

Facilitating Virtual Testing at an Industrial Level by Simulation Data Management

The Future of Virtual Certification
for Automotive Crash Safety

Bengaluru, India
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nafems.org

THE MODELLING AND SIMULATION COMMUNITY

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02

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05

Conclusion

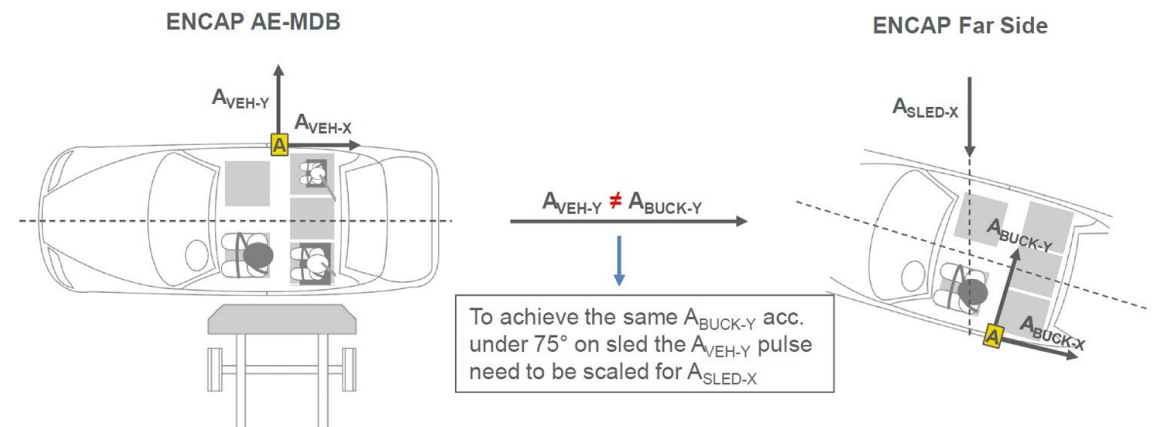
Outlook on Further Work

Far Side Occupant Test – Virtual Certification

- No physical tests by Euro NCAP
 - Replace physical tests by simulation
- OEM submits 8 simulation results:
 - 2 for model *Validation*
 - 6 for virtual testing (VT) or certification
- Euro NCAP checks data and accepts it
- OEM performs physical sled test
- Euro NCAP validates simulation model
- Euro NCAP rates virtual testing load cases

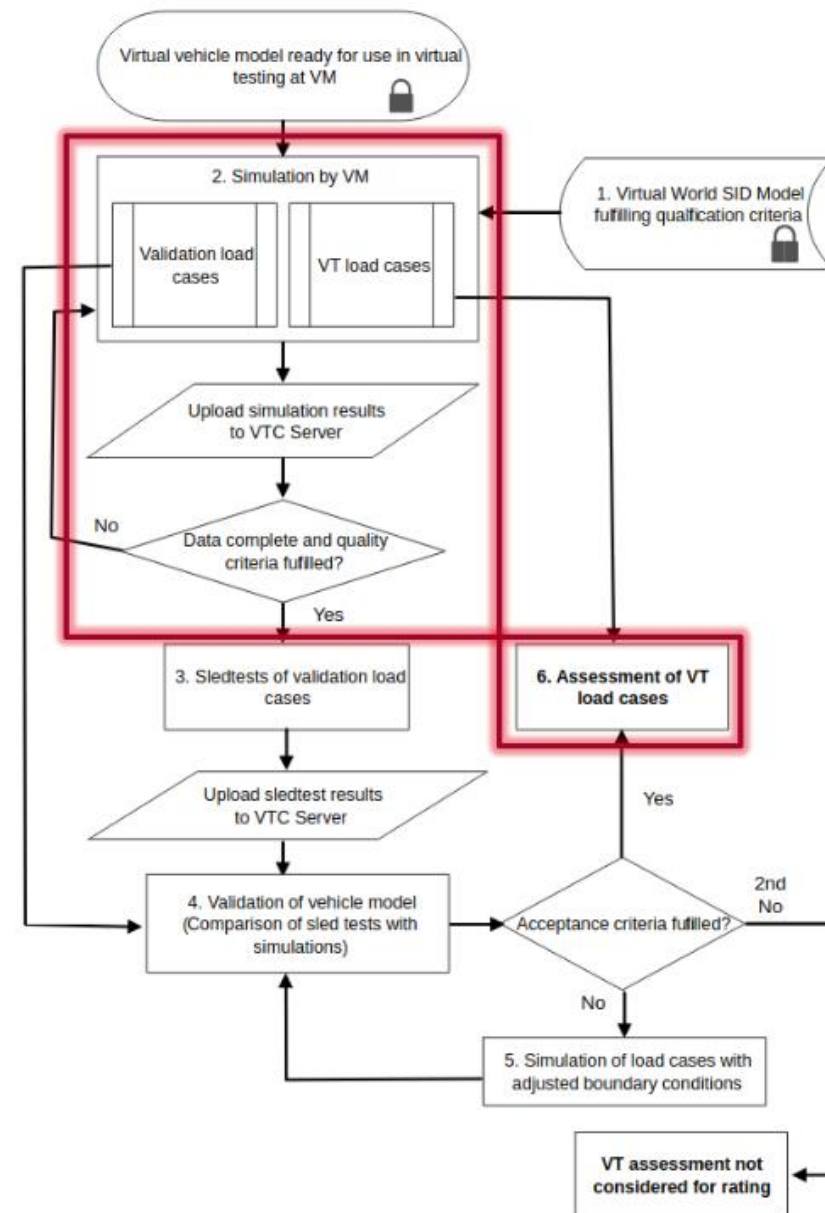


This marks a significant shift in methodology.

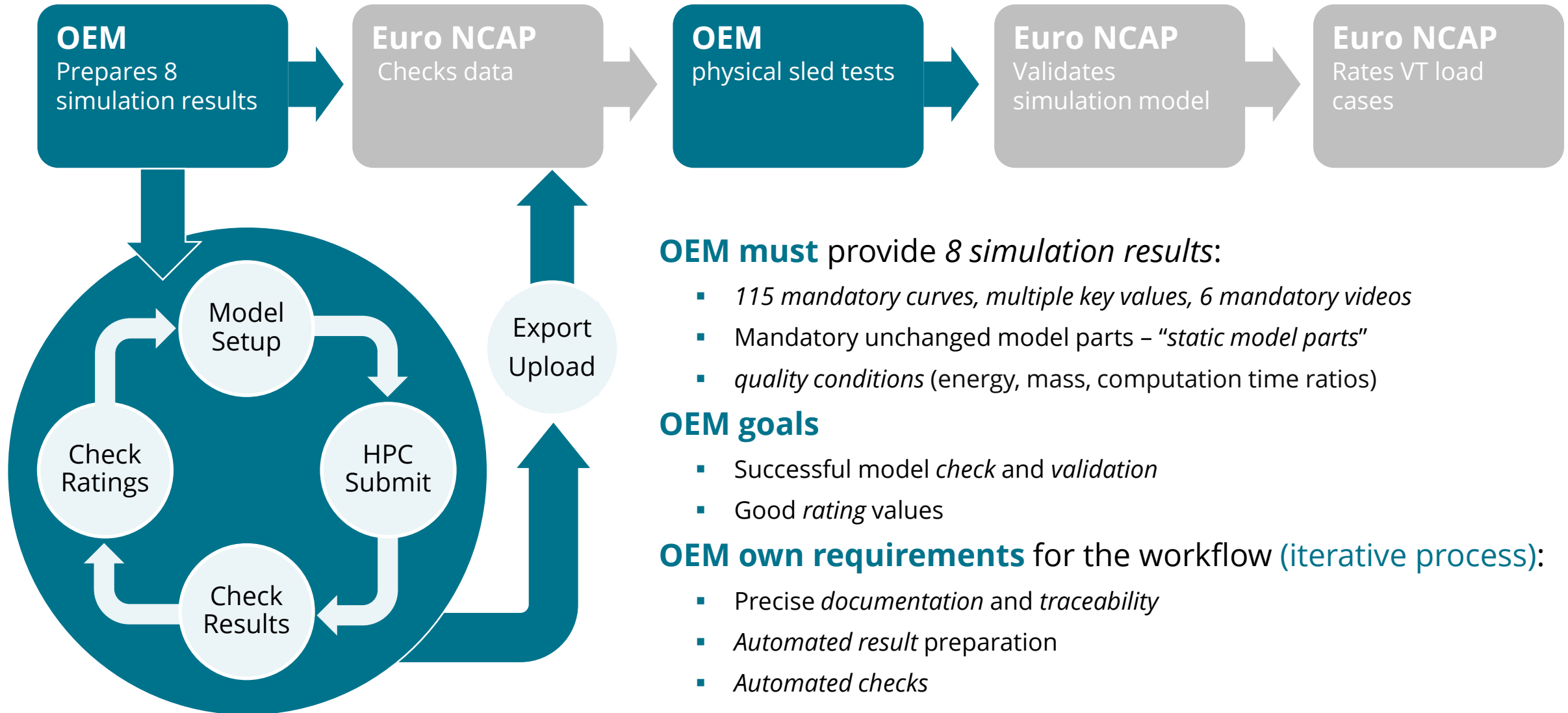


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- OEM performs physical sled test
- Euro NCAP validates simulation model
- Euro NCAP rates virtual testing load cases
 - CAE Engineer needs and objectives
 - Data preparation and completeness
 - Euro NCAP quality criteria
 - Static model parts
 - Rating values



Virtual Testing Workflow and Challenges



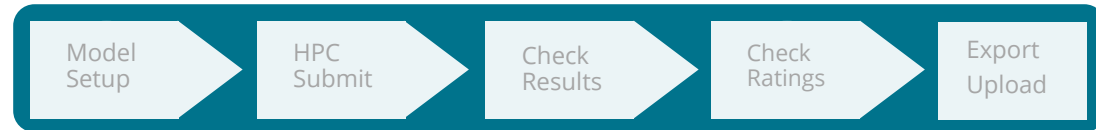
How Simulation Data Management (SDM) Can Help

- Single point of truth
for input and output, simulation and tests
- Collaboration
teamwork, sharing of data, speedup of development
- Standardized data structure
homogeneous visualization, evaluation, assessment
- Predictable & robust assessment
automatic generation of hashes, extraction of key-results, reports
- Traceability and documentation
each change by each user is captured and documented

The screenshot displays the SCALE.sdm software interface. The top bar shows the application name 'SCALE.sdm', a 'Result' dropdown, a 'Confidential information' warning, and a 'Yaris Demo' project selector. The main workspace is divided into several panels:

- Projects and Collections:** A sidebar on the left showing a list of projects and collections. The 'Collections' section is expanded, showing a list of items with names like '1484_YARIS_USNCAP_RW_f_56kmh_lhd_59_._.lsdyna'.
- Scenarios:** A panel below the collections showing a list of scenarios with checkboxes for 'Front', 'Side', 'Rear', and 'Other'. The 'Front' scenario is selected.
- Attributes, Photos, Videos, Documents, Channels, Events:** A row of tabs at the bottom of the main workspace.
- Legend:** A panel on the right showing a list of items with names like 'TEST_YARIS_USNCAP_RW_f_56kmh_lhd_._.T5677' and '1484_YARIS_USNCAP_RW_f_56kmh_lhd_67_._.lsdyna'. It includes a table with columns for 'Front Impact' and 'km/h'.
- Overview Crash:** A section showing a photograph of a red car in a crash test, with a yellow car model overlaid for comparison.
- Bottom View Crash:** A section showing a photograph of the car's undercarriage after a crash test, with a 3D model overlaid.
- 3D Model Left Rail:** A section showing a 3D model of the car's left rail.

Setup in SDM: Requirements



- Project setup in SCALE.sdm

- Responsibilities
- Milestones
- Requirements

thresholds for measurements

- Quantity and quality criteria for Euro NCAP

assuring the quality of the simulation result data

- Energy of dummy and whole system
- Added mass
- Simulation run time
- Reasonable displacements

- Rating criteria for Euro NCAP

used everywhere for coloring in order to always have an eye on the critical values for the rating

- Accelerations
- Forces
- Displacements

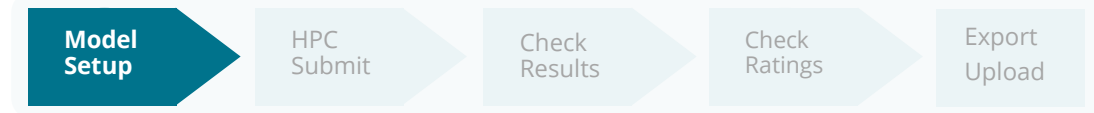
Thresholds for quality criteria

| WSID: Houghlass / Internal Energy | $-\infty \leq x < 0.1000$ | $0.1000 \leq x < \infty$ |
|---|-----------------------------|----------------------------|
| Simulation Run Time / Max. Y Displacement ti... | $-\infty \leq x < 1.200$ | $1.200 \leq x < \infty$ |
| Max. H-point Z displacement (first 5ms) | $-\infty \leq x < 10.00$ | $10.00 \leq x < \infty$ |
| Full Setup: Houghlass / Internal Energy | $-\infty \leq x < 0.1000$ | $0.1000 \leq x < \infty$ |
| Added / Total Mass | $-\infty \leq x < 0.005000$ | $0.005000 \leq x < \infty$ |

Thresholds for EuroNCAP rating criteria

| 6.3 Table 7.: EuroNCAP VTC (10) | | | |
|---------------------------------|-----------------------|--------------------------|-------------------------|
| ✓ | Head a3ms | $-\infty \leq x < 80.00$ | $80.00 \leq x < \infty$ |
| ✓ | Abdomen compression | $0.000 \leq x < 65.00$ | $65.00 \leq x < \infty$ |
| ✓ | Chest compression | $0.000 \leq x < 50.00$ | $50.00 \leq x < \infty$ |
| ✓ | Head excursion | $0.000 \leq x < 80.00$ | $80.00 \leq x < \infty$ |
| ✓ | Head HIC (15 ms) | $-\infty \leq x < 700.0$ | $700.0 \leq x < \infty$ |
| ✓ | Lumbar Fy | $0.000 \leq x < 2.000$ | $2.000 \leq x < \infty$ |
| ✓ | Lumbar Fz | $0.000 \leq x < 3.500$ | $3.500 \leq x < \infty$ |
| ✓ | Lumbar Mx | $0.000 \leq x < 120.0$ | $120.0 \leq x < \infty$ |
| ✓ | Pubic symphysis force | $0.000 \leq x < 2.800$ | $2.800 \leq x < \infty$ |
| ✓ | Neck moment y | $0.000 \leq x < 50.00$ | $50.00 \leq x < \infty$ |
| > Static bending, NVH (1) | | | |

Setup in SDM: Model Setup



- Modular structure
*version control, parametrization
imported, versioned, managed*
- Shared data among users and load cases
includes, parameters, ...
- Parameterization
restraint system parameters
- Attribute based load case definition
more efficient alternative to a matrix-based approach

| Sort | Name | Short Descripti... | Barrier | Impact_angle | FileType |
|------|----------------------------|--------------------|---------|--------------|----------|
| | ⇒ FS_Pole_75_x-ref_z-re... | pole | p | 75 | |
| 17 | ⇒ Airbag | dab_03 | | | key |
| | ⇒ Body in White | pulse_aemdb_90deg | a | 90 | key |
| | ⇒ Body in White | pulse_aemdb_75deg | a | 75 | key |
| | ⇒ Body in White | pulse_aemdb_60deg | a | 60 | key |
| | ⇒ Body in White | pulse_pole_90deg | p | 90 | key |
| 1 | ⇒ Body in White | carpet_02 | | | key |
| 3 | ⇒ Body in White | hvac_04 | | | key |

| Sort | Name | Short Descripti... | Barrier | Impact_angle | FileType |
|------|-------------------------|--------------------|---------|--------------|----------|
| | ⇒ FS_AEMDB_75_x-ref_... | aemdb | a | 75 | |
| 17 | ⇒ Airbag | dab_03 | | | key |
| | ⇒ Body in White | pulse_aemdb_60deg | a | 60 | key |
| 6 | ⇒ Body in White | pulse_aemdb_75deg | a | 75 | key |
| | ⇒ Body in White | pulse_aemdb_90deg | a | 90 | key |
| 4 | ⇒ Body in White | ip_03 | | | key |
| 5 | ⇒ Body in White | pedals_06 | | | key |
| | ⇒ Body in White | pulse_pole_75deg | p | 75 | key |
| 7 | ⇒ Body in White | sled_body_04 | | | key |


```

graph LR
    A[Model Setup] --> B[HPC Submit]
    B --> C[Check Results]
    C --> D[Check Ratings]
    D --> E[Export Upload]
  
```

Model Setup HPC Submit Check Results Check Ratings Export Upload

- ```

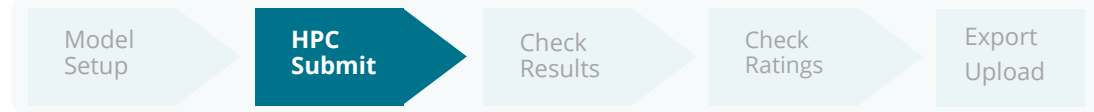
graph TD
 14["14 R
EuroNCAP Validation runs (x-ref z-ref)
complete for submission
Arthur Dent 01.10.24 09:03"]
 16["16
Positioning for z-high load cases
Marvin 01.10.24 09:09"]
 15["15
Optimized airbag time to fire for both z-ref
with validation and VT loadcases
Arthur Dent 01.10.24 09:04"]
 17["17
Optimization of airbag time to fire for
z-high load cases
Marvin 01.10.24 09:10"]
 19["19
small fix for dummy positioning
Marvin 01.10.24 09:16"]
 18["18
further refinement to 90deg pole load
cases for z-high position
Marvin 01.10.24 09:14"]
 20["20 S
Merged optimizations for z-ref and z-high
load cases. Status for sumition to
EuroNCAP
Marvin 01.10.24 09:17"]

 14 --> 16
 14 --> 15
 16 --> 17
 15 --> 19
 17 --> 18
 18 --> 20
 19 --> 20

```



# Setup in SDM: „Static Model Parts“



- “static model parts” needed

Proof that certain data of the model has not changed with respect to the validation models

- Format of “static model parts”

disassembled into groups to allow teamwork

- Should work for only some lines

- Entities that are allowed to change

with respect to Euro NCAP

- Crash pulses for sled acceleration
- Nodes of dummy & seat

- Advantage of setup in SDM

automation, consistency, efficiency

- Automatic calculation of hashes upon assembly
- Integration of hashes in reports for assessment
- Integrated in job-submit and carried out for each simulation

Begin of block of static model part

NOT allowed to change

allowed to change

```

$-----BEGIN STATIC KEY BLOCK: dummy content 1 -----
*CONTROL_ACCURACY
 0 2 0 0
*CONTROL_CONTACT
 0.0 0.0 1 2 1 0 1
 0 0 0 0 0.0 1 0
...
 5000268 5000263 5000263 0 5000263 0 0
$----- END STATIC KEY BLOCK -----
$=====
$ NODE cards
$=====
$
*NODE
5000001 -146.83640 -0.21606500 766.60809 0
5000002 -149.25600 -0.19832100 773.21039 0
5000003 -151.81239 -0.18168300 779.76093 0
```

End of block of static model part

Jobs

- FS\_Pole\_75\_x-ref\_z-high\_50M\_Sim\_1\_0012\_VT\_- (2024-09-27 13:59:48)
  - Solving job: Solving: simulation time 0.053999 of 0.2 computed (Energy Info after 5) [Job Folder Log](#)
  - Model assembly job
    - Scheduler-Information: Submitted Job 56462
  - Solving job
    - Solving: simulation time 0.053999 of 0.2 computed (Energy Info after 5) [Job Folder Log](#)

# Setup in SDM: Assessment of Results

Model  
Setup

HPC  
Submit

Check  
Results

Check  
Ratings

Export  
Upload

- Interactive web report
  - Runs everywhere in any web browser
  - Select simulations
  - Compare on the fly
- Access to all simulations & tests
  - Search
  - Filter
- Custom reports
  - Access to all data of selected simulations
  - Tables with key results
  - Colored assessments from defined requirements
  - Channel plotter
  - Synchronous video playback

The screenshot displays the SCALE.sdm web interface. On the left, a table lists simulations with columns for Star, Run Name, Owner, and Date. The selected simulation is 'FS\_AEMDB\_90\_x-ref\_z-high\_50M\_Sim\_1\_0013\_VT\_'. On the right, a 'Report' window is open, showing a 'Legend' table with columns for Test Name, Overall Result, # Invalid Result Criteria, # Mismatched Parts, # Invalid Rating Criteria, # Channels, and # Videos. Below the legend, the 'Quality Criteria for EuroNCAP' table is shown, with columns for Result, Limit, and a status indicator. The table lists various criteria such as 'Full Setup - Maximum Hourglass Energy < 10% of Maximum Internal Energy' and 'WSID Dummy - Maximum Hourglass Energy < 10% of Maximum Internal Energy'. At the bottom, the 'Validation of Static Model Parts' table is visible, listing parts like 'carpet part 1', 'carpet part 2', 'biw column (full)', etc., with their respective IDs and status indicators.

| Star | Run Name                                      | Owner       | Date                  |
|------|-----------------------------------------------|-------------|-----------------------|
| ☆    | FS_Pole_75_x-ref_z-high_50M_Sim_1_0013_VT_    | Arthur Dent | 2024-09-29, 10:59:... |
| ★    | FS_AEMDB_90_x-ref_z-high_50M_Sim_1_0013_VT_   | Arthur Dent | 2024-09-29, 10:13:... |
| ☆    | FS_AEMDB_75_x-ref_z-high_50M_Sim_1_0013_VT_   | Arthur Dent | 2024-09-29, 9:48:5... |
| ★    | FS_AEMDB_90_x-ref_z-ref_50M_Sim_1_0013_VT_    | Arthur Dent | 2024-09-29, 9:40:2... |
| ☆    | FS_AEMDB_60_x-ref_z-ref_50M_Sim_1_0013_VT_    | Arthur Dent | 2024-09-29, 9:39:0... |
| ☆    | FS_AEMDB_75_x-ref_z-ref_50M_Sim_1_0013_VT_    | Arthur Dent | 2024-09-29, 9:38:3... |
| ★    | FS_Pole_90_x-ref_z-ref_50M_Sim_1_0013_VT_     | Arthur Dent | 2024-09-28, 8:39:5... |
| ☆    | FS_Pole_75_x-ref_z-ref_50M_Sim_1_0013_Vali... | Arthur Dent | 2024-09-27, 4:27:2... |
| ☆    | FS_AEMDB_90_x-ref_z-high_50M_Sim_1_0010_VT_   | Arthur Dent | 2024-09-24, 9:11:2... |
| ☆    | FS_Pole_90_x-ref_z-ref_50M_Sim_1_0010_VT_     | Arthur Dent | 2024-09-24, 9:11:2... |
| ☆    | FS_Pole_75_x-ref_z-ref_50M_Sim_1_0010_Vali... | Arthur Dent | 2024-09-24, 9:11:2... |

| Test Name                                   | Overall Result | # Invalid Result Criteria | # Mismatched Parts | # Invalid Rating Criteria | # Channels | # Videos |
|---------------------------------------------|----------------|---------------------------|--------------------|---------------------------|------------|----------|
| FS_AEMDB_90_x-ref_z-high_50M_Sim_1_0013_VT_ | Ok             | 0                         | -                  | 0                         | 115        | 6        |

| Result                                                                       | Limit   | Status   |
|------------------------------------------------------------------------------|---------|----------|
| Full Setup - Maximum Hourglass Energy < 10% of Maximum Internal Energy       | ≤ 0.1   | 0.01676  |
| WSID Dummy - Maximum Hourglass Energy < 10% of Maximum Internal Energy       | ≤ 0.1   | 0.02547  |
| Maximum Added Mass (%) < Total Model Mass at the beginning of the simulation | ≤ 0.005 | 5.016e-4 |
| Z Displacement (mm) in the first 5 ms of the simulation                      | ≤ 10    | 4.2      |
| (Time of Maximum Head Y Displacement) + 20% < Simulation Time                | ≥ 1.2   | 1.5      |
| Number of Mandatory Channels                                                 | 115     | 115      |
| Number of Mandatory Videos                                                   | 6       | 6        |

| Part              | Status   |
|-------------------|----------|
| carpet part 1     | ...30321 |
| carpet part 2     | ...1817a |
| biw column (full) | ...de3eb |
| biw hwac (full)   | ...bc2df |
| biw ip03 (full)   | ...1c29f |
| biw pedals (full) | ...083d7 |
| sled part 1       | ...51d71 |
| sled part 2       | ...88c9c |
| contact_05 (full) | ...d86e2 |
| control_02        | ...36e3e |

# Setup in SDM: Quality Criteria of Data



- Quality criteria for Euro NCAP

*compare for each selected simulation*

- Hourglass Energy of WSID Dummy & full Setup
- Added Mass
- Displacements of Dummy

| Result                                                                       | Limit   |          |          |          |
|------------------------------------------------------------------------------|---------|----------|----------|----------|
| Full Setup - Maximum Hourglass Energy < 10% of Maximum Internal Energy       | ≤ 0.1   | 0.01943  | 0.01871  | 0.001888 |
| WSID Dummy - Maximum Hourglass Energy < 10% of Maximum Internal Energy       | ≤ 0.1   | 0.02882  | 0.02759  | 0.005757 |
| Maximum Added Mass (%) < Total Model Mass at the beginning of the simulation | ≤ 0.005 | 5.016e-4 | 5.016e-4 | 5.016e-4 |
| Z Displacement (mm) in the first 5 ms of the simulation                      | ≤ 10    | 4.2      | 4.2      |          |
| (Time of Maximum Head Y Displacement) + 20% < Simulation Time                | ≥ 1.2   | 1.5      | 1.5      |          |
| Number of Mandatory Channels                                                 | 115     | 115      | 115      | 61       |
| Number of Mandatory Videos                                                   | 6       | 6        | 6        | 6        |

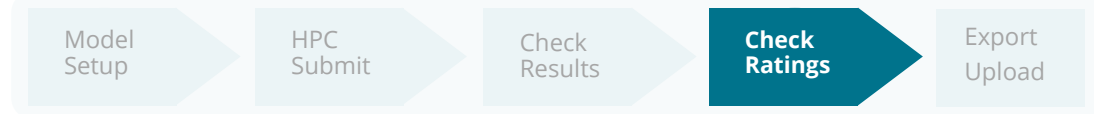
- Summary of “static model parts”

*compare to validation simulation and see instantly where are unintended changes*

- 1<sup>st</sup> column the reference simulation (from validation)
- Subsequent columns from other simulations of other load cases

| Part              |          |          |          |
|-------------------|----------|----------|----------|
| carpet part 1     | ...30321 | ...30321 | ...30321 |
| carpet part 2     | ...1817a | ...1817a | ...1817a |
| biw column (full) | ...de3eb | ...de3eb | ...de3eb |
| biw hwac (full)   | ...bc2df | ...bc2df | ...bc2df |
| biw ip03 (full)   | ...1c29f | ...1c29f | ...1c29f |
| biw pedals (full) | ...083d7 | ...083d7 | ...083d7 |
| sled part 1       | ...51d71 | ...51d71 | ...51d71 |
| sled part 2       | ...88c9c | ...88c9c | ...88c9c |
| contact_05 (full) | ...d86e2 | ...d86e2 | ...d86e2 |
| control_02        | ...36e3e | ...36e3e | ...36e3e |
| dummy content 1   | ...1670a | ...9592a | ...1670a |
| dummy content 2   | ...5414c | ...5414c | ...5414c |
| seat part 1       | ...813c9 | ...813c9 | ...813c9 |
| seat part 2       | ...3ca67 | ...3ca67 | ...3ca67 |
| seat belt content | ...61b01 | ...61b01 | ...61b01 |
| seat belt part 2  | ...df543 | ...467cf | ...df543 |

# Setup in SDM: Rating Criteria



- Rating criteria for Euro NCAP

*compare for each selected simulation see instantly  
where are still problems*

- Accelerations
- Forces
- Displacements
- ...

- Channel plotter

*inspect and compare all channel data from selected simulations*

- Interactively select and deselect simulations
- Choose location, parameter and axis to be displayed

- Video player

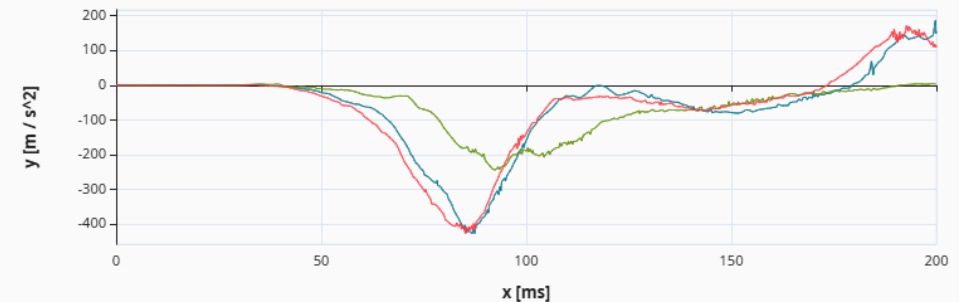
*inspect and compare all videos from selected simulations*

- Synchronously play videos side by side to compare load cases
- Inspect videos frame by frame with common slider for all videos

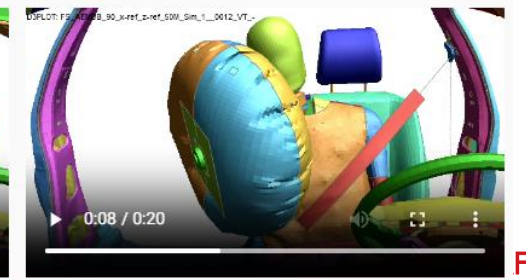
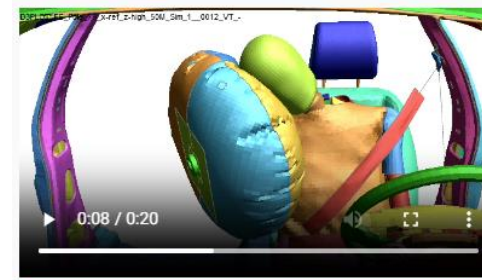
| Assessment Criterion        | Limit  |             |              |             |
|-----------------------------|--------|-------------|--------------|-------------|
| HIC15                       | ≤ 700  | 169         | 33.67        | 143.8       |
| A3ms                        | ≤ 80   | 43.31 G     | 23.76 G      | 41.9 G      |
| Upper Neck Fz               | ≤ 3.74 | 0.296 kN    | 0.465 kN     | 0.192 kN    |
| Upper Neck MxOC             | ≤ 248  | 21.9608 N m | 142.298 N m  | 24.4736 N m |
| Upper Neck MyOC             | ≤ 50   | 22.7058 N m | 46.3669 N m  | 14.2845 N m |
| Lower Neck Fz               | ≤ 3.74 | 0.154 kN    | 0.054 kN     | 0.115 kN    |
| Lower Neck Mx(base of neck) | ≤ 248  | 6.24678 N m | 0.496497 N m | 4.60146 N m |
| Lower Neck My(base of neck) | ≤ 700  | 11.7259 N m | 7.50386 N m  | 5.74929 N m |
| Chest compression           | ≤ 50   | 0.0         | 0.0          | 0.0         |
| Abdomen compression         | ≤ 65   | 0.0         | 0.0          | 0.0         |
| Pubic Symphysis force       | ≤ 2.8  | 0.0         | 0.0          | 0.0         |
| Lumbar Fy                   | ≤ 2    | 0.423 kN    | 2.07 kN      | 0.404 kN    |
| Lumbar Fz                   | ≤ 3.5  | 0.126 kN    | 1.01 kN      | 0.106 kN    |
| Lumbar Mx                   | ≤ 120  | 5.95886 N m | 120.588 N m  | 8.51914 N m |
| Head excursion              | ≤ 80   | 44.3 mm     | 45.8 mm      | 45.6 mm     |

Location: Head CoG accelerometer... Parameter: Accelerations [3] Axis: y [3]

Plot [m/(s\*s)]



00:08 / 00:20



# Setup in SDM: Export and Upload

Model  
Setup

HPC  
Submit

Check  
Results

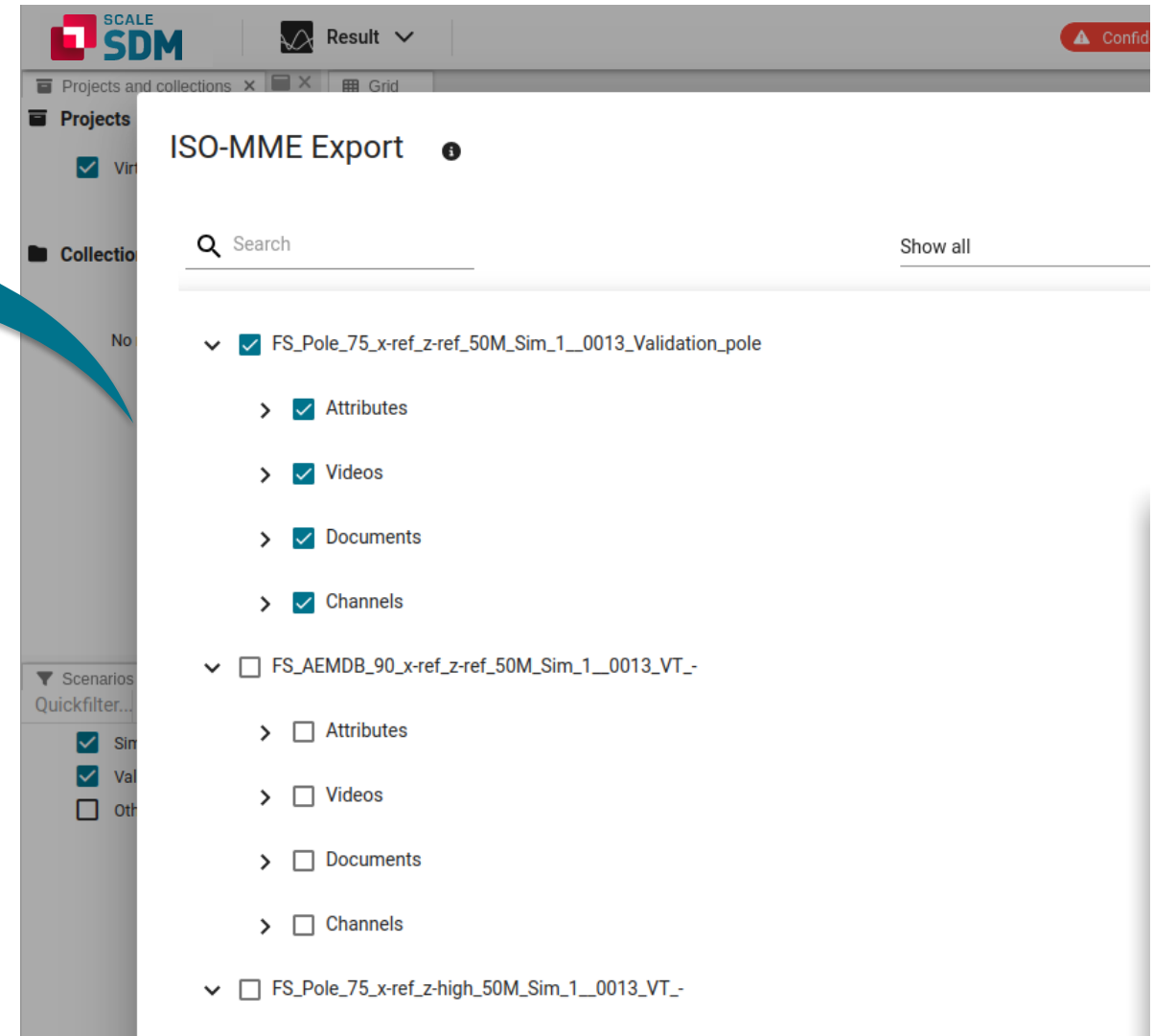
Check  
Ratings

Export  
Upload

## ISO-MME Export

|                                                                                   | Name        | Size    |
|-----------------------------------------------------------------------------------|-------------|---------|
|  | results.zip | 1.1 MiB |

- Select Simulations / Tests
  - Select the 8 simulation results
  - Export directly as ISO-MME

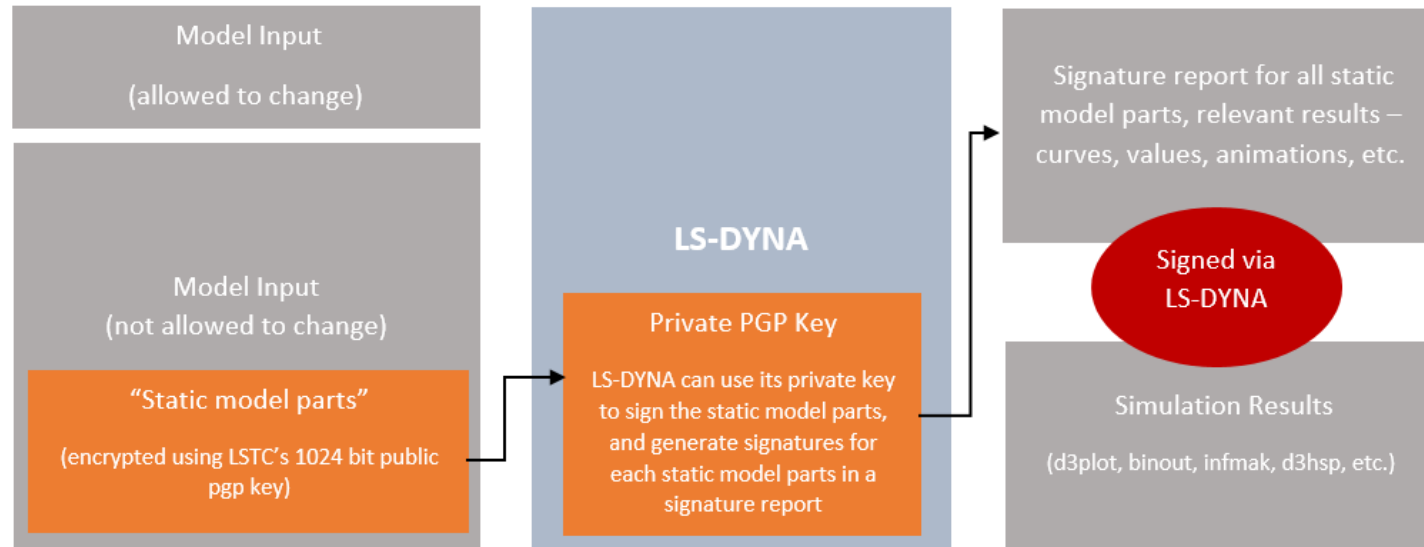


The screenshot shows the SCALE SDM web interface. On the left, a sidebar lists 'Projects' and 'Collections'. The main area is titled 'ISO-MME Export' and contains a search bar and a 'Show all' link. Below these, there are three simulation entries, each with expandable options for 'Attributes', 'Videos', 'Documents', and 'Channels'. The first entry, 'FS\_Pole\_75\_x-ref\_z-ref\_50M\_Sim\_1\_\_0013\_Validation\_pole', has all four options checked. The second entry, 'FS\_AEMDB\_90\_x-ref\_z-ref\_50M\_Sim\_1\_\_0013\_VT\_-', has all four options unchecked. The third entry, 'FS\_Pole\_75\_x-ref\_z-high\_50M\_Sim\_1\_\_0013\_VT\_-', also has all four options unchecked. A large blue arrow points from the 'results.zip' file in the left panel to the 'Attributes' checkbox in the first entry.



# Safeguarding against data manipulation

- Signing instead of hash
  - Would allow to proof that a given input was used to create a specific output (simulation result)
  - “static model parts” of OEMs would not need to be disclosed to testing authority



- Problems
  - Signatures cannot proof that “static model parts” do not contain any model data that is somehow tampering the simulation results in 1<sup>st</sup> place
  - All output needs to be signed, and it would be probably best if the output complies to the requirements of Euro NCAP (e.g. channels and key results already in ISO-MME)
  - Need to be implemented by developers of solvers

# Summary and Outlook

- Virtual Testing workflow at an industrial level
  - High complexity in the CAE world (model, load cases, processes)
  - Virtual testing adds to the complexity
  - Tools for efficient data and process management required for a productive usage
- Using an SDM-System for the Virtual Testing use cases
  - Efficient integration of the iterative development process
  - Version control, traceability and documentation
  - Automated result data preparation and checks
- Challenges & Outlook:
  - Safeguarding against malevolent data manipulation
  - Mechanisms on the FEM solvers side mandatory but not sufficient



# SO LONG, AND THANKS

FOR ALL THE FISH



<https://www.linkedin.com/company/scale-gmbh/>

**SCALE**

IT-Solutions for CAE

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# Setup in SDM: workflow buildup

