UNSW THE UNIVERSITY OF NEW SOUTH WALES

TARS Research

Never Stand Still | Science | Transport and Road Safety (TARS) Research

Verification and Validation of Models Used in Computer Simulations of Roadside Barrier Crashes

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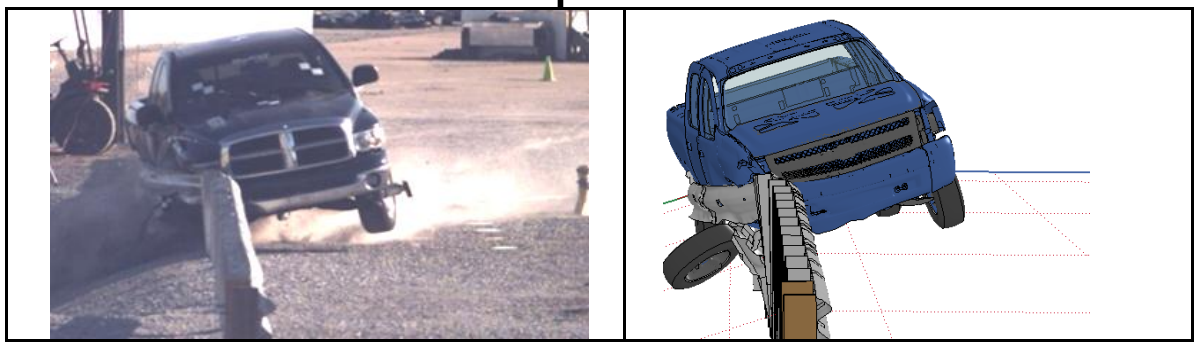
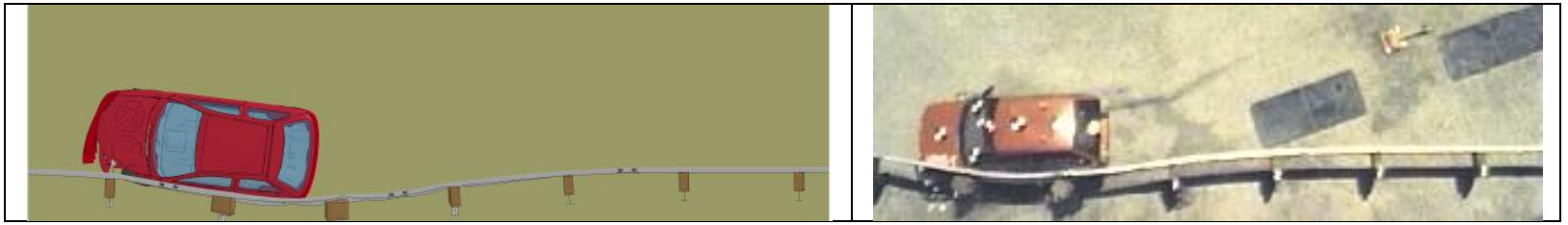
Outline

- INTRODUCTION
- V&V PROCEDURES IN ROADSIDE SAFETY
- APPLICATION CASE
- CONCLUSIONS

Computer Simulations for Barrier Crashes

- Powerful tool to predict outcome of full-scale crash tests





Computer Simulations for Barrier Crashes

- Powerful tool to predict outcome of full-scale crash tests
  - Identify potential problems before testing
  - Optimise barrier performance
  - Accept incremental design (w/o testing)

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- Need to reproduce reality under investigation
  - No cartoons!

- Verification & Validation (V&V) guarantees realistic results

Verification & Validation

- Definitions

  - Verification:

    Process of determining that a computational model accurately represents the underlying mathematical model and its solution.

  - Validation:

    Process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

V&V in Roadside Safety

- Overview of the V&V procedure proposed in the USA
  - Verification
  - Validation
  - Documenting Relevant Phenomena

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No specific formulas to predict a full-scale crash test!

Verification based on:

- Conservation of Mass and Energy
- Stability of Contact definitions / Element formulations

V&V in Roadside Safety

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  - Verification
  - **Validation**
  - Documenting Relevant Phenomena

Comparison of Experimental vs. Simulation data:

- Specific safety indexes used in barrier crash testing
- Acceleration and Rotation Speed

Qualitative (comparison metrics)

V&V in Roadside Safety

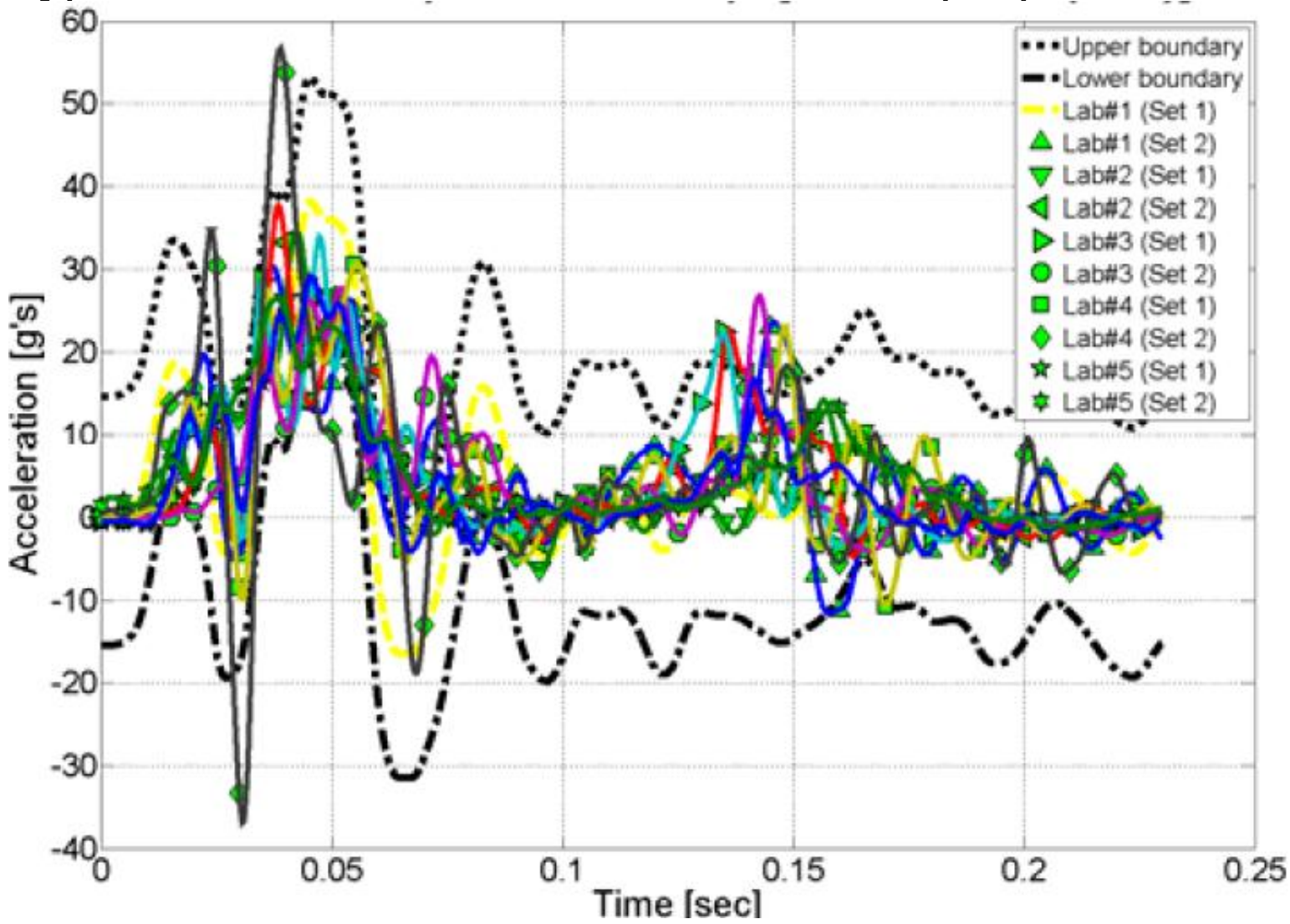
❑ Comparison metrics & acceptance criteria

		Formulation	Acceptance Criteria
Sprague & Geers	*Magnitude Component* (M_{SG})	$M_{SG} = \sqrt{\frac{\sum c_i^2}{\sum m_i^2}} - 1$	≤ 40%
	Phase Component (P_{SG})	$P_{SG} = \frac{1}{\pi} cos^{-1} \frac{\sum c_i \ m_i}{\sqrt{\sum c_i^2 \sum m_i^2}}$	≤ 40%
ANOVA (based on residual error*)	*Average* ($\bar{e}^r$)	$\bar{e}^r = \frac{\sum_{i=1}^{n} (m_i - c_i)/m_{max}}{n}$	≤ 5%
	Standard Deviation (σ^r)	$\sigma^r = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (e^r - \bar{e}^r)^2}$	≤ 35%
(*) normalized to the peak of the measured values			

Acceptance criteria
based on scatter of results from repeated full-scale crash tests

V&V in Roadside Safety

- Typical Scatter in full-scale crash tests (Repeated tests)



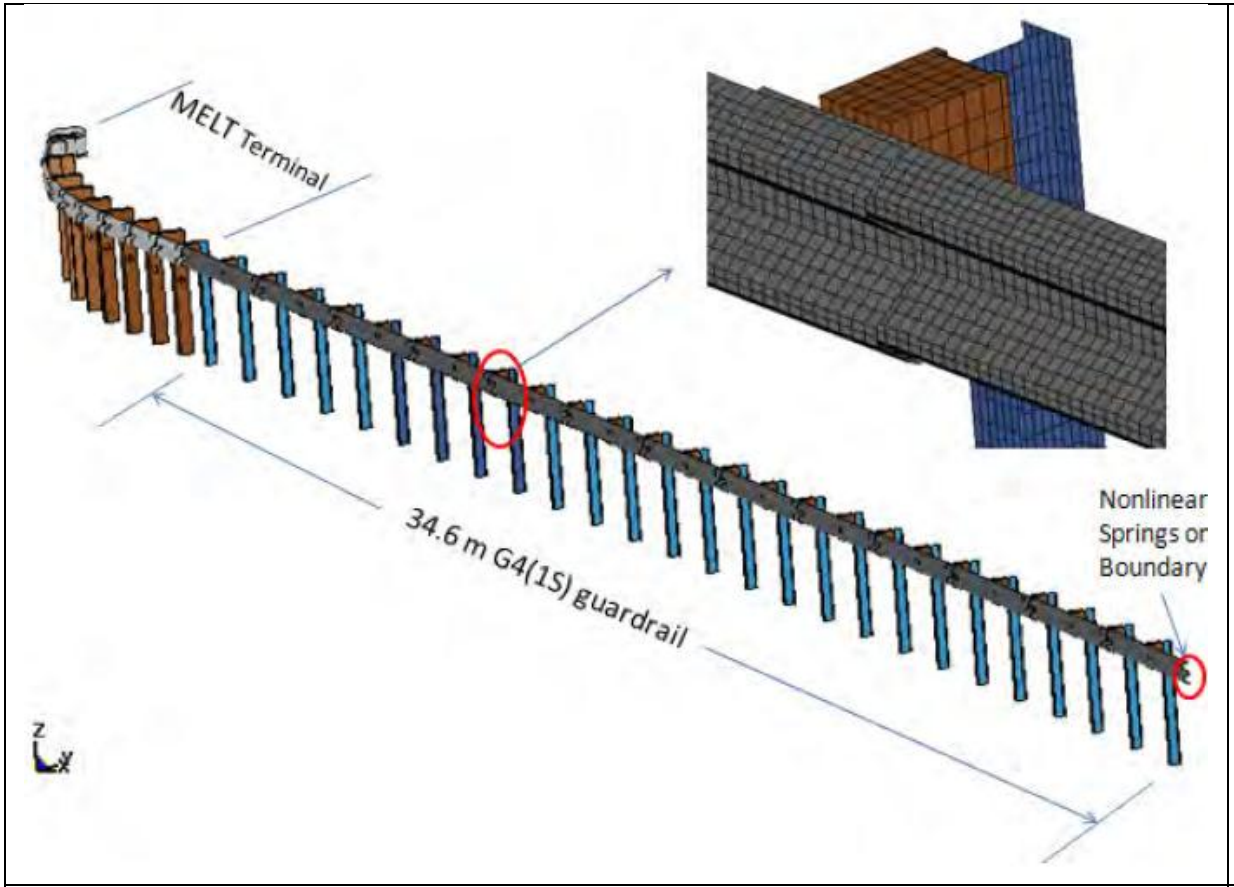
V&V in Roadside Safety

- Overview of the V&V procedure proposed in the USA
  - Verification
  - Validation
  - **Documenting Relevant Phenomena**

- Others can use the model in the future
- PIRT table reports relevant physical phenomena the model has proven to reproduce

Crash Test into a Guardrail Barrier

- Most common guardrail system in USA – G1(1S)



FE Model	Actual Guardrail System

Crash Test into a Guardrail Barrier

- Most common guardrail system in USA – G1(1S)
- Steps followed:
  - V&V of a baseline model (against an initial crash test)
  - Simulations w/ modified model (kerb added) Assess predictive capacity of modified model (against a second crash test)

Crash Test into a Guardrail Barrier

- V&V of baseline model
  - Verification

Energy & Mass Conservation

Verified Quantity	Model Entity	Stage of Simulation	Verification Criteria	Quantity Value	Pass? (Y/N)
Total Energy	Global	Throughout	≤ 10% Total Init. Energy @ t=0	1.3%	Y
Hourglass Energy	Global	Termination	≤ 5% Total Init. Energy @ t=0	0%	Y
		Termination	≤ 10% Total Internal Energy @ end	0%	Y
	Specific Parts	Throughout	≤ 5% Total Init. Energy @ t=0	0%	Y
Added Mass	Global	Start	≤ 5% Total Mass @ t=0	0%	Y
		Throughout	≤ 10% Total Mass @ t=0	0%	Y
	Specific Parts	Throughout	≤ 10% Mass of Part @ t=0	0%	Y
	Global (Moving Parts Only)	Throughout	≤ 5% Mass of Moving Parts @ t=0	0%	Y
Shooting Nodes?	Global	Throughout	Y/N	N	Y
Solid Elements w/ Negative Volume?	Global	Throughout	Y/N	N	Y

Crash Test into a Guardrail Barrier

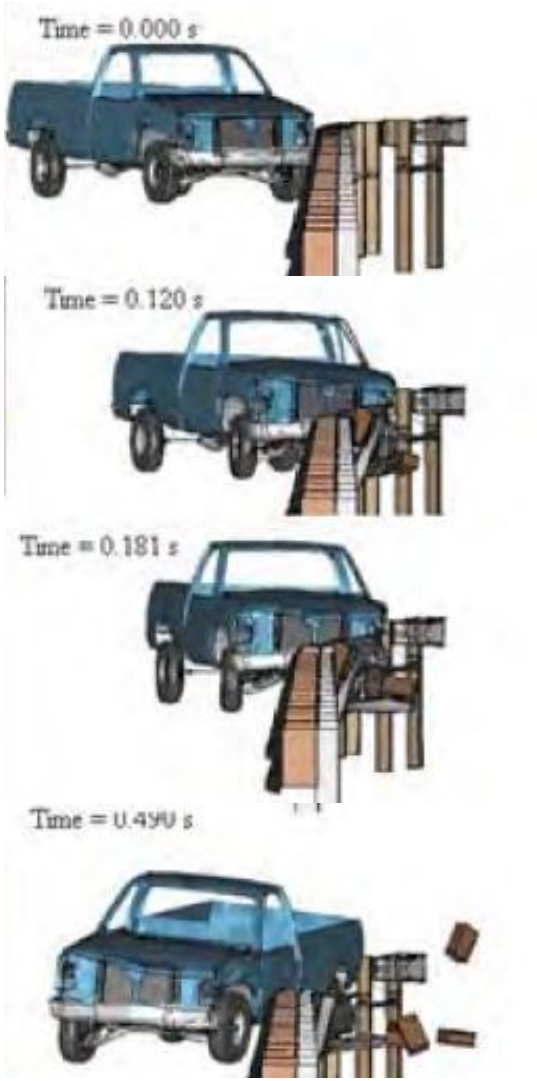
- V&V of baseline model
  - Verification

Model Stability

Verified Quantity	Model Entity	Stage of Simulation	Verification Criteria	Quantity Value	Pass? (Y/N)
Total Energy	Global	Throughout	≤ 10% Total Init. Energy @ t=0	1.3%	Y
Hourglass Energy	Global	Termination	≤ 5% Total Init. Energy @ t=0	0%	Y
		Termination	≤ 10% Total Internal Energy @ end	0%	Y
	Specific Parts	Throughout	≤ 5% Total Init. Energy @ t=0	0%	Y
Added Mass	Global	Start	≤ 5% Total Mass @ t=0	0%	Y
		Throughout	≤ 10% Total Mass @ t=0	0%	Y
	Specific Parts	Throughout	≤ 10% Mass of Part @ t=0	0%	Y
	Global (Moving Parts Only)	Throughout	≤ 5% Mass of Moving Parts @ t=0	0%	Y
Shooting Nodes?	Global	Throughout	Y/N	N	Y
Solid Elements w/ Negative Volume?	Global	Throughout	Y/N	N	Y

Crash Test into a Guardrail Barrier

- V&V of **baseline** model
  - Verification
  - Validation
    - Qualitative

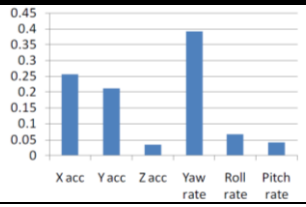


Crash Test into a Guardrail Barrier

- V&V of baseline model
  - Verification
  - Validation
    - Qualitative
    - Quantitative

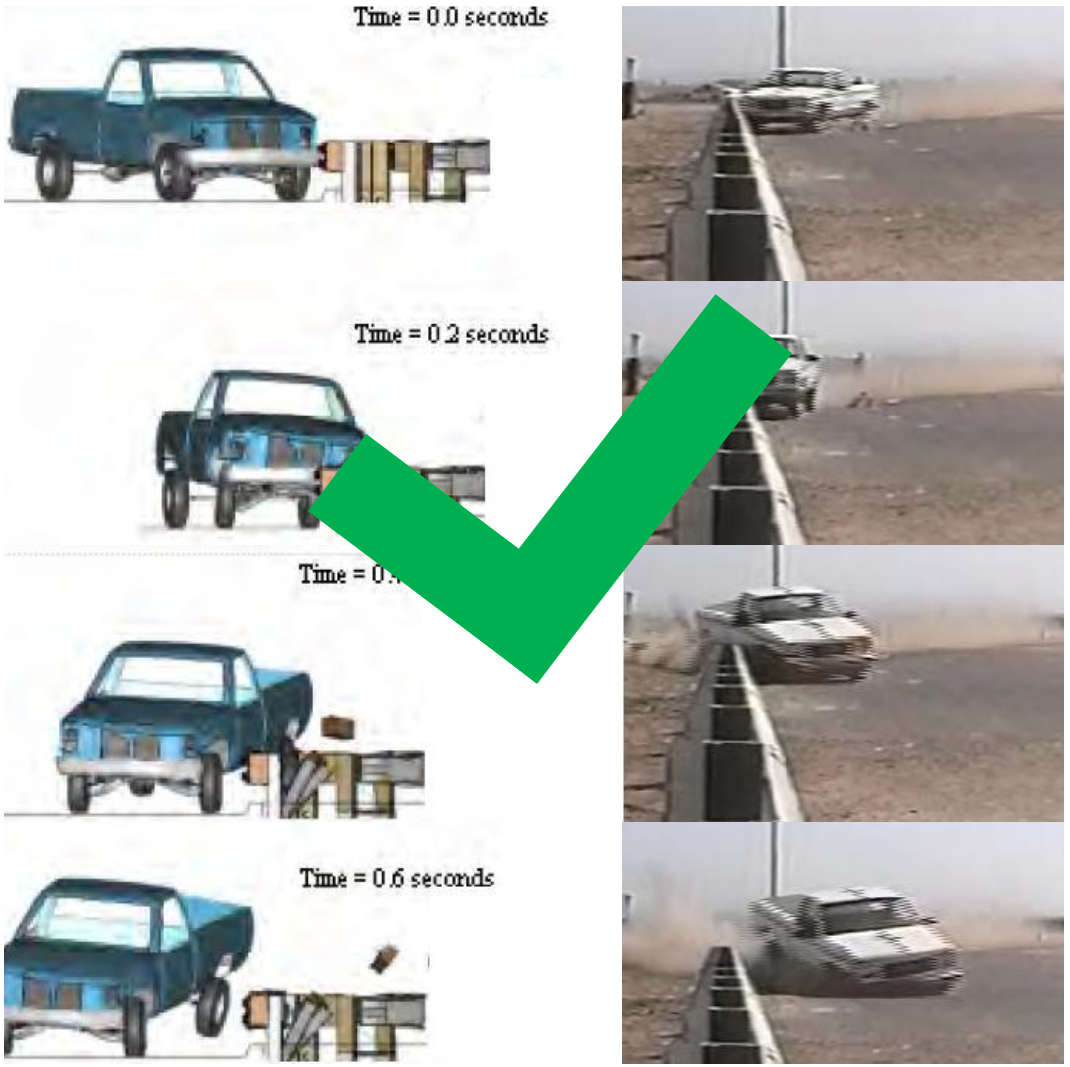
Individual Channels

Weighted Average

Single Channels	Sprague&Geers		ANOVA		Pass?
	M	*P*	*Mean Residual*	*STD of Residual*	
X Acceleration	21.5	33.3	0.02	0.34	Y
Y Acceleration	43.9	35.7	0.05	0.27	N
Z Acceleration	21.1	43.0	0.02	0.32	N
Roll Rate	35.3	32.7	0.02	0.27	Y
Pitch Rate	13.3	48.0	0.05	0.36	N
Yaw Rate	11.7	8.7	0.04	0.12	Y
Multichannel Weights					
Weighted average	Sprague&Geers		ANOVA		Pass?
	M	*P*	*Mean Residual*	*STD of Residual*	
	22.9	25	0.03	0.24	Y

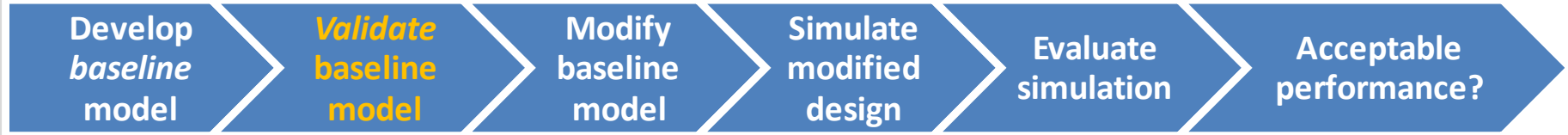
Crash Test into a Guardrail Barrier

- Predictive capacity of **modified** model



Conclusions

- Quantitative V&V allows for a more reliable use of computer simulations in roadside safety
- Basis for approval of incremental hardware improvements through simulations only
  - Support regulators in taking approval decisions
  - NO need for re-testing modified system
- Suggested implementation of V&V into simulation process:



- V&V Guidelines (NCHRP Report 179) available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w179.pdf

Acknowledgments

❑ V&V Guidelines were developed under the US National Cooperative Highway Research Program (NCHRP), Project No. 22-24.

Questions ?