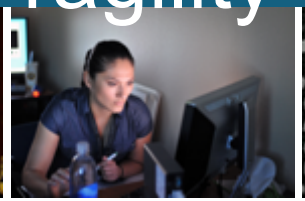
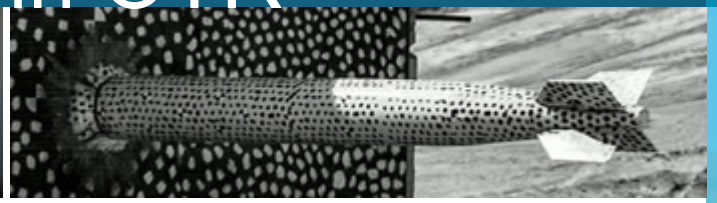
SAND2020-11386C

Sandia National Laboratories

Statistical Hazard Analysis and Implementation of Performance-Based Engineering via Structural Fragility in OTR





October 2020

David “Joey” Flores

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The UMTRI Database

Sample of UMTRI database format shown to the right

- Output for Single Vehicle (SV) and for Multivehicle (MV)

CompositeNo_4	Yr	CollisionID	Pcv	qryOST_PCV	SNL_ID_TIFA	MOST HAF	MHE_Desc	CaseWeight
93-6-3224-1	93	39	-2	0	Bottom	1	Overturn	1.688888889
94-12-1351-1	94	75	-2	0	Bottom	1	Overturn	4.59375
96-6-944-1	96	176	-2	0	Bottom	8	Pedestrian	10.34782609
96-6-1668-1	96	177	-2	0	Bottom	8	Pedestrian	10.34782609
96-12-1923-1	96	184	-2	0	Bottom	8	Pedestrian	10.34782609
96-6-2102-1	96	299	-2	0	Bottom	5	Fell from vehicle	2.666666667
97-39-425-1	97	256	-2	0	Bottom	1	Overturn	2.234567901
97-42-830-1	97	298	-9	0	Bottom	2	Fire/explosion	1.894736842
97-6-727-1	97	310	-2	0	Bottom	5	Fell from vehicle	3.5
98-6-2731-1	98	75	-1	0	Bottom	2	Fire/explosion	1.5
98-8-208-1	98	86	-2	0	Bottom	8	Pedestrian	9.52
98-29-30-1	98	167	-2	0	Bottom	8	Pedestrian	9.52
99-1-118-1	99	4	-1	0	Bottom	43	Other fixed object	1.913793103
99-1-867-1	99	21	-1	0	Bottom	2	Fire/explosion	2
99-6-1927-1	99	395	-1	0	Bottom	9	Pedalcycle	10.33333333

Each accident gives data on:

- PCV (shown right)
- Weight of Vehicles involved
- Orientation of Crash

$$PCV = \frac{V_r}{1 + \frac{M}{m}}$$

The Frequency of Occurrence Equation

$$\frac{F(OST\ PCV > EBA\ PCV)}{yr} = \frac{\frac{OST\ Mile}{yr}}{\frac{Commercial\ Mile}{yr}} * TCF * \left(\frac{OSTMF * (\#SV\ cases > PCV) * SF + (\#MV\ cases > PCV) * SF}{\#\ years\ of\ data}\right)$$

The Equation

The frequency (number of times per year) that OST would see an accident that exceeds some Threshold (EBA) PCV

Corrects for decrease in accident frequency from the 1990's to now

$$\frac{F(OST\ PCV > EBA\ PCV)}{yr} = \frac{\frac{OST\ Mile}{yr}}{\frac{Commercial\ Mile}{yr}} * TCF * \left(\frac{OSTMF * (\#SV\ cases > PCV) * SF + (\#MV\ cases > PCV) * SF}{\#\ years\ of\ data}\right)$$

OST Mileage Factor

When <u>OSTMF = 1</u>, this term calculates the frequency (number of times per year) that commercial industry would see an accident that exceeds some threshold (EBA) PCV

OST Mitigation Factor

$$\frac{F(OST\ PCV > EBA\ PCV)}{yr} = \frac{\frac{OST\ Mile}{yr}}{\frac{Commercial\ Mile}{yr}} * TCF * \left(\frac{OSTMF * (\#SV\ cases > PCV) * SF + (\#MV\ cases > PCV) * SF}{\#\ years\ of\ data} \right)$$

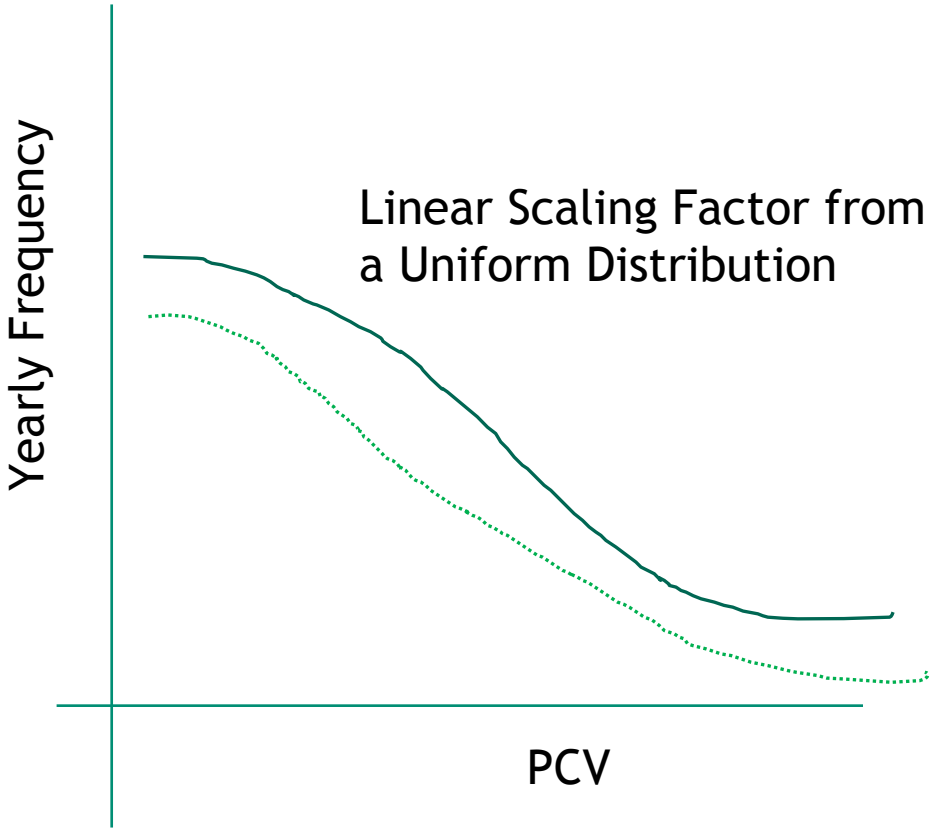
OST Mitigation Factor gives credit to OST ConOps and procedures that assist in preventing accidents

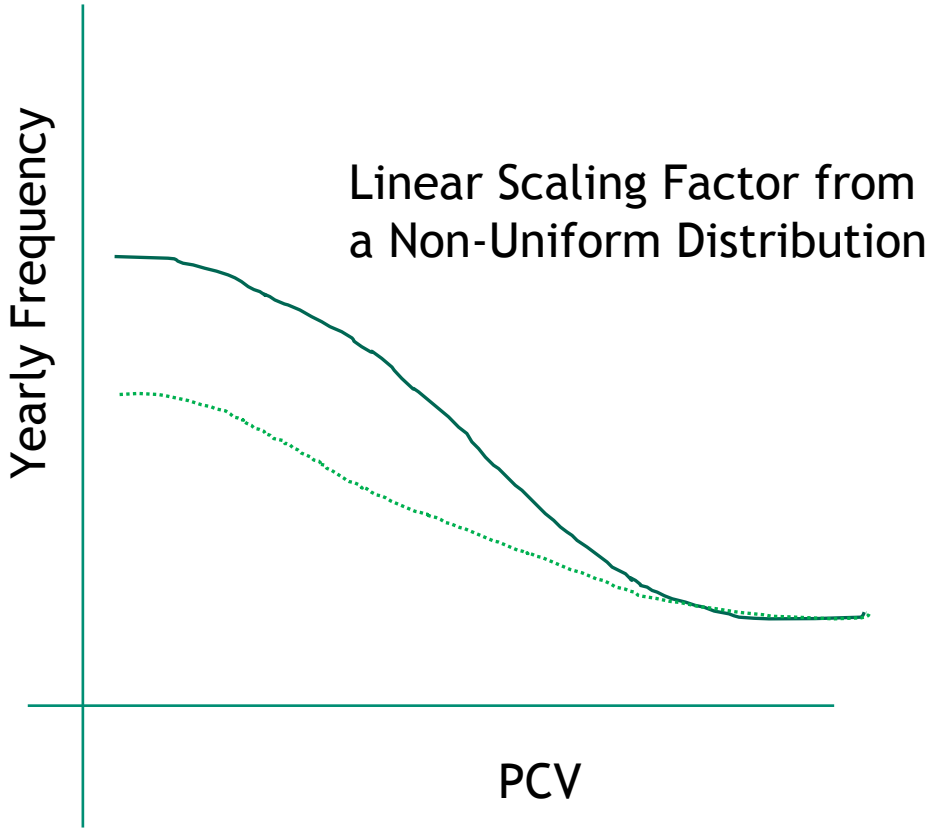
- Human Factors study gives counts of accidents by cause
  - Take a ratio of unmitigated accidents over total single vehicle accidents to obtain ratio
- When the factor = 0, represents total mitigation of single vehicle (SV) accidents
  - Taken as “best case bound”
- When the factor = 1, represents “OST is no better/worse than the commercial trucking industry in the 1990’s”

Precedence: 1975 report attempted a similar method

- Much less conservative results

Assumption: Issue With Assuming Uniform Distribution for OST Mitigation Factor





Conservatism

Side Impact: Cases where the only the tractor's side was struck are included, and only the tractor's weight are considered. For cases where the trailer was struck, only the trailer's mass is considered.

+3 mph added to the impactor vehicle's relative velocity to account for the speed limit change

Only an 11.7% Time Correction Factor reduction taken

- From the mid-1990s (1992-1999) to 2017, the frequency (per 100 million miles) of fatal crashes has been reduced:
  - involving combination trucks by 43%.
  - involving large trucks by 41%.
  - involving passenger vehicles by 31%.
- From 1997-2017, the frequency (per 100 million miles) of injury crashes has been reduced:
  - involving combination trucks by 24%.
  - involving large trucks by 28%.
  - involving passenger vehicles 33%.

Reasonable and realistic credit given to single-vehicle accident mitigation

- No credit is taken for multivehicle accidents (conservative because defensive drivers could mitigate an accident caused by another driver).

Thermal

Similar approach is used for thermal

Database contains distributions for the main fire characteristics

- Size
- Duration
- Temperature
- Distance from the vehicle of interest

$$\frac{F(OST\ fire > EBA)}{yr} = \frac{\frac{OST\ Mile}{yr}}{\frac{Commercial\ Mile}{yr}} * P(d = 0\ ft) * P(A > A_{EBA}) * P(t > t_{EBA}) * \frac{(\#\ fire\ cases) * SW}{\#\ years\ of\ data}$$

Application to Mod-Sim

Once a severity has been established, a means of evaluating it must be implemented.

Modern-day modelling capabilities are useful for this

- Some testing for model validation
- Full-up system model can be used to evaluate high-level hazards
  - Does cargo get released? If so, are there electrical hazards nearby?
- Also useful for implementing Performance-Based Engineering

Performance-Based Engineering

Performance-Based Engineering
- How reliably and predictably a system responds to a input, per some performance metric
  - Performance Metric for Weapons: “Don’t go boom.”

Earthquake engineers use “performance-based engineering” procedures to design structures with predictable and defined seismic performance
- Structural Fragility
  - The sensitivity of the structure to variation in production to a severity input

Important to know the severity at which a well-defined system reliably and predictably fails
- More important for systems with high-level consequences

Performance-Based Engineering in the Nuclear Industry

Not a new or a novel approach, but has never been used in OTR

Well known approach in industry

- Simple: bolt failure
- Complex: Nuclear Power Plant Failure

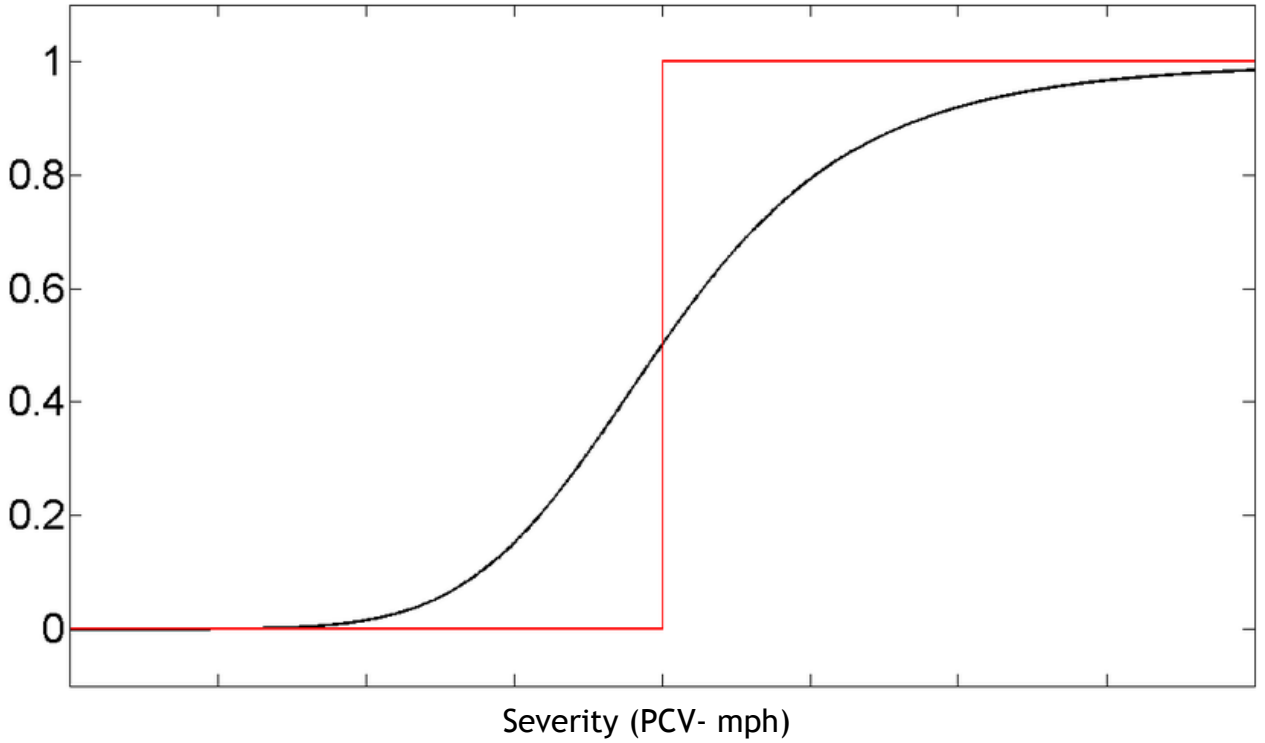
Fragility Curve

Perfectly defined system has 0 uncertainty in failure point

- Step function at failure severity

A real system has variability

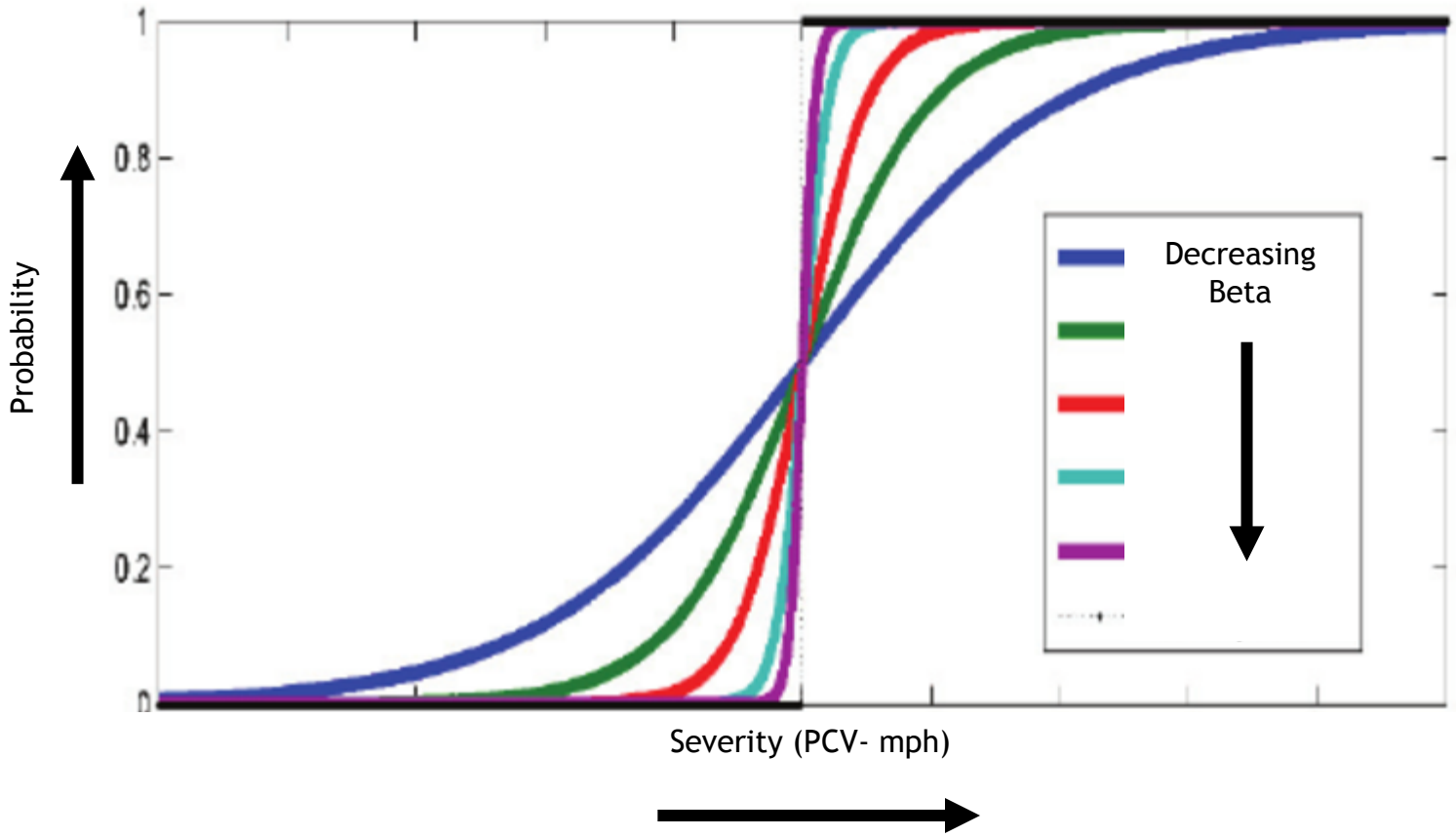
- Dimensional and Material Tolerances
- Variability of input (where and how the accident occurs).
- Takes on a “Beta Distribution”



Fragility Curve

Process is iterative

- Better defined models results in lower beta
- Can be used to help influence design to improve (reduce) systen response uncertainty



Developing a Fragility Curve

Pick a hazard severity (e.g., 65 mph head on)

Create a matrix of potential combinations of parameter variations

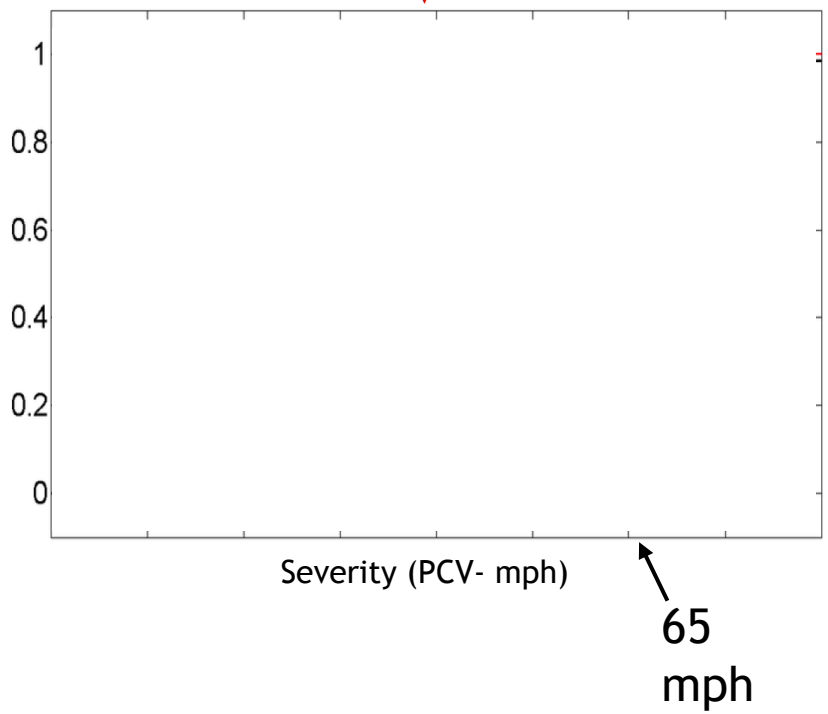
- Includes variability on material strengths or dimensional tolerances
- Using sampling (e.g., LHS) to pick 10 of those possible parameter combinations

Run the system model and receive 10 outputs for insult to skin of the weapon

Physics labs provides weapon response for those 10 outputs

- For now, assume it is as simple as Pass/Fail
- Assume 9/10 fail = 90% failure

Repeat for 35 mph and 50 mph, resulting in 10% and 50% failure, respectively



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$$\mathrm{M} = \begin{bmatrix} a_0 & \cdots & a_{N_1} & 0 & \cdots & 0 \\ c_1 & a_0 & \cdots & a_{N_1} & 0 & \cdots \\ \vdots & \ddots & \ddots & & \ddots & \ddots \\ c_{N_2} & \cdots & c_1 & a_0 & \cdots a_{N_1} & \cdots 0 \\ 0 & & \ddots & \ddots & & \vdots \\ \vdots & & c_{N_2} & & c_1 & a_0 & a_{N_1} \\ \vdots & & & \ddots & & \ddots & \vdots \\ 0 & \cdots & & 0 & c_{N_2} & \cdots & c_1 & a_0 \end{bmatrix}.$$

Min Strength of struts
Max strength of …
Min tolerance for …
Etc…

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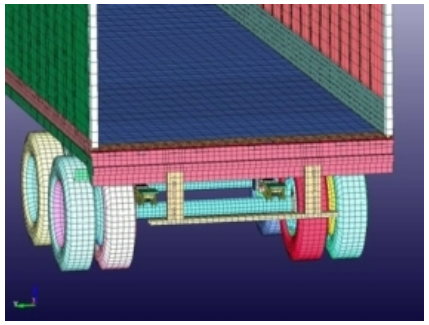
10 Model Runs



10 Sets of Outputs

WR parameter #1
WR parameter #2
…

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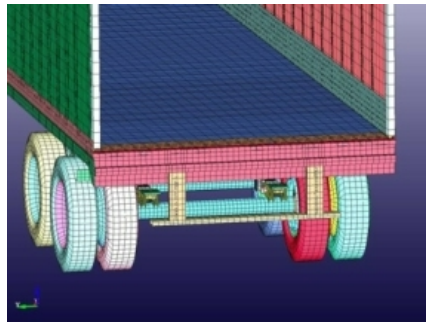

10 Sets of Outputs

WR parameter #1
WR parameter #2
…

10 Sets of Weapon Response

WR #1: Pass
WR #2: Pass
…

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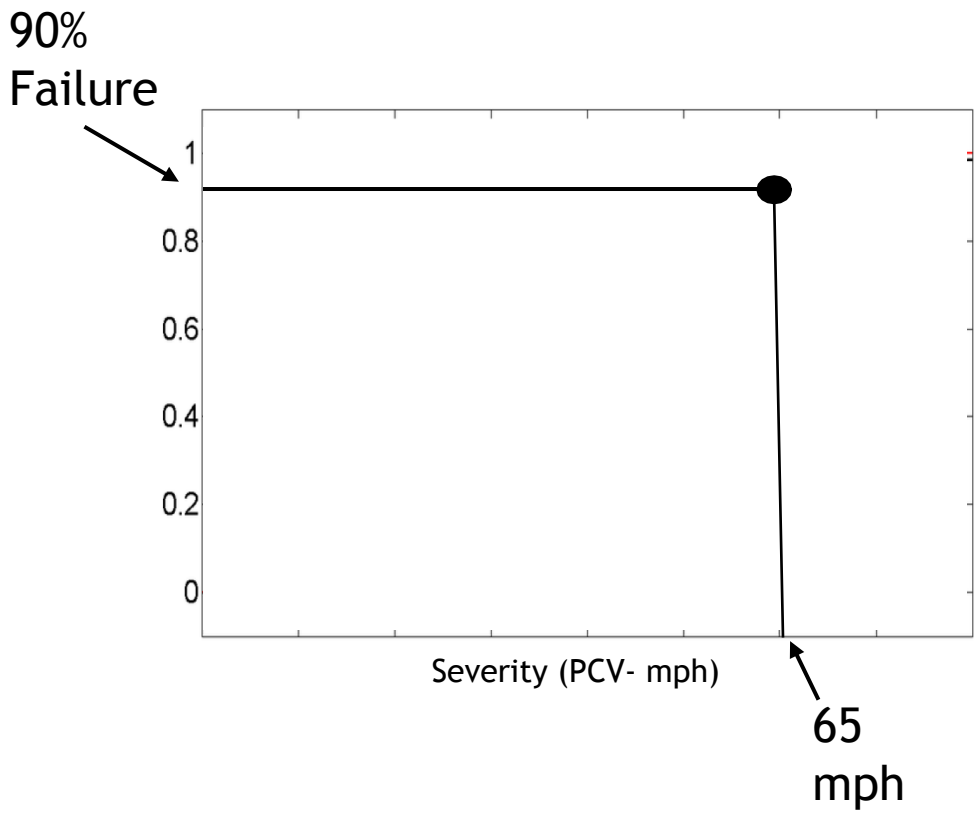

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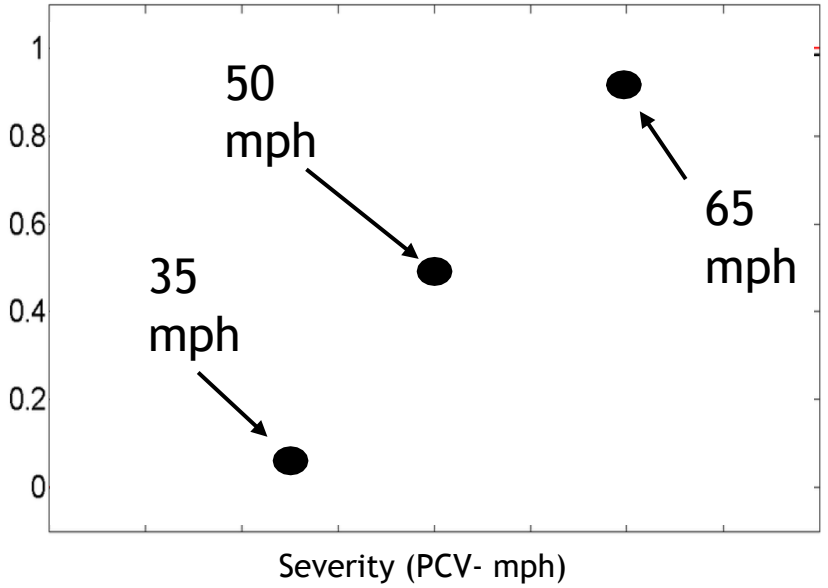

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