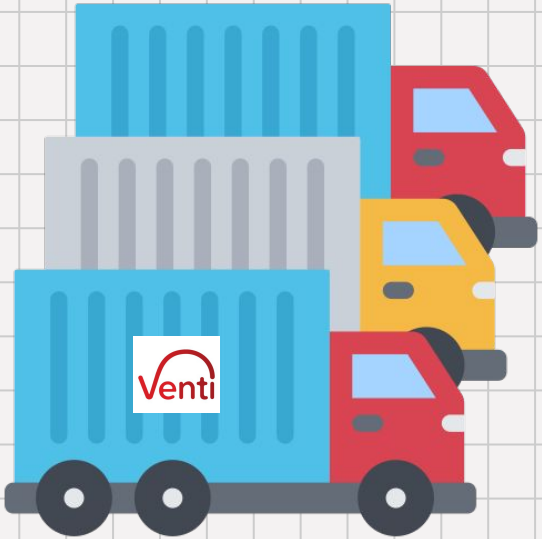
Advanced

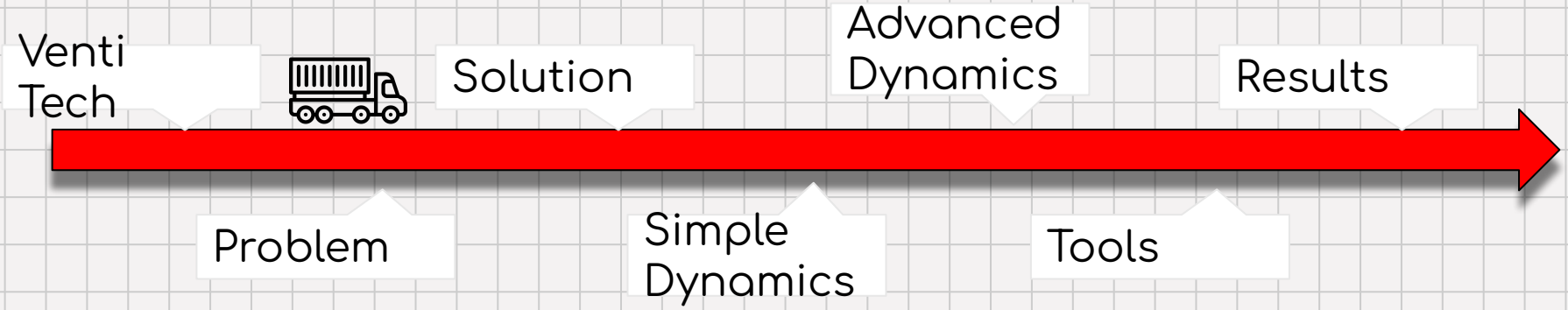
Vehicle Dynamics

for Autonomous Vehicles



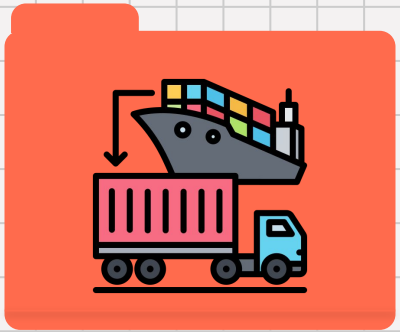
By Huang Wei Jhin

Agenda

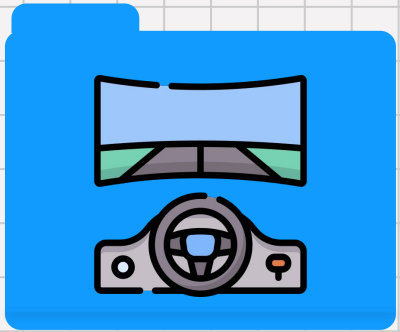

Venti Tech
Problem
Solution
Simple Dynamics
Advanced Dynamics
Tools
Results

Introduction

Venti
Technologies

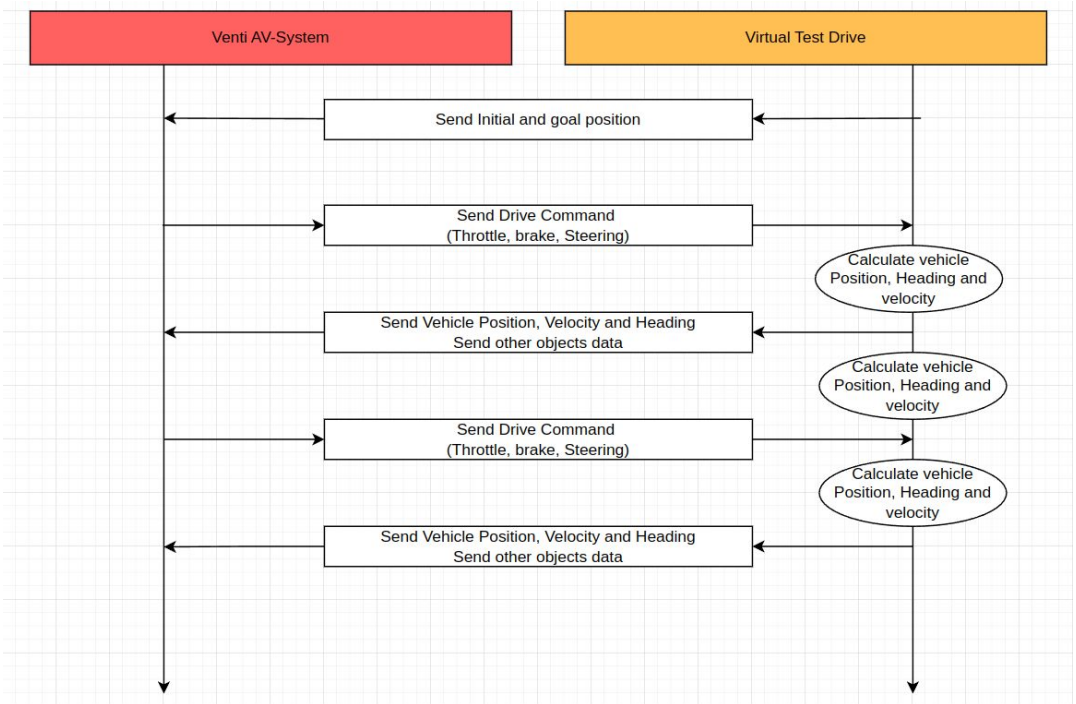


Autonomous
Prime Movers



Simulation
Validation

Current Workflow



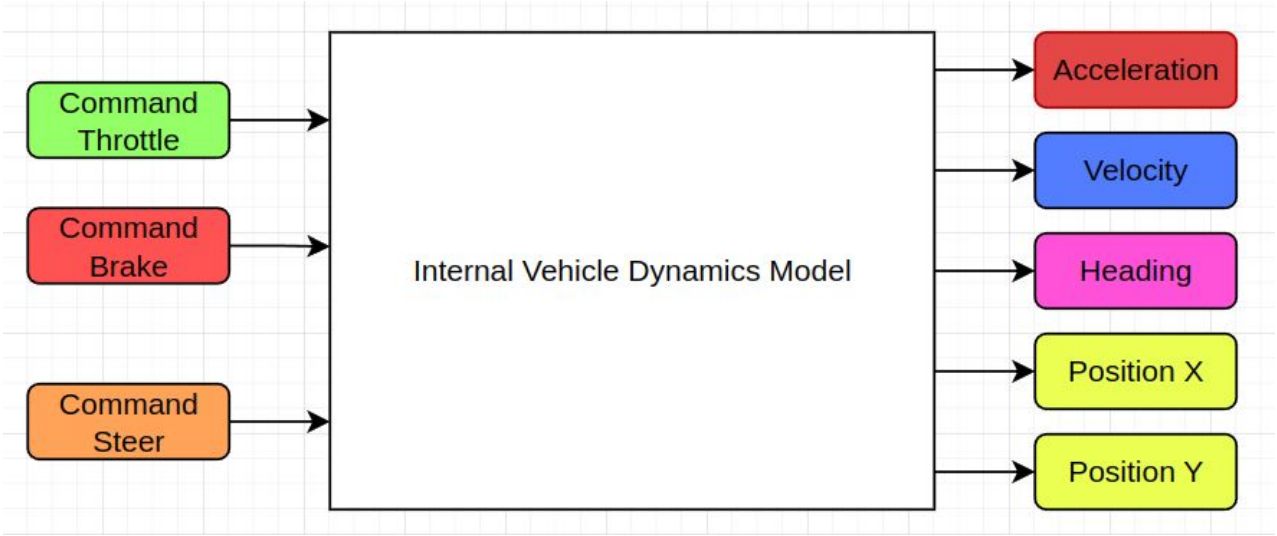
Problem Statement

High-Fidelity
dynamics for simulation

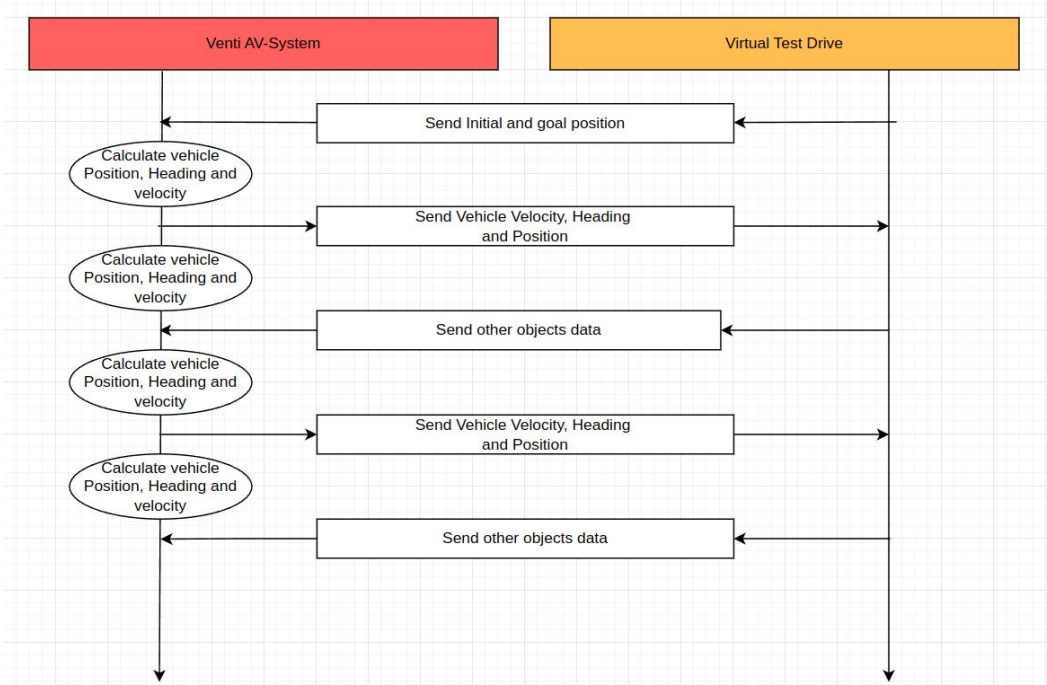
Different Vehicles
configuration

High Cost
of VTD software

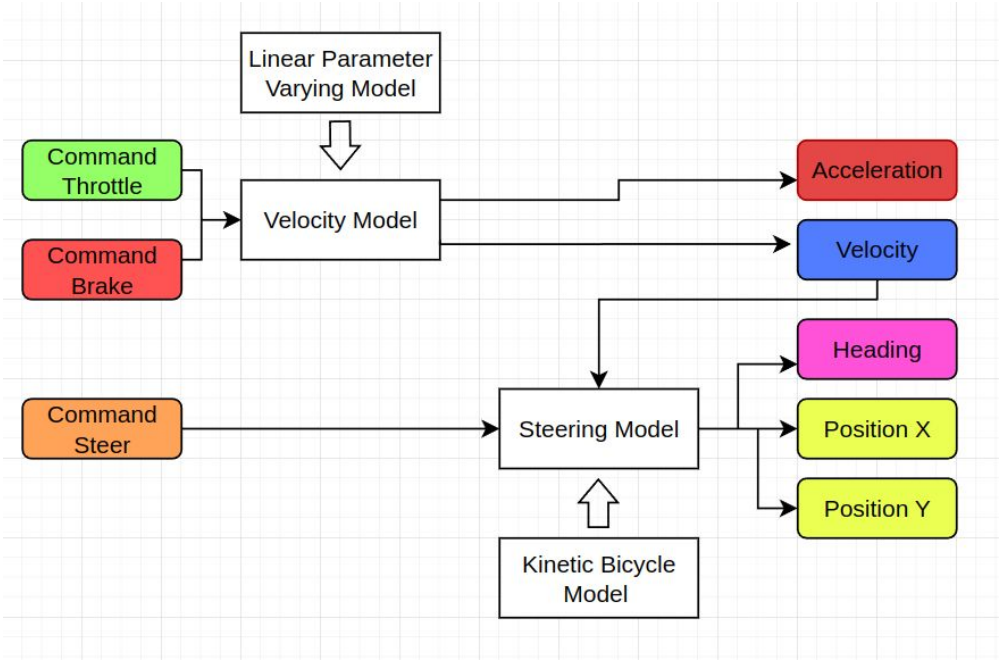
Solution


Command Throttle
Command Brake
Command Steer
Internal Vehicle Dynamics Model
Acceleration
Velocity
Heading
Position X
Position Y

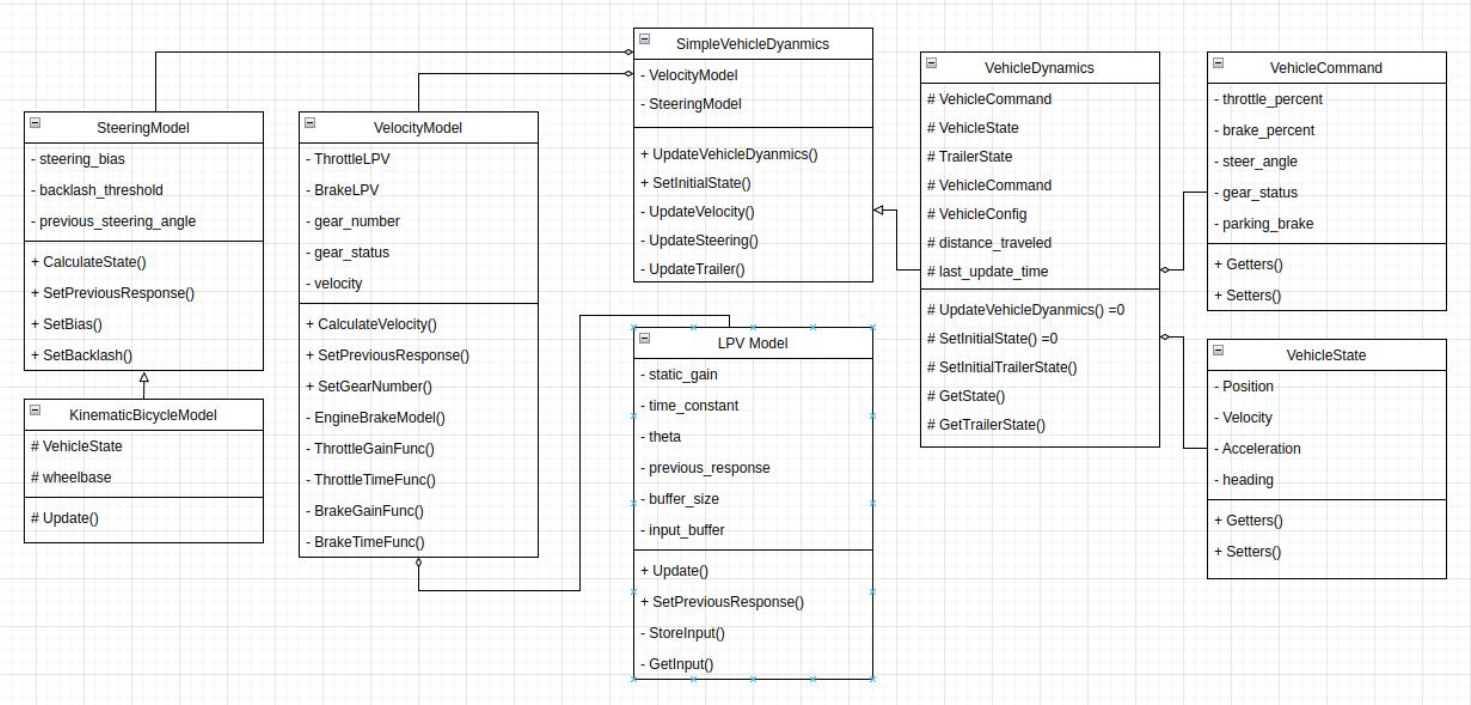
New Workflow



Simple Dynamics



Simple Dynamics



Linear Parameter Varying

Static Gain

Time Constant

Theta

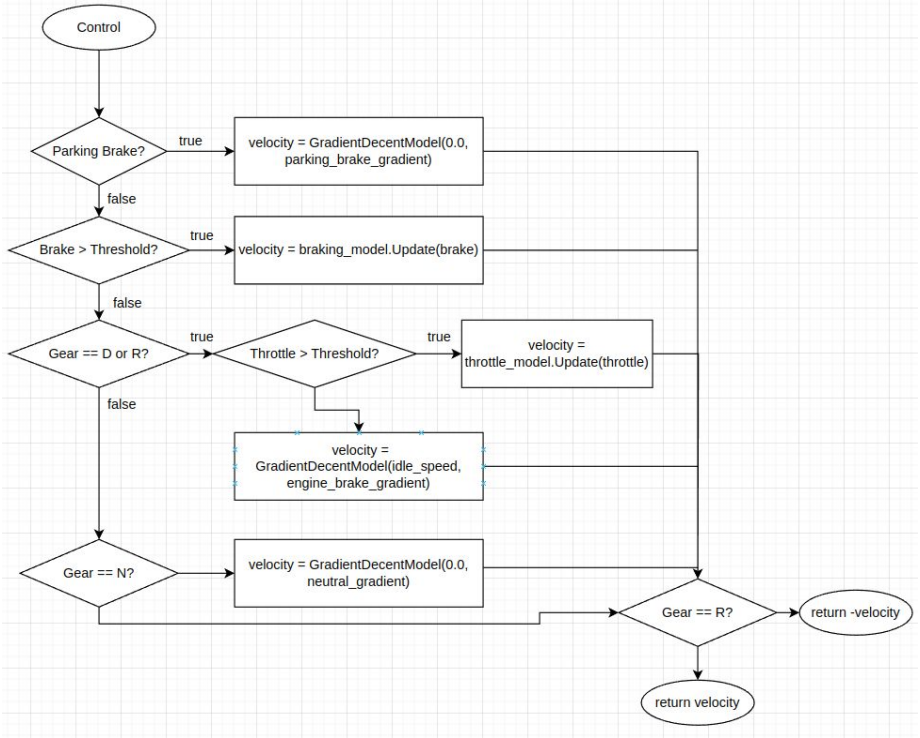
Velocity Model

2 LPV models
Throttle
Brake

Gear Status
(P R N D)

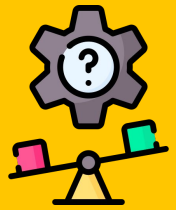
Engine Brake

Velocity Model



Kinematic Bicycle Model

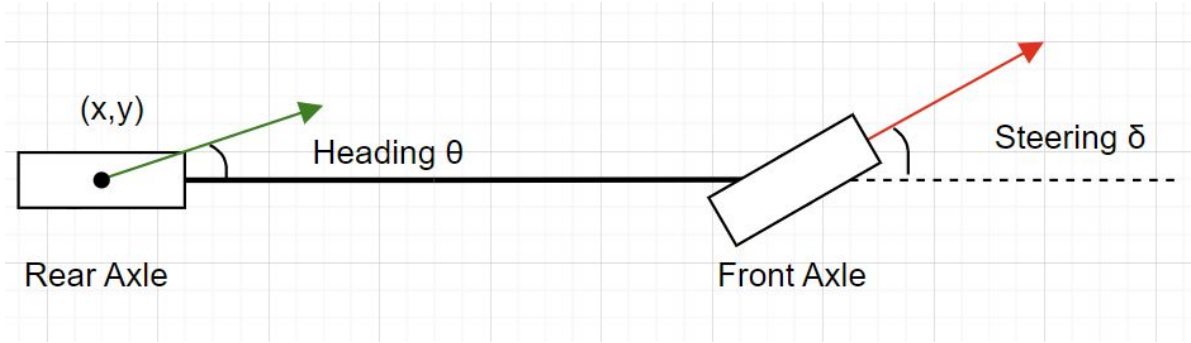
Inputs:
Velocity
Steering



Modifications:
Bias
Backlash

Output:
Position
Heading

Kinematic Bicycle Model



$$x = v \cdot cos(\theta)$$

$$y = v \cdot sin(\theta)$$

$$\theta = \frac{v}{L} \cdot tan(\delta)$$

- x, y are the current position coordinates
- θ is the current heading (orientation)
- v is the current velocity (from the velocity model)
- δ is the steering angle
- L is the wheelbase (distance between front and rear axles)

Initial Result...

Improvements

Throttle

Gear Number
Velocity Cap

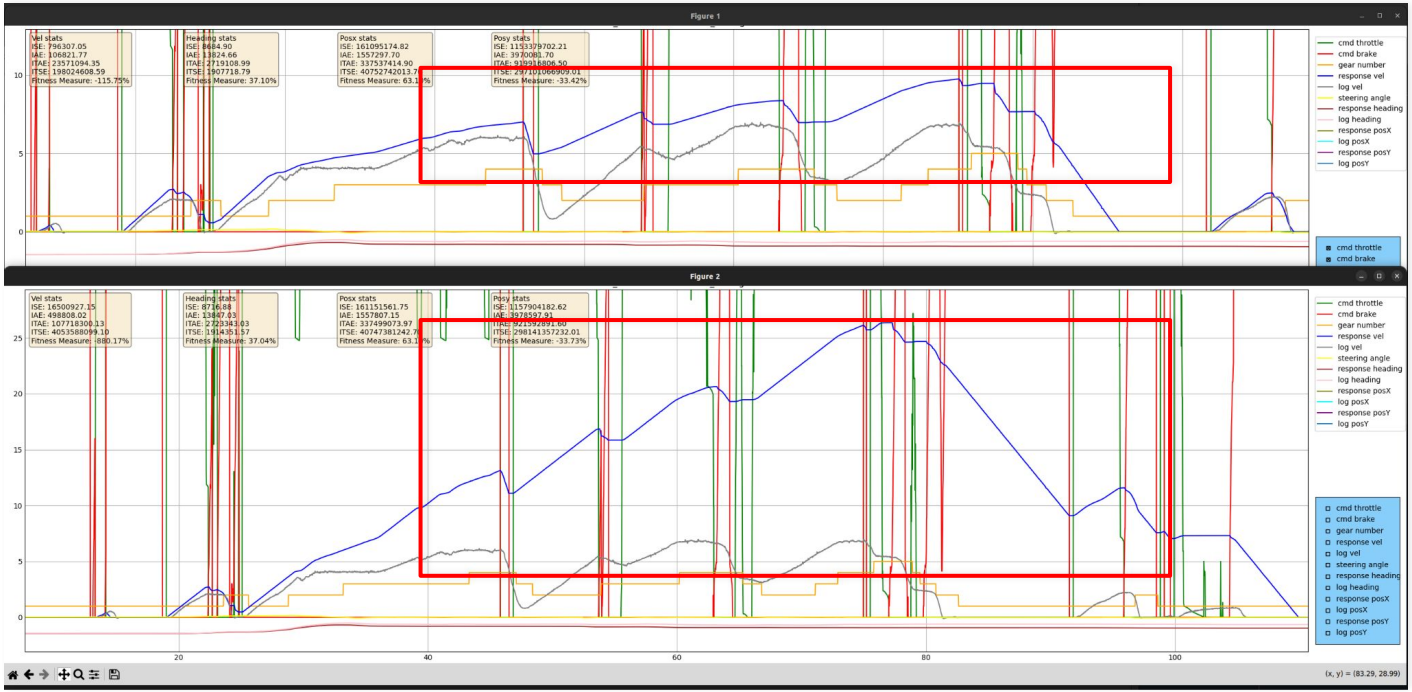
Braking

Static gain
Engine Brake

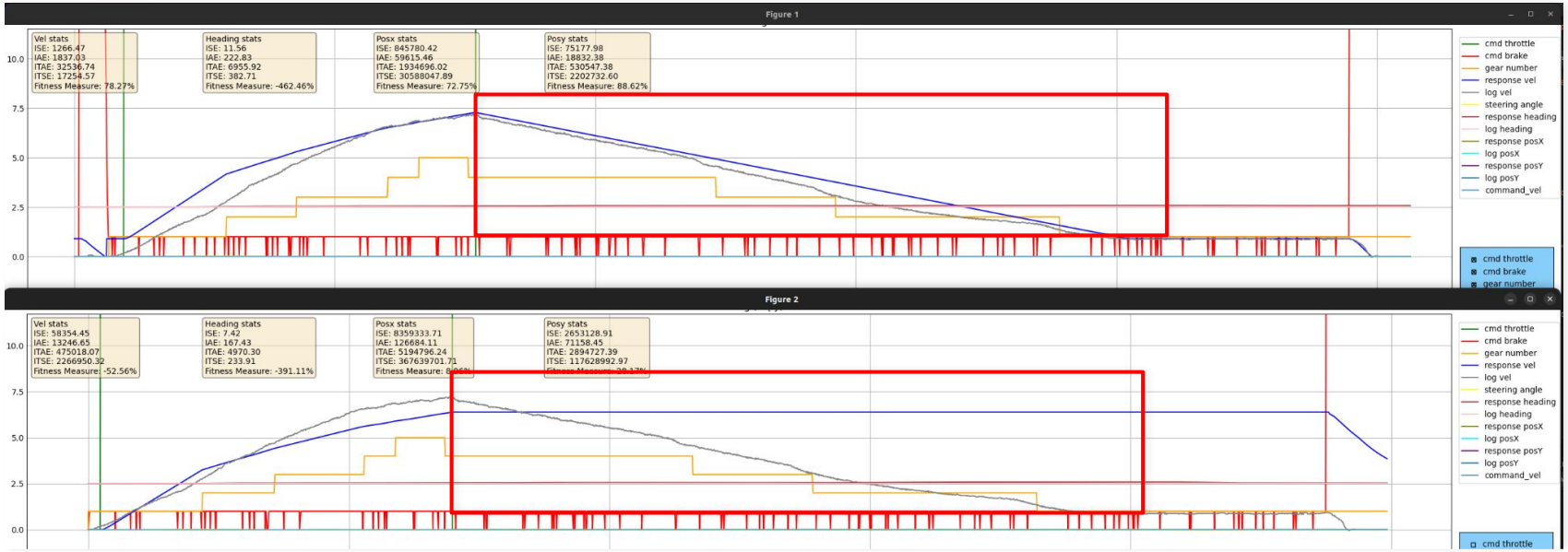
Steering

Backlash
Bias

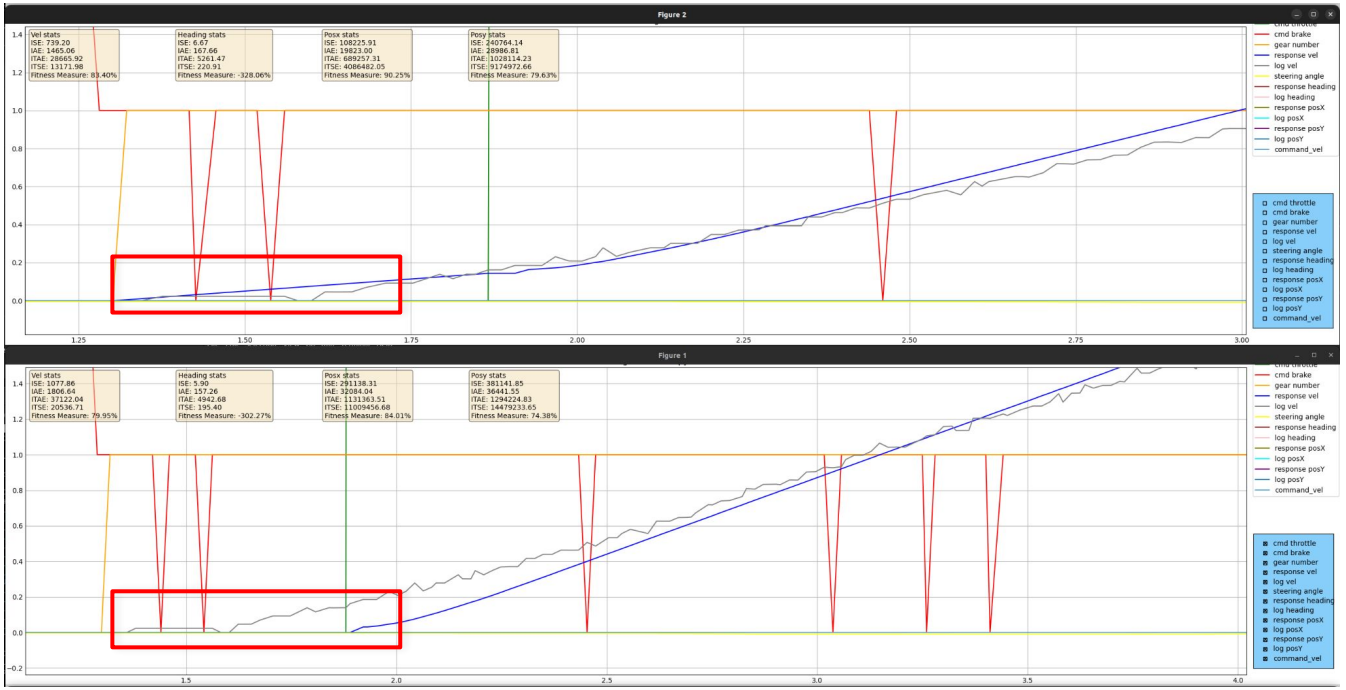
Improvements



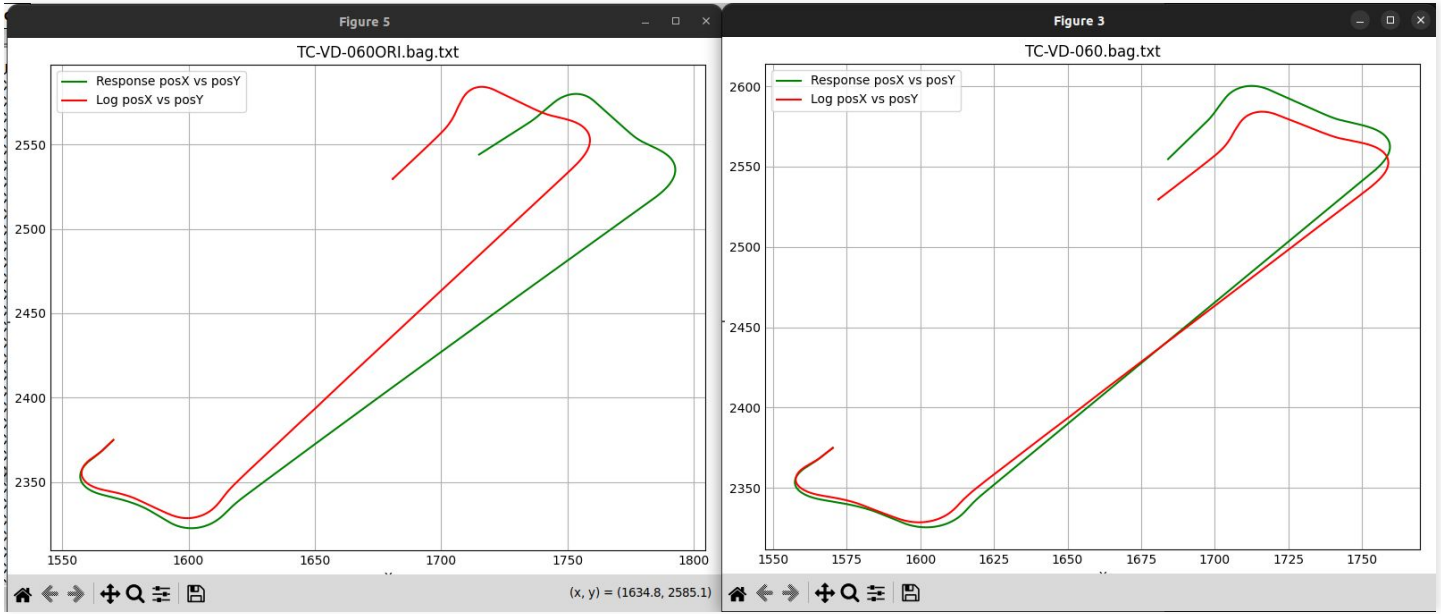
Improvements



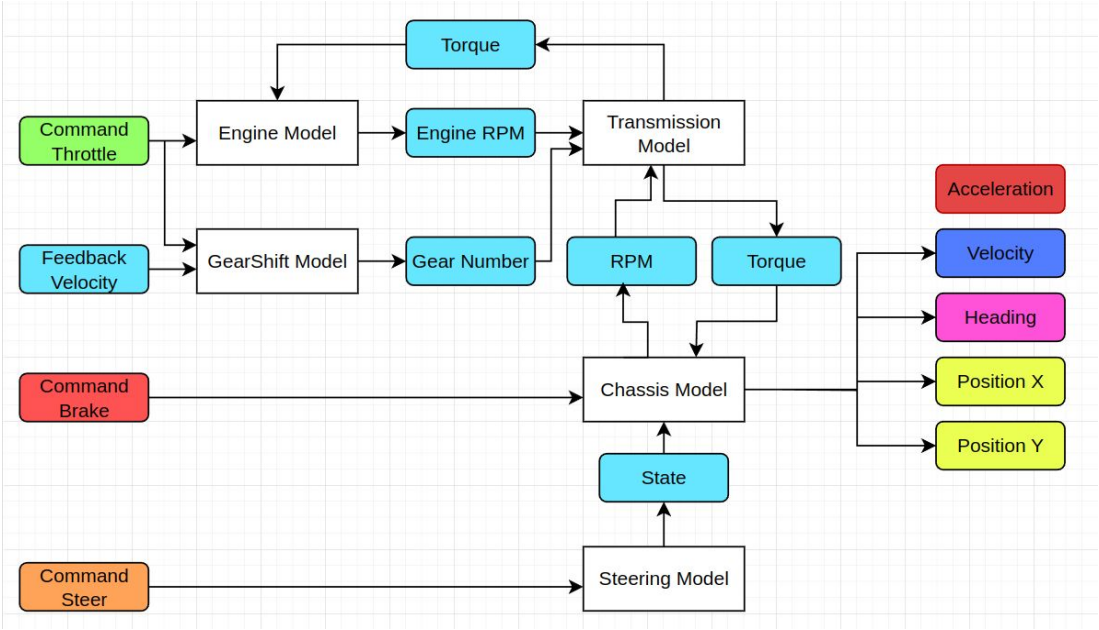
Improvements



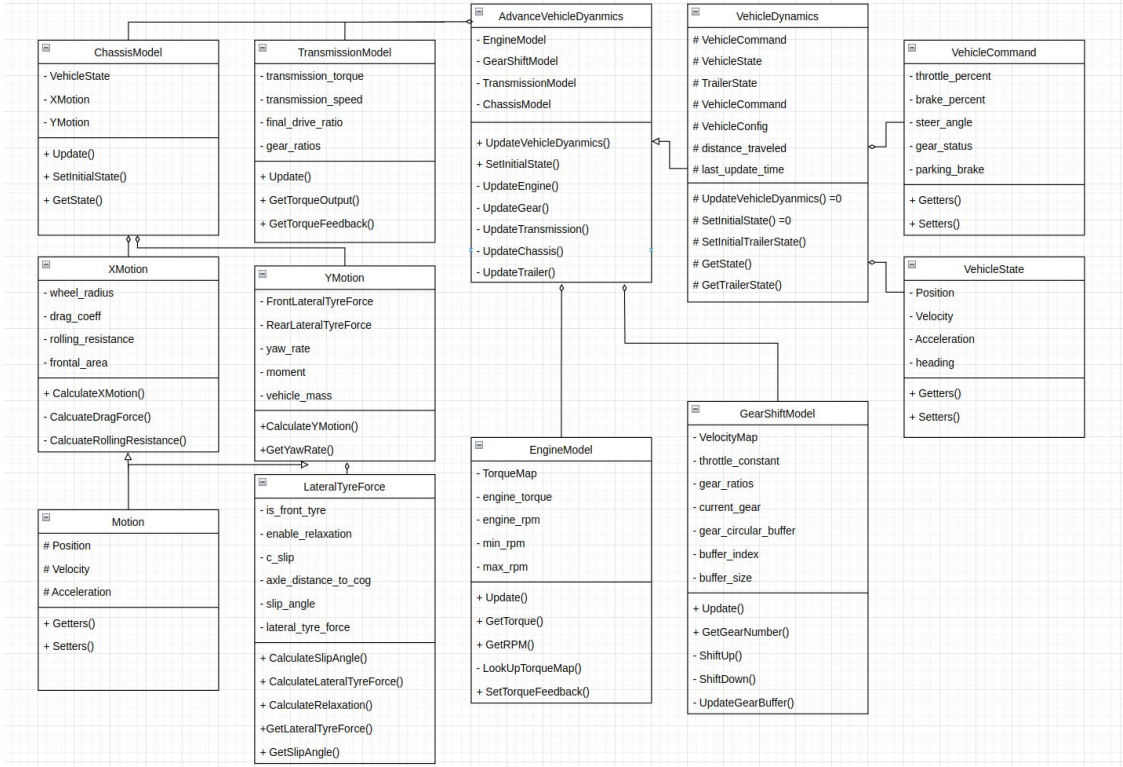
Improvements



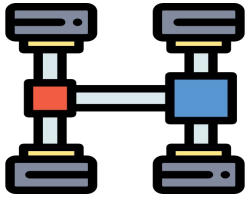
Advanced Dynamics



Advanced Dynamics



Chassis model

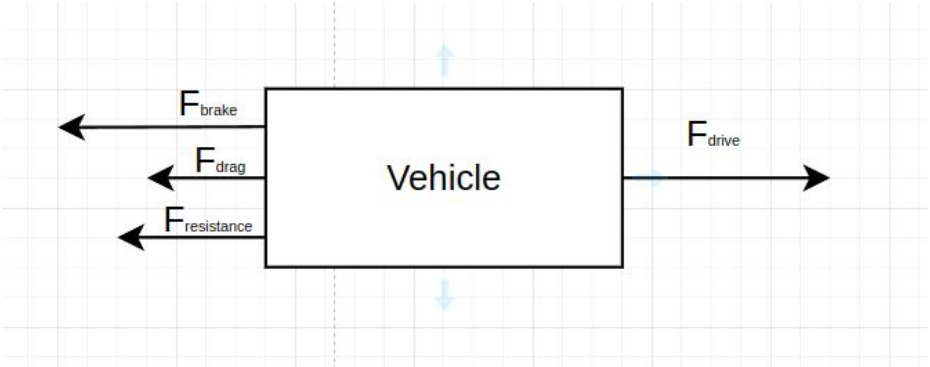


Input	Output
Transmission torque	Acceleration
Command steer	Velocity (x,y,z)
Command brake	Heading
Current vehicle state	Position (x,y,z)

Chassis Model - X motion

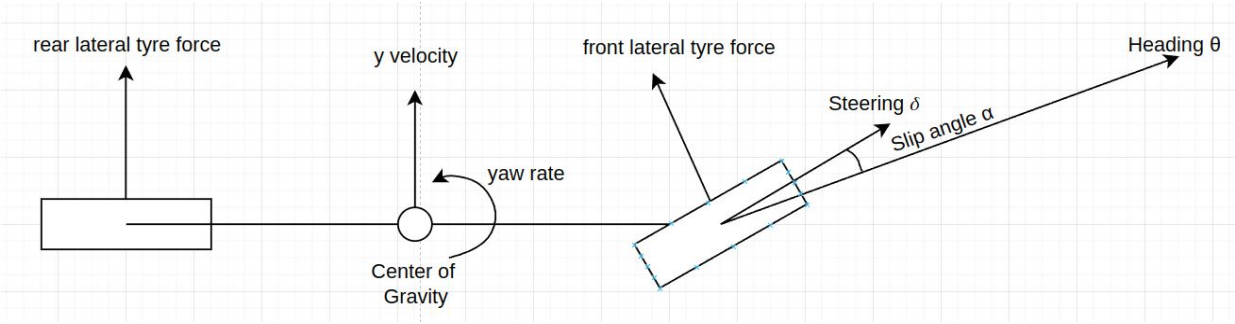
$$F_{net} = F_{drive} - F_{brake} - F_{drag} - F_{resistance}$$

$$a_x = \frac{F_{net}}{m}$$



- F_{drive} is the forward drive force from the engine
- F_{brake} is the force front he brakes
- F_{drag} is the drag from air resistance
- $F_{resistance}$ is the rolling resistance
- m is the mass of the vehicle
- a_x is the longitudinal acceleration

Chassis Model - Y motion



$$\alpha_f = arctan(\frac{v_y + l_f \cdot \omega}{v_x}) - \delta$$

$$\alpha_r = arctan(\frac{v_y - l_r \cdot \omega}{v_x})$$

- δ is the steering angle
- v_x , v_y is the longitudinal and lateral velocity
- α is the slip angle

Chassis Model

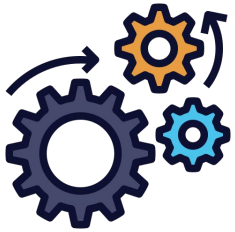
$$x_{t+1} = x_t + (v_x \cdot cos(\theta) + v_y \cdot sin(\theta)) \cdot \Delta t$$

$$y_{t+1} = y_t + (v_x \cdot sin(\theta) + v_y \cdot cos(\theta)) \cdot \Delta t$$

$$\theta_{t+1} = \theta_t + \omega \cdot \Delta t$$

- θ is the heading
- ω is the yaw rate
- x_t, y_t is the x and y positions

Transmission model



Input	Output
Engine RPM Gear number Feedback torque	Transmission torque Engine speed

Transmission Model

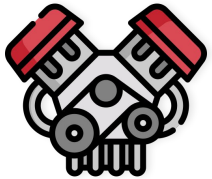
$$T_{trans} = T_{engine} \times R_{gear} \times R_{final\ drive} \times L$$

- T_{trans} is the transmission torque output
- T_{engine} is the torque from the engine
- $R_{final\ drive}$ is the final drive ratio
- R_{gear} is the gear ratio of the current gear
- L is the transmission loss

$$\omega_{engine} = \omega_{wheel} \times R_{gear} \times R_{final\ drive} \times L$$

- ω_{engine} is the engine rotational speed
- ω_{wheel} is the wheel rotational speed

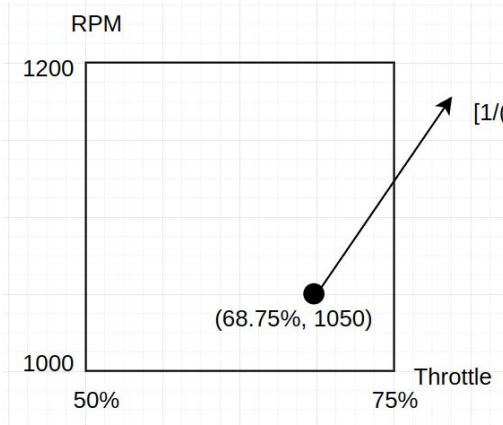
Engine Model



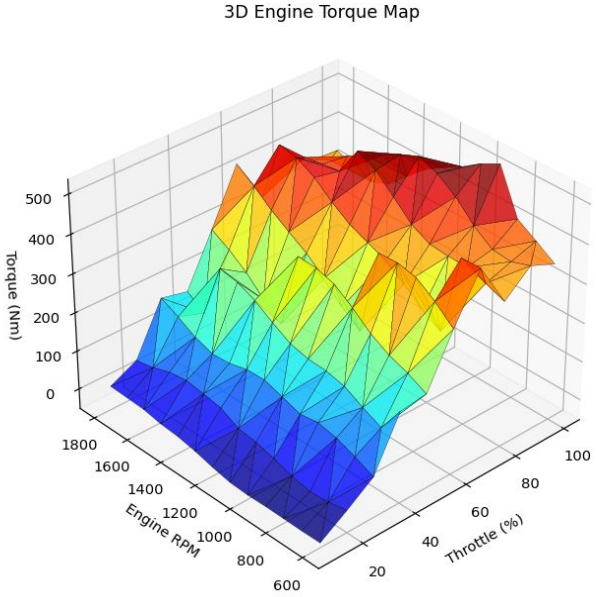
Input	Output
Throttle command Engine RPM speed	Engine Torque

Engine Model

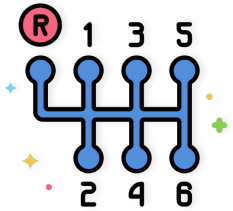
Throttle\ RPM	800	1000	1200	1400
25%	200	300	400	380
50%	250	350	450	430
75%	350	450	590	500
100%	400	480	620	550



$$T(68.75,1050)= T(0.6875, 0.4166)$$
$$[1/(0.25)(0.3334)]\ [350\cdot(0.75-0.6875)(0.6667-0.4167)$$
$$+450\cdot(0.6875-0.5)(0.6667-0.4167)$$
$$+450\cdot(0.75-0.6875)(0.4167-0.3333)$$
$$+590\cdot(0.6875-0.5)(0.4167-0.3333)]$$
$$= 457.3\text{Nm}$$



Gear Model



Input	Output
Velocity Throttle command	Gear number (e.g., 1, 2, 3, 5, 6)

Gear Model

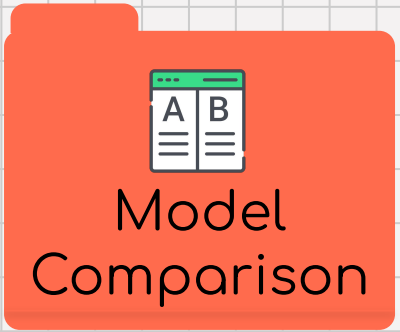
throttle \ gear	1	2	3	4
0%	1.76	3.31	4.36	6.15
50%	1.89	3.55	4.68	6.60
100%	2.29	4.30	5.67	8.00

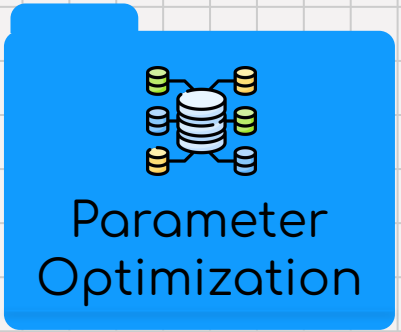
Throttle constants = { 6.15, 6.6,8.0 } for 0%, 50%, 100%

Gear ratios = { 3.49,1.86,1.41,1.0 } for gears 1 to 4

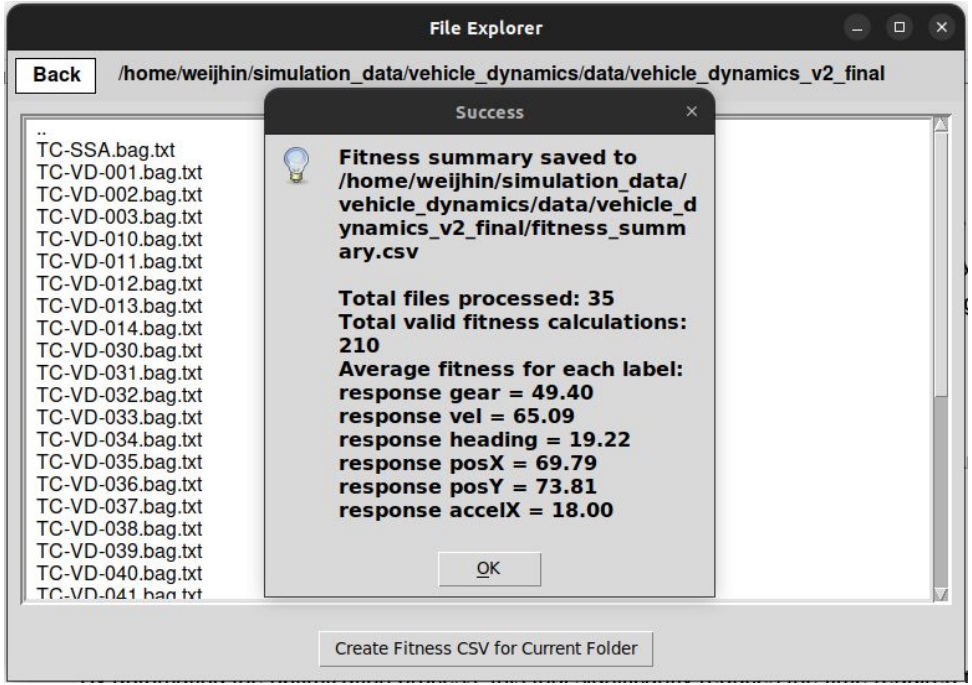
$$velocity\,(1,\ 50\%) \ = \ \frac{6.6}{3.49} \ = \ 1.89111$$

Additional Tools

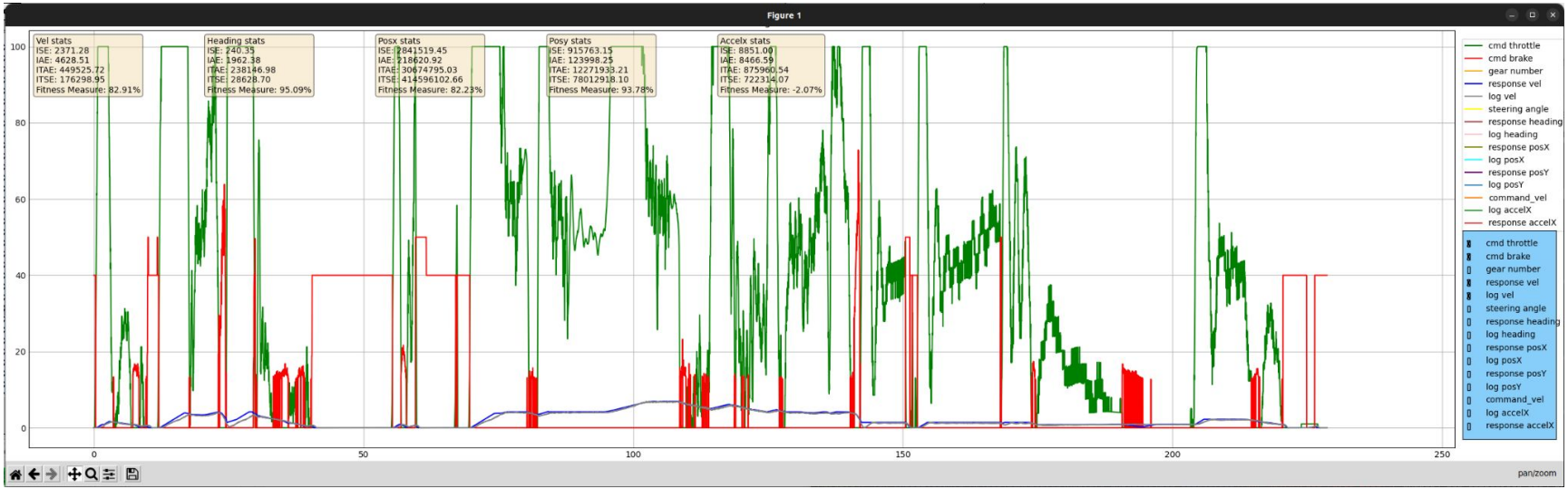




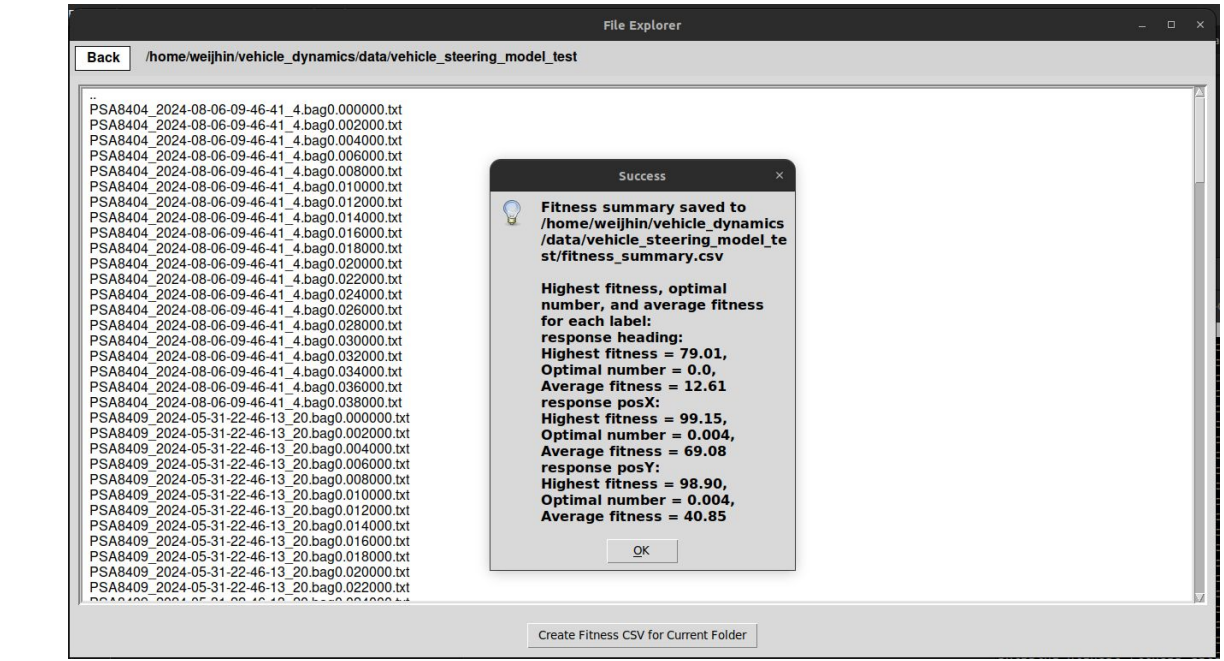
Model Comparison



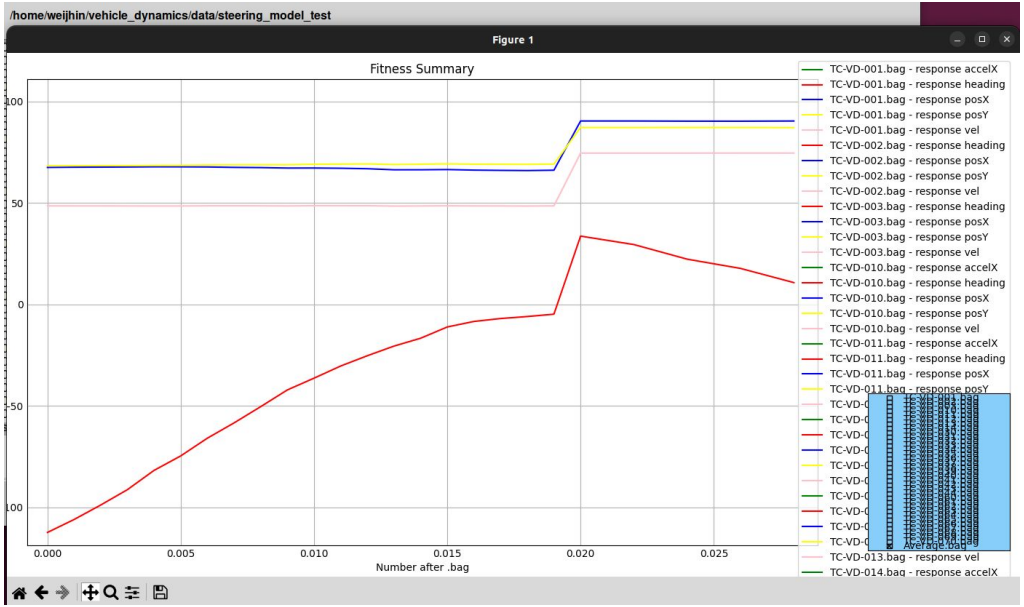
Graph plots and fitness



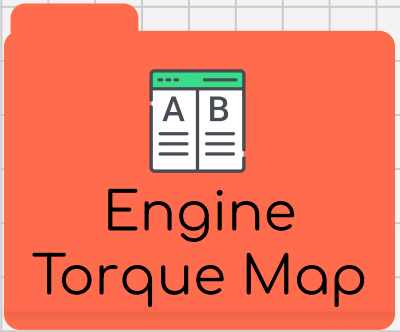
Optimization



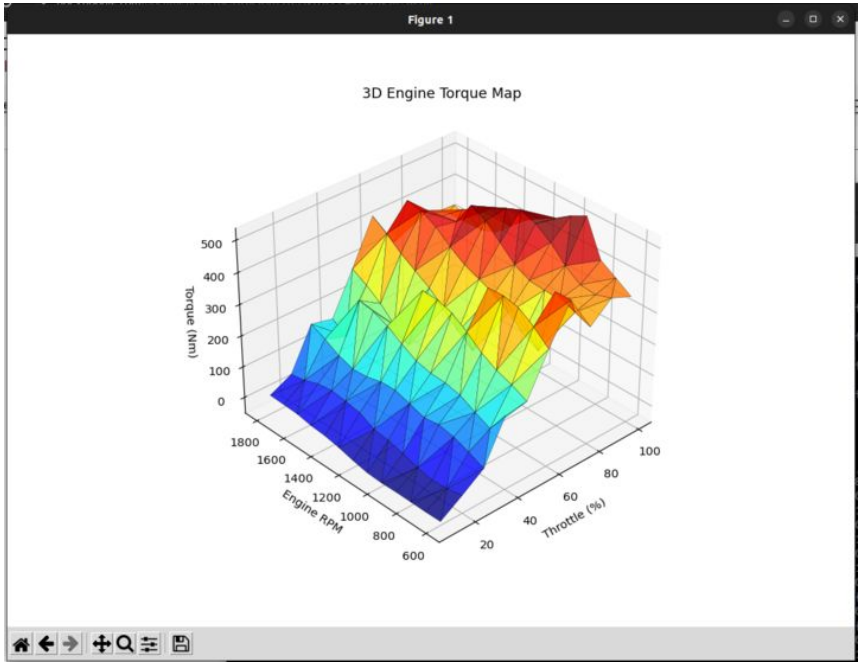
Optimization



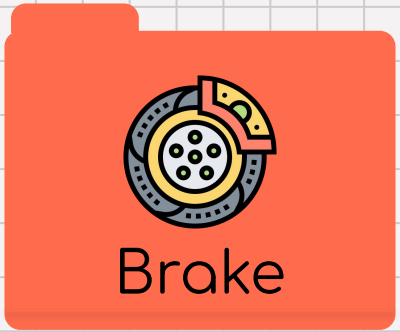
Additional Tools



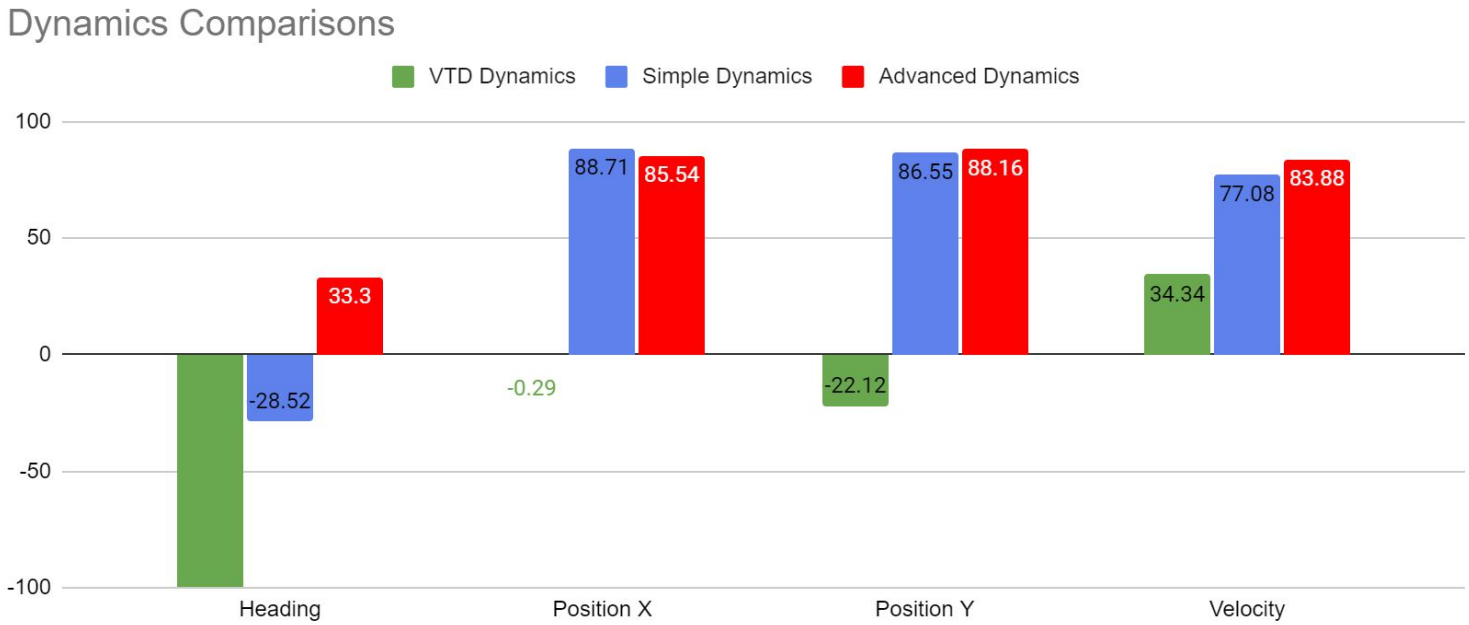
Engine Torque Map



Test Cases



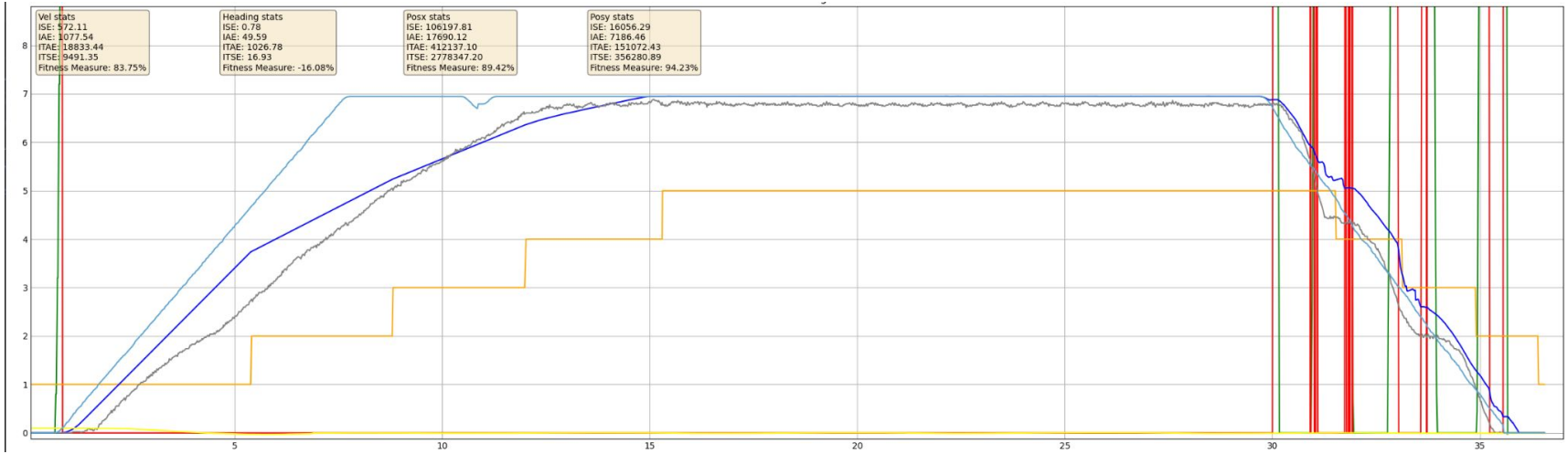
Result Analysis



Results

Graph Fitness:
Velocity: 83.75
Position X: 89.42
Position Y: 94.23

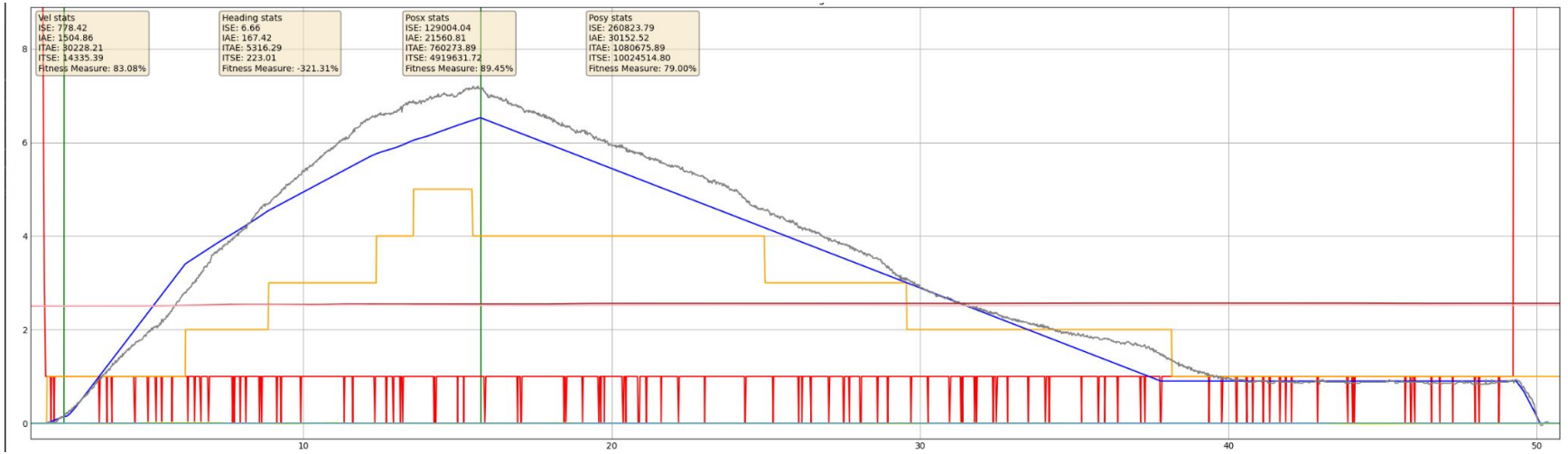
Vehicle accelerates to 25 km/h in a straight line



Results

Graph Fitness:
Velocity: 83.08
Position X: 89.45
Position Y: 79.00

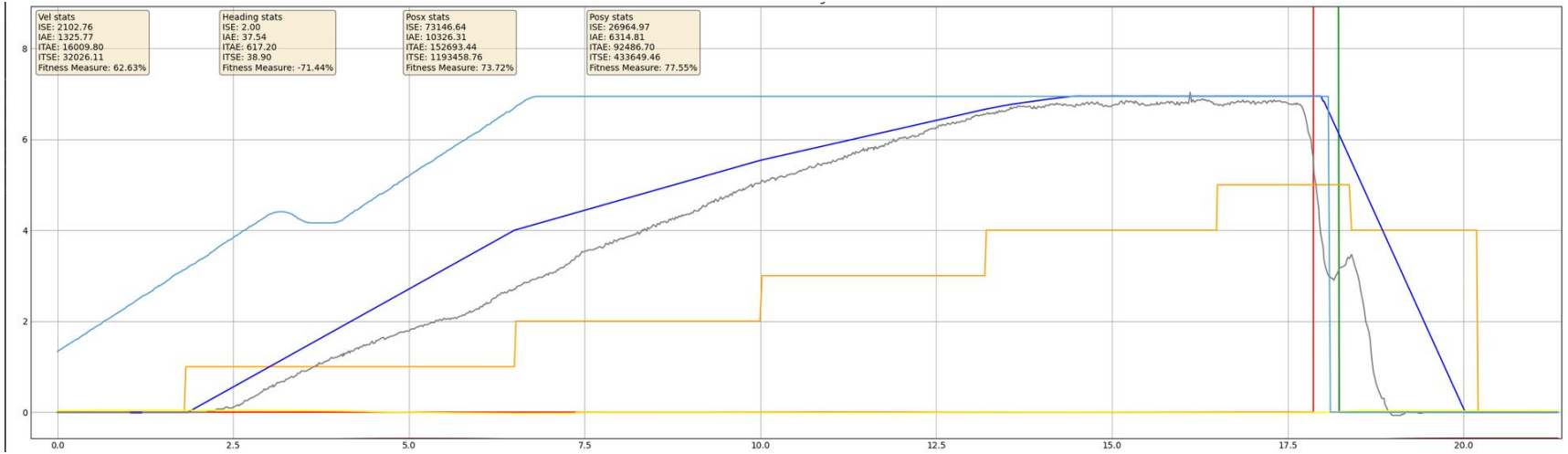
Vehicle accelerates to 25 km/h then coast to a stop



Results

Graph Fitness:
Velocity: 62.63
Position X: 73.72
Position Y: 77.55

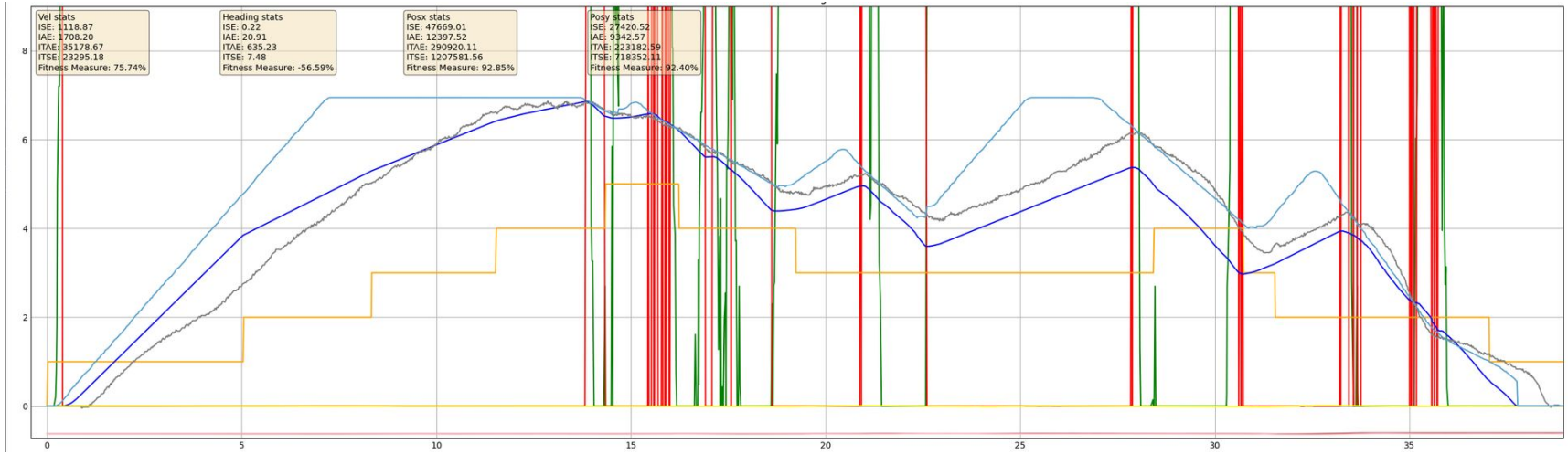
Vehicle does a emergency Stop from 25 km/h



Results

Graph Fitness:
Velocity: 75.74
Position X: 92.85
Position Y: 92.40

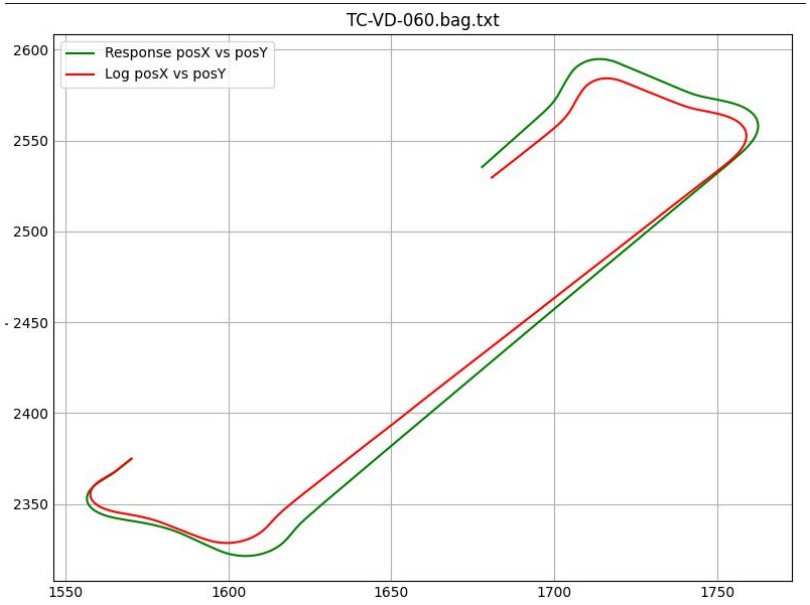
Vehicle gradually comes to a stop from 25 km/h

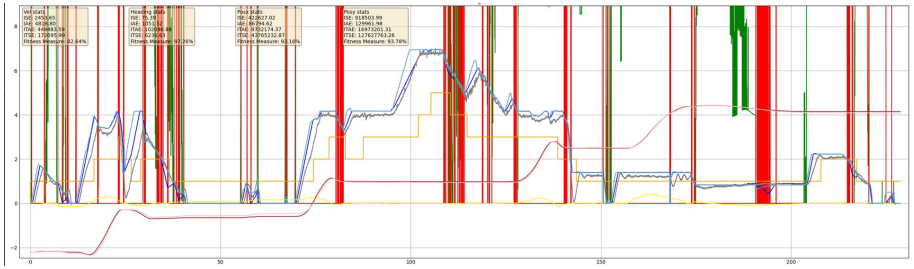


Results

Graph Fitness:
Velocity: 74.13
Heading: 96.44
Position X: 87.90
Position Y: 95.75

Vehicle makes 4 Right turns

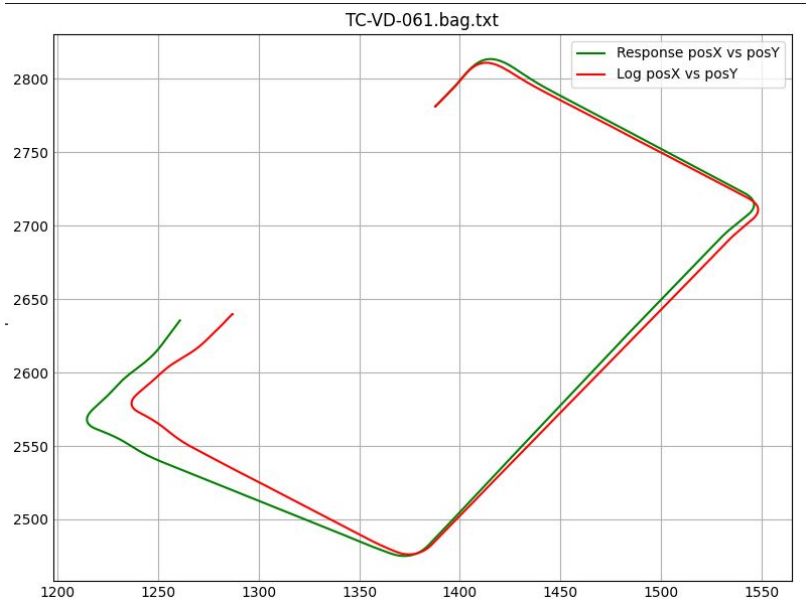


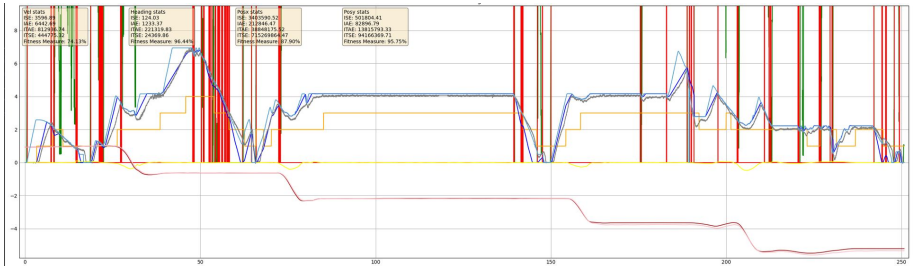


Results

Graph Fitness:
Velocity: 82.64
Heading: 97.26
Position X: 93.16
Position Y: 93.78

Vehicle makes 4 Left turns



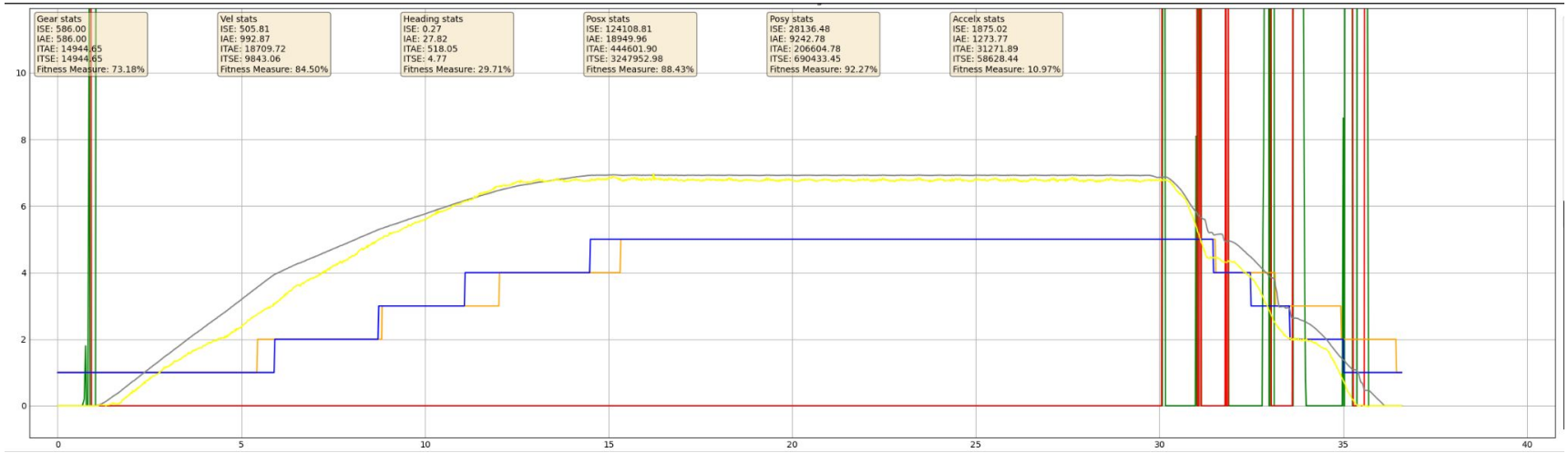


Result Analysis - Simple

Results

Graph Fitness:
Velocity: 84.55
Position X: 88.43
Position Y: 92.27

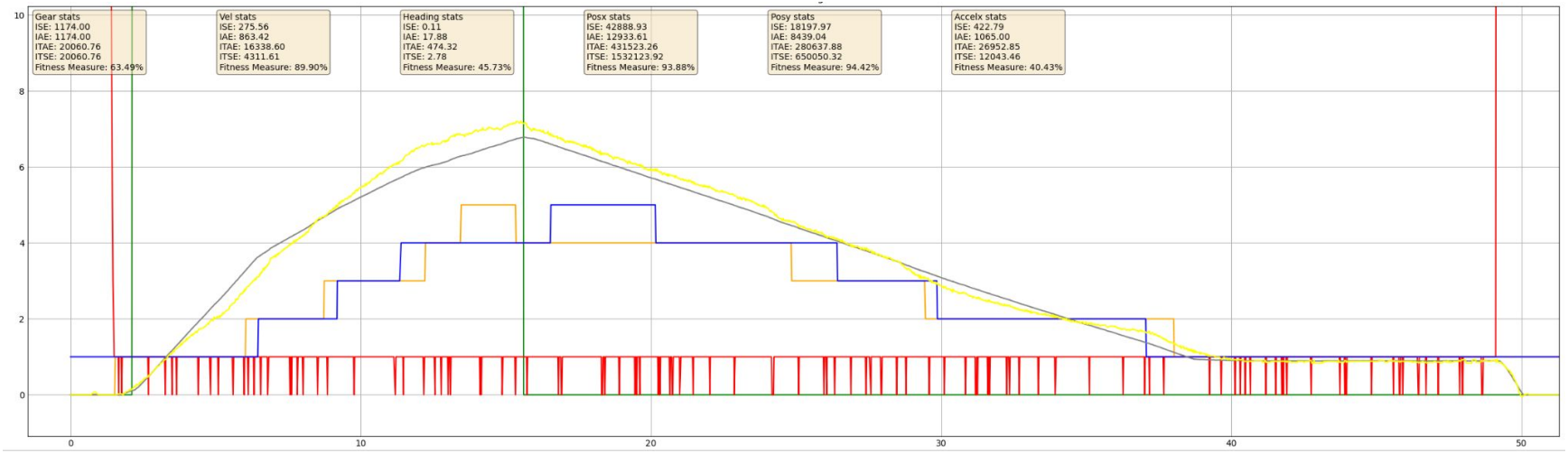
Vehicle accelerates to 25 km/h in a straight line



Results

Graph Fitness:
Velocity: 83.90
Position X: 93.88
Position Y: 94.42

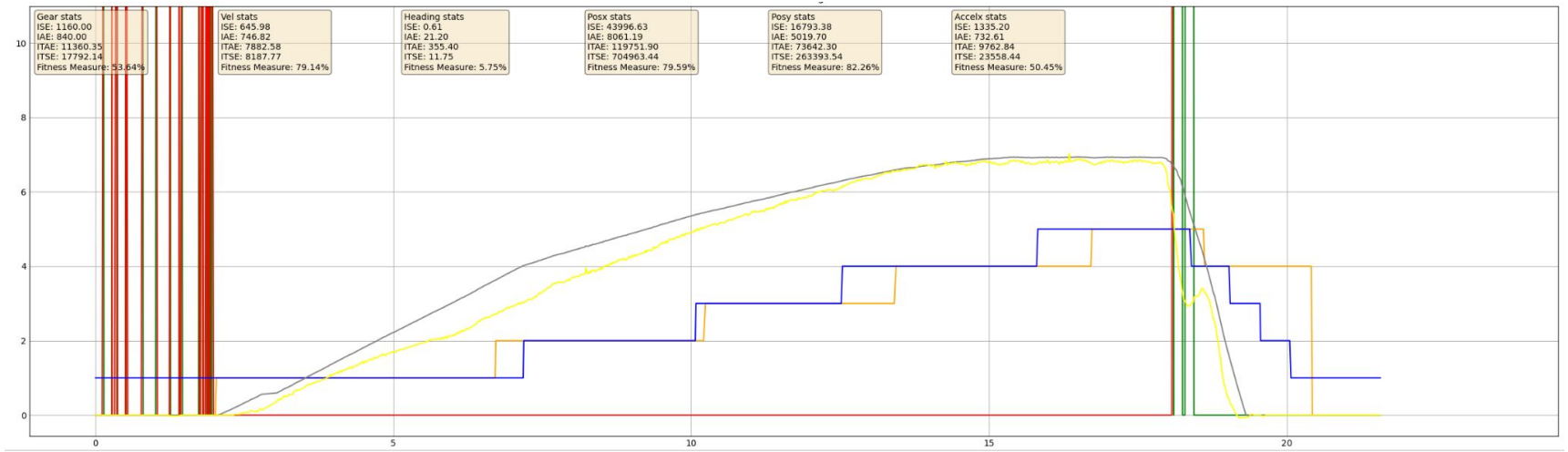
Vehicle accelerates to 25 km/h then coast to a stop



Results

Graph Fitness:
Velocity: 79.14
Position X: 79.59
Position Y: 82.26

Vehicle does a emergency Stop from 25 km/h



Results

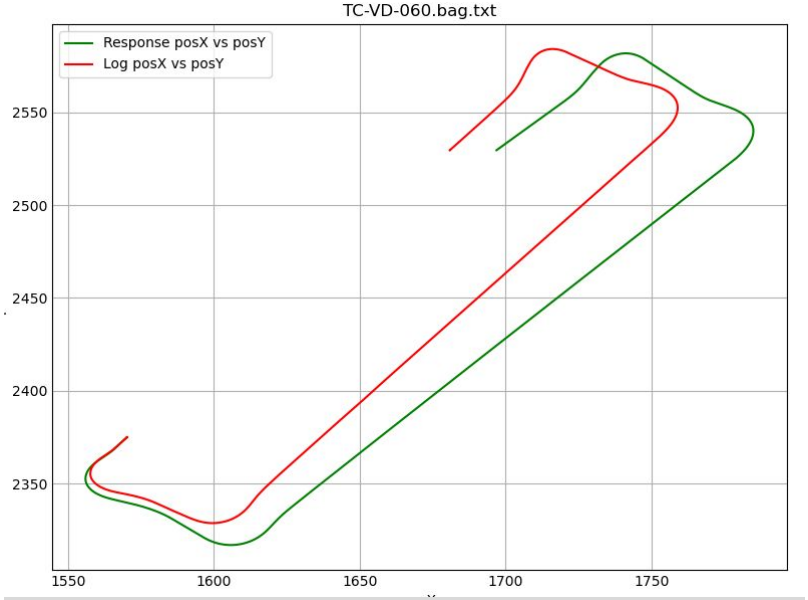
Graph Fitness:
Velocity: 83.20
Position X: 89.63
Position Y: 88.89

Vehicle gradually comes to a stop from 25 km/h

Results

Graph Fitness:
Velocity: 85.11
Heading: 78.87
Position X: 72.99
Position Y: 91.99

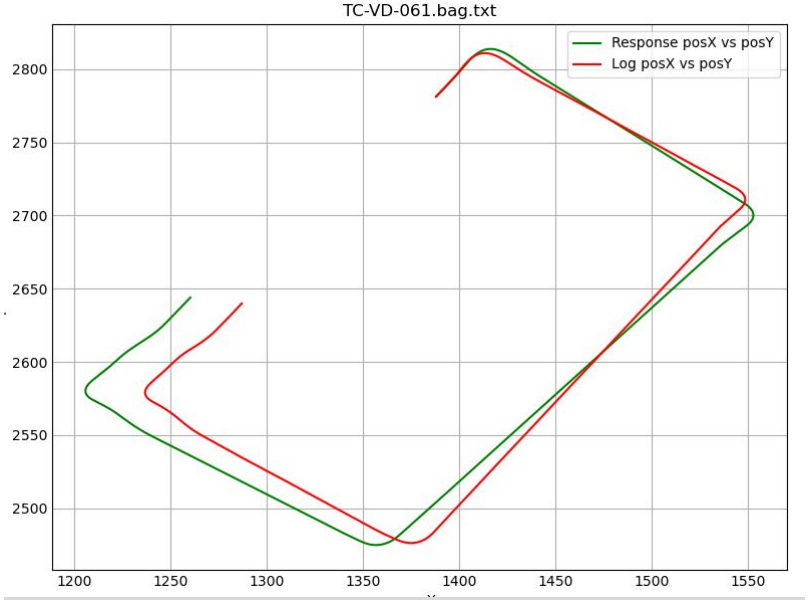
Vehicle makes 4 Right turns

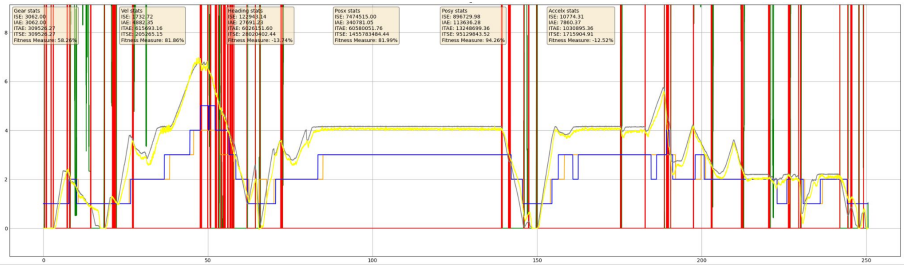


Results

Graph Fitness:
Velocity: 81.86
Heading: 13.74
Position X: 81.99
Position Y: 94.26

Vehicle makes 4 Left turns

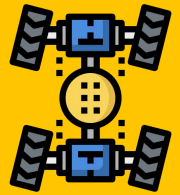




Result Analysis - Advanced

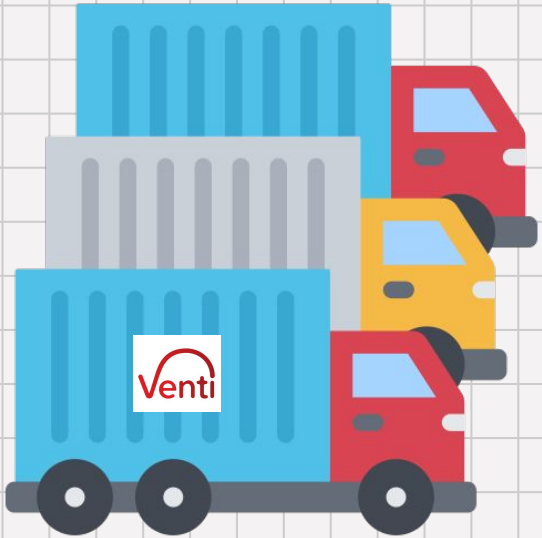
Limitations

Diesel-Powered
Prime movers



Unique Vehicles
Only front-wheel steering

Slope Terrain
Assumes a flat road surface



Thank You