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Improving Performance and Stability of AMRs and AGVs using a Dynamic Simulation Model

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Introduction

Automation of internal logistics is an effective approach for streamlining repetitive and labor-intensive tasks across multiple industries. In industrial settings, automation has gained traction. Its use is more widespread because the technology is more readily available and the efficiency and performance of the products have improved.

Several different options currently exist for logistics automation. The available solutions vary based on the level of technology employed, the environments in which they may operate, and the tasks which they are able to accomplish.

- Automated Guided Vehicles (AGVs): AGVs use less sophisticated technology, typically relying on fixed routes which may be marked by wires, magnetic strips or other means.

- Autonomous Mobile Robots (AMRs): AMRs have more advanced means of navigation, using data from sensors, cameras and software to determine destinations and paths with more flexibility.

While these technologies differ in their capabilities, they share similar behavioral concerns in terms of safety and stability.

It is in this context that we will explore a dynamic model of an AGV. First, we will test its stability in maneuvers like braking and cornering and then we will consider alternative configurations.

The model we will use to analyze the AGV was built using Simcenter Amesim, a system simulation tool used across multiple industries, from automotive to industrial machinery to medical devices.

Figure 1 3D Model of the AGV and track

AGV Design

Several AGV design configurations are possible. These typically have to do with the arrangement of the wheels, and which are driven, steering or rollers. Some of the options include:

- Steer Drive
- Quad Drive
- Differential Drive
- Steerable Differential Drive
- 4-Wheel Drive (Skid Steer)

For the purposes of this study, we've used an AGV model with a differential drive configuration that uses 2 independent motors to drive the front wheels.

The motor torque commands will be controlled based on a calculation of the vehicle's actual trajectory against its reference trajectory.

System Model

The system model was created using the system simulation tool Simcenter Amesim. It is available as part of the demonstration models for the robotics solutions.

The model uses the dedicated libraries for mechanical components and the library for vehicle dynamics. It includes the following components:

- Chassis
- Front Axle
- Rear Caster
- Sensor

In addition to these elements, the trajectory of the AGV is included in the model, as are position and speed control loops.

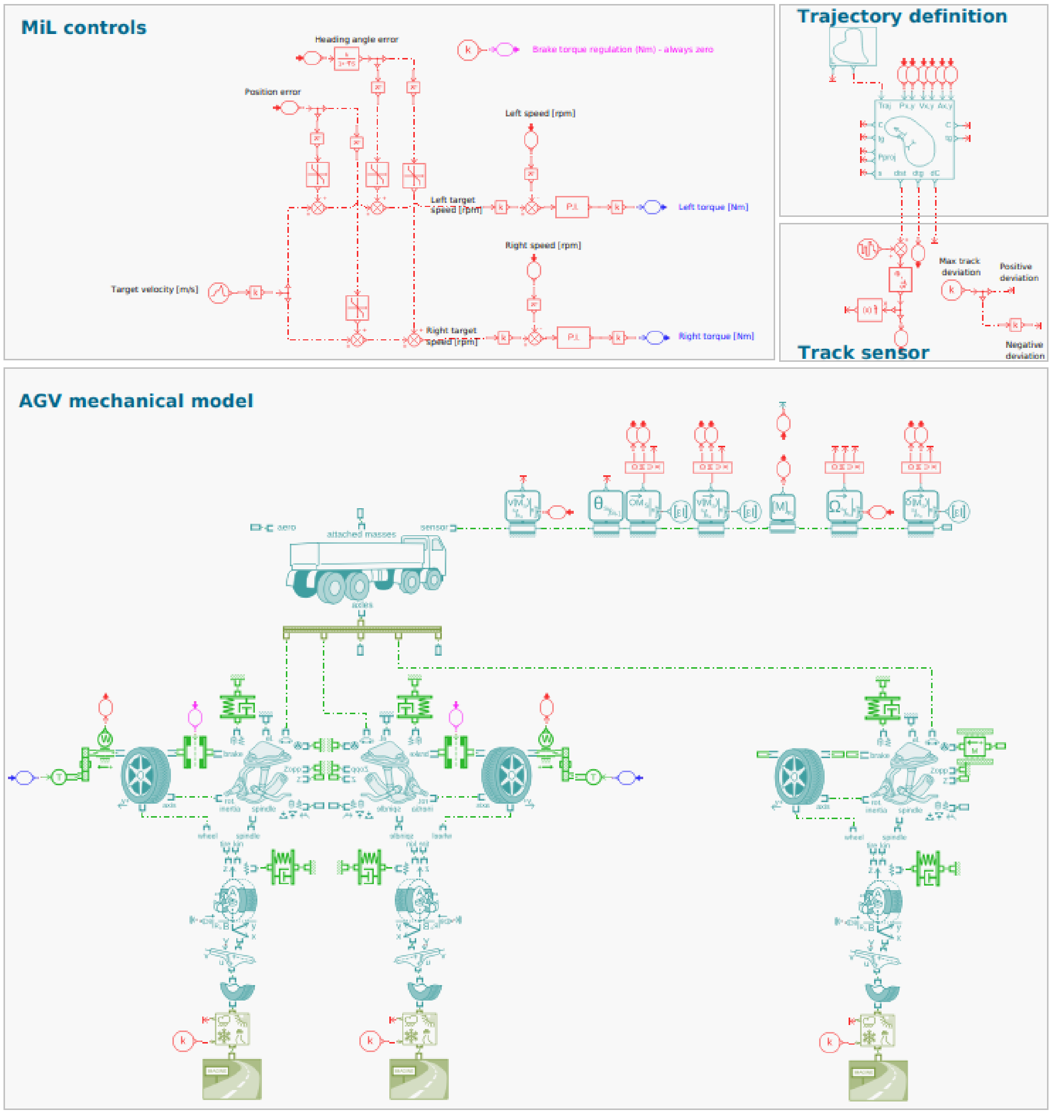

Figure 2 Simcenter Amesim model of the AGV

The model was modified to accommodate two variations of the chassis configuration:

- Differential Drive configuration
- Steer Drive configuration

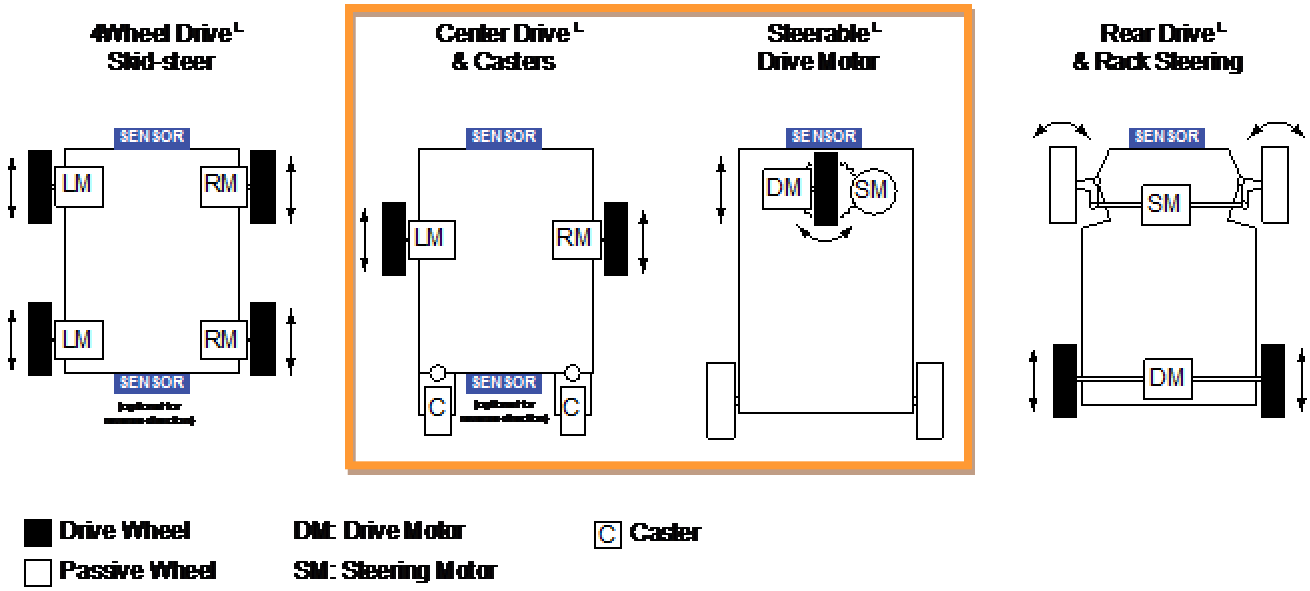

Figure 3 Different AGV chassis design types[1]

The first, Differential Drive, is the default configuration of the AGV model; the second, Steer Drive, has been modified to include a single drive and steering wheel at the front of the vehicle, with the two rear wheels as passive rollers.

The two chassis configurations chosen for this study are the Centre Drive & Casters and the Steerable Drive Motor.

The control scheme was also modified to provide a steering force to the steering motor and a torque to the drive motor.

Chassis Parameters

The chassis of the AGV is modeled using several key components;

- Tire Kinematics
- Front Axle with emulated motor torque
- AGV Body Dynamics
- Rear caster wheel

[1] https://www.roboteq.com/images/2019/10/04/chassis-design.gif

Tire Kinematic Elements

The tire kinematics are modeled with an assembly of different components, pictured below:

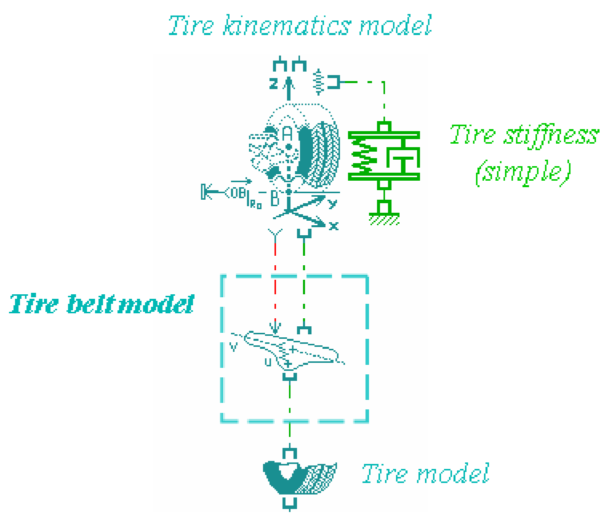

Figure 4 Detail view of wheel model

The wheels use a Pacejka 92 definition for effective rolling radius where it is assumed constant. Additionally, the tire model subcomponents also contain elements for tire longitudinal stiffness and cornering stiffness, as well as overall inertia of the wheel along the axis of rotation.

The kinematics of the tire are represented by the normal load of the tire, tire deflection, tire velocity, at the center and deflection velocity:

$$\vec{F}_{ztire}\cdot\vec{z}_w = \left(K_{tire}dz|_{R_{2bis}} + B_{tire}\frac{d}{dt}dz|_{R_{2bis}}\right)\cdot\cos(\varepsilon_v)$$

Equation 1 Normal load exerted on the chassis by the tire

$$dz|_{R_{2bis}} = R_{free} - \frac{\left(\vec{O}A_2|_{R_0}\cdot\vec{Z}_0 - Hz|_{R_0}\right)\cdot\vec{Z}_w\cdot\vec{Z}_0}{\cos(\varepsilon_v)}$$

Equation 2 Tire deflection

$$\vec{V}_{R_{2bis}/R_0}(B)\Big|_{R_{2bis}} = \vec{V}_{R_2/R_0}(A_2)\Big|_{R_{2bis}} + \vec{BA_2}\wedge\vec{\Omega}_{R_{2bis}/R_0}\Big|_{R_{2bis}}$$

Equation 3 Tire velocity taken at center of tire

$$\frac{d}{dt}dz\Big|_{R_{2bis}} = -\frac{\left(\vec{V}(A_2)\Big|_{R_0}\cdot\vec{Z}_0 - Vz\Big|_{R_0}\right)\cdot\vec{Z}_w\cdot\vec{Z}_0}{\cos(\varepsilon_v)}$$

Equation 4 Tire deflection velocity

$dz|_{R2bis}$: Crush of the tire expressed in steered cambered frame.

R_{Free} : Free radius of the tire (tire radius without vertical load).

$OA_2|_{R0}$: Absolute position of center of wheel expressed in Galilean frame.

$Hz|_{R0}$: Height of the ground expressed in Galilean frame.

Z_W : Ground normal vector expressed in steered frame (Rw).

Z_0 : Vertical component of Galilean frame.

ε_V : Camber angle (Wheel/Ground).

Note that in the model, a side slip angle sensor measures the absolute velocity of center of tire contact (B), and a frame change sensor allows for the projection of the measured velocity in Rw frame to compute velocity ratio Vy/Vx.

To measure the side slip angle with belt deformation effect (relaxation length), a sensor must be connected to belt model.

Additionally, the tire belt model is used to compute slip angles and camber calculations according to PACEJKA 97 formulation.

Trajectory Parameters

The trajectory is computed using a dedicated component for the projection in comparison with a reference trajectory.

This component is responsible for computing the error between a reference trajectory and the actual heading and curvature of a measured vehicle. It provides the information necessary for the speed and position controllers, which govern the drive and steering motors.

AGV Body

The wheels and axles are attached to a body that is represented by a 3D sprung mass. It computes the roll and bump of the chassis communicated by the wheel and axle loads.

Reference Trajectory

The initial model has three different paths for use in studying stability:

- S Curve
- Figure 8
- Rounded rectangle

Ground Surface

In this modified model, the ground surface is also modified to include sinusoidal elevation and a rough surface to further test stability.

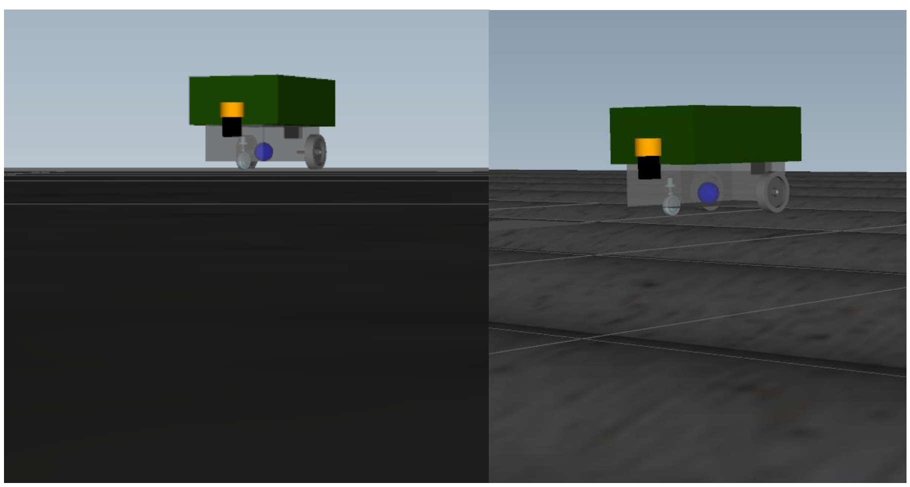

Figure 5 Variations in ground surface between iterations

Emergency Braking

The model has also been modified to include an emergency braking signal. When selected, it will remove the drive torque to the wheels and apply a braking force.

Stability Study

The first study is a baseline analysis of the ability of the AGV to maintain its trajectory at different commanded speeds.

A typical AGV speed is around 1m/s, and so, two vehicle velocities will be tested here:

- 0.5 m/s
- 1 m/s

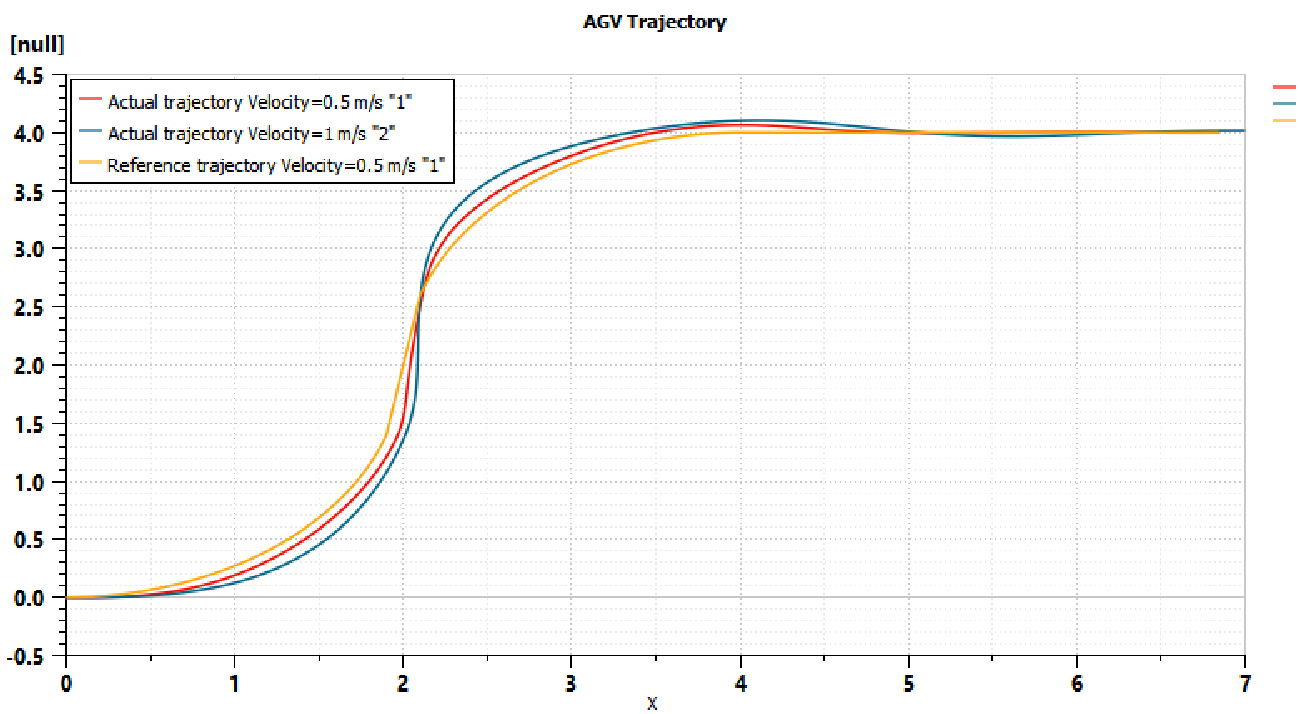

Figure 6 S Shaped trajectory of the differential drive AGV

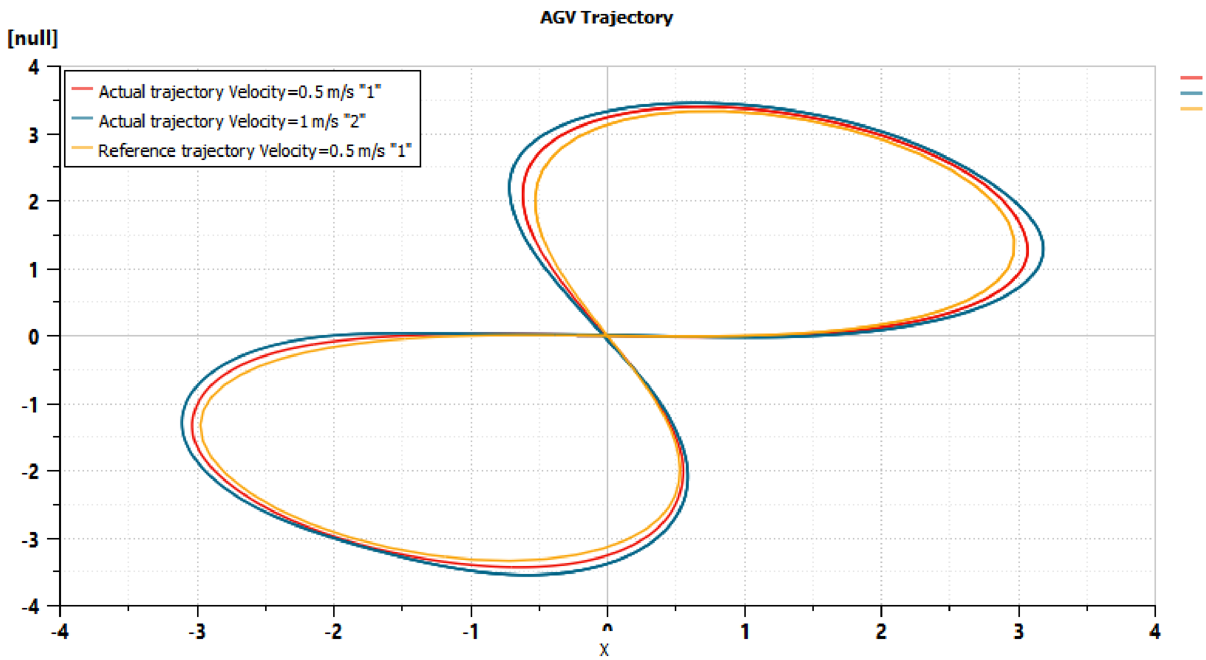

Figure 7 Figure eight trajectory of the differential drive AGV

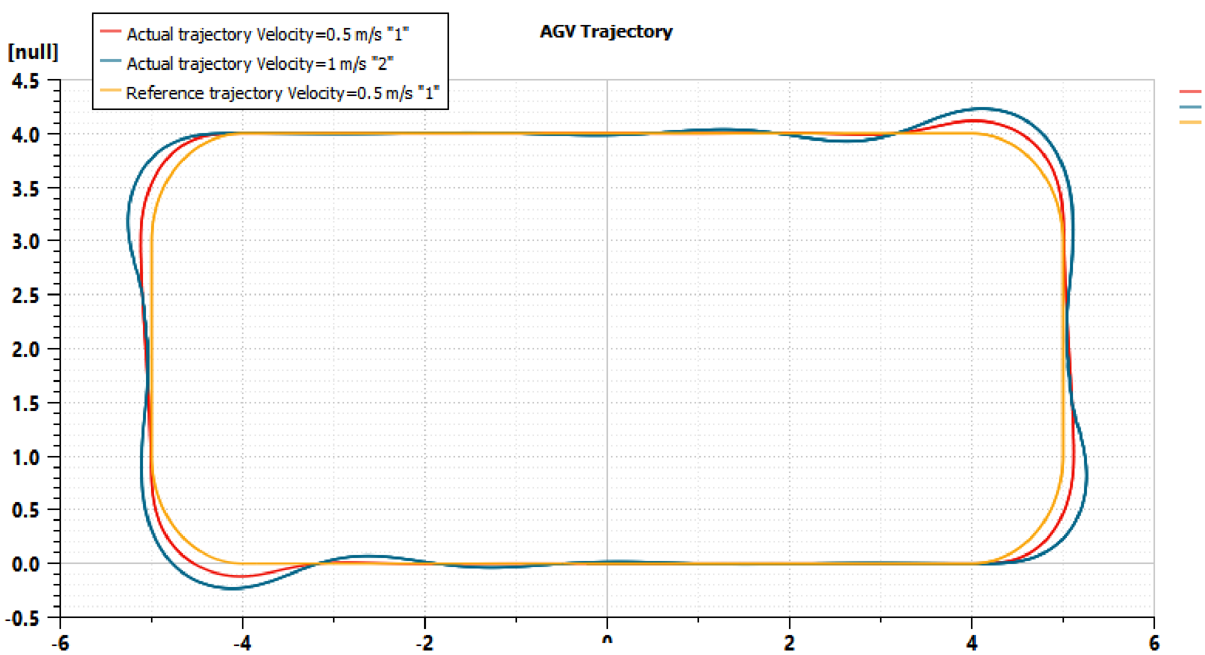

Figure 8 Rounded rectangle trajectory of the differential drive AGV

Ground Surface Study

In addition to testing various speeds of the AGV, the model was used to test robustness of the control given more uneven ground surface conditions.

The road contact portion of the model uses preset conditions for road surface:

- Flat road
- Sinusoidal road
- Sloped road
- Uneven road
- Custom 3D road

The sinusoidal road was chosen with an amplitude of 10 cm and a wavelength of 1 m.

For the S shaped turn, the AGV was able to complete the circuit, but with a higher degree of error. When testing the rounded rectangle circuit under the same road conditions, the AGV completed the circuit under low command speed, but the control system failed to keep the vehicle on track at high speed.

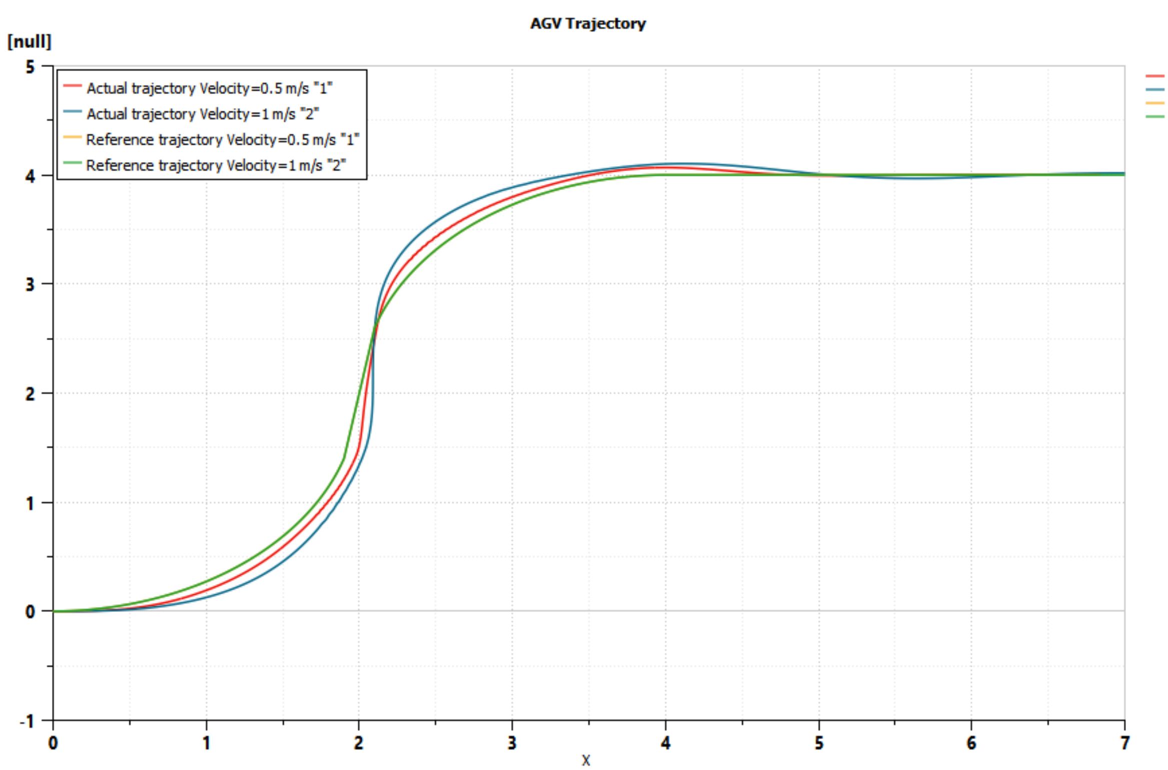

Figure 9 S shape trajectory on sinusoidal road

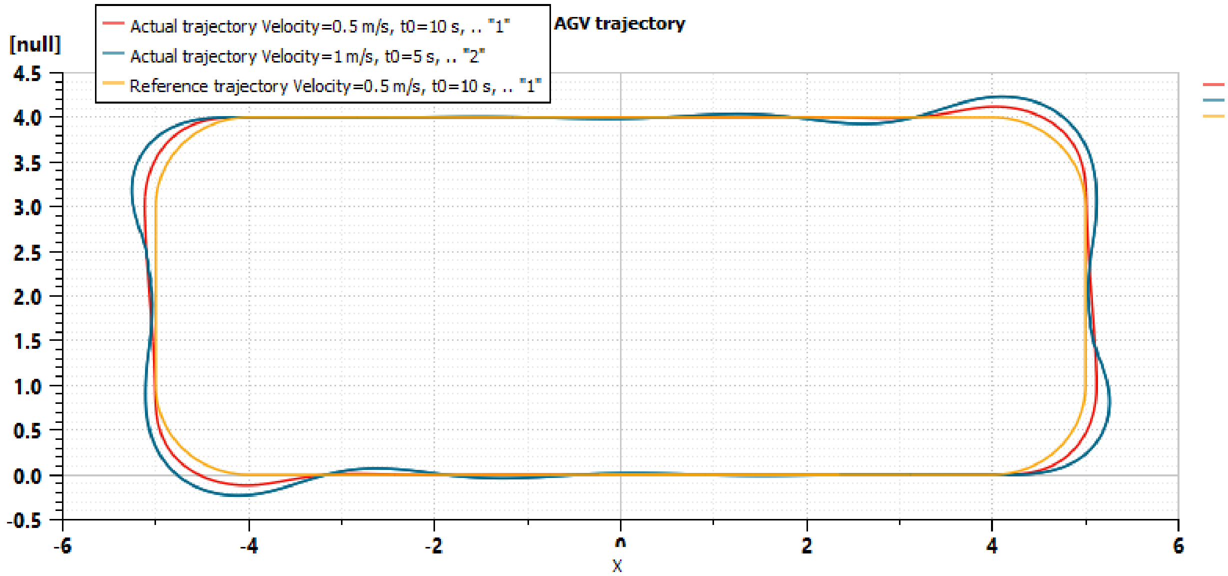

Figure 10 Rounded rectangle trajectory on sinusoidal road

Emergency Braking

The next scenario tested was emergency braking. The AGV was subjected to a sudden braking torque at the wheels of 10 N/m at 10 seconds for the low-speed test and 5 seconds for the high-speed test.

In both cases, the vehicle was fully immobile within 1 second. However, at the high-speed setting, the AGV exhibited more instability during braking.

This instability at higher speeds is a product of the vehicle dynamics as opposed to the control system. This is shown in the model, as when the emergency braking signal is activated, the torque command to the drive motors is disabled.

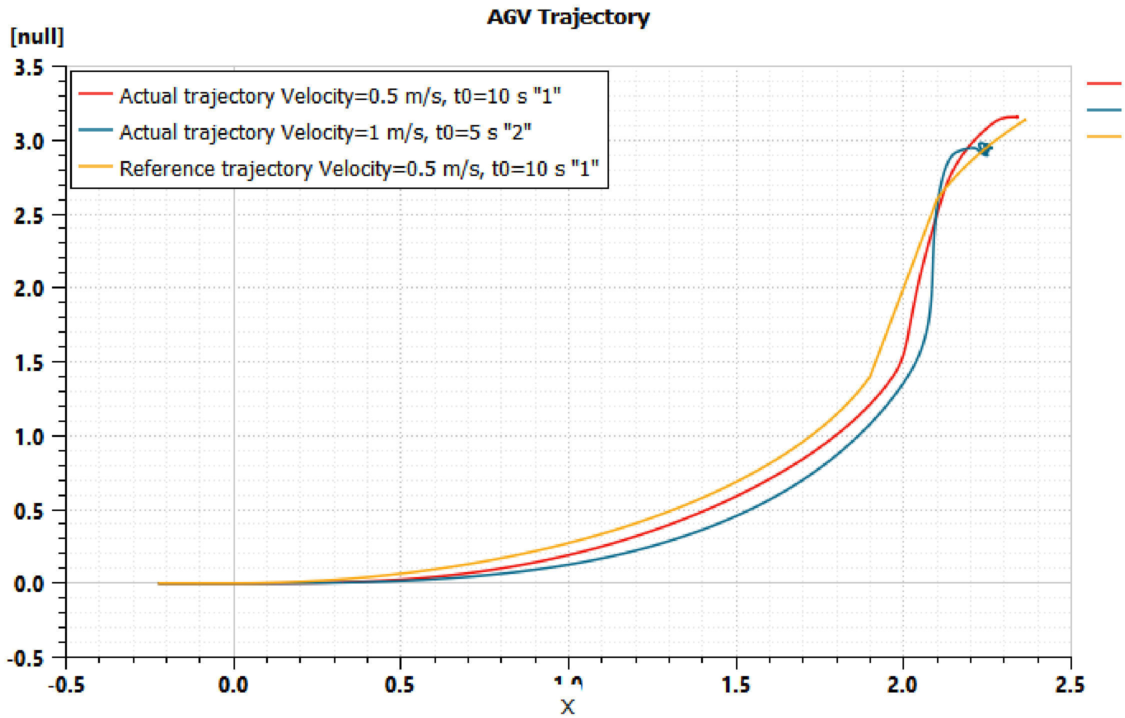

Figure 11 S shaped trajectory under emergency braking

Alternative Configuration

Aside from the baseline chassis configuration, the Simcenter Amesim model was also modified to include the steer drive type to assess the effectiveness of multiple chassis types given the same scenarios.

Modifications

The sole modifications to the baseline chassis to create a steer-drive configuration are as follow:

- Modification of the single wheel to be both driven and steering
- Placement of the single drive wheel to the front of the chassis

This new steer-drive model was subjected to the same testing sequence as the differential-drive model.

Stability Study

Once again, the new AGV was commanded to follow the three pre-defined set paths at 0.5 m/s and again at 1 m/s.

Some drift was observed in the control of the AGV for the rounded rectangle at higher speed. This can be observed in the rectangular path becoming gradually larger for each consecutive loop.

When applying the same sinusoidal road conditions as in the previous configuration, the AGV can be seen exhibiting the same type of drift as previously displayed. In the case of the figure eight, a high degree of instability can be observed at both command speeds. At low speed, the AGV is not able to complete the reference trajectory for the second loop. At high speed, the same drift can be observed as in all previous cases.

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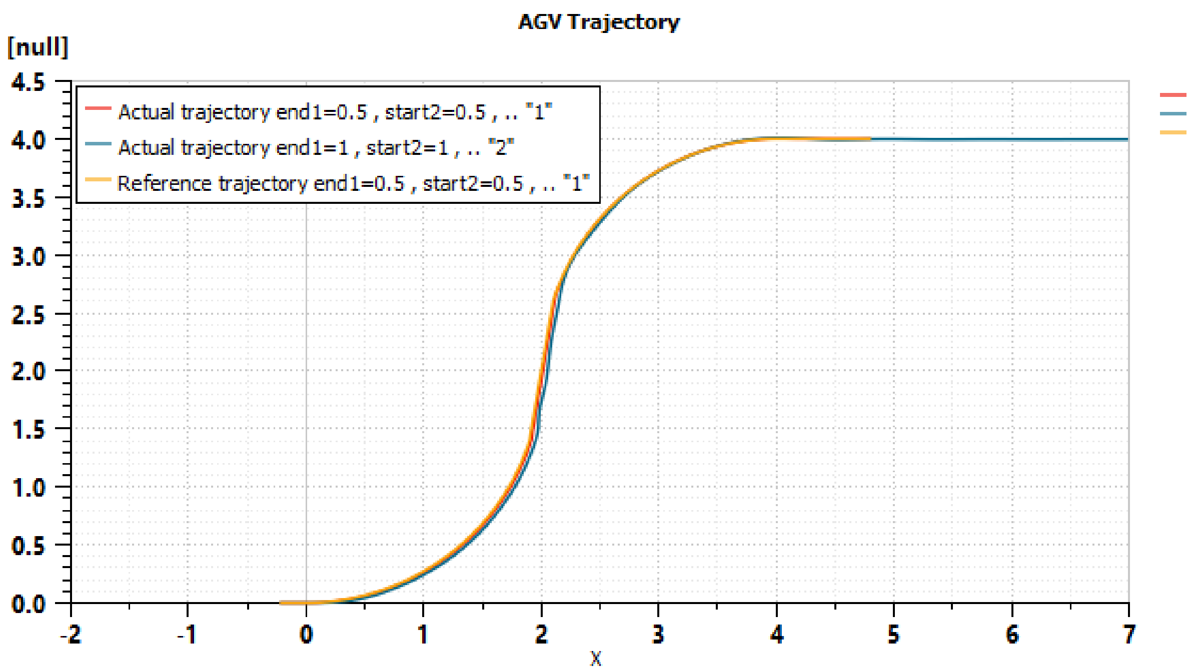

Figure 12 S shape trajectory of the steer drive configuration

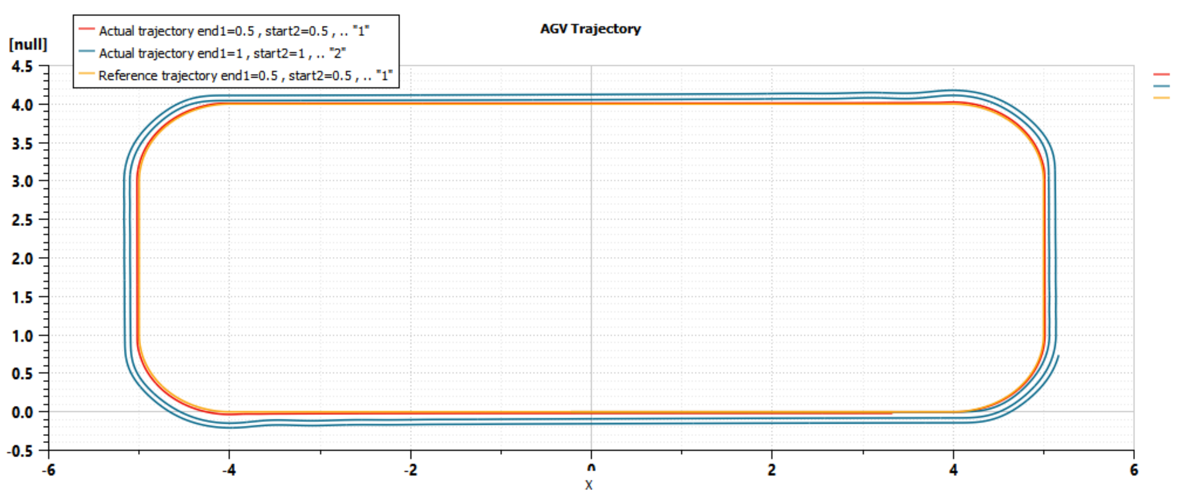

Figure 13 Rounded rectangle trajectory for the steer drive configuration

Ground Surface Study

The same sinusoidal road was applied to the new AGV with an amplitude of 10 cm and a wavelength of 1 m.

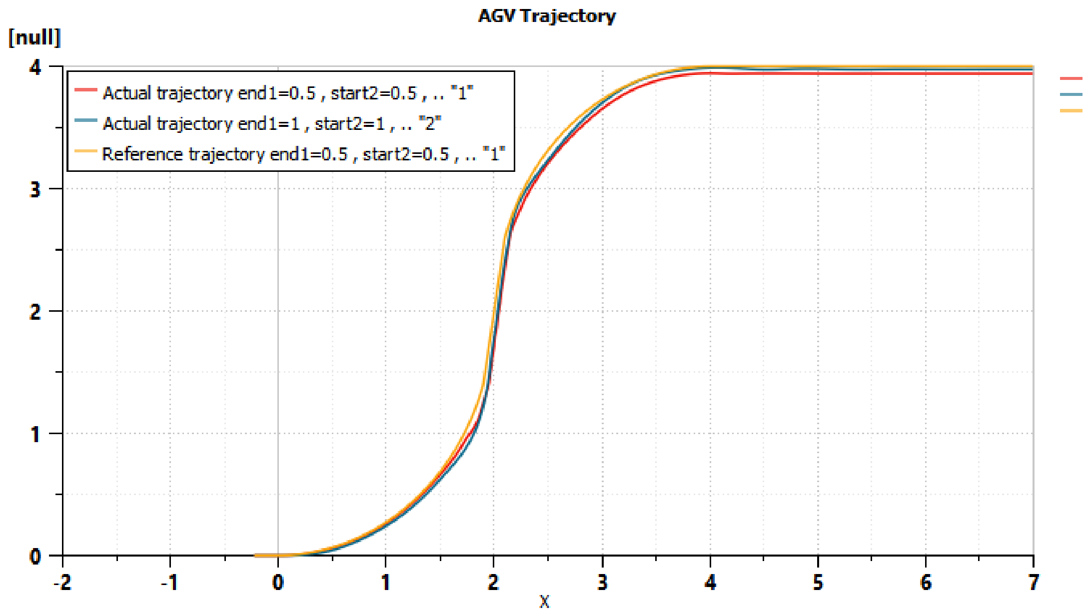

Figure 14 S shape trajectory of the sinusoidal road

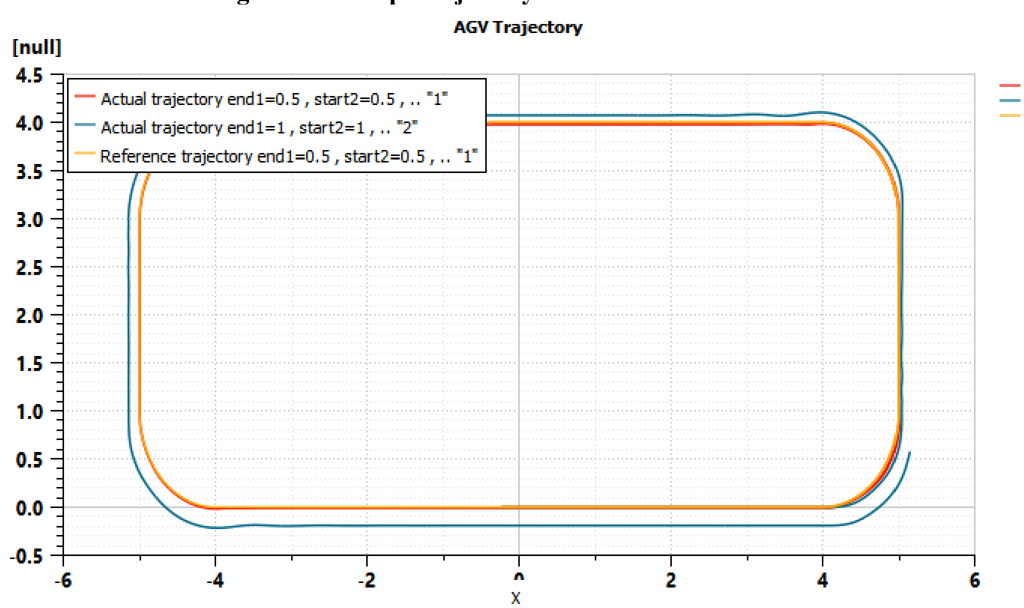

Figure 15 Rounded rectangle trajectory of the sinusoidal road

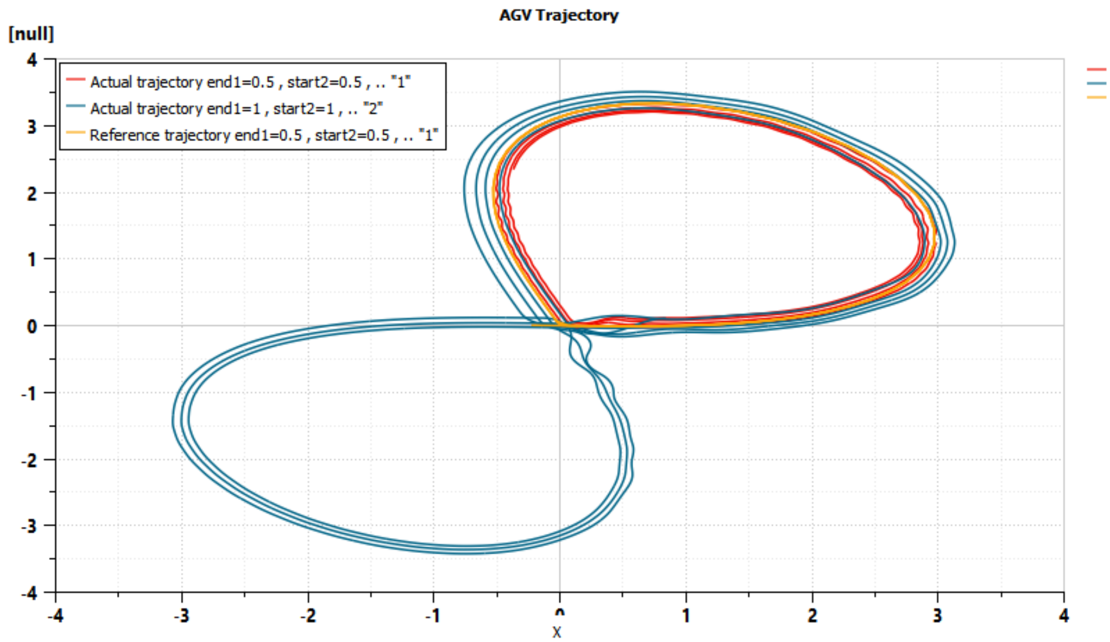

Figure 16 Figure eight trajectory of the sinusoidal road

Emergency Braking

The same emergency braking signal was provided to the AGV in its new configuration

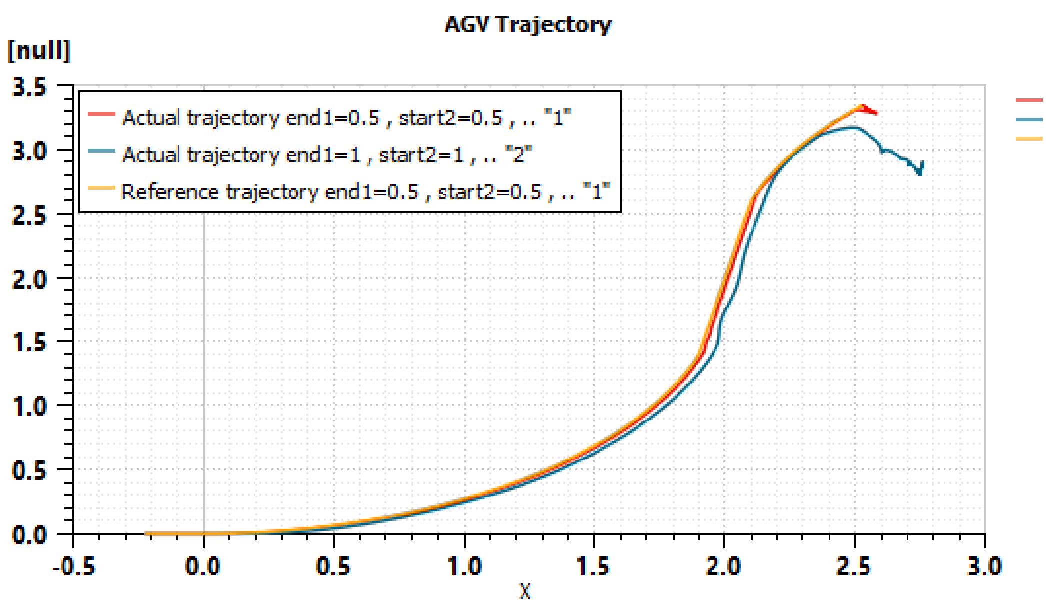

Figure 17 S shape trajectory for emergency braking

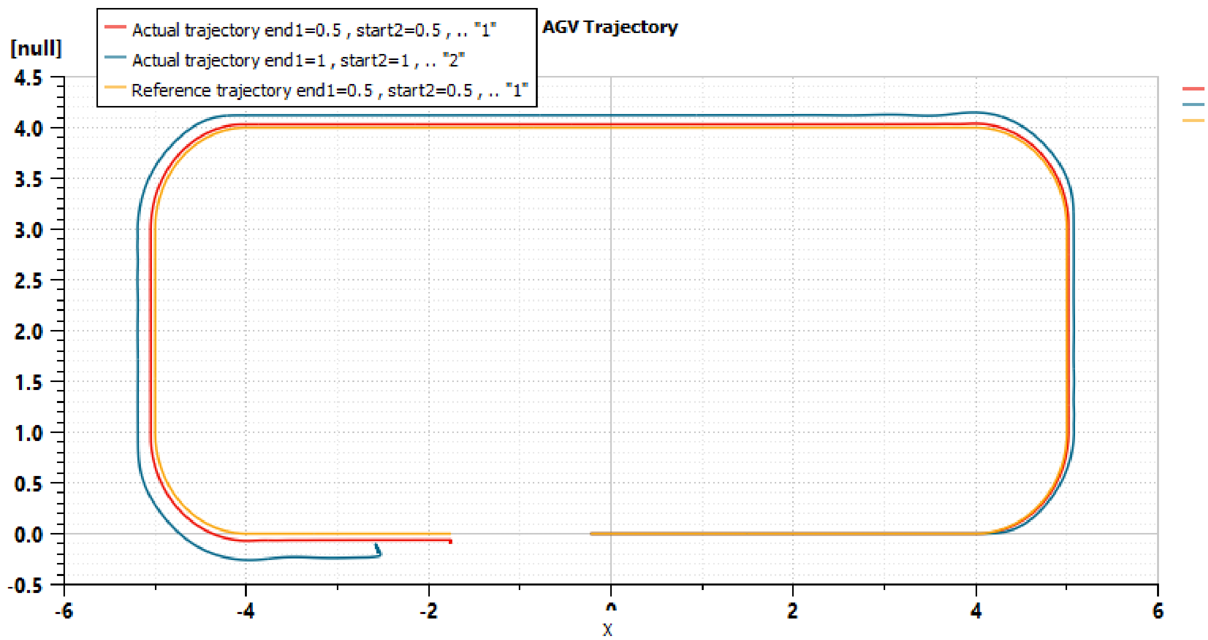

Figure 18 Rounded rectangle trajectory for emergency braking

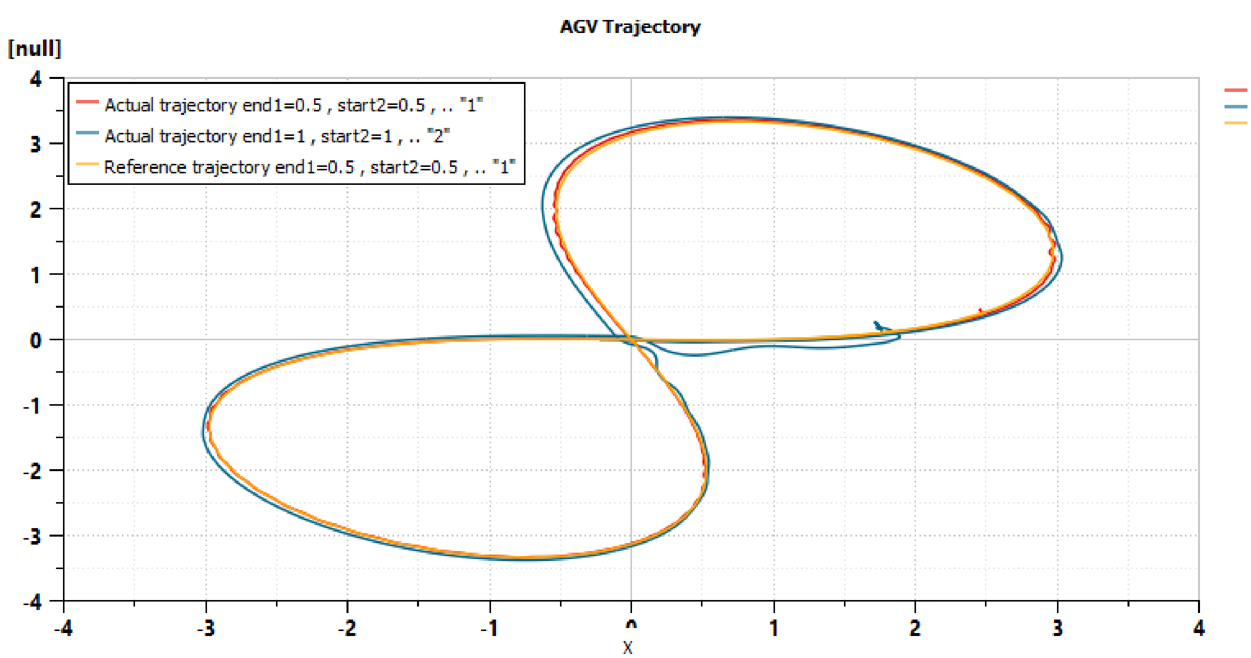

Figure 19 Figure eight trajectory for emergency braking

Summary of Findings

In conclusion, the system model supported the validation of multiple AGV configurations under various road conditions. The findings are summarized here:

	Differential Drive	***Steer Drive***
Low Speed	✓	✓
High Speed	✓	✓
Uneven Ground	✓	
Emergency Braking	✓	

The steer-drive configuration of the AGV proved more unstable and the controls less robust when faced with the different operating conditions, such as speed, uneven ground, and emergency braking. This could be linked to multiple drive inputs being transmitted to a single driving and steering wheel. As stated in Yi Yao and Ye Sun 2021 [1], the addition of a steered wheel adds a new degree of freedom to the overall kinematic model of the vehicle.

The differential drive configuration proved more capable in navigating all trajectories under the conditions provided. The configuration of two front drive wheels produced more stable performance.

Future Considerations

Aside from validating vehicle dynamics and architecture selection, the system model produced in Simcenter Amesim may also serve as a digital plant model for the virtual commissioning of the AGV's actual control logic.

Simcenter Amesim allows for the connection of various real or virtual automation controllers. It features an interface that can map and exchange variables between the controls and the simulation model, allowing for testing of Software-in-the-Loop and Hardware-in-the-Loop use cases.

References

AGV vehicle differential drive model. Yi Yao 1 and Ye Sun 1. Published under licence by IOP Publishing Ltd Journal of Physics: Conference Series, Volume 1941, 2021 3rd International Conference on Applied Machine Learning and Data Science (ICAMLDS 2021) 14-16 May, 2021; Chengdu, China Citation Yi Yao and Ye Sun 2021 J. Phys.: Conf. Ser. 1941 012031