Project Proposal Summary Sheet

Project Number	**C_2023_3**
Project name	ASAM OpenX standards in Offroad Applications
Domain	Simulation
Impacted standard(s)	OpenCRG, OpenDRIVE, OpenSCENARIO, OSI, OpenLABEL, OpenMATERIAL, OpenODD, possible new standard(s)
Project type	Concept
Start date	01.11.2023
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Initiating Companies	*Mississippi State University, Mathworks, Algoryx*
ASAM funds	
Backwards Compatibility	N/A

For more information on the ASAM project process and the proposal phase in particular, please refer to the ASAM Project Guide.

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1 Executive Summary

To date, the development of ASAM's standards within its simulation domain has been driven by the need in the automotive industry for solutions to developing and testing ADAS/AD for on-road driving. There are many other applications that also aim to or are already leveraging highly automated driving functionality, including the operation of autonomous heavy machinery in landfill, construction, agriculture or mining. These operations normally occur in areas with restricted public access, a clear understanding of other traffic participants, and more controlled environments. This corresponds to significantly smaller Operational Design Domains than many applications for on road driving. A smaller ODD often means a smaller space for which safe functionality must be tested. Deployment of highly automated driving functions is hence closer than for many on-road driving applications.

In many cases, the stakeholders involved in the respective areas of industry are not the same, particularly at the OEM level, leading to a lack of exchange of experiences, tools, and standards between them. The ASAM OpenX standards are a suite of standards directly supporting many workflows for the development of AD functions, particularly in the areas of simulation and scenario-based testing. But application of the OpenX standards in these other domains is limited. Awareness is lacking for the use cases for which they are intended and there is a lack of examples demonstrating this use for such domains. Due to the overlap in workflows, many of the toolchains are the same. Showing the application of ASAM standards in these tools will help give the standards visibility to the domains as a whole.

The off-road environment in which these systems often operate has unique requirements that are not currently addressed by ASAM OpenX standards. This includes characterizing soil strength to simulate slip and sinkage, simulating interaction with the terrain (digging and moving), and working in close proximity with other vehicles (loaders filling haulers).

It is proposed to initiate a project to define working examples for a range of use cases in these domains. These examples will be defined at an abstract enough level for them to be applicable across multiple domains, with a strong focus on functionality of the standards. Navigation, sensor integration, traffic participant interaction, and scenario-driven descriptions of maneuvers or actions for machinery are all examples that cover use cases in multiple domains. Where gaps are identified in the standards, a proposal will be delivered by the project to address the gaps in follow-up activities. These follow-up activities may lead to domain-specific extensions to the standards.

2 Overview

2.1 Motivation

Industries involving landfill, construction, agriculture, and mining are also looking to deploy or have already deployed highly automated driving functionality. There is a strong overlap in the use cases for ASAM OpenX standards across on-road ADAS/AD and these domains. There are also unique requirements for simulating operations in off-road domains. To support companies in these domains and to prevent redundancy, there is a need to demonstrate the application of ASAM OpenX standards in these areas. The experiences gained here will lead to expansion of the use of ASAM OpenX standards and may also be beneficial for applications in on-road driving.

2.2 Relations to other standards, projects or organizations

ASAM standards

- ASAM OpenCRG
- ASAM OpenDRIVE
- ASAM OpenSCENARIO
- ASAM OSI
- ASAM OpenLABEL
- ASAM OpenMATERIAL
- ASAM OpenODD

External standards

- EMESRT PR-5A Vehicle interaction systems
- Landxml 1.2 (specifically infra model 4.0.4)
- NATO AMSP-06 Guidance for standards applicable to the development of next-generation NATO reference mobility models
- ISO/CD 7334 Earth-moving machinery – Taxonomy and vocabulary for automation and autonomy
- ISO 15143-4 Worksite data exchange
- ISO 6165 Earth-moving machinery – Basic types
- ISO 17757 Earth-moving machinery and mining – Autonomous and semi-autonomous machine system safety
- ISO 21815 Earth-moving machinery – Collision warning and avoidance
- ISO 23725 Autonomous System and Fleet Management System Interoperability

Commercial implementations

- Algoryx agvTerrain Implementation

3 Technical content

The project covers extensions to existing standards and development of new standards required to support modeling and simulation of (a) vehicle mobility in off-road conditions and (b) earth moving for digging, loading, and hauling.

3.1 Developing Examples to Highlight Required Extensions to Standards

Within this project, a set of examples will be developed that demonstrate multiple vehicles operating in an off-road area with non-public access. These areas are most often soft, unpaved terrain with no road markings. They may have pre-defined tracks on which vehicles move.

The examples will be based on a single ego vehicle (haulage truck or digger) and other vehicles (NPCs) moving in the same area. Later examples (potentially in later activities) may look at multiple ego vehicles and a controller entity. Whilst many use cases require more complexity, trying to address all of this in a first set of examples will likely be difficult and hence out of scope. Experiences gained in this activity will be built on to iteratively grow the complexity and use case coverage of the available examples.

The examples focus on a single self-driving ego vehicle, without an active controller entity. The example scenarios aim to cover multiple types of movement, categorized as:

1. **Movements on the driving plane** - Navigation and interaction with 3d objects. A vehicle, a building, a mound of earth, vegetation, a muddy patch, a ditch, or some other obstacle is in the way of the vehicle under test. It must perceive the obstacle, understand the scene, develop a plan for addressing the obstacle, and execute the plan. Simulations of offroad applications should provide sufficiently defined environments to reasonably estimate how a vehicle will negotiate obstacles in real situations.

2. **Movements outside of the driving plane** – interactions with soil and material. An excavator is digging out material, lifting it, and depositing it into a hauler. This also covers vehicle-to-vehicle and vehicle-to-machine interactions where the vehicle under test must align itself, in coordination with another vehicle or machine, to receive or deposit material.

3.2 Relevant Domains

Military operations and industry operations, such as in the sectors of mining, forestry, agriculture, and construction, often take place in complex off-road environments due to the nature of their objectives and tasks. Military operations take place in varied and often challenging terrains to achieve strategic advantages, conduct surveillance, or carry out missions. These operations require traversing through forests, mountains, deserts, and other rugged landscapes that lack conventional road infrastructure. Similarly, industries such as mining and forestry inherently work in off-road environments as their activities are centered around extracting resources from the earth, often in remote or inaccessible areas. Agriculture requires management of large sections of land, which may encompass a variety of terrain types and conditions, particularly at the transitions between fields and the bordering terrain. In construction, particularly in initial phases like land clearing and foundation setting, the terrain is often unstructured and variable. These conditions require vehicles that can navigate and perform tasks efficiently and safely in off-road environments.

During off-road operations, a vehicle may encounter unforeseen static objects, such as rocks or vegetation, or dynamic objects such as pedestrians or animals, that require a robust perception and decision-making system. Off-road environments have a broader variety of potential obstacles in comparison to on-road environments, ranging from rocks and fallen tree branches to variations in terrain. Vegetation and other objects may occlude perception of both static and dynamic objects increasing the challenges to detecting obstacles. Terrain conditions affect how the vehicle can respond in these scenarios. Further complexity arises from the dynamic nature of the off-road environment, where weather changes, lighting variations, and seasonal shifts can affect object visibility and appearance. Interaction between objects and terrain can be intricate and unpredictable, such as when loose soil collapses under the vehicle's weight or a rock rolls down a slope. To represent these interactions, modeling and simulation tools must present static and dynamic objects in a complex, unstructured off-road environment to test the vehicle's ability to detect and classify objects, assess the risk they pose, and decide on an appropriate action, such as stopping, slowing down, or navigating around, over, or through the obstacle. The vehicle may consider its current speed, load, and the terrain's condition.

There are numerous off-road scenarios that may demonstrate the need for extensions to current standards:

- On-trail driving
  - Similar to on-road driving
  - More varied road surfaces
  - More varied topography (washes, ruts, etc.)
  - Sharp inclines, sharp declines, sudden changes in elevation
  - Special driving regulation, prioritization of loaded vehicles
- Off-trail, cross-country navigation
  - Through a field (small diameter, dense but traversable vegetation)

    - Through woods (larger diameter, untraversable vegetation, canopy, range occlusion, no straight paths)

Off-road operations may be more greatly affected by conditions and features of the environment:

- Terrain Conditions
    - Rough, uneven terrain
    - Varying terrain soil strength
    - Loose terrain (loose soil, gravel, slip)
- Vegetation
    - Dense, small vegetation (fields of grass, flowers, thin trees)
    - Traversable trees and bushes (<1” diameter stem)
    - Non-traversable trees and vegetation
    - Vines
- Obstacles
    - Rocks, boulders, fences, buildings, etc.
    - Movable obstacles (e.g., rolling logs, rolling rocks, etc.)
    - Compressible obstacles (e.g., rotting logs)
- Negative Obstacles
    - Ditches, holes
    - Possibly filled with water, leaves, other cover material
    - Combinations of positive and negative obstacles (e.g., fallen tree partially in a ditch)

The off-road environment may require extensions to current standards for representation of complex 3D terrain, the subsurface (e.g., soil strength, density, temperature, water content), sensors and surface materials, object representation (meshes, materials, and physics), effects of weather conditions, accumulation of material on vehicles, occlusions of sensors, and cover materials (e.g., leaves, water, snow).

3.3 Example Scenarios

For the ASAM OpenX standards in Offroad Applications project, twelve example scenarios were identified that may exercise the current standards and demonstrate requirements for extensions to the standards. Three general types of operations were identified: navigating from a starting position to an end goal, interacting with other vehicles on the roadway, and working closely with other vehicles and infrastructure during loading and hauling operations.

Moving from Point A to Point B

1. Following a Path
2. Finding a Path
3. Carrying a Load
4. Using Sensors to Respond to the Environment
5. Navigating without GPS

Vehicle Interaction

6. Following a Lead Vehicle
7. Dealing with Environmental Effects

8. Interacting with Traffic
9. Incorporating Drones for Ground-Air Vehicle Teaming

Load and Haul

10. Loading a Hauler - Hauler
11. Loading a Hauler – Excavator
12. Evaluating fuel efficiency

The example scenarios present a use case for simulation of off-road autonomous ground vehicles that is expected to help exercise the current standards and highlight requirements for new standards or extensions to current standards.

3.3.1 **Moving from Point A to Point B**

In the following examples, an automated vehicle is finding its way from its current location to a goal location. In some examples, the vehicle is following a pre-defined path with limited freedom to deviate from the path. In other examples, the vehicle has significant freedom in defining its own path. Some metrics of interest may be related to operational goals such as minimizing fuel or energy consumption or maximizing the transportation of ore. There are constraints that may be imposed on pathfinding and path-following behaviors. For example, there may be speed limits, one-way roads, height and width limitations, incline limits, load limits, and traction challenges. During the drive, the vehicle is affected by various vehicle and environmental factors. For example, soft soil may affect trafficability or obstacles may force significant deviations in the path. Additionally, some traffic regulations and traffic situation resolution algorithms may apply. For example, loaded vehicles might have priority over unloaded vehicles.

3.3.1.1 **Scenario #1 – Following a Path**

A vehicle operating at a mine is given a pre-defined path from location A to location B. The vehicle tracks its current location using GPS and on-board sensors. The vehicle uses a controller to follow the pre-defined path with desired (optimal) velocity. As the vehicle follows the path, variations in the environment will lead to variations in the vehicle's path following performance. For example, soft soils may lead the vehicle to lose traction and experience slip.

The purpose of the scenario is to evaluate the performance of the path following algorithm in an environment characterized by soft soils. In the example, the evaluation will estimate how well the vehicle could follow the desired path and speed profile. In addition to deviation from desired path and speed, additional metrics such as fuel consumption and time to traverse the scenario may be collected for analysis.

3.3.1.2 **Scenario #2 – Finding a Path**

In addition to characteristics of the terrain, objects can impede the motion of the vehicle. Depending on various vehicle and environmental factors, the objects may be passable or blocking. The position of static obstacles may be known. The vehicle's ability to identify and plan a route that takes into account the positions of known static obstacles is an integral part of the route planning process.

A vehicle operating at a mine is given a goal position. The vehicle uses a combination of global knowledge (e.g., a stored map of the mine) and sensor data (e.g., on-board LiDAR sensor) to determine an appropriate path from its current location to the goal location. The vehicle follows the path to the goal location. Variations in the environment will lead to variations in the path.

The purpose of the scenario is to evaluate pathfinding capability of the vehicle. In this example, the evaluation will determine the vehicle's ability to find an acceptable or optimal route according to some criteria. The scenario environment should be able to vary the position, size, and other characteristics of the obstacles to evaluate the vehicle's abilities.

3.3.1.3 Scenario #3 – Carrying a Load

In the construction industry, a specific use case involves the transportation of earth from a construction site, navigating through challenging terrain including uneven and muddy surfaces, as well as temporary access roads off-site. Carrying a load of earth significantly impacts the vehicle's performance, necessitating adjustments in acceleration, braking, and steering due to the increased weight and altered center of gravity. Traversing steep slopes and maneuvering through muddy surfaces become more challenging, requiring careful assessment of navigability and the implementation of proper driving techniques. Safety measures such as speed restrictions and precautions against tipping, sliding, or immobilization are crucial considerations in this scenario.

This example focuses on the scenario of carrying a load, highlighting its impact on the vehicle and the surrounding environment. The language allows for the specification of the type of material being transported, such as soil, rock, or a specific composition, which is essential for accurately describing the behavior of the load. The language provides mechanisms to describe the distribution of the load across axles or compartments. This enables the description of various effects caused by the load on the vehicle, including considerations for stability, road traction, deformation of road surfaces, and maneuverability.

The purpose of the scenario is to evaluate how different loads affect the vehicle's interaction with the terrain. In this example, the evaluation will assess whether the vehicle can successfully reach the goal without rollover or loss of material while optimizing transportation time, fuel consumption, and tire wear.

Scenario #4 – Using Sensors to Respond to the Environment

In addition to static obstacles, obstacles may appear or move between drives. For example, a rock may have fallen onto the path. The obstacle may be passable or may block the path. A vehicle may need a perception system to take necessary measures to avoid a collision. In this example, we assess the ability of the vehicle to respond to differences in the environment compared to stored maps of the environment.

A vehicle operating at a mine is given a goal position. The vehicle is equipped with sensors and algorithms for detecting and characterizing obstacles (e.g., a fallen rock, standing water and mud).

The vehicle uses a combination of global knowledge and sensor data to determine an appropriate path from its current location to the goal location. As the vehicle follows the global path, it detects and responds to local obstacles. The vehicle's path will vary in response to environment factors and the presence of obstacles.

The purpose of the scenario is to evaluate the ability of the vehicle to recognize unexpected changes in the environment and effectively respond to them. In this example, the evaluation will assess whether the vehicle can monitor the state of the environment, detect potential threats to mobility (e.g., fallen rock, mud pit, flooded regions, etc.) and determine a new route or stop if the path is completely blocked.

Scenario #5 – Navigating without GPS

The vehicle may need to adapt to the loss of sensor data. In some cases, there may be no infrastructure (no roads, no detailed maps) and the terrain and vegetation may block GPS signals. As a vehicle moves into a densely vegetated environment, it becomes unable to reliably detect a GPS signal. The vehicle has a good fix on its current location and a goal position. The vehicle must rely on local sensor data to make its way to the goal location.

The purpose of the scenario is to evaluate the ability of the vehicle to traverse a path despite the loss of sensor data. In this example, the evaluation will assess whether the vehicle can maintain localization necessary to complete navigation task. The example requires the ability to define loss of sensor data.

3.3.2 Vehicle Interaction

3.3.2.1 Scenario #6 – Following a Lead Vehicle

In a convoy of vehicles, a lead vehicle generates a path that the other vehicles in the convoy should follow. The follower vehicles should be able to maintain specified distances between themselves and a lead and a following vehicle and should follow the previous vehicle's path except where necessary to avoid damaging the roadway or becoming stuck in soft soil.

A vehicle is following a lead vehicle through an environment. The lead vehicle is following a scripted path through an environment. The vehicle is using sensors or GPS breadcrumbs from the lead vehicle to follow its path. 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.

The vehicle also uses its sensors to determine the distance to the lead vehicle. Depending on the road conditions, the vehicle should maintain an optimal distance to optimize timing, reduce fuel consumption and prevent brake degradation.

The purpose of this scenario is to evaluate the ability of the vehicle to follow a lead vehicle. In this example, the vehicle will be evaluated based on whether speed and relative distance are within optimal ranges and whether the following vehicle adjusts its path if the terrain has been modified by the lead vehicle.

This example requires the deformation of terrain and modification of soil properties by leading vehicles that will affect the mobility of follower vehicles.

3.3.2.2 Scenario #7 – Environmental Effects

When operating in an off-road environment, the vehicle is more likely to have to deal with adverse conditions affecting the operation of its sensors. This could include water or mud splatter onto the surface of sensors or dust clouds in the environment created by the vehicle or other vehicles operating in the environment.

A vehicle is following a lead vehicle through a dry off-road environment. The lead vehicle is creating a dust cloud as it moves through the environment. The vehicle is using sensors to follow the lead vehicle's path. The vehicle must track the lead vehicle's movements despite the dust cloud and follow it without significant deviation from the path.

The purpose of this scenario is to evaluate the effects of environmental effects such as rain, dust, mud splatter, etc. on perception and mobility. In this example, the vehicle will be evaluated based on whether tracking of lead vehicle is consistently effective in a dirty environment and identify critical environmental parameters where tracking becomes impossible. The ability of the vehicle to self-estimate its performance and recognize environmental impact should be measured for analysis.

This example requires models of vehicle-terrain interaction that will capture effects that affect sensors (occluding sensor field of view), vehicle mobility (mud accumulating on tires), etc.

3.3.2.3 Scenario #8 – Interacting with Traffic

The vehicle is following a path through an environment. As the vehicle approaches a narrow section of roadway, an oncoming vehicle is approaching from the other direction. The two vehicles must negotiate the narrow section. The vehicle-under-test is using sensors or GPS breadcrumbs to determine its path along a roadway. The traversable space is limited to the width of the roadway. The vehicle uses local sensor data to detect an oncoming vehicle. The vehicle determines whether there is sufficient room for the two vehicles to pass on the roadway, considering the stability of the roadway and risk associated with the borders of the roadway. The vehicle passes the oncoming vehicle.

The purpose of this scenario is to evaluate the vehicle's ability to handle traffic in an unstructured environment. In this example, the vehicle will be evaluated based on whether the vehicle can successfully negotiate the narrow section of roadway with the other vehicle allowing both vehicles to cross.

The scenario may vary including having the section of the roadway be too narrow to pass such that one vehicle must reverse to a location with sufficient width to pass. Vehicles may need to follow certain algorithms, e.g. loaded vehicle has priority. There may appear to be sufficient space to pass on the shoulder of the roadway but the edge of the roadway is soft and, if the vehicle drives on the shoulder, it risks sliding off of the roadway. Also, the oncoming vehicle may refuse to give way sufficient for the vehicle-under-test to pass.

This example requires simulation of the second agent. Some variations require models of soft soil and other dynamic objects.

3.3.2.4 **Scenario #9 – Incorporating Drones for Ground-Air Vehicle Teaming**

An remotely piloted aircraft (RPA) or uncrewed aerial system (UAS) flies over a field or construction site. The UAS provides a live sensor feed to an autonomous ground vehicle. The UAS generates a map of the terrain providing a view of the surrounding area, identifying potential regions of interest for the vehicle, and mapping negative obstacles such as ditches and holes that may be difficult for the ground vehicle to perceive. The ground vehicle leverages the provided data to execute its task.

The purpose of this scenario is to evaluate the ability of the UAS to provide actionable data to the ground vehicle. In this example, the vehicle would be evaluated based on whether the vehicle can use the provided map and sensor data to perform its task efficiently.

This example requires simulation of a second agent, the UAS, its sensor systems, on-board processing, and communication links between the UAS and the ground vehicle. Variations of the scenario may adjust the types and difficulty associated with detecting ground features from the air.

3.3.3 **Load and Haul**

Loading and hauling processes in mining, agriculture, and construction vary depending on the specific industry and the materials being transported. In agriculture, trailers or other transportation vehicles are loaded with conveyor belts or mechanical loaders to transfer harvested crops. In mining, trucks or dumpers are loaded with conveyor systems, hydraulic shovels, front-end loaders, or excavators to transfer minerals. In construction (i.e., deconstruction of a landfill), trucks or dumpers are loaded with an excavator or front-end loader to transfer earth.

Some key aspects that these examples could include:

- Vehicle Specification: type, size, weight capacity
- Load Description: type of material e.g., soil, rock, or a specific composition
- Load Distribution and Balance: distribution across axles or compartments, to maintain vehicle stability (vehicle dynamics, sensors, load monitoring)
- Terrain Description: slope, roughness, etc.
- Environmental factors: weather, lighting etc.
- Loading Procedure (Interaction with Other Equipment): Communication and coordination with excavator, front-end loader and other loading systems. Queueing with multiple vehicles.
- Unloading Procedure: designated location, procedures for material discharge
- Route Planning: addressed in 1 & 2; waypoints via temporary access road or open space; navigability uphill/downhill, obstacles etc. following lead vehicles (how does the terrain change addressed in 2.)

There are additional aspects from the perspective of an excavator that the examples could include:

- Vehicle Specification: type, size, weight, arm length, bucket capacity, and any additional attachments or specialized equipment
- Digging Parameters: the type of material being excavated e.g., soil, rock, or a specific composition
- Loading Procedure: Communication and coordination with truck or dumper

3.3.3.1 **Scenario #10 – Loading & Unloading - Hauler**

In domains such as construction, mining and agriculture, a vehicle will interact with loading systems such as conveyor belts, mechanical loaders, hydraulic shovels, front-end loaders, or excavators to unload or load the vehicle. GPS coordinates and mapping systems are used to identify the precise location for loading and unloading operations. The vehicle will position itself relative to the un-/loading system or in the specified area, perform loading/unloading and depart. The vehicle will coordinate its task with the un-/loading system and communicate information on positioning, readiness for un-/loading and departure with feedback from the loading/unloading systems. Additionally, the vehicle must plan and coordinate with other actors involved in the loading and unloading process, such as other vehicles in a queue waiting to be loaded/ unloaded or other heavy machinery operating in the vicinity. Further considerations for loading or unloading operations include obstacles and altered terrain resulting from previously deposited loads or digging operations related to the loading, which present challenges. Additionally, specifying the necessary alignment, distance, and angle is essential for ensuring seamless interaction between the vehicle and the loading/unloading system.

The purpose of this scenario is to evaluate the vehicle's ability to receive a load of material and unload material. In this example, the vehicle will be evaluated based on whether the vehicle can successfully approach a loader, communicate with the loader, and receive an optimal load in a timely manner without damage to the vehicle-under-test or the loader. The vehicle will also be evaluated on its ability to successfully deliver a load of material to the desired location.

3.3.3.2 **Scenario #11 – Loading the Vehicle – Excavator**

Loading and hauling processes in mining, agriculture, and construction vary depending on the specific industry and the materials being transported. In agriculture, trailers or other transportation vehicles are loaded with conveyor belts or mechanical loaders to transfer harvested crops. In mining, trucks or dumpers are loaded with conveyor systems, hydraulic shovels, front-end loaders, or excavators to transfer minerals. In construction (i.e., deconstruction of a landfill): trucks or dumpers are loaded with an excavator or front-end loader to transfer earth (thus loading is directly related to digging).

In this scenario, the excavator will drive to the load area and position itself relative to the loading system, which may involve a queue of vehicles. The excavator will manipulate the material using arms and buckets to load the material onto the vehicle. This will require communication and collaboration with the hauler vehicle.

The purpose of this scenario is to evaluate the vehicle's ability to position itself next to the hauler, to manipulate the material, and to load the hauler. In this example, the vehicle will be evaluated based on its ability to successfully load the hauler in an optimal time without tipping over or colliding with the hauler.

This example requires simulation of the hauler, models of articulating arms and buckets, and simulation of the manipulation of the material.

3.3.3.3 Scenario #12 – Evaluating fuel efficiency

A facility is evaluating options for powering automated ground vehicles at a worksite. The options include (1) fuel supplied at a centralized depot, (2) fuel supplied at multiple depots located at strategic locations around the facility, (3) recharging stations located at a centralized depot, (4) recharging stations located at strategic locations around the facility, and (5) continuous power supplied via a tram system. In this example, multiple vehicles will be modeled with various routes driven between locations in the facility. Routes through the facility will include low quality dirt roads in various states including soft soils that are expected to adversely affect vehicle fuel efficiency. The vehicles will include a power management system that drives them to nearby fuel supplies when levels drop below a given threshold (e.g., 20% fuel capacity, <5 mile range, etc.). Fuel efficiency calculations should accurately reflect effects of slope, soil strength, loads, etc.

The purpose of this scenario is to evaluate the operational effects of choices for powering autonomous ground vehicles on-site. In this example, the site will be evaluated to determine the the effect of different strategies on wear and tear of the terrain, on vehicle performance, on logistical outcomes (e.g., time to delivery, downtime for vehicles, etc.), and overall efficiency.

3.3.4 Building Scenarios to Exercise Standards

While the 12 example scenarios present interesting challenges for use of OpenX standards for offroad applications, the ASAM OpenX standards in Offroad Applications project scope must be limited to what can be reasonably accomplished in less than 12 months (allowing time for further defining the selected scenarios, evaluation of the implementation effort, and documentation of the project). We propose to develop **two scenarios**: one representing the Moving from Point A to Point B example scenarios (specifically 1 and 4) and one representing the Loading and Hauling example scenarios (specifically, 10 and 11). The vehicles defined for the project will include data for vehicle dynamics necessary for these tasks as well as the Carrying a Load example (3).

The scenario can be broken into two major components: the environment and the vehicle-under-test. The environment can be further broken down to 7 layers: the subsurface, the topography, the road network, objects, agents, conditions, and communication systems. The vehicle-under-test can be broken down to the vehicle, the sensors on the vehicle, and the control systems operating the vehicle.

Table 1. Components and layers used by scenarios to demonstrate use case requirements.

Component/Layer	Scenario	Use cases
Subsurface	1-12	1, 2, 3, 5, 8-10, 15, 17, 20, 21
Topography	1-12	2-5, 8-10, 17, 20, 21
Road network	3, 6, 8, 12	8-10, 20, 21
Objects	1-12	4-7, 9, 10, 13, 14, 18-21

Agents	4, 6-11	9, 12, 16, 21
Conditions	1-12	5, 6, 9, 20
Communications	6, 8-11	20
Vehicle	1-12	1-3, 8-11, 13-18, 20-22
Sensors	1-12	2, 4, 5, 6, 9, 12, 16, 17, 19-21

4 Use-cases

4.1 Use Cases

ID	Description	Relevant Example Scenario	Relevant ASAM Standards	Type [Business or Technical]
1	Modelling of navigation of heavy machinery on soft terrain (deep tracks)	1-3, 5, 6	OpenCRG, OpenDRIVE	Technical
2	Model vehicle perception and mobility and dynamics as it traverses an off-road environment	1, 3, 4, 6-8	OSI	Technical
3	Model effects of terrain and soil properties on vehicle-terrain interaction and mobility/dynamics including loss of traction, slip	1, 3, 6,	OpenCRG, OpenDRIVE	Technical
4	Model GPS sensor data accounting for effects of vehicle movement, terrain, and vegetation including loss of signal, multipath, etc.	1, 5	OSI	Technical
5	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.	2, 6,	OSI	Technical

6	Represent objects with appropriate mesh and material attributions for common sensors	2, 4	OpenSCENARIO, OSI	Technical
7	Represent physics of objects for appropriate vehicle-object interactions	2, 4, 5	NA	Technical
8	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	3, 6, 9	NA	Technical
9	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.)	7	OSI	Technical
10	Represent vehicle components relevant to VTI/mobility	1-3	NA	Technical
11	Represent driveline/powertrain for the vehicle	1-3	NA	Technical
12	Represent other vehicles acting appropriately in the off-road environment	6, 8	OpenSCENARIO	Technical
13	Incorporate fuel depot/charging stations (capacity, charge/refuel rate)	11	NA	Technical
14	Tram systems (external power lines; temporary disconnect from power supply/charging)	11	NA	Technical
15	Articulated effectors	9-10,	NA	Technical

16	Model vehicle cooperation – specific positioning relative to each other	6, 8, 9-10	OpenSCENARIO, OSI	Technical
17	Model effects of terrain and soil properties on digging and moving soil	9-10	NA	Technical
18	Estimate effects of vegetation on vehicle mobility	1, 2, 4, 7	NA	Technical
19	Estimate effects of vegetation on sensors and perception		OSI	Technical
20	Generate prior information to the autonomy stack (e.g., simulate extraction of maps, etc. from previous drives, UAS, or other sources)	1	NA	Technical
21	Extract sensing and mobility data for learning how to traverse terrain	1, 4, 6	OSI	Technical
22	Evaluate or optimize efficiency of vehicle systems in the operating environment	11	NA	Business
23	Collecting performance data for benchmarking systems (e.g., specifying and recording various metrics for evaluating system performance)	All		Technical
24	Share and reuse off-road scenarios in a common format for shared understanding	All	All	Business

4.2 User Stories

ID	Description	Related Use Cases (IDs)
1	As a vehicle developer, I want to evaluate the performance of autonomous system components in an off-road environment to	2, 4-7, 9, 12, 15, 16, 19-24

	understand how the vehicle will act in such an operating environment. (*Mobility Application*)	
2	As a vehicle developer, I want to develop new capabilities and test the vehicle against off-road scenarios. I want to develop and test mechanical, electrical, hydraulic, and electro-mechanical systems.	1, 3, 7-11, 15, 17, 18, 22-24
3	As an autonomy software developer, I create algorithms, software and supporting documentation for perception, planning and control of the vehicles and their support tools. I work with control engineers to investigate, test, and select software toolsets or hardware components and peripherals (programmable logic controllers, mobile computers, display/touch screens, etc.). I want to collect sensor and mobility data for training AI/ML models. I want to develop new algorithms and test the vehicle against off-road scenarios. I want to work with other engineers to investigate and test vendors' products.	2, 4-7, 9, 12, 15, 16, 19-24
4	As a test engineer, I want to develop and evaluate detailed off-road test scenarios for both component and system level testing and validation.	1-24
5	As a system integration engineer, I work in early planning stages and define the scope of projects. I am making decisions about interfaces between the systems. I create scenarios to help understand the requirements for systems. I create schematic representations of mechanical, electrical, hydraulic, and electro-mechanical systems and work with other disciplines to create the specifications that outline the control system logic necessary for haul truck functions.	1, 3, 7-15, 17, 18, 22-24
6	As a site manager, I manage and assess the application of vehicle systems on-site. I work	12-14, 16, 22-24

	with the environment, health, and safety teams and security teams to conduct regular risk assessments. I maintain a risk register and develop and implement risk mitigation plans. A digital twin of the site that can simulate scenarios will help me to understand site operations, assess risks, and predict the effectiveness of mitigation strategies.	
7	As a vehicle developer, I want to build physics-based vehicle models to test vehicle behavior in 3D simulations	1, 3, 7-11, 15, 17, 18, 22-24

5 Project resources

All information for project resources can be found in the accompanying Excel file.

Filename/URL:

5.1 Work Packages

WP ID	Title	Resources (Man-days)
	Project Coordination	174
1	Evaluate Existing Offroad Data Standards or Formats	26
2	Implement a 'Moving from Point A to Point B' scenario	53
3	Implement a 'Loading and Hauling' scenario	81
4	Implement a 'Hauler' vehicle	30
5	Implement an 'Excavator' vehicle	56
6	Identify gaps and requirements for standard based on example scenario exercises	30
7	Link gaps and requirements with ASAM standards	30
8	Create concept document for offroad extensions	40
9	Propose further development	40
	Review	

6 Deliverables

At the end of the project, the project group will hand over the following deliverables to ASAM:

Item No.	Description
1	Example Scenario Implementation and Documentation
2	Technical Report on Recommended Extensions for Standards
3	Extension Project Proposal

6.1 Review Process

The process for deliverable review documented in the project guide is applicable to all projects (see here).

The ASAM OR will provide further details on quality criteria and tools used prior to the initiation of a review in a project.

This project will be subject to the following 2 Review Phases:

Project Review
Public Review

7 References

1. *North Atlantic Treaty Organization. (July 2021). Guidance for standards applicable to the development of next generation NATO reference mobility models (NG-NRMM). NATO Standardization Office (NSO). 214 pages.*