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TAILORING OF FAILURE MODE AND EFFECTS ANALYSIS (FMEA) TO DOD SYSTEMS AND PROGRAMS AS AN EFFECTIVE RISK IDENTIFICATION AND PRIORITIZATION TOOL

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ABSTRACT

In light of the cancellation of MIL-STD 1629A on 4 August 1998 with no superseding document, this paper outlines the tailoring of an effective industry tool for risk identification and prioritization that will lead to more reliable weapon systems for the warfighter, with reduced total ownership costs. The canceled MIL-STD 1629A used Failure Mode Effects and Criticality Analysis (FMECA) which is similar in method to FMEA but with an added factor called Criticality for prioritization. In FMEA approach, criticality is addressed by the Risk Priority Number (RPN) and other ways to prioritize risk beyond those single criteria.

Tank Automotive Research Development and Engineering Center (TARDEC), Systems Engineering Group (SEG) has tailored the FMEA's Severity, Occurrence, and Detection ranking tables to suit DOD Systems by developing an additional scale (1 – 5) for severity and occurrence parameters for the existing industry scale (1 – 10). This will facilitate transitioning risks to the DOD risk ranking scale, and for transitioning to the army owned Risk Recon risk management software for mitigation plan implementation and tracking.

TARDEC SEG is also involved in an Army working group for the development of a new guidance/handbook for FMEA/FMECA for the Army to replace the cancelled MIL-STD 1629A.

This paper also outlines a systematic process used to evaluate and manage contractors' FMEAs, and provides a recommended FMEA contract language for Technology Development (TD) and Acquisition programs for the sharing of contractors' FMEAs with Government for review of quality and completeness..

INTRODUCTION

Failure mode and effects analysis (FMEA) is an analysis of all potential failure modes within a system or subsystem. It provides an organized, critical analysis of potential failure modes and identifies associated causes and effects. FMEA can be performed on systems, subsystems, components, functions, interfaces, software, and any process that has potential to fail. FMEA is a risk assessment tool where possible failure modes, their effects, and possible causes are identified and ranked according to their level of risk. It is a widely accepted analysis procedure which should be used at the initial stages of development as well as throughout the life cycle.

Types of FMEA:

Design FMEA – Also known as DFMEA. It identifies how a product may fail to perform its intended function(s).

Process FMEA – Also known as PFMEA. It identifies the possibilities of incorrectly manufacturing or assembling a product, or incorrectly performing a set of tasks.

Program/Transactional FMEA - It identifies potential failure modes in non-technical processes (business systems, procurement processes, hiring practices, etc.) or any process that is not describing a product or the manufacturing or assembly of that product.

Other FMEA - FMEA has been adapted over the years to address failures in very specific areas such as machinery, services, etc.

FMEA and the Risk Management Process – The risk management process includes the following key activities, performed on a continuous basis: risk identification, risk analysis, risk prioritization and mitigation planning, mitigation planning implementation, and risk tracking and reporting. Risks that are identified and prioritized by performing FMEA can be fed to the Army owned and developed risk management software tool called Risk Recon. Once a risk is realized, it becomes an issue and may be tracked separately in the issues tracking database (Issue Recon) with corrective action(s) developed and applied if necessary.

Benefits of Using FMEA Early in a Program

FMEA is a proactive approach which should start early in program life, and be maintained throughout the life cycle. FMEA provides benefits in the following areas:

- **More Robust Design/Process:**
  It can identify the need to alter the development of the design and/or the manufacturing process to prevent major risks, reduce failure, minimize cost, or reduce development time.
- **Upfront Risk Identification and prioritization:**
  FMEA feeds the larger risk management process. The analysis prioritizes the actions that should be taken to reduce risk. It also highlights where further actions would result in further risk reduction.
- **Effective Risk Mitigation:**
  Failures can be identified and mitigated before they happen. FMEA helps a program "do it right the first time" saving time and money.
- **Improved Control Plans:**
  Design and process FMEAs can help to identify design and process controls that need to be put in place.
- **Foundation for Root Cause Analysis:**
  Root cause analysis, failure investigation, and corrective action planning time can be greatly reduced using FMEA. This includes diagnosing failures in theatre.
- **Provide Repository for Lessons Learned:**
  A FMEA is a living document and provides basis for lessons learned and best practices which can be shared for use in other programs.
- **Increase Reliability and Maintainability:**
  FMEA improves reliability and maintainability through risk mitigation.
- **High Reuse for Next Program.**

PREPARING FOR FMEA

A cross functional team should be formed to perform a FMEA. Members should include, but not be limited to, representatives from the areas involved in designing, manufacturing, assembling and servicing a product. Input material from many sources can provide a head start to a new FMEA such as customer requirements, FMEA from similar products, engineering specifications and standards, development test data, best practices, warranty data, manufacturing and assembly requirements, and benchmarking.

TOOLS USED: Understanding how something works is imperative to identifying how it can fail. Some effective and proven tools which can describe all the elements of the product/process are: Parameter Diagram (P diagram), Block Diagram, Work/product Breakdown Structure (WBS), Process Map (PMAP), and Process Flow Diagram. All these tools contain elements which can help populate certain fields within the FMEA. They provide information about the item/process step, function, failure mode, or causes of failure. Figure 1 provides suggested application of tools to populate a FMEA.

	Design FMEA	Process FMEA	Transactional FMEA
Parameter (P) Diagram	X	X	X
Block Diagram	X		
WBS	X		
Process Map (PMAP)		X	X
Process Flow Diagram		X	

Figure 1: Suggested Application of FMEA Tools

STEPS TO COMPLETE A FMEA

1. For each subsystem, component, or process, determine the ways in which the item functions or process steps can go wrong (these are the potential failure modes).
2. For each failure mode, determine the effect(s) of the failure mode on the function as perceived by the customer(s) (internal customer and/or end user).
3. Identify potential cause(s) of each failure mode.
4. List the current controls to prevent or detect each cause.
5. Assign a severity (S) rating to the effect, and occurrence (O), and detection (D) ratings to each cause.
6. Calculate the risk priority number (RPN).
   RPN = S x O x D
7. Using RPN as the measure, develop mitigation recommendations for high RPN failures.
8. Take appropriate mitigation actions and document responsible persons and completion date(s).
9. Re-evaluate RPN after mitigation action is complete.
10. Repeat steps 1 through 9 until all RPNs represent acceptable risk and whenever the process or product undergoes change, revision, or unidentified failure.

DESIGN FMEA AND PROCESS FMEA

Design FMEA identifies failure of a product to function. Process FMEA can identify the failures in manufacturing and assembly. Process (manufacturing and/or assembly) FMEA is similar to Design FMEA, but each identifies

different sets of risks which need to be addressed in different ways. It is not sufficient to do one without the other.

When creating the PFMEA, it is general practice to assume that the design is correct. This will insure that you do not accidentally associate design failures with manufacturing or assembly failures.

TAILORED INDUSTRY RANKING TABLES FOR DOD APPLICATIONS

The FMEA IPT at Tank Automotive Research, Development and Engineering Center (TARDEC) has tailored the industry ranking table definitions for severity (S), occurrence (O), and detection (D) to suite DOD systems and programs. The IPT also added a 1 – 5 scale to both the severity and occurrence parameters to facilitate transitioning risks to the DOD ranking scale, and for transitioning to the Army owned Risk Recon software for electronic mitigation plan implementation tracking. Detection ranking does not transfer to Risk Recon, as the DOD 5x5 risk ranking matrix does not include detection. Therefore, the detection ranking table has only 1 – 10 scale.

Figures 2, 3, and 4 show the tailored ranking tables for DFMEA Severity (S), Occurrence (O), and Detection (D).

Ranking tables for PFMEA, blank DFMEA and PFMEA templates with customized DOD explanations, DFMEA and PFMEA Checklists, and contract language are available upon request from the author by e-mailing Kadry.w.rizk.civ@mail.mil .

TRANSACTIONAL FMEA

Transactional processes are non-technical and have more to do with documents and data than components and machines.

Using the PFMEA form is most appropriate when risk reducing transactional processes because like assembly processes they are typically a combination of steps. Transactional processes are often overlooked in risk reduction although the consequences of their failure still equate to cost and time. Whether new or already in use, transactional processes should be understood and risk reduced using all the tools mentioned above.

Category (Product)	Severity of Effect on Product (DFMEA)	FMEA Rank	Risk Consequence Rank
Safety and/or Regulatory Compliance	Failure could injure the user or an employee.	10	5
	Failure would create noncompliance with federal regulations.	9	
Primary Function (Essential)	Failure renders the unit inoperable or unfit for use.	8	
	Failure causes a high degree of user dissatisfaction.	7	4
Secondary Function (Convenience)	Failure results in a subsystem or partial malfunction of the product.	6	
	Failure creates enough of a performance loss to cause the user to complain.	5	3
Annoyance	Failure can be overcome with modifications to the user's process or product, but there is minor performance loss.	4	
	Failure would create a minor nuisance to the user, but the user can overcome it without performance loss.	3	2
	Failure may not be readily apparent to the user, but would have minor effects on the user's process or product.	2	
No Effect	Failure would not be noticeable to the user and would not affect the user's process or product.	1	1

Figure 2: Tailored DFMEA Severity Ranking Table

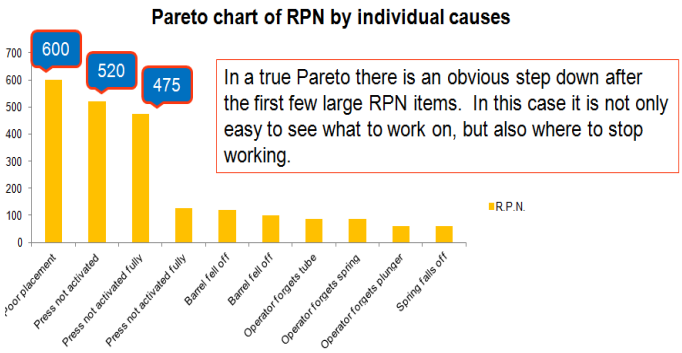

Figure 5: Example of a Pareto

Likelihood of Failure	Occurrence of Cause (DFMEA)	FMEA Rank	Risk Likelihood Rank
Very High	New technology/new design with no history.	10	5
High	Failure is inevitable with new design, new application or change in duty cycle/operating conditions.	9	
	Failure is likely with new design, new application or change in duty cycle/operating conditions.	8	4
	Failure is uncertain with new design, new application or change in duty cycle/operating conditions.	7	
Moderate	Frequent failures associated with similar designs or in design simulation and testing.	6	3
	Occasional failures associated with similar designs or in design simulation and testing.	5	
	Isolated failures associated with similar design or in design simulation and testing.	4	2
Low	Only isolated failures associated with almost identical design or in design simulation and testing.	3	
	No observed failures associated with almost identical design or in design simulation and testing.	2	1
Very Low	Failure is eliminated through preventive control.	1	

Figure 3: Tailored DFMEA Occurrence Ranking Table

Category (Product)	Detection of Cause (DFMEA)	FMEA Rank
Absolute Uncertainty	No current design control; cannot detect or is not analyzed.	10
Difficult to Detect	Design analysis/detection controls have a weak detection capability; virtual analysis (e.g., CAE, FEA, etc.) is not correlated to expected actual operating conditions.	9
Post-Design Freeze and Prior to Launch	Product verification/validation after design freeze and prior to launch with pass/fail testing (sub-system or system testing with acceptance criteria, e.g., ride and handling, shipping evaluation, etc.).	8
	Product verification/validation after design freeze and prior to launch with test to failure testing (sub-system or system testing until failure occurs, testing of system interactions, etc.).	7
	Product verification/validation after design freeze and prior to launch with degradation testing (sub-system or system testing after durability test, e.g., function check).	6
Prior to Design Freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using pass/fail testing (e.g., acceptance criteria for performance, function checks, etc.).	5
	Product validation (reliability testing, development or validation tests) prior to design freeze using test to failure (e.g., until leaks, yields, cracks, etc.).	4
	Product validation (reliability testing, development or validation tests) prior to design freeze using degradation testing (e.g., data trends, before/after values, etc.).	3
Virtual Analysis - Correlated	Design analysis/detection controls have a strong detection capability. Virtual analysis (e.g., CAE, FEA, etc.) is highly correlated with actual and/or expected operating conditions prior to design freeze.	2
Detection Not Applicable; Failure Prevention	Failure cause or failure mode cannot occur because it is fully prevented through design solutions (e.g., proven design standard/best practice or common material, etc.).	1

Figure 4: Tailored DFMEA Detection Ranking Table

DETECTION RANKING AND RISK RECON

Risk Recon utilizes the DOD 5x5 risk ranking matrix which is a two dimensional scale for ranking severity and likelihood/occurrence of risk. Detection is not transferred into Risk Recon from the FMEA. However, failures which were significant due to the inclusion of poor detection rankings on the FMEA cannot be ignored in Risk Recon. To manage risk completely, transfer ALL high risk failures and their mitigation actions to Risk Recon.

PRIORITIZING FAILURE MODES/MITIGATION ACTIONS.

How does one decide where to focus resources?

The following steps are recommended for prioritization:

Rank order all failures by descending RPN and work on the highest RPNs. This most simple approach is straight forward but does not always indicate where to stop working.

- Identify if a Pareto exists within the rank order. Unlike a simple rank order, a Pareto has a natural boundary between higher and lower RPNs. This suggests a goal to work to. Reference Figure 5.
- Create a chart of RPN by grouped causes and again look for the Pareto. Multiple similar causes might be mitigated using the same action. This approach is usually the most economical.

If a Pareto exists, then the 80/20 rule starts to apply, meaning that the majority of our concerns can be

eliminated by addressing the relatively few but very potent top items.

- Prioritize using severity only or severity with occurrence together. If severity (or severity + occurrence) alone was of great concern it could be used to dictate the focus of mitigation actions.

Government Contracts and FMEA

Many government products are designed, manufactured, and assembled by contractors through written contracts.

We have learned that without some structured approach to reducing risk, such as FMEA, failures with various levels of effect can and will result. This is unacceptable to the Warfighter. Therefore the Government should expect contractors to complete any and all appropriate FMEAs needed to risk reduce a product.

Government contracts need to be written such that the FMEA and its supporting documents will be able to be utilized, shared, and audited by the Government. This will insure that failures are minimized, and costs stay within expectations.

EVALUATING/MANAGING CONTRACTORS' FMEA

There are three stages for working with a contractor to achieve complete and quality FMEA:

1) **Stage 1**: **Preparing for FMEA**
   - Ensure appropriate contracting language is crafted and understood by parties involved.
   - Construct internal reference documents as appropriate (P-diagram, Functional Diagram, WBS, etc.)
   - Determine the "key subsystems" for which FMEA has to be delivered to the Government for review, and ensure they are documented in the contract.

   Contractors are required to complete FMEA on all systems, and they should be visible to the Government. Key subsystems are determined using lessons learned in the TD phase or using engineering judgment.
   - Assemble appropriate cross-functional teams.

   Depending on area of DFMEA or PFMEA being reviewed, the teams will include different sets of participants.

2) **Stage 2: Evaluating FMEA**
   - Cross-check reference documents against internal documents for concurrence.
   - Use checklists to insure content and quality of FMEAs.
   - Identify gaps

   Establish action item lists detailing activities necessary to improve quality and/or content of FMEA.

   Ensure appropriate participants are notified of action items via appropriate contracting channels.

   Confirm that the design-in process parameters meet user requirements if specifically spelled out as a requirement.

3) **Stage 3**: **Managing FMEA**
   - Work with FMEA owners to address and close identified action items.
   - Ensure FMEAs are reviewed at appropriate times throughout contract execution (technical reviews, appropriate IPT meetings)
   - Ensure FMEAs are treated as living documents and updated throughout the lifecycle of the product

   (Feedback from reviews, risk mitigation activities, root cause analysis/issue resolution, whenever a change is made to the system).

REFERENCES

[1] SAE J-1739 Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Process (Process FMEA).

[2] SAE ARP-5580: "Recommended failure mode and effects analysis (FMEA) practices for non-automobile applications". Aerospace Recommended Practice

[3] Automotive Industry Action Group FMEA reference manual: Automotive applications of SAE J-1739