

Deriving Failure Rates in a Hierarchy of FMEAs

Samer Abbas and John Joyce
 Ford Motor Company

ABSTRACT

When analyzing the failure rate (or occurrence) of a system failure cause, the typical approach is to obtain an occurrence rating from the results of testing. However, in many cases, the occurrence of a system failure cause can be derived from a combination of occurrences of failure causes of the element (sub-system) failure mode coinciding with the system failure cause being assessed. This paper explores a few approaches for deriving occurrences from element FMEAs over a majority of cases before settling on a probabilistic approach that converts occurrences to worst-case failure rates to achieve the most fine-tuned combined occurrence rating. Finally, a “complex analysis” worksheet, where the logical combination of occurrences and failure rates is custom defined by the engineer, is introduced for handling special cases.

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INTRODUCTION

Systems engineering has been taking a much more central role in the automotive industry as vehicle systems become more complex and interconnected. In order to practically tackle such complex systems, hierarchical abstraction is useful for analyzing and developing systems one “layer” at a time. The failure mode Effect Analysis (FMEA) of such a hierarchy of systems is in turn hierarchically abstracted so that the root failure cause(s) of a system failure mode may be buried several layers in the system-hierarchy along with the associated occurrence rating.

The goal of this paper is to present a method for deriving failure cause occurrence ratings from existing occurrence ratings in hierarchically lower level FMEAs. There are three fundamental cases to be addressed: This paper will

1. Define the assumptions and establish a link between FMEAs within a hierarchy of systems.
2. Explore methods for deriving failure rates from lower level FMEAs in the hierarchy.
3. Define a method for handling special case combinations of failure causes.

ASSUMPTIONS

Relationship between Failure Rate and Occurrence

In order to understand the methodology put forth in this paper, it is important to first establish the link between failure and the occurrence rating. Failure rate is defined by the Ford FMEA Handbook simply as incidents per item/vehicles [1] so it is a ratio that can describe the probability that a failure will occur.

Occurrence is a rating, on a scale of 1 to 10, which describes the likelihood that a specific failure cause will occur [1]. The occurrence rating, in essence, is a logarithmic representation of the failure rate. Table 1 outlines the mapping of failure rates to occurrence ratings.

Table 1. Occurrence Rating and Failure Rate

Failure rate (Failures per Thousand)	O
Failure eliminated through preventative measure	1
≤ 0.001 per thousand	2
0.01 per thousand	3
0.1 per thousand	4
0.5 per thousand	5
2 per thousand	6
10 per thousand	7
20 per thousand	8
50 per thousand	9
≥ 100 per thousand	10

Given this understanding of the relationship between occurrence and failure rate, it is more intuitive to approach mathematical operations involving occurrence by converting to failure rates and then back to occurrence at the end.

Link between Failure Mode and Failure Cause

In order to derive information from an FMEA at one layer for use in another, a link between failure modes on those layers is needed. This can be done by considering the relationship between failure modes and failure cause. A failure mode refers to a failure of the current system

of interest in an FMEA. The failure causes of that failure mode are simply failures of the element(s) (sub-system) of the system of interest. Put another way, a failure cause on a system-level FMEA is a failure mode at the element level and failure mode at system level is a failure cause at the super system level.

With this relationship established, a failure mode's causes can be traced down any number of system layers. This is the basis at which it becomes possible to take failure rates from the lower-level FMEAs and cascade them up to the higher levels.

DERIVING FAILURE RATES FROM LOWER-LEVEL FMEAS

The basis for approaching all three of the following cases is: The failure rates of any given system-level failure cause is some combination of the failure rates of the failure causes of the associated element-level failure mode (where element failure mode = system failure cause). In other words, a failure cause's failure rate is derived from its own failure causes' failure rates.

Vehicle (Supersystem)	Function	Failure Mode	Cause	O
	Decelerate vehicle	Vehicle fails to decelerate	No brake torque	4
Brake System (System)	Function	Failure Mode	Cause	
	Provide brake torque	No brake torque	No brake pressure	3
			No pedal travel	3
Brake Actuation (Element)	Function	Failure Mode	Cause	
	Control Brake Pressure	No brake pressure	Master cylinder damaged	2
			Brake line torn	2
		No pedal travel	Seized piston	3

Figure 2. Representation of Occurrence Relationship between Layers of a System Hierarchy. (Note that this image represents three FMEAs at three hierarchical layers.)

Method 1: Summing Failure Rates

The most common case found in an FMEA is the case where the failure causes of a given failure mode are independent of one another. That is to say that if one failure cause occurs, it has no effect on the potential for another failure cause to occur.

Considering failure rate in the context of probability makes this a simple probability problem. The failure rate of a failure cause can be considered as the probability that the failure cause will occur. For two independent events, the probability that at least one event will happen is [2]

$$P(A \cup B) = P(A) + P(B) - P(A \cap B) \\ = P(A) + P(B) - P(A)P(B) \quad (1)$$

Consider the example in Figure 2. The occurrence for the brake system-level failure cause "No brake pressure" is some combination of the occurrences attributed to the "No brake pressure" failure mode at the brake actuation level. If it is assumed that the master cylinder being damaged has no effect on the potential for the brake line to tear and vice versa then the probability of failure, or failure rate, of "No brake pressure" is simply the probability of "Master cylinder damaged" or "Brake line torn" occurring. Using Table 1, the maximum failure rate for each occurrence can be determined, combined probabilistically and then converted back to an occurrence as follows

$$\text{Combined Failure Rate, } R_C = \sum R_1, R_2 \dots R_N - \prod R_1, R_2 \dots R_N \quad (2)$$

$$\text{Max. Failure Rate("Master cylinder damaged")} = \frac{0.001}{\text{thousand}}$$

$$\text{Max. Failure Rate("Brake line torn")} = \frac{0.001}{\text{thousand}}$$

Combined Failure Rate

$$= \frac{0.001 + 0.001}{\text{thousand}} - \frac{0.001}{\text{thousand}} * \frac{0.001}{\text{thousand}} \approx \frac{0.002}{\text{thousand}}$$

$$\text{Combined Occurrence} = \text{Occurrence} \left(\frac{0.002}{\text{thousand}} \right) = 3$$

Since any occurrence rating under 10 requires a failure rate of less than 10% and the occurrences are separated by failure rates on the order of 2-10x, the $P(A \cap B)$ part of the probability equation can be ignored for a simpler estimated sum of failure rates:

$$\text{Combined Failure Rate, } R_C = \sum R_1, R_2 \dots R_N \quad (3)$$

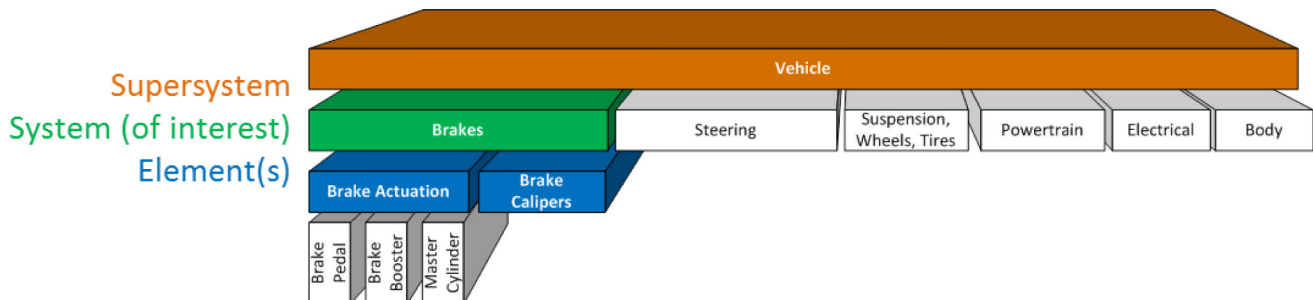


Figure 1. Example Illustration of a Hierarchy of Systems