BURGE HUGHES WALSH

The Systems Engineering Tool Box

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"Give us the tools and we will finish the job"

Winston Churchill

Functional Failure Modes and Effects Analysis (FFMEA) Alias System FMEA

What is it and what does it do?

Functional Failure Mode and Effects Analysis (FFMEA) is a tool that allows a team to systematically identify, document, and prioritise potential *functional* failure modes, their effects and causes. It is a member of the family of Failure Mode and Effects Analysis tools and like its siblings (Design FMEA and Process FMEA) uses, and relies upon, the available experience and expertise of a the team to identify the level or criticality of potential problems. It differs from its relatives in that its purpose is not to determine corrective actions but to avoid them in the first place! Sometimes called a System Failure Mode and Effects Analysis, FFMEA aims to identify and analyse potential issues thereby identifying new system functionality or design ideas that can be incorporated into the yet to be designed system. It is very much intended to be a pro-active tool that will identify functionality and features that will make the product more robust and failure resilient in the hands of the user.

Why do it?

There are basically two approaches to making system designs robust against failures:

1. Design the system and then analyse it (and even build it) to discover potential failure modes, which leads to corrective action – i.e. a redesign.
2. Think about the generic system functional failure modes and guard against these with appropriate design choice (i.e. design the problem out) or identify new functionality that either prevents the failure or warns of its imminent arrival.

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The first approach is the basis for the classic Design FMEA. While this is good practice, it is a corrective action philosophy. This means that there may be situations where a system design has advanced to such a point that the changes suggested by the Design FMEA cannot be implemented on the ground of cost or technical incompatibility. The Function FMEA can overcome this issue by considering potential failures before design commences; hence the suggestions can be included *ab initio.*

We are conducting the FFMEA to identify functionality (since FFMEA is performed before any design decisions have been made we are actually determining requirements) that can help to make the system more resilient to failure. This functionality is called Emergent Functionality since it protects the system against failures (undesirable emergent behaviour) or detects that failures are impending or have occurred. This type of system functionality is strictly not necessary for a system to achieve its Operational Requirement, but makes the system more robust and available to the user. Emergent Functionality is often a delighter. Conducting a FFMEA will also help identify possible design features or part solutions that again help to make the system more resilient to failure.

Where and when to use it?

FFMEA should be used before design commences in order to influence the design. However, it requires knowledge of the system functionality and typically follows a Viewpoint Analysis or the creation of a functional model. Both of these tools are used to identify and determine the operational functionality[1] of the system, knowledge of which is a necessary pre-requisite for conducting a FFMEA.

Who does it?

FFMEA is team-based tool that fundamentally relies on the experience and expertise in that team. It is important to emphasise that the quality of the outcome from using the tool is dependent upon the team. Hence, the team selection is critical. The team really needs to comprise members who have good knowledge of:

- existing and previous designs
- expected usage profile
- life cycle of similar systems

There is great benefit in terms of quality of output and time efficiency if the FFMEA sessions are facilitated by a tool expert. It is very easy for teams to get “bogged” down in too much detail or to get side tracked in to discussing solutions and solution based failure modes.

[1] As a reminder, systems comprise three types of functionality:

- Operational: the functionality necessary for the system to achieve its operational requirements
- Architectural: the functionality necessary to support, contain and protect the other system functionality
- Resilience: the functionality that can protect the system against failure or detect that failures have occurred

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How to do it?

The process for conducting an FFMEA can have different levels of ceremony; whether an organization adopts a bureaucratic disciplined process or an open flexible but ill-disciplined process. There are benefits and drawbacks to either approach but there is a set of steps that are recommended that are shown in Figure 1.

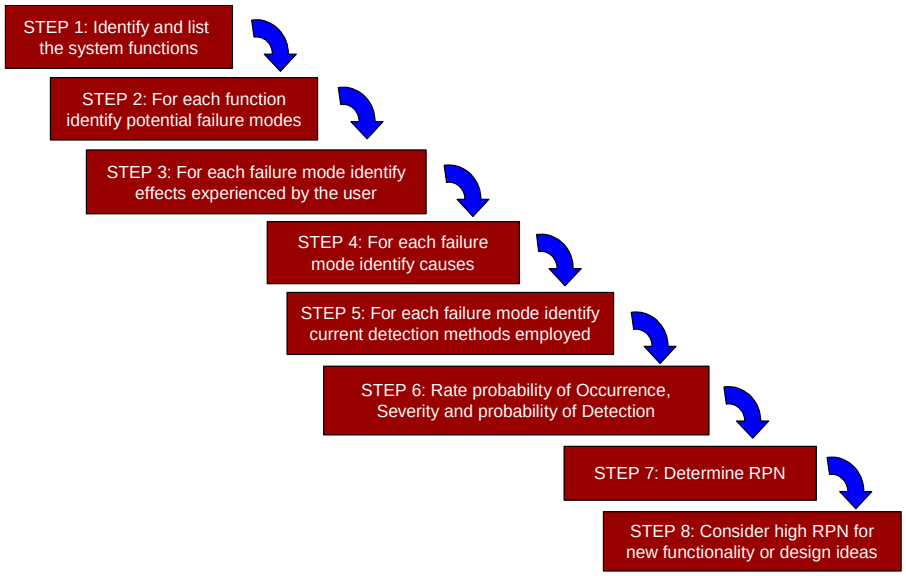

Figure 1: The basic FFMEA process

STEP 1: Identify and list the system functions

For the FFMEA to be undertaken we need to know the system functionality. Consequently, the use of tools such as Viewpoint Analysis and functional modeling are recommended since these are likely to guarantee a complete (or near complete) set of operational functionality. It is also beneficial to include any architectural functionality in the FFMEA analysis. The FFMEA should be performed at the primitive level of functionality. The functions should be written as a simple verb noun phrase that defines what action has to be carried out.

It is important that the team performing the FFMEA have a common understanding of what any function does. If this is not apparent from the functional name it should be written down elsewhere.

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STEP 2: For each Function identify the potential failure modes

A Functional FMEA examines the functions and how the functions could fail. Thus, the functional failure modes need to be expressed in this context. Indeed, failure modes should be written in the context of the function's verb description effectively as "anti-functions". A simple approach here is to use the function's verb as a basis for the failure mode description together with the "usual suspects" of:

- Over
- Under
- No
- Intermittent
- Unintentional or unintended.

For example, one of the functions of a washing machine is to "Wash Load". To determine functional failure modes the verb "wash" is moved behind each the usual suspects:

- Over Wash
- Under Wash
- No Wash
- Intermittent Wash
- Unintentional Wash.

It may be necessary to interpret these failure modes and provide a brief description of what exactly they mean. For example the "unintentional wash" would include foreign objects left in the clothing (coins in pockets) or even the family pet.

It is important to note that for any specific function not every type functional failure case will apply.

STEP 3: For each failure mode identify the effects experienced by the user

The EFFECT of a potential failure mode is what the user of the system might experience as a result of that failure mode. It is important to recognise here that for any potential functional failure mode there can be several possible effects experienced by the user of the system. Each of these should be recorded. For example the wash function has the potential functional failure mode of "over-wash" this could have several effects including:

- Shrinkage
- Colour run
- Physical fibre damage
- Fading

Note that different failure modes could have the same effect.

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STEP 4: for each failure mode identify the Failure Mode causes

The CAUSE of a potential failure mode is the basic reason for that failure mode. In many situations there may be more than one cause for a particular failure mode. When determining the causes it is important to assume that the system will be realised (manufactured/produced) correctly. It is also important to remain within the applicable system and interfaces to adjacent systems.

Causes must be identified for a failure mode, not an individual effect. If it appears that there are different causes for different effects, then it is likely that there are different failure modes. Both potential and actual causes should be captured.

STEP 5: for each failure mode identify the current detection method employed

On a Functional FMEA "detection" relates to what we did last time. There is an implicit assumption that we have designed a similar system before and may, therefore, have experienced the failure mode. In which case, it is possible some detection or prevention method has been incorporated in the previous design. The purpose of the detection column is to identify and record the currently employed method. If there was none, then "none" should be written. This often happens if it is an unprecedented function or system.

STEP 6: Determine ratings

For each failure mode–effect-cause assign:

- Probability of occurrence. This is typically performed on a scale of 1 to 10, where 1 is a remote occurrence and 10 is highly likely (pervious history of regular failures). The probability occurrence relates to the causes since if the cause occurs the failure mode will occur and the user will experience the named effects.
- Severity of the effect of the failure mode. Again a scale of 1 to 10 is used. A score of 1 equates to not severe the user may not even notice the failure. A score of 10 equates to a very serious effect. In many situations, a score of 10 is reserved for situations where the failure mode could result in injury to, or death of the user. For any particular analysis it is recommended that the team "calibrate" the effects identified.
- Probability of detection. Again a scale of 1 to 10 is used; however, this particular rating is often the one that causes most concern. To help here it is worth remembering why we are bothering to undertake a FFMEA. The purpose of the FFMEA is to identify functions and design ideas that will make the system more robust. Either by designing the potential problem out, or by including functionality that can provide a warning of impending failure. The detection is therefore based on what we have done in the past with previous system designs and what is technically possible. If we have a known and proven method for detecting the failure mode and can do so before the customer experiences the failure a low rating should be given. For example a

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car running out of fuel is a potential failure mode. The effect is the vehicle will not move. However, there is a known and proven method of detecting this potential failure mode before it happens with a fuel gauge. This would be given a low rating of 1. In a similar vein, there is no known technology that can inform the driver that the front offside tyre will “burst” is 17 miles! This failure mode would be given a detection rating of 10.

Most organizations that regularly apply FMEA in its various forms attempt to develop standard rating scales based on their experience for occurrence, severity and detection. This can greatly help a team in assigning the ratings, but can also lead to teams not thinking about a situation fully.

STEP 7: Determine RPN

The Risk Priority Number (RPN) or Criticality Index (CI) is calculated by the multiplication of the Occurrence, Severity and Detection ratings.

$$RPN = SOD$$

The larger the number the more serious or more critical the failure mode. An important point to note is that criticality of a failure is not just dependent on is likelihood of occurrence. Indeed, emphasis is placed on how the user might feel if the failure, however remote, were to occur.

Once all the criticality indices have been calculated, a summary of the most critical is extracted in order to highlight those areas where priority action must be directed.

STEP 8: Consider high RPN for new functionality or design ideas

This step is what FFMEA is all about; coming up with design ideas or new functionality that will either:

- Remove the possibility for failure.
- Provide a method for detecting the failure early (preferably, before the customer experiences it).

At this stage, it is perfectly permissible to generate solutions. Indeed, it should be encouraged. Remember we are trying to design out problems from the beginning. Removing (designing out) the possibility of failure is the ultimate aim, but if this proves impossible then the next level of intervention is devise methods to detect the potential failure. Here the emphasis should be on detection methods that will allow the system to warn the user of an impending failure. A classic example of this is fuel monitoring systems that most cars have. These typically constantly advise the driver how many miles before the car runs out of fuel.

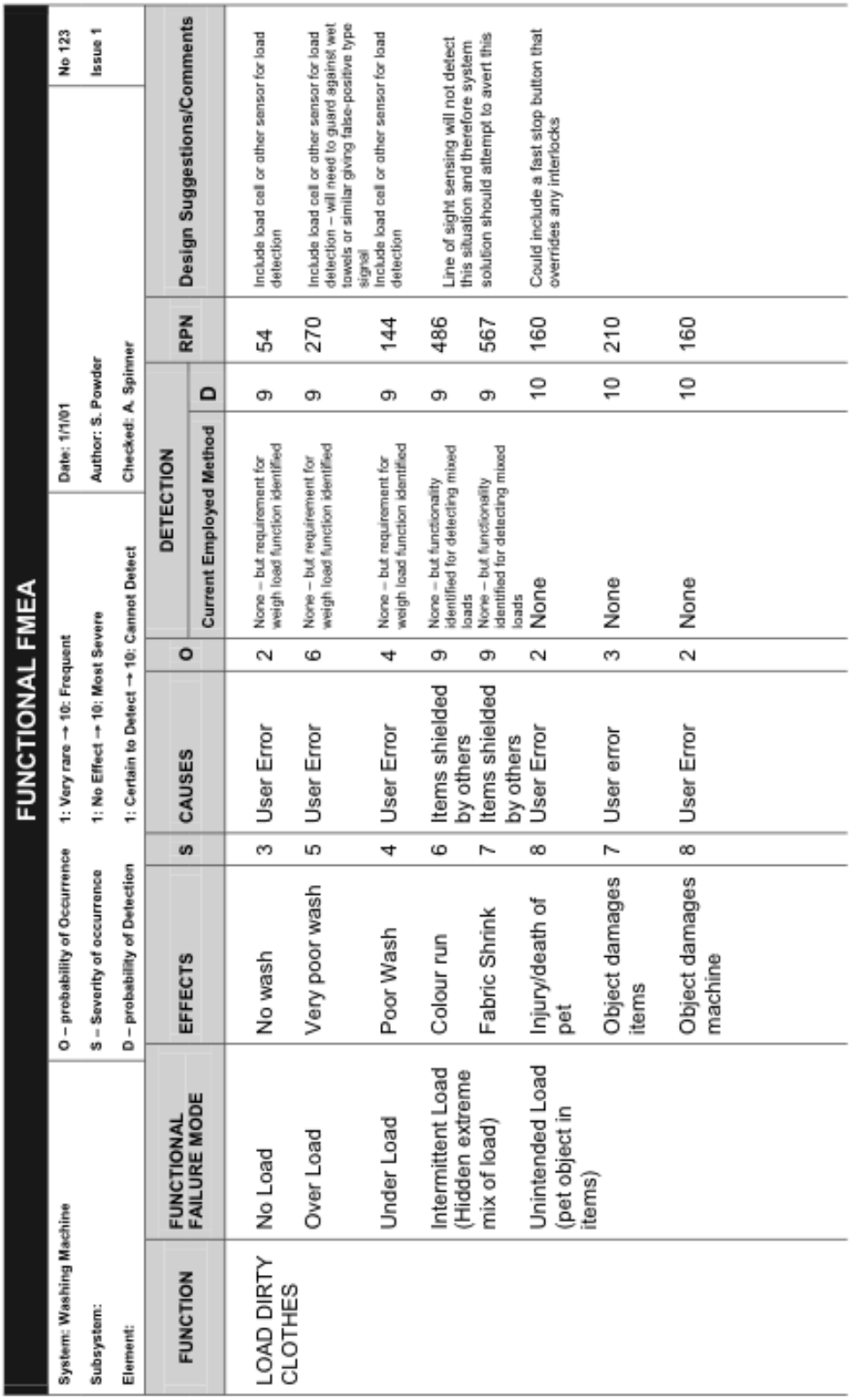
To assist in undertaking an FFMEA a proforma is used, which when completed will take the user through the seven steps given above. An example of such a form is show in figure 2. Companies will have their own derivatives but they are all more or less the same. Having said that, the FFMEA form does have a fundamental xdifference with Design and Process FMEA forms in that the rating columns are not repeated.[2]

An important point to note is that FFMEA (like all FMEA) is a **relative** and **subjective** analysis. Indeed, if two teams perform an FFMEA on the same function, the ratings given are likely to be different. However, the ranking of the failure modes by the RPN is likely to be the same. That is, both teams will identify the same critical failure modes and causes. Care must therefore be exercised when comparing two FFMEAs. Some companies have attempted to overcome the subjectivity of conducting an FFMEA by defining the criteria for each rating. An example of such guidelines is given in Table 1.

OCCURRENCE RATINGS			
Rating	**Description**	**Criteria**	**Probability of Failure**
1	Remote Occurrence	Failure highly unlikely to occur. History of similar design satisfactory with no failures	1 in 1,500,000
2	Very Slight Occurrence	Failure very unlikely to occur. History of very few failures	0.0000067
3	Slight Occurrence	Very few and infrequent failures	0.000067
4	Low Occurrence	Few and infrequent failures may be expected	0.0005
5	Medium Occurrence	Some failures likely, but not in major proportions	0.0025
6	Regular Occurrence	Regular failures may be expected	0.0125
7	Moderately High Occurrence	Frequent failures may be expected	0.05
8	High Occurrence	Failure of major proportions may be expected	0.125
9	Very High Occurrence	Frequent failures. History of similar design unsatisfactory	0.33
10	Extremely High Occurrence	Constant failure	0.5

Table 1: FFMEA Occurrence Ratings

[2] In classic Design and Process FMEA the emphasis is on determining corrective actions to potential failure modes. It is common to measure the efficacy of the proposed corrective actions by re-rating the Occurrence, Severity and Detection and thereby showing a drop in the RPN. Since the FFMEA is not aimed at corrective action but at *ab initio* design ideas and functionality this is not necessary.



FUNCTIONAL FMEA

System: Washing Machine | O – probability of Occurrence | 1: Very rare → 10: Frequent | Date: 1/1/01 | No 123
Subsystem: | S – Severity of occurrence | 1: No Effect → 10: Most Severe | Author: S. Powder | Issue 1
Element: | D – probability of Detection | 1: Certain to Detect → 10: Cannot Detect | Checked: A. Spinner

FUNCTION	FUNCTIONAL FAILURE MODE	EFFECTS	S	CAUSES	O	DETECTION	D	RPN	Design Suggestions/Comments
						Current Employed Method			
LOAD DIRTY CLOTHES	No Load	No wash	3	User Error	2	None – but requirement for weigh load function identified	9	54	Include load cell or other sensor for load detection
	Over Load	Very poor wash	5	User Error	6	None – but requirement for weigh load function identified	9	270	Include load cell or other sensor for load detection – will need to guard against wet towels or similar giving false-positive type signal
	Under Load	Poor Wash	4	User Error	4	None – but requirement for weigh load function identified	9	144	Include load cell or other sensor for load detection
	Intermittent Load (Hidden extreme mix of load)	Colour run	6	Items shielded by others	9	None – but functionality identified for detecting mixed loads	9	486	Line of sight sensing will not detect this situation and therefore system solution should attempt to avert this
		Fabric Shrink	7	Items shielded by others	9	None – but functionality identified for detecting mixed loads	9	567	
	Unintended Load (pet object in items)	Injury/death of pet	8	User Error	2	None	10	160	Could include a fast stop button that overrides any interlocks
		Object damages items	7	User error	3	None	10	210	
		Object damages machine	8	User Error	2	None	10	160	

Severity Calibration

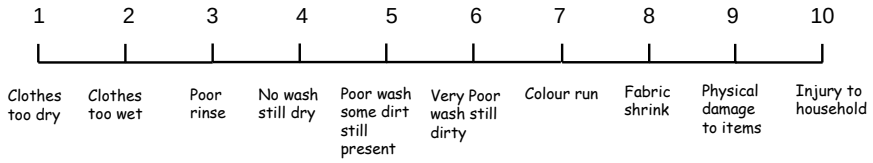


Figure 2: A typical FFMEA form containing an example

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Similar tables exist for the probability of detection as shown in Table 2. Such tables can be helpful but it is important to remember the emphasis of FFMEA is to design the failure out and not to rely on detection. Indeed, detection should only be considered once all the possible re-design avenues have been exhausted.

DETECTION RATINGS		
Rating	**Description**	**Criteria**
1	Remote probability of failure reaching the user	A known detection method exists for similar systems with a strong history of excellent performance and is included in the system requirements.
2	Very Slight probability the failure mode will reach the user	A known detection method exists for similar systems and is included in the system requirements.
3	Slight probability the failure mode will reach the user	A known and robust detection method exists for other systems and is included in the system requirements.
4	Low probability the failure mode will reach the user	A known detection method exists for other systems and is included in the system requirements.
5	Medium probability the failure mode will reach the user	A known and robust detection method exists for other systems but is not included in the system requirements.
6	Moderately probability the failure mode will reach the user	A known method exists for other systems but is not included in the system requirements.
7	Moderately High probability the failure mode will reach the user	An experimental detection method exists for other systems and is included in the system requirements.
8	High probability the failure mode will reach the user	An experimental detection method exists for other systems but is not included in the system requirements.
9	Very High probability the failure mode will reach the user	No known detection method but one is included in the system requirements.
10	It is certain that the failure mode will reach the user	No known detection method and no requirement to do so specified.

Table 2: FFMEA Detection ratings

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Some people have produced similar tables for the severity of failure but these are specific to a particular industry or sector. It is always recommend that whenever a FFMEA is conducted, one of the first activities (STEP 0 perhaps) is to “calibrate” the severity scale. That is, the team should determine what symptoms experienced by the customer could be and assigned a rating of 10, through to 1. An example of such a calibration is given in Figure 3.

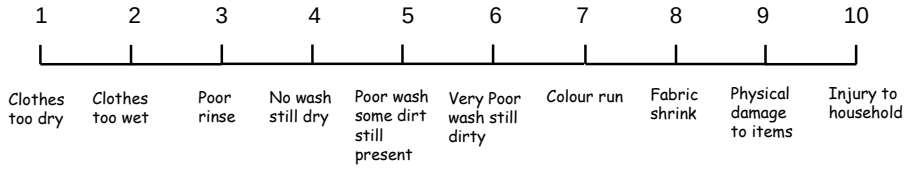

Figure 3: Calibrating the Severity Scale.

This calibration performed by the team aligns expected Effects (symptoms) that could be experienced by the user against the 1 to 10 scale. Effects not captured on this scale but emerge later during the analysis can be easily graded. Moreover, if the calibration is preserved with the FFMEA it provides useful guidance for future analyses and reference. Indeed, you might well notice that the example FFMEA given in Figure 2 has the calibration scale.

What Goes Wrong: The limitations of FFMEA

Exclusion of human frailties and errors. There is a tendency when conducting (any type of) an FMEA to use potential equipment failures as the basis for the analysis. If human errors are include this is typically only to the extent that human errors produce equipment failures of interest. Human errors that result in miss-operations that do not cause equipment failures are often not considered. They should be. Identifying this type of problem can often lead to design features that impress and delight the customer. The secret here is to recognise that the equipment rarely operates in isolation and has to interface with other systems. It is all a matter of defining the system boundary correctly and identifying those elements in the environment that have direct impact.

You will notice in the washing machine example given in Figure 2 that several of the causes of the failure modes are attributed to “user error”. In this instance, this type of error is not so much an error but a form of miss-use by the user. However, by recognising the potential problem and making the machine robust against these potential failure modes will result in a better system as perceived by the user.

Only one level of cause and effect at a time. The failure modes identified in performing an FFMEA are generally analysed one at a time. This has several implications:

- Important combination of failure modes or causes may be overlooked.
- Can only analyse one level of cause and effect at a time.

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Failure Modes are dependent on the mode of operation. The effects of certain failure modes often vary widely, depending on the mode of system operation. For example, the fuel system of a commercial aircraft during refuelling will have different failure modes to that while it is delivering fuel during flight.

This is actually more of a problem with Design FMEAs and should not be a problem when conducting a Functional FMEA since having moded operation is more likely to be a feature of the design domain. Indeed, provided the system functionality encompasses all the operational situations, a FFMEA will help to ensure no mode dependent failure modes are overlooked.

Success Criteria

The following list represents a set of criteria that have been found to be useful when undertaking a Functional FMEA. Ignore them at your peril!

- Team size between five and eight.
- Team constitution covers system life cycle and potential technology.
- Use an experience independent facilitator.
- Plan for boredom and tiredness (a series of half day sessions spread out over a month is better than two weeks of intensive slog).
- Focus on functional failures and aim to design problems out *ab inito.*
- Functional FMEA is not an add on – it is what the world's best organizations do – it is part of the job.

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