AuE881 – Automotive Systems and Functions
Group HW assignment – Vehicle Automation Module

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Adaptive Cruise Control (ACC)

Introduction of ACC control

Autonomous cruise control (ACC) is a cruise control system for road vehicles that automatically adjusts the vehicle speed to maintain a safe distance from vehicle ahead. ACC systems may use a radar or laser sensor or a stereo camera setup allowing the vehicle to brake when it detects the car is approaching another vehicle ahead, then accelerate when traffic allows. In this assignment, we assume the main vehicle uses a long range radar sensor that can detect a target vehicle up to 200 meters in front to automatically adjust the ACC vehicle speed and gap accordingly.

ACC automatically decelerates or accelerates the vehicle according to the desired speed and distance settings established by the driver. As per standard cruise control the driver can override the system at any time.

Model free control

Concept of model free control

Different from model based control, the controller in model free control is not based on vehicle system model and there is no any equations of motion of the model needed. Model free control is also called 'Black Box Plant'. Typically, model free control uses non-model based controller like PID controller to finish the task. In this Simulink exercise, we use P controller in Simulink work.

Flowchart of model-free ACC Programming

As noted on the assignment instruction, ACC is to be tested for cases where another vehicle traveling with constant speed appears in front of the main vehicle. Prior to detecting the vehicle, the main vehicle is to maintain its ACC velocity which is typically set by its user. The overview of the flow is as follow: 1. The main vehicle starts moving with a set initial velocity, 2. The main vehicle is given a set ACC velocity which it needs to maintain unless there is an object or another vehicle in front, 3. The main vehicle will adjust its velocity to the ACC velocity by adding certain amount of change to its throttle angle, 4. If there is another vehicle in front, the main vehicle must analyze the distance to the vehicle and find if the distance is greater or less than the current safe braking distance,

5. If the vehicle in front is within the safe distance, the primary action is to slow down the main vehicle velocity by decreasing the throttle angle, 6. If the vehicle is located outside of the safe distance, the vehicle is considered as the target vehicle, and the main vehicle will follow the target vehicle velocity by adjusting the throttle angle.

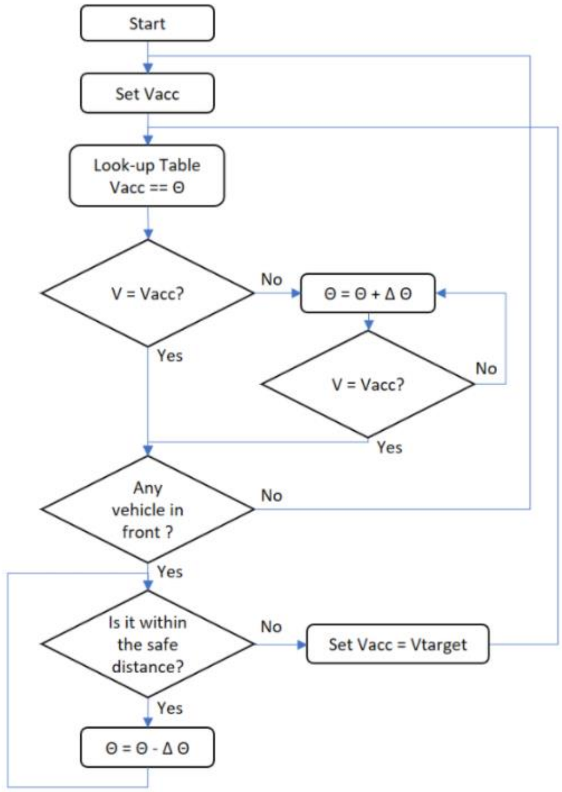

Figure 1. Model-free control flow chart

Simulink model of model-free control

The Simulink model is constructed by following the flowchart shown above. As noted in the assignment instruction, a simple 1-D lookup table is used to represent the relationship between the throttle angle and the speed of the main vehicle. 'Gain' blocks are used to convert the time unit of the velocity before integrating the velocity to calculate the distance traveled using the 'integrator' blocks. This is done for both the main vehicle and the target vehicle.

'IF' block is used to construct three different conditions in relation to the actual distance between the two vehicle and the safe braking distance of the main vehicle. It is assumed that the visual field distance of the main vehicle is 200 m, which means that the main vehicle will see the target vehicle when the distance between the two vehicles is less or equal to 200 m. The three conditions are as follow: Condition#1. The main vehicle does not see the target vehicle, Condition#2. The main vehicle sees the target vehicle, and the target vehicle is outside of the safe braking distance of the main vehicle, Condition#3. The main vehicle sees the target vehicle, and the target vehicle is within the safe braking distance of the main vehicle.

As shown in the figure below, three corresponding subsystems are constructed to respond to the three conditions generated by the 'IF' block. The first subsystem responds to Condition#3, which is to output adjusted throttle opening to decrease the speed of the main vehicle. The amount of change in throttle angle is determined by multiplying a set gain to the amount of the violated safe braking distance. The formulation resembles a P-controller. The second subsystem responds to Condition#1, which is to output an appropriate throttle opening to maintain the Vacc velocity set initially. This is also done using a P-controller which determines the change in throttle angle by multiplying a set gain to the Vacc tracking error. The third subsystem responds to Condition#2, which is to follow a new Vacc value that is equal to the target vehicle velocity. The throttle angle change is again calculated by a P-controller with the target vehicle velocity tracking error as an input.

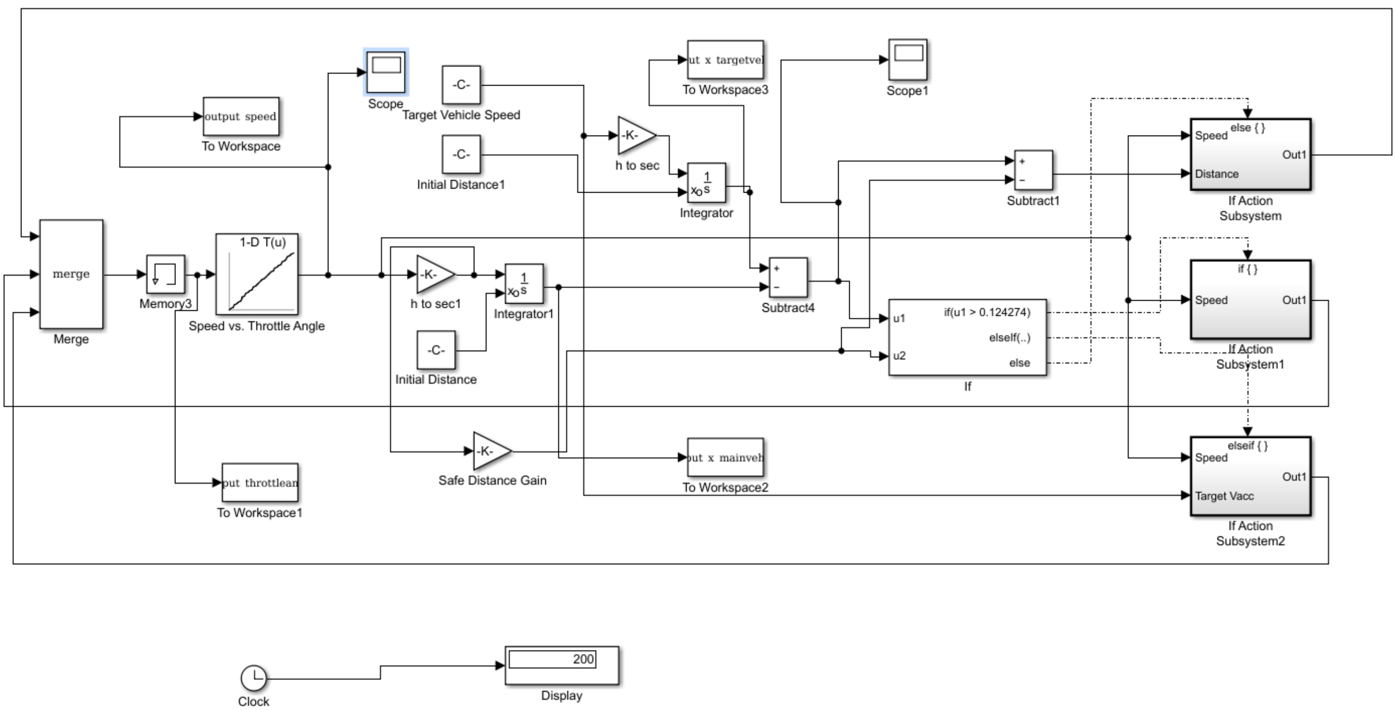

Figure 2. Simulink model layout diagram of model-free control

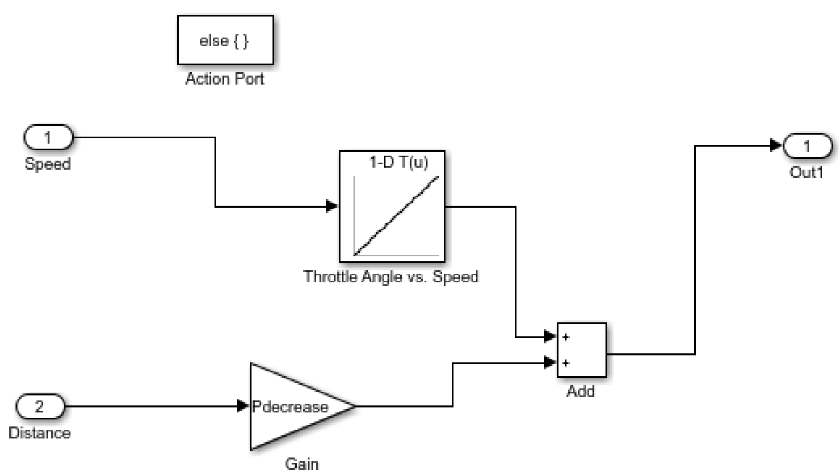

Figure 3. Simulink model 1st action subsystem

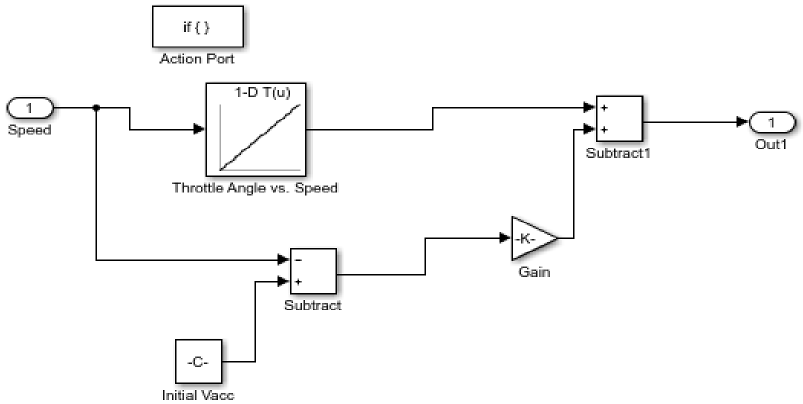

Figure 4. Simulink model 2nd action subsystem

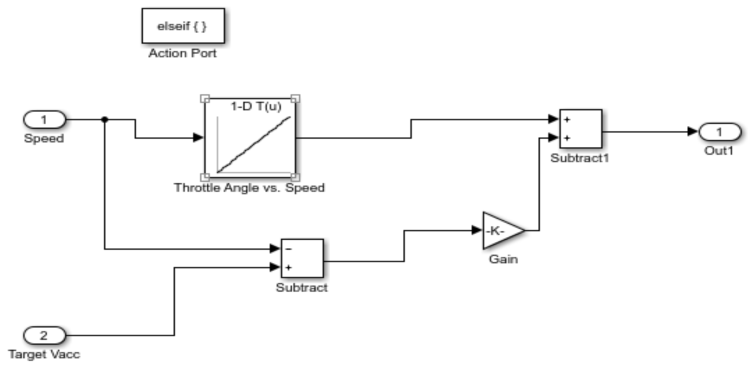

Figure 5. Simulink model 3rd action subsystem

Simulink result of model-free control and evaluation

After finishing the Simulink model above, we can gain variation of main vehicle speed and distance between the two vehicles by simulating scenarios of different target vehicle speeds. In this report, we show the results in circumstance that target vehicle speeds respectively are 40 mph, 45 mph, 50 mph and 55 mph when ACC vehicle approaches at 60 mph.

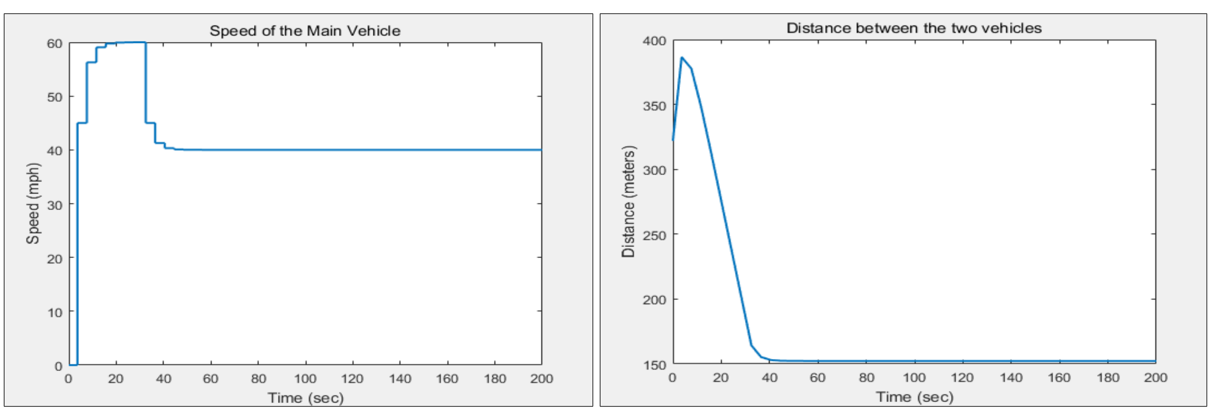

Figure 6. Vehicle speed and distance diagram with 40 mph target vehicle speed

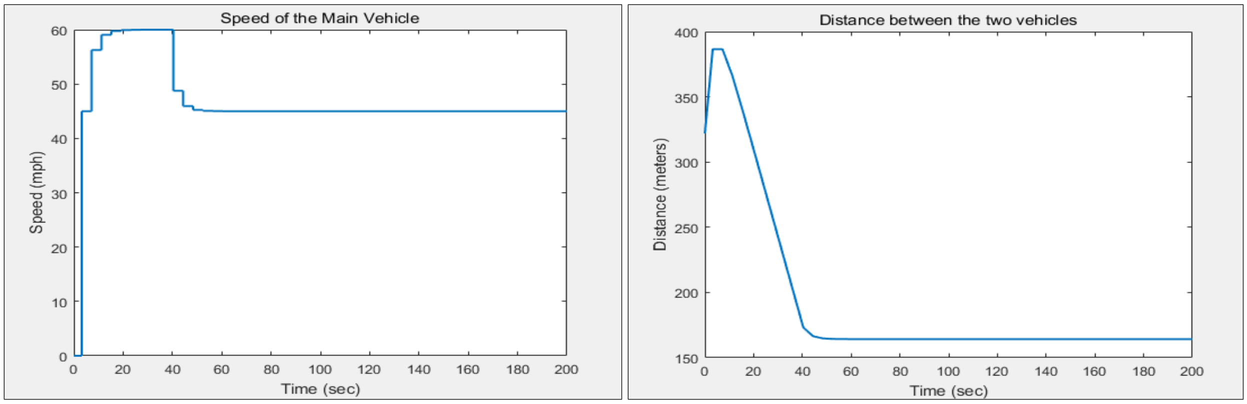

Figure 7. Vehicle speed and distance diagram with 45 mph target vehicle speed

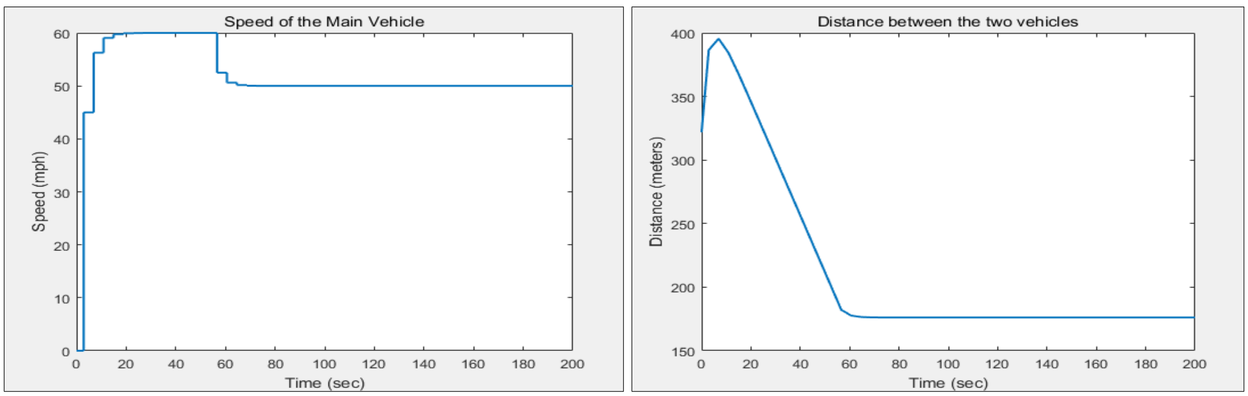

Figure 8. Vehicle speed and distance diagram with 50 mph target vehicle speed

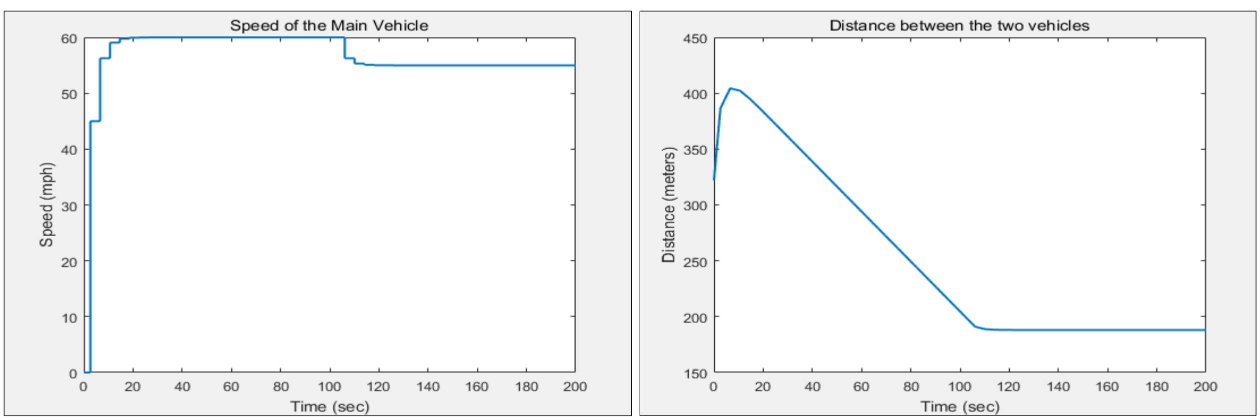

Figure 9. Vehicle speed and distance diagram with 55 mph target vehicle speed

target vehicle speed (mph)	final distance kept (m)
40	152
45	167
50	180
55	193

Table 1. Final distance kept in different target vehicle speed

Evaluation:

From the diagrams above, it can be seen that with our model-free simulink model, the ACC vehicle can automatically adjust its speed to desirable speed with high accuracy. Then the ACC vehicle will keep the cruise speed which is typically set by driver until detecting that a vehicle ahead is within the safety distance. The ACC vehicle will finally keep the same speed with the target vehicle with a safe distance between them. Above all, our model-free simulink model meets the requirement and achieves the original aim of ACC system.

Model based control

Concept of model based control

Model based control uses vehicle model for a car and a truck. The model parameter values of car and truck are provided in detail further in the report. We have used a PID controller tuned respectively for each vehicle model. The equations of the controller and logic of operation explained in a flow chart is also covered.

Flowchart of model based ACC Programming

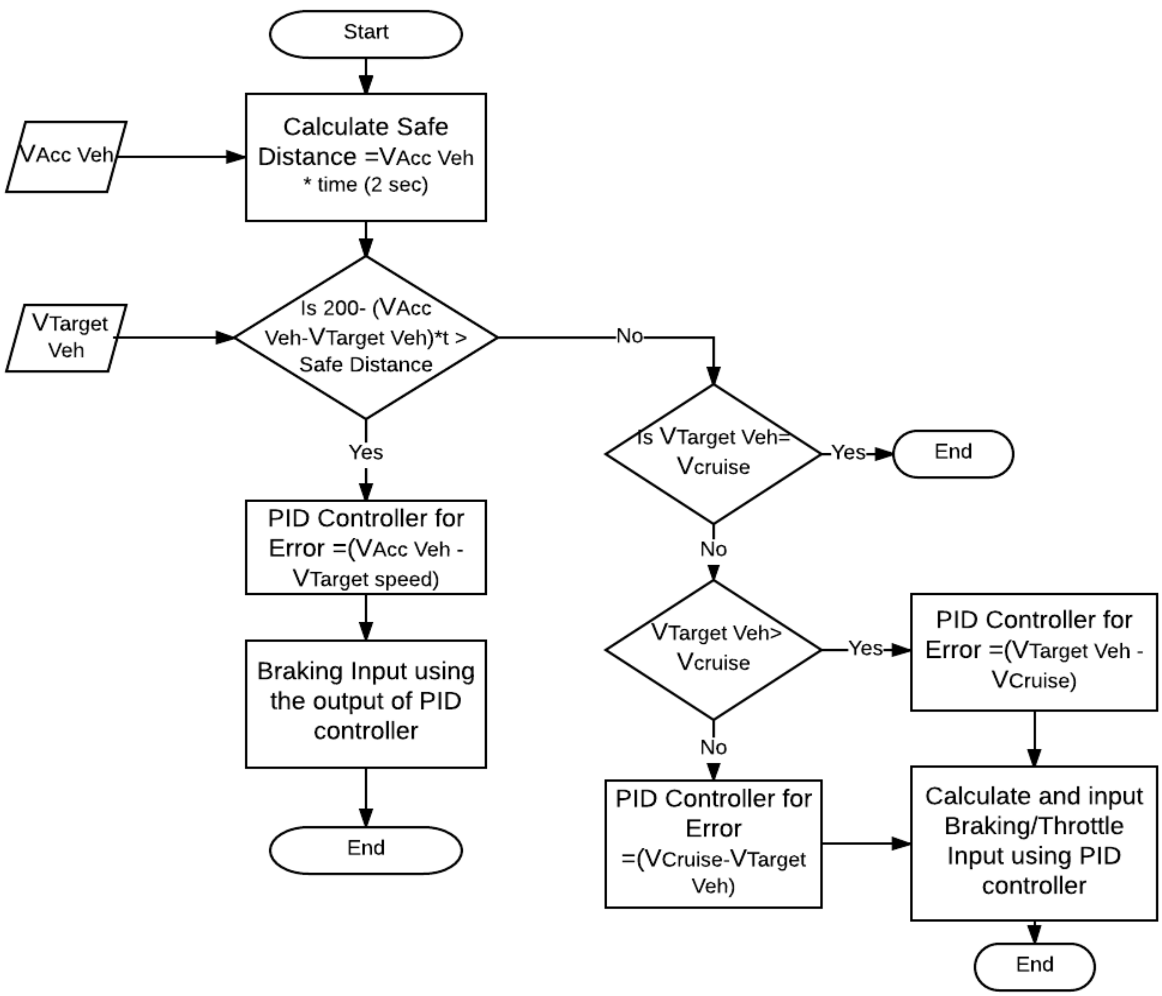

Figure 10. Model based control flow chart

Simulink model of model based control

The Simulink model is constructed by following the flowchart shown above. 'Gain' blocks are used to convert the time unit of the velocity before integrating the velocity to calculate the distance traveled using the 'integrator' blocks. This is done for both the main vehicle and the target vehicle.

'IF' block is used to construct three different conditions in relation to the actual distance between the two vehicle and the safe braking distance of the main vehicle. It is assumed that the visual field distance of the main vehicle is 200 m, which means that the main vehicle will see the target vehicle when the distance between the two vehicles is less or equal to 200 m. Thus, the initial condition of distance between the two vehicles in 200m. The three conditions are as follow: Condition#1. The main vehicle is at a safe distance and has velocity less than cruising speed #2. The main vehicle is at a safe distance and has velocity greater than cruising speed, Condition#3. The main vehicle is at a distance less than the safe distance from the target vehicle

The distance between the vehicles is calculated by integrating the difference in velocity and subtracting from the initial distance. This is done by using the integrator block for which initial conditions are set appropriately. For condition #1, the PID controller calculates the throttle input taking the difference between cruise speed set and the acc vehicle. For condition #2 and #3 braking inputs are decided by using PID controller. The error for condition #2 is V_{acc}-V_{cruise} and for condition #3 is V_{acc}-V_{target}.

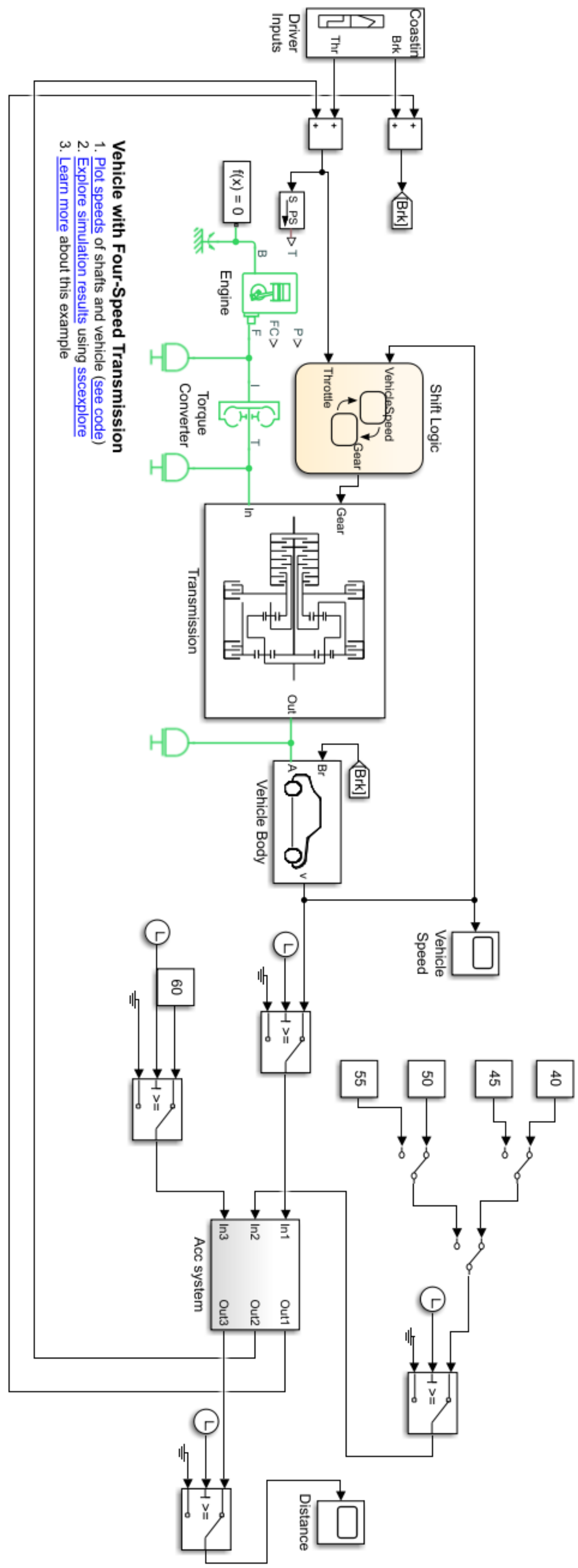

Figure11. Simulink model layout diagram of model based control

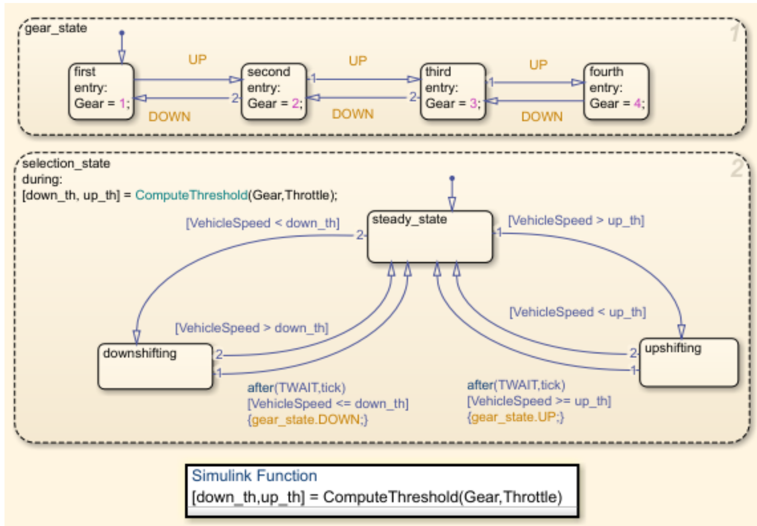

Figure 12. Simulink model of the Shift Logic

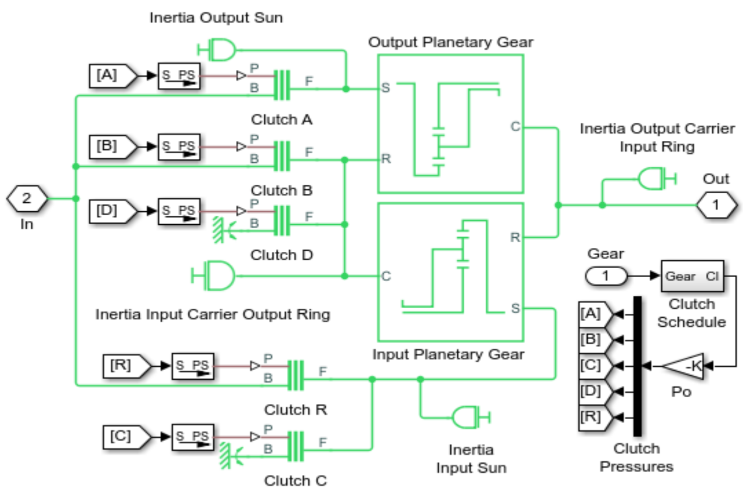

Figure 13. Simulink model of the Transmission

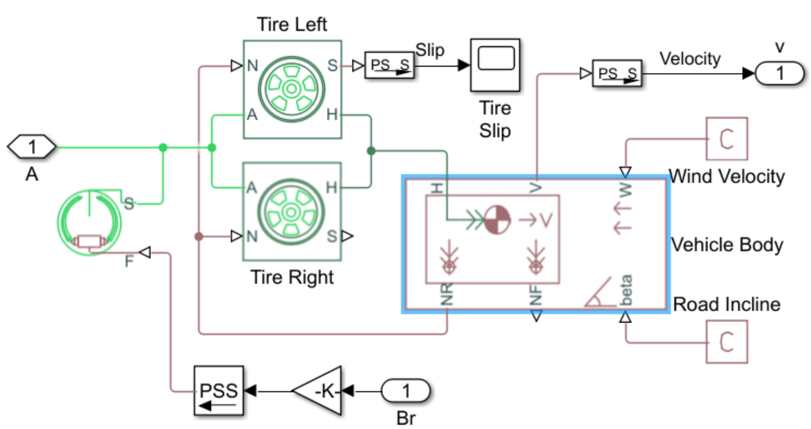

Figure 14. Simulink model of the Vehicle Body

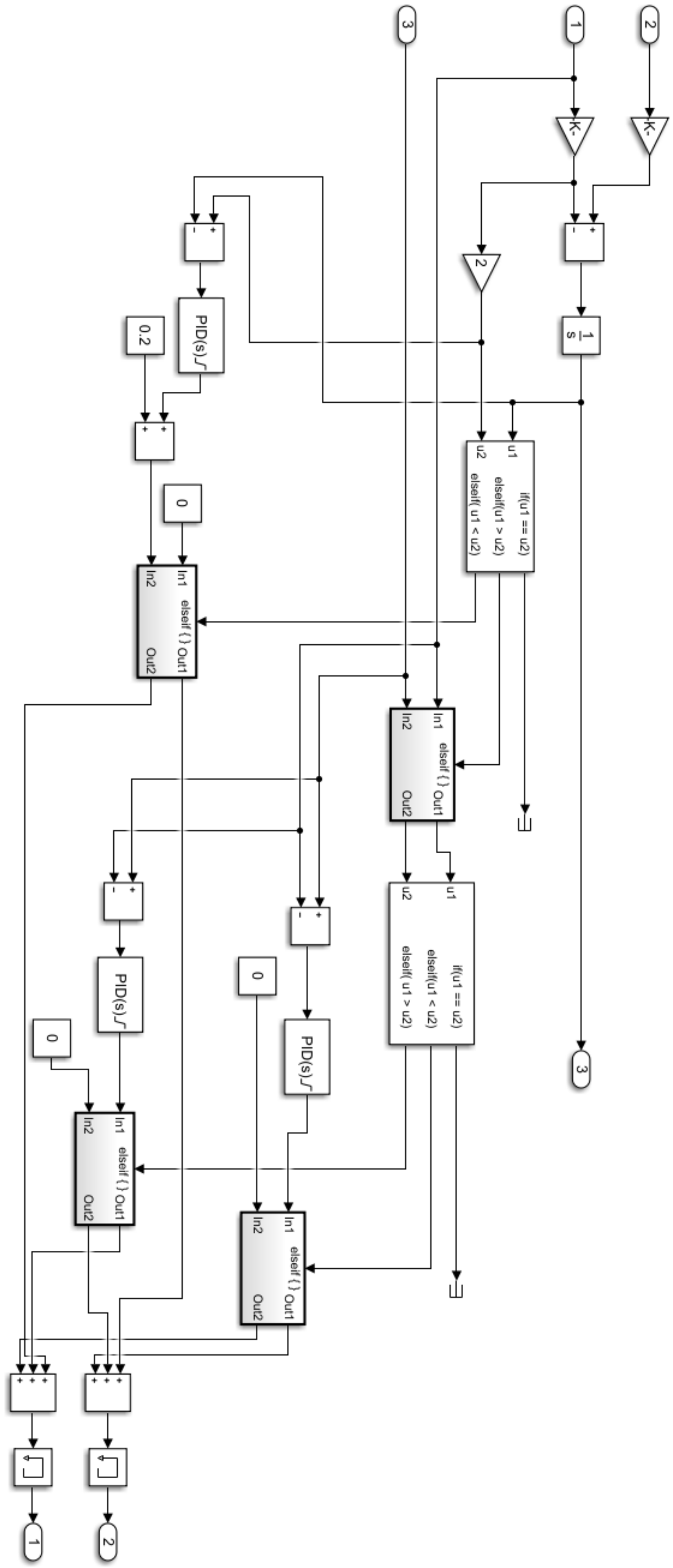

Figure 15. Simulink model of ACC system

Model Equations

Based on the input parameters- cruising vehicle speed(V_{acc}), target vehicle speed(V_{target}) and cruise speed set(V_c), we calculate the input throttle and braking. The distance between the two vehicles is calculated by integrating the difference in velocity over time. The initial distance between the vehicle is assumed to be 200 m as the radar sensing capabilities limit it to that. The logic for determining the braking and throttle is explained in the flow chart.

Distance between vehicles = 200-(V_{acc} - V_{target})*time

It is displayed using a scope in the model.

In the flow chart we have three conditions, calculations and equations used are explained below for these three conditions:

Condition I - Safe Distance > (V_{acc} - V_{target})*time and V_{acc} < V_c

PD controller determines throttle input

e = Error = (V_c - V_{acc})

$\text{Throttle Input } = k_{p1} * e(t) + k_{i1} * \int e(t)dt + k_{d1} * \frac{de(t)}{dt}$

Braking Input is set to zero.

For car, $k_{p1} = 300, k_{i1} = 0, k_{d1} = 1000$

For truck, $k_{p1} = 500, k_{i1} = 0, k_{d1} = 5$

Condition II – Safe Distance < [200- (V_{acc} - V_{target})*time]

PID controller determines braking input

e = Error = (V_{acc} - V_{target})

$\text{Braking Input } = k_{p2} * e(t) + k_{i2} * \int e(t)dt + k_{d2} * \frac{de(t)}{dt} + 0.2$

Throttle Input is set to zero.

For car, $k_{p2} = 1000, k_{i2} = 1.3, k_{d2} = 1000$

For truck, $k_{p2} = 500, k_{i2} = 0, k_{d2} = 0$

0.2 constant factor is used, as the braking input required was more and it was easier to tune this way.

Condition III - Safe Distance > [(V_{acc} - V_{target})*time] and V_{acc} > V_c

PD controller determines braking input

e = Error = (V_{acc} - V_{target})

$\text{Braking Input } = k_{p2} * e(t) + k_{i2} * \int e(t)dt + k_{d2} * \frac{de(t)}{dt}$

Throttle Input is set to zero.

For car, $k_{p3} = 500, k_{i3} = 0, k_{d3} = 500$

For truck, $k_{p3} = 500, k_{i3} = 0, k_{d3} = 500$

Model Parameters for the Simulink model

Car

Source: Example model in Simscape driveline

Engine

Torque characteristics
Type: Spark Ignition
Maximum Power: 150 kW
Speed @ maximum power: 4500 rpm
Maximum speed: 6000 rpm

Dynamics
Engine inertia: 0.08 kg.m^2
Initial velocity: 960 rpm
Engine time constant: 0.4 s

Limits
Speed threshold: 100 rpm

Fuel consumption: 25 mg/rev

Transmission

Input Planetary Gear
Ring gear to sun gear ratio: 2.2258

Output Planetary Gear
Ring gear to sun gear ratio: 1.84

Tires

Tire Force
Rated vertical load: 3000 N
Peak longitudinal force at rated load: 3500 N
Slip at peak force: 10%

Dimensions
Rolling radius: 0.3 m

Slip
Velocity threshold: 0.1 m/s

Tire inertia: 0.01 kg.m^2

Truck

Source: http://www.atraonline.com/gears/2005/2005-09/2005-09_56.pdf
http://www.diesel-engine.cn/ISUZU/4HF1.htm
http://www.isuzutruckservice.com/pdf/BodyBuilder/2015/15BBG_Sec07_NPR%20NPRHD%20Gas_040914%20final.pdf

Engine

Torque characteristics
Type: Compression Ignition
Maximum Power: 85 kW
Speed @ maximum power: 3200 rpm
Maximum speed: 3600 rpm

Dynamics
Engine inertia: 0.056 kg.m^2
Initial velocity: 750 rpm
Engine time constant: 0.4 s

Limits
Speed threshold: 100 rpm

Fuel consumption: 225 g/kWh

Transmission

Input Planetary Gear
Ring gear to sun gear ratio: 2.2258

Output Planetary Gear
Ring gear to sun gear ratio: 1.84

Tires

Tire Force
Rated vertical load: 5052 N
Peak longitudinal force at rated load: 5900 N
Slip at peak force: 10%

Dimensions
Rolling radius: 0.316 m

Slip
Velocity threshold: 0.1 m/s

Tire inertia: 0.01 kg.m^2

Brakes – Double shoe drum brakes

Geometry
Drum radius: 150 mm
Actuator location radius: 100 mm
Pin location radius: 125 mm
Pin location angle: 15 degrees
Shoe beginning angle: 5 degrees
Shoe span angle: 120 degrees

Friction
Contact friction coefficient: 0.3
Angular velocity threshold: 0.01 rad/s

Vehicle Body

Mass: 1200 kg
No. of wheels per axle: 2
Center of gravity to front axle distance: 1.4 m
Center of gravity to rear axle distance: 1.6 m
Height of center of gravity: 0.5 m
Frontal area: 3 m^2
Drag coefficient: 0.4
Acceleration due to gravity (g): 9.81 m/s^2
Air density: 1.18 kg/m^3

Brakes – Double shoe drum brakes

Geometry
Drum radius: 250 mm
Actuator location radius: 200 mm
Pin location radius: 225 mm
Pin location angle: 15 degrees
Shoe beginning angle: 5 degrees
Shoe span angle: 120 degrees

Friction
Contact friction coefficient: 0.3
Angular velocity threshold: 0.01 rad/s

Vehicle Body

Mass: 2310 kg
No. of wheels per axle: 4
Center of gravity to front axle distance: 1.47 m
Center of gravity to rear axle distance: 2.97 m
Height of center of gravity: 0.6 m
Frontal area: 4.83 m^2
Drag coefficient: 0.64
Acceleration due to gravity (g): 9.81 m/s^2
Air density: 1.18 kg/m^3

Simulink result of model based control (Car)

After finishing the Simulink model above, we can gain variation of main vehicle speed and distance between the two vehicles by simulating scenarios of different target vehicle speeds. In this report, we show the results in circumstance that target vehicle speeds respectively are 40 mph, 45 mph, 50 mph and 55 mph when ACC vehicle approaches at 60 mph.

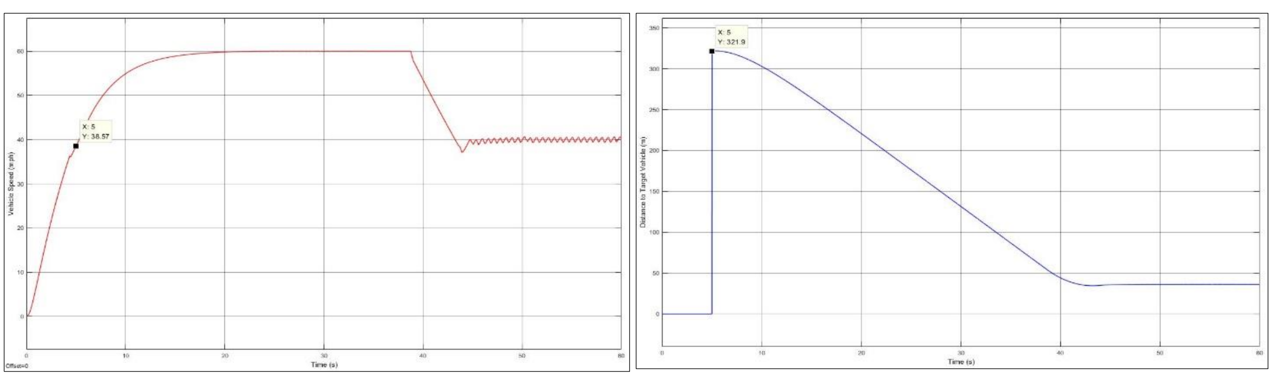

Figure 16. Vehicle speed and distance diagram with 40 mph target vehicle speed

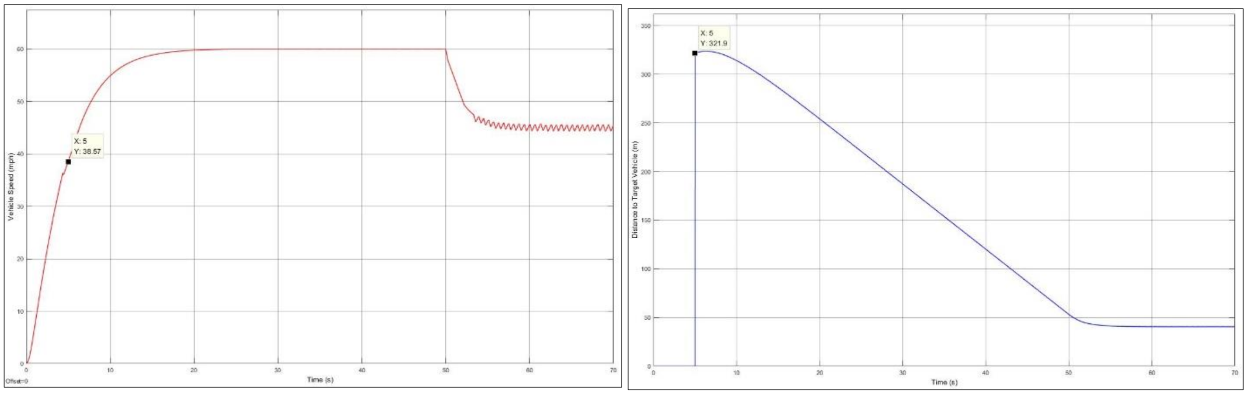

Figure 17. Vehicle speed and distance diagram with 45 mph target vehicle speed

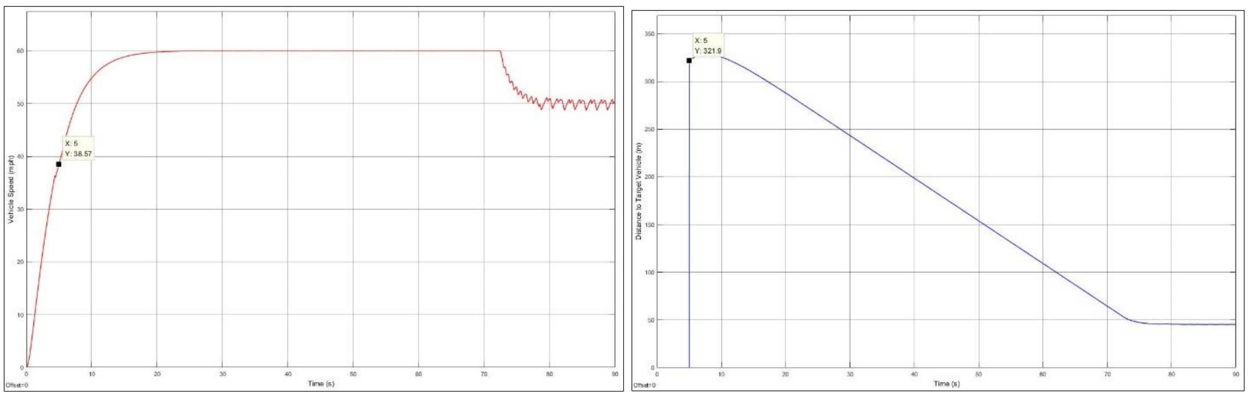

Figure 18. Vehicle speed and distance diagram with 50 mph target vehicle speed

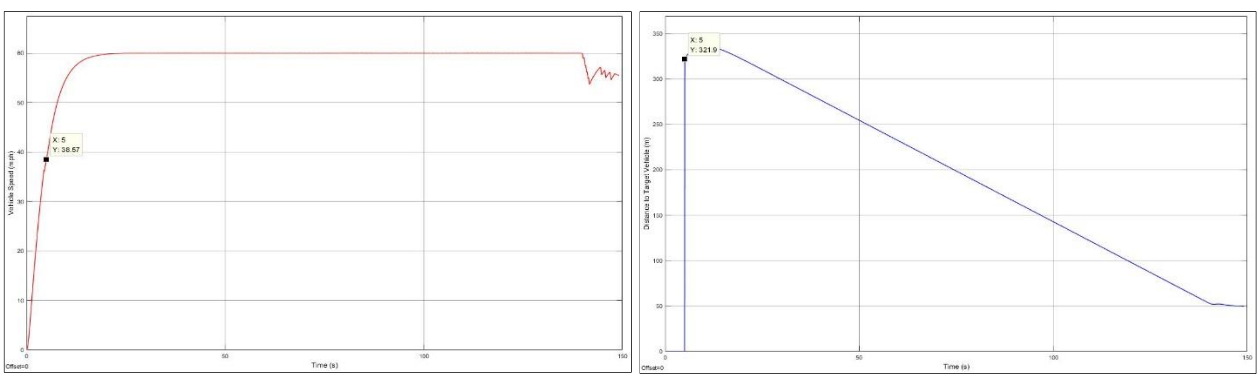

Figure 19. Vehicle speed and distance diagram with 55 mph target vehicle speed

Evaluation of model based ACC

We use the same scenario as which used in the model free ACC. The initial distance between target vehicle and main vehicle is 200 m and the safe distance is calculated in the format of speed *2s. We also give an initial throttle input for 5 seconds to reach an initial speed. Here are the results.

Evaluation between model free and model based ACC

Because there is no vehicle model involved in model free ACC and the using for table between throttle and vehicle speed in that ACC, the result curve of model free ACC is not smooth enough and it is like a kind of step response. However, just due to the simple relationship between throttle and vehicle speed, it is easy for PID controller to control the system and as a result, there is small oscillation. For the model based ACC, there is a vehicle model involved in it and the relationship between throttle and vehicle speed is not just simple linearity. So it is a little hard for PID controller to control it. Also we use three PID controllers in model based ACC system so it is a little to tune the three PID parameters at the same time. The speed result for model based ACC has some oscillation but the error is still small enough which is about 0.5 mph. and just because of the vehicle model, model based ACC has smoother results than model free ACC.

Evaluation between sedan and truck.

For the truck with ACC system, we use the same model as previous sedan with ACC system, but we changed some parameters.

Because of the lower peak power, lower maximum speed of the engine and bigger frontal area and mass, truck is less powerful than a sedan and less sensitive to the throttle input. It means that for the same throttle input value, truck obtains less acceleration than a sedan. As a result, truck is easier for control than sedan. Here are the simulation results for truck.

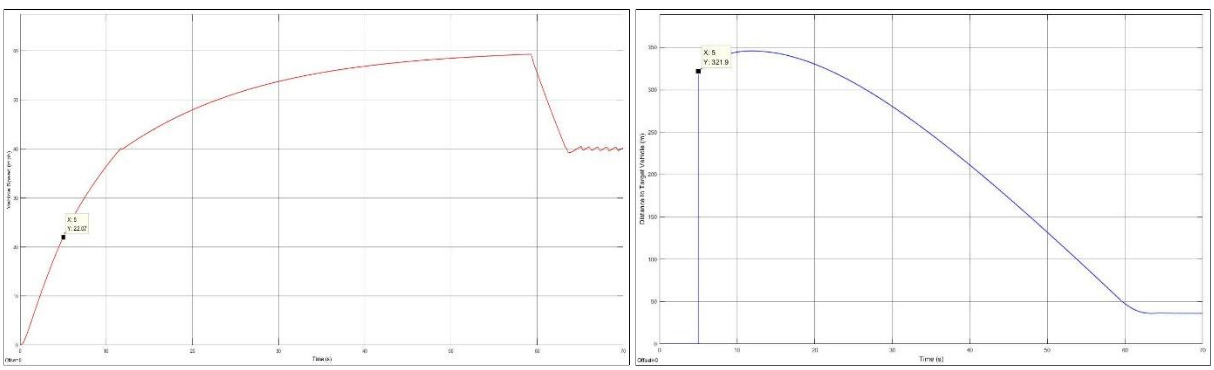

Figure 20. Vehicle speed and distance diagram with 40 mph target vehicle speed

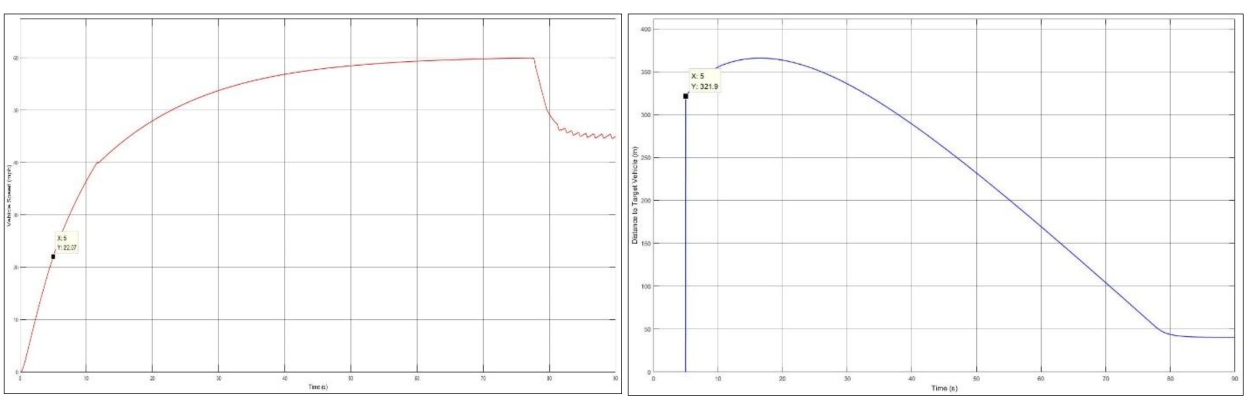

Figure 21. Vehicle speed and distance diagram with 45 mph target vehicle speed

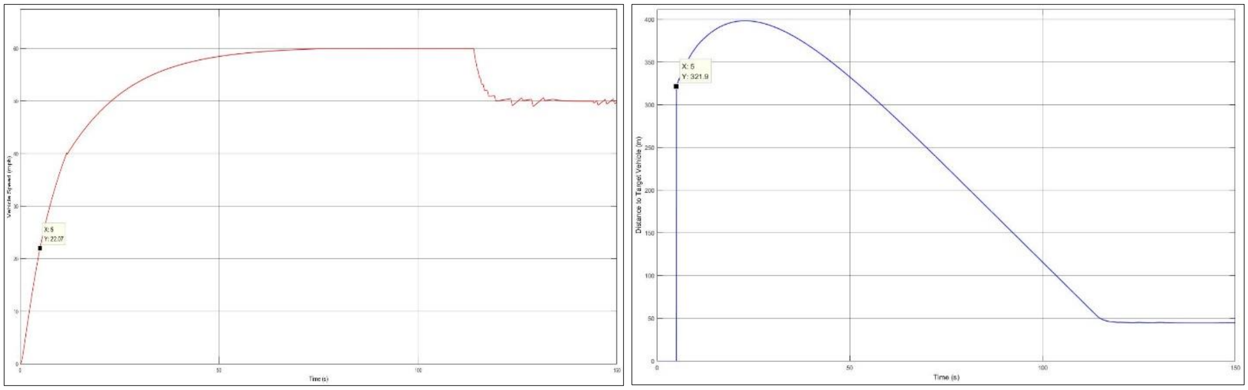

Figure 22. Vehicle speed and distance diagram with 50 mph target vehicle speed

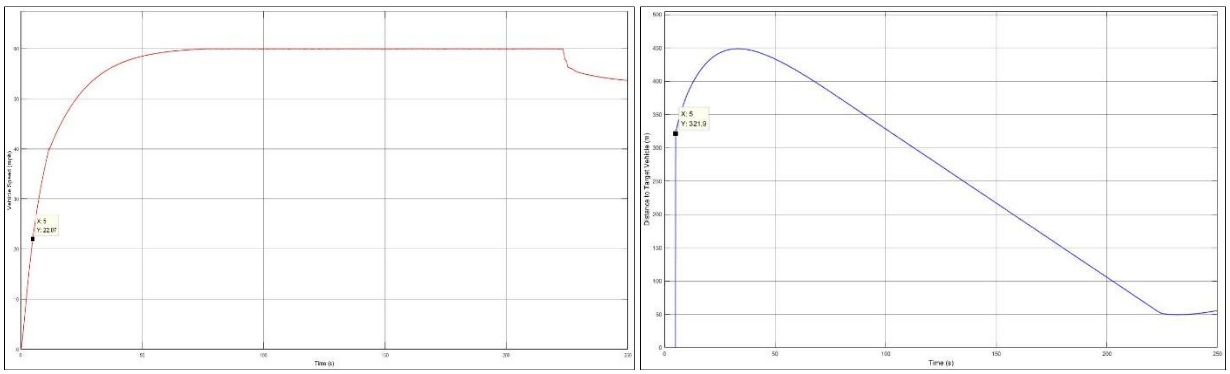

Figure 23. Vehicle speed and distance diagram with 55 mph target vehicle speed

The initial condition is same with model based on sedan. The initial distance between main vehicle and target vehicle is 200m and there is also an initial throttle input for the first 5 seconds. Comparing results with sedan model, we can see that in the same scenario, truck is not able to accelerate to the ACC set speed (60 mph) very fast. However, the speed curve of truck model is smoother, which means the truck is much easier to obtain the steady state.