Bouncing Failure Analysis (BFA):
The Unified FTA-FMEA Methodology

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SUMMARY & CONCLUSIONS

This paper introduces Bouncing Failure Analysis (BFA) – an innovative combination of two traditional and widely used Failure Analysis (FA) techniques: Failure Mode Effect Analysis (FMEA) and Fault Tree Analysis (FTA), presenting the methodology and the procedure able to maximize the advantages and at the same time to minimize the shortcomings of both known methodologies.

1. INTRODUCTION

FMEA and FTA have three main differences: boundaries of the analysis, direction of analysis, and presentation of the analysis process and results. FMEA deals with single point failures, is built bottom-up, and is presented as a rule in the form of tables. FTA analyzes combinations of failures, is built top-down, and is visually presented as a logic diagram. By taking into account combinations of failures, FTA avoids the obvious shortcomings of FMEA. However, being heavily dependent on personal experience and knowledge, even "fine art" of a performer-analyst, FTA has a tendency to miss some of failure modes (FM) or FM combinations.

Most failure analyses and studies are based on either FMEA or FTA. Rarely, both FMEA and FTA will be performed, and when both are performed, these will be separate activities executed one after another – without significant intertwining.

2. BACKGROUND

BFA connects the two methodologies allowing an analyst to "bounce" between top-down and bottom-up, from FT diagram to FM table and back, changing the presentation and the direction of the analysis for convenience of analysis at any point in the process. BFA extends FMEA methodology by taking into account the combinations of failure modes (as in FTA, instead of just one failure mode at a time as in traditional FMEA). BFA replaces the traditional top-down FTA process with the bottom-up approach, far more intuitive and easy for most engineers. It initiates bouncing from time to time to the top-down and back, ensuring analysis verification and subsequent update. BFA results in a highly efficient, systematical study of failure modes and a dramatic decrease of TTAA (Time to Acceptable Analysis), i.e. decreasing the period of time from the beginning of analysis to the satisfactory report.

This paper provides a clear and easy step-by-step guide to perform Bouncing Failure Analysis (BFA). The result is a complete coverage of all failure modes followed by the testability and detectability analyses. BFA starts with the definition of all possible End Effects for the System Under Analysis (SUA), shows the creation of a complete Interaction Matrix (Pair-Combination Matrix) for double-, triple- and multi-point failures, explains the ways to bounce between FMEA and FTA methodologies, introduces the methodology for cutting down the size of the Interaction Matrix, and finally presents comprehensive results: concurrent combinations of SUA failures, external triggers, catalysts with corresponding sequences. The introduction of BFA provides a solution, long-awaited by industry, which is at the same time complete, time-saving, and easily implemented in software interpretation of the traditional practices: FMECA, FTA, Testability, Detectability, and RPN (Risk Priority Number).

3. BOUNCING FAILURE ANALYSIS

The suggested analysis (BFA) implies the usage of the combination of tabular analysis (FMEA-style) and graphical analysis (FTA-style). Both types of analyses require the deep understanding of the SUA behavior: System End Effects and Failure Modes. Such understanding is essential for decomposition of the system and compilation of complete End Effects and Failure Modes lists/libraries where each FM or combination of FMs causes one or more End Effects. The way to define the End Effects list is to investigate the SUA functional requirements, i.e. "What the system is required to do" ($F1, F2 \ldots Fj$), as well as SUA safety requirements, i.e. "What the system is required not to do" ($Fj+1, \ldots, Fk$). For example, for a communication system with functions: F1=Receiving, F2=Transmitting …Fk = Dangerous level of radiation. The function F1 will have the following End Effects: EE11=No Signal, EE12=Signal Distortion, EE13=Noisy Signal, etc. Therefore, setting up the End Effects list is the first important step of the BFA procedure.

Following is the step-by-step description of the BFA methodology.

1. Define all possible End Effects (EE), i.e. the effects at the *top system level*. In most cases the EE list can be derived from the list of the functional requirements for the System Under Analysis (SUA). In our example "Function 1" has two possible End Effects: EE11 and EE12.
2. Assign the appropriate Severity to each EE, subject to the SUA improper operation consequences.
3. Define all possible failure modes on the bottom level. Failure modes for the bottom (component) level are usually well known and can be found in the existing failure modes databases (see Fig. 1), i.e. "Item 3" has three Failure Modes: I3FM1, I3FM2, and I3FM3.

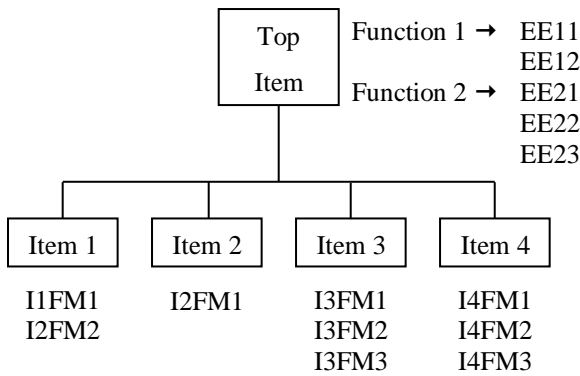We have now ensured the **completeness** of the future analysis.

Fig. 1

- Select a specific EE.
- Build a complete Interaction Matrix of all failure modes at the bottom level (Pair-Combination Matrix) (see Fig. 3a).
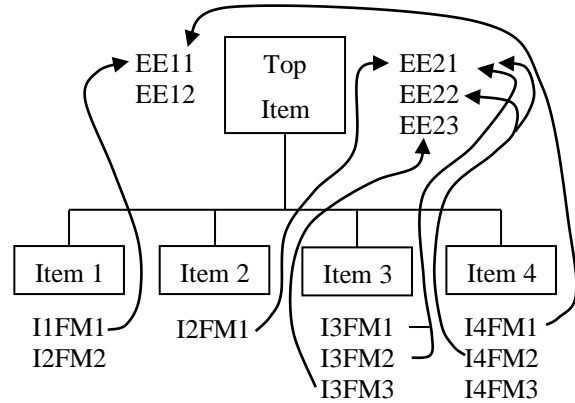

Fig. 2

4. Perform the traditional (single-point failure) FMEA, evaluating each failure mode at the bottom level and assigning an appropriate effect at the next higher level and the EE (see Fig. 2). The drawback of the FMEA may be an absence of any single FM causing some/any specific EE (no single-point failures).
5. Use the single-point FMEA as a basis for the failure analysis of a higher order: double-point failures, triple-point failures, n-point failures.

We suggest the Hierarchical Interaction Matrix approach, with its sub-steps, applied to each EE one-at-a-time and "do until" we finish the EE list:

For example, for the first EE of Function 2, i.e. EE21:

Our analysis focuses on the upper half of the matrix. Due to matrix symmetry we can exclude the lower half of the matrix from our analysis (see Fig. 3a).

EE21

	I1FM1	I1FM2	I2FM1	I3FM1	I3FM2	I3FM3	I4FM1	I4FM2	I4FM3
I1FM1									
I1FM2									
I2FM1									
I3FM1									
I3FM2									
I3FM3									
I4FM1									
I4FM2									
I4FM3									

Fig. 3a

- Now we can exclude the failure modes that cannot be a multi-point cause of the selected end effect EE21:

first exclude all failure modes that cause the EE21, based on the single-point failure analysis (I2FM1, I3FM1, I3FM2 and I4FM2) – darkest grey cells on Fig. 3b.

second (optional – added to demonstrate an additional consideration) exclude all failure modes that can never be a cause for the selected effect (in our example: I4FM3) – cells with pattern on Fig. 3b.

EE21

	I1FM1	I1FM2	I2FM1	I3FM1	I3FM2	I3FM3	I4FM1	I4FM2	I4FM3
I1FM1									
I1FM2									
I2FM1									
I3FM1									
I3FM2									
I3FM3									
I4FM1									
I4FM2									
I4FM3									

Excluded because never can cause EE21

The marked Failure Modes are excluded - as each of them is a single point for EE21 (see Fig. 2).
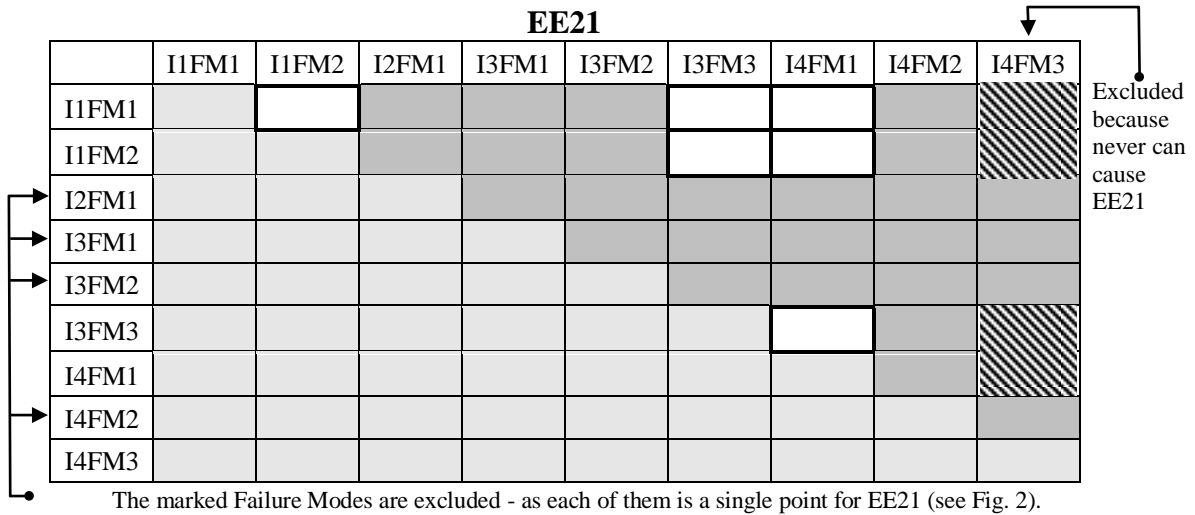
Fig. 3b

- The transparent cells indicating the combinations to be analyzed form the basis of the shortened Interaction Matrix (see Fig. 4).

The shortened interaction matrix covers the internal SUA **FM** only. One can enhance the analysis by taking into account additional significant factors:

Catalysts – failure accelerators increasing the probability of a particular FM causing the given EE.

Triggers – external factors activating the EE. Trigger actually enables an internal failure mode to become the EE cause.

Shortened Interaction Matrix: Double-Point Failure

EE21

I1FM1 appears as disabled because it cannot be a player in a triple-point failure

	I1FM1	I1FM2	I3FM3	I4FM1
I1FM1			✳	✳
I1FM2				
I3FM3				
I4FM1				

Legend:
✳ - I1FM1 together with I4FM1
↕ - I1FM1 then I4FM1
↵ - I4FM1 then I1FM1

I1FM1 * I3FM3 and I1FM1 * I4FM1: two double-point failures are the analysis outcome
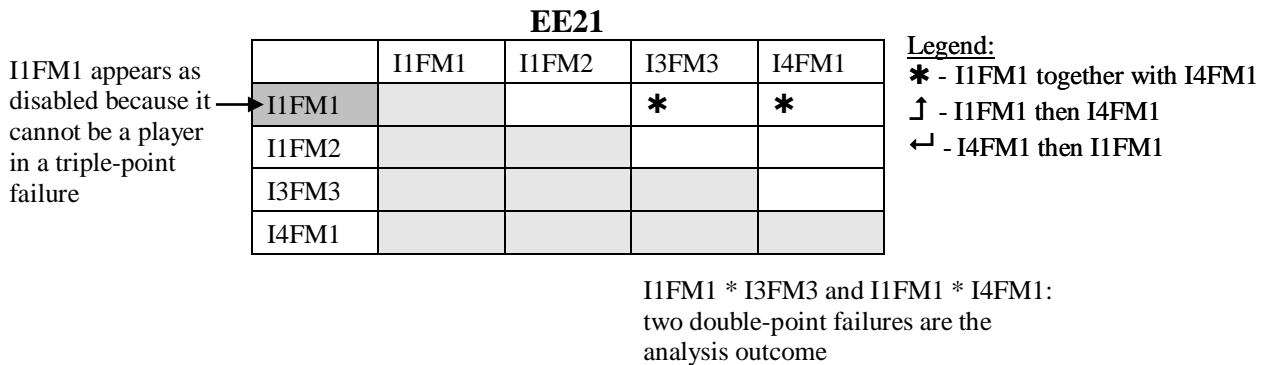
Fig. 4

- Let's now proceed to double-point failures investigation, repeating the procedure of a selection of the appropriate cells in the matrix. Now each selected cell represents a double-point failure (a combination of two failure modes leading to a failure).
This selection has 3 options:
The particular EE will happen **if and only if:**
  - both FM A and FM B happen simultaneously. In this case, place an "*" in the A-B intersection cell.
  - FM A happens, and then FM B happens. In this case, place the arrow "↕" from A to B in the intersection cell.
  - FM B happens, and then FM A happens. In this case, place the arrow "↵" from B to A in the intersection cell.

This method allows us to define the sequence of failure modes causing the double/multi-point failure. FTA presents the double/multi-point failures with their sequence with the help of the Priority gate.

- Selection of FMs in the matrix is accompanied by an additional background process - all FMs that cannot be a part of the triple-point failure will be disabled automatically.
- We now continue to the triple-point failure investigation by drilling down to the desired failure mode, enabled in the double-point matrix. Our investigation results in the selection of a failure mode together with its operator (can be "*" or "→") and creation of a shortened matrix. Applying the same technique used for the double-point failures, we select a cell of the matrix that will now present a triple-point failure. (See Fig. 5).

Shortened Interaction Matrix: Triple-Point Failure
EE21

I1FM2	✳	↓

✳ - together
➔ - first

	I3FM3	I4FM1
I3FM3		✳
I4FM1		

➔ Triple-point failure
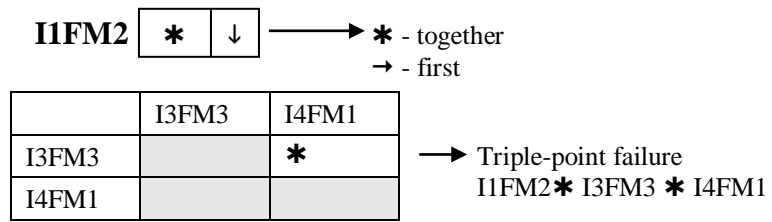I1FM2 ✳ I3FM3 ✳ I4FM1

Fig. 5

6. All along the FM investigation process described above, the target Fault Tree and/or FMEA table are displayed automatically. The analyst switches/bounces between bottom-up to top-down represented by table (FMEA) and graphical presentation (FT).

Empowered with FMEA and FTA software, with implemented BFA, the analyst can decide at every point to transfer results of the evaluation to the FMEA tables. The FMEA table will present the rising order of the failure analysis: first build the FMEA table for single-point failures, then for double-point ones, and so on. Such an FMEA table is an equivalent of the list of the minimal cut-sets (MCS) in the FTA. FMEA is able, of course, to produce all traditional FMEA outputs (e.g. Criticality Matrix) and has the built-in testability analysis capability.

On the other hand, the analyst has the option of bouncing to the FTA for calculation, sensitivity analysis, etc. (see Fig. 6) at every point of the process. The conditional probability (Beta) of the End Effect acquired from the FMECA can be evaluated by the Inhibit gate of the FTA.
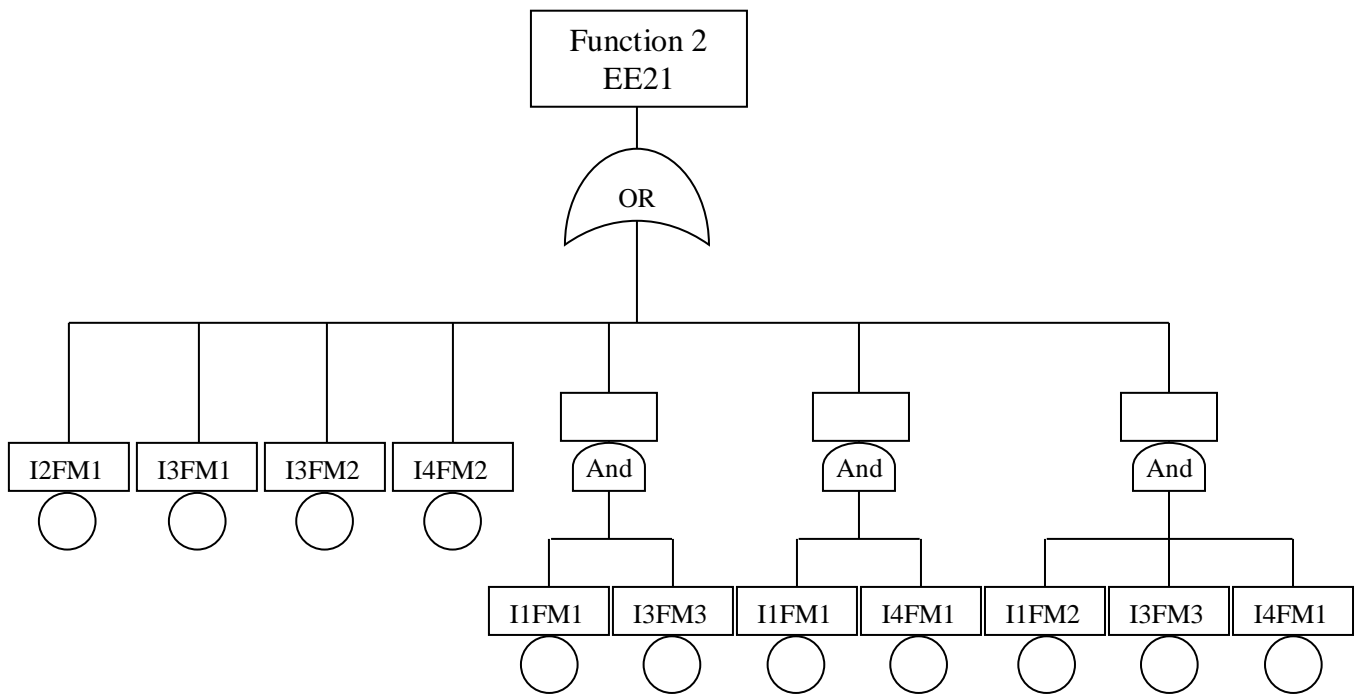
Fig. 6

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