

Thesis Title: -Design and Simulation of an Automatic Hydraulic Retarder of Vehicle Speed Control using Fuzzy Logic Controller

ABSTRACT

This thesis presents the design and simulation of an automatic hydraulic retarder for vehicle speed control utilizing a fuzzy logic controller, specifically targeting downhill driving conditions. Vehicle motion during operation can be regulated through various mechanisms, including accelerator pedals, antilock braking systems (ABS), and hydraulic retarders. However, emergency braking at high speeds on downhill roads poses significant risks of accidents, necessitating the development of a more responsive braking system. The research employs slope, speed, and acceleration feedback sensors to assess the vehicle's dynamic conditions while navigating downhill, enabling the retarder to apply braking torque as required. The primary objective of this study is to design and simulate a hydraulic retarder that maintains a constant vehicle speed of 30 km/h (8.33 m/s) based on guidelines from the Ethiopian Road Authority (ERA) manual. The study focuses on a heavy truck model, specifically the TGS33.400 6×4 BBS-WW-CKD/L76WAE33, powered by a D2066LF06-400hp/298.4kw EUR02-1900Nm engine. Notable considerations for the system include external resistance forces, dynamic vehicle loads, oil viscosity, the effect of disturbance signal on system response, turbine blade angles, and driver behavior. The dynamic vehicle model was established using SolidWorks, ADAMS, and MATLAB/Simulink, allowing for the integration of a fuzzy logic controller to fine-tune vehicle speed. The controller collects real-time data from the sensors and adjusts the actuation signal to a DC motor, managing the oil flow rate into the working chamber by modulating the throttle valve. Simulation results indicate that the proposed controller maintains the desired speed on downhill slopes, achieving a steady state error of 0.12 m/s, 0.086 m/s, and -0.1465 m/s for slopes 10^0 , 8^0 , and 6^0 , respectively. Furthermore, as the simulation result of multi-vehicle models on different road conditions validated the constant speed control strategy is effective for vehicle masses (total loads) of up to 33,000 kg across all road conditions; however, it faces challenges when the vehicle mass exceeds this threshold, especially at a 10^0 downhill slope.

Keywords: hydraulic retarder, tilt and speed sensor, fuzzy logic, filling ratio, road condition, vehicle dynamics.

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Presentation Outline

- Introduction
- Review of related Literature
- Statement of the Problem
- Objectives
- Methodology
- Mathematical Modeling
- Controller Design
- Result and Discussion
- Conclusion and Recommendation

Introduction

Background and Justification

- ❖ The first-time motor drive developed in 1769, but 1770 car accident was happened
- ❖ According to WHO, road accidents caused an estimated 1.25 million deaths worldwide in the year 2010.
- ❖ In Ethiopia(2013) car accident has been
 - One of the top ten causes of death
 - Road traffic accident was equal to malarial death

| Causes of car accident | Fatal | Serious injury | Slight injury | Property damage | Total | %age |
|-------------------------------------|------------|----------------|---------------|-----------------|-------------|-----------|
| Influence of alcohol or drug | 51 | 7 | 17 | 193 | 268 | 2 |
| Failure to respect right hand rule | 110 | 129 | 131 | 856 | 1226 | 8 |
| Failure to give way for vehicle | 20 | 65 | 112 | 1507 | 1704 | 11 |
| Failure to give way for pedestrians | 598 | 661 | 728 | 2058 | 4045 | 27 |
| Following too closely | 39 | 77 | 69 | 161 | 346 | 2 |
| Improper overtaking | 44 | 52 | 78 | 547 | 721 | 5 |
| Improper turning | 37 | 71 | 98 | 1317 | 1523 | 10 |
| Over speeding | 426 | 436 | 295 | 852 | 2009 | 13 |
| Failure to respect traffic signs | 16 | 27 | 11 | 123 | 177 | 1 |
| Driving with fatigue | 30 | 20 | 20 | 23 | 93 | 1 |
| Driving without attention | 10 | 18 | 15 | 9 | 52 | 0 |
| Improper parking | 52 | 62 | 81 | 772 | 967 | 6 |
| Excess loading | 76 | 135 | 88 | 43 | 342 | 2 |
| Failure in vehicle | 79 | 73 | 110 | 171 | 433 | 3 |
| Defective road environment | 12 | 13 | 19 | 62 | 106 | 1 |
| Pedestrian error | 34 | 164 | 29 | 17 | 244 | 2 |
| Other | 81 | 81 | 162 | 240 | 564 | 4 |
| Unidentified | 87 | 65 | 60 | 54 | 266 | 2 |

Car Accident data for Tigray regional state 2017/18

| Cause of Traffic Accident | Fatal | Serious Injury | Slight Injury | Property | Total |
|---------------------------|-------|----------------|---------------|----------|-------|
| Over speed | 6 | 15 | 0 | 48 | 69 |
| | 6 | 19 | 0 | 52 | 77 |
| Driver Negligence | 42 | 99 | 3 | 208 | 302 |
| | 39 | 107 | 5 | 167 | 318 |

| Road condition | Fatal | Serious Injury | Slight Injury | Property | Total |
|-----------------|-------|----------------|---------------|----------|-------|
| Downslope | 9 | 19 | 0 | 36 | 64 |
| | 11 | 26 | 0 | 32 | 69 |
| Smooth Asphalts | 35 | 85 | 3 | 173 | 296 |
| | 37 | 93 | 4 | 150 | 284 |

Literature Review Inference

| No | Paper | Methods | Research gap |
|----|---------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| 1 | Sunil R. Kewate and his partners(2016), has been designed an automatic speed control system by the color sensor for automobiles | ➤ Based on color sensor information control the fuel flow to engine | ➤ Not applicable for off-road condition ➤ Color intensity may changed through time |
| 2 | Jake S. Schwartz(2017), done his thesis on designing of an automobile accelerator (Brake Pedal) robot for advanced driver assistance system | ✓ Vehicle speed controlled by design accelerator and brake pedal ✓ PID and fuzzy logic controller | ✓ For straight line road ✓ Automobile car ✓ Using the accelerator pedal can't control at downslope |

cont...

| | | | |
|---|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| 3 | Yulong Lei(2017), Hongpeng Zheng(2016) and their partners presented on design of a filling ratio observer for a hydraulic retarder | <ul style="list-style-type: none">➤ Uses retarder actuator➤ Speed reduction and constant speed fuzzy controller➤ Speed sensor | <ul style="list-style-type: none">➤ Constant speed controller activated by the driver |
|---|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|

But this research uses an automatic hydraulic retarder which regulate the vehicle dynamics using fuzzy logic controller based on the sensors feedback without driver contribution.

Statement of the Problem

- As per the statistical data in 2017/18 indicated, road accident is the leading causes of death and injury in Ethiopia.
- Factors that cause car accidents are
 - ✓ Driver negligence
 - ✓ Overloaded
 - ✓ Over speed drive
 - ✓ Influence of alcohol and etc.
- This research designed an automatic retarder to apply braking torque over the vehicle slightly and smoothly to drive at constant speed without driver effort.

Objectives

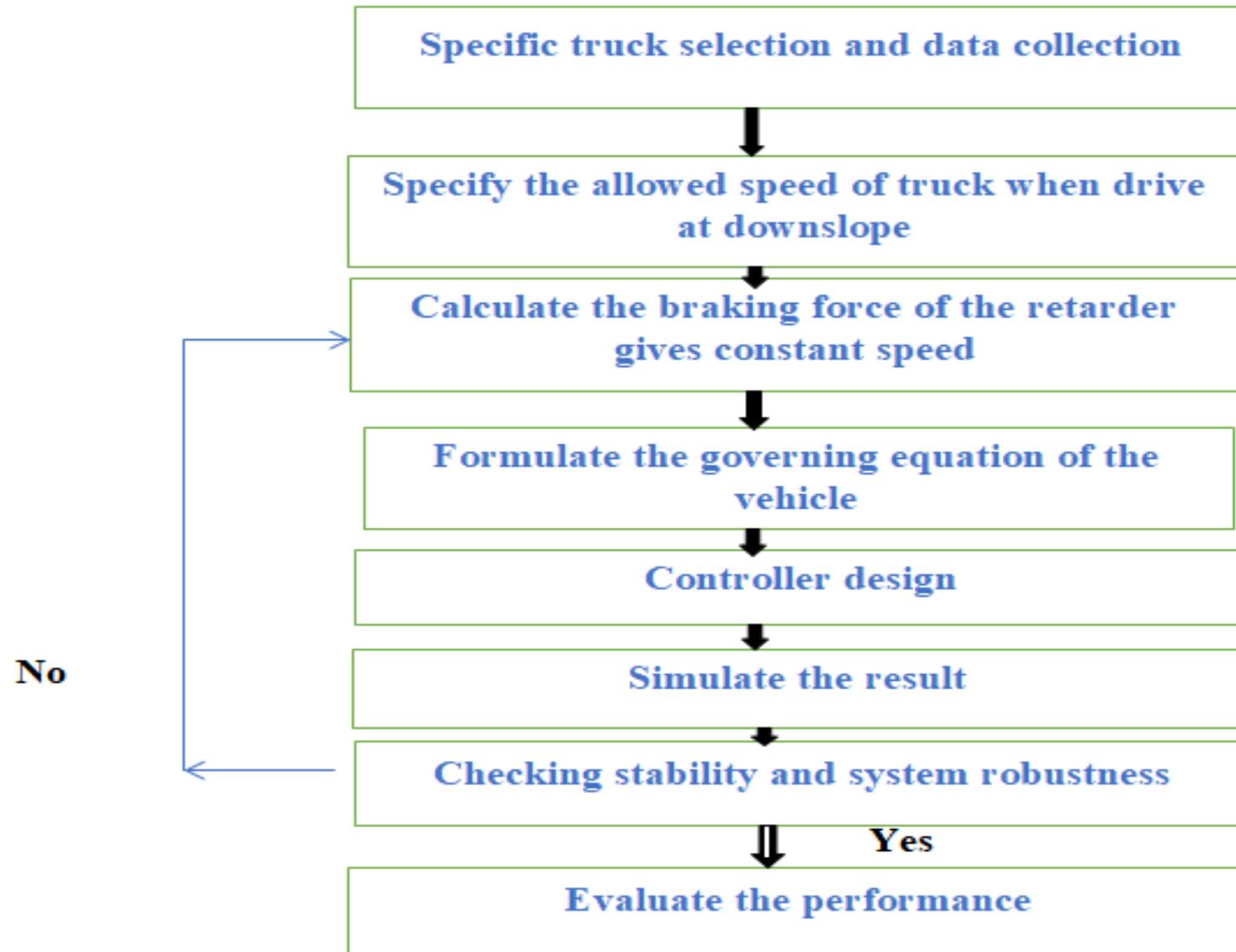
General objective

The main objective of this thesis is to design an automatic hydraulic retarder using fuzzy logic controller for vehicle speed control on downslope road condition.

Specific objective

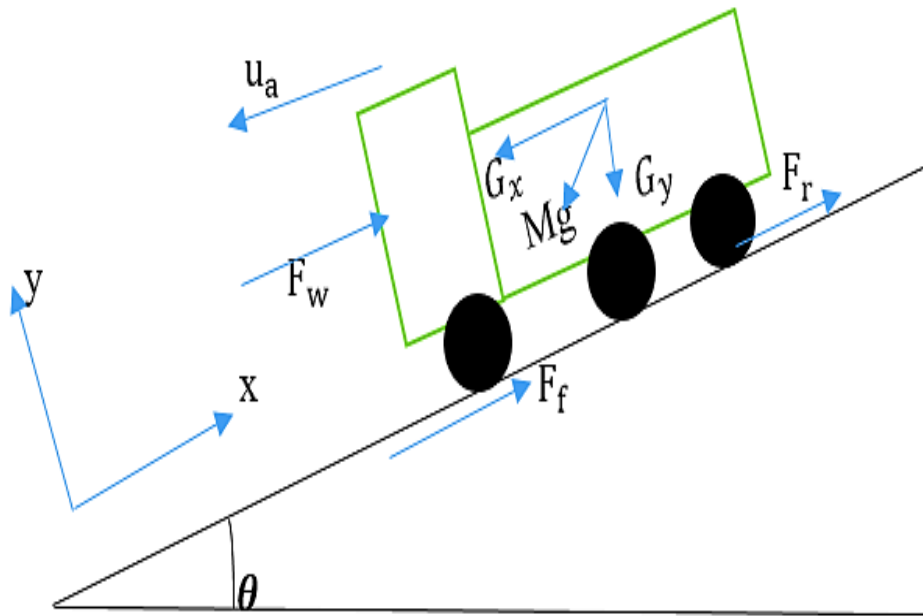
- To drive the mathematical model of the vehicle
- To design and simulate fuzzy logic controller
- To compare the analytical result with the simulation results
- To evaluate the system performance regarding to variable vehicle mass, road slope and disturbance effect on system response

Methodology



Mathematical Modeling

❖ Vehicle model



Vehicle modeling from vehicle dynamic forces

$$M \frac{du_a}{dt} = Mg \sin \theta - F_f - F_r - F_w$$

My basic assumption was $\frac{du_a}{dt} = 0$

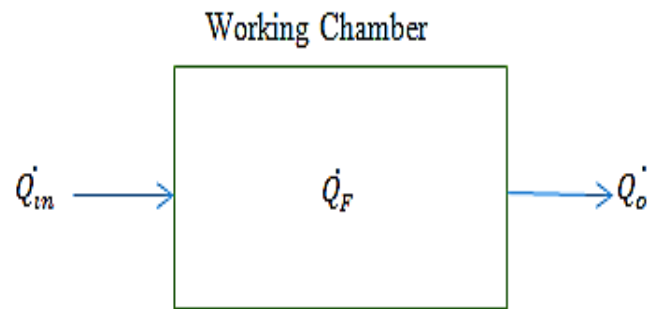
$$F_r = 56921.53 \alpha(t), \text{ for } \theta = 10^\circ$$

$$U_a(S) = \frac{323730(\sin \theta - 0.00076) - 56921.53 \alpha(S)}{33000S + 20}$$

Is the governing equation of the vehicle dynamics

cont....

❖ Retarder model



$$\dot{Q}_F = \dot{Q}_{in} - \dot{Q}_o = \Theta(t) R^2 C_d \sqrt{\frac{2\Delta P_d}{\rho_{oil}}}$$

$$\alpha(t) = \frac{\int_0^t \dot{Q}_F dt}{V_C}$$

$$\alpha(t) = 0.636\Theta(t)$$

❖ DC servo motor modeling

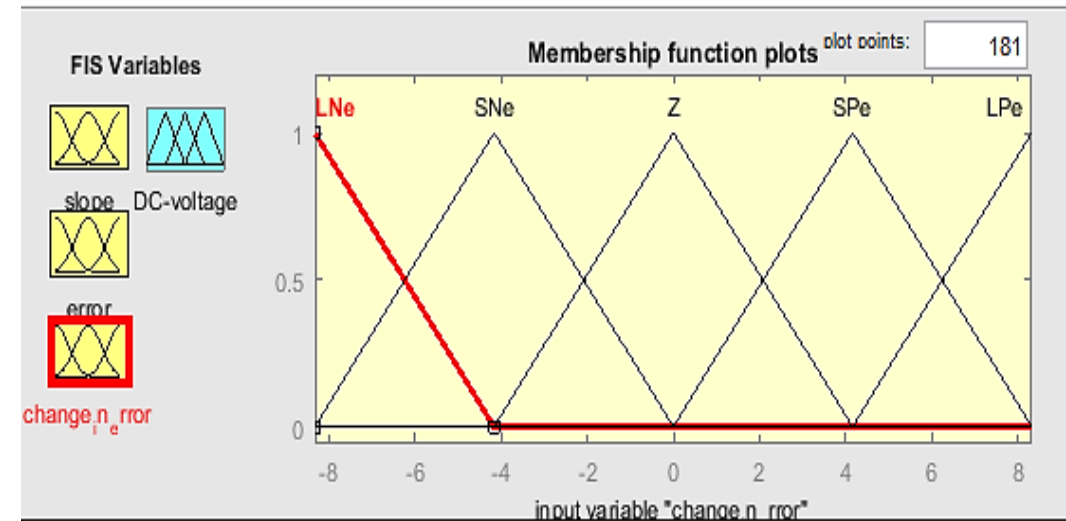
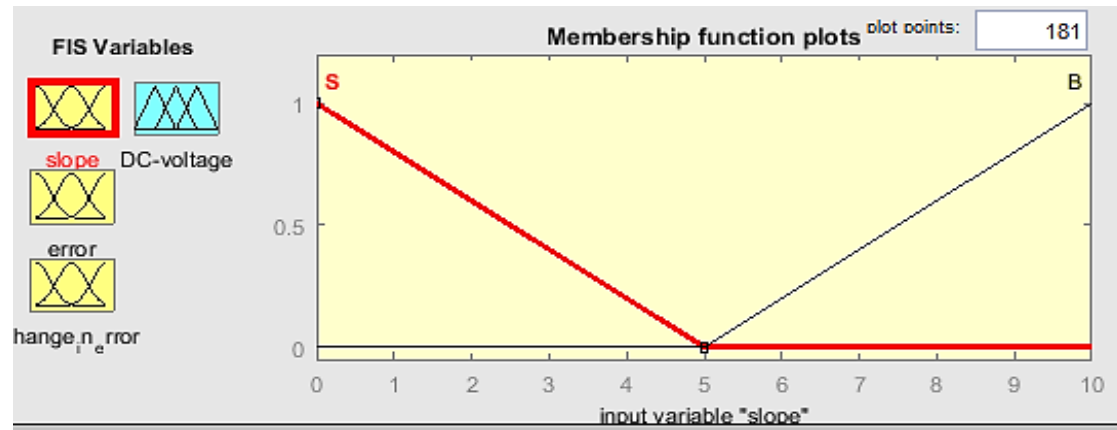
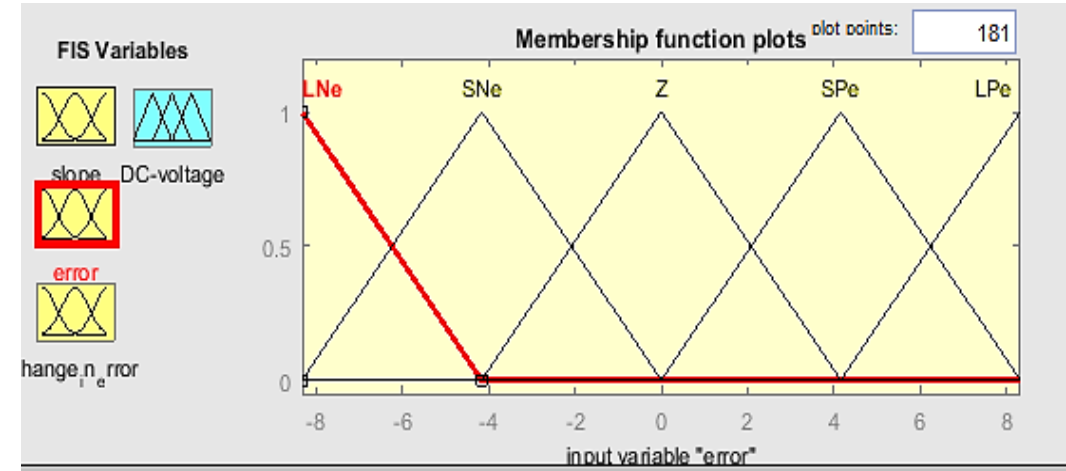
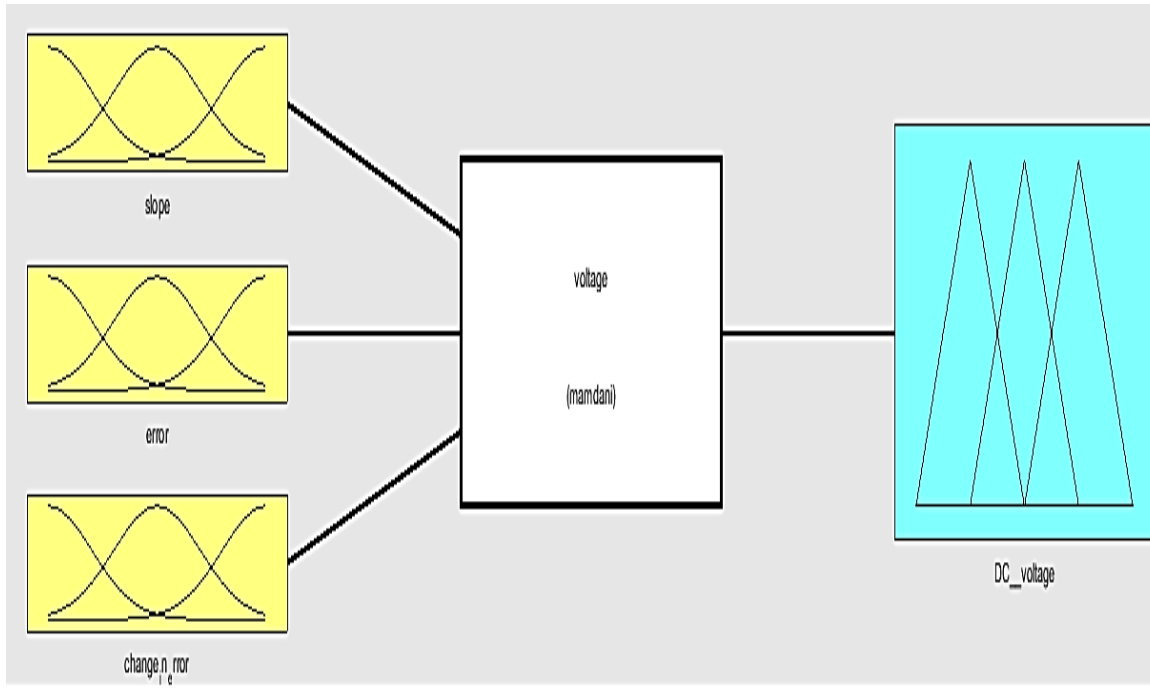
$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} + v_b(t) = v_a(t)$$

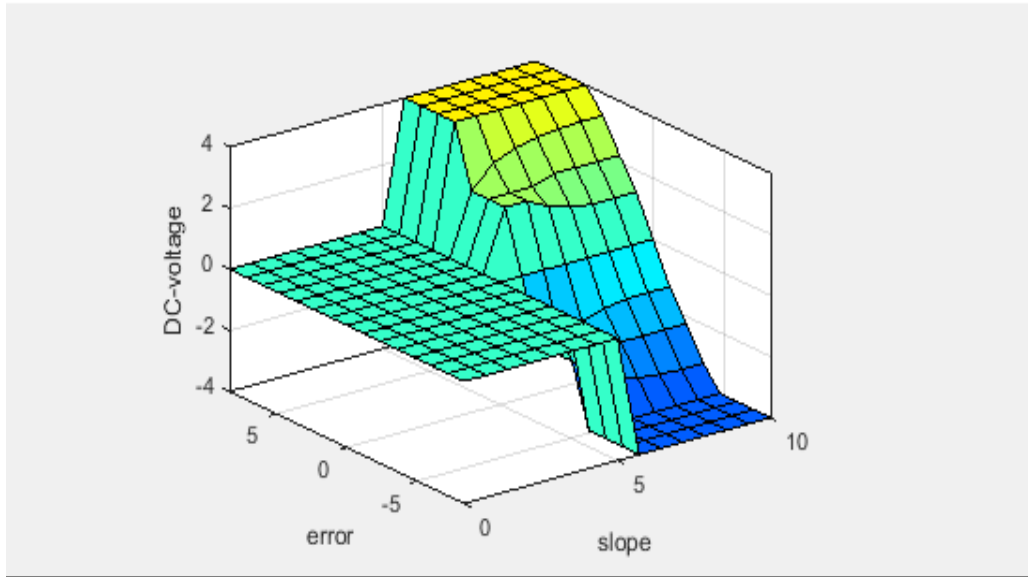
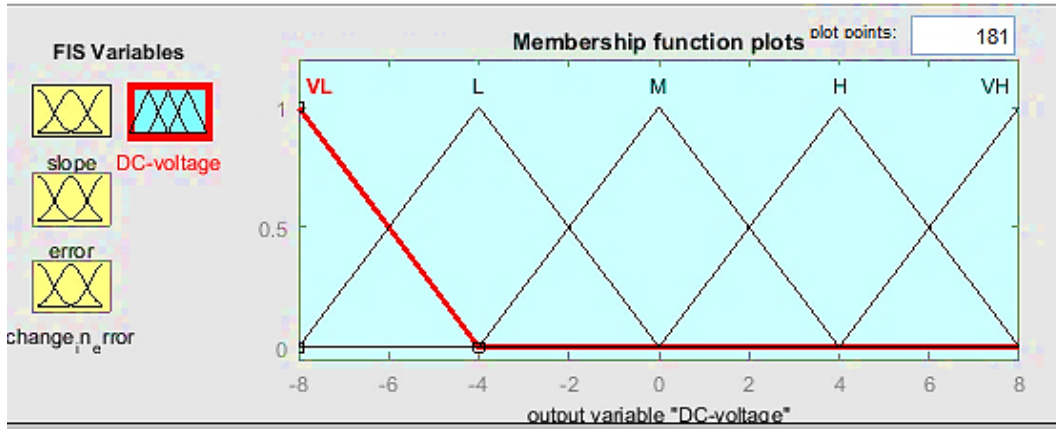
$$J \frac{d}{dt} \left(\frac{d\theta(t)}{dt} \right) + B \frac{d\theta(t)}{dt} = T_M(t) - T_L$$

$$J \frac{d}{dt} \left(\frac{d\theta(t)}{dt} \right) = T_M(t), \text{ But, } B \text{ and } T_L \approx 0$$

$$\frac{\Theta(S)}{V_a(S)} = \frac{2.13}{0.0002166S^3 + 0.038S^2 + 2.556S}$$

Controller Design

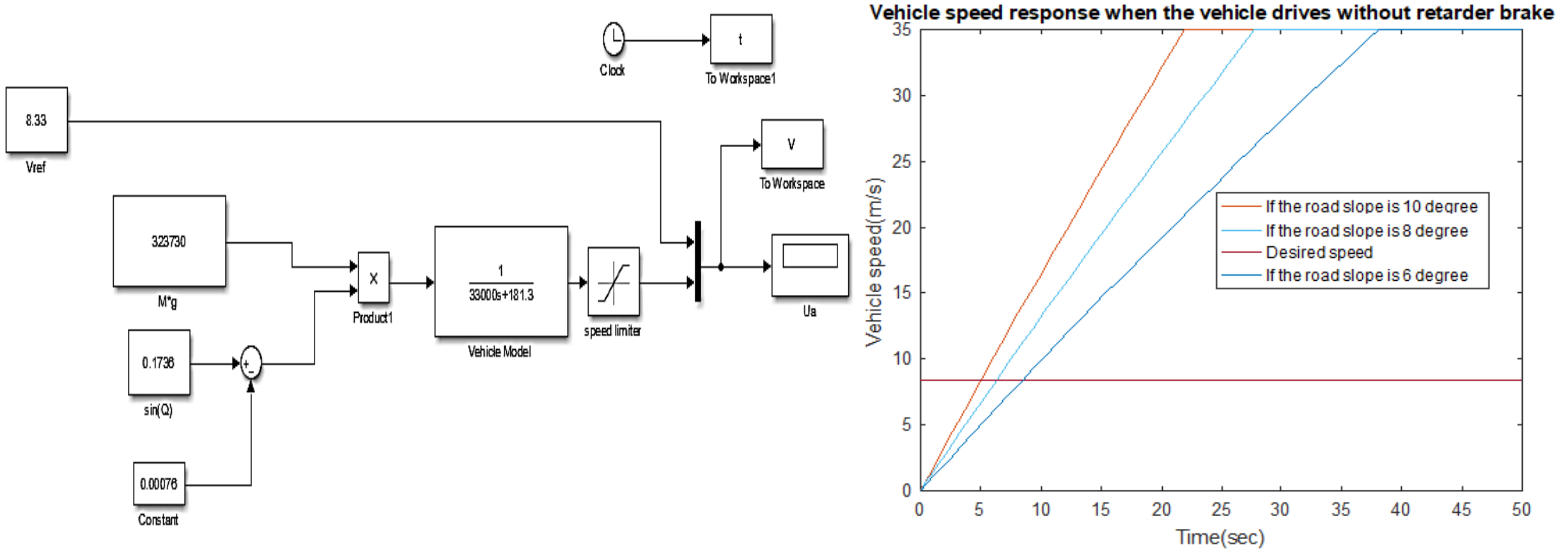




| | | \dot{e} | | | | | | |
|------------------------|--|-----------|-----|---|-----|-----|---|-------|
| $e \backslash \dot{e}$ | | LNe | SNe | Z | SPe | LPe | | |
| LNe | | VL | VL | M | L | H | S | Slope |
| SNe | | VL | VL | M | M | H | | |
| Z | | VL | VL | M | M | H | | |
| SPe | | VL | VL | M | H | VH | | |
| LPe | | VL | VL | M | H | VH | | |
| $e \backslash \dot{e}$ | | LNe | SNe | Z | SPe | LPe | B | |
| LNe | | VL | VL | L | L | H | | |
| SNe | | VL | L | L | M | H | | |
| Z | | L | L | M | H | H | | |
| SPe | | L | M | H | H | VH | | |
| LPe | | L | H | H | H | VH | | |

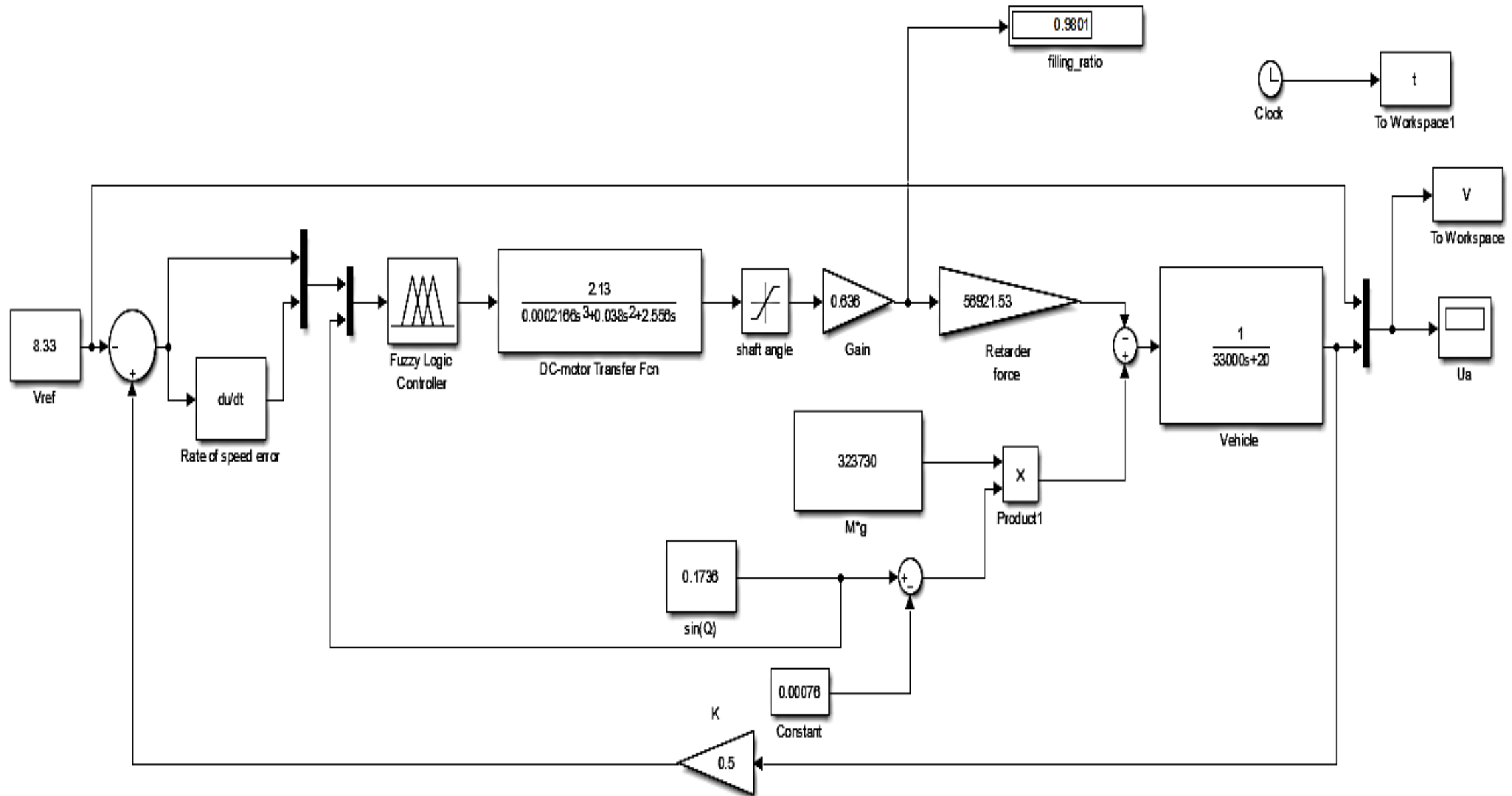
- It indicates for road slope $< 5^\circ$ the controller output voltage is no change(zero)
- If the $e < 0$, $\dot{e} < 0$ and slope is S then voltage is decreased(low)
- If $e > 0$, $\dot{e} > 0$ and slope is B then voltage is increased(high)

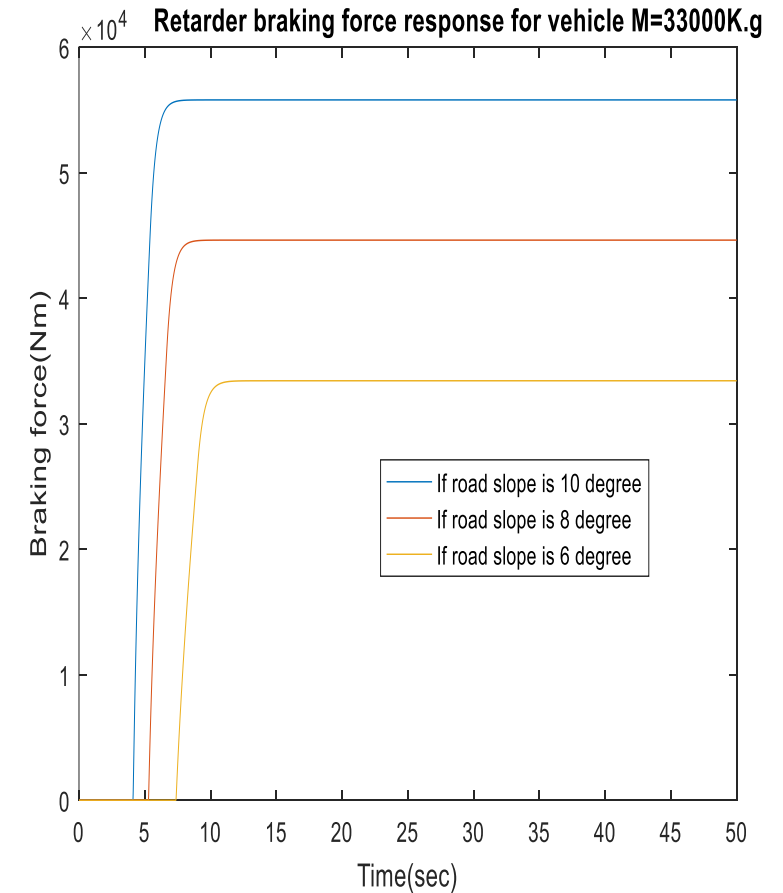
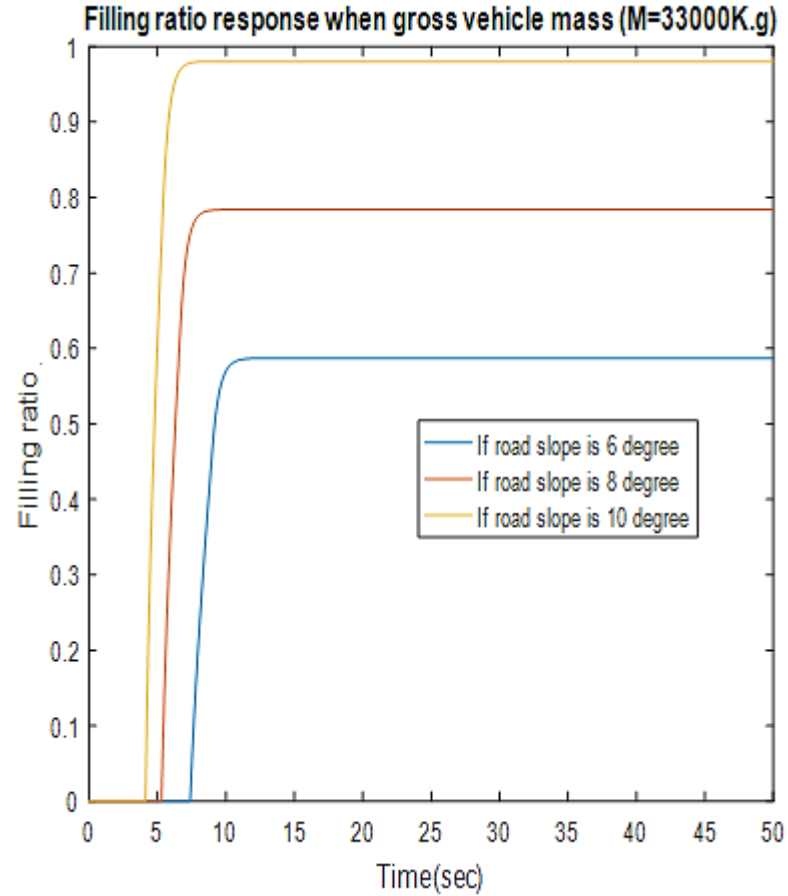
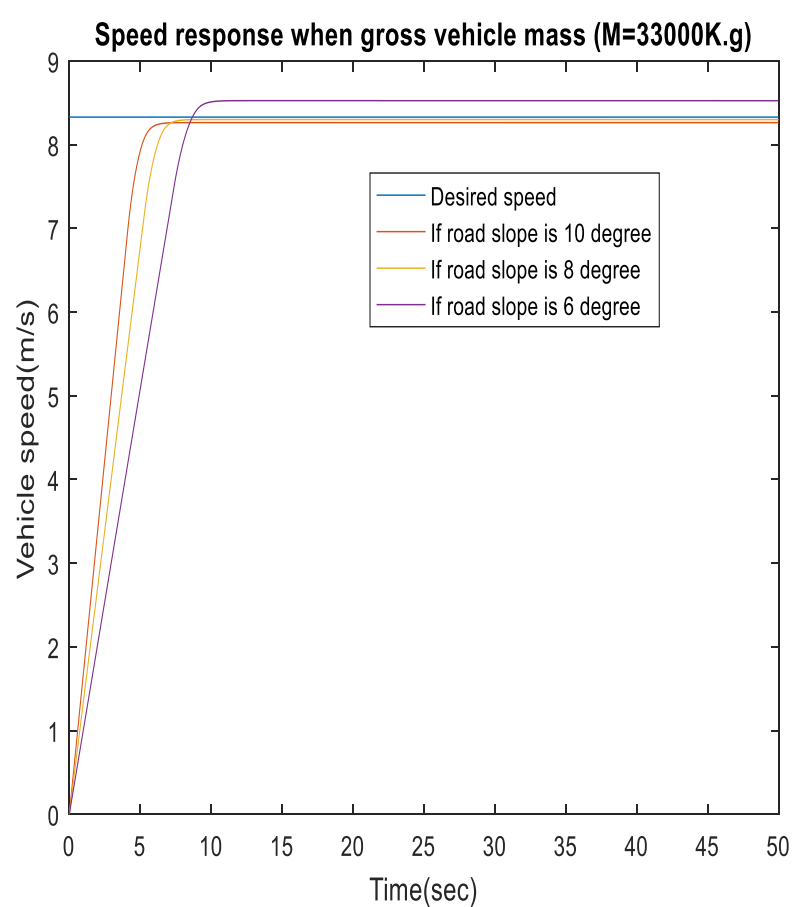
Result and Discussion



Describes the open loop vehicle speed response is linearly increase when driving at 10° downslope without the retarder braking system.

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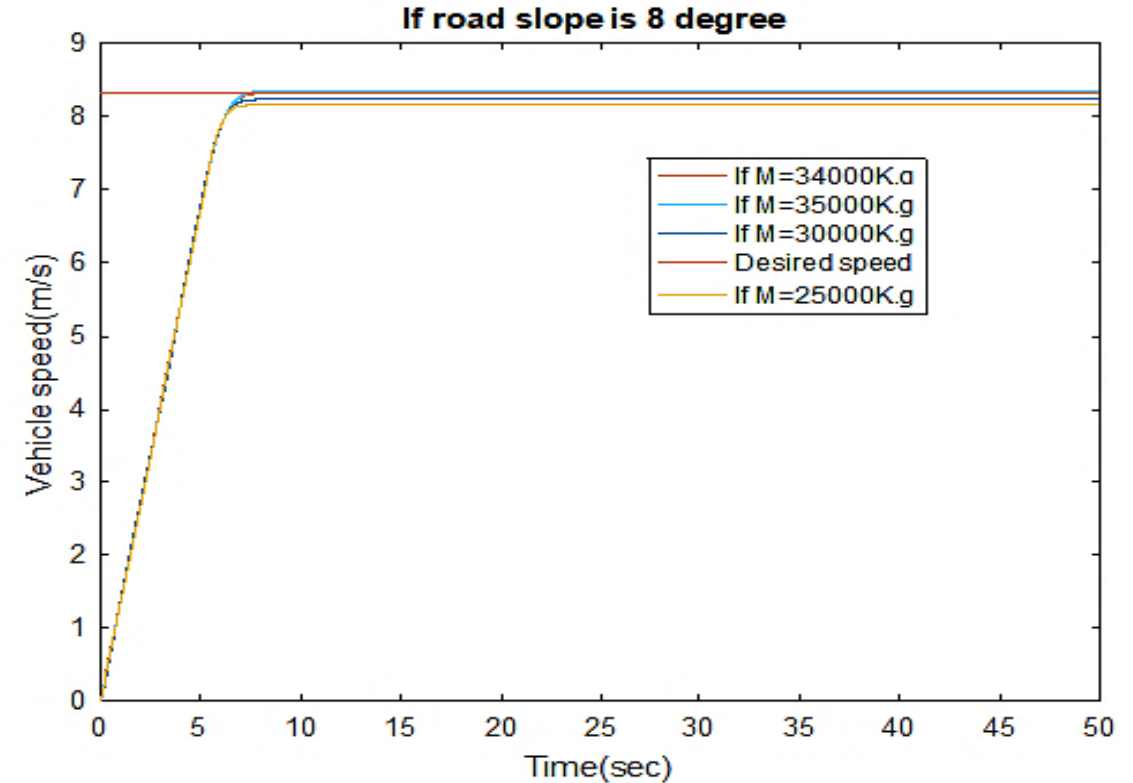
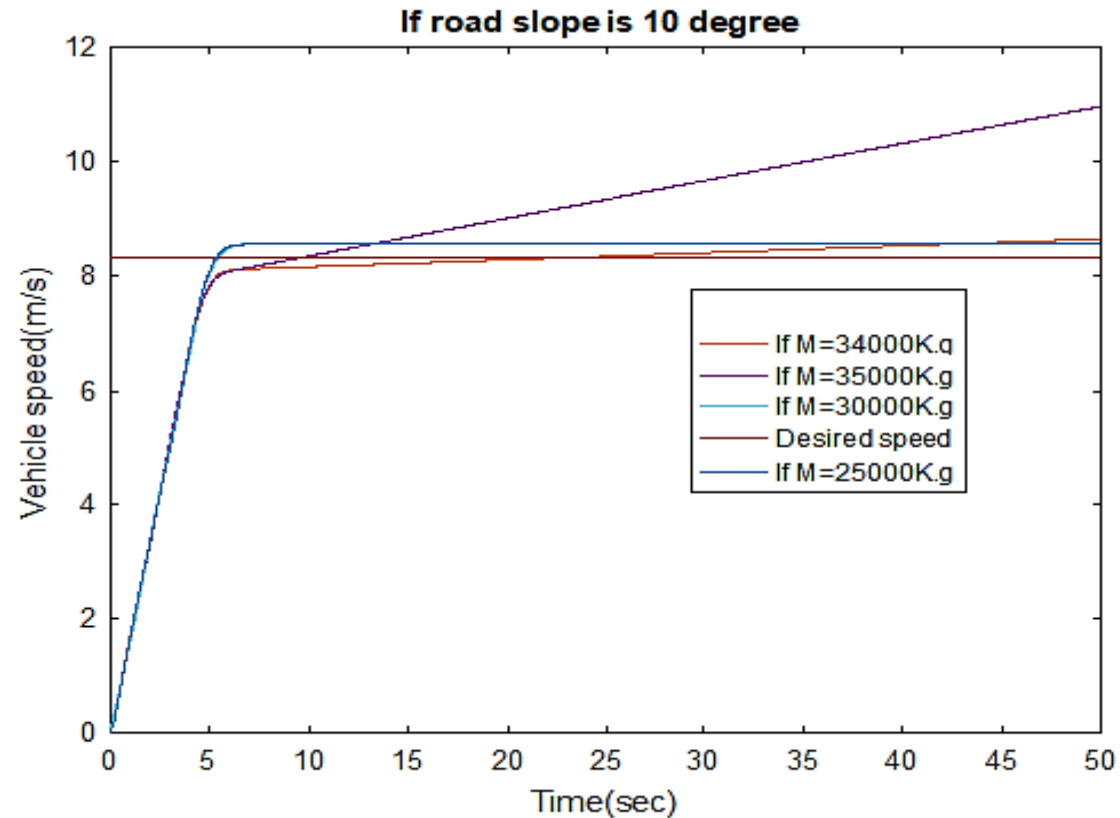




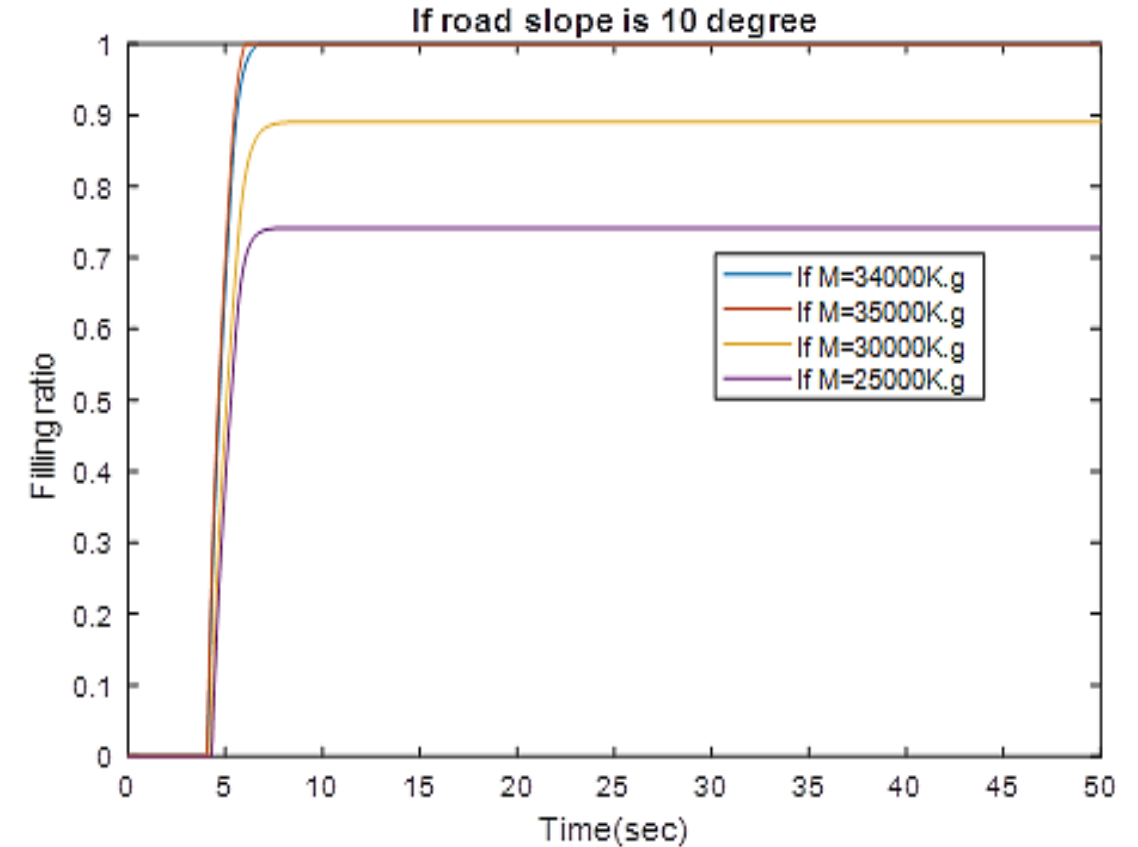
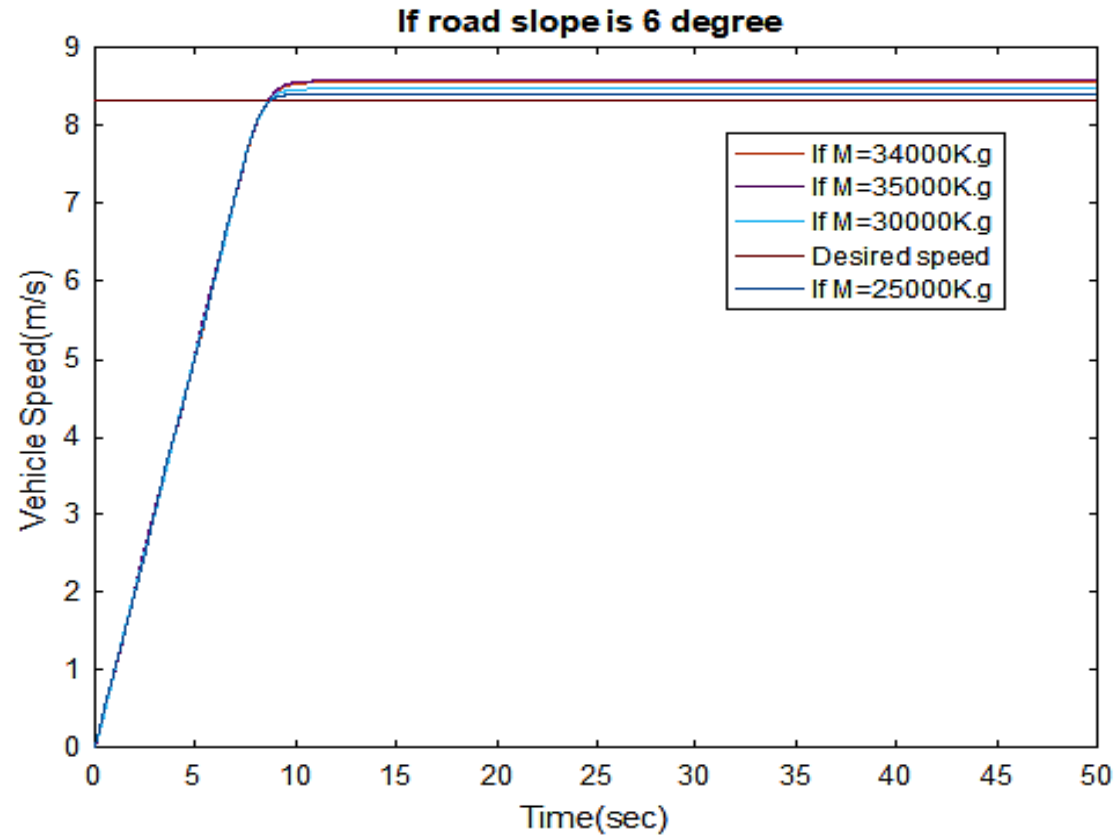
- The result indicates the vehicle speed is constant for all road condition
- Filling ratio and braking forces are decrease as the road slope is decrease.

cont....

Effect of variable gross vehicle mass on speed and filling ratio response

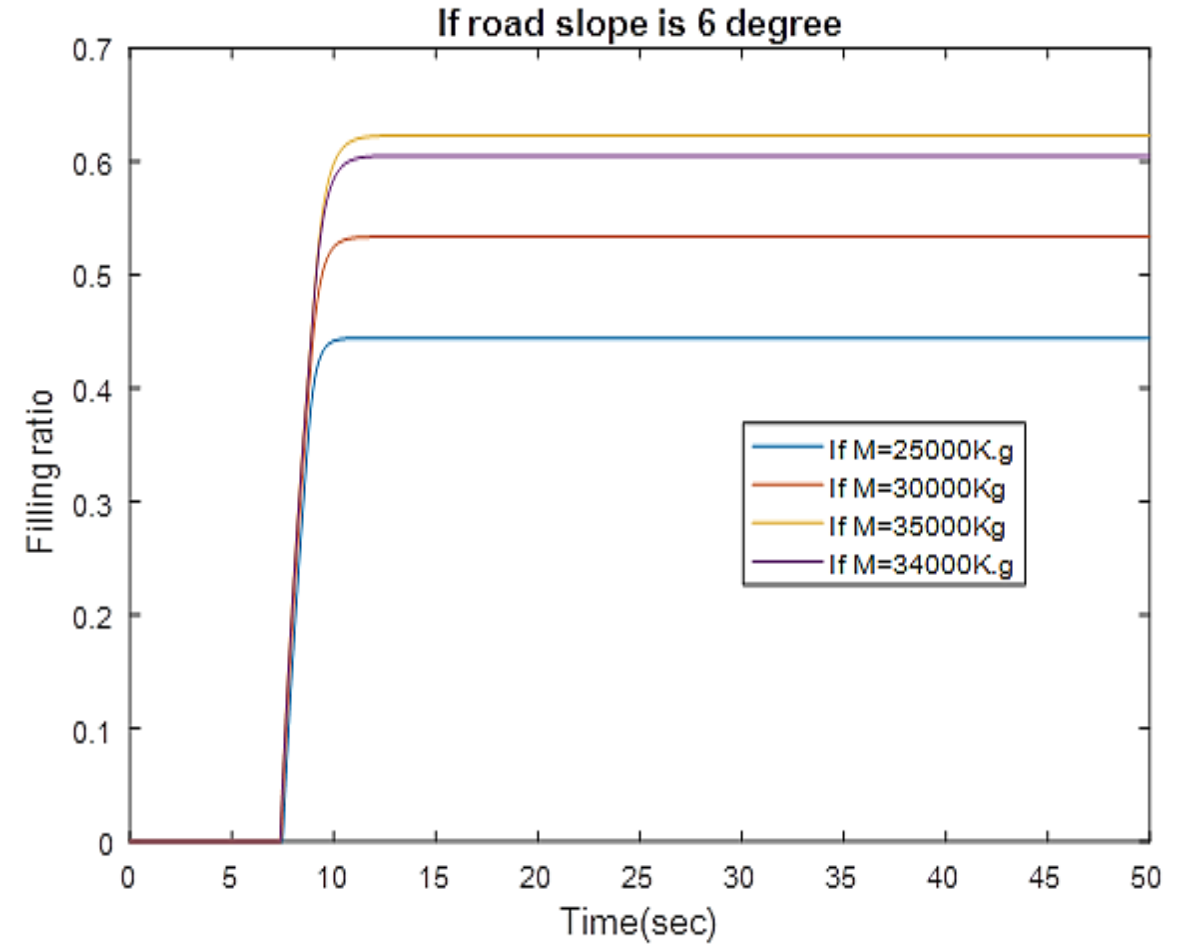
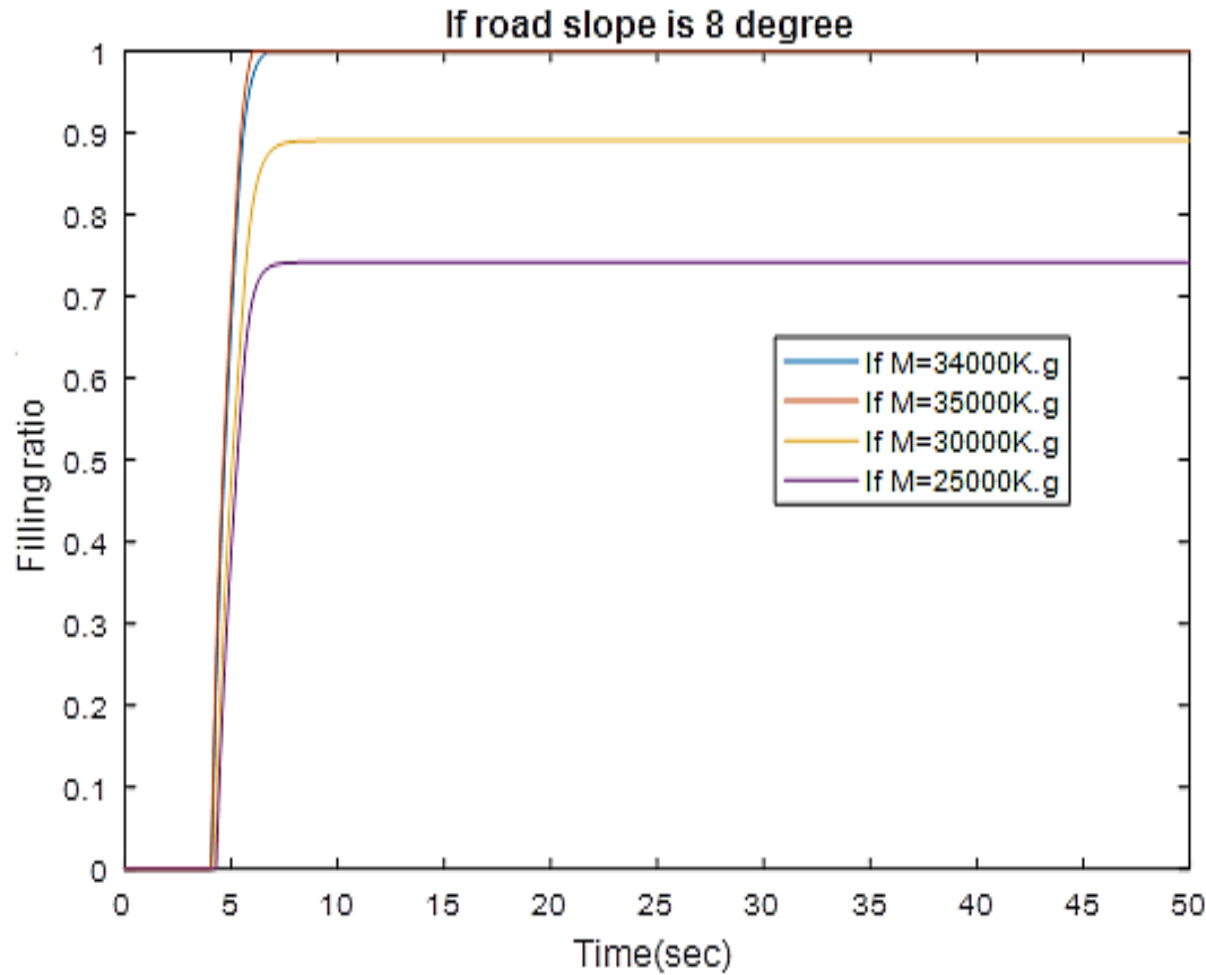


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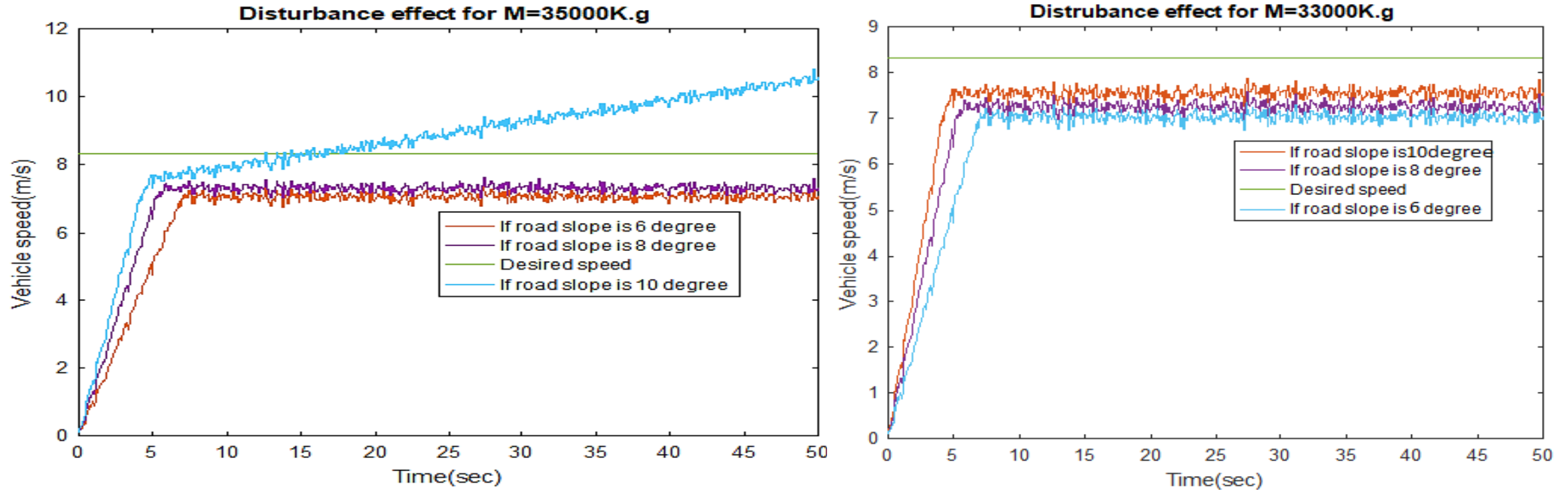
The result represents the retarder failed for vehicle $M > 33000 \text{ K.g}$ for 10° road slope but constant when the vehicle $M \leq 33000 \text{ K.g}$ for all road condition.

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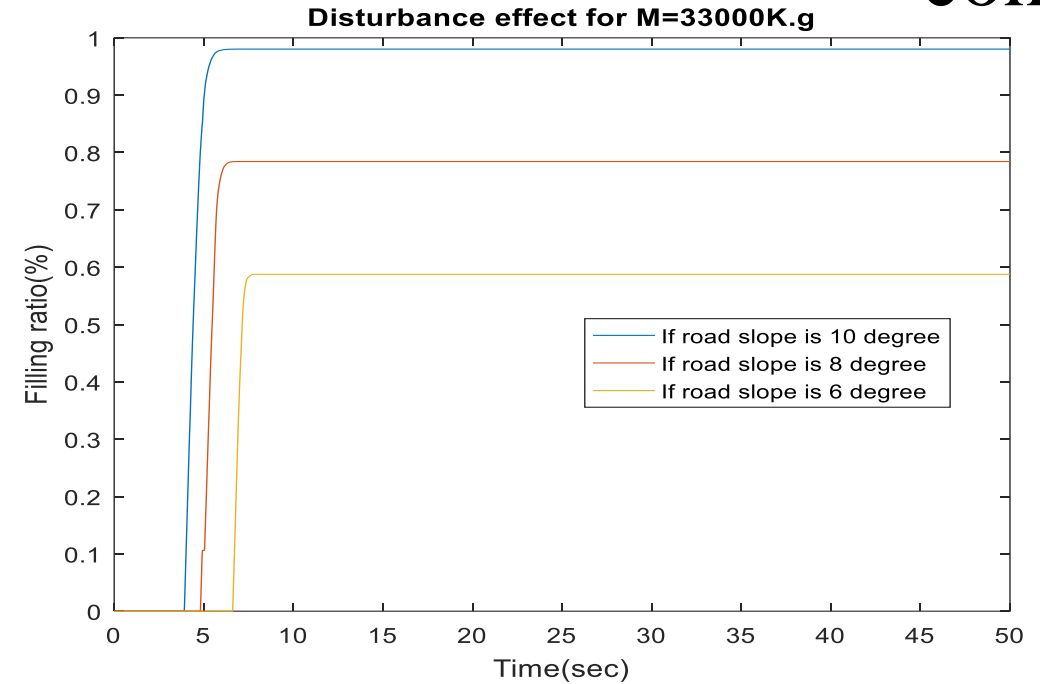
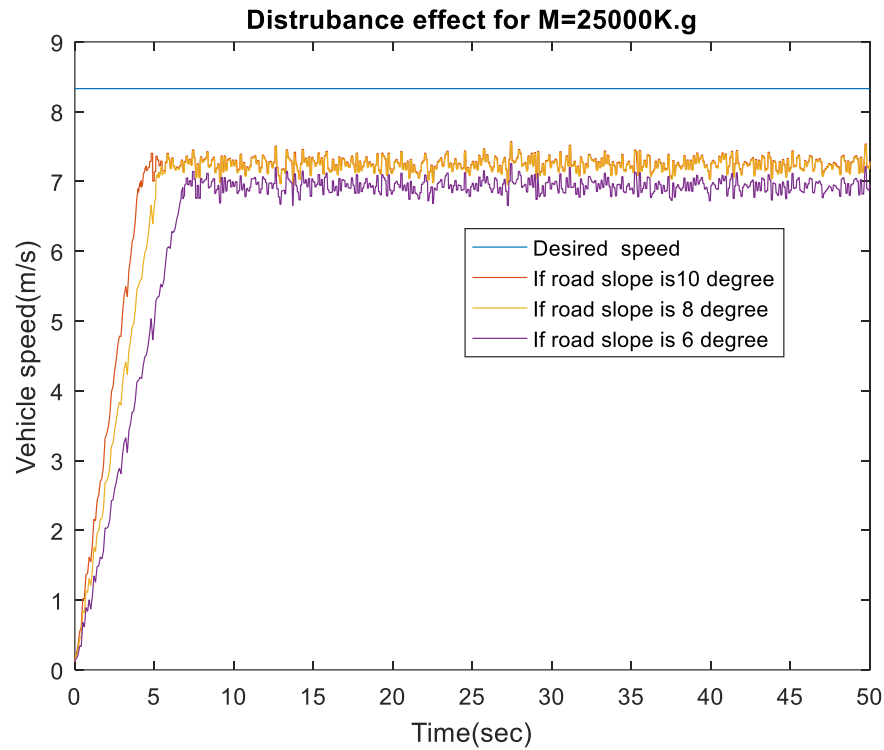


The filling ratio value of a chamber is increase if the vehicle mass or road slope increase or the reverse is true for the vehicle mass $M \leq 330000\text{K.g}$.

The Effect of disturbance on system response

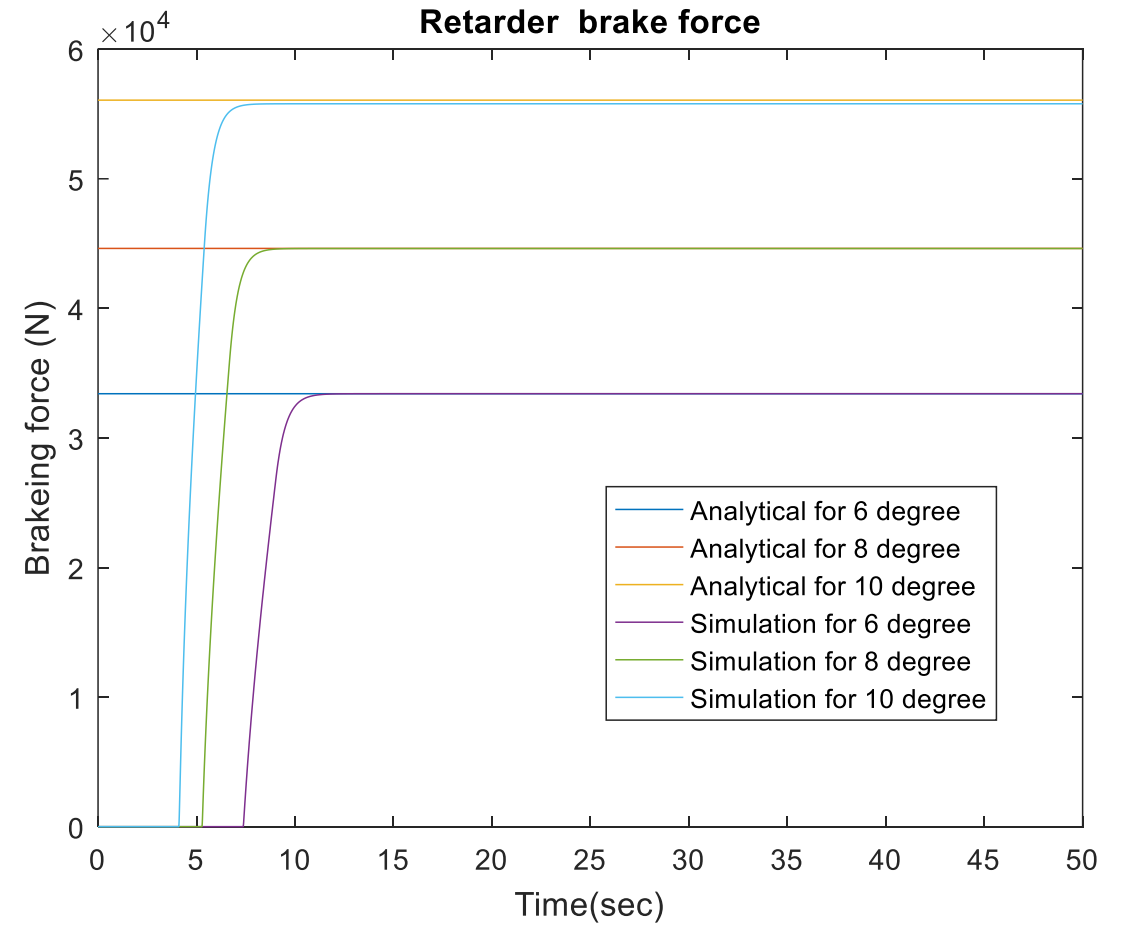
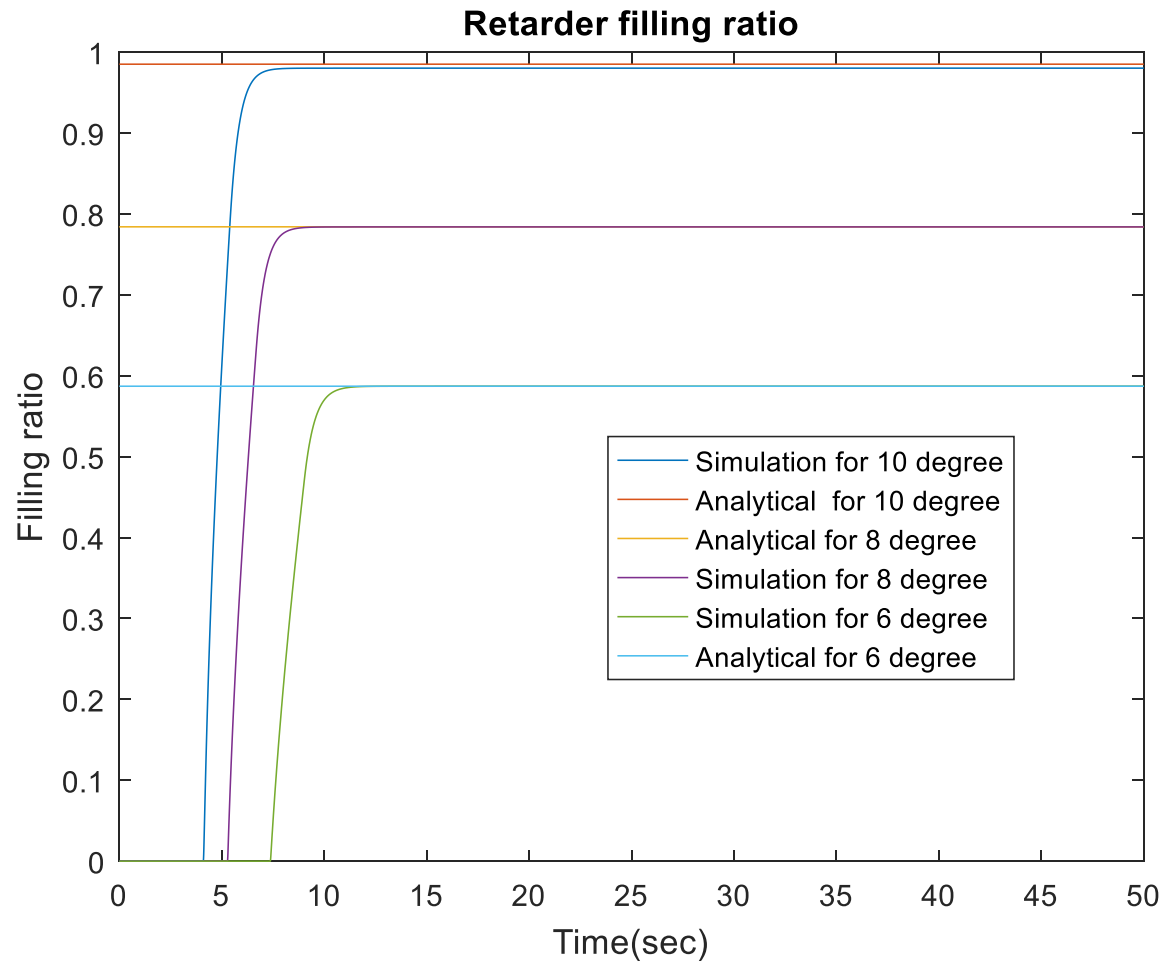


The result indicates, the retarder brake failed to slowdown the vehicle if its mass $M > 33000\text{K.g}$ for 10° road slope and over damped speed response for all vehicle mass $M < 33000\text{K.g}$.

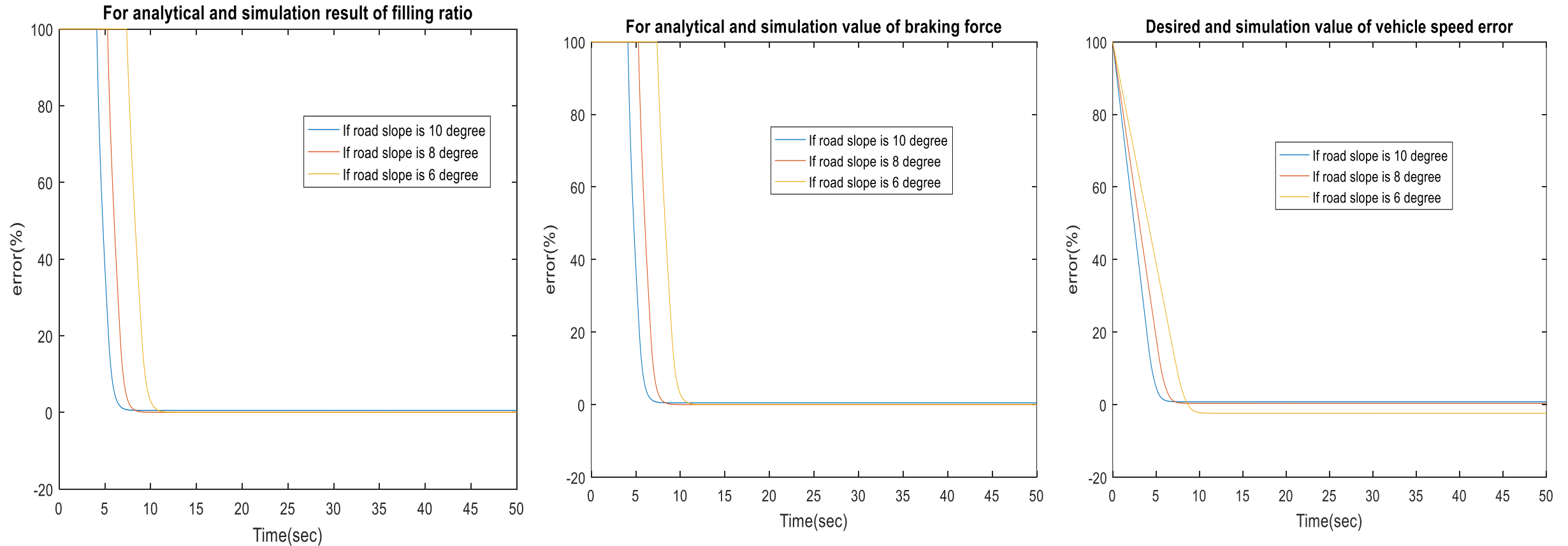


- It indicates the filling ratio of the retarder under disturbance has small incremental value 0.0002, 0.0004 and 0.0006 for road slope 10^0 , 8^0 and 6^0 respectively.
- Due to the vibration effect the valve couldn't fully closed and filling ratio also increase and the speed is decrease.

Comparison the result



cont...



The result shows very small steady state error between analytical and simulation for a vehicle mass $M=33000\text{K.g}$

Conclusion

- The fuzzy controller scored a successful result and meets the constant speed strategy for all road condition if $M \leq 33000 \text{K. g}$.
- When compare fuzzy simulation result with the desired vehicle speed (8.33m/s), it has a steady state error less than 1%.
- The actuator has a delay time greater than 4sec is caused when the vehicle starts from rest condition and $e < 0$, as a result the controller didn't take action over the actuator until $V_{actual} > 8.33 \text{ m/s}$.
- The speed response of the vehicle under disturbance has over damped response which is resulted from vibration effect on valve late to close, and extra oil leakage happened into the chamber.

Recommendation

- As a future work, researchers are advised to validate the simulation results achieved in this research experimentally.
- The same approach can be extended for different car model and road condition.
- Different controllers which can give better results can be designed and simulated to improve the performance.

Thank You!