Mechanical Simulation

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VS Virtual Proving Ground

This technical memo discusses the Virtual Proving Ground (VPG) in the VehicleSim (VS) products CarSim, TruckSim, and BikeSim. It provides technical details about the test surfaces that comprise the VPG as well as information about how they can be included in simulations. The VPG also provides a ready-made arena for various types of Driver-in-the-loop tests.

How to Access the VPG

The VPG are currently provided as a tile in the VS Scene Builder. The VS Scene Builder is a standalone application that provides a variety of pre-built visual assets for inclusion into CarSim, TruckSim, and BikeSim simulations. In addition to the visual assets, the VS Scene Builder also provides the ability to add additional visual content such as signs, barriers, traffic control devices, and other props like fire hydrants, lampposts, and parking meters. The VS Scene Builder also generates the VS Terrain surface used by the solver for road definition.

This guide provides a high-level overview of using the VS Scene Builder to include the VPG into your simulation. For more details about the features and use of the VS Scene Builder, please see the VS Scene Builder Manual, available from the **Help** menu.

The VS Scene Builder is accessible via the **VS Scene Builder…** menu item in the **Tools** menu. Within the VS Scene Builder, the VPG tile is in the Standalone category in the item palette. It is recognizable by the high-speed circle track which encloses the rest of the facility (Figure 1).

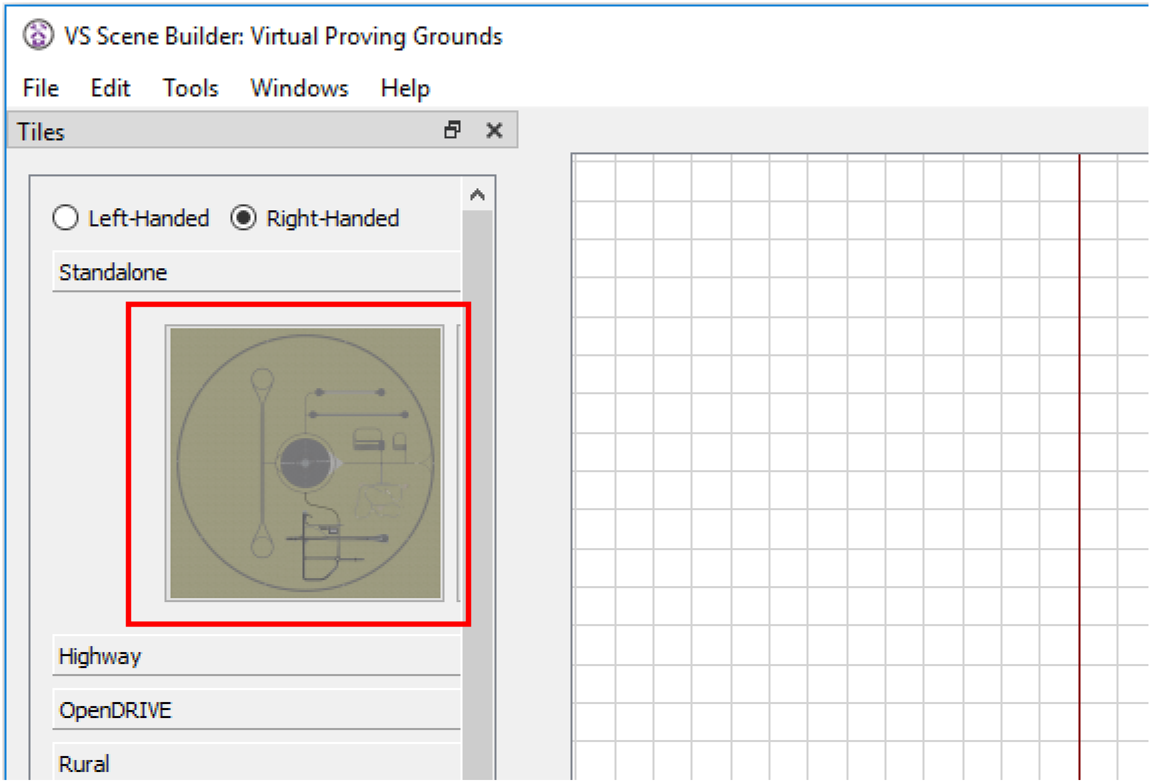

Figure 1: The VPG tile in the VS Scene Builder Window.

When using the VPG tile, it is advantageous to center the tile in the CarSim, TruckSim, or BikeSim Global (Inertial) reference frame. This means that the tile coordinates will match the Global X and Global Y coordinates used by the solver. To locate the tile, right-click on the tile to bring up the context menu (Figure 2). Select the option to **Match Tile Origin to Scene Origin**. The tile will snap to the desired location.

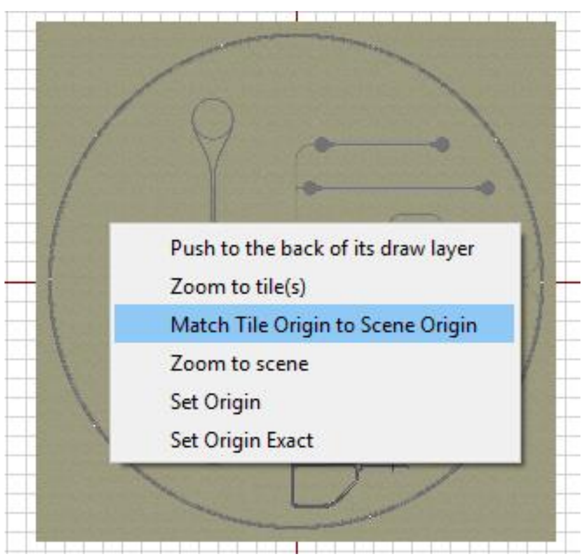

Figure 2: Tile Right-Click context menu.

Once the scene is exported from the VS Scene Builder, the data can be included into a CarSim, TruckSim, or BikeSim simulation with the use of the **Scene: External Import** library (Figure 3). Datasets in this library are typically linked in place of the path in a **Road: 3D Surface (All Properties**) dataset. For more information on the **Scene: External Import** library, please see the library documentation available from the **Help** menu under **Paths, Road Surfaces, and Scenes > Scene External Import**.

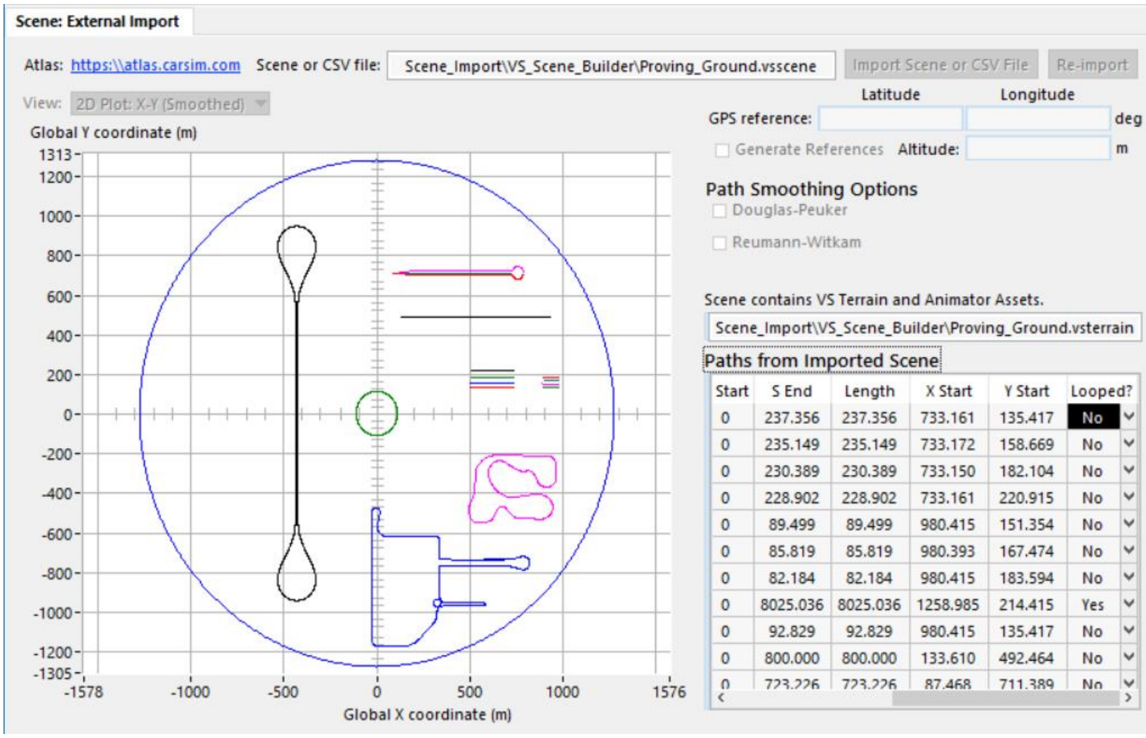

Figure 3: A Scene: External Import dataset with paths from the VPG.

Once the scene is included, any paths specified in the VS Scene Builder will be displayed in the box in the lower right-hand corner of the **Scene: External Import** dataset. The paths are automatically numbered by default in the order in which they are specified. If the imported scene contains multiple paths, the Set ID? Control can be set to Yes and then a custom identifier entered for each of the different paths. This will allow the specific path to be set for each simulation by entering the parameter `PATH_ID_DM`, followed by the desired path ID, into any miscellaneous yellow field that will be read after the Scene: External Import dataset.

Technical Details

This section will provide more a more in-depth look at the different environments included in the VPG. There are 9 distinct test surfaces, described in more detail below. The outside of the VPG is defined by the high-speed circular track, with each of the additional surfaces included within its borders. The map shown in Figure 4 shows the test surfaces in bold lines, with the connector roads in a lighter grey. The test areas include:

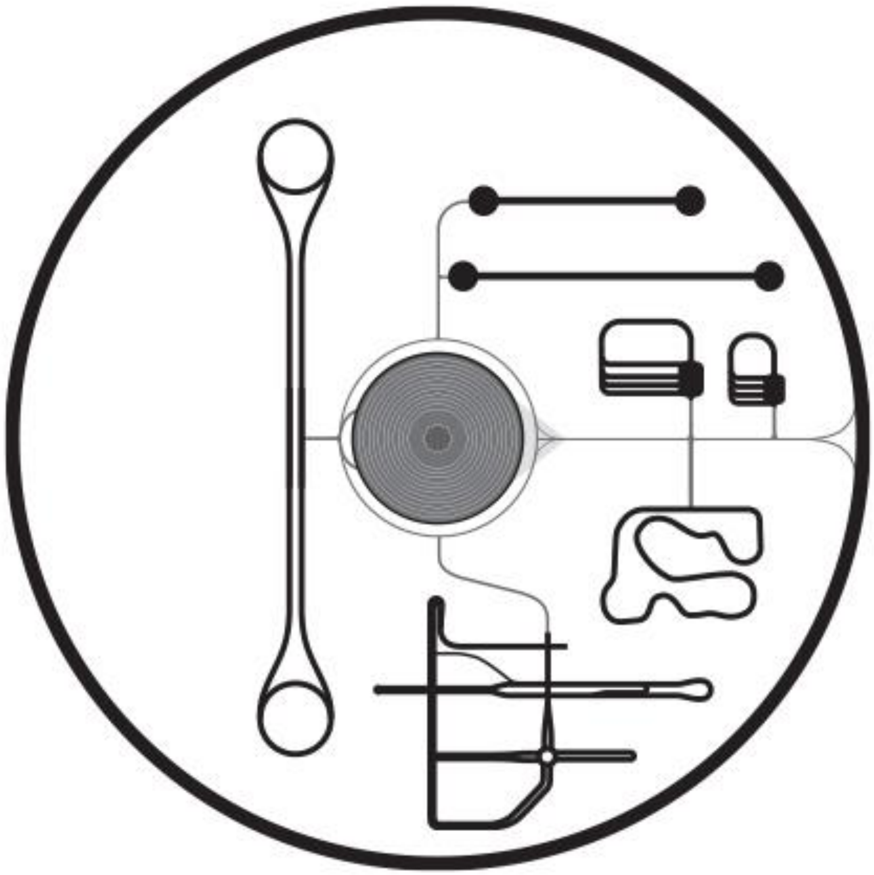

Figure 4 : A Map of the VPG.

- A high-speed circle,
- a hill grade test area,
- a graded area with low-friction road surfaces,
- a split-mu area with multiple types of low-mu surfaces,
- a ride test area with different road waveforms,
- a one kilometer straight,
- a 250m radius vehicle dynamics area (VDA),
- a handling course, and
- an ADAS testing facility.

The test surfaces are connected by a road network, with signage at intersections to help users find their desired test surface when using the VPG in a driver-in-the-loop context.

Global Details

The VPG surfaces, including non-road surfaces like grassy areas and gravel shoulders, are all defined with a VS Terrain surface. VS Terrain provides the VS Solver with values for road properties such as elevation, friction coefficient, rolling resistance, and slope. For more details on VS Terrain, please see the VS Terrain documentation. To achieve the precise surface geometry required by engineered test surfaces, high-precision 3D modeling software was used to develop the geometric mesh that underlies the road surface.

High-Speed Circle Track

The high-speed circle track shown in Figure 5 consists of 5 concentric lanes.

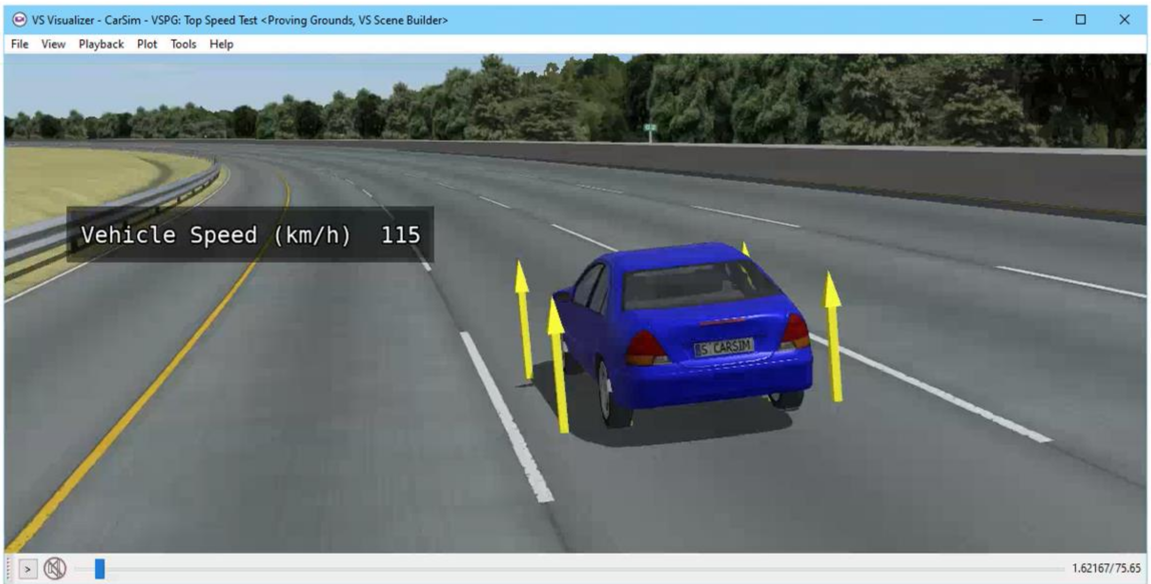

Figure 5: An F-Class Sedan on the high-speed circle track.

Each lane is 4 meters across and has a constant banking angle for its entire length. The lanes are smooth asphalt, with the properties indicated in Table 1.

Table 1: Road properties for the high-speed circle track.

	Radius (m)	Lap Length (m)	Banking Angle (deg)	Neutral Speed (km/h)	Surface Friction (-)	Surface Rolling Resistance (-)
Lane 1	1,269.2	7,974.9	0	-	0.80	1.0
Lane 2	1,273.2	8,000.0	5	96.552	0.80	1.0
Lane 3	1,277.2	8,025.0	10	120.69	0.80	1.0
Lane 4	1,281.2	8,050.0	15	136.782	0.80	1.0
Lane 5	1,285.2	8,074.9	20	160.92	0.80	1.0

Hill Climb

The Virtual Proving Ground also includes an area (shown in Figure 6) designed to allow for testing hill ascension maneuvers like handbrake function and on-grade launching.

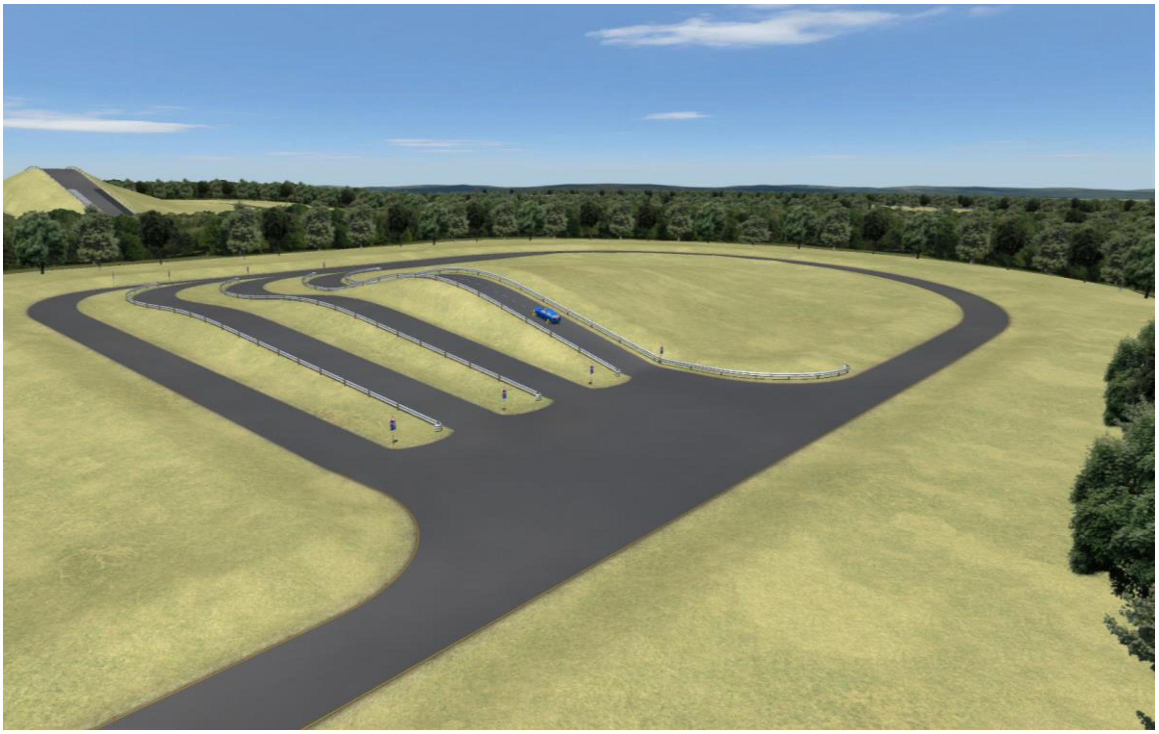

Figure 6: An aerial view of a C-Class Hatchback performing a hill climb test.

This area has four separate graded hills, with the properties indicated in Table 2.

Table 2: Road properties for the hill climb graded surfaces.

	Grade (%)	Grade Length (m)	Surface Friction (-)
Hill 1	3	80	0.8
Hill 2	6	50	0.8
Hill 3	9	40	0.8
Hill 4	15	30	0.8

On-Grade Split Mu

In addition to a series of standard graded surfaces, a selection of grades with varying surface friction are also available. Figure 7 shows a large SUV using the ice surface type while attempting a hill climb maneuver.

The grades match those of the Hill Climb area, so a comparison between split-mu and constant-mu vehicle performance is possible. The hills are designed with an apron area at the base of the hill so that they may be used in either direction, uphill for traction type tests and downhill for braking and deceleration tests. The properties of the On-Grade Split-Mu surfaces are given in Table 3:

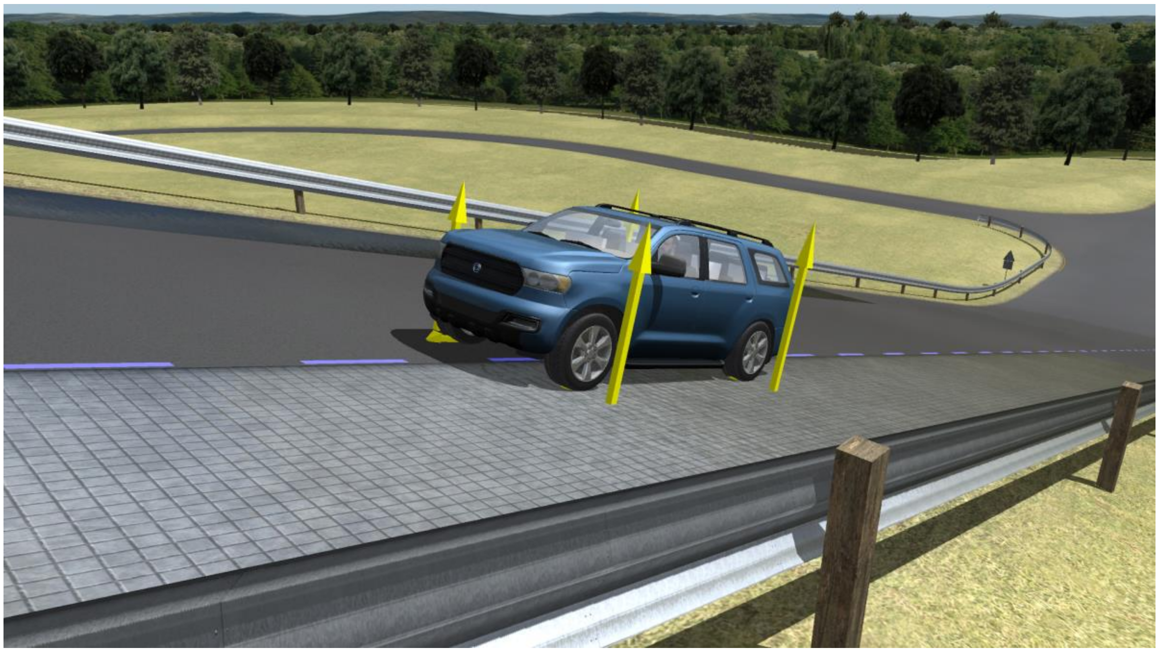

Figure 7: A large SUV attempting a split-mu hill climb.

Table 3: Road properties for the on-grade split-mu surfaces.

	Grade (%)	Length of Split Mu Surface (m)	Surface Friction (-)		
			Ice	Asphalt	Wet
Hill 1	3	121.7	0.1	0.8	0.4
Hill 2	6	115.1	0.1	0.8	0.4
Hill 3	9	91.5	0.1	0.8	0.4
Hill 4	15	44.3	0.1	0.8	0.4

Level Split-Mu Surface

The level Split-Mu surface shown in Figure 8 consists of six 800m lanes.

Each lane has a different value for surface friction. The lane surface types are Asphalt, Concrete, Ice, and Wet, and are arranged such that there are five unique surface combinations in total. The lanes are numbered from left to right as the vehicle enters the area from the connector road network. The lane properties are listed in Table 4:

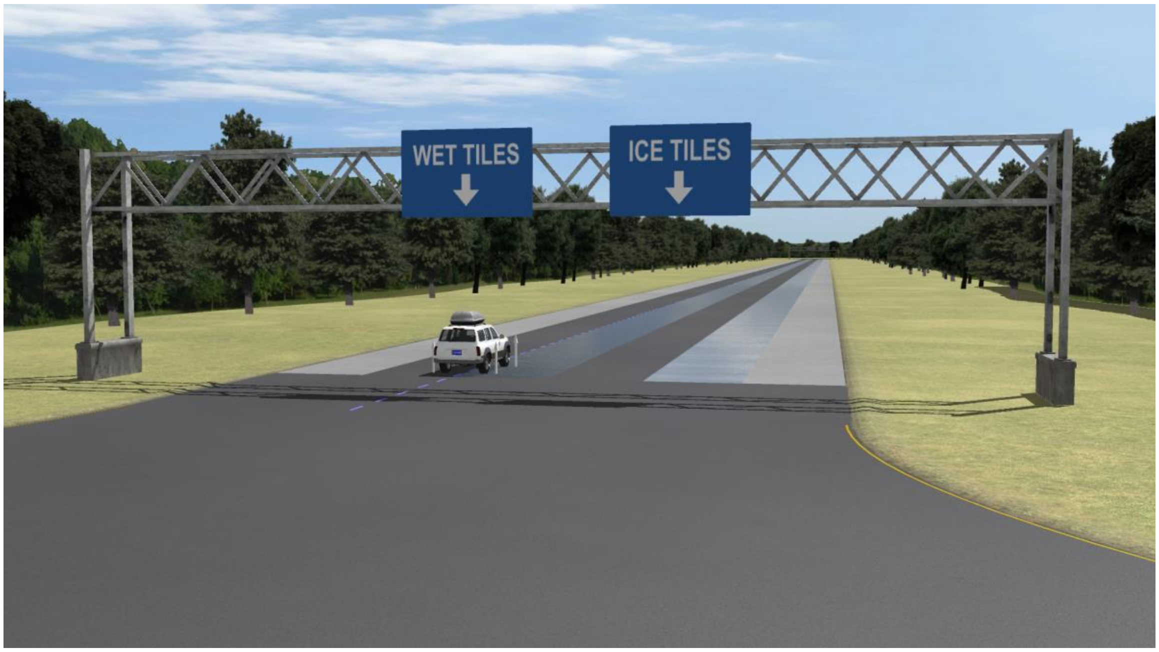

Figure 8: A mid-size SUV performing split-mu testing at the VPG.

Table 4: Road properties for the level split-mu surfaces.

	Lane Width (m)	Surface Type	Surface Friction (-)
Lane 1	3.65	Asphalt	0.8
Lane 2	3.65	Concrete	0.8
Lane 3	3.65	Wet	0.4
Lane 4	3.65	Asphalt	0.8
Lane 5	3.65	Ice	0.1
Lane 6	3.65	Concrete	0.8

Rough Road Surfaces

The Rough Road area shown in Figure 9 has three different waveforms that can be used for suspension and ride testing.

Each of the roads are 500m long. There are three different types of waveforms available. The first is a set of offset square-edged bumps. The second is a constant-frequency sine wave, with the left and right side out of phase by 180 degrees. The final waveform is a constant-frequency sine wave, with the left and right side in phase. There is a turn-around area at each end of the surfaces, and a smooth asphalt return lane for situations where a test is concluded at the far end of the rough road surfaces.

Figure 9: An A-Class Hatchback testing in the rough road area at the VPG.

Offset Square-Edged Bumps

This surface is composed of two lanes of rectangular bumps, each 4 meters wide. The bumps are 0.1 m high, 1m long, and have a 1m gap between bumps. The lanes are offset longitudinally from one another by 1 meter. The large width of these lanes allows for travel fully within each lane for a regular, repeating input as well as down the center of the two lanes for offset inputs. To get a base frequency of 1 Hz on the square edged bumps road, the target velocity is 7.2 km/h.

Notes When using the square edged bumps course, the tire model selection can have a large impact on the results. Most common tire models have a built-in assumption that the tire Z-direction occurs normal to the road surface. When sampling a small bump with a steep gradient at low speeds, the sample will occasionally fall on the "edge" of the bump, causing the vector normal to the road surface to deviate a large amount from the road normal vector on most of the road. This is true of both the CarSim internal tire model, as well as basic third-party tire models like MF-Tyre / MF-Swift.

In CarSim, TruckSim, and BikeSim, there is an option to expand the tire contact patch beyond the single-point model. This option works reasonably well on the square edged bumps course, when the vehicle is traveling at the types of speeds used for ride evaluation. Similarly, MF-Swift offers, and CarSim, TruckSim, and BikeSim support, a small-wavelength model with enveloping that also can work reasonably well on the square-edged bumps.

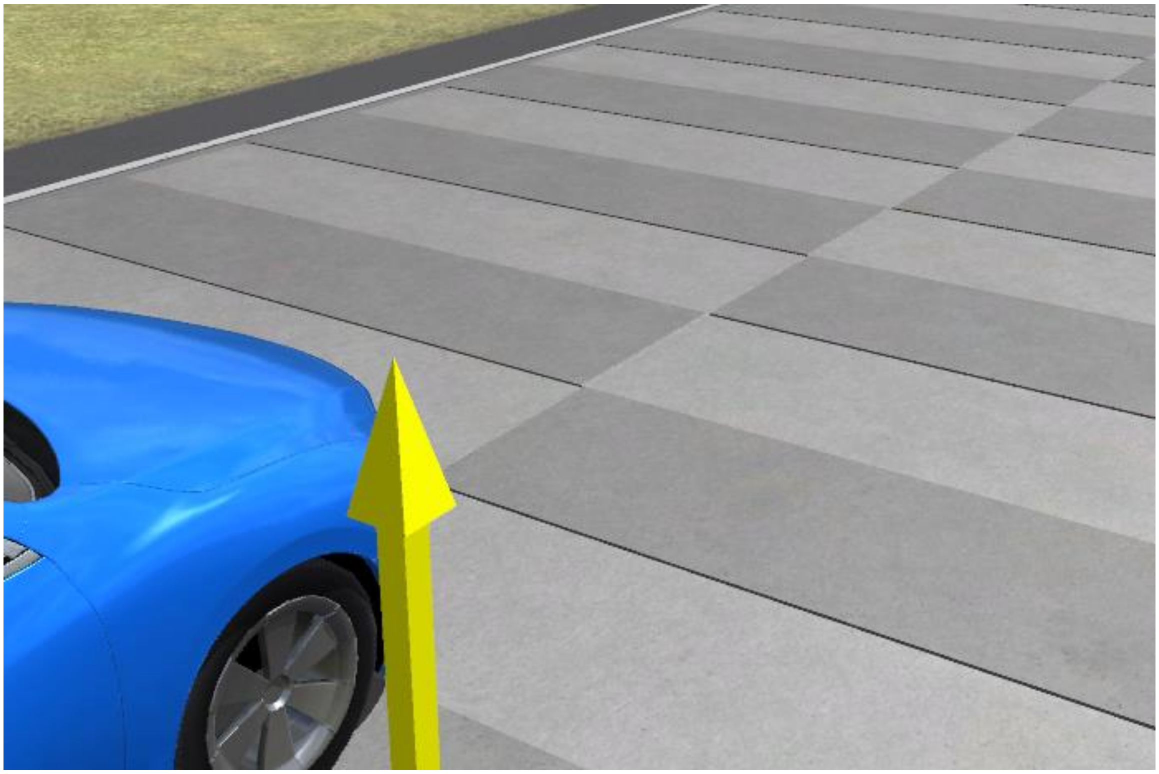

Figure 10: A D-Class Sedan using the square-edged bumps road on the Virtual Proving Ground

> For a full evaluation of tire performance on the square-edged bumps at low speeds, a finite-element-based tire model such as Cosin FTire (also supported by CarSim, TruckSim, and BikeSim) would be most appropriate. MF-Swift and FTire co-simulations require additional licenses beyond a CarSim license which may be obtained from their respective developers.

Out-of-Phase Sine Wave

The out-of-phase sine wave road consists of two lanes, each 1.75m wide. The vertical displacement is a sinusoid, with a 10mm amplitude and 5.557m wavelength, giving the road a one Hertz frequency at 20km/h. The left lane is 180 degrees out-of-phase with the right lane. While a 10mm amplitude does not seem significant visually – note here Figure 11, below - the displacement is significant enough to excite the vehicle body and to disturb the cabin occupants.

Figure 11: A D-Class sedan driving on the out-of-phase sine wave road

In-Phase Sine Wave

The in-phase sine wave road consists of a single 3.5m wide lane. The vertical displacement is a sinusoid, with a 10mm amplitude and 5.557m wavelength, giving the road a one-Hertz frequency at 20km/h. As with the out-of-phase sine wave road, the 10mm amplitude may not seem significant visually (Figure 12) but the displacement is significant enough to excite the vehicle body and to disturb the cabin occupants.

Figure 12: A D-Class Sedan on the in-phase sine bumps road.

1 Kilometer Straight

The one-kilometer straight area shown in Figure 13 provides a surface for a variety of performance and handling tests.

Figure 13: A pickup truck pulling a small cargo trailer on the 1 kilometer straight.

The area consists of two straight sections, each one kilometer long, joined by a banked turn-around to help maintain speeds. Additionally, there is a break in the guardrails separating the sections near the midpoint, allowing for the option to turn around or exit the straight without needing to proceed to the ends of the straight.

The straight sections are composed of three asphalt lanes, each 3.85m wide. The surface friction coefficient for the lanes is 0.80, and the rolling resistance coefficient is 1.0.

250m Radius Vehicle Dynamics Area

The Vehicle Dynamics Area, or VDA, shown in Figure 14 is a circular area with a radius of 250m, and a surface area of about 200,000 square meters (48.5 US Acres).

The main area has entrances from the East and West, with the eastern entrance also serving as an acceleration road for various maneuvers. There is an access road which rings the VDA and offers easy connection to other parts of the VPG. The surface is marked with concentric rings, which are labeled both with road paint and a floating billboard indicating the approximate circumference for that ring. In addition to the concentric rings, the center of the VDA also contains a set of tangentially joined circles making a figure 8, and some smaller diameter circles for other steering tests.

The VDA is centrally located within the VPG, and if the scene is centered, then the center of the VDA surface will be at the global origin, allowing for the easy construction of tests. The surface is asphalt, with a friction coefficient of 0.8, and a rolling resistance coefficient of 1.0.

Figure 14: A D-Class Sedan performing a constant radius lateral acceleration test on the VDA.

Handling Course

The handling course is a 2.3 km road course with 8 major corners and 13 total turns of varying geometry. The turns vary in radius from 15m to 500m and the elevation ranges between -2.8m and 5.3m. The course layout is shown in Figure 15, with the turns numbered starting with the first corner after the course entrance and concluding with the turn before the course exit. Turn 5 is a sweeping compound corner with two distinct radii connected by a clothoid.

The VPG handling course is very similar to the standalone handling course that ships with CarSim, TruckSim, and BikeSim (Figure 16). The primary differences are the location of the course entrance – midway between corners 13 and 1 in Figure 15 for the VPG while it is between 5B and 6 for the standalone handling course – and the surface friction. For the VPG, the friction coefficient is 0.80, and the rolling resistance coefficient is 1.0.

ADAS Development Area

The ADAS Development Area is a region just under 0.5 square kilometers (about 495,000 square meters) in size. Within the region there are about 32 different intersections and road features.

The access road for the ADAS area begins south of the VDA. The features are listed below, with the number corresponding to the numbers in Figure 17.

1. Stop sign with horizontal stop marking on road.
2. Small security building with cautionary road markings.
3. Four-way stop with un-signaled pedestrian crossings.
4. Parking lot with spaces defined both parallel and perpendicular to the direction of travel.

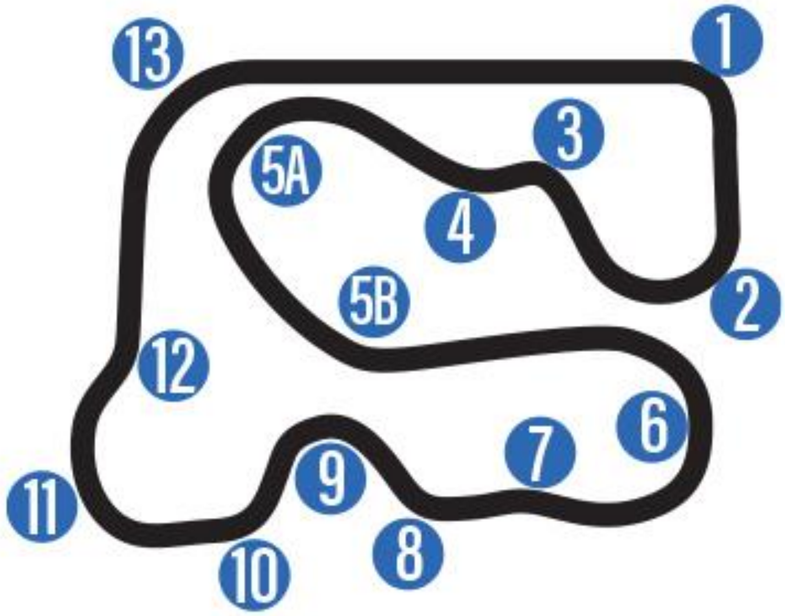

Figure 15: Course map for the VPG handling course.

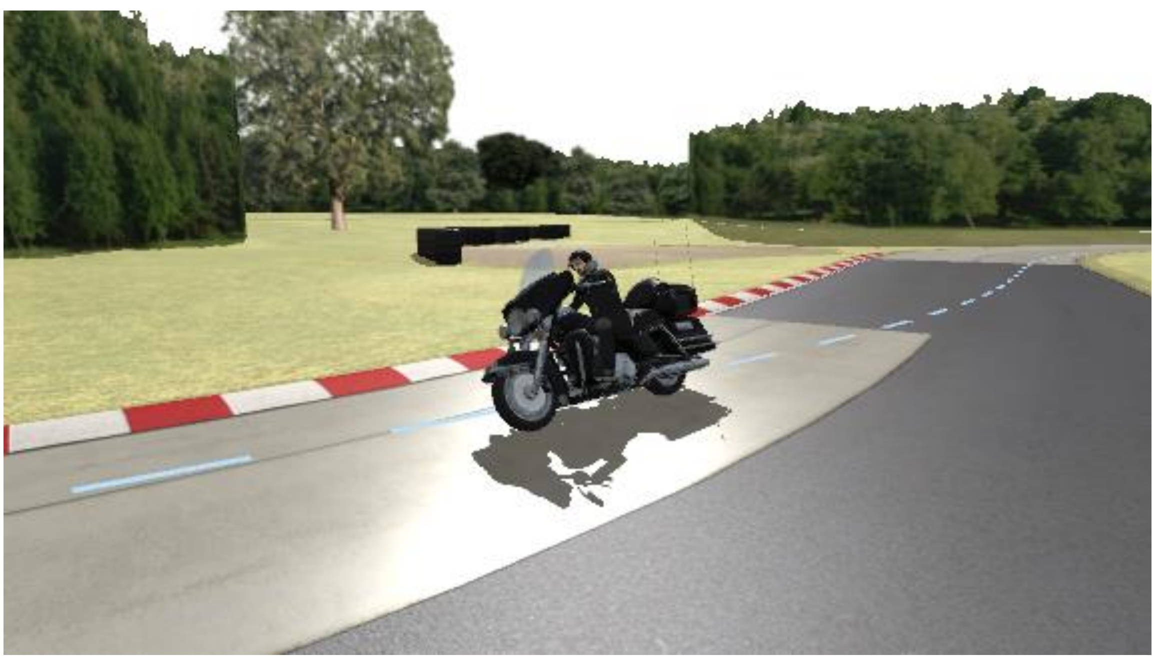

Figure 16: A touring-style motorcycle testing on the VPG handling course.

5. 4-way signalized intersection. North-South roads have one through lane and one right-turn lane. East-West roads are divided with two through lanes and one right turn lane. No left turn is permitted from the East-West roads.
6. Divided service road turn around, to provide Northbound access from Eastbound divided lanes.

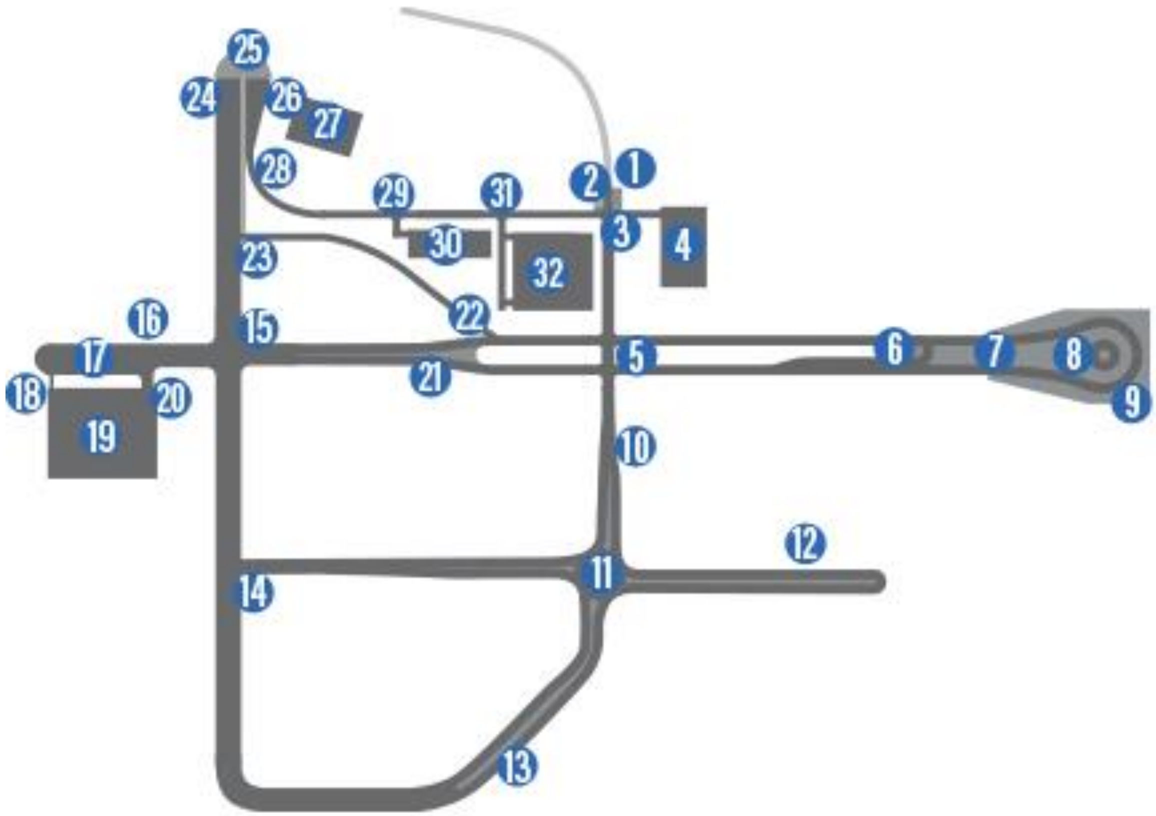

Figure 17: Map of VPG ADAS Development Area

7. Angled parking stalls built into the divided service road infield.
8. Two-lane small diameter circle. Inside lane radius is 7.8m, outside lane radius is 13.1m. Lanes are about 5.25m wide.
9. Circular turn-around to convert Eastbound traffic into Westbound traffic on the divided service road
10. Start of road division to separate roundabout entrance and exit traffic.
11. Two-lane roundabout. Entrances to and exits from the roundabout are off-center ()Figure 18.
12. Signalized railroad level crossing with road paintings, crossbuck, and cantilever signal lights
13. Start / stop of road division and conversion from 2 lanes in each direction to 3 lanes in each direction.
14. Signalized 3-way intersection with signs and road paintings indicating lane use. Building facades obstruct the view of the terminating road.
15. Signalized 4-way intersection with signs and road paintings indicating lane use. Broken line road paintings indicate lane connections for turning lanes. Building facades obstruct the view for vehicles attempting to turn.

Figure 18: A small SUV traversing the roundabout in the ADAS development area in the VPG.

16. Unmarked driveway access to the right lane
17. Bike lane indicated via road markings.
18. Single lane driveway with un-signaled pedestrian crossing road markings.
19. Parking lot and loading dock. Lot has marked spots parallel to the direction of traffic flow and a series of loading dock stalls marked with road paintings perpendicular to the direction of traffic flow.
20. Wide driveway access to loading dock parking lot.
21. Road type conversion between divided and adjacent lanes for opposing traffic.
22. Exit ramp entrance from westbound divided highway.
23. Signed exit ramp terminus at service road. Available turn directions are indicated with road paintings.
24. Signed pedestrian crossing.
25. Turn-around and connector for the 3-lane adjacent traffic service road.
26. Two-lane access road for parking lot
27. Parking lot with stalls that are parallel and perpendicular to the traffic flow.
28. Stop sign with small security building.
29. Three-way signed intersection with un-signaled pedestrian crossing
30. Parking lot with adjoining stalls perpendicular to the traffic flow.

31. Three-way signed intersection with broken lines used as traffic guides and un-signaled pedestrian crossings.
32. Warehouse / Storage Unit facility with multiple buildings and low visibility for vehicles in the alleys between buildings.

Within the ADAS development area, the road surfaces are asphalt, with a friction coefficient of 0.8 and a rolling resistance coefficient of 1.0. In addition to the built-in features provided with the VPG, additional buildings, traffic objects, pedestrians, and other environmental props may be added to the scene either through the VS Scene Builder, or through the CarSim, TruckSim, and BikeSim GUI as moving objects.