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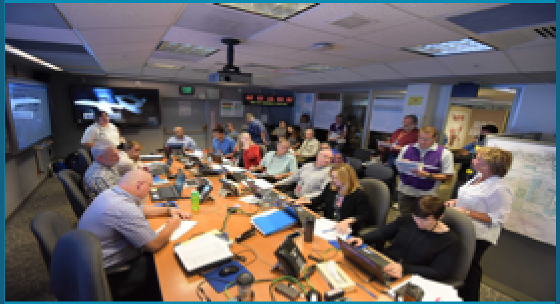
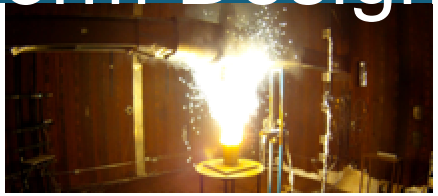
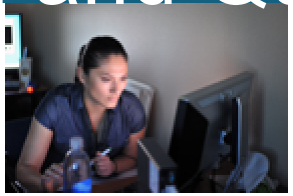
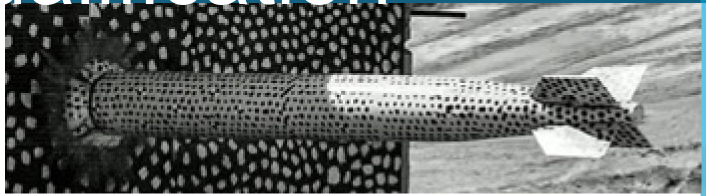
Sandia National Laboratories

Determining Hazard Severity via Probabilistic Risk Assessment in the Commercial Trucking Industry to Inform Design and Qualification









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David “Joey” Flores

U.S. DEPARTMENT OF ENERGY NNSA

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Why is this work relevant?

Support my customer

- The Office of Secure Transportation
- The mission: The safe and secure transport of high-security assets
- Excellent driving record: Well over a hundred million miles travelled on the road without an accident of significance
  - But if it did, what would likely happen? How would the system perform?

Utilizing a Statistical Approach

The “Needs”

1. Need statistical thresholds for credible frequency of event occurrence and for system response to bound a “good enough” space within system performance needs
   - DOE Standards provide both for my work
2. Need a severity metric for each hazard within that space
   - Crash: Peak Contact Velocity (PCV)
   - Fire: Size, location, and duration
3. Need data for evaluating event frequency
   - UMTRI Database
4. Need a formula to use that data
5. Need a method for evaluating the performance
   - Modsim and performance-based engineering

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

The UMTRI Database

Sample of UMTRI database format shown to the right

- All fatal tractor-trailer accidents from 1992-1999 (~22,800 accidents)
- Output for Single Vehicle (SV) and for Multivehicle (MV)
- Weight, Orientation, Fire Occurrence, Relative Velocity at Impact, etc…

CompositeNo_4	Yr	CollisionID	Pcv	qryOST_PCV	SNL_ID_TIFA	MOST HAI	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

Developing Formulas to Determine Frequency of Occurrence

Frequency vs. Probability

- Frequency expresses the amount of occurrences of an event over some time interval
  - e.g., "I put gas in the car once a week."
- Probability expresses the possibility of an event occurring
  - Must be a value between 0 (impossible) and 1 (certain), unit-less.
  - Probability can be used to augment frequency
    - e.g., "Since I am telecommuting half of the time, I have reduced my frequency of trips to the gas station by 50% (once every 2 weeks)."

$$F(event) = \frac{\#\ event}{interval}$$

$$P(event) = \frac{\#\ event}{\#\ possible\ outcomes}$$

When using raw numbers in a database, frequency of an event can be determined two ways:

1. Counting the number of times an event happened over a time period, divided by the time period

2. Use the data to construct a distribution, then use the distribution to create a probabilistic factor that can be multiplied against the base accident frequency

$$F(rollover) = \frac{\#\ rollovers}{\#\ years\ in\ database}$$

$$F(rollover) = P(rollover) * F(accident)$$

$$= \frac{\#\ rollovers}{\#\ accidents\ in\ database} * \frac{\#\ accidents\ in\ database}{\#\ years\ in\ database}$$

$$= \frac{\#\ rollovers}{\#\ years\ in\ database}$$

The Crash Equation

The frequency (number of times per year) that OST would see an accident that exceeds some threshold PCV for an Evaluation Basis Accident (EBA)

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

The Crash Equation

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

When OSTMF = 1, this term calculates the frequency (number of times per year) that 1990's commercial industry would see an accident that exceeds some threshold (EBA) PCV

The Crash Equation

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

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"

The Crash Equation

Time Corrective Factor: Conservatively reflects the decrease in accident frequency from the 1990’s to now

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

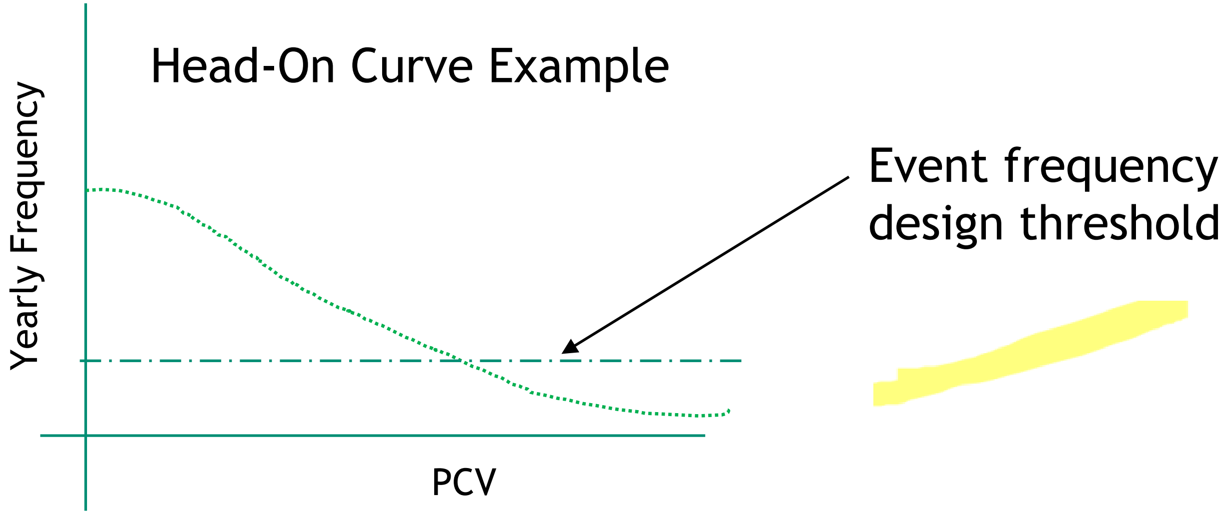
The Crash Equation

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

OST Mileage Factor

The Crash 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 Fire Equation

Database contains distributions for the main fire characteristics

- Size (d)
- Duration (t)
- Temperature
- Distance from the vehicle of interest (s)

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

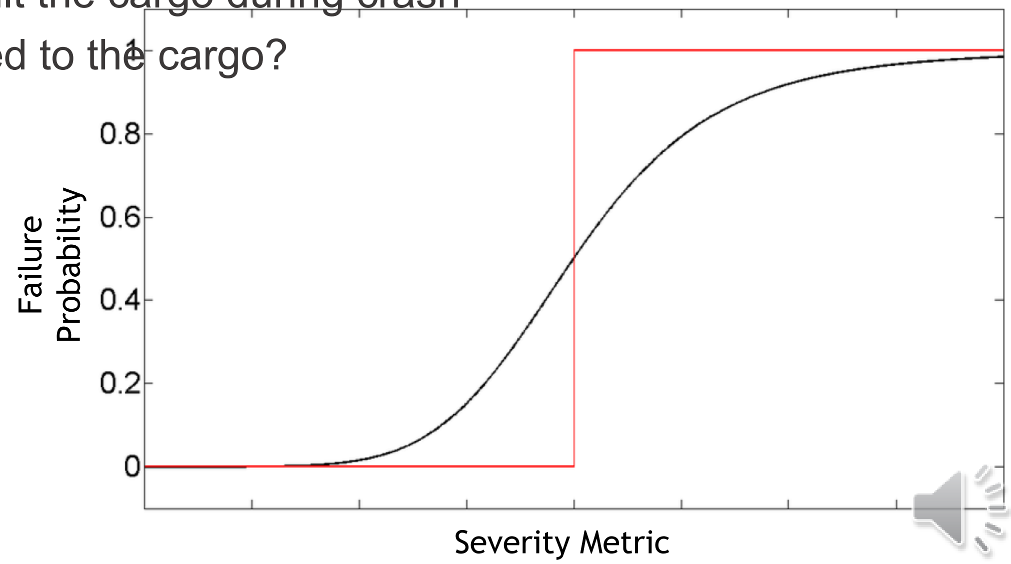
Recall, the database also tells us what the other vehicle involved was…

$$\frac{F(OST\ fire > EBA)}{yr} = \frac{\frac{OST\ Mile}{yr}}{\frac{Commercial\ Mile}{yr}} * \frac{1}{N_{yr}} \sum_{v \in V} \left(P(s = 0|v) * P(d > d_{EBA}|v) * P(t > t_{EBA}|v\ AND\ d) \sum_{i=1}^{N_v} n_{v,i} w_{v,i} \right)$$

Application to ModSim

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

- Modern-day modelling capabilities are useful for this
  - Bound infinite space of a chaotic accident environments to provide better information on trailer behaviors in an accident.
  - Allows for a true “system of systems” integration approach with the trailer, restraints, and cargo models
    - Full-up system model can be used to evaluate high-level hazards to the cargo
      - e.g., Electrical hazards nearby?
      - e.g., What are the states of the container and the trailer?
    - Can also evaluate discrete quantities of interest that directly insult the cargo during crash
      - e.g., What was the acceleration of the cargo or energy imparted to the cargo?
- Some testing to anchor the model



Software: SIERRA

- SM: Mechanical
- Fuego and Aria: Thermal
- SD: Normal Environments