Usage of ASAM OpenX standards in Offroad Applications

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Virtual Proposal Workshop

Agenda – Offroad Applications

- Introduction
- Motivation
- User stories
- Offroad features and requirements
- Proposed approach for concept project
- Review of selected examples
- Expected outcomes
- Relevant Standards
  - ASAM OpenX Standards
  - Other standards

Introduction

- ASAM standards within the Simulation domain have been driven by automotive industry need for testing and developing on-road ADAS/AD functions
- ASAM standards apply to other application domains, particularly as scenario-based and simulation-based testing becomes more prevalent
  - Offroad Applications Areas - Landfill, construction, agriculture, and mining

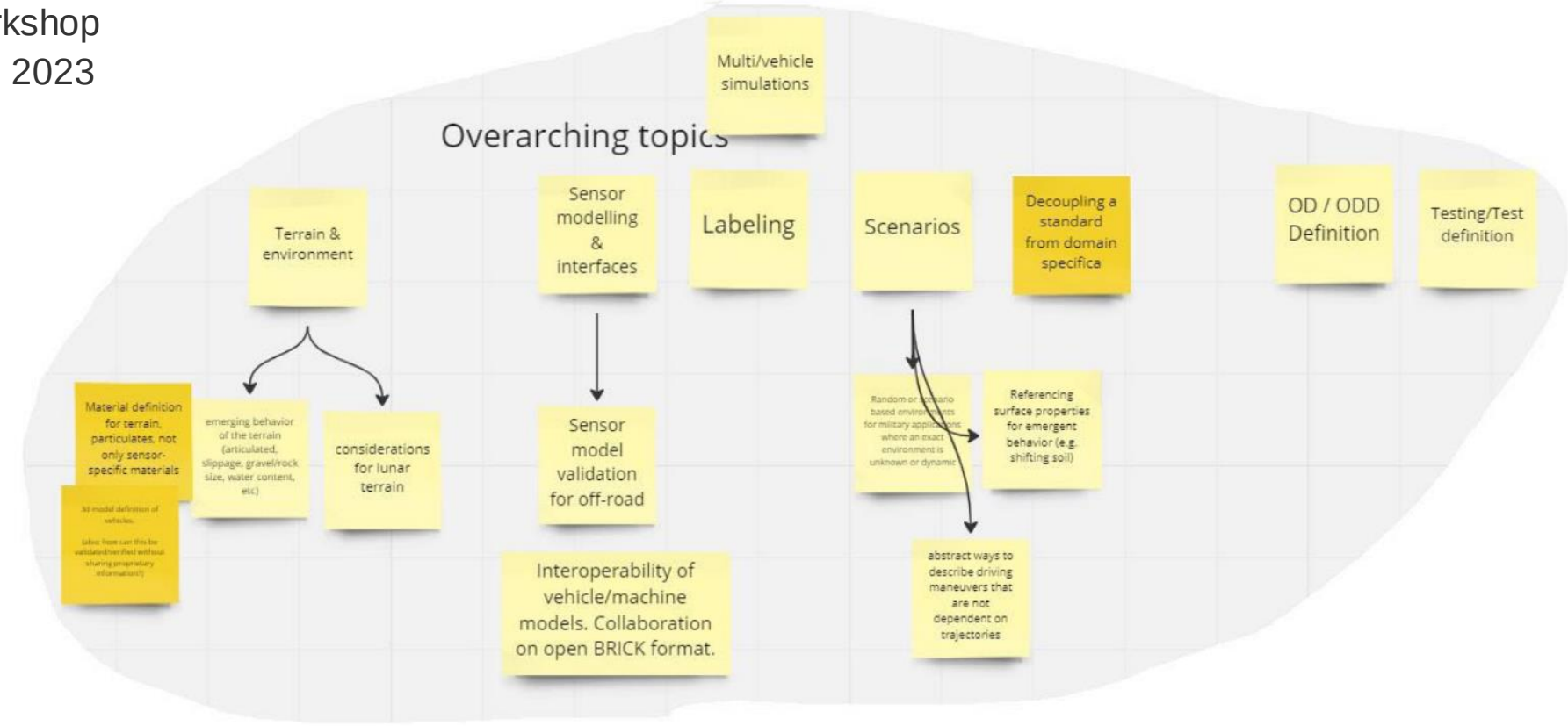
Motivation for the Activity

Interest in offroad applications

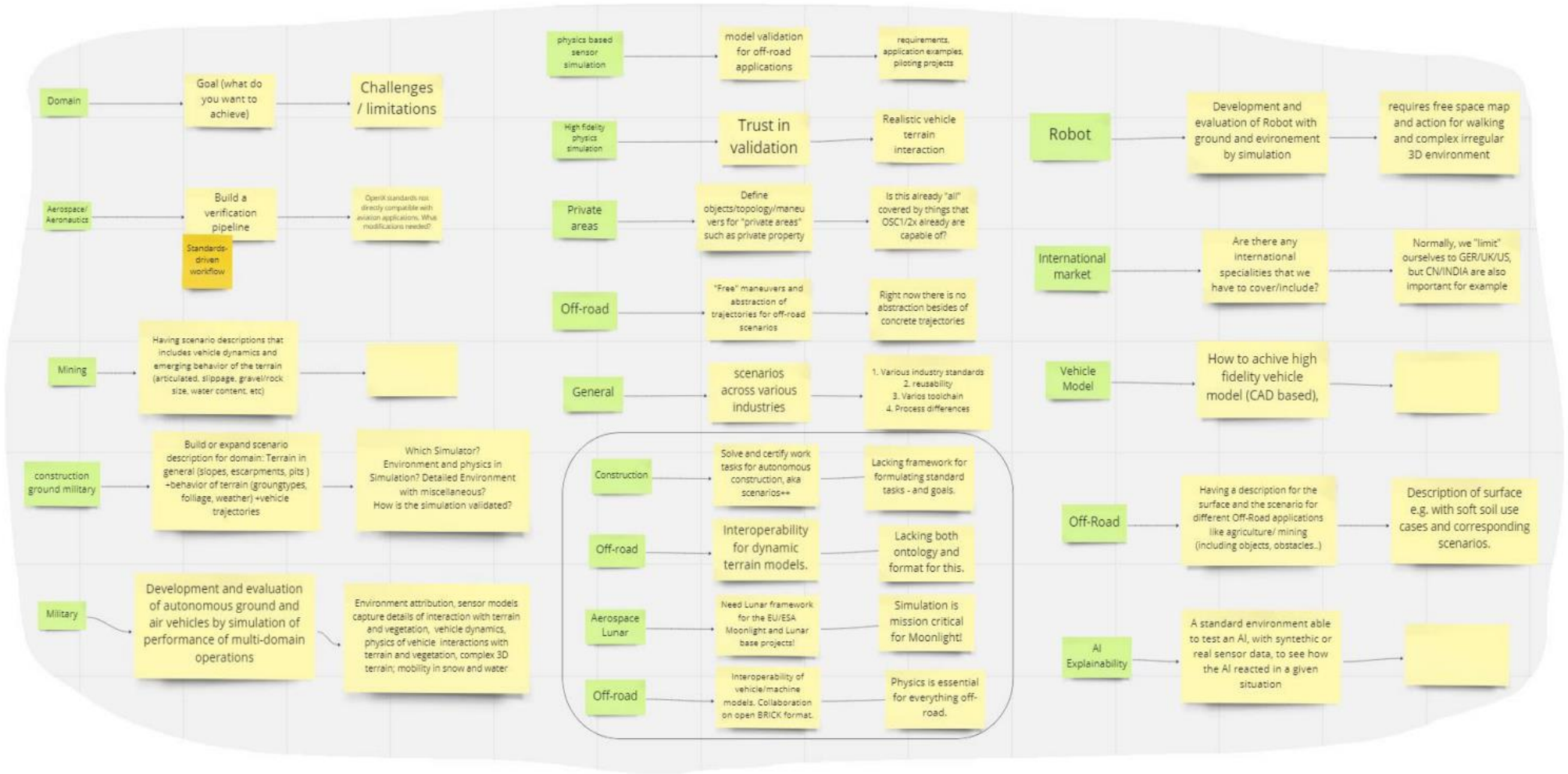
- Landfill
- Construction
- Agriculture
- Mining
- Military
- Recreational

Offroad Applications Ideation Group

- ASAM OpenX standards for offroad applications
- Ideation Workshop
- February 23, 2023



Ideation Workshop Topic Areas



Characteristics of Offroad Applications

- Potential beneficial features
  - restricted public access
  - controlled environments
  - clear understanding of other traffic participants
  - smaller Operational Design Domains

- Offroad application requirements
  - vehicle-terrain interactions
  - complex terrain and vehicle dynamics
  - working in close proximity with other vehicles

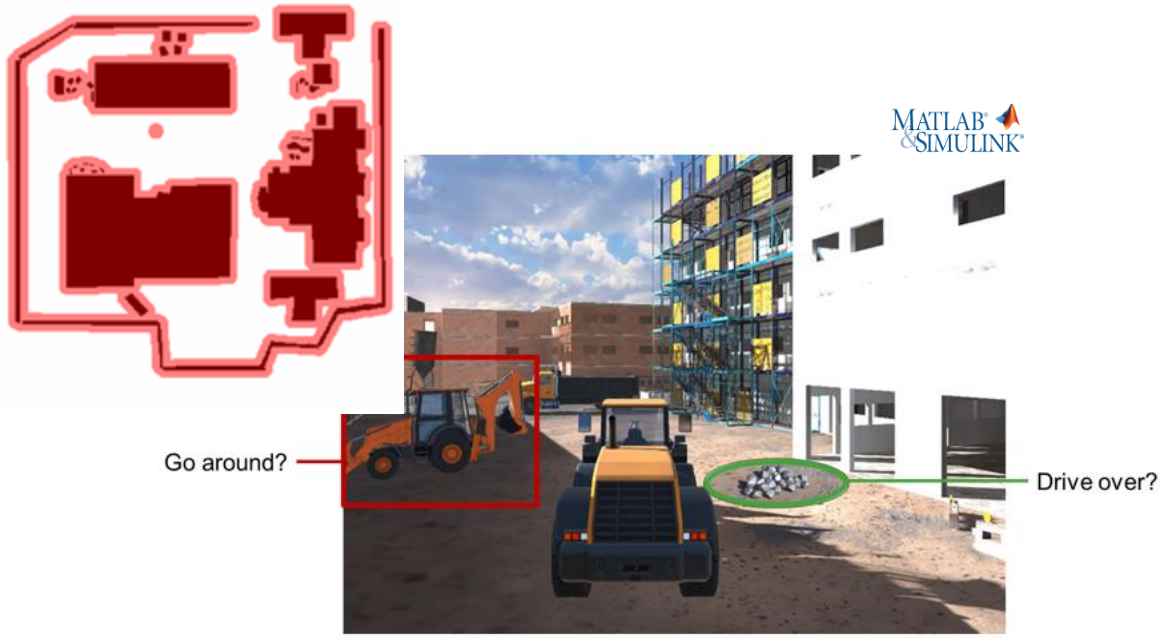
Offroad Challenges

- Complex 3D terrain
- Representation of the subsurface
  - Soil strength, density, temperature, water content
  - Effects on mobility
- Surface materials (including link between appearance and physical characteristics)
- Vehicle-terrain interaction and material dynamics
  - Mud and water spray
  - Mud and snow deformation
  - Accumulation of material on vehicles
- Object representation
  - Vegetation and other natural obstacles
  - Meshes, materials, physics
- Weather conditions
- Occlusion of sensors
  - Mud, snow, dirt in the air and on camera lens

Operations and Activities

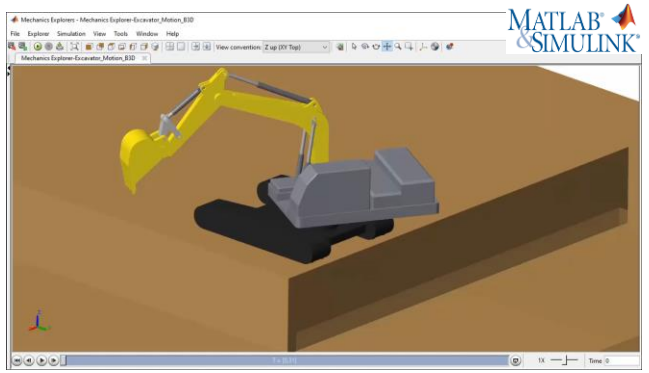
Based on where the activity is happening

Movement on the driving plane



- Navigation
- Interaction with objects

Movement outside the driving plane



Excavating a pit

Manipulating material

Loading a vehicle

Excavator Simulation Model - https://www.mathworks.com/matlabcentral/fileexchange/119268-excavator-design-with-simscape

MathWorks Webinar on "Design and Simulating Autonomy for Construction Vehicles", https://www.mathworks.com/videos/design-and-simulating-autonomy-for-construction-vehicles-1679066541903.html

Kaibab National Forest, 2019,[Grassland Restoration 2019(4886791186).jpg][Photograph], https://commons.wikimedia.org/wiki/File:Grassland_Restoration_2019_(4886791186).jpg, CC-BY-SA-4.0.

Proposed Approach

Exercise the Standards

Offroad Applications Concept Project

Hypothesis: Current standards do not adequately support requirements for offroad applications

Exercising the Standards

Use cases and requirements for offroad applications

Use Cases Driven by Personas

- What kind of simulations do users want to build for offroad applications?

Vehicle Developer

- Develop and test mechanical, electrical, hydraulic, and electro-mechanical systems for offroad scenarios
- Build physics-based vehicle models to test vehicle behavior in 3D simulations

Autonomy Developer

- Create algorithms, software and supporting documentation for perception, planning and control of the vehicles and their support tools
- Collect sensor and mobility data for training AI/ML models
- Work with control engineers to investigate, test, and select software toolsets or hardware components and peripherals

Test Engineer

- Develop and evaluate detailed offroad test scenarios for both component and system level testing and validation.

System Integration Engineer

- Create scenarios to help understand the requirements for systems.
- Create schematic representations of mechanical, electrical, hydraulic, and electro-mechanical systems
- Work with other disciplines to create the specifications that outline the control system logic necessary for haul truck functions

Site Manager

- Manage and assess the application of vehicle systems on-site.
- Work with the environment, health, and safety teams and security teams to conduct regular risk assessments
- Maintain a risk register and develop and implement risk mitigation plans

Technical Requirements Driven by Use Cases

Vehicle Developer

- Represent vehicle components relevant to VTI/mobility
- Represent driveline/powertrain for the vehicle
- Modelling of heavy machinery on soft terrain (deep tracks)
- Represent vehicle loads including specification of type and volume of material being transported and estimating effects caused by the load including stability, traction, deformation of road surfaces, and maneuverability
- Evaluate or optimize efficiency of vehicle systems in the operating environment

Autonomy Developer

- Model vehicle perception and mobility and dynamics as it traverses an offroad environment
- Model GPS sensor data accounting for effects of vehicle movement, terrain, and vegetation including loss of signal, multipath, etc.
- Model common sensors (e.g., LiDAR, EO camera, IR, radar, GPR, etc.) accounting for effects of vehicle movement, terrain, and vegetation including occlusion, material attribution, etc.

Test Engineer

- Evaluate or optimize efficiency of vehicle systems in the operating environment
- Represent effects of adverse conditions (dust, standing water, mud, etc.) on terrain properties and on sensors (e.g., occlusions from dust clouds, water spray, water or mud on lenses, etc.)
- Estimate effects of vegetation on sensors and vehicle mobility
- Extract sensing and mobility data for learning how to traverse terrain

System Integration Engineer

- Generate prior information to the autonomy stack (e.g., simulate extraction of maps, etc. from previous drives, UAS, or other sources)
- Represent vehicle loads including specification of type and volume of material being transported and estimating effects caused by the load including stability, traction, deformation of road surfaces, and maneuverability
- Share and reuse off-road scenarios in a common format for shared understanding

Site Manager

- Incorporate fuel depot/charging stations (capacity, charge/refuel rate)
- Collecting performance data for benchmarking systems

Exercising the Standards

Example Scenarios to Investigate Level of Support

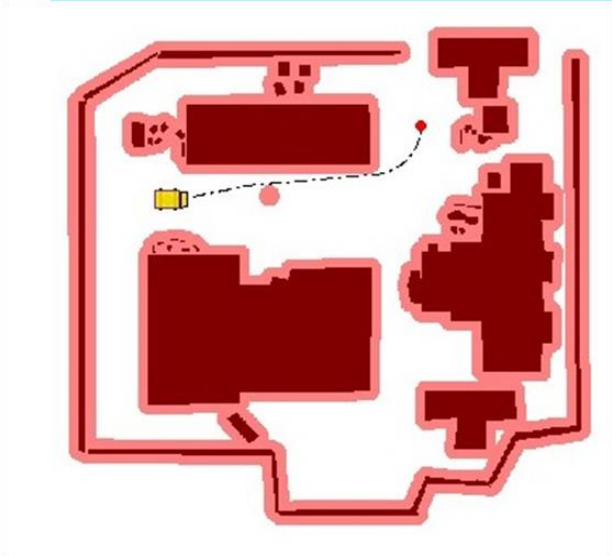
Scenarios

- **Basic Navigation (Moving from Point A to Point B)**
  - Following a Path
  - Finding a Path
  - Carrying a Load
  - Using Sensors to Respond to the Environment
  - Navigating without GPS
- **Vehicle Interaction**
  - Following a Lead Vehicle
  - Environmental Effects
  - Interacting with Traffic
  - Incorporating drones – ground-air vehicle teaming
- **Loading and Hauling**
  - With a Hauler
  - With an Excavator
  - Evaluating Fuel Efficiency

Finding a Path

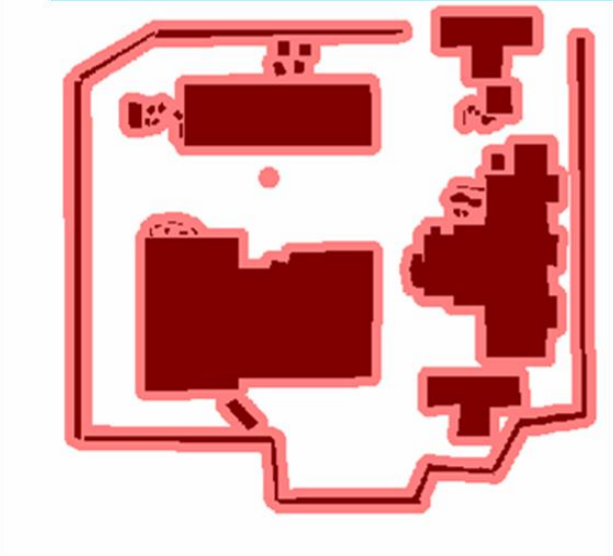
Basic Navigation (Moving from Point A to Point B)

Global Path Planning



Find a path from a start position to a goal position that is obstacle-free and satisfies operators' requirements

Local Path Planning



Define what vehicles should do in certain situations, such as running into an unexpected obstacle

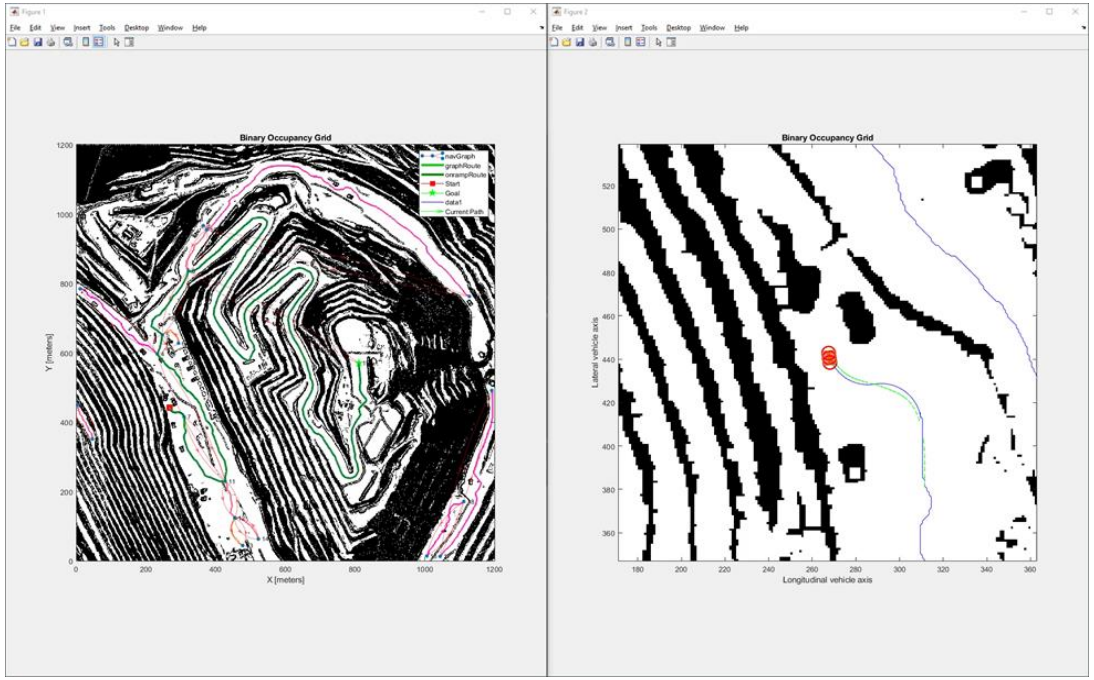
MathWorks Webinar on "Design and Simulating Autonomy for Construction Vehicles", https://www.mathworks.com/videos/design-and-simulating-autonomy-for-construction-vehicles-1679066541903.html

Following a path requires handling unexpected objects

Following a Path

Basic Navigation (Moving from Point A to Point B)

- Evaluate the performance of the path following algorithm in an environment characterized by soft soils
- Define safe velocity profiles for the controller
- Define metrics for path planning and following such as safe distance from obstacles

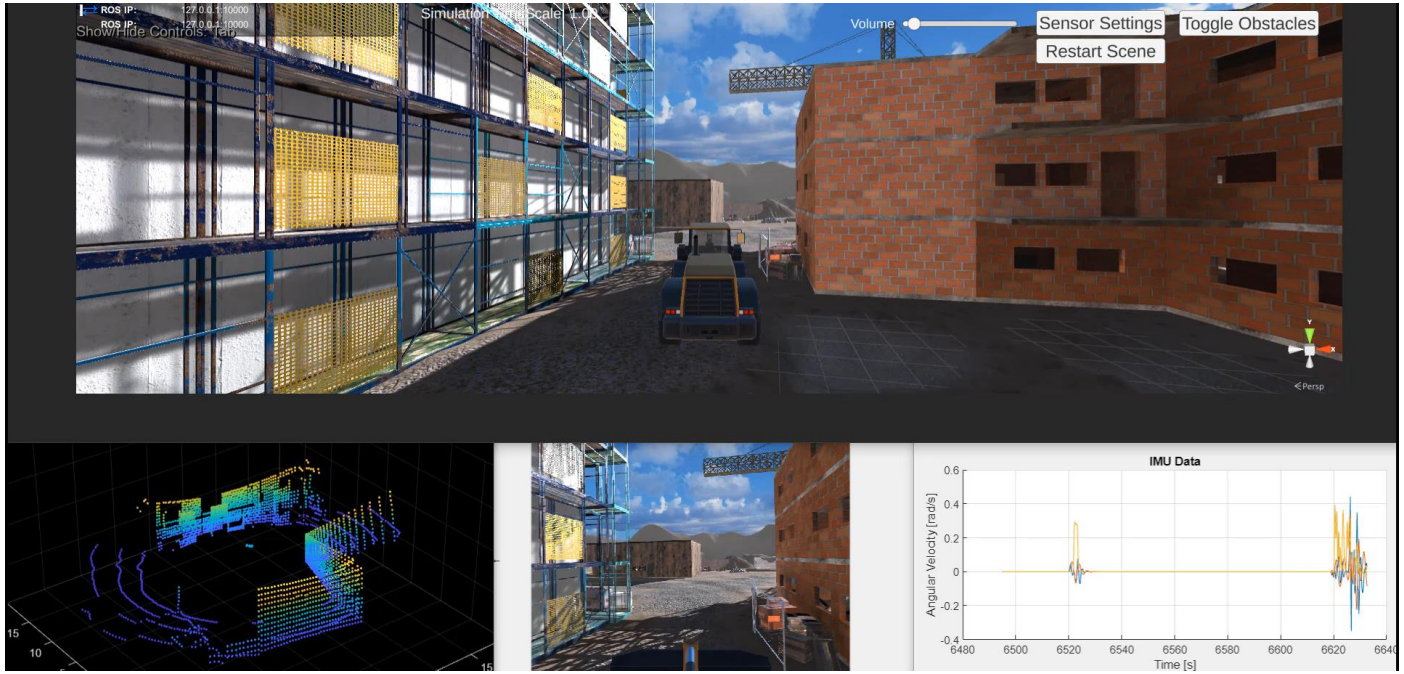


MathWorks Navigation Toolbox Example - https://www.mathworks.com/help/nav/ug/offroad-planning-on-digital-elevation-models.html

Using Sensors to Respond to the Environment with/without GPS

Basic Navigation (Moving from Point A to Point B)

- Requirements for Perception Systems
- Defining different Operational Design Domains (ODDs) for off-road scenarios
- Define sensor failure and edge cases – maintaining localization in case of loss of sensor data



Hauling a Load

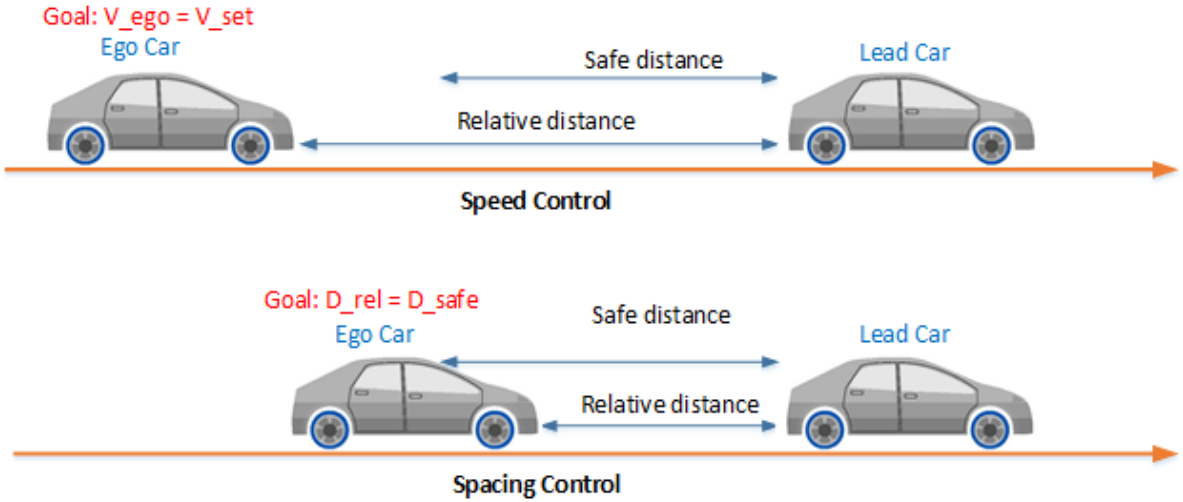
Basic Navigation (Moving from Point A to Point B)

- Define the impact of carrying a load on the vehicle's interaction with the terrain and impact on controller performance
- Assess whether adjustments in acceleration, braking, steering is required due to increased weight and altered center of gravity
- Assess slipping, tipping, sliding or immobilization
- Assess whether the vehicle can successfully reach the goal without rollover or loss of material while optimizing transportation time, fuel consumption, and tire wear.

Vehicle Interaction – Following a Lead Vehicle

Loading and Hauling

- Define speed and relative distance to be in optimal ranges
- The vehicle uses local sensor data to determine if the soil is soft such that the follower vehicle should deviate in its path sufficiently to avoid damage to the roadway or becoming stuck.

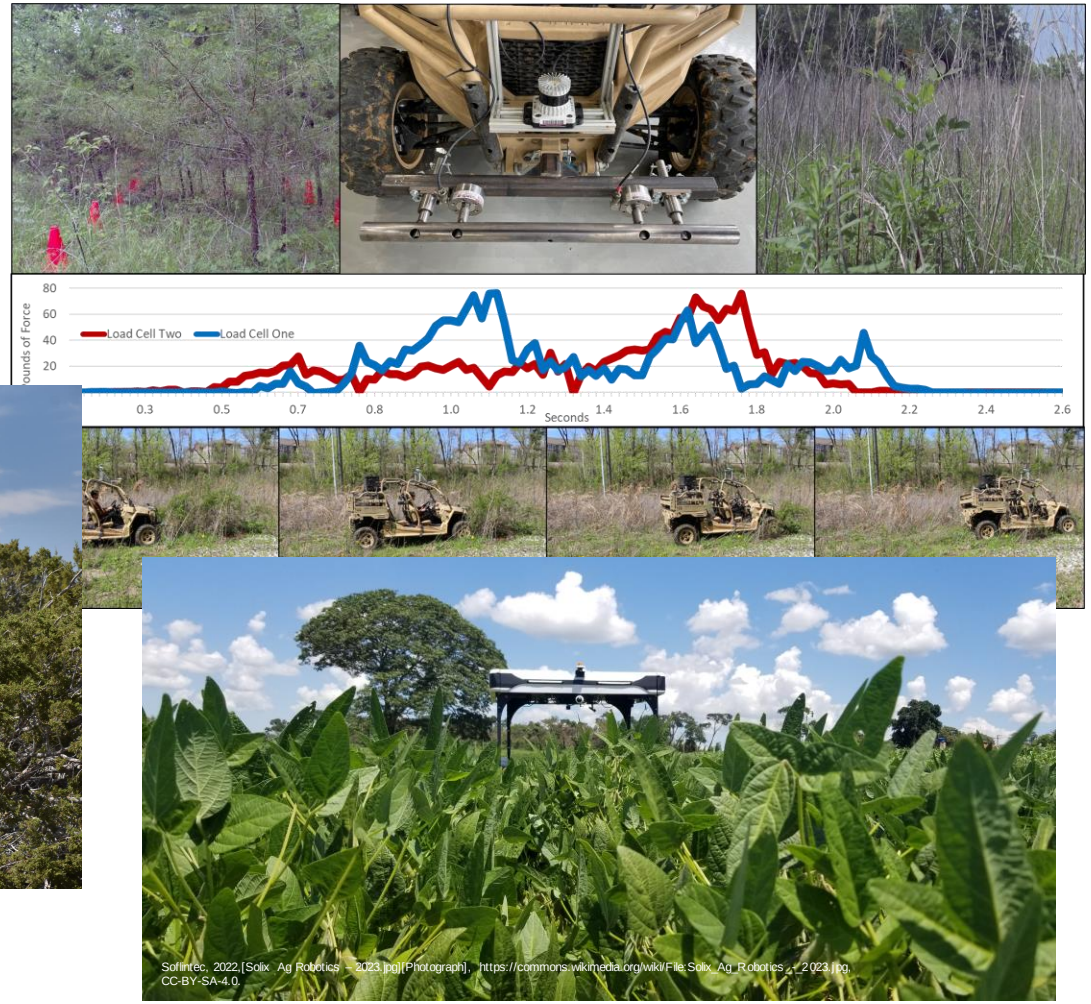


Dealing with Vegetation

- Many tasks require interaction with different levels of vegetation
  - Infrastructure inspection
  - Logging
  - Site clearing
  - Agriculture

- Effects on
  - Perception
  - Mobility
  - Tasks

- Object representation
- Physics

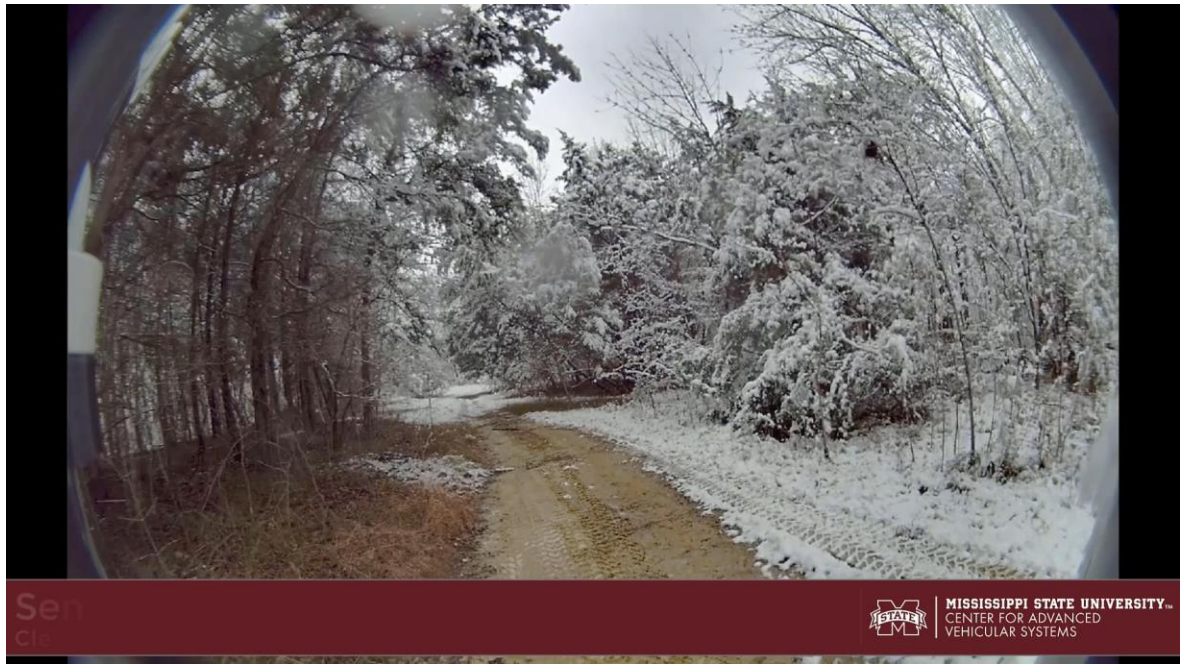


Kaibab National Forest, 2019.[Grassland Restoration 2019(48867911186).jpg][Photograph], https://commons.wikimedia.org/wiki/File:Grassland_Restoration_2019_(48867911186).jpg, CC-BY-SA-4.0.

Sofiintec, 2022.[Solix_Ag_Robotics_-_2023.jpg][Photograph], https://commons.wikimedia.org/wiki/File:Solix_Ag_Robotics_-_2023.jpg, CC-BY-SA-4.0.

Dealing with Environmental Effects

- Effect of weather and environmental conditions such as rain, fog, dust, snow, etc. on vehicle's perception and mobility

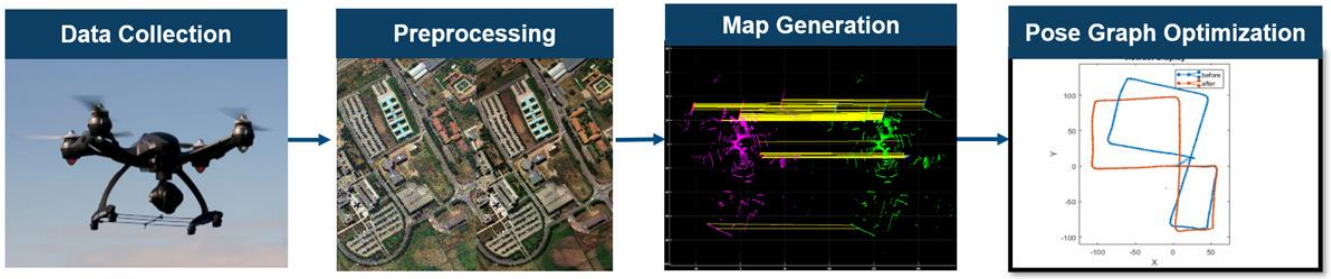


Interacting with Traffic

- Define traffic negotiations
- Requires simulation of the second agent
- Define constraints such as traversable space and width for the vehicle

Video courtesy of Mathworks.

Incorporating Drones – Ground-Air Teaming

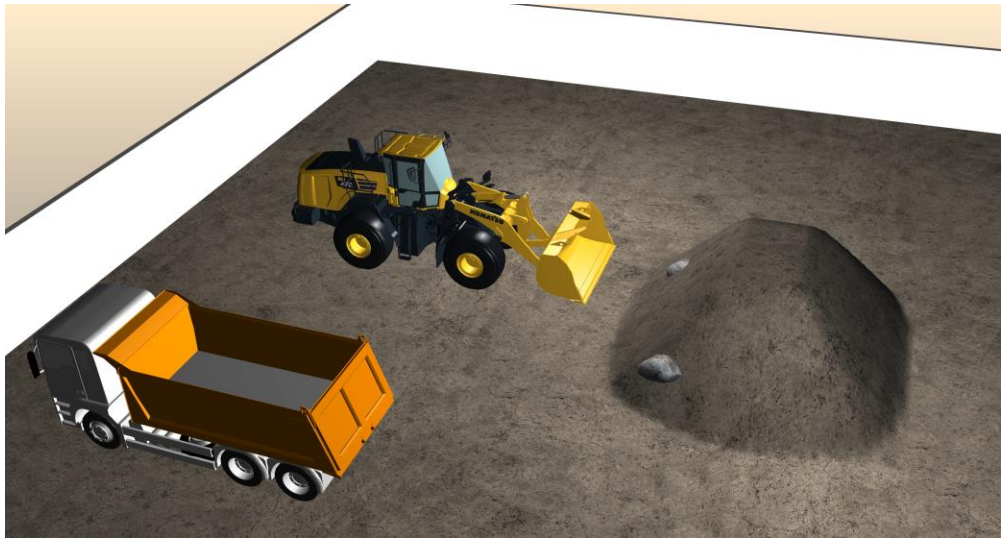


Loading and Unloading Material

Vehicle Interaction

- Define ability to position the vehicle next to the hauler, to manipulate the material, and to load the hauler
- Define ability to successfully load the hauler in an optimal time without tipping or colliding with the hauler
- Requires simulation of the hauler, models of articulating arms and buckets
- Requires simulation of the manipulation of the material

Loading the Vehicle

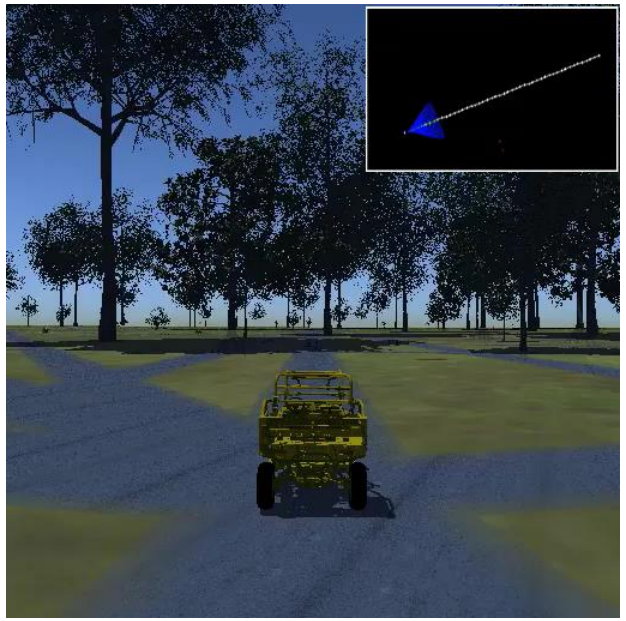


Video courtesy of Algoryx.

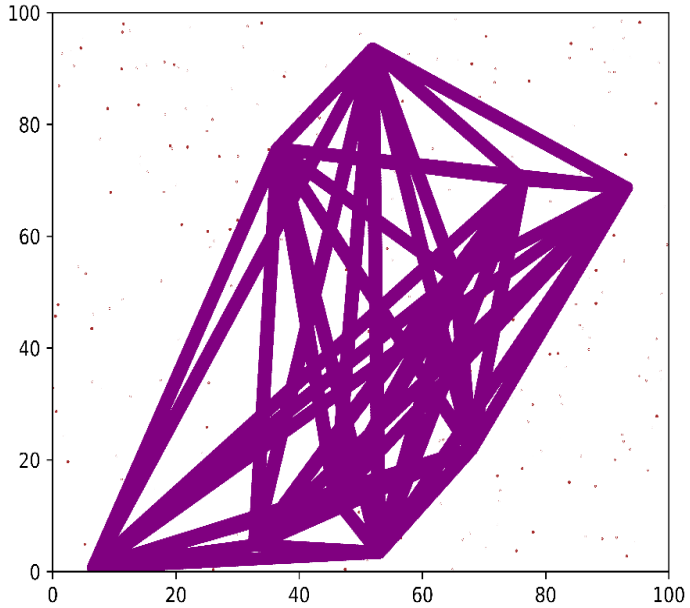
Evaluating Fuel Efficiency

- Site development and management
  - Evaluate fuel use
  - Determine optimal placement of depots, consider different power options (gas, diesel, electric, hybrid, etc.)
  - Fleet management and task assignment

- Environmental effects on vehicle powertrain and fuel efficiency
  - Travel on slopes, soft soils



Video courtesy of Mississippi State University. .



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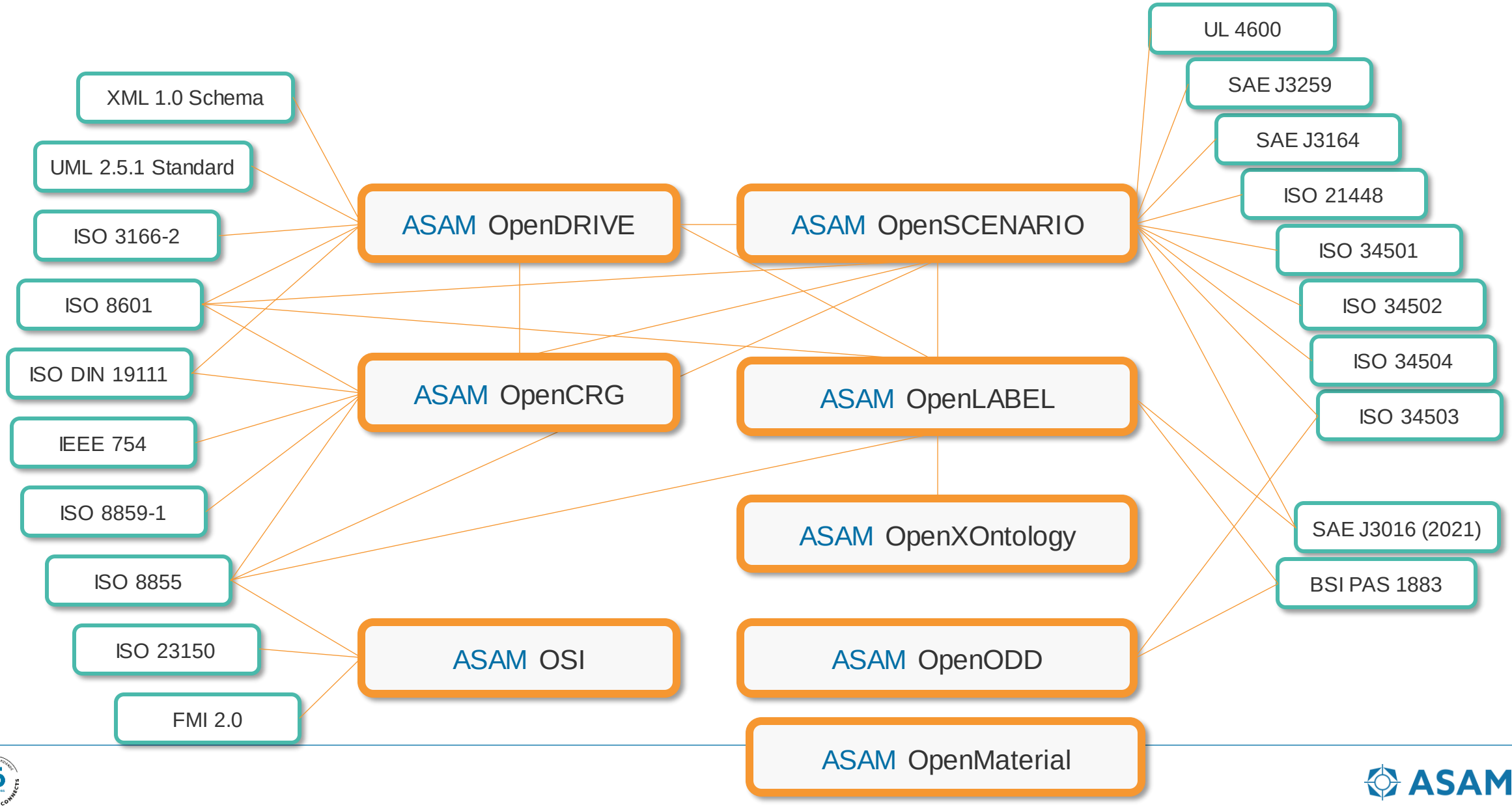
Exercising the Standards

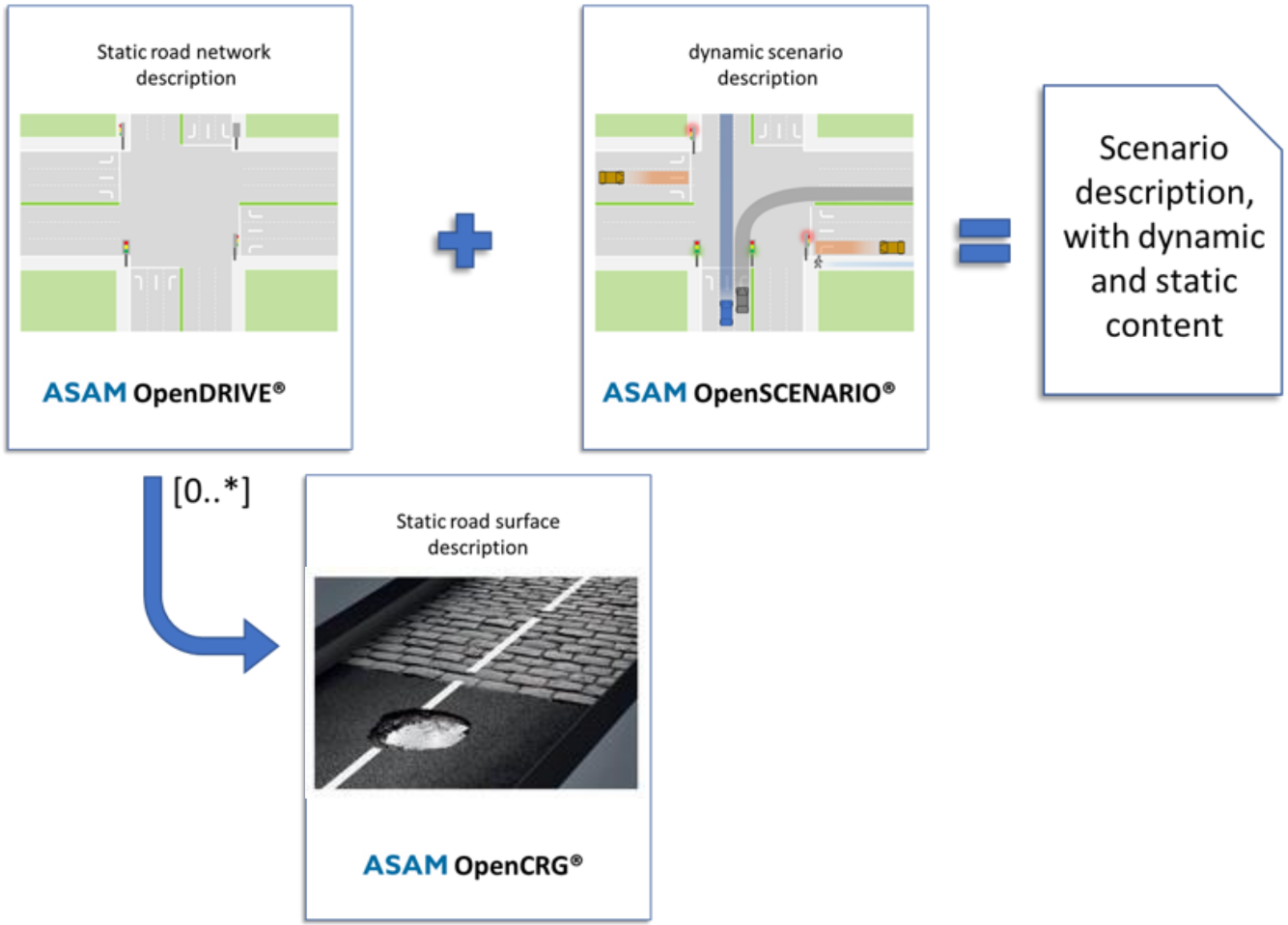
Finding Gaps in Current Standards

Interconnected Standards



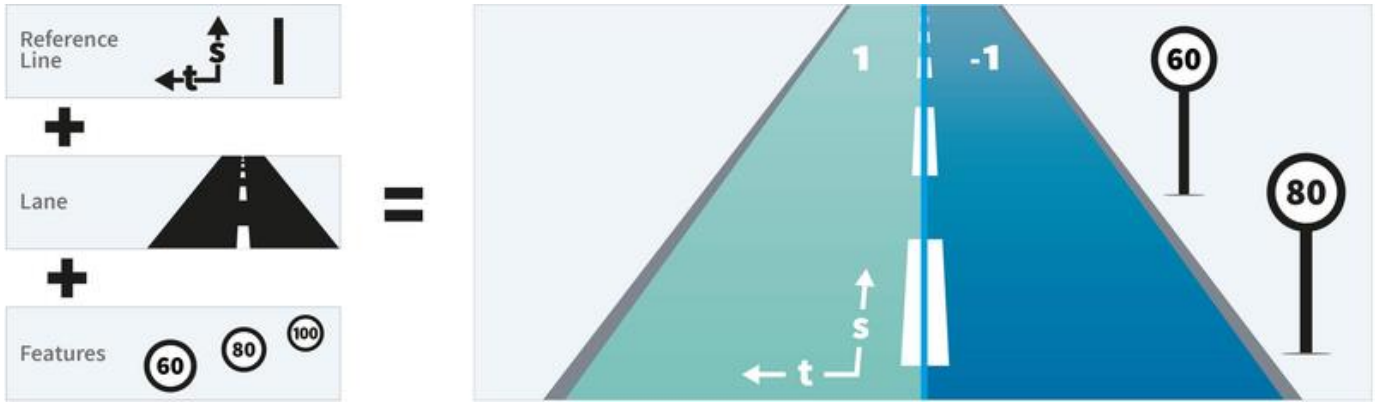
ASAM OpenDRIVE + OpenCRG + OpenSCENARIO

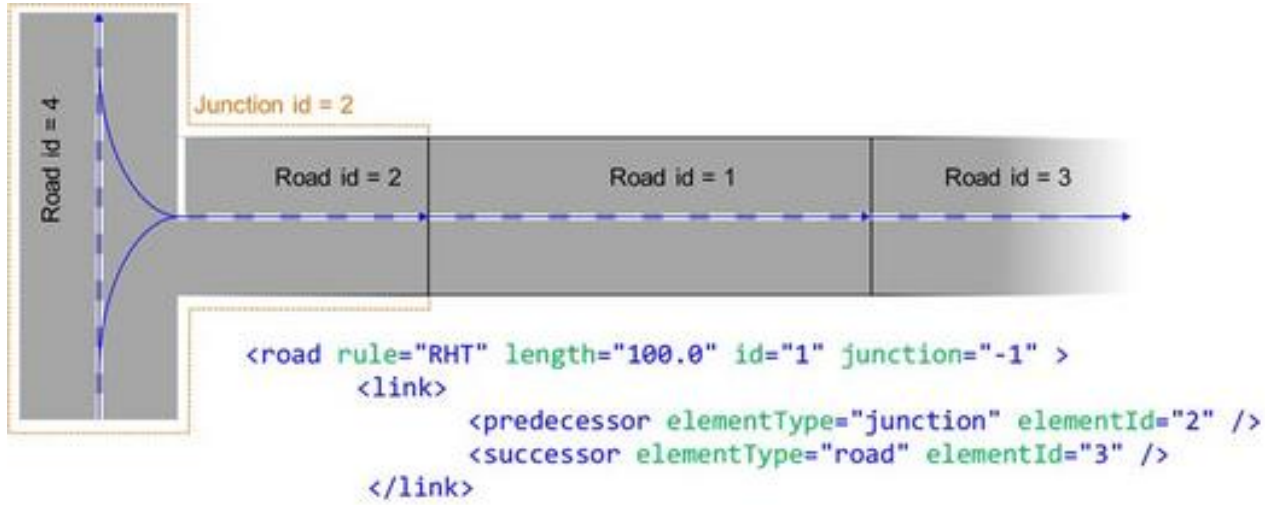
Defining the Environment and the Scenario



ASAM OpenDRIVE

Defining the Environment and the Scenario



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                <successor elementType="road" elementId="3" />
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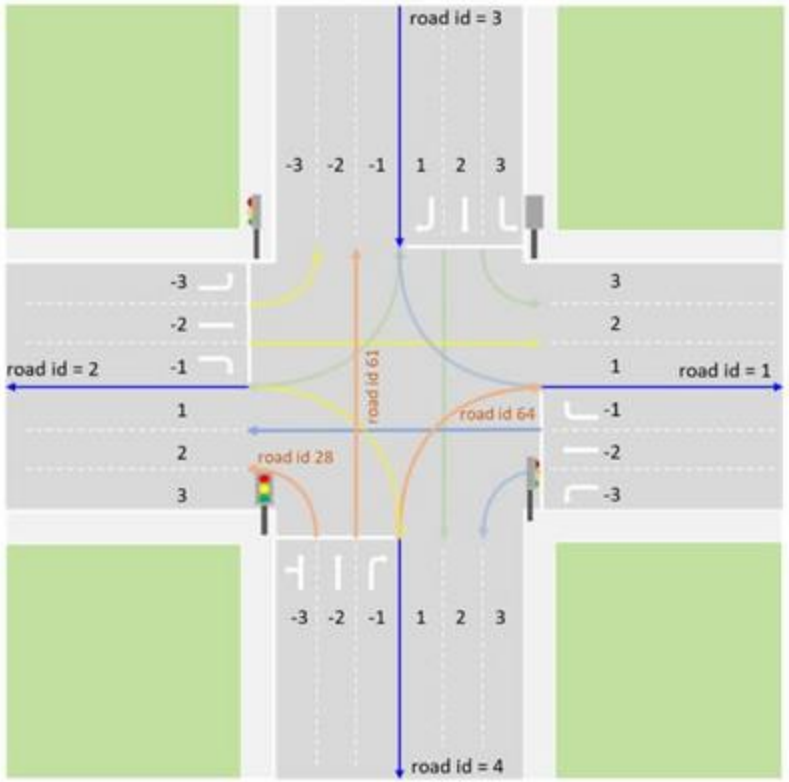
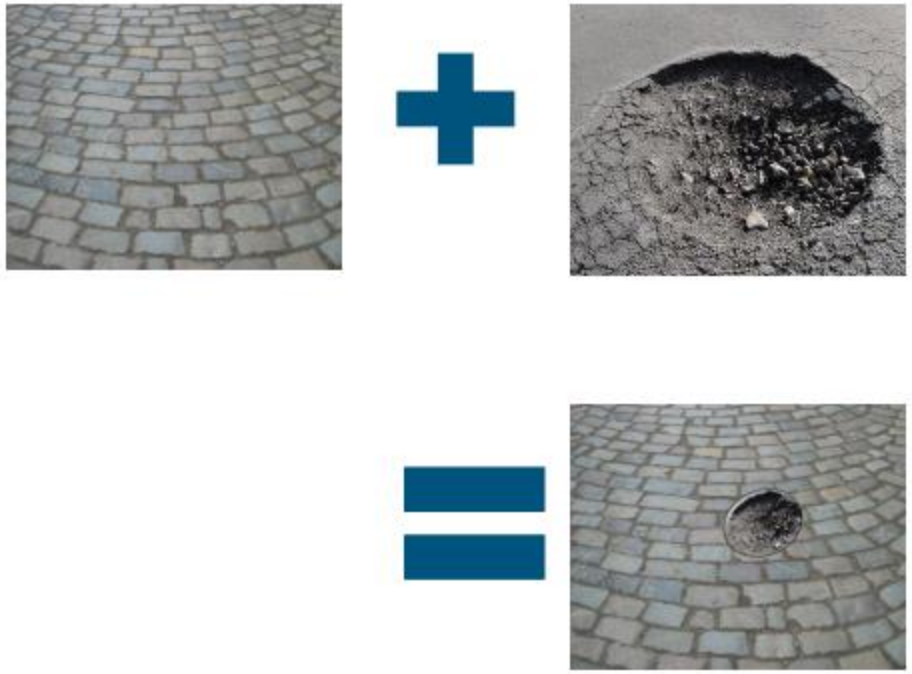
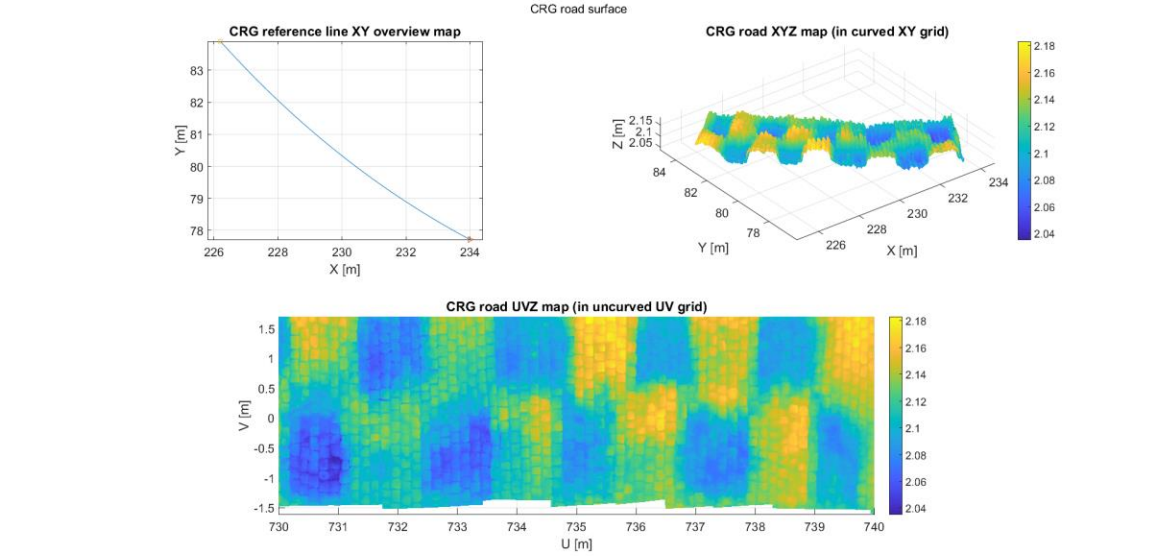
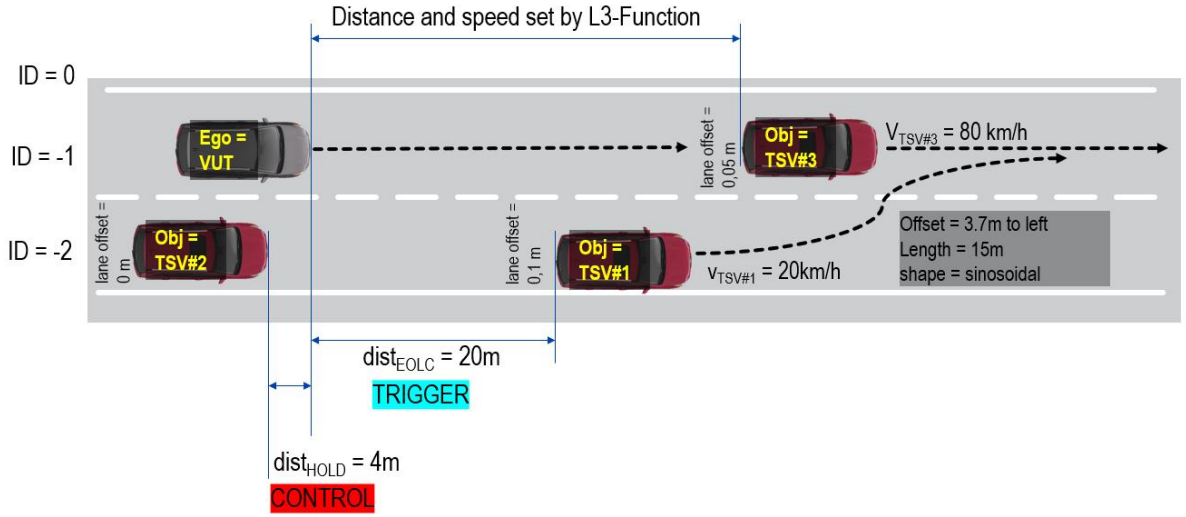


ASAM OpenCRG





ASAM OpenSCENARIO




```
scenario sut.my__scenario:
    car1: vehicle
    car2: vehicle

    do serial:
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            speed([40kph..80kph], at: end)
            lane([2..4])
        phase2: car1.drive(duration: 24s) with:
            speed([70kph..60kph], at: end)
```
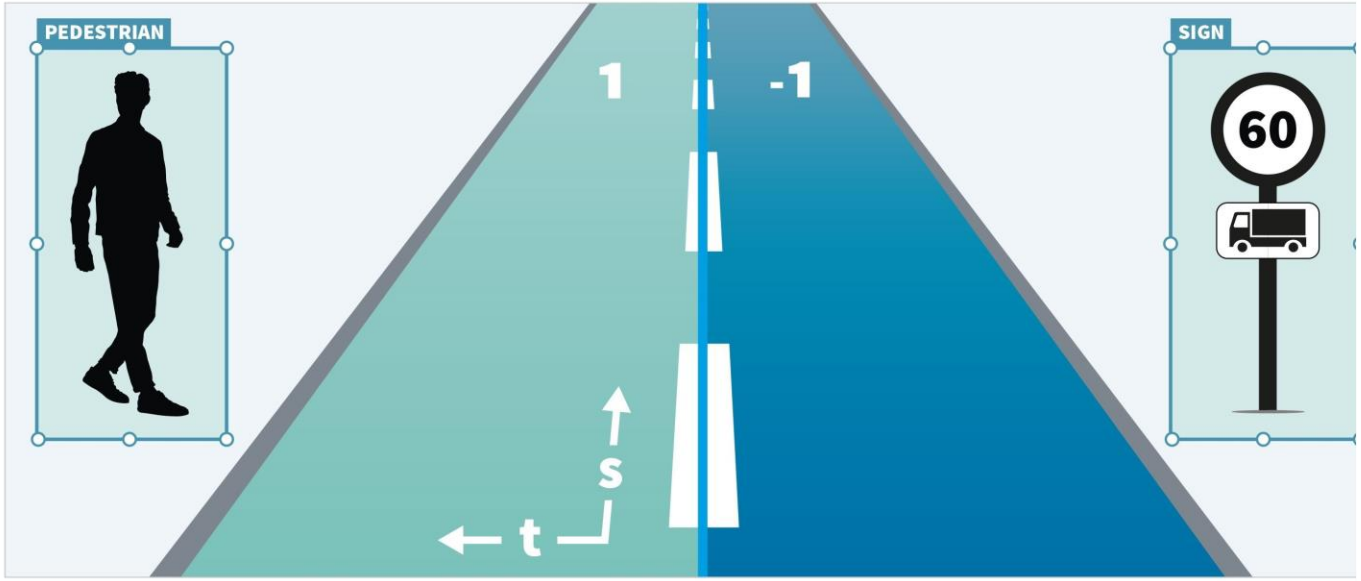
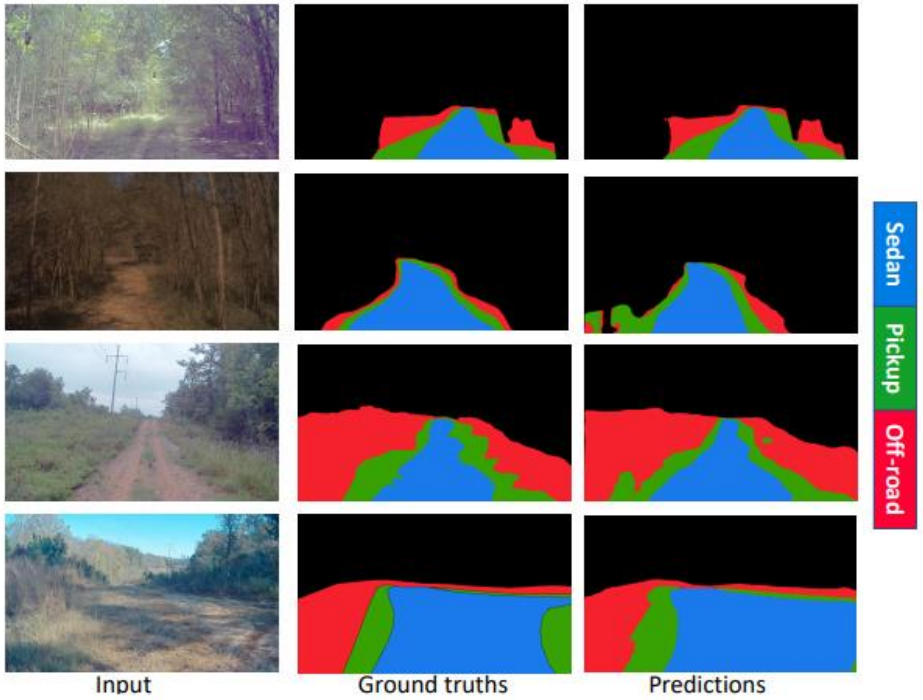
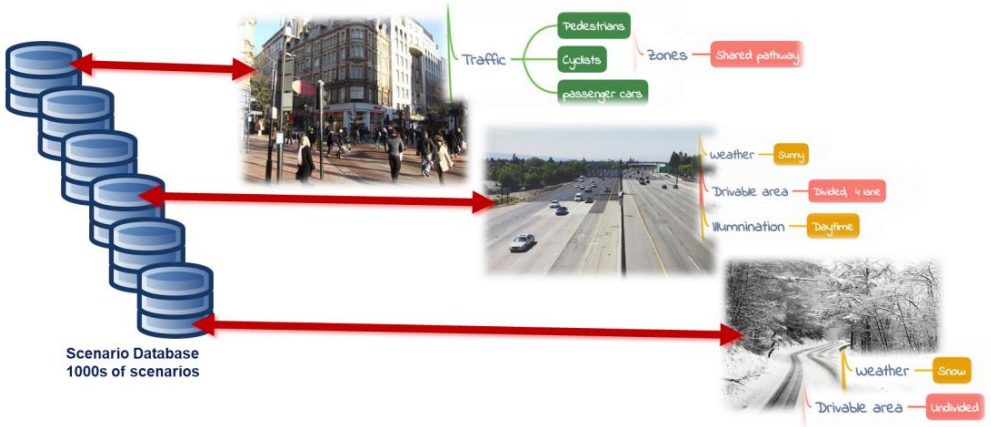
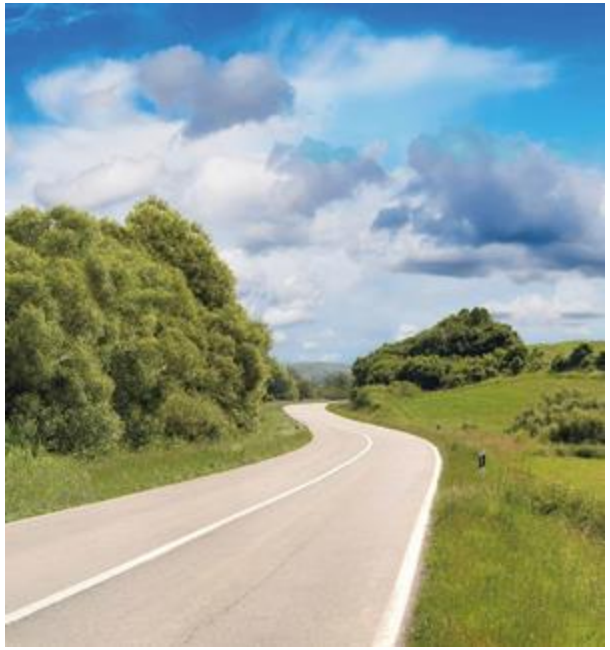

ASAM OpenLABEL





ASAM OpenODD

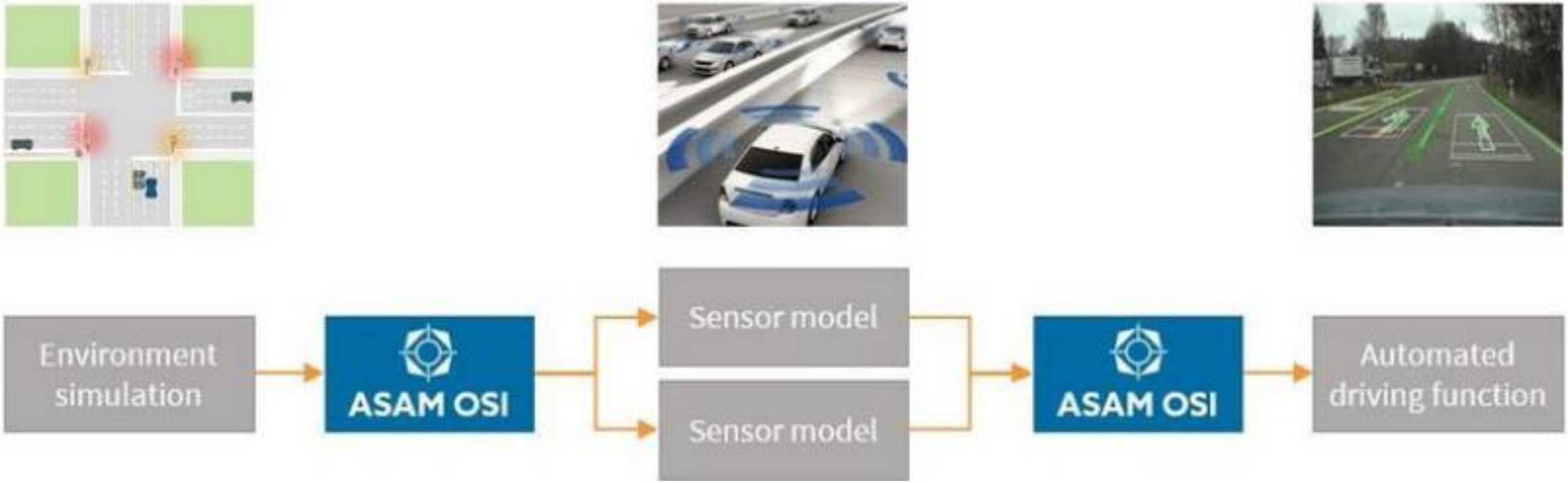


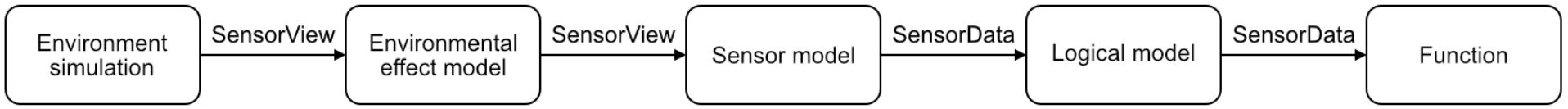


ODD Features

- Paved Road
- Right hand traffic
- Country Road
- No visibility limitation due to weather or time of day
- All possible traffic participants
- Animals
- …

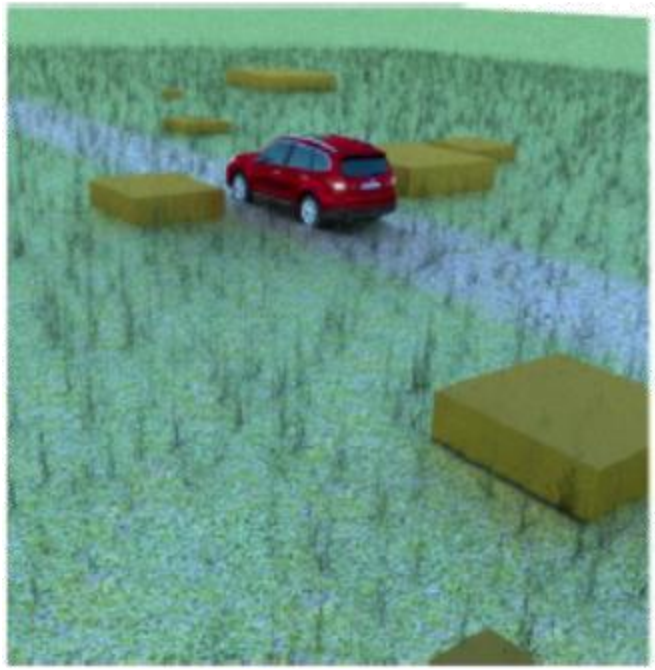
ASAM OSI Open Simulation Interface

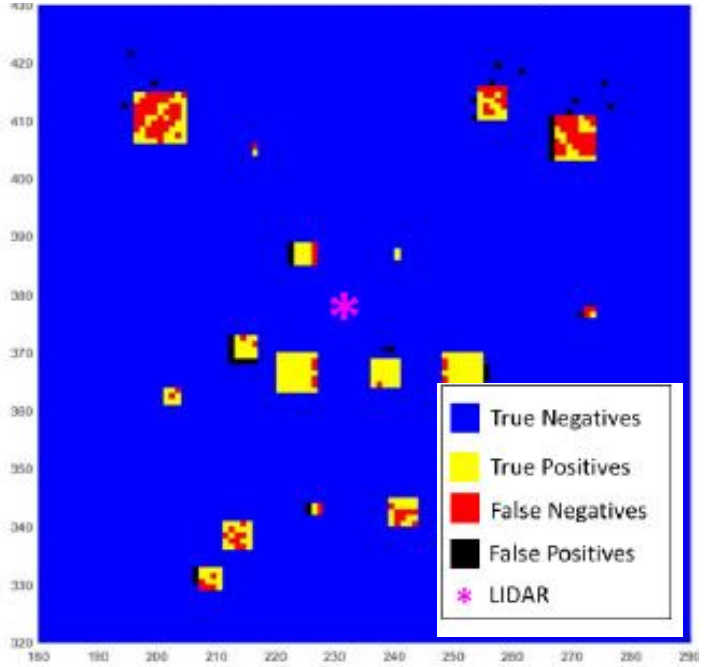




OpenMaterial

- Material measurement
- 3D Model structure
- Data structures
- OSI sensor view plugin





Existing Standards

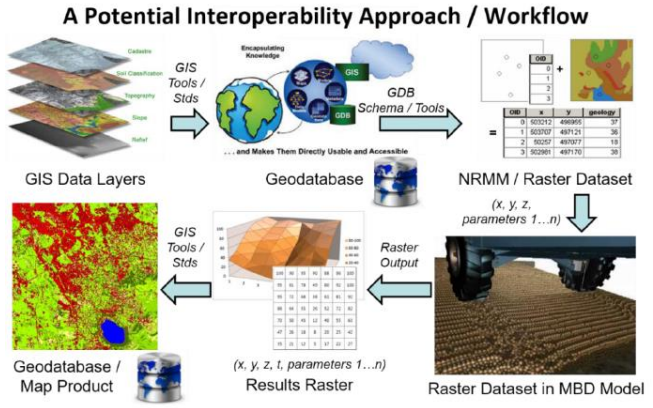
Terrain, drivable area, and materials

- Terrain, drivable area, and materials
  - Landxml 1.2 (infra model 4.0.4)
  - ASAM OpenCRG
  - ASAM OpenDRIVE
  - NATO AMSP-06

  - Algoryx agxTerrain implementation

NATO AMSP-06

- Addresses mobility modeling and simulation tools for military vehicle operations.
- Modernizes modeling and simulation for probabilistic mobility predictions of ground and amphibious vehicles.
- Enhances interoperability, portability, and extensibility of models.
- Addresses uncertainty quantification.
- Includes verification, validation, and benchmarking approaches.



- 24 attributes for describing soil characteristics.
- Representation of complex 3D terrain.
- Recommendations for 3D multibody dynamics modeling of vehicles.
- Description of environment requirements for modeling sensors for intelligent vehicles.

Existing Standards

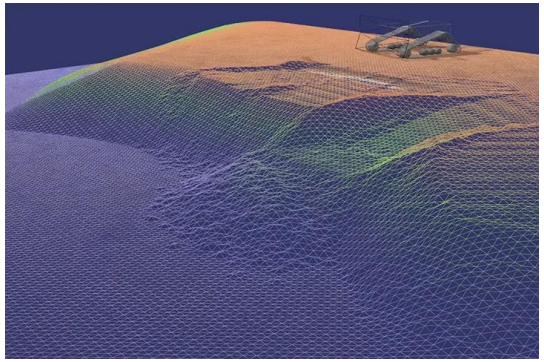
Terrain, drivable area, and materials

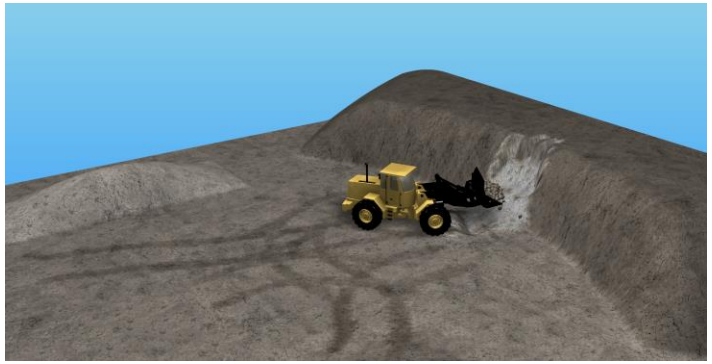
- Terrain, drivable area, and materials
  - Landxml 1.2 (infra model 4.0.4)
  - ASAM OpenCRG
  - ASAM OpenDRIVE
  - NATO AMSP-06

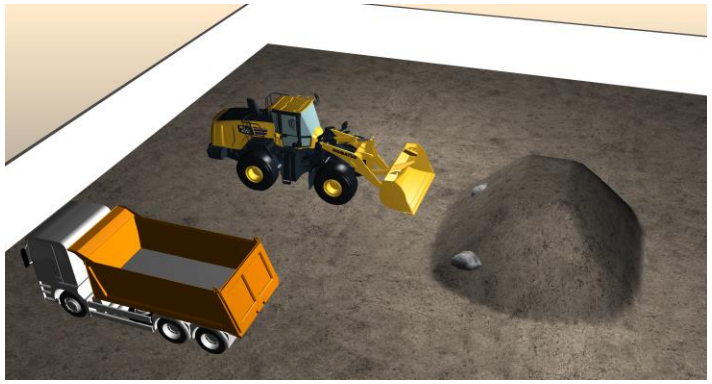
  - Algoryx agxTerrain implementation

Algoryx agxTerrain

- Algoryx's AGX Dynamics physics simulation toolkit.
- agxTerrain implements a deformable terrain model.
- Symmetric 3D grid data structure with overlapping surface height field.
- Supports digging, push/pull, and grading operations for bulldozing, wheel loading, excavation, etc.







Scenario Evaluation

- Documentation of requirements driven by offroad application
- Evaluation of current ability to meet requirements with current standards
  - Able to meet requirement with current standard
  - Unable to meet requirement with current standards
  - Unable to demonstrate proprietary capability
  - When met, document the standard, method, and grade level of support
  - When not met, identify potential standard that could support, possible definitio
- Estimate overall level of support for offroad applications

<u>Unsupported requirements</u>
- Soft terrain – deep tracks deformation

<u>Possible solutions</u>
- Extend OpenDRIVE with 3D terrain elements and soil characteristics

OR
- New OpenTERRAIN or OpenOFFROAD standard

Requirement	Met?	Standard	
Modelling of navigation of heavy machinery on soft terrain (deep tracks)	N	NA	
Model vehicle perception as it traverses an offroad environment	Y	OSI	3
Model effects of terrain and soil properties on vehicle-terrain interaction and mobility/dynamics including loss of traction, slip	Y	OpenCRG	2
Overall Support	**66%**	**-**	**2.5**

Summary

- Introduce offroad applications
- Motivation for exploring usage of OpenX standards
- User stories for offroad applications
- Offroad features and requirements
- Proposed approach for concept project
- Discussed scenarios for evaluation
- Relationship to relevant standards
  - ASAM OpenX Standards
  - Other standards
- Evaluation approach