Expanded FMEA (EFMEA)

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SUMMARY & CONCLUSIONS

The main FMEA objective is the identification of ways in which a product, process or service fail to meet critical customer requirements, as well as the ranking and prioritization of the relative risks associated with specified failures. The effectiveness of prioritization can be significantly improved by using a simple graphical tool, as described by the authors. Evaluation of the adequacy of correction actions proposed to improve product/process/service, and the prioritization of these actions, can be supported by implementing the procedure proposed here, which is based on the evaluation of correction action feasibility. The procedure supports evaluation of both the feasibility of a corrective action implementation and impact of the action taken on failure mode.

1. INTRODUCTION

Failure Mode Effect Analysis (FMEA) is one of the well-known risk-assessment methodologies. FMEA, first used in 1960's in the Aerospace industry, is now recognized as a fundamental tool in the Reliability Engineering field.

The purpose of FMEA is to examine possible failure modes and determine the impact of these failures on the product (Design FMEA - DFMEA), process (Process FMEA - PFMEA) or service (Service FMEA - SFMEA):

- DFMEA is used to analyze product designs before they are released to production. DFMEA focuses on potential failure modes associated with the functions of product and caused by the design deficiencies;
- PFMEA is used to analyze the already developed or existing processes. PFMEA focuses on potential failure modes associated with both the process safety/effectiveness/efficiency, and the functions of a product caused by the process problems;
- SFMEA is used to analyze the product serviceability, i.e. it is focused on the potential problems associated with both maintenance issues and field failures of the manufactured products.

2. BACKGROUND

FMEA represents a 'Step by Step' procedure (some sequence of questions & answers) implying, at its first steps, a tabulation of system functions or system equipment items, the failure mode of each item, and the effects of the failures on the system:

- o What is the input for FMEA? Functions or items identified as candidates for analysis.
- o What can go wrong? – The following is a list of potential failure modes for every identified item:
  - The item doesn't perform the intended function;
  - The item's performance is poor;
  - The item performs an unintended function.
- o What is the effect on the system's output? – The expected result that the given failure will have on people, system (equipment) or environment.

After the failure effects have been identified, the consequences associated with each effect should be evaluated. One possible method is the use of the conventional ranking procedure to rank the severity (S) of the failure effect. It is ranked on a '1' (Best Case) to '10' (Worst Case) scale, which appears on standard FMEA forms [1]. The ranking procedure takes into account considerations of safety, system downtime, defective unit appearance, reduced performance level, system instability, etc.

The following sequence of questions & answers is needed to perform the root-cause analysis of failure modes, as well as to evaluate the occurrence (O) and detectability (D) ranks:

- o What is the cause of every identified failure? – Specific cause(s) for each failure mode must be identified. Root-cause analysis can be supported by relevant historic data, reports, complaints, service calls, etc.;
- o How often does this cause happen? – Evaluate the probability of occurrence of the cause that resulted in the failure. The likelihood of occurrence should be ranked also on a '1' (Best Case) to '10' (Worst Case) scale [1] using historical data (failure rate, MTBF, FRACAS reports, Cpk data, etc.).
- o How, when and where can we detect this cause and/or a relevant failure mode? – Current control activities associated with given cause and/or related failure mode should be considered.
- o How well can we detect this cause and/or relevant failure mode? – The probability that the control system will detect failure mode and/or cause when they occur should be evaluated. Similar to severity and occurrence, detectability is ranked on a '1' (Best Case) to '10' (Worst Case) scale [1] using the data

characterizing the effectiveness of control (testing, inspection, measurements, etc.).

Obtained ranks of severity (S), occurrence (O) and detectability (D) are used for risk assessment via an index called RPN (Risk Priority Number) calculated by multiplying the severity, occurrence and detection ranking factors for every cause:

$$RPN = S * O * D$$

Once all items have been analyzed and assigned a RPN value, it is common to plan corrective actions from the highest RPN value down. The intent of any corrective action is reduction of any of the severity, occurrence and/or detection rankings.

3. PITFALLS OF CONVENTIONAL FMEA AND PROPOSED SOLUTIONS

Conventional FMEA procedure is characterized by some pitfalls. The Expanded FMEA (EFMEA) procedure proposed by the authors, improves the FMEA effectiveness providing solutions to two very important problems:

- RPN prioritization,
- Corrective actions comparison.

3.1. RPN prioritization

The items covered by the FMEA procedure are usually very different from the risk values point of view. Obviously, the most important items, characterized by high RPN, should be separated from those characterized by a significantly lower RPN value. Selected 'High Priority' items represent issues for corrective action plan development. The question is 'How such separation can be performed?'

Common recommendations of the conventional FMEA concerning calculated RPN values are usually very general. For example,

- 'For higher RPN's the team must undertake efforts to reduce the calculated risk through corrective action(s)' [1];
- 'Focus attention on the high RPN's' [2];
- 'Expend team effort on top 20 to 30% of problems as defined by RPN values' [3].

The common practice of an FMEA team analyzing RPN values in Pareto fashion is to limit the list of recommended corrective actions to 'Top 'X' Issues'. Chosen X-value could be 3 or 5 or 10, etc. In any case, the 'X' will be an absolutely random choice. Obviously, this kind of decision-making is very problematic.

How can we decide which RPN values characterize critical issues that should be immediately treated? This question can be answered by a distribution analysis of the RPN values. Although there is some rather sophisticated statistical techniques supporting distribution analysis, we recommend the application of a very simple and quite effective graphical tool for RPN value analysis. This tool actually represents graph of ordered RPN values and is similar to so-called *Scree Plot* used in principal component analysis.

Scree Plot settings require preliminary ordering of the RPN values by size, from smallest to largest. These values are then plotted, by size, across the graph. Normally, when observing from the right, *Scree Plot* appears like a cliff, descending to base level of ground (see Fig. 1).

The calculated RPN usually form a right-skewed distribution, with a short tail on the left (negligible risk values) and a long tail on the right (due to critical risk values representing 'outliers' from the distribution analysis point of view). Therefore, the shape of the points forms a non-symmetrical upward curve on a *Scree Plot.*

The lower long part of the plot is characterized by a gradual increase of the RPN values that can, usually, fit a straight line with a rather slight slope (showed by 1st dotted line on plot). The RPN values scattered around this line should be considered as a kind of 'Information Noise'. The issues characterized by these RPN do not require immediate attention.

The short uppermost part of *Scree Plot* is characterized by a very steep increase of the RPN values (RPN jumps). A straight line with a very strong slope (showed by 2nd dotted line on plot) could fit it. The RPN values scattered around this line are related to the most critical issues of FMEA that need to be dealt with promptly.

3.2. Choice of preferable corrective action

There are, usually, several possible competitive corrective actions that, theoretically, are capable of reducing the RPN for any given failure mode. Although there are actions that aim at failure mode severity reduction (usually by redesign), the bulk of the actions, deemed appropriate, aim at either occurrence ranking reduction or detectability ranking reduction. Actions aimed at occurrence ranking reduction seek to prevent the occurrence of the cause of failure mode, or to reduce the rate at which the cause and/or the failure mode occur. Actions aimed at detectability ranking reduction adopt a course of action focused on improvement or on the detection of the cause and/or the failure mode prior to its occurrence and to issue a warning.

Since conventional FMEA does not provide any guidelines for the optimal choice between competitive corrective actions, the FMEA team faces a difficult task. Priority of the alternatives under comparison usually is subjectively established based on intuition, experience and/or feelings of FMEA team members. The final solution recommended by the FMEA team is, often, far from being the optimal one, such as an action preferable from the department manager's point of view or the one suggested by the loudest member of the team.

The EFMEA procedure provides the basis for the optimal corrective action choice. This procedure implies evaluation of both the feasibility of a corrective action implementation and the expected RPN value after implementing this action. Since feasibility estimation is a multidimensional problem, its evaluation should be performed by posing the question: 'How feasible is it to implement a given corrective action under the existing constraints of safety, cost, resources, time, quality & reliability requirements, organizational structure, personnel resistance, etc.?' Moreover, EFMEA takes into consideration both chance of success (i.e. the RPN reduction) and the probability of an undesirable impact (on people, system, product, process or environment) as a result of a corrective action implementation.

Similar to the conventional FMEA's procedure, the feasibility rank (F) is estimated on a '1' (Best Case) to '10' (Worst Case) scale using the criteria proposed by the authors and presented in Table 1.

The EFMEA procedure results in prioritization of the analyzed alternatives. The final decision, i.e. the choice of the optimal corrective action, is based on the results of the comparative analysis of the differences between the RPN values before and after the implementation of given corrective actions divided by the corresponding feasibility ranking factors

$$\frac{RPN_{i\,Before} - RPN_{i\,After}}{F_i} = \frac{\Delta RPN}{F_i}$$

Where: $RPN_{i\,Before}$ and $RPN_{i\,After}$ are RPN values for a given item before and after implementation of the *i-th* corrective action, ΔRPN is the difference between these values; F_i is the feasibility rank of *i-th* corrective action.

The calculated ratio belongs to the family LTB ('The Larger-the Better'), i.e. the most preferable corrective action is characterized by the largest ratio.

There is an alternative approach for feasibility evaluation based on a known procedure of Pareto Priority Index calculation [4]. The feasibility estimate can be calculated as the geometrical mean of values of all feasibility related dimensions (such as cost, time consumption, chance of success, etc.) [5]. Obviously, the same dimensions, measured on the same scales, should characterize all competitive corrective actions.

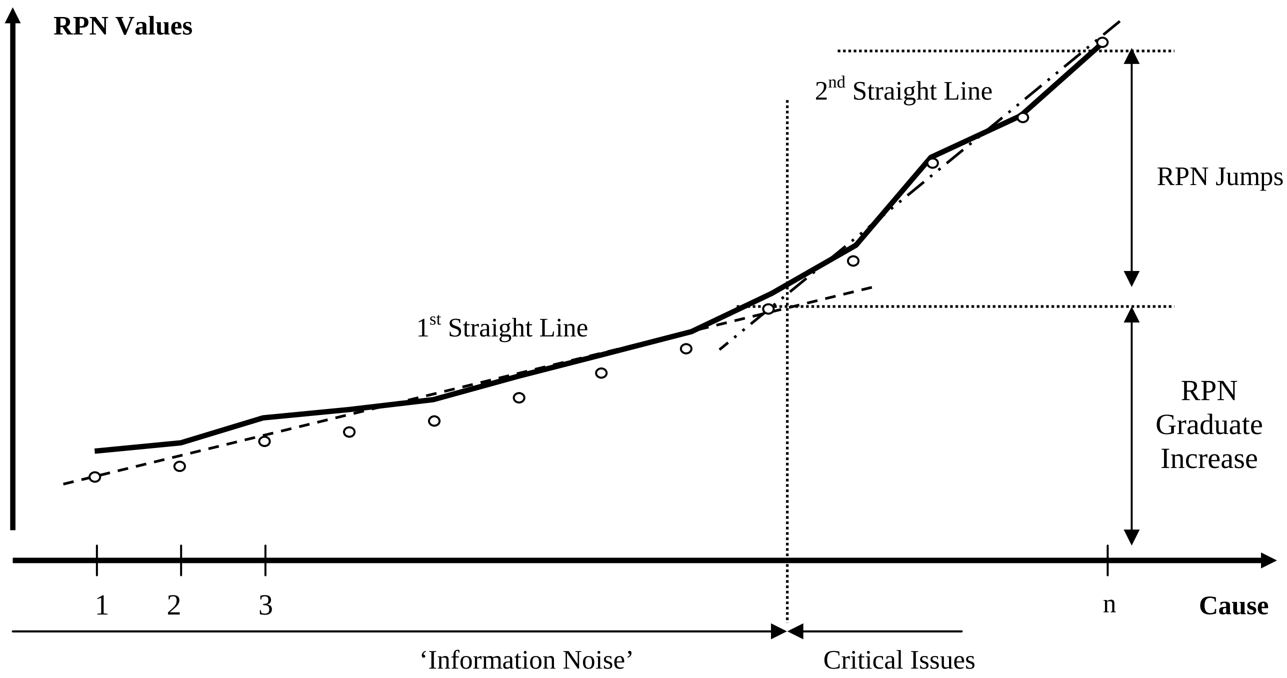

Figure 1. Scree Plot RPN

Criteria: Feasibility of Corrective Actions Implementation	**Ranking**
Safety Problem and/or Noncompliance to Government Regulation and/or unavailable necessary resources and/or unacceptable cost and/or time consumption and/or zero chance of success and/or 100% probability of undesirable impact.	10
Very remote availability of necessary resources and/or almost unacceptable cost and/or time consumption and/or almost zero chance of success and/or almost 100% probability of undesirable impact.	9
Remote availability of necessary resources and/or near unacceptable cost and/or time consumption and/or remote chance of success and/or near 100% probability of undesirable impact.	8
Very low availability of necessary resources and/or very high cost and/or time consumption and/or very low chance of success and/or very high probability of undesirable impact.	7
Low availability of necessary resources and/or high cost and/or time consumption and/or low chance of success and/or high probability of undesirable impact.	6
Rather low availability of necessary resources and/or rather high cost and/or time consumption and/or rather low chance of success and/or rather high probability of undesirable impact.	5
Moderate availability of necessary resources, cost, time consumption, chance of success and probability of undesirable impact.	4
Rather highly available resources, rather low cost and time consumption, rather high chance of success and rather low probability of undesirable impact.	3
Highly available resources, low cost and time consumption, high chance of success and low probability of undesirable impact.	2
Fully available resources, very low cost and time consumption, near 100% chance of success and near zero probability of undesirable impact.	1

Table 1. Feasibility Ranking

Item (Failure Mode & Cause)	Recommended Corrective Action	Current Vs. Expected									F	$\frac{\Delta RPN}{F}$	Corrective Action's Priority
		S		O		D		RPN					
		Current	Expected	Current	Expected	Current	Expected	Current	Expected	Difference			
Failed Product Due to Insufficient Strength	Change of raw material	9	9	8	1	6	8	432	72	360	8	45	2
	Change of process temperature	9	9	8	4	6	8	432	288	144	2	72	1
	Change of process pressure	9	9	8	4	6	8	432	288	144	5	29	3

Table 2. Example of Corrective Actions Prioritization

4. CASE STUDY

The proposed procedure has been applied for evaluation of the communication device, designed by Motorola. After identification of all failure effects and root-cause analysis of failure modes in teamwork, all corresponding RPN values have been calculated (see Table 3)

ID	Function Description	FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECT(S) OF FAILURE	SEV	CLASS	POTENTIAL CAUSE(S)/ MECHANISM(S) OF FAILURE	OCCUR	CURRENT DESIGN CONTROLS	DETECT	RPN
Note: The FMEA will use the "circuit block" approach in which all parts in a circuit block are treated as an FMEA one item.											
BB-1	**RS 232**	RS 232 port	NO DTE/DCE communication	Data portion is not working	7		U5201 is damaged Due to ESD	6	Test ESD (x KV) after Pilot	3	126
			NO DTE/DCE communication	Data portion is not working	7		Unit set to communicate in other modes of communication (e.g. USB)	4	Verify integration	6	168
			NO DTE/DCE communication	Data portion is not working	7		DTR or RTS are not connected to the processor Reasons may be contacts in J1/J10/J11 or customer installation problems.	4	RTS / DTR connections are checked in final test (Installations recommendations in the developer guide).	2	56
BB-2	**Analog Audio signals**	TX Path	High Distortion	Distorted sound in the uplink	4		Injected signal was too high	3	N/A	10	120
		RX Path	Aux. Audio "Pop"	"Pops" heard when pressing On/Off switch	5		wrong integration	10	N/A	10	500
			Low (auxiliary) audio	Radio turns on automatically, with applying Vcc, low or no handsfree audio	6		AUDIO_OUT_ONOFF DC loaded/shorted to gnd	3	Checked at final test	3	54
							Line loaded due to bad assembly	2	N/A	10	120
BB-3	**Logic circuits & Memories**	Main functionality of the phone	Flash Corruption	Phone is not functioning at all	8		unpower/ Disconnected the unit during SW load	3	Final Test or before	1	24
			Flash Boot Sector Corruption	Phone is not functioning at all	8			3	Final Test or before	1	24
			Unit issues reset out and turns off at OS startup (after completing initialization) - logo presented	Phone is not functioning at all	8		Internal Discontinuity in PCB	7	N/A	10	560
BB-4	**Power Management**	Main functionality of the phone	Very High Current Consumption (>xA) at power-up	Phone is not functioning at all, excessive heat	8		"A" damaged by overvoltage although there are recommendations in Developer guide	3	Checked at final test	3	72
			Very High Current Consumption (>xA) at power-up	Phone is not functioning at all, excessive heat	8		RF PA damaged	3	Checked at final test, replace PA	2	48
			High Current Consumption (yA < I < xA) at power-up	Radio powers up, but draws high current, excessive heat in "A" area	6		one of "A" regulators supplying RF is shorted	3	Checked at final test	4	72
			No current	Phone is not functioning at all	8		Main FET not properly soldered	2	Checked at final test	3	48
BB-5	**IGNITION**	No Ignition functionality	Radio doesn't turn on/off due to Ignition, but turns on/off from audio_out_onoff	Protection diode and resistor burn-out,	5		inadequate zener diode, burs out easily, drawing additional current through the resistor as well	10	N/A	10	500

ID	Function Description	FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECT(S) OF FAILURE	SEV	CLASS	POTENTIAL CAUSE(S)/ MECHANISM(S) OF FAILURE	OCCUR	CURRENT DESIGN CONTROLS	DETECT	RPN
RF-1	**RF RX Path**	FER	Unit not receiving / Poor RX quality	Poor receive levels, dropped calls	7		1. Factory assembly defects. 2. Defective parts.	3	100% test on final test	1	21
				Wrong RSSI indication to user	7		Phasing problem	2	100% test on final test	1	14
RF-2	**RF TX Path**	Output power.	No output power/ Low power	Limited TX dynamic range - limited unit coverage	3		1. Factory assembly defects. 2. Defective parts.	5	N/A	9	135
		timing error / Frequency error	TX parametric errors: timing error / Frequency error	Dropped calls.	7			5	Tested any proto in extremes	9	315
			Damage to power amplifiers	Loss of radio fuctionality	8		High VSWR on the antenna ports Due to Damage to output cable / antenna	5	N/A	10	400
RF-3	**RF - Front End**	Antenna path	Component damage	Loss of radio fuctionality	8		ESD although coil is placed- L450	1	1. ESD tested during qualification tests 2. parameters tested 100% in factory.	4	32
RF-4	**Antenna Connector**	50ohm connectors	Connector becomes detatched from the PCB	Anything from degradation in receive and transmit	8		1. Connector not soldered properly 2. High pull force by the user	5	Visual inspection in factory.	1	40

Table 3. Failure Mode and Effects Analysis (DFMEA)

All RPN values were sorted and plotted on a graph in ascending order (see Fig. 2). The critical issues belonging to the uppermost part of *Scree Plot* have been identified and reviewed.

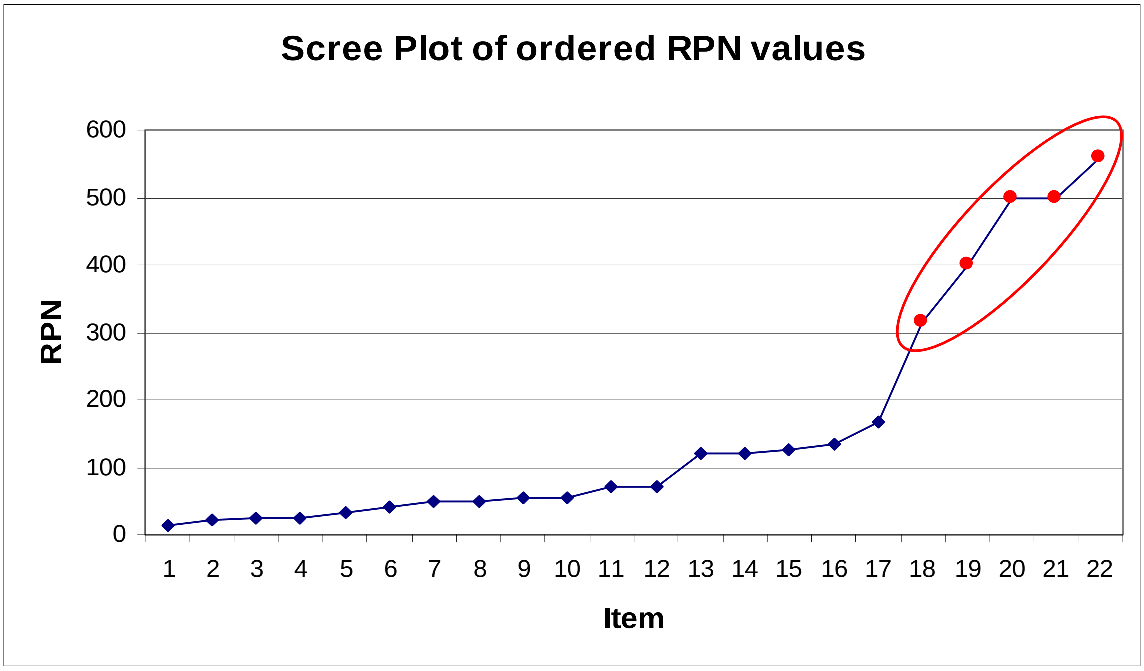

Figure 2. Scree Plot of ordered RPN values

ID	Function Description	FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECT(S) OF FAILURE	SEV	CLASS	POTENTIAL CAUSE(S)/ MECHANISM(S) OF FAILURE	OCCUR	CURRENT DESIGN CONTROLS	DETECT	RPN	RECOMMENDED ACTION(S)	ACTION RESULTS					
													SEV	OCC	DET	RPN	F	□RPN/F
BB-2	**Analog Audio signals**	RX Path	Aux. Audio "Pop"	"Pops" heard when pressing On/Off switch	5		Wrong Integration	10	N/A	10	500	1. Add recommendations in Developer guide	5	3	10	150	1	350
												2. Integration with host product	5	2	10	100	5	80
BB-3	**Logic circuits & Memories**	Main functionality of the phone	Unit issues reset out and turns off at OS startup (after completing initialization) - logo presented	Phone is not functioning at all	8		Internal Discontinuity in PCB	7	N/A	10	560	1. Improve the vendor's process	8	2	10	160	9	44
												2. Add test at the vendor facility before shipping to Motorola for every batch (sampling)	8	3	10	240	4	80
												3. Add Acceptance Inspection (100% at Motorola door)	8	1	10	80	8	60
BB-5	**IGNITION**	No Ignition functionality	Radio doesn't turn on/off due to Ignition, but turns on/off from audio_out_onoff	Protection diode and resistor burn-out,	5		inadequate zener diode, burs out easily, drawing additional current through the resistor as well	10	N/A	10	500	1. Protection diode 2. Resistor derating	5	1	10	50	3	150
												3. Add testing in the Final Test	5	10	4	200	2	150
												Improve Design (1.2) & Increase Detectability (3)	5	1	4	20	3	160
RF-2	**RF TX Path**	timing error / Frequency error	TX parametric errors: timing error / Frequency error	Dropped calls.	7		1. Factory assembly defects. 2. Defective parts.	5	Tested any proto in extremes	9	315	Test 100% in factory.	7	5	1	35	3	93
			Damage to power amplifiers	Loss of radio fuctionality	8		High VSWR on the antenna ports Due to Damage to output cable / antenna	5	N/A	10	400	PA's specified to ruggedness of x:1 which is sufficient because of the loss from the PA output pin to the antenna ports.	8	1	10	80	2	160

Table 4. Corrective Action Analysis & Prioritization (EFMEA)

From 1 to 3 alternatives for every issue have been revealed during discussion of the corrective actions plan by the FMEA team. Prioritization of the proposed alternatives has been performed using the software supporting the suggested procedure of EFMEA [6]. Every corrective action has been evaluated taking into account both the expected RPN value after this action implementation and the feasibility of the action implementation under the existing constraints of cost, resources, time, as well as quality & reliability requirements. Comparative analysis of adequacy of the alternatives has been performed using the proposed 'standardized-improvement' criteria (ΔRPN /F). Post-FMEA activity (design and testing improvement) was based on chosen preferable corrective actions (see Table 4).

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