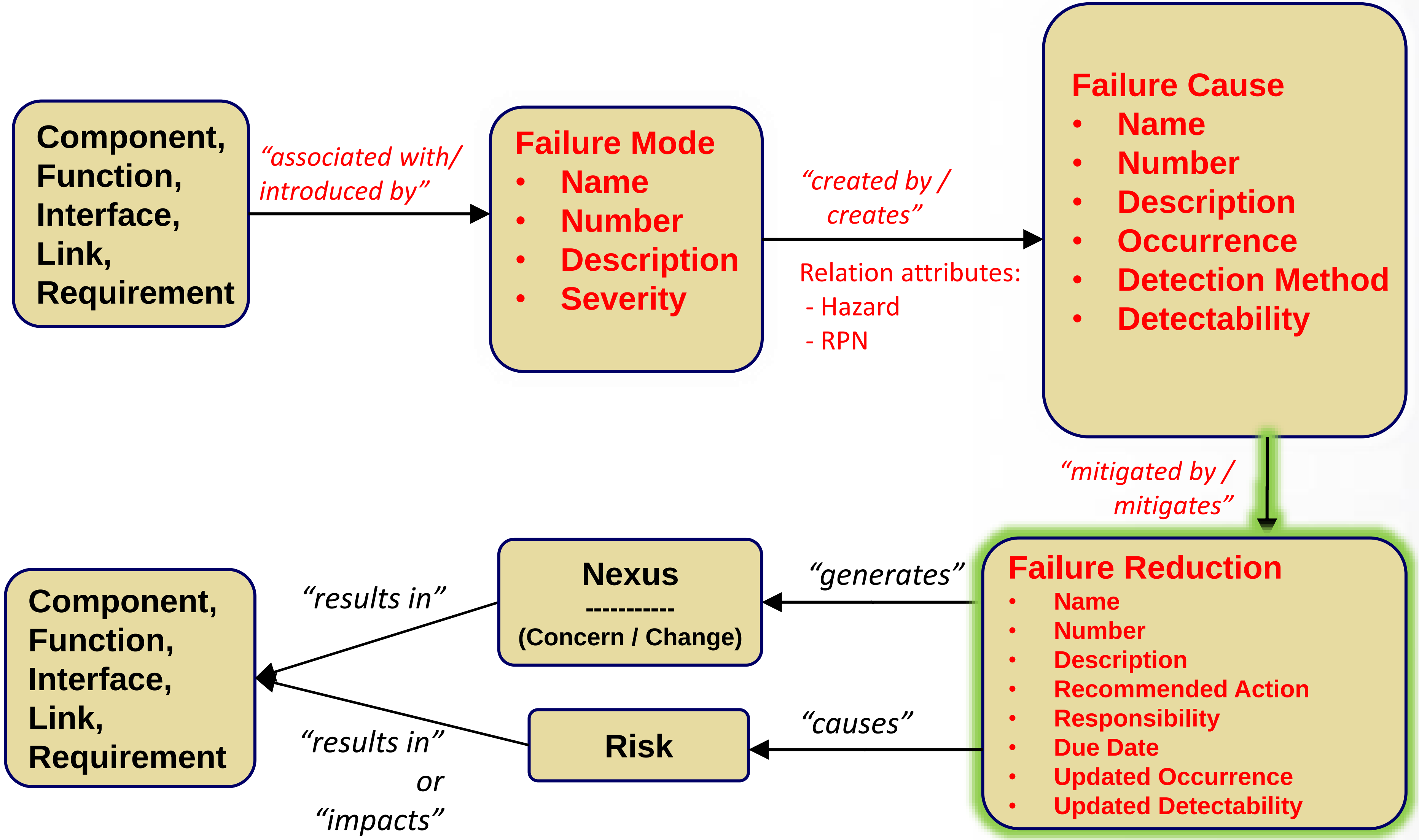
| System Element | Failure | Failure Description | Severity | Cause of Failure | Occurence | Detection Method | Dectectability | Criticality | RPN |
|---|---|---|---|---|---|---|---|---|---|
| Cooling Motor and Fan Assembly | Fan Vibration and Interference | Audible Noise, vibration; increased motor wear. | 5 | Fan Center of Gravity off axix of rotation causing 2-plan imbalance. | 5 | Design calls for lightweight fan with minimum band mass, part thickness. | 4 | 25 | 100 |
| Cooling Motor and Fan Assembly | Misalignment of Fan and Shroud | Fan and shroud mis-aligned cause reduction or complete loss of cooling. | 7 | Fan contacts shroud, noise or motor burnout. | 2 | Designed for easy assembly and alignment. | 3 | 14 | 42 |
| Cooling Motor and Fan Assembly | Motor Burnout | Motor Burnout causes loss of cooling to the system. | 5 | Overheating of motor assembly due to lack of air circulation around motor. | 2 | Vent holes in motor casing, fins in fan hub pull air throught motor body. | 5 | 10 | 50 |
| Cooling Motor and Fan Assembly | Reduced Fan Efficiency | Fan motor is assembled 120 degrees off nominal angle causes reduction of cooling effectiveness. | 6 | Symmetrical spacing of screw holes allows for non-unique mounting of fan motor. | 7 | Cuurent design requires visual verification of assembly. | 7 | 42 | 294 |
| | | | | Misassebly of Fan and Motor causes pinched wire. | 7 | Visual Inspection of Fan and Motor assembly. | 6 | 42 | 252 |

# High RPN Values

| System Element | Failure | Failure Description | Severity | Cause of Failure | Occurence | Detection Method | Dectectability | Criticality | RPN |
|---|---|---|---|---|---|---|---|---|---|
| Cooling Motor and Fan Assembly | Fan Vibration and Interference | Audible Noise, vibration; increased motor wear. | 5 | Fan Center of Gravity off axix of rotation causing 2-plan imbalance. | 5 | Design calls for lightweight fan with minimum band mass, part thickness. | 4 | 25 | 100 |
| Cooling Motor and Fan Assembly | Misalignment of Fan and Shroud | Fan and shroud mis-aligned cause reduction or complete loss of cooling. | 7 | Fan contacts shroud, noise or motor burnout. | 2 | Designed for easy assembly and alignment. | 3 | 14 | 42 |
| Cooling Motor and Fan Assembly | Motor Burnout | Motor Burnout causes loss of cooling to the system. | 5 | Overheating of motor assembly due to lack of air circulation around motor. | 2 | Vent holes in motor casing, fins in fan hub pull air throught motor body. | 5 | 10 | 50 |
| Cooling Motor and Fan Assembly | Reduced Fan Efficiency | Fan motor is assembled 120 degrees off nominal angle causes reduction of cooling effectiveness. | 6 | Symmetrical spacing of screw holes allows for non-unique mounting of fan motor. | 7 | Cuurent design requires visual verification of assembly. | 7 | 42 | 294 |
| | | | | Misassebly of Fan and Motor causes pinched wire. | 7 | Visual Inspection of Fan and Motor assembly. | 6 | 42 | 252 |

Values above a threshold require mitigation. Threshold Value varies based on project and industry.

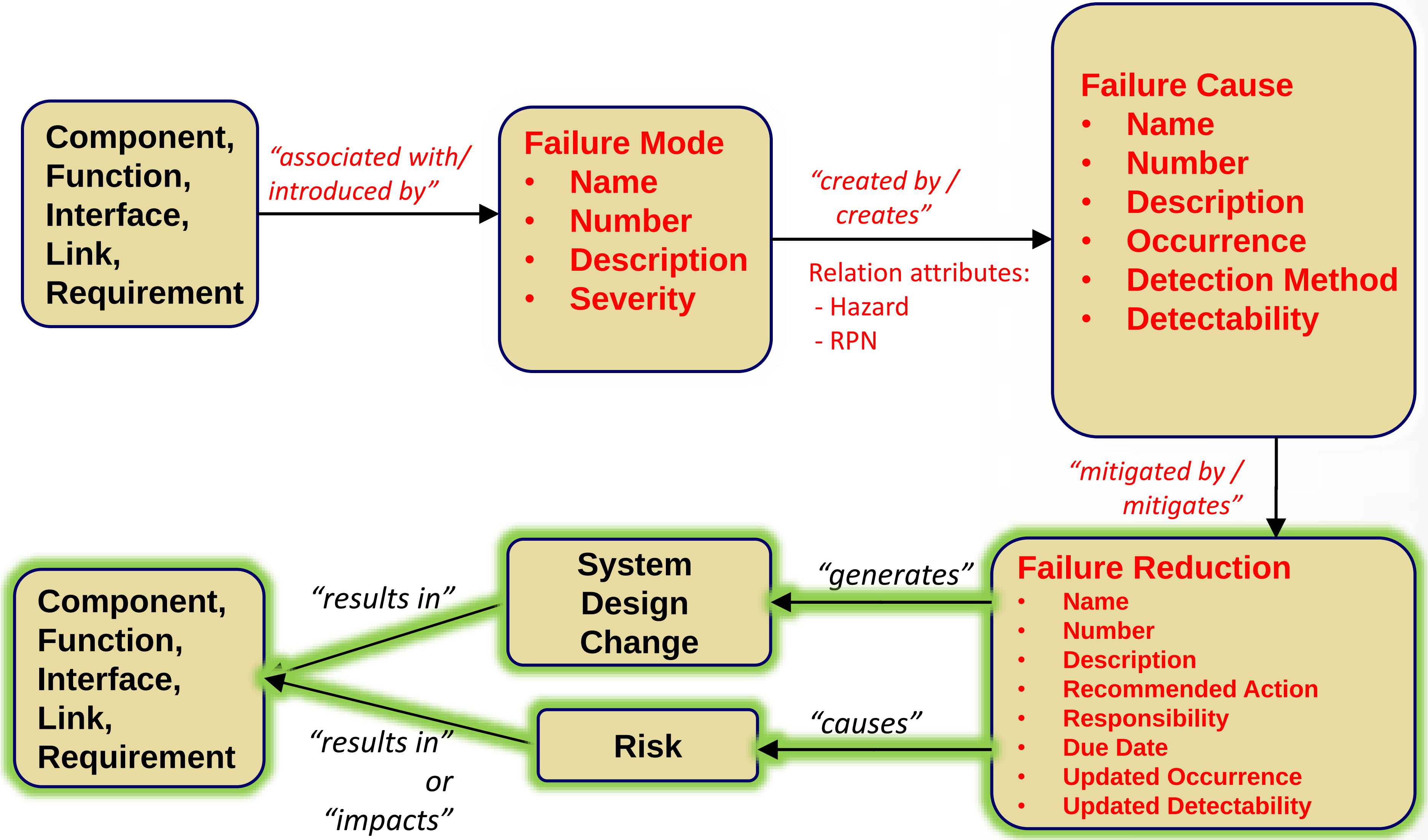
# Failure Reduction…



# FMEA Report with Failure Reduction

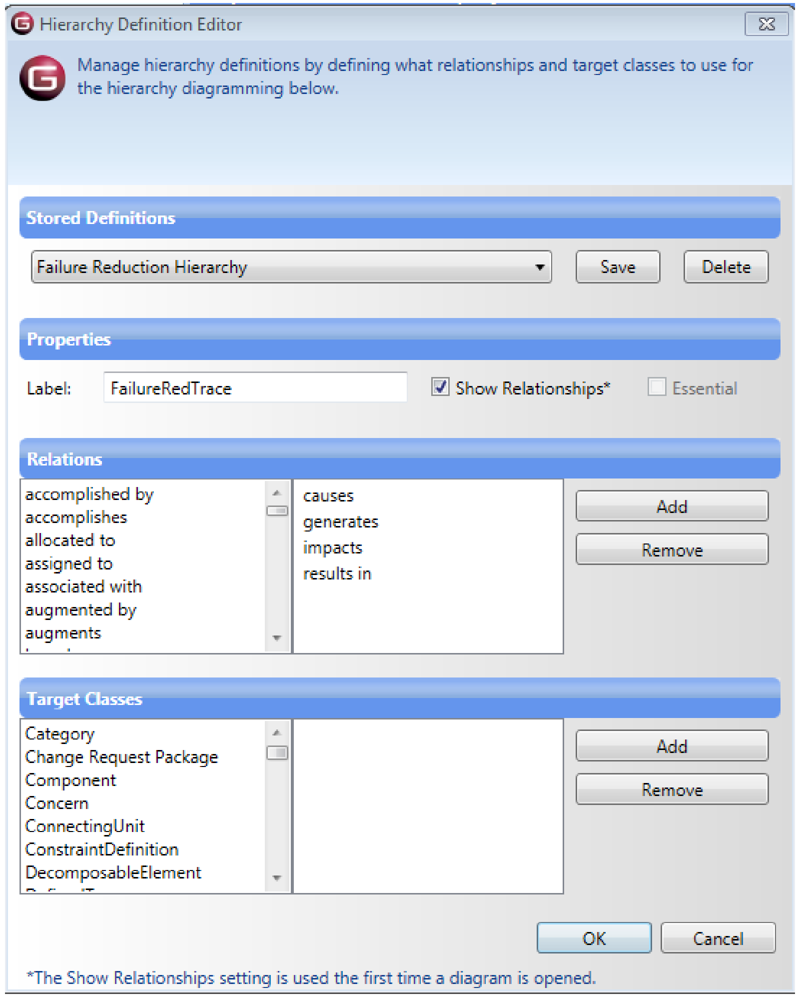
| System Element | Failure | Failure Description | Severity | Cause of Failure | Occurrence | Detection Method | Detectability | Criticality | RPN | Recommended Action | Responsibilit | Due Date | Updated urrence | Updated ectability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooling Motor and Fan Assembly | Fan Vibration and Interference | Audible Noise, vibration; increased motor wear. | 5 | Fan Center of Gravity off axix of rotation causing 2-plan | 5 | Design calls for lightweight fan with minimum band mass, | 4 | 25 | 100 | | | | | |
| Cooling Motor and Fan Assembly | Misalignment of Fan and Shroud | Fan and shroud mis-aligned cause reduction or complete | 7 | Fan contacts shroud, noise or motor burnout. | 2 | Designed for easy assembly and alignment. | 3 | 14 | 42 | | | | | |
| Cooling Motor and Fan Assembly | Motor Burnout | Motor Burnout causes loss of cooling to the system. | 5 | Overheating of motor assembly due to lack of air | 2 | Vent holes in motor casing, fins in fan hub pull air | 5 | 10 | 50 | | | | | |
| Cooling Motor and Fan Assembly | Reduced Fan Efficiency | Fan motor is assembled 120 degrees off nominal angle causes reduction of cooling effectiveness. | 6 | Symmetrical spacing of screw holes allows for non-unique mounting of fan motor. | 7 | Cuurent design requires visual verification of assembly. | 7 | 42 | 294 | Develop a unique, non-symmetrical bolt pattern for the motor / fan | Joe Engineer | 31-Aug-17 | 2 | 2 |
| | | | | Misassebly of Fan and Motor causes pinched wire. | 7 | Visual Inspection of Fan and Motor assembly. | 6 | 42 | 252 | Develop a unique, non-symmetrical bolt pattern for the motor / fan | Joe Engineer | 31-Aug-17 | 2 | 2 |

# Capture Design Changes based on FMEA

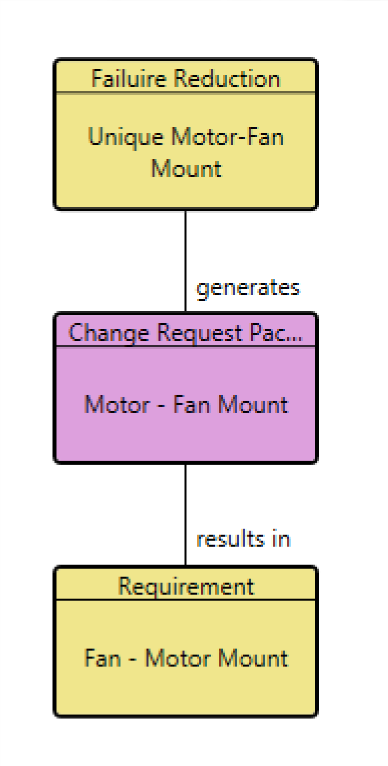


# Failure Reduction Hierarchy

Using the Schema diagram, determine what relations need to be included in the custome hierarchy…




To create the diagram on the left



# Organizing FMEA Analyses

Over the lifecycle you may have several different FMEA Analyses.  How can we organize these?

Option 1 – Create individual folders within the Failure Mode Class

Option 2 – Create a Category for a particular analysis, then have the Category *"categorize"* a set of Failure Modes

Option 3 – Create a Package and have the package include the Failure Modes, Causes, and Reduction Methods

# Summary / Conclusion

- Provided an examination of how to do a basic FMEA
- Looked at what we needed in an MBSE environment
- Examined a series of reports need to be produced from the MBSE environment
- Used a hierarchy to trace from the FMEA to the design model

# Questions?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