Effects of Event and Vehicle Variability on Durability Loads

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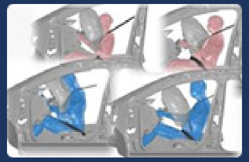
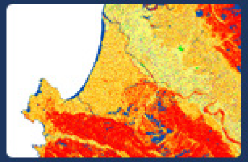
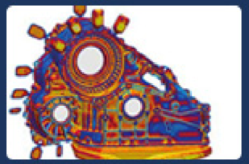
UQ – V&V – RBDO



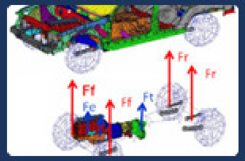
CRASH & SAFETY



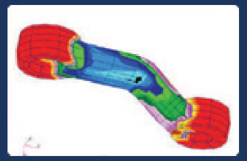
MOBILITY MAPPING



CASTING



NOISE & VIBRATION



DURABILITY & FATIGUE

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Content

- Project Goals
- Input Variability
- Variable Screening
- Uncertainty Quantification
- Model Validation
- Conclusions
- Future Work

Project Goals

- Study effect of event & vehicle variability on durability loads.

Event Variability

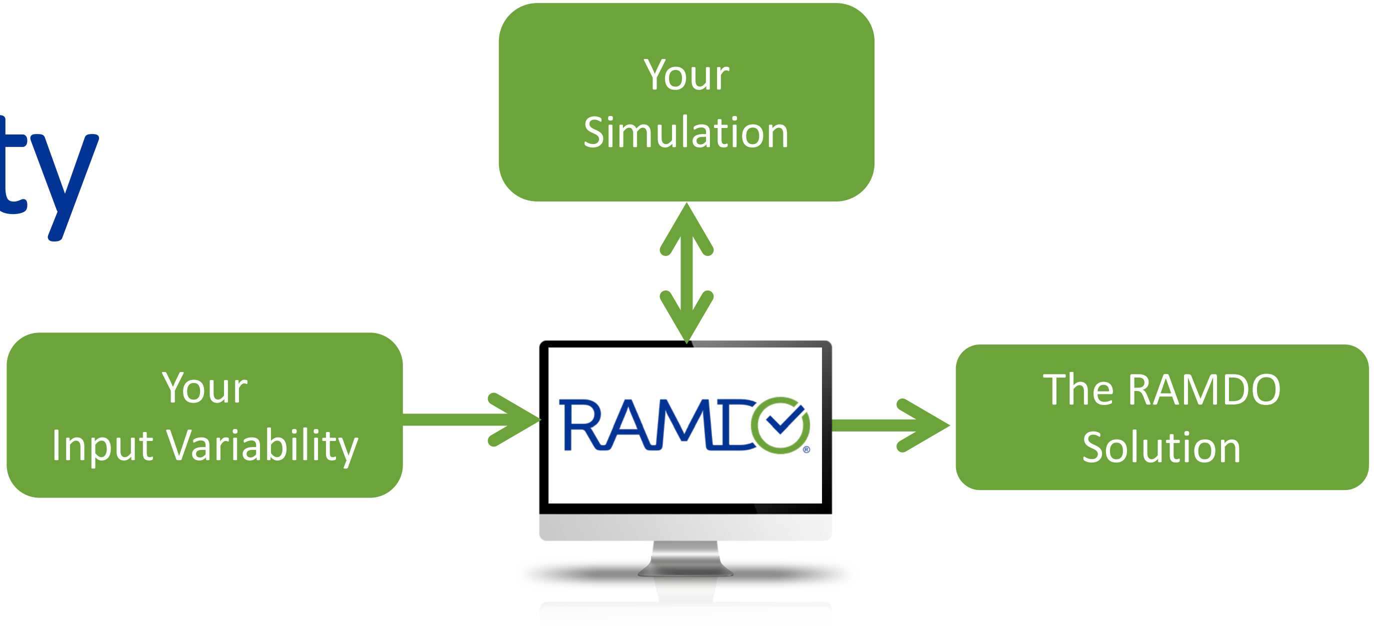
- Tire pressure
- Speed

Vehicle Variability

- Bushing stiffness & damping
- Sprung & Un-sprung Mass
- Torsional Stiffness of Stabilizer Bar
- Stiffness of Vehicle Springs

- Compare simulation-based durability loads to physical proving ground measured loads – using statistical V&V method.
  - Pseudo-Damage
  - Load Range

Identifying Input Variability



Identifying Input Variability

- Identified all variables of interest that may have potential impact on durability loads.
- 320 variables were identified.
- Identifying variability of the variables:
  - When possible, used manufacturing and supplier specifications, e.g., tolerances and confidence of tolerance.
  - Used best engineering knowledge, experience, and judgement to determine a reasonable percentage variation and confidence when specs were not available.
  - Assumed normal distribution used for all variables.

320 Input Variables

Description	Variation Type	Variation	Number of Variables
Critical Hardpoints	Fixed Amount	±10 mm @ 99% confidence	4
Minor Hardpoints	Fixed Amount	±3 mm @ 99% confidence	36
Body Mass	Fixed Amount	±100 kg @ 99% confidence	1
Suspension Part Mass	Percentage	±15% @ 99% confidence	8
Wheel Part Mass	Percentage	±15% @ 99% confidence	4
Spindle Part Mass	Percentage	±15% @ 99% confidence	4
Moment of Inertia	Percentage	±10% @ 90% confidence	43
Jounce Bumper Gap	Fixed Amount	±5 mm @ 99% confidence	4
Rebound Bumper Gap	Fixed Amount	±5 mm @ 99% confidence	4
Body CG	Fixed Amount	±50 mm @ 99% confidence	1
Suspension Part CG	Fixed Amount	±3 mm @ 99% confidence	8
Snubber Gap	Fixed Amount	±3 mm @ 99% confidence	4
Snubber Stiffness	Percentage	±15% @ 99% confidence	2
Snubber Damping	Percentage	±20% @ 99% confidence	2

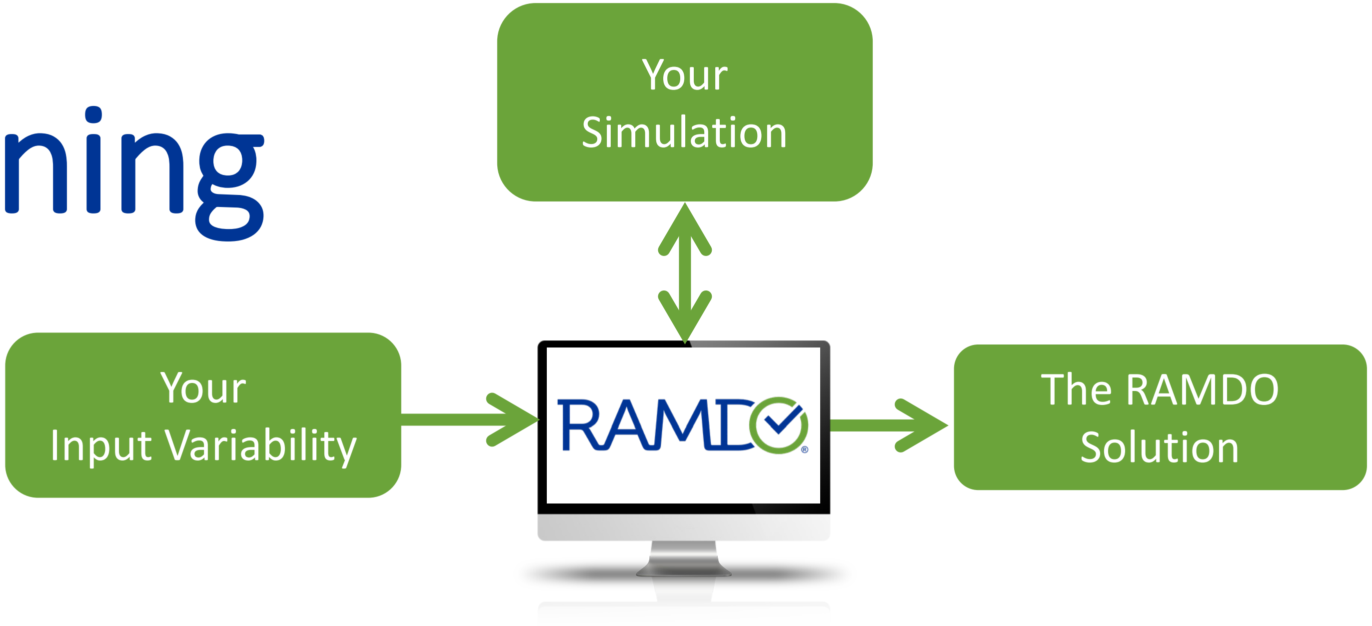
320 Input Variables

Description	Variation Type	Variation	Number of Variables
Spring Rate	Percentage	±3% @ 99% confidence	4
Damper Rate	Percentage	±15% @ 99% confidence	4
Stabar Rate	Percentage	±10% @ 99% confidence	2
Jounce Rebound Stiffness	Percentage	±15% @ 99% confidence	8
Primary Bushing Stiffness	Percentage	±15% @ 99% confidence	20
Secondary Bushing Stiffness	Percentage	±30% @ 99% confidence	60
Primary Bushing Damping	Percentage	±20% @ 99% confidence	20
Secondary Bushing Damping	Percentage	±30% @ 99% confidence	60
Rear Suspension Primary Bushing Stiffness	Percentage	±15% @ 99% confidence	4
Rear Suspension Secondary Bushing Stiffness	Percentage	±30% @ 99% confidence	4
Rear Suspension Primary Bushing Damping	Percentage	±20% @ 99% confidence	4
Rear Suspension Secondary Bushing Damping	Percentage	±30% @ 99% confidence	4
Speed	Fixed Amount	±2 mph @ 99% confidence	1

Output Variables

- Pseudo-Damage
- Load Range
- Started with 98 total outputs (49 Pseudo-Damage & 49 Load Range)
- Reduced the number of outputs to 36 (18/18 Pseudo-Damage/Load Range)
  - Responses that have measured proving ground data were selected.
  - Responses of highest interest selected.

Variable Screening



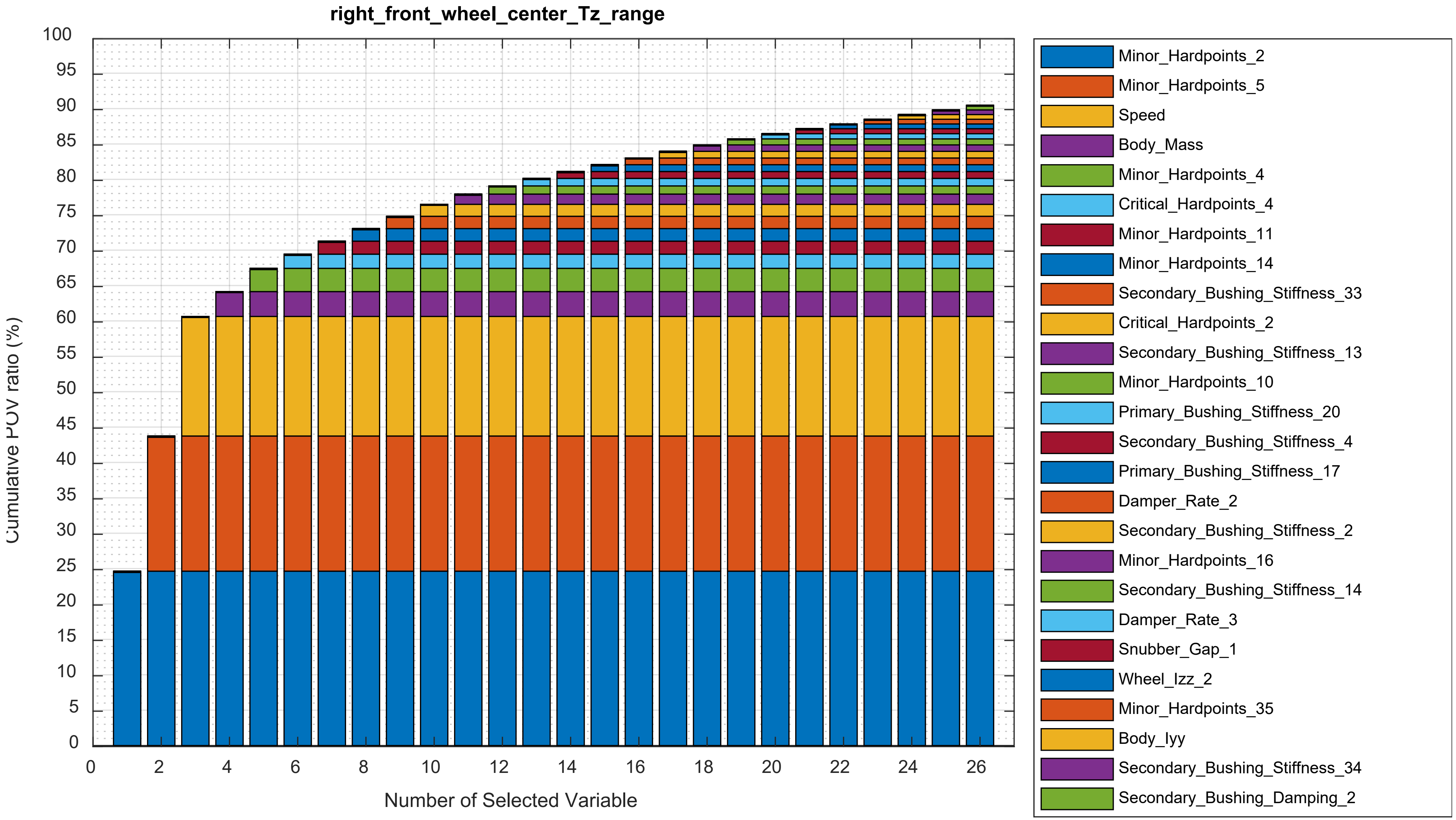
Variable Screening

- Obtaining accurate uncertainty quantification (UQ) results is extremely difficult to obtain with 320 variables.
- Need to reduce problem to a manageable number of variables that can be used to obtain accurate UQ results.
- Used RAMDO’s Variable Screening method to determine which variables contribute the most to the variability in the pseudo-damage and load range.
  - Required running 641 DOE.

Variable Screening

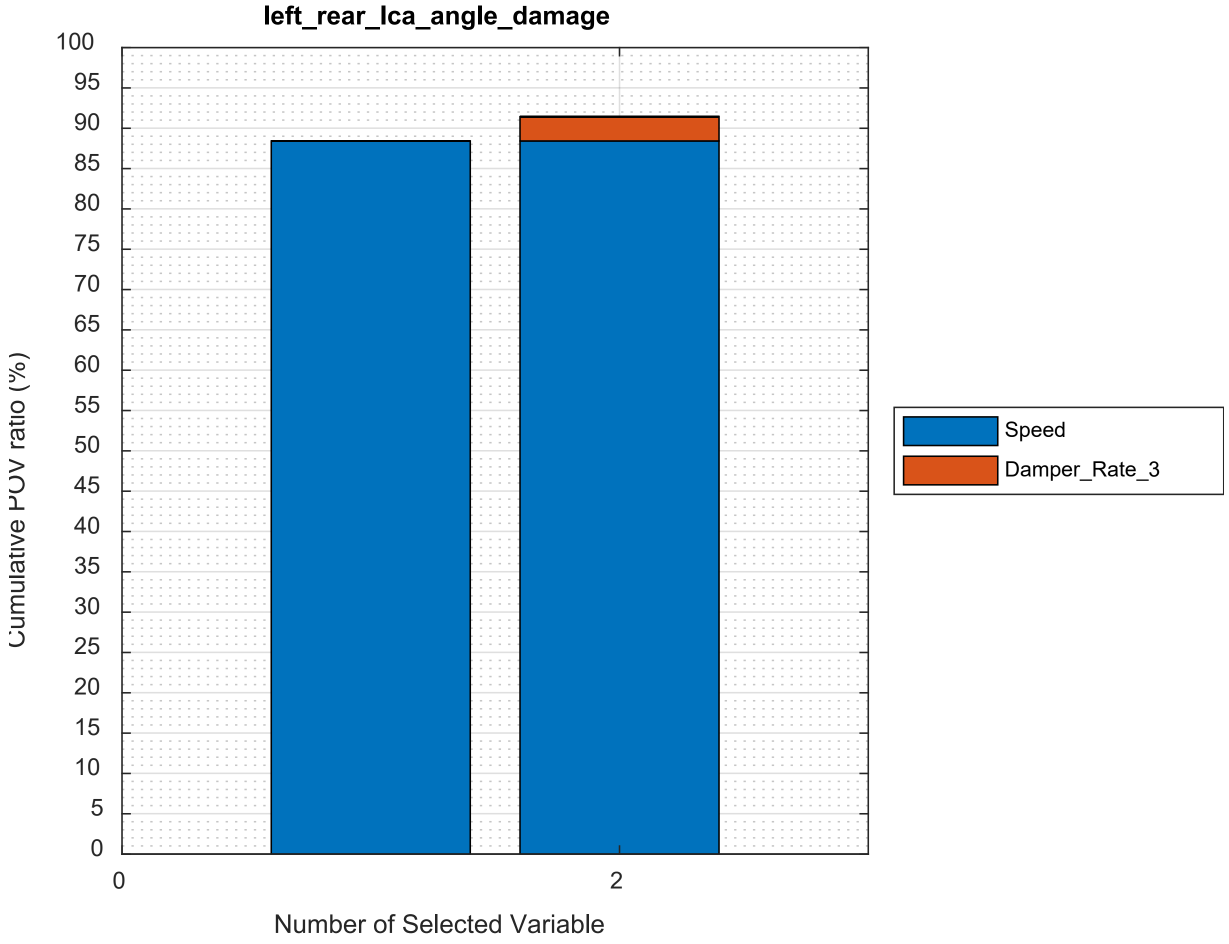
- Using all 98 outputs – it was found that 81/320 variables cover approximately 90% of the total output variability for all 98 responses.
- 81 variables is still a large number of variables when doing UQ.
- Looking at each of the individual joint loads:
  - Number of important variables for a given joint load ranged from: 2–26 variables
  - It was found that for a given joint, the important variables for pseudo-damage and load range were very similar.

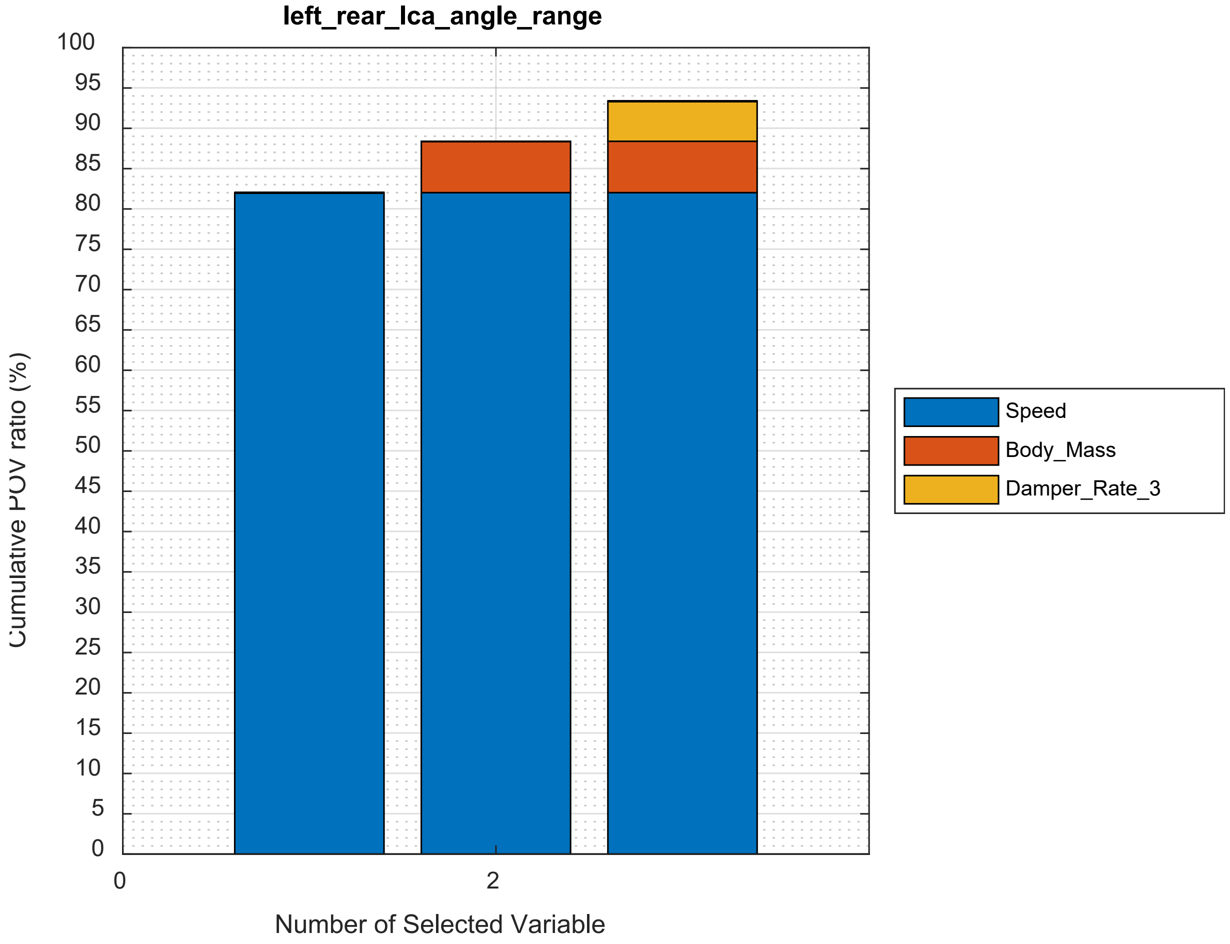
Variable Screening



8 variables required to cover 73% POV.

Variable Screening



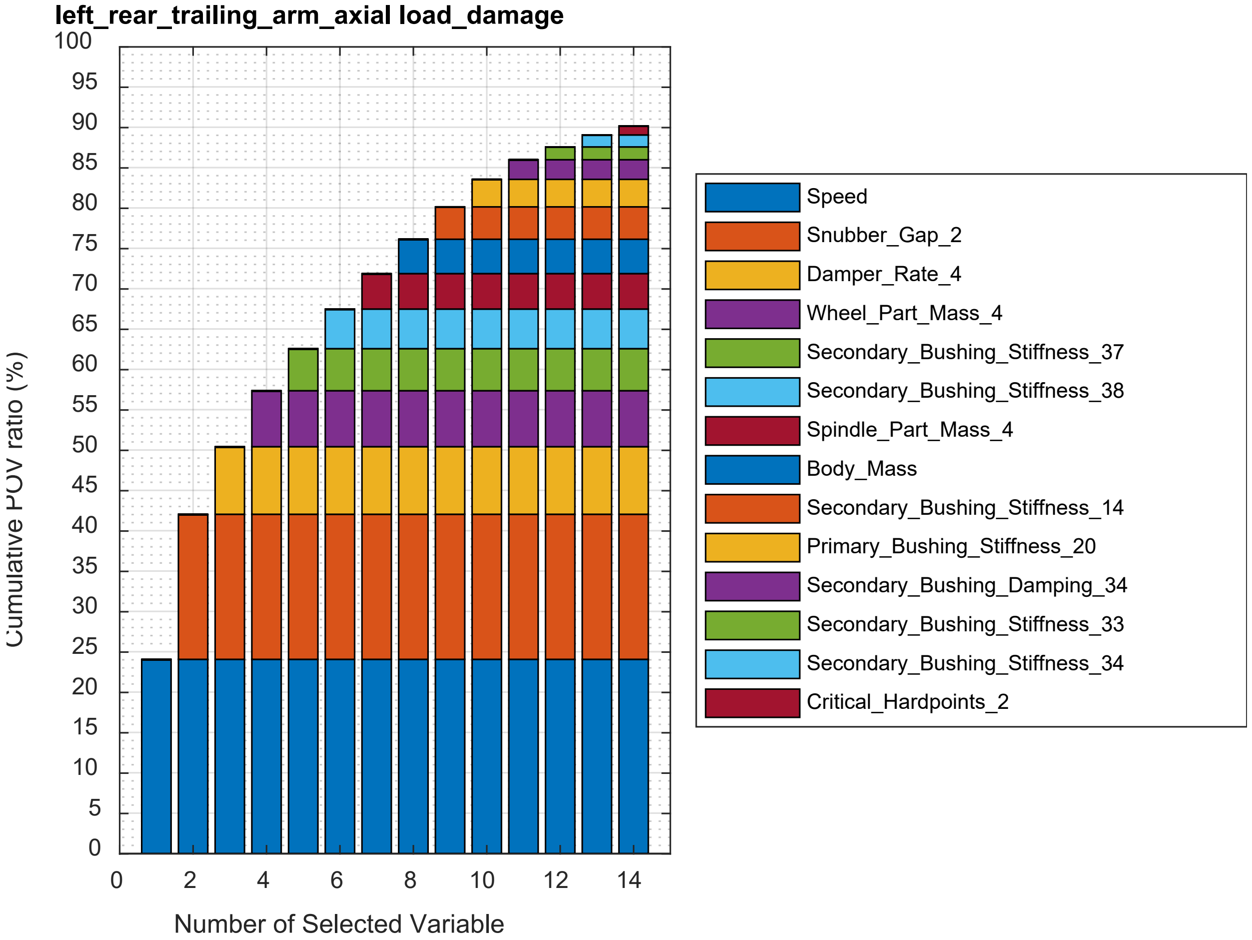


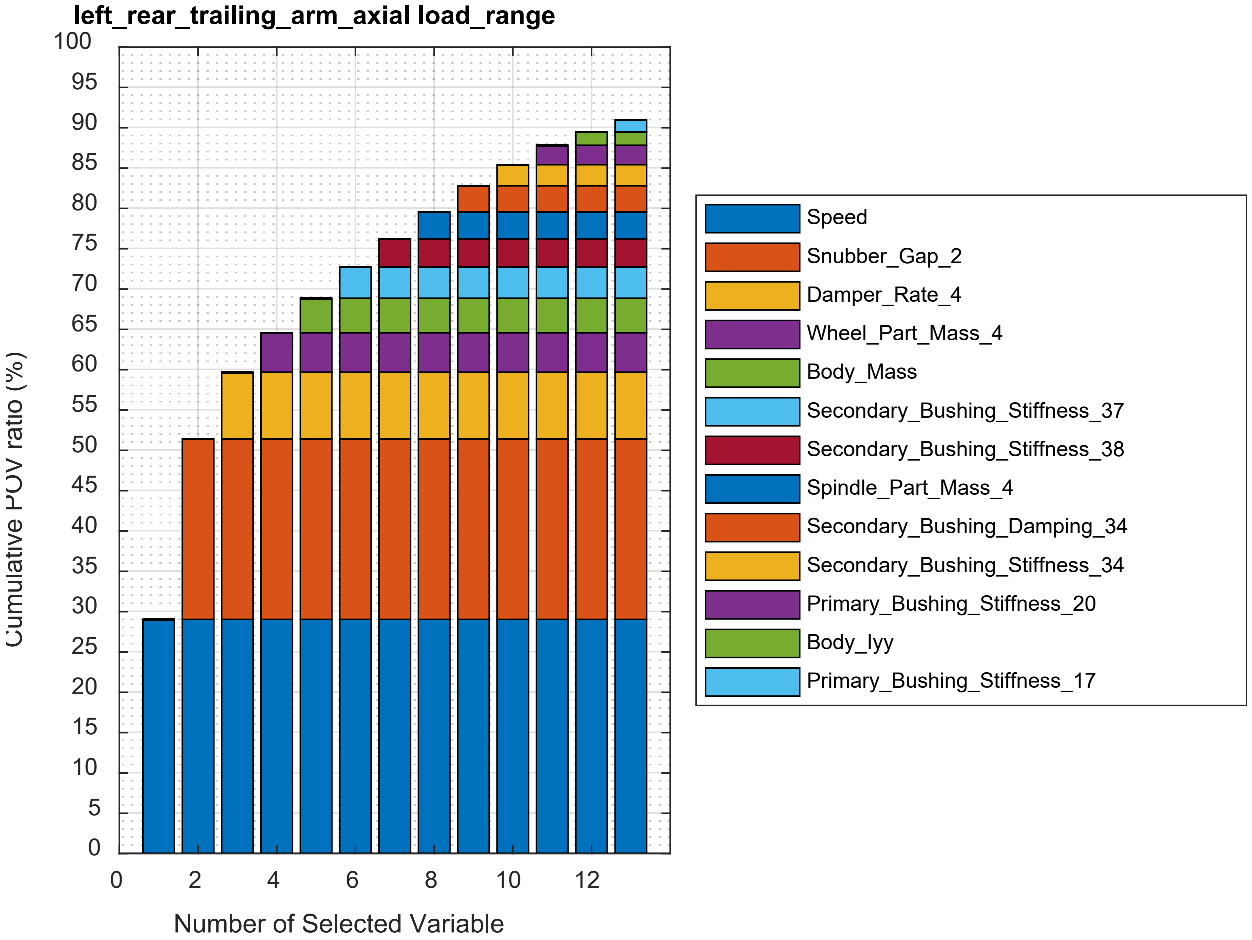
Only 2 variables required to cover 90% POV.

Only 3 variables required to cover 90% POV.

2 common variables for pseudo-damage and load range.

Variable Screening

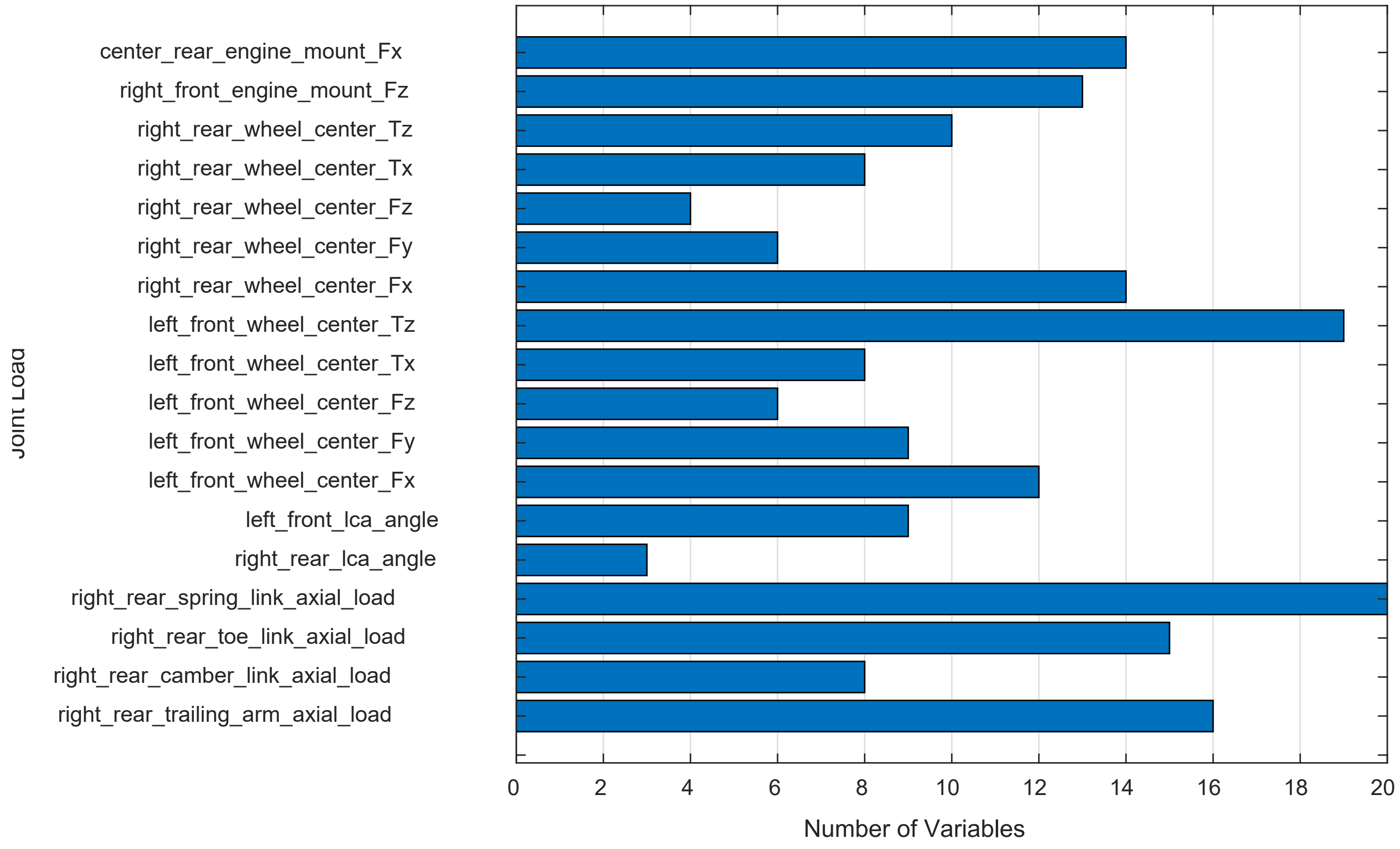




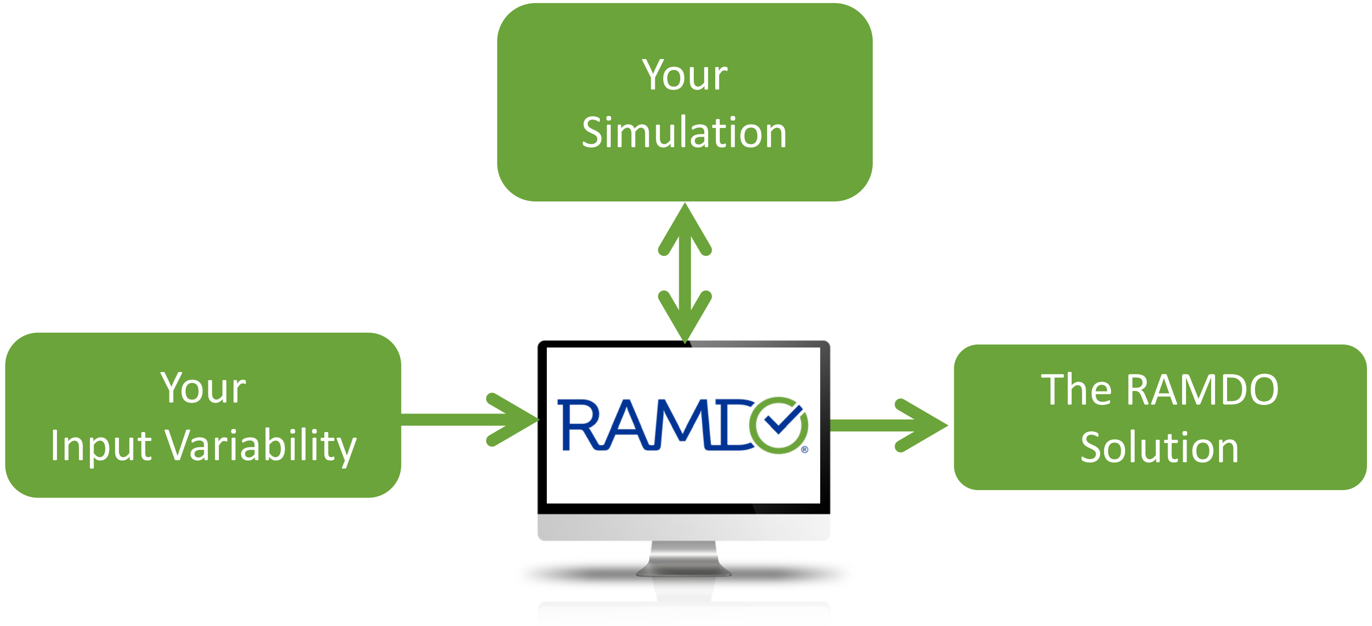
16 unique variables to cover 90% POV for both pseudo-damage and load range.

Variable Screening Results

- Decided to reduce the total number of outputs from 98 (49/49) to 36 (18/18).
- Decided that the important variables for pseudo-damage and load range for each of the 18 joint loads would be combined → 18 UQ problems to solve.



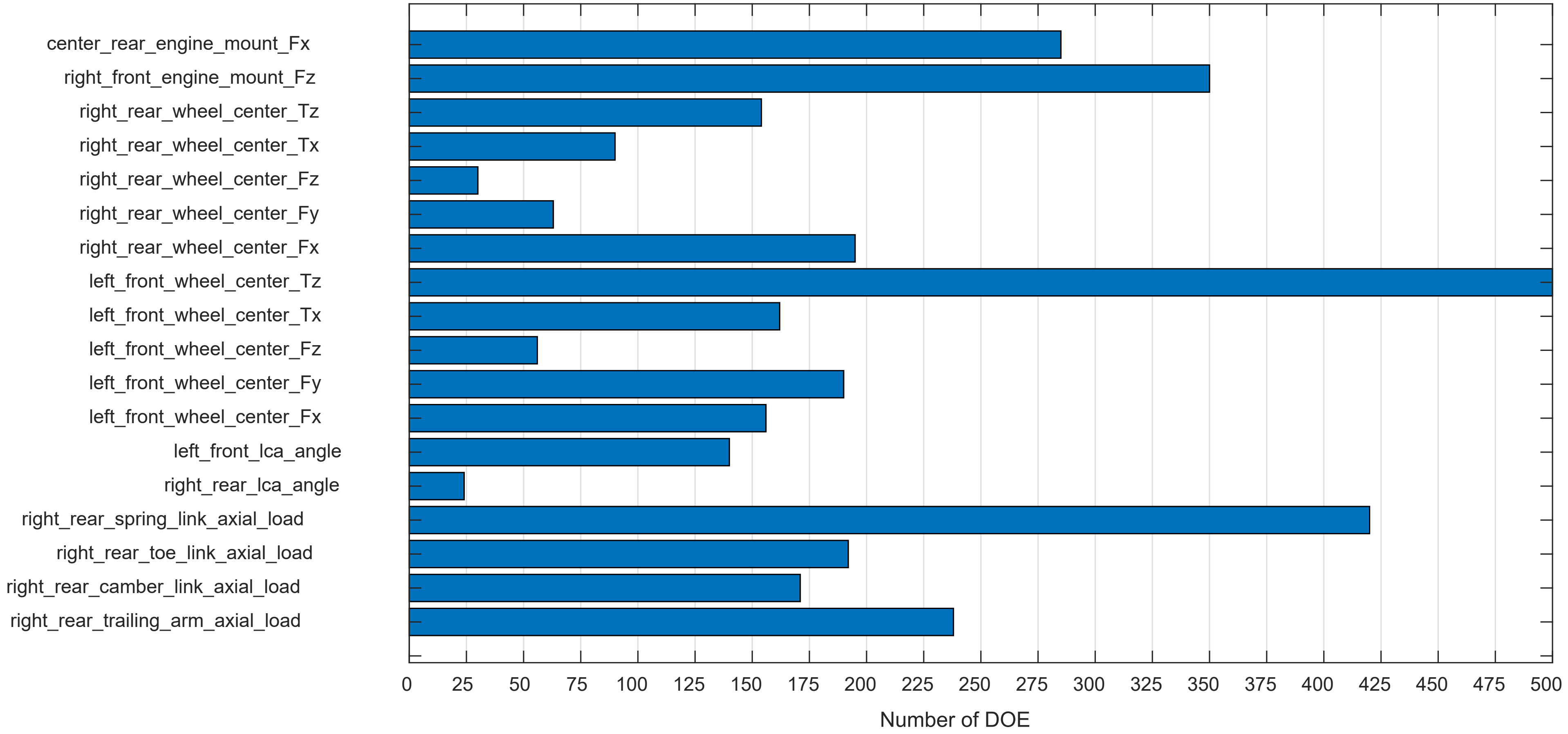
Uncertainty Quantification



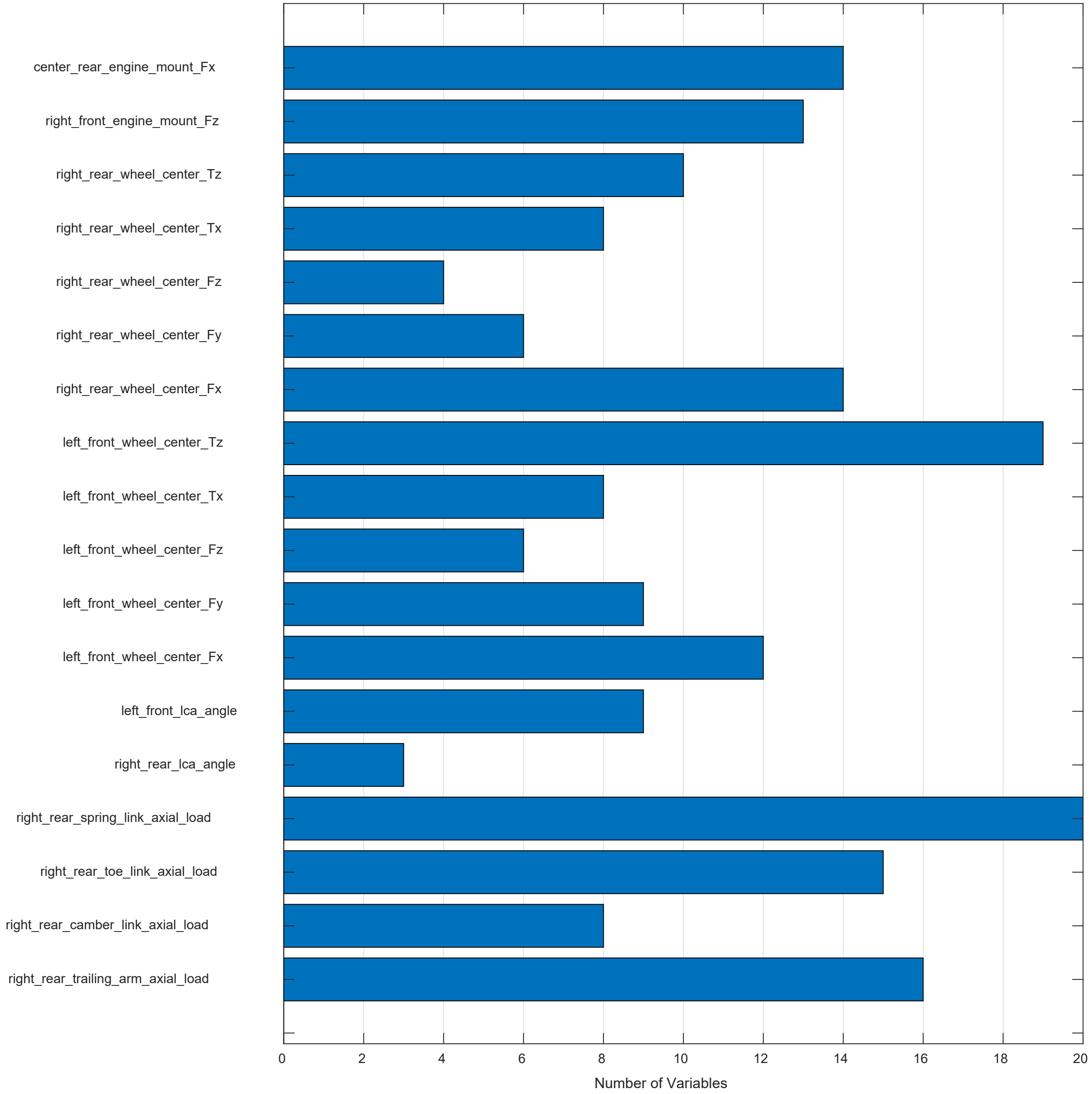
Uncertainty Quantification

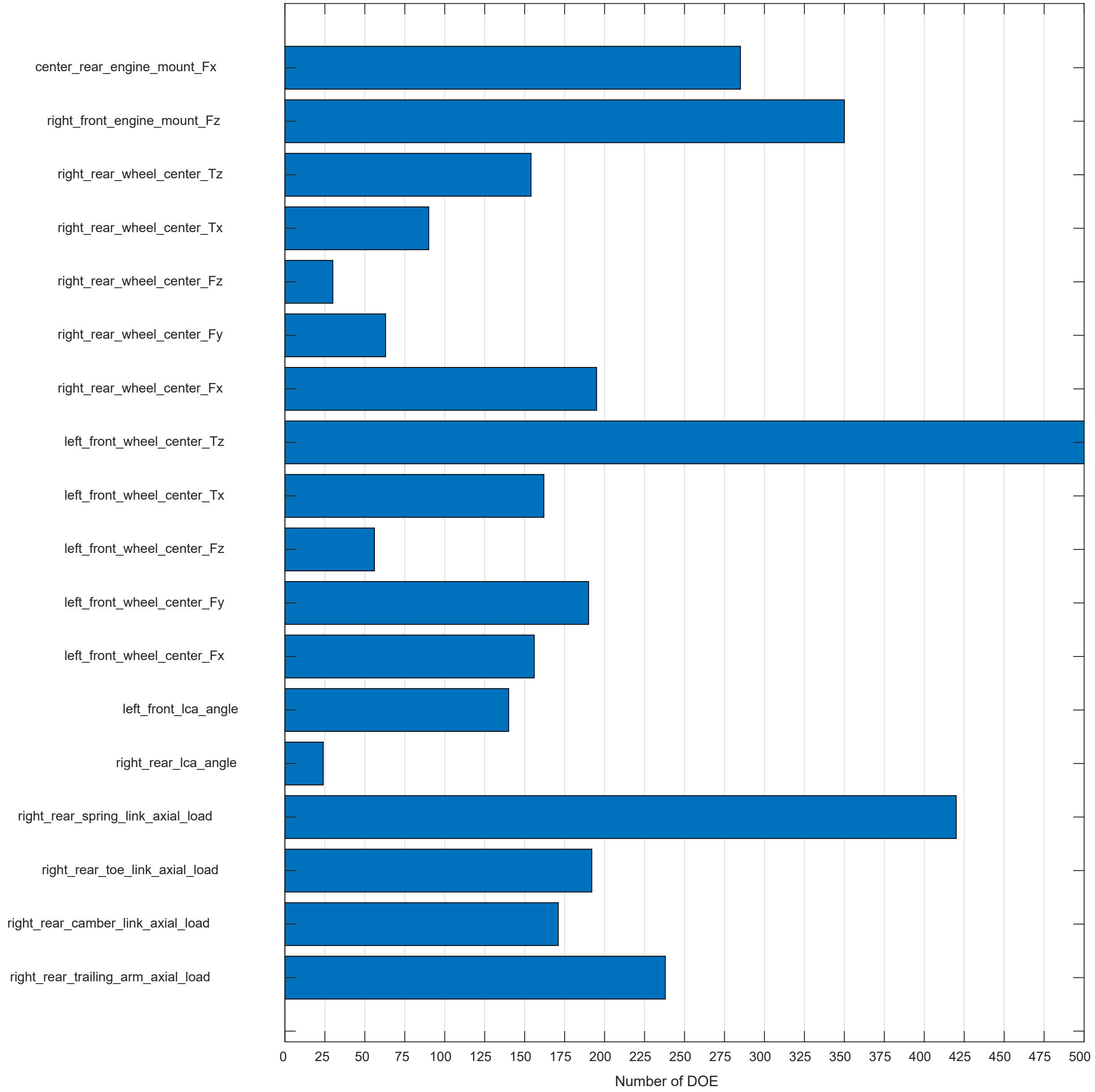
- 18 UQ problems defined with their own important variables.
- Carried out DOE for all 18 models.
  - Total of 3,416 DOE

3,416 DOE for UQ is equivalent to running 18 Million Simulations



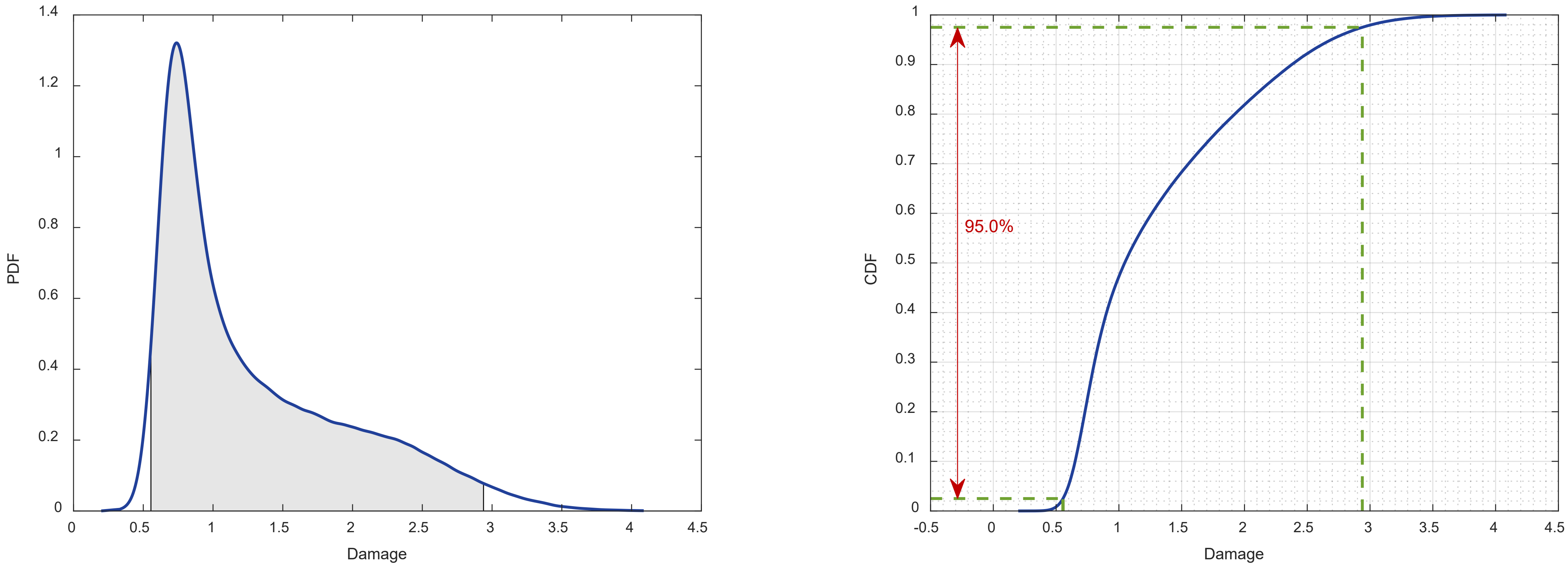
Uncertainty Quantification





UQ – Left Front Wheel Center Fx

	Mean	Standard Deviation	95% Interval	
Damage	1.30	0.68	0.55	2.94
Range	1.02	0.08	0.90	1.18



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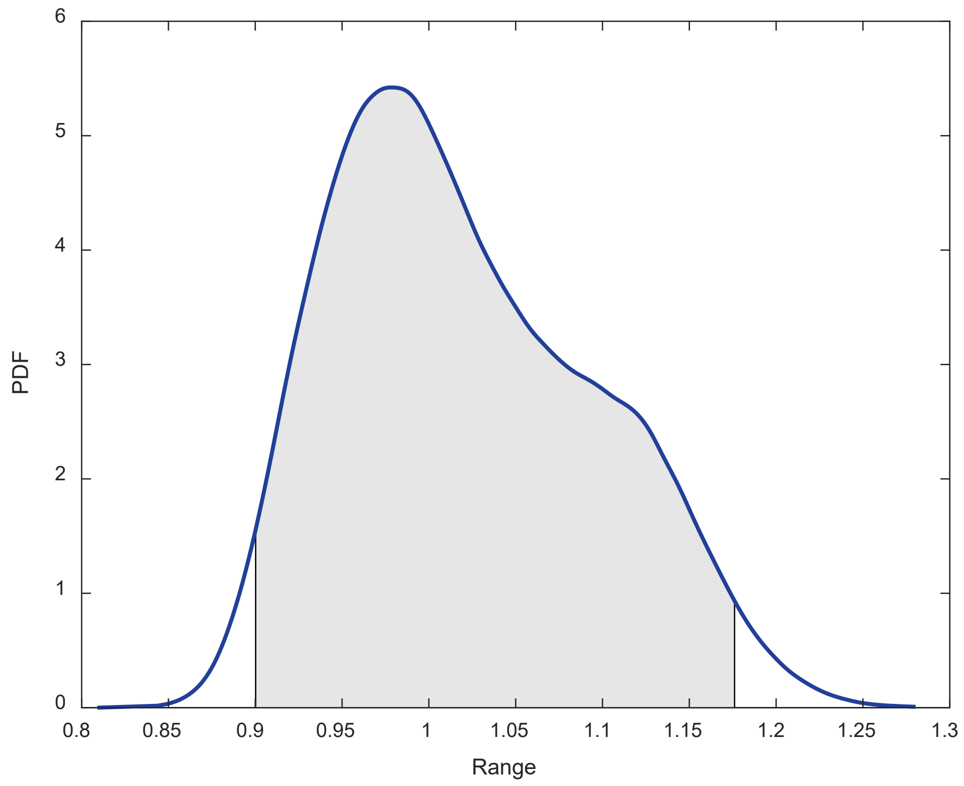
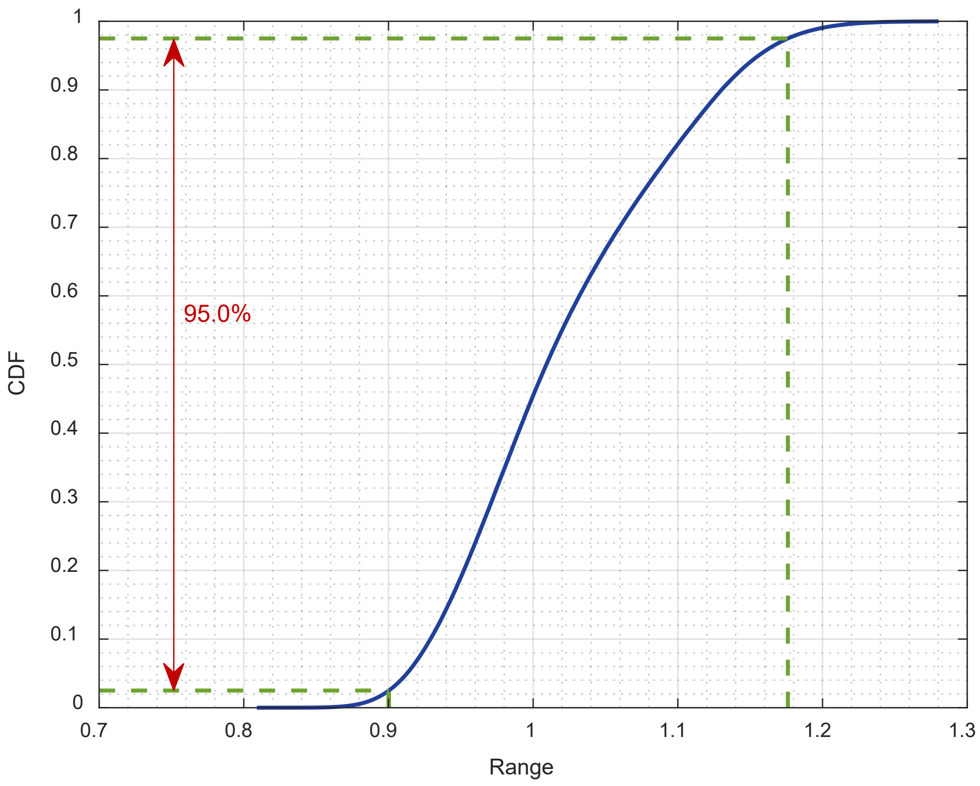


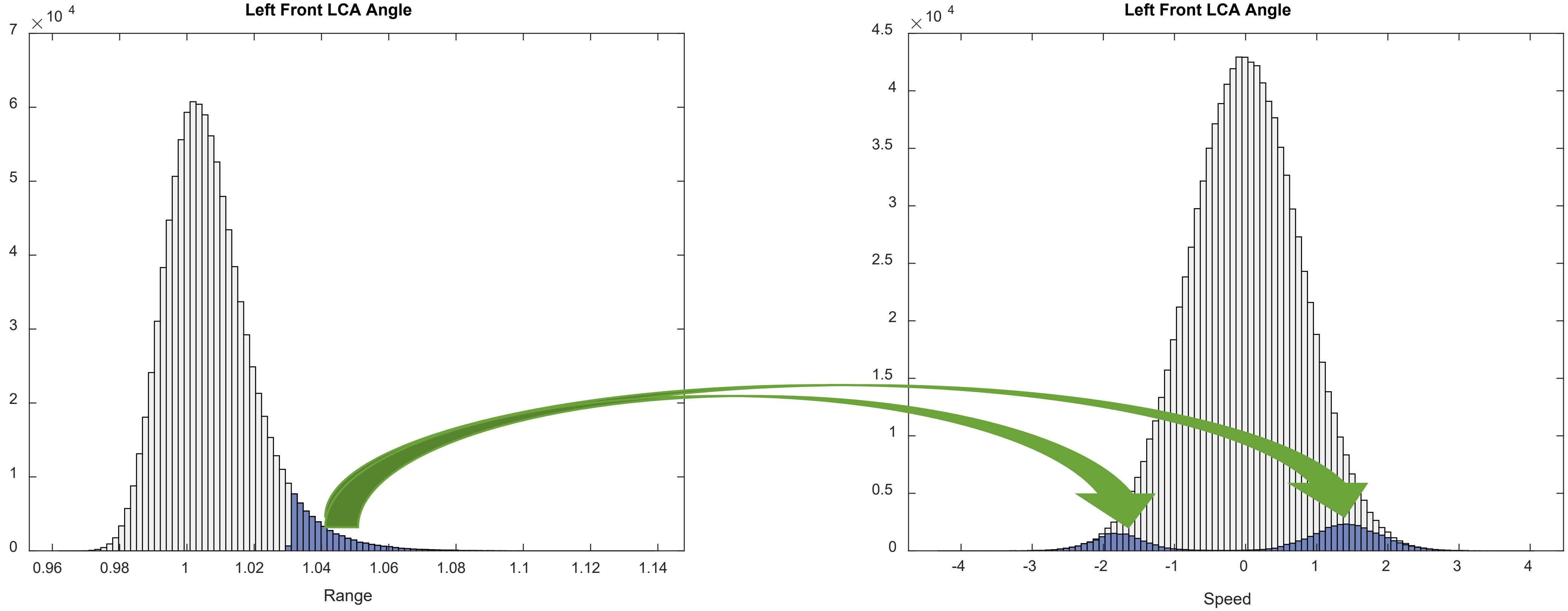


UQ – All 18 Joint Loads

Joint Load		Damage				Range			
		Mean	Std	95% Interval		Mean	Std	95% Interval	
1	right rear trailing arm axial load	1.26	0.62	0.37	2.74	1.00	0.08	0.84	1.17
2	right rear camber link axial load	1.36	0.54	0.76	2.81	1.07	0.09	0.95	1.28
3	right rear toe link axial load	1.32	0.79	0.26	3.29	1.00	0.09	0.83	1.19
4	right rear spring link axial load	1.39	0.75	0.32	3.22	1.03	0.09	0.87	1.21
5	right rear lca angle	1.04	0.10	0.93	1.29	1.00	0.02	0.97	1.06
6	left front lca angle	1.04	0.07	0.93	1.20	1.01	0.01	0.99	1.04
7	left front wheel center Fx	1.30	0.68	0.55	2.94	1.02	0.08	0.90	1.18
8	left front wheel center Fy	1.56	1.82	0.07	6.08	1.06	0.15	0.85	1.43
9	left front wheel center Fz	1.06	0.16	0.82	1.43	1.01	0.03	0.95	1.06
10	left front wheel center Tx	1.38	0.94	0.30	3.82	1.03	0.11	0.84	1.26
11	left front wheel center Tz	3.20	4.01	0.00	13.92	1.18	0.21	0.88	1.69
12	right rear wheel center Fx	1.26	0.53	0.40	2.51	1.00	0.07	0.86	1.15
13	right rear wheel center Fy	1.15	0.59	0.43	2.65	1.01	0.09	0.85	1.20
14	right rear wheel center Fz	1.06	0.19	0.76	1.53	1.01	0.04	0.94	1.08
15	right rear wheel center Tx	1.13	0.51	0.41	2.38	1.00	0.08	0.84	1.17
16	right rear wheel center Tz	1.77	1.07	0.38	4.51	1.08	0.11	0.88	1.31
17	right front engine mount Fz	0.63	0.56	0.00	1.72	0.87	0.17	0.56	1.15
18	center rear engine mount Fx	1.69	1.90	0.00	6.40	0.98	0.23	0.64	1.41

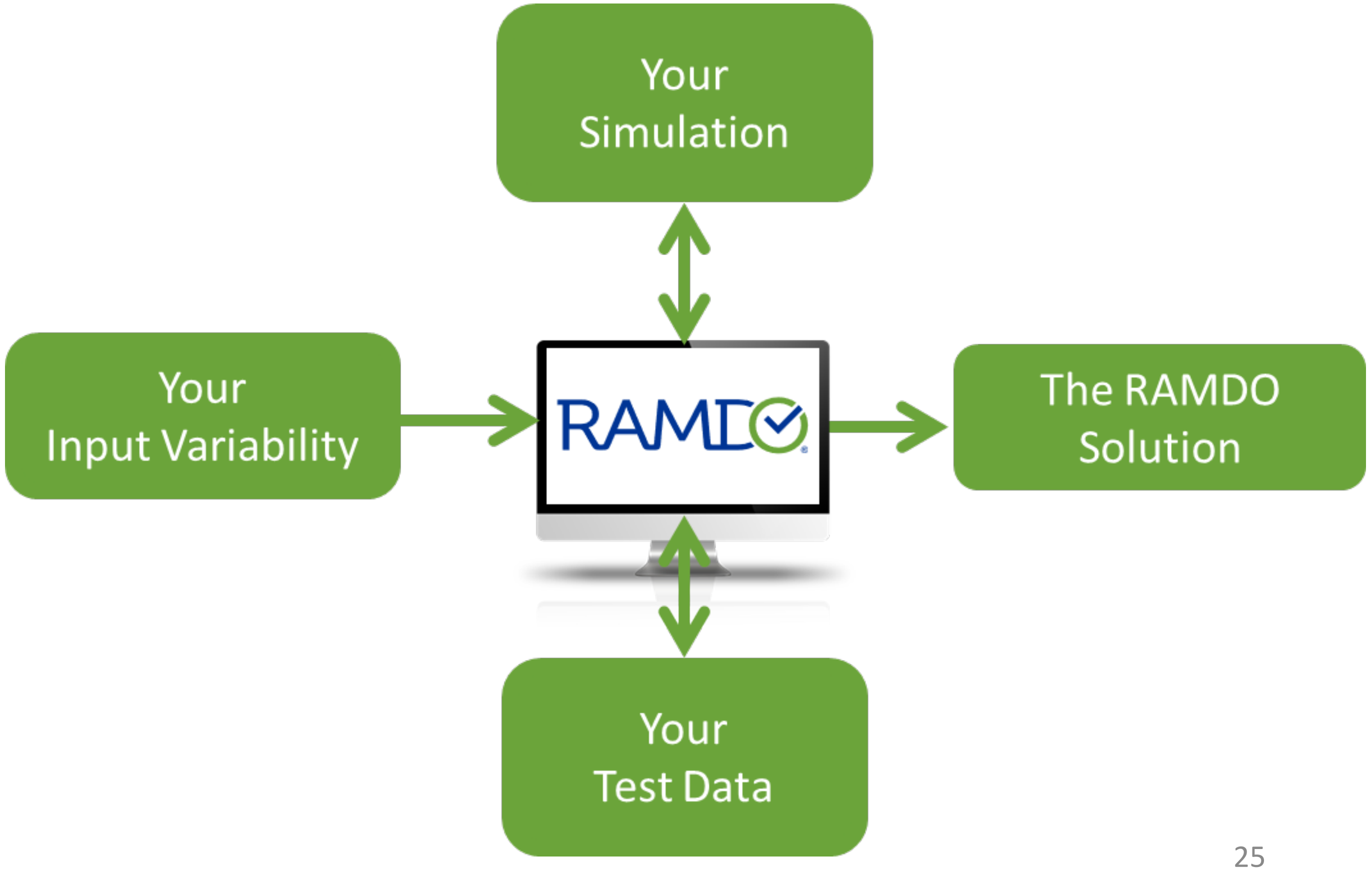
UQ – Mapping Outputs to Inputs

- Identifying inputs for critical load range Left Front LCA Angle



Mapping critical load range values to the corresponding inputs is not trivial.

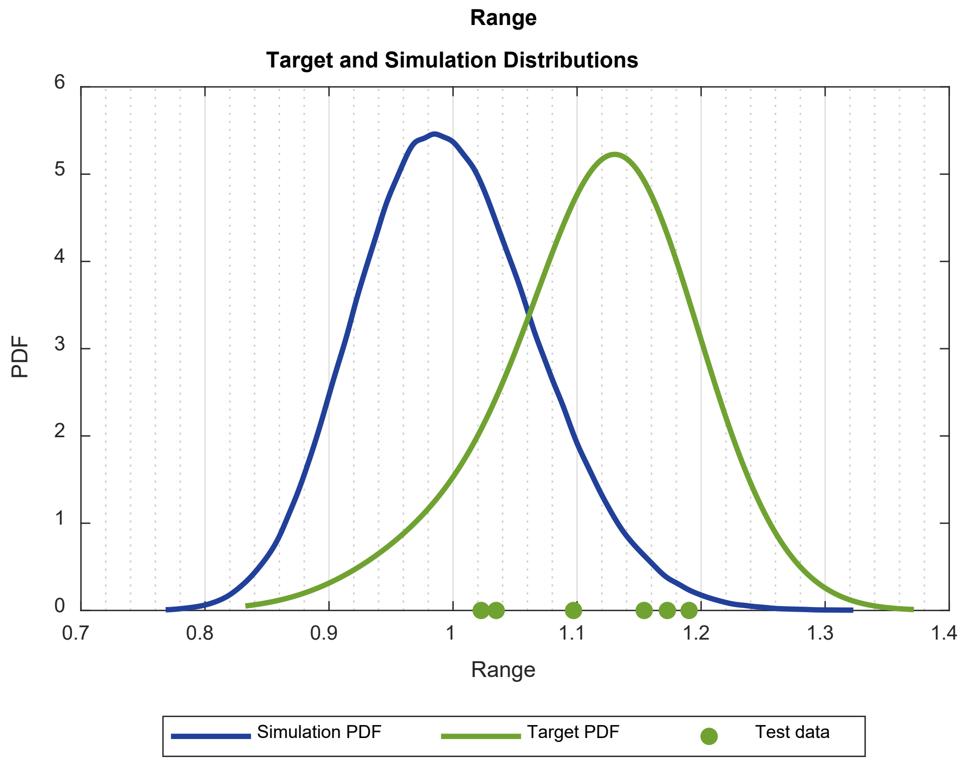
Model Validation

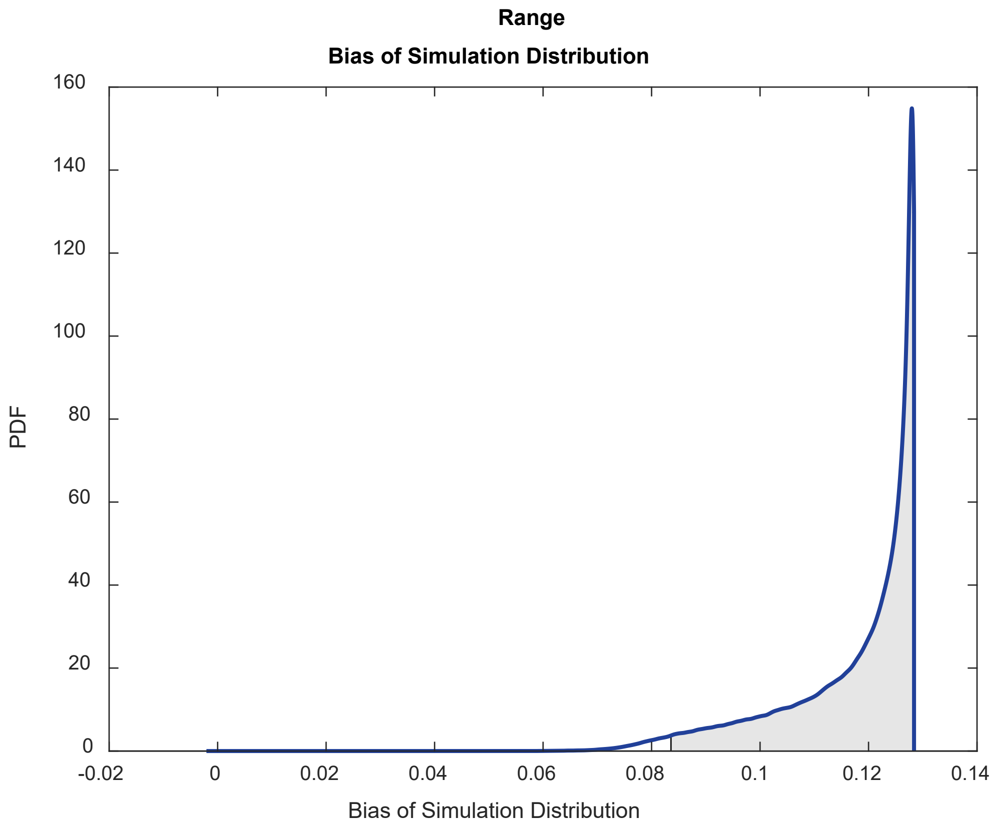


Model Validation

- Test Data
  - Mule & Production (3 data for each – 6 data total)
- The only variability in test data
  - Only speed for a data set, i.e., mule or production, e.g., bushings are not changed between test.
  - Variability between mule and production includes variability in other parameters, e.g., bushing properties because bushings are different.

MV – Right Rear Wheel Center Fx





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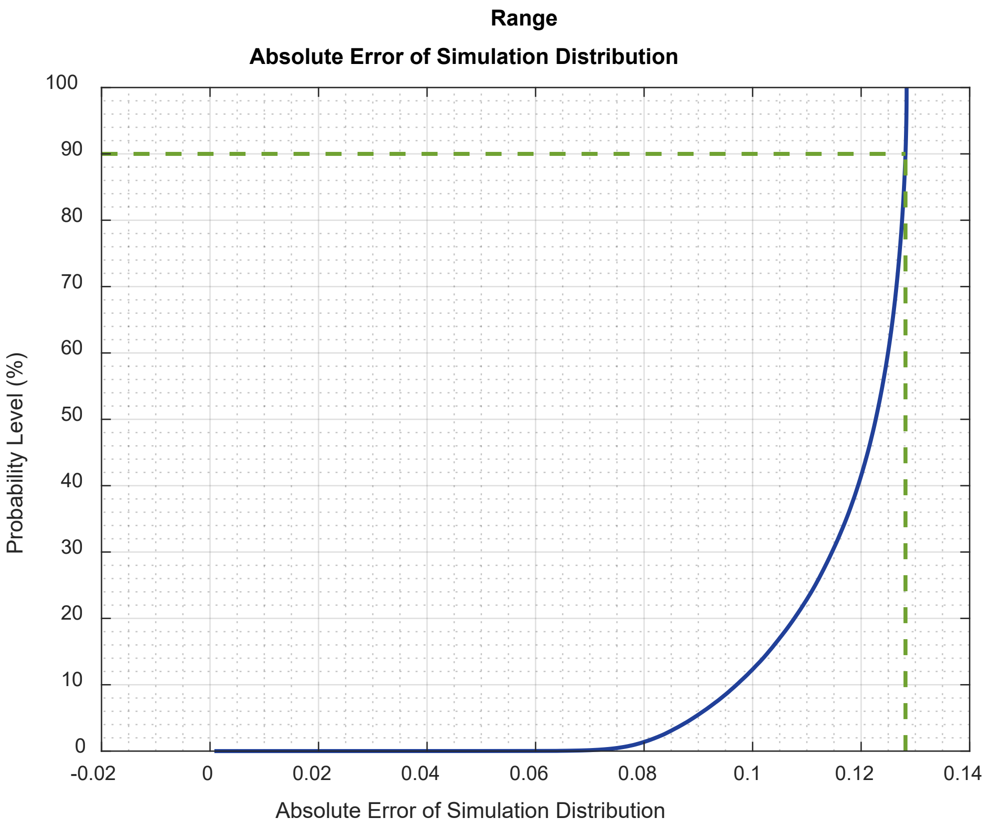

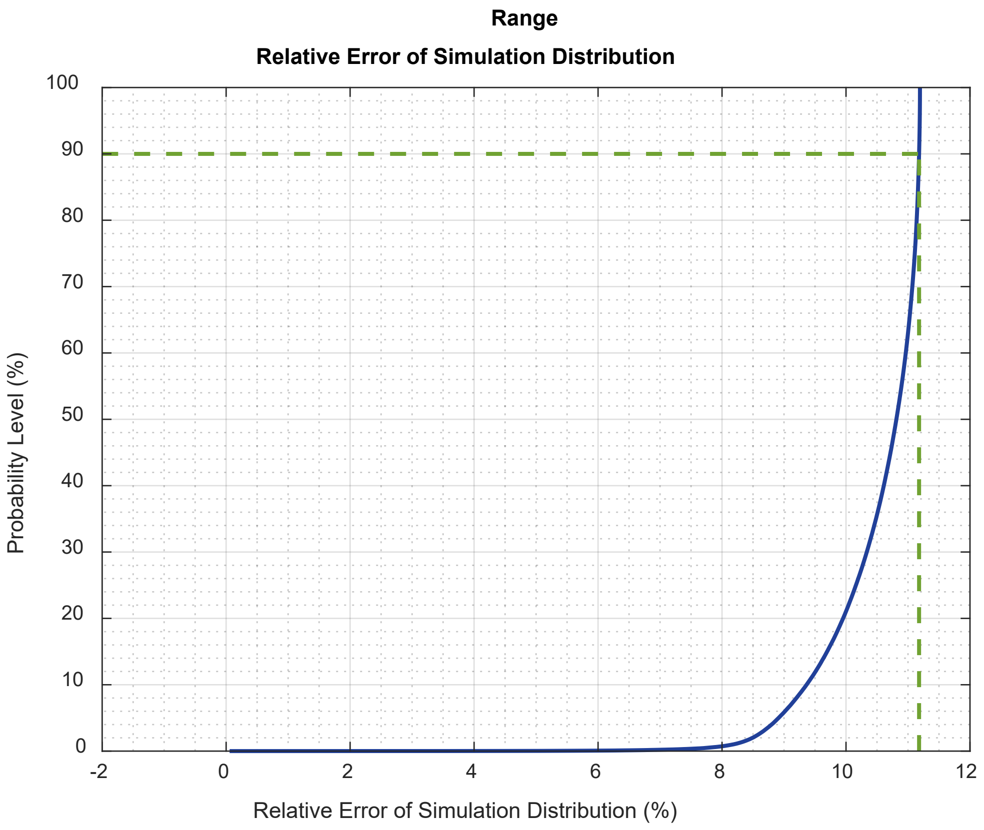

Conclusions

- Successfully reduced 320 variables to only 81 critical variables.
- Successfully carried out UQ providing damage and load range variability distributions, statistics, probability intervals, etc.
  - Previously never seen the damage and range interval given this many inputs.
- It is hard to map outputs to clusters of inputs that cause large damage or large load range.
  - It was seen that there are correlations between input variables and damage/load range.
- Showed a model validation method that provides a way to statistically compare and quantify how well the simulation results compare to the measured proving ground results.

Future Work

- Continue to study how to best map the outputs, i.e., damage and range, to the input variables.
- Determine how the model validation results can be used to help improve simulation models.
- Take the resulting durability load variability and propagate it through to find the actual simulation-based fatigue variability.
  - Planning this as a continuation project for next year.
- Compare simulation-based fatigue variability to actual measured fatigue variability data when available.

Questions?

Thank You

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