VOLVO

VaViM

Validation of Virtual Models – a pre study with SOTA analysis

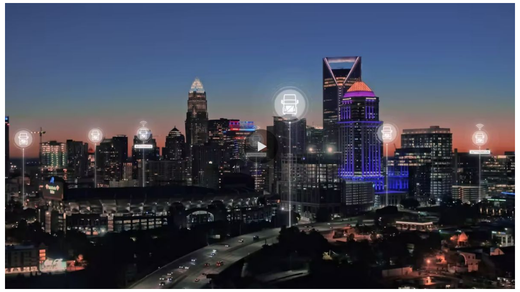
Marco Bertoni, Blekinge Institute of Technology

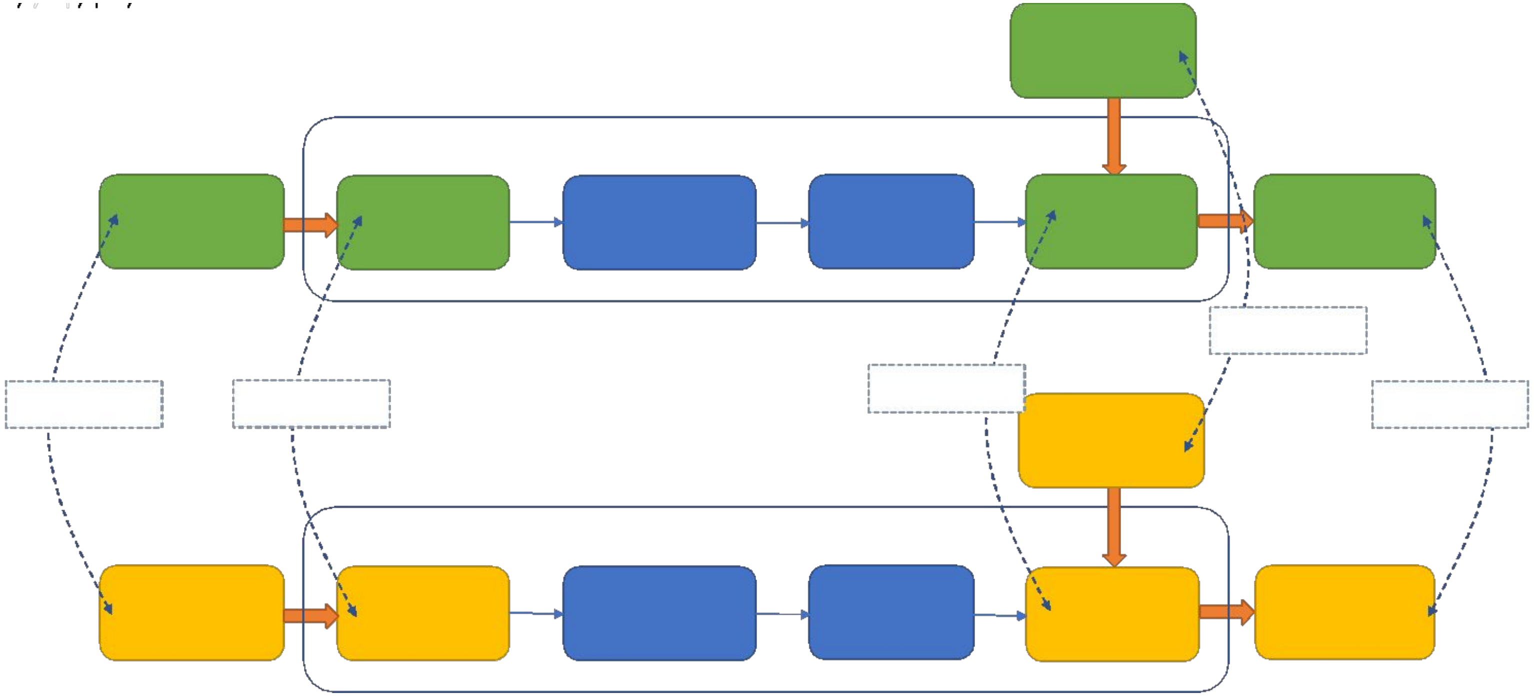
Stefan Thorn, Volvo Autonomous Solutions

With support from VINNOVA Sweden's Innovation Agency

BACKGROUND

- In order to achieve scalability and robustness, tests of self-driving vehicle systems need to be largely performed virtually
- Reliable virtual tests require validated models on sensors, vehicles and environment where the systems are to operate;





GOALS / WORK PACKAGES

- **WP1:** Analyze the **state-of-the-art** (SOTA),
- **WP2:** Identify **prioritized research questions**,

related to **validation of models** used in **virtual tests of autonomous vehicle systems**

- **WP3:** Perform a **feasibility study** with demonstration of a **model validation approach**
- **WP4:** Formulate a **draft project proposal** for future studies

WP1 – SOTA ANALYSIS

- **Focus:**
  - Interaction between environmental models and sensor models / vehicle models
  - Methods to obtain measures of the correlation with the physical equivalents.
- **Outcome:**
  - Review of 87 research publications between 2001-2022, from 15+ research centers, groups and universities;
    - Lidar/Radar/Camera modeling: 60%
    - Vehicle modeling: 15%
    - Model verification techniques: 20%
    - Miscellaneous: 5%

WP1 – SOTA ANALYSIS

On a high level, the autonomous vehicle shall perform the tasks **sense**, **plan** and **act**;

- **Sense**: sensors provide information about the environment, in which the vehicle moves, to the planning unit
- **Plan**: based on sensor inputs, the planning unit calculates the action of the vehicle
- **Act**: considering the result of the planning unit, the ego- vehicle moves in the environment accordingly.

There are well-developed virtual models for the latter two tasks: **plan** and **act**.

Models and model validation methodologies for the **sense** task are **relatively immature** (e.g.: Schlager et al. 2020; Donà and Ciuffo 2022; Magozi et al. 2022).

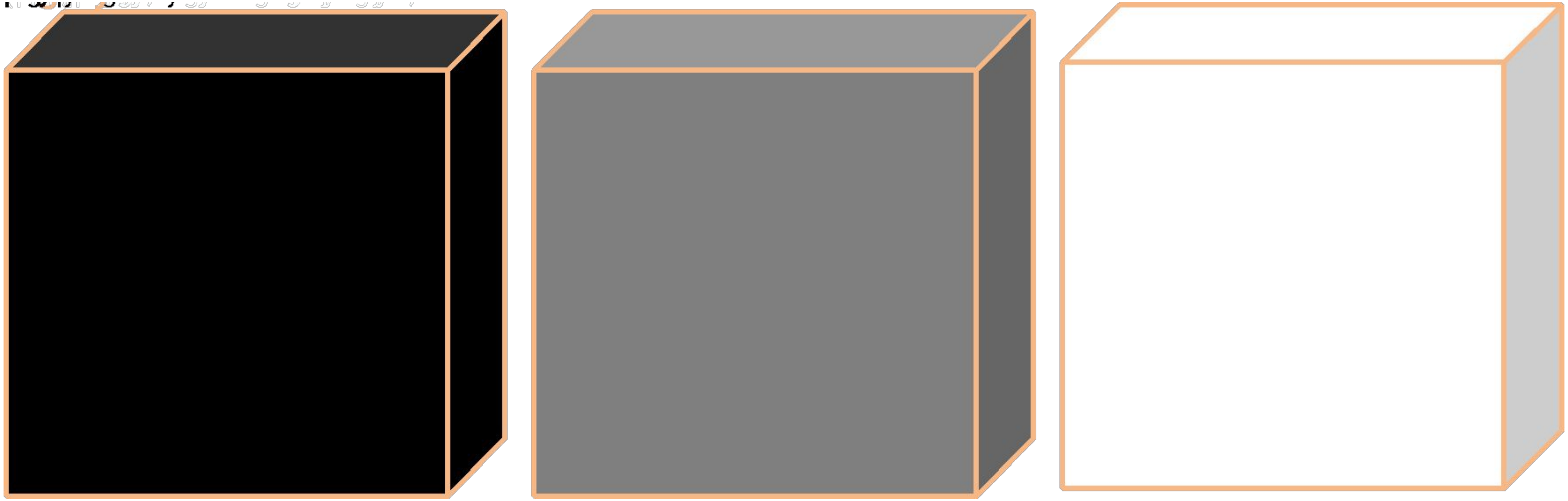
Schlager, B., Muckenhuber, S., Schmidt, S., Holzer, H., Rott, R., Maier, F. M., et al. (2020). State-of-the-art sensor models for virtual testing of advanced driver assistance systems/autonomous driving functions. SAE International Journal of Connected and Automated Vehicles, 3(12-03-03-0018), 233-261.

Donà, R., & Ciuffo, B. (2022). Virtual testing of Automated Driving Systems. A survey on Validation Methods. IEEE Access.

Magosi, Z. F., Wellershaus, C., Tihanyi, V. R., Luley, P., & Eichberger, A. (2022). Evaluation Methodology for Physical Radar Perception Sensor Models Based on On-Road Measurements for the Testing and Validation of Automated Driving. Energies, 15(7), 2545.

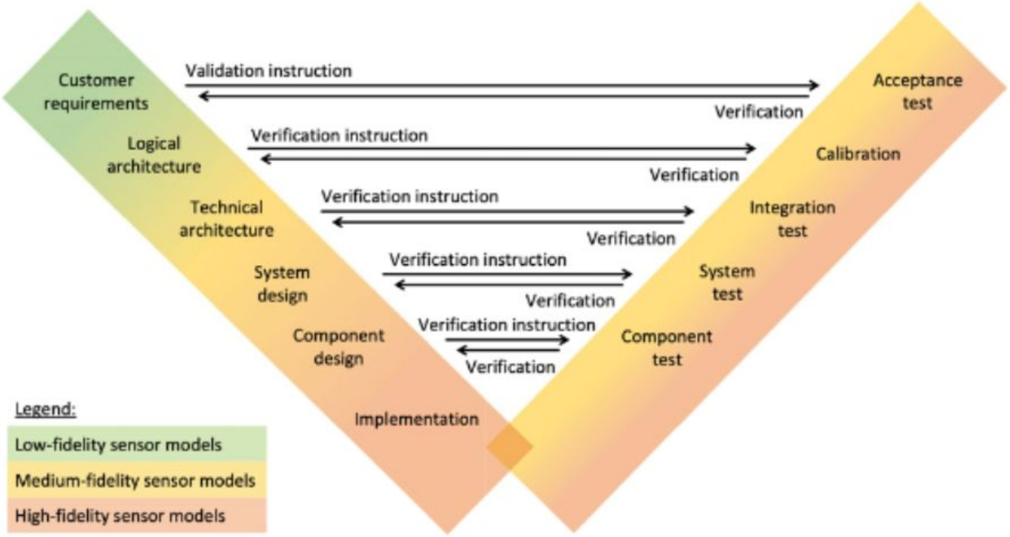
WP1 – SOTA ANALYSIS

The targeted sensor model fidelity may be grouped by three levels (Schlager et al. 2020):



WP1 – SOTA ANALYSIS

Suggested fidelity levels at different stages of the development process:



(Source: Schlager et al., 2020)

A variety of papers addressing sensor modeling and model validation techniques:

	Radar	Lidar	Camera
Low fidelity	Hanke et al. (2015) Muckenhuber et al. (2019) Stolz and Nestlinger (2018)		
Medium fidelity	Bernsteiner et al. (2015) Bühren and Yang (2006, 2007a, 2007b, 2007c, 2007d,) Cao (2015, 2017), Danielsson (2010) Hammarstrand et al. (2012a, 2012b) Hirsenkorn et al. (2015) Mesow (2006) Schuler (2007) Schuler et al. (2008) Wheeler et al. (2017)	Hirsenkorn et al. (2015) Li et al. (2016, 2020)	Hirsenkorn et al. (2015)
High fidelity	Hirsenkorn et al. (2017) Maier et al. (2018) Holder et al. (2019) Peinecke et al. (2008)	Bechtold and Höfle (2016) Brown, Blevins, and Schott (2019a, 2019b) Doria (2019a, 2019b) Fang et al. (2020), Goodin et al. (2009) Gschwandtner (2013) Gschwandtner et al. (2011) Hanke et al. (2017) OBrien and Fouche (2005) Peinecke et al. (2008), Rossmann et al. (2012), Su et al. (2019) Wang (2015) Wang et al. (2012) Woods (2019a, 2019b)	Carlson et al. (2019a, 2019b) Goodin et al. (2009) Schneider and Saad (2018) Wittpahl et al. (2018)

WP1 – SOTA ANALYSIS

Pros and cons of different fidelity levels:

	Low fidelity	Medium fidelity	High fidelity
Operating principles	Geometrical aspects	Physical aspects, detection probabilities	Rendering (rasterization, ray tracing, etc.)
Input	Object lists	Object lists	3D scene (meshs)
Output	Object lists	Object lists or raw data	Raw data
Pros	Low computational power needed	Trade-off between computational power and realistic output, a lot of effects can be considered	Most realistic output
Cons	High abstraction level, no realistic output	Lots of training data may be required	High computational power needed
V-model phases	First specification phases	Specification phases in the middle and integration phases	Component specification, implementation and integration phases
Design question	What point(s) or shape represents objects and which need to be in the line of sight for detection?	What point(s) or shape represents objects and which need to be in the line of sight for detection? What effects are considered?	What is the detection threshold? Which effects, material properties, and weather conditions are considered?

WP1 – SOTA ANALYSIS

CONCLUSIONS:

- There are well-developed virtual models for the **plan** and **act** tasks
- Models and model validation methodologies for the **sense** task are **relatively immature**
- Several papers are addressing initiatives to **close the sense gap**

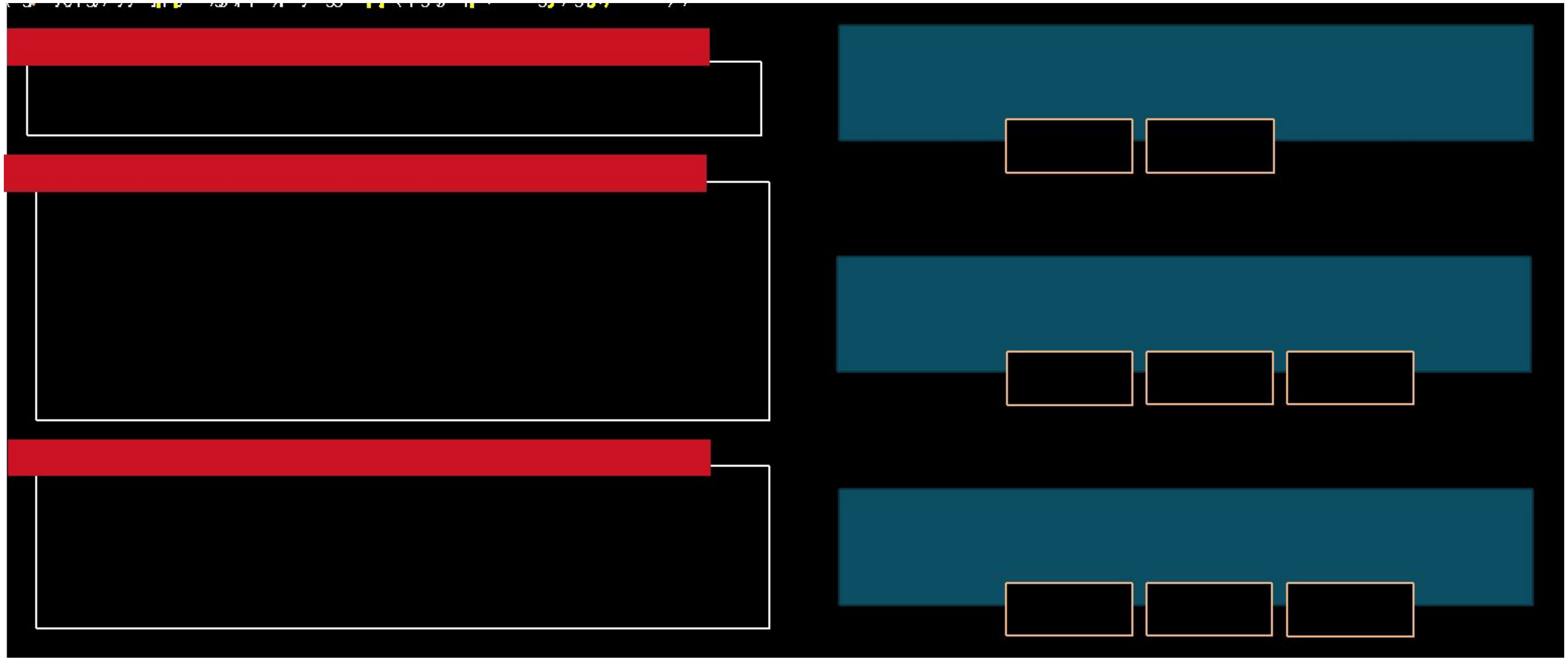
REMAINING GAPS:

1. *No generally accepted **evaluation criteria** to validate a virtual sensor model, nor **unified testing procedure***
2. *Knowledge lacking on how to **evaluate the value** (benefit vs. cost) of a selected modeling approach to the stakeholders of the simulation output*

VOLVO

WP2 – RESEARCH QUESTIONS

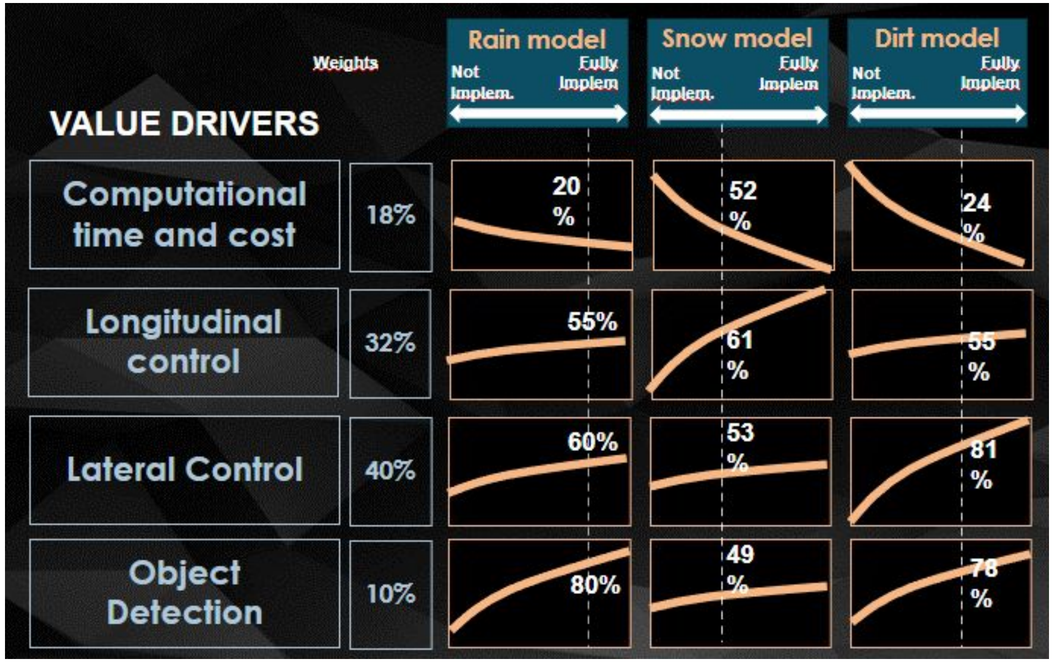
Three high level research questions were identified:



WP2 – RESEARCH QUESTIONS

[redacted]

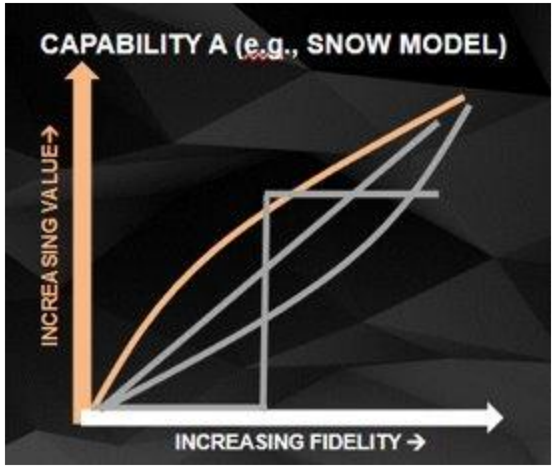
Example:

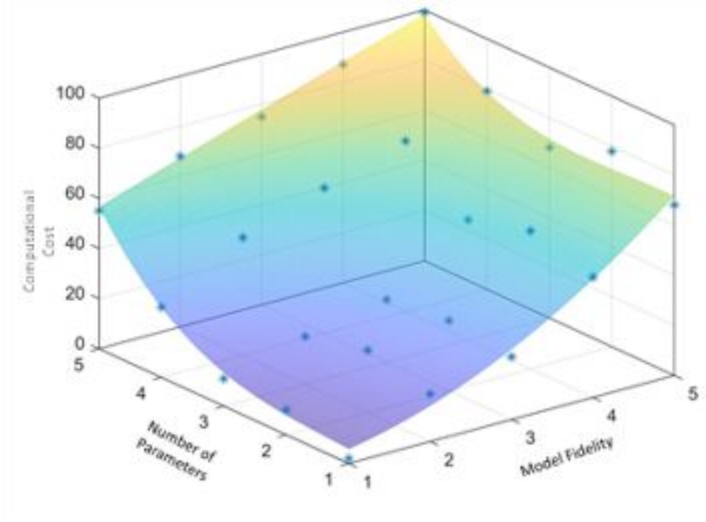


WP2 – RESEARCH QUESTIONS

[redacted]

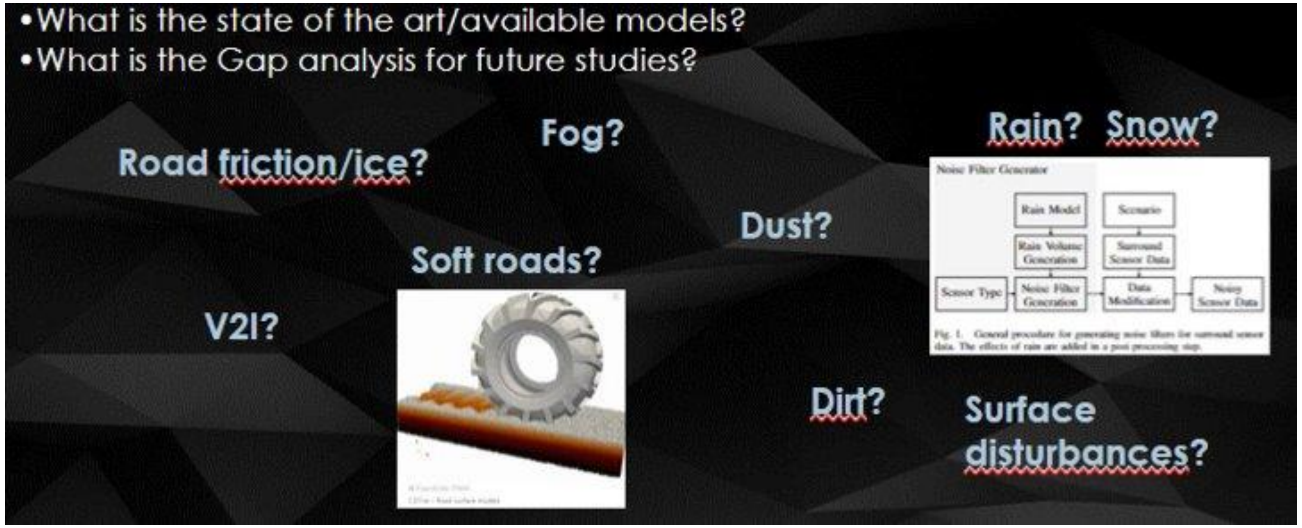
Examples:





WP2 – RESEARCH QUESTIONS

Examples:

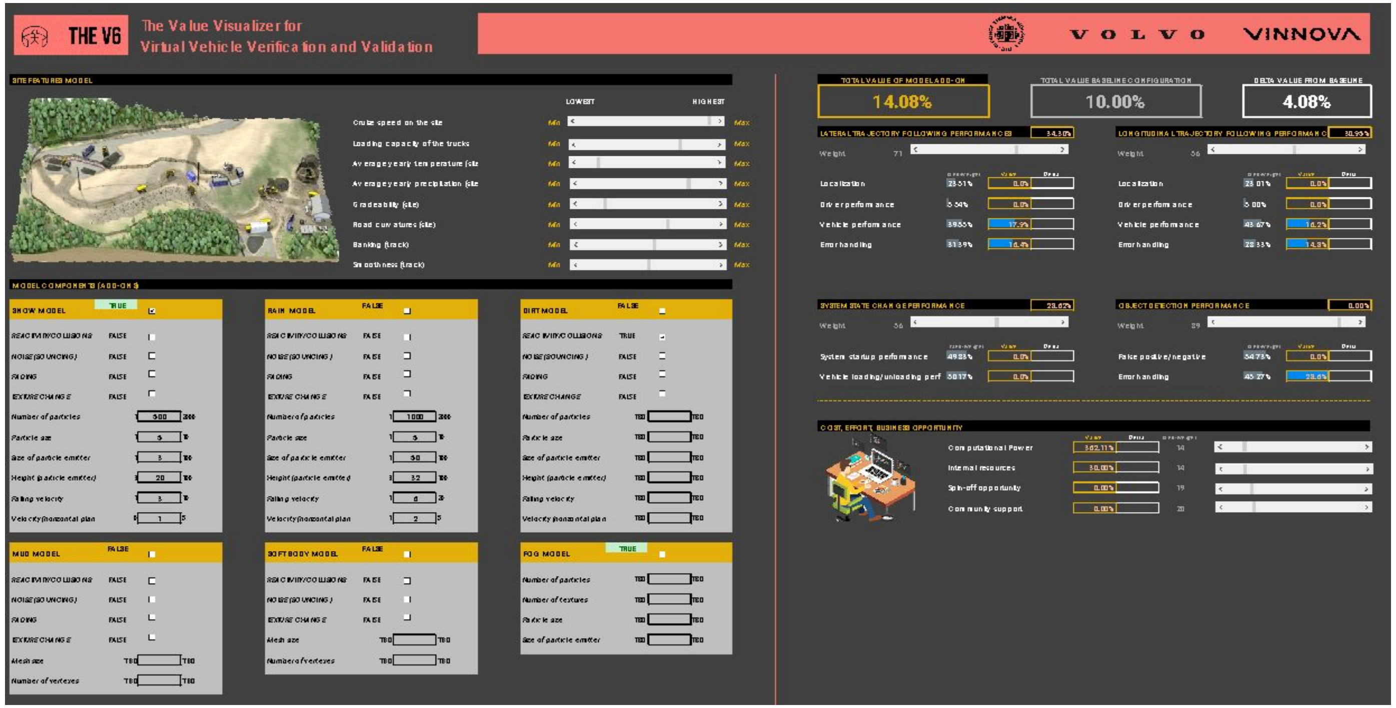


WP3 – FEASIBILITY STUDY

Concept tool to visualize the value of a selected modeling setup for simulation of autonomous vehicles

Goal:

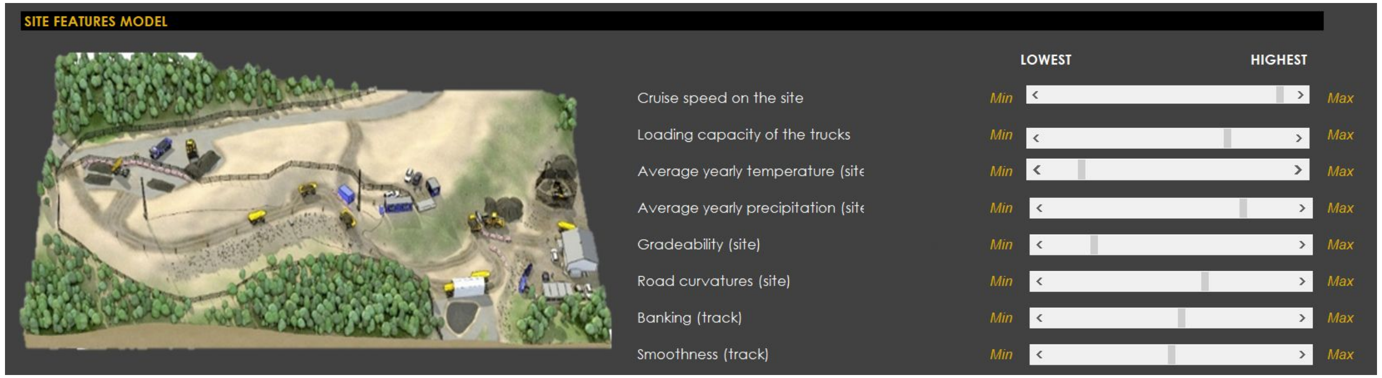
- How valuable is a model component (e.g., a snow model) based on the specific scope with the simulations?
  – Balances the value to estimated cost (computational power, internal resources) required
  – Guides to model components to be prioritized and/or exploited in the simulation setup

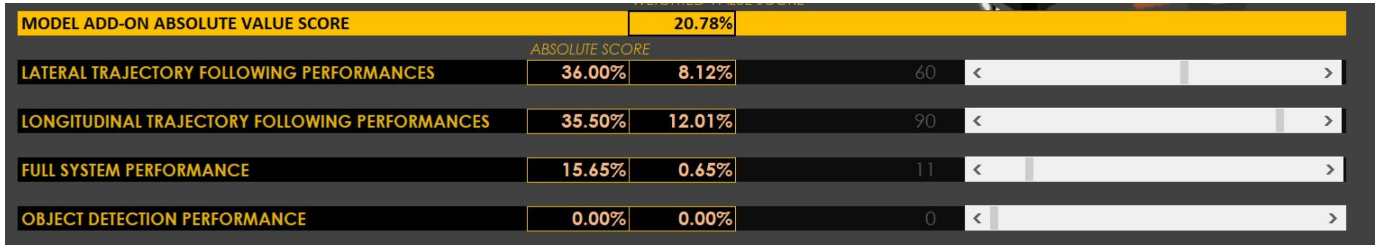


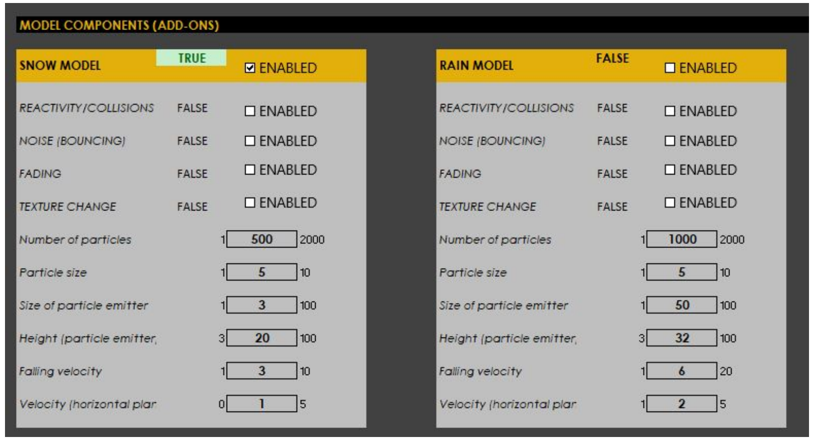
WP3 – FEASIBILITY STUDY

Inputs:

- Site features: Characteristics of the operational design domain
- Value drivers: phenomena that are important to be evaluated by the simulation
- Model components: Selection of modeling capabilities and granularities to be evaluated







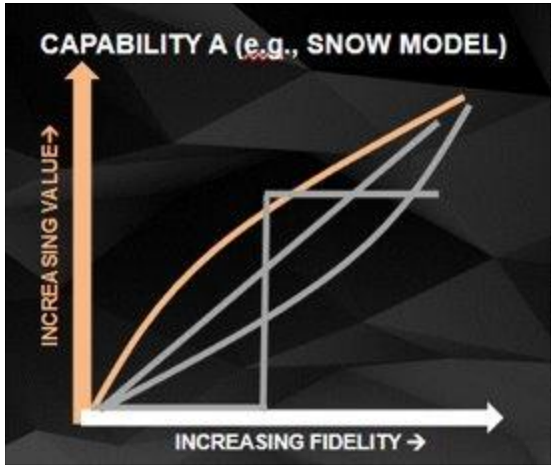
WP3 – FEASIBILITY STUDY

Setup:

- Qualitative rather than quantitative evaluation;

  – Which new model components (and level of granularity) give <u>most</u> added value to the simulation setup, not stating an absolute number on how much added value

- Modeling knowledge is indicated with a maturity index (1-5);
  – The level of existing knowledge of the relation between a model component and the its ability to address a particular part of the value drivers
  – How much can you trust your value adding results
  – Where are the important knowledge gaps



WP4 – PROJECT PROPOSAL

Status

- Draft project proposal addressing:
  - research questions identified in WP2
  - concept tool demonstrated in WP3
- Will now reach out for partner interests for future collaborations

- Contact: stefan.thorn@volvo.com

V O L V O