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.

Contents

Final Thesis Defense of PG Program in Mechatronics Engineering

Design and Simulate an Automatic Hydraulic Retarder using Fuzzy Logic Controller
for
Vehicle Speed Control

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August 2020

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	➢ Uses retarder actuator ➢ Speed reduction and constant speed fuzzy controller ➢ Speed sensor	➢ 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

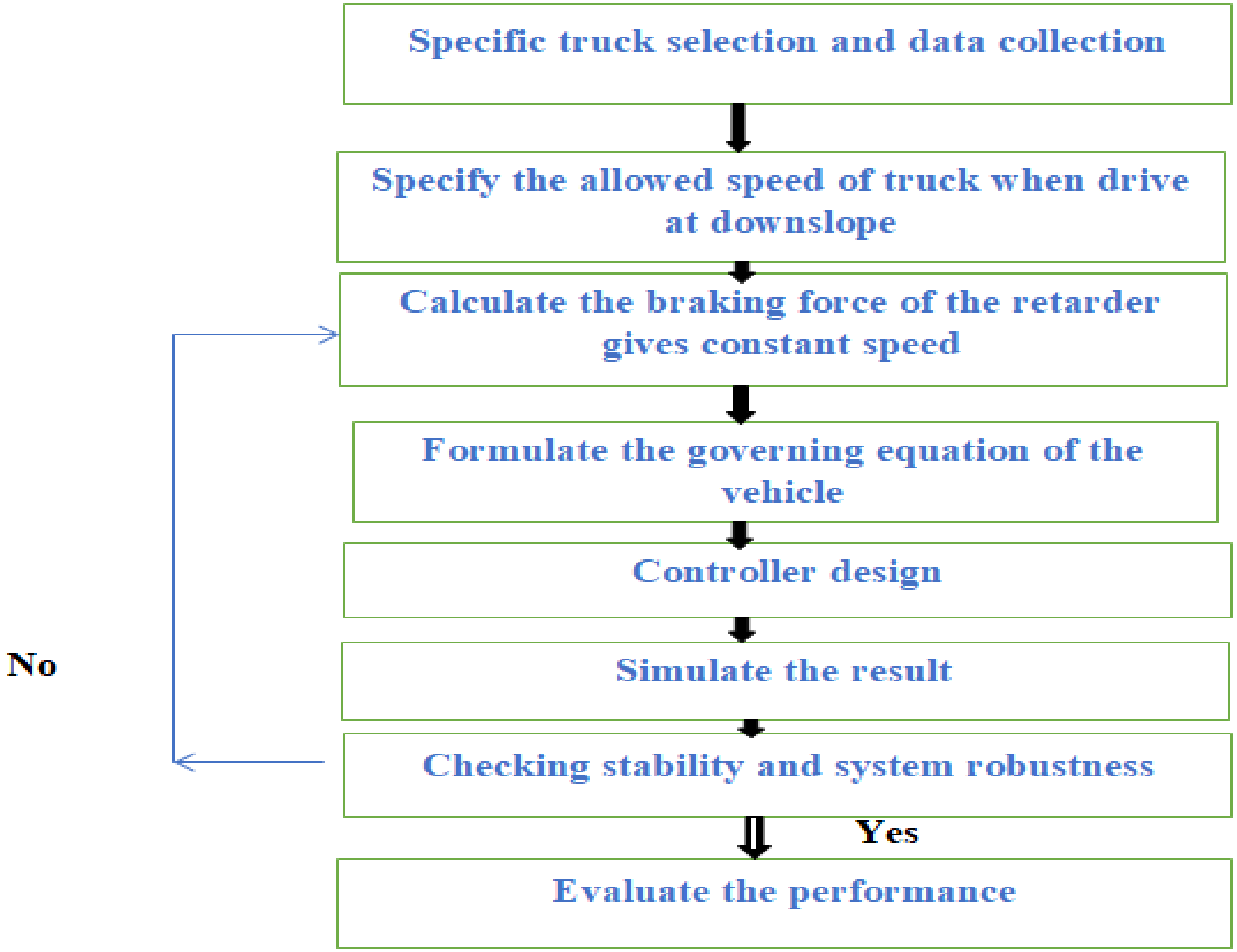
General objective

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

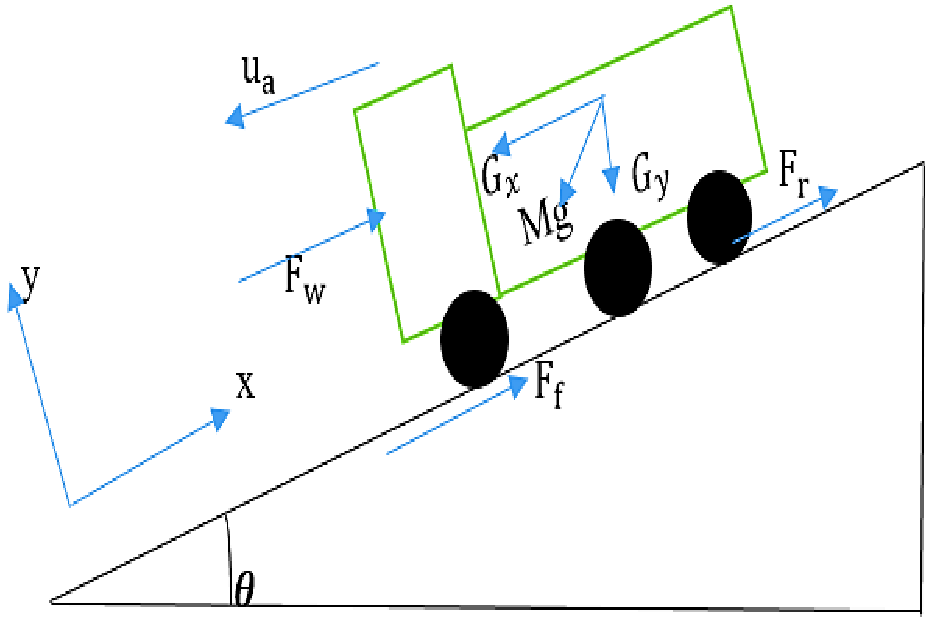
- To drive the mathematical model of the vehicle
- To design and simulate fuzzy logic controller
- To compare the analytical result with the simulation results
- To evaluate the system performance regarding to variable vehicle mass, road slope and disturbance effect on system response

Methodology



Mathematical Modeling

❖ **Vehicle model**



Vehicle modeling from vehicle dynamic forces

$$M\frac{du_a}{dt} = \mathrm{Mgsin}\,\theta - F_f - F_r - F_w$$

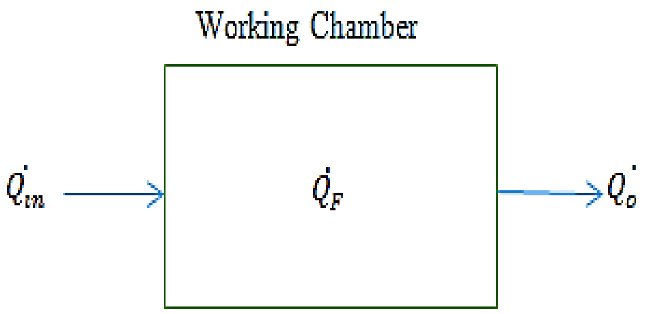
My basic assumption was $\frac{du_a}{dt} = 0$

$$F_r = 56921.53\alpha(t), \text{ for } \Theta = 10°$$

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

Is the governing equation of the vehicle dynamics

❖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

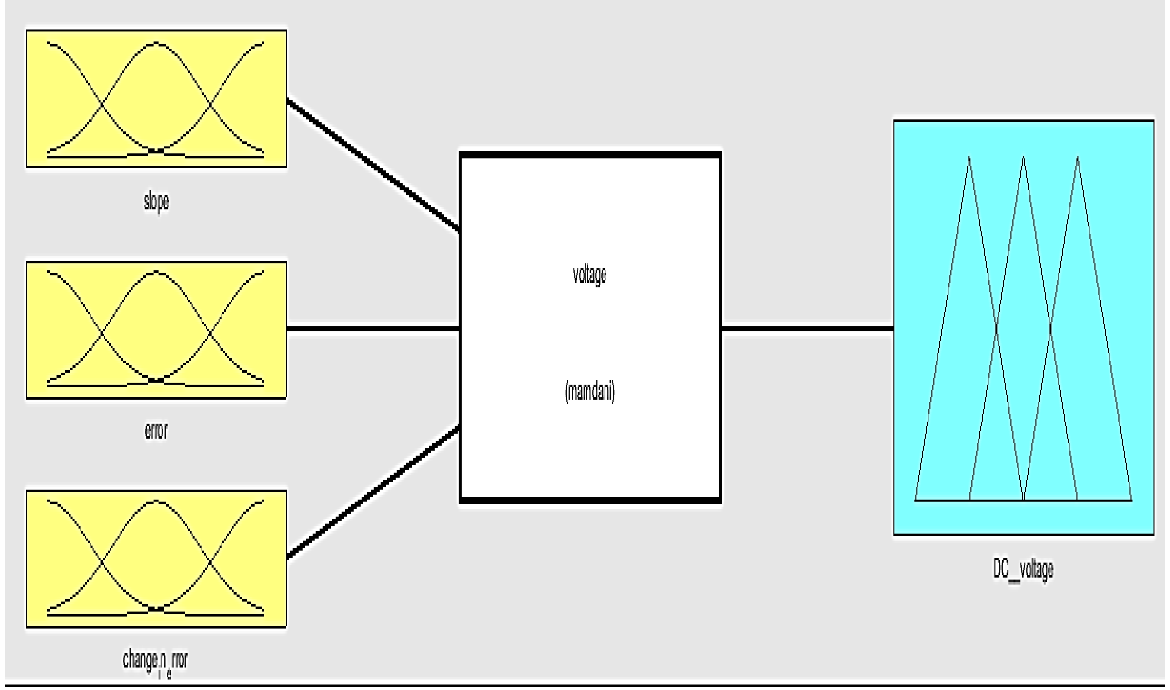
$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} + v_b(t) = v_a(t)$$

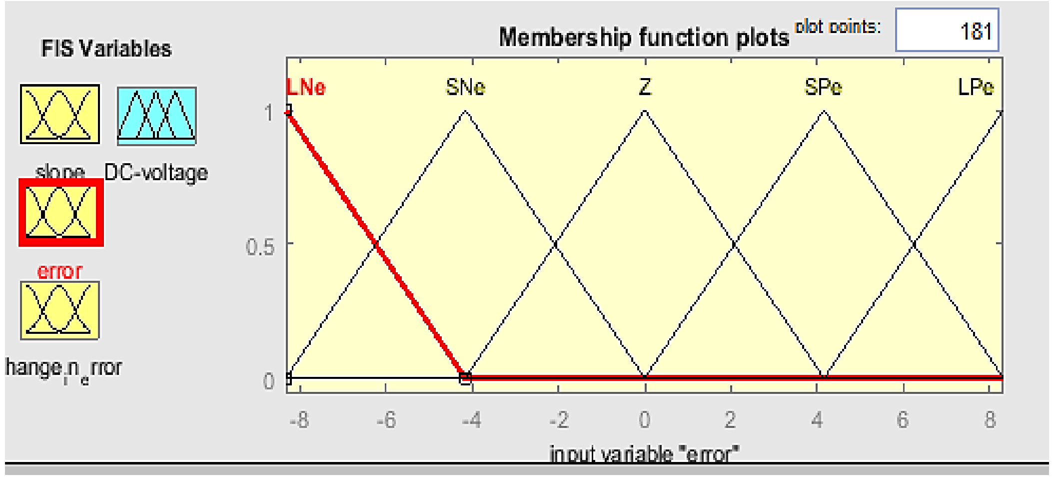
$$J\frac{d}{dt}\left(\frac{d\Theta(t)}{dt}\right) + B\frac{d\Theta(t))}{dt} = T_M(t) - T_L$$

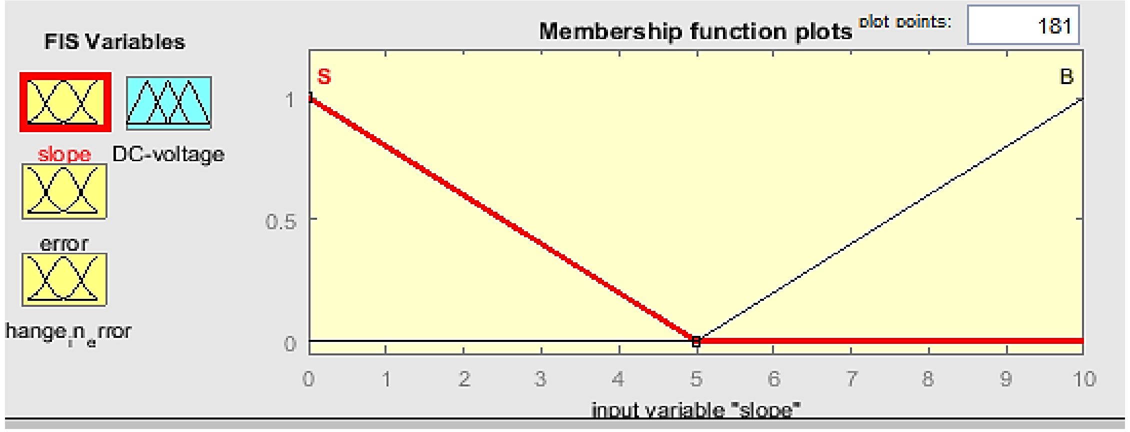
$$J\frac{d}{dt}\left(\frac{d\Theta(t)}{dt}\right) = T_M(t), \text{ But, B and } T_L \approx 0$$

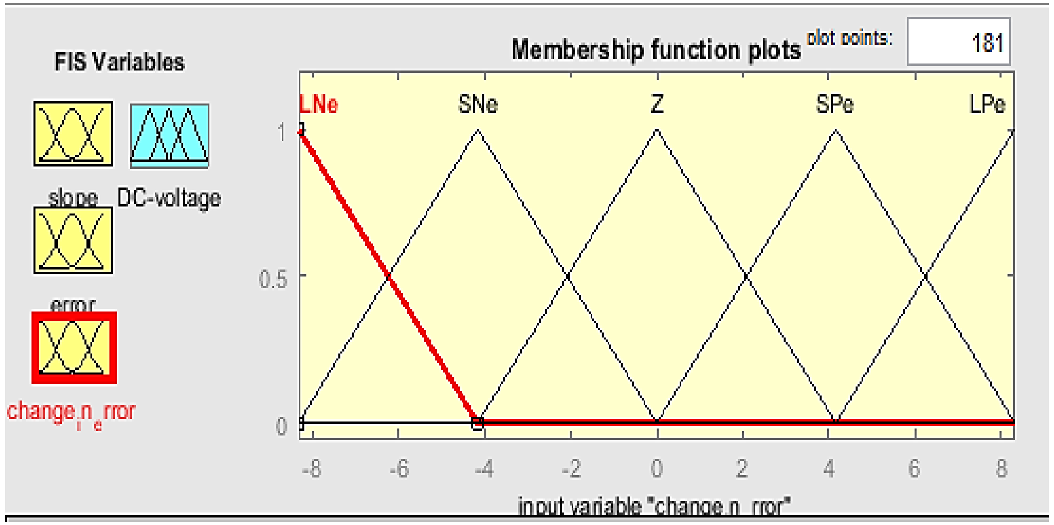
$$\frac{\Theta(S)}{V_a(S)} = \frac{2.13}{0.0002166S^3 + 0.038S^2 + 2.556S}$$

Controller Design









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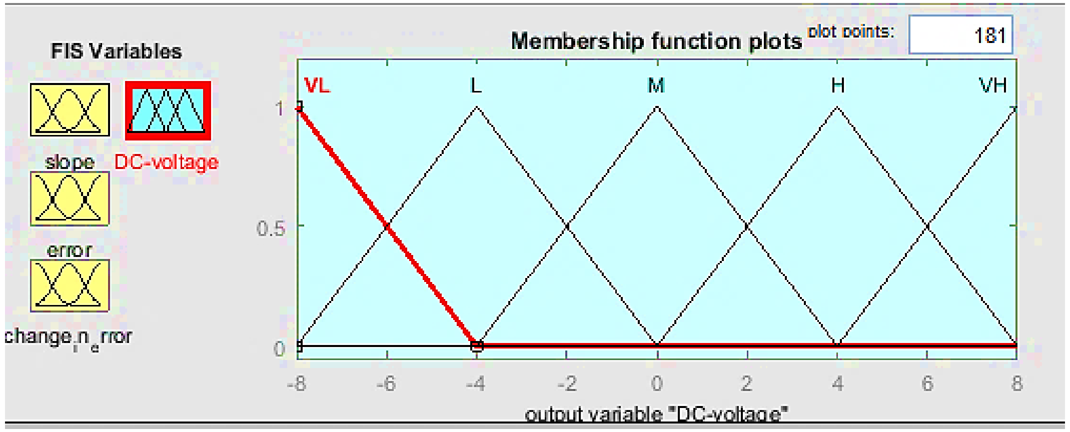
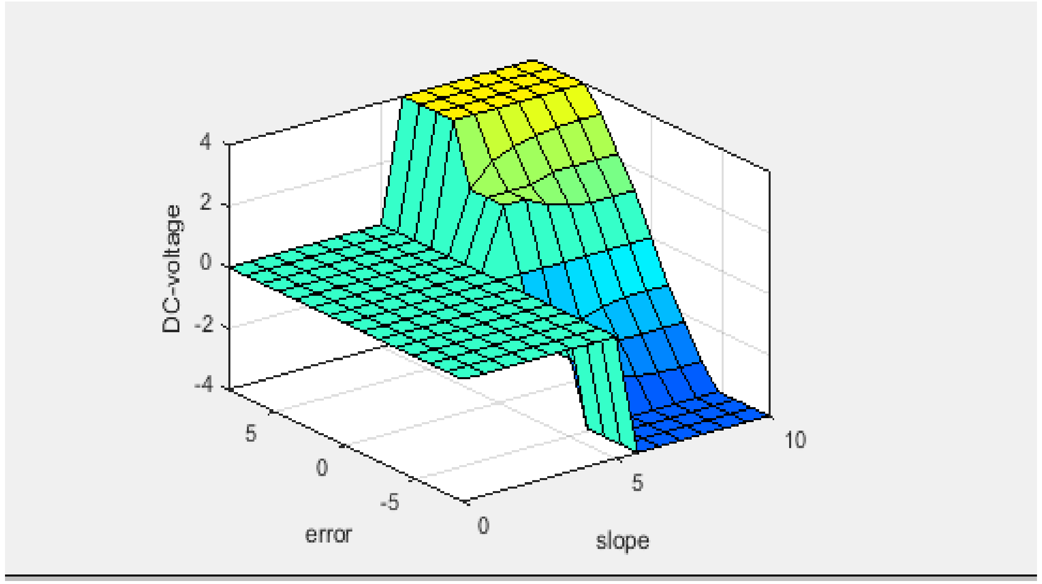
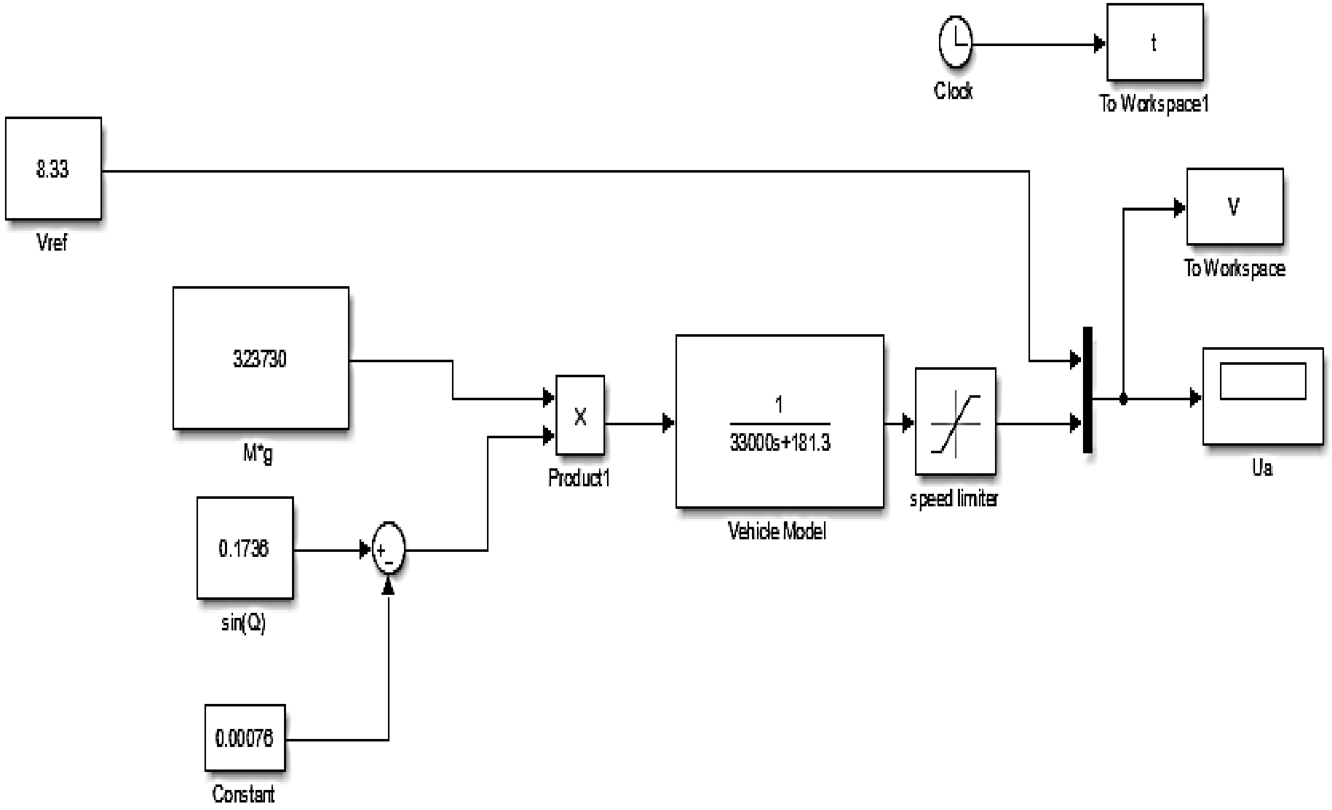


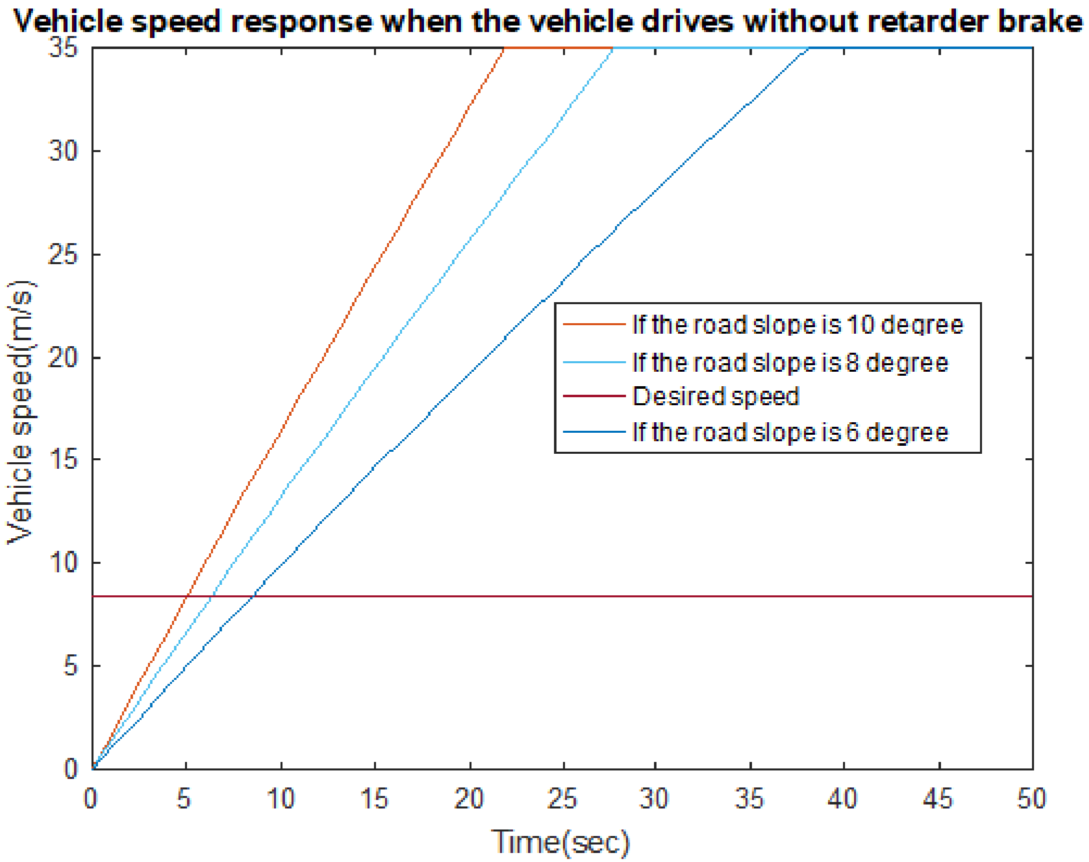


e \ $\dot{e}$	LNe	SNe	Z	SPe	LPe		Slope
LNe	VL	VL	M	L	H	S	
SNe	VL	VL	M	M	H	S	
Z	VL	VL	M	M	H	S	
SPe	VL	VL	M	H	VH	S	
LPe	VL	VL	M	H	VH	S	
e \ $\dot{e}$	LNe	SNe	Z	SPe	LPe		
LNe	VL	VL	L	L	H	B	
SNe	VL	L	L	M	H	B	
Z	L	L	M	H	H	B	
SPe	L	M	H	H	VH	B	
LPe	L	H	H	H	VH	B	

- It indicates for road slope < 5° 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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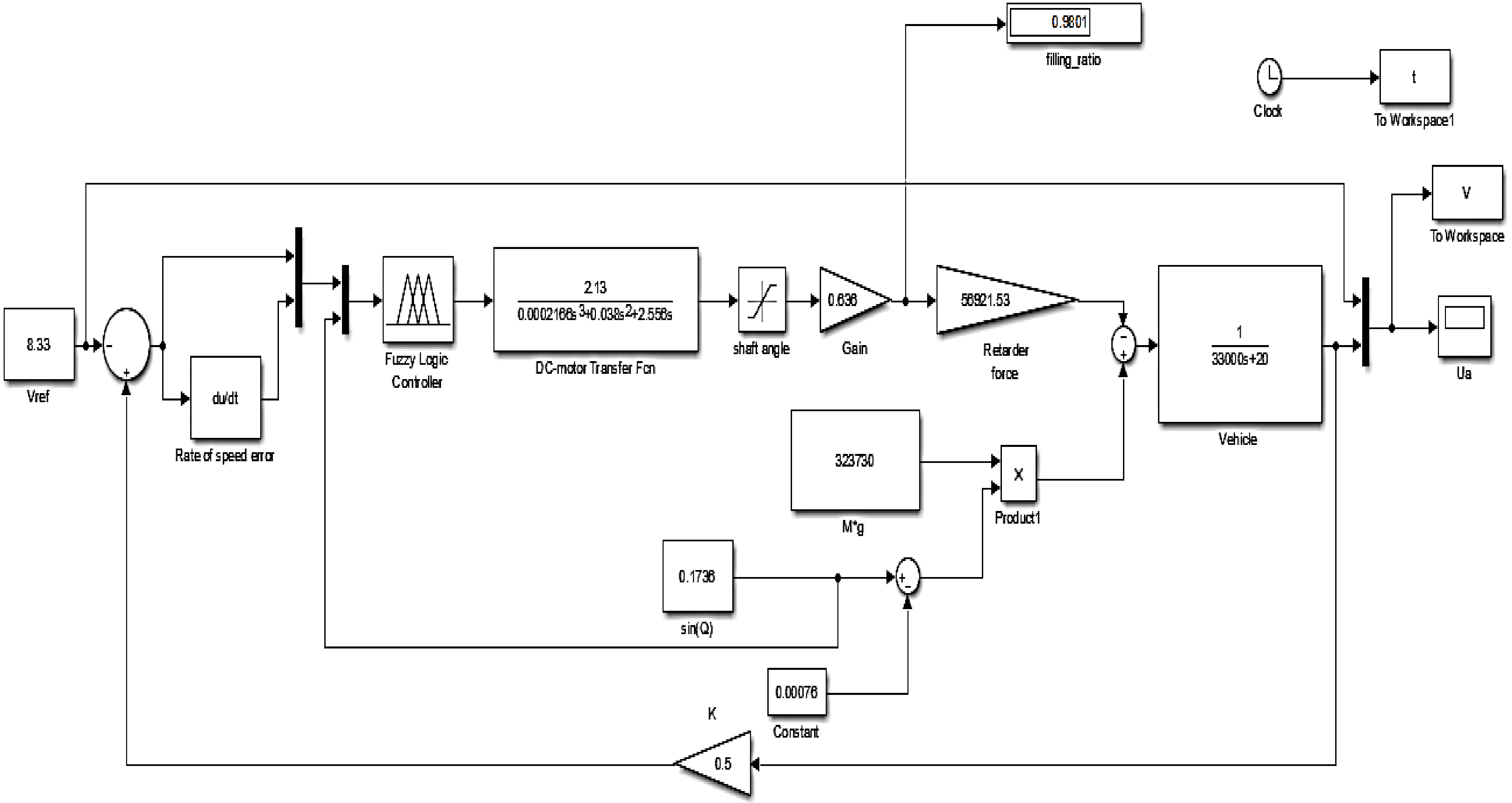
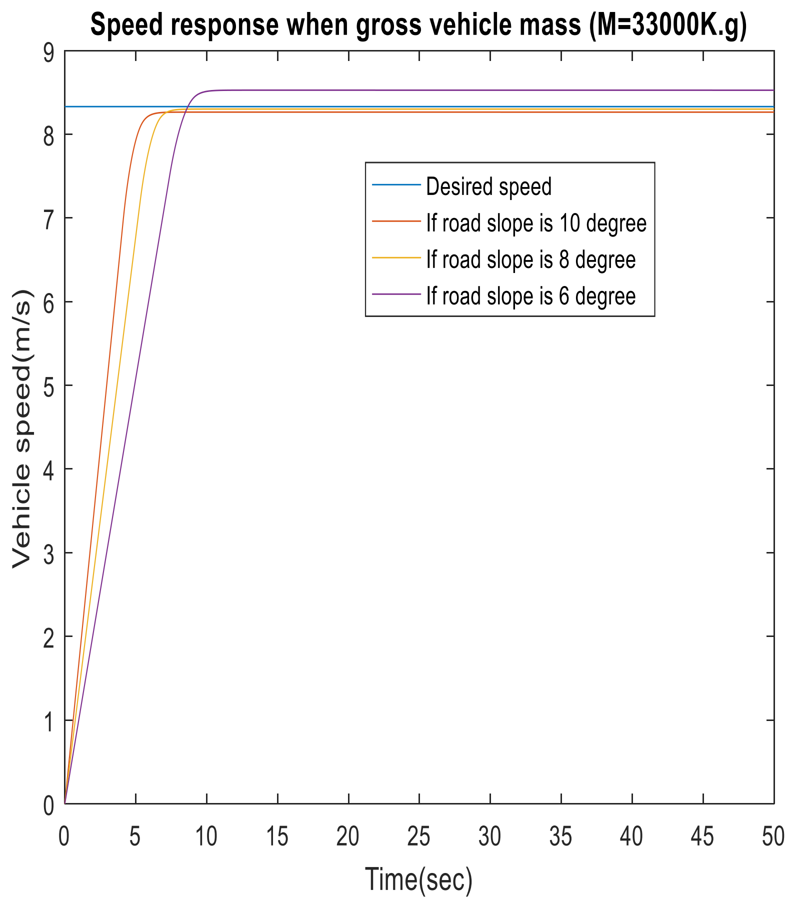
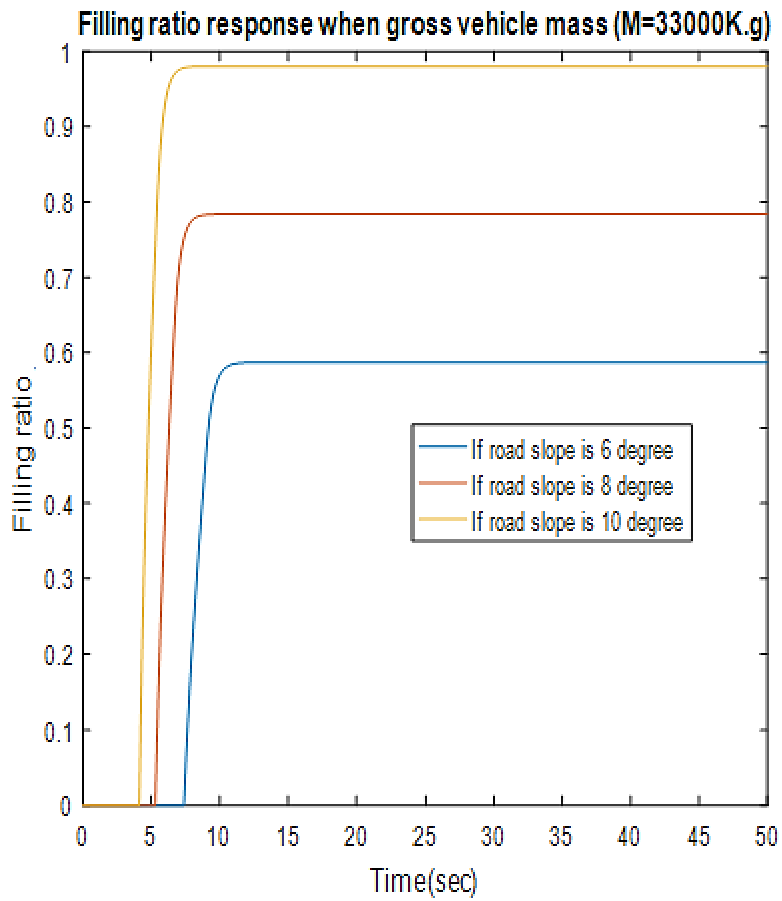
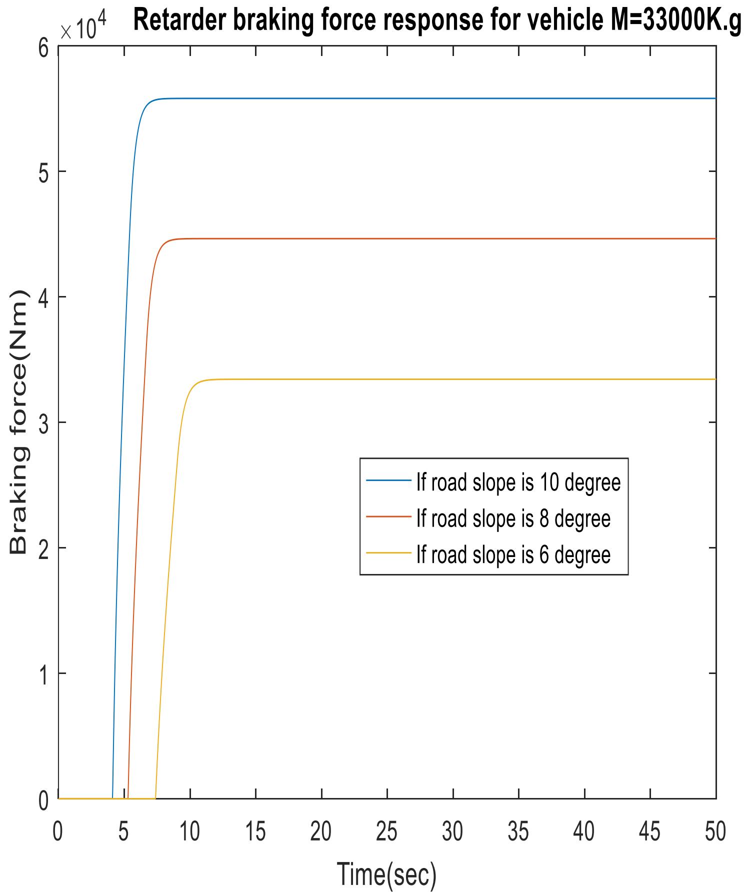


0.9801
filling_ratio
Clock
t
To Workspace1
V
To Workspace
8.33
Vref
du/dt
Rate of speed error
Fuzzy Logic
Controller
2.13
0.0002168s3+0.038s2+2.558s
DC-motor Transfer Fcn
shaft angle
0.636
Gain
56921.53
Retarder
force
1
33000s+20
Vehicle
Ua
323730
M*g
X
Product1
0.1736
sin(Q)
0.00076
Constant
K
0.5

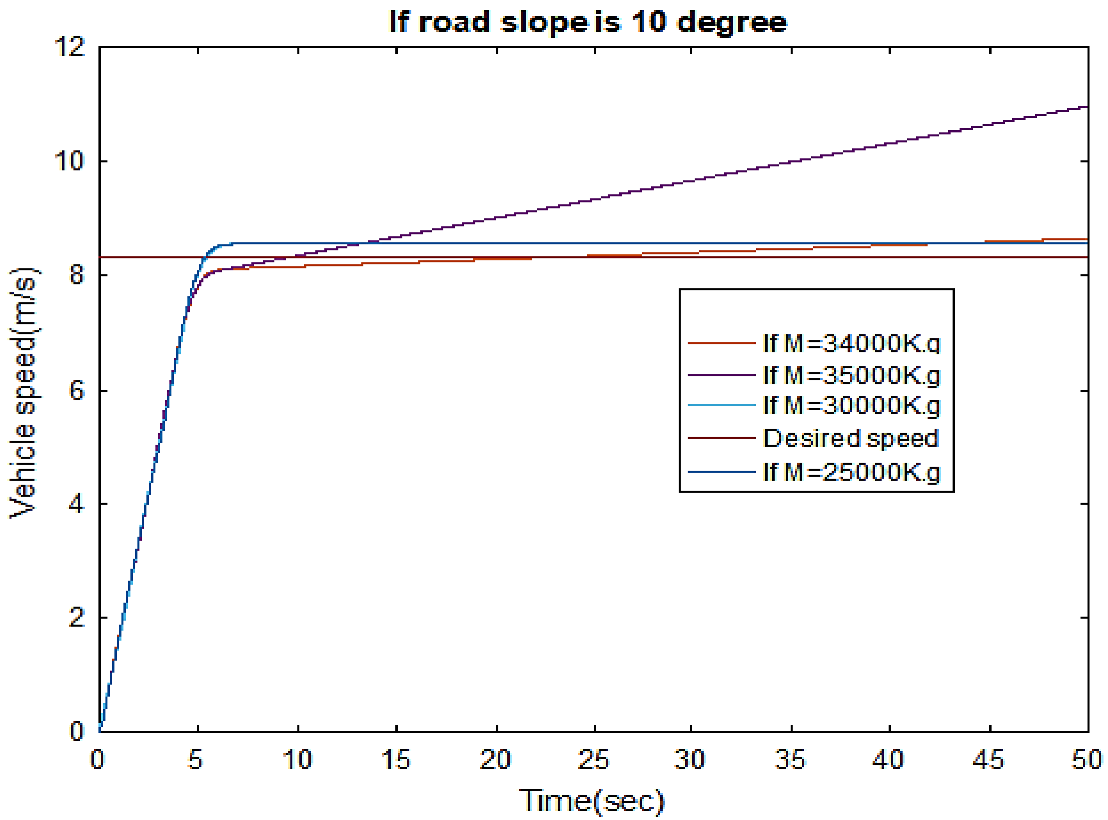


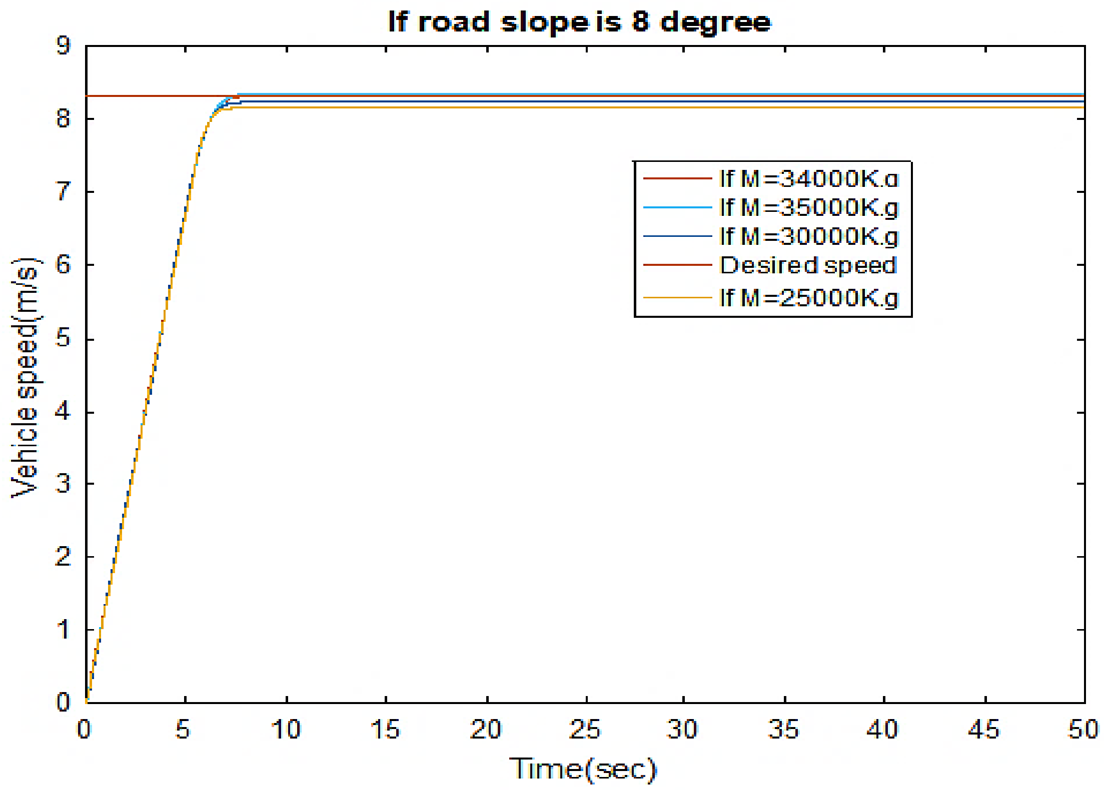




- ➢The result indicates the vehicle speed is constant for all road condition
- ➢Filling ratio and braking forces are decease as the road slope is decease.

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





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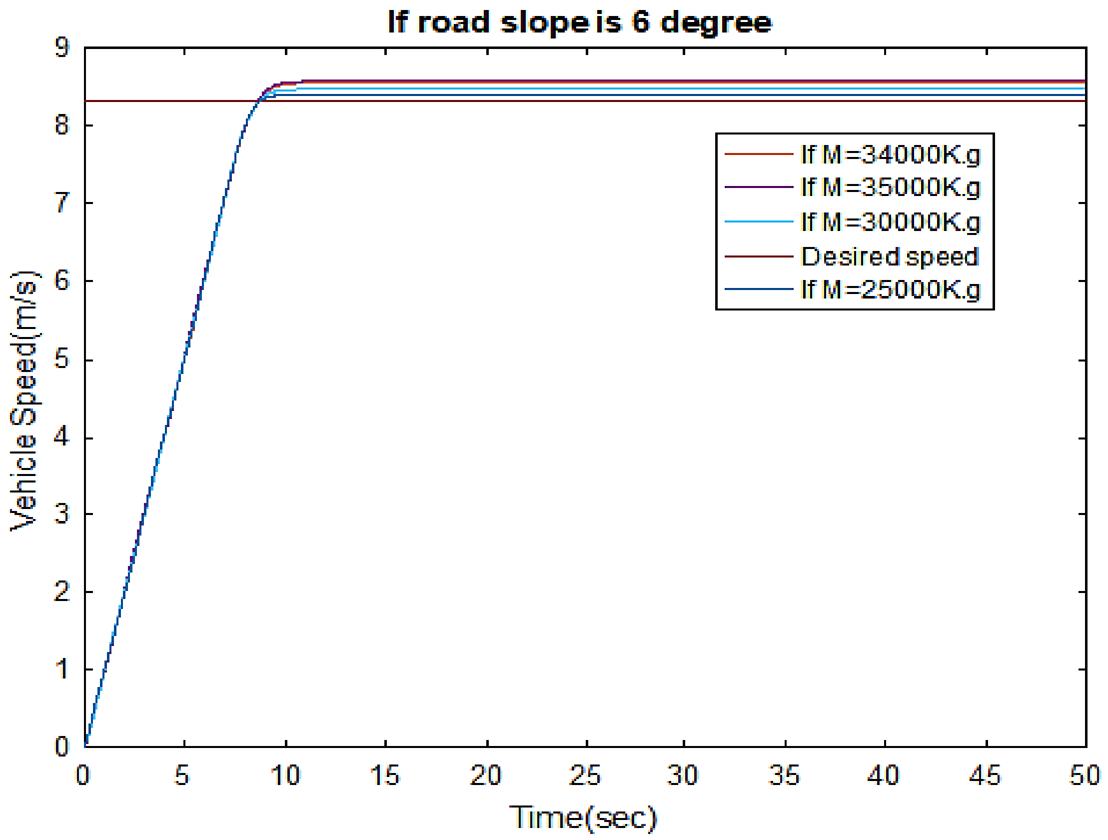

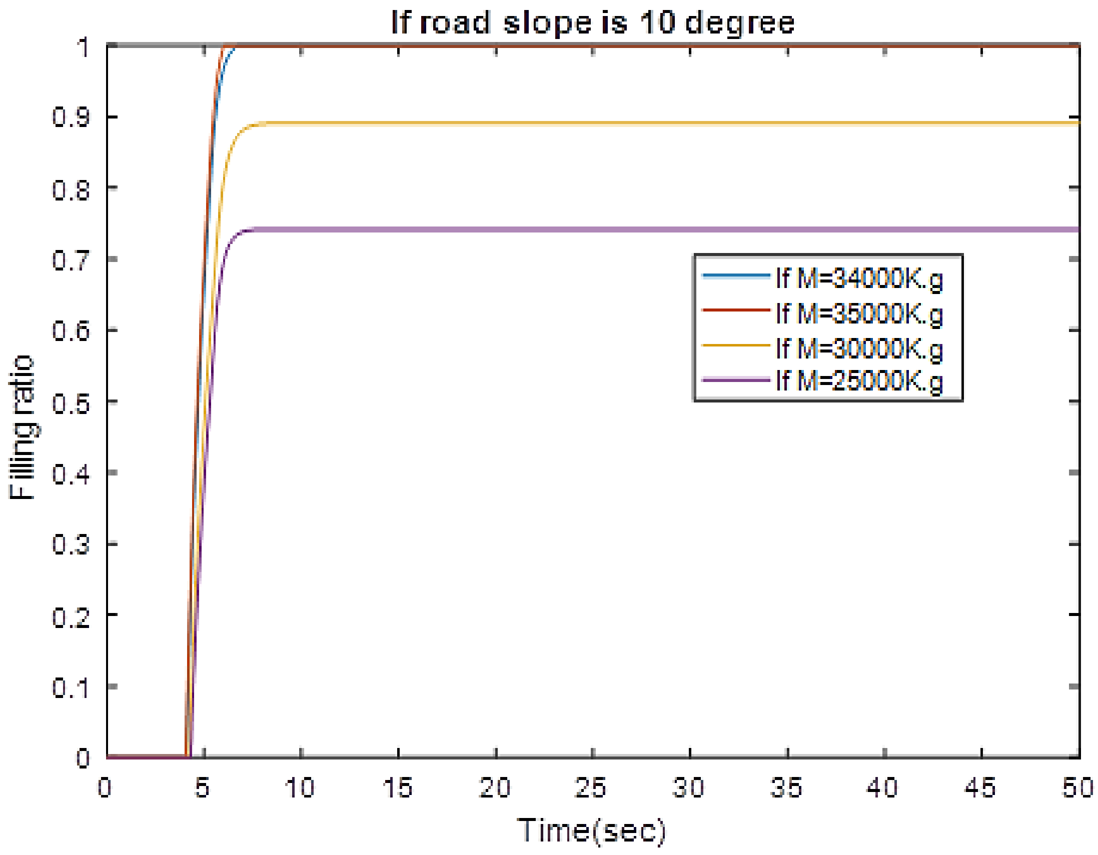

The result represents the retarder failed for vehicle M>33000K.g for 10° road slope but constant when the vehicle M≤33000K.g for all road condition.

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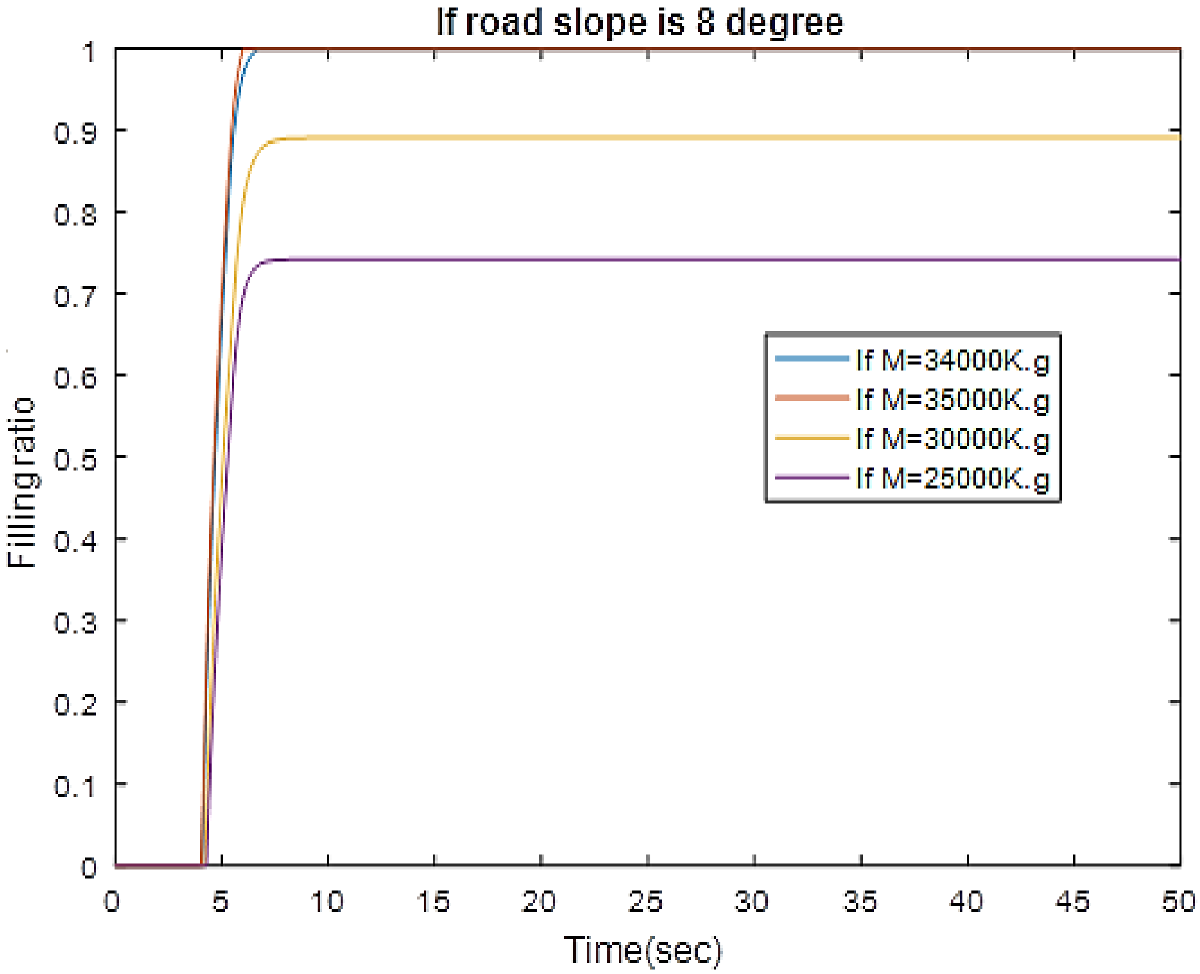
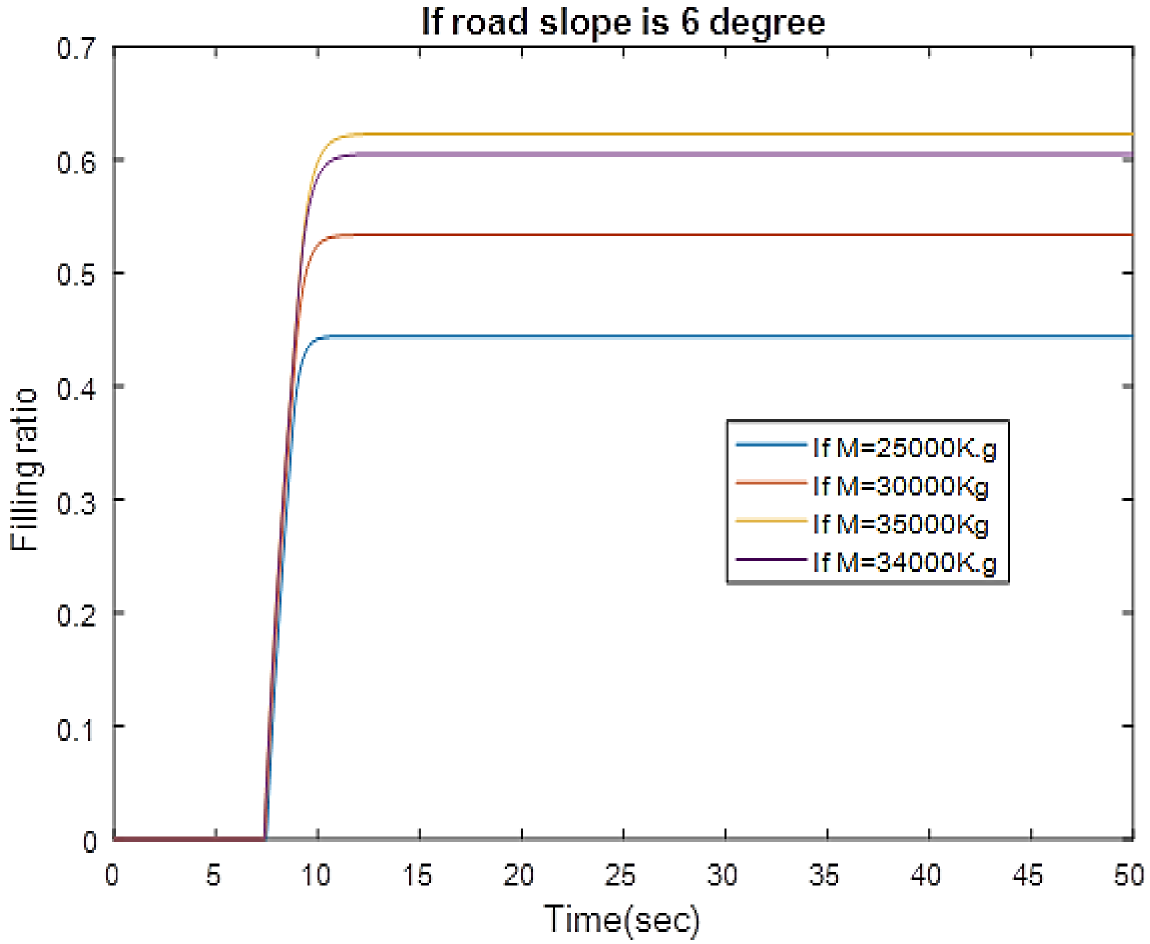
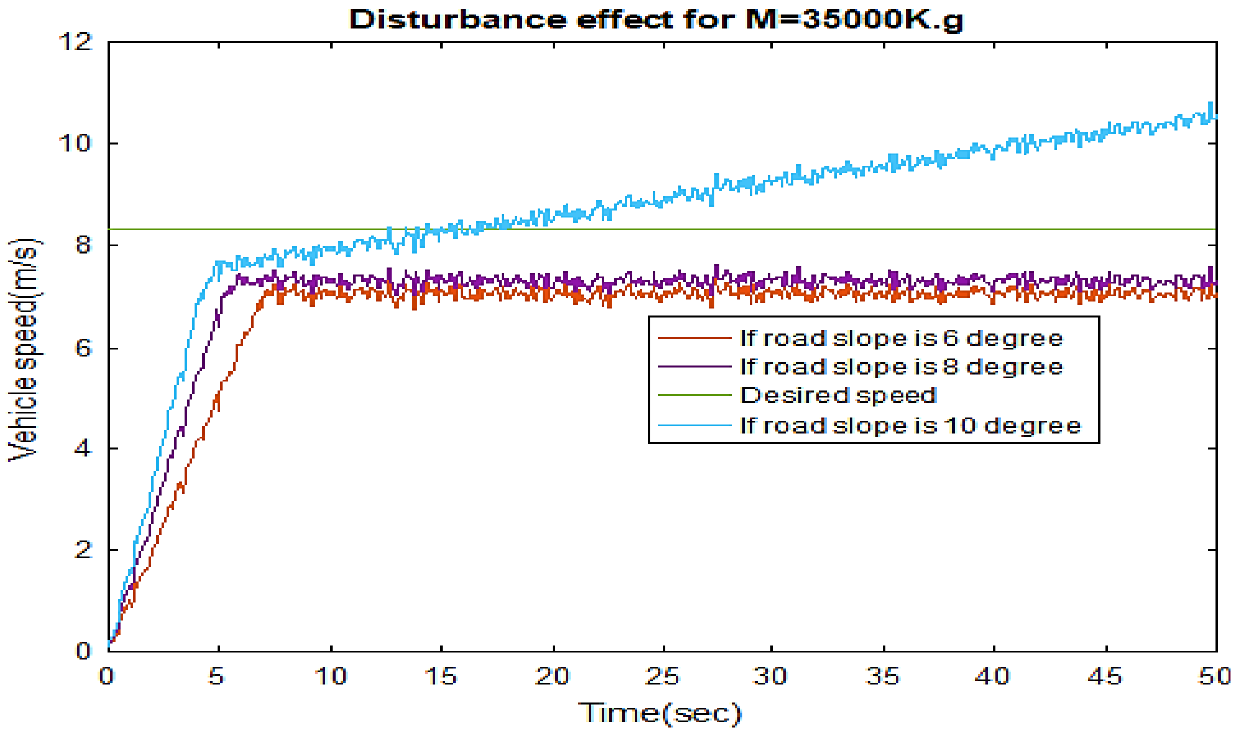
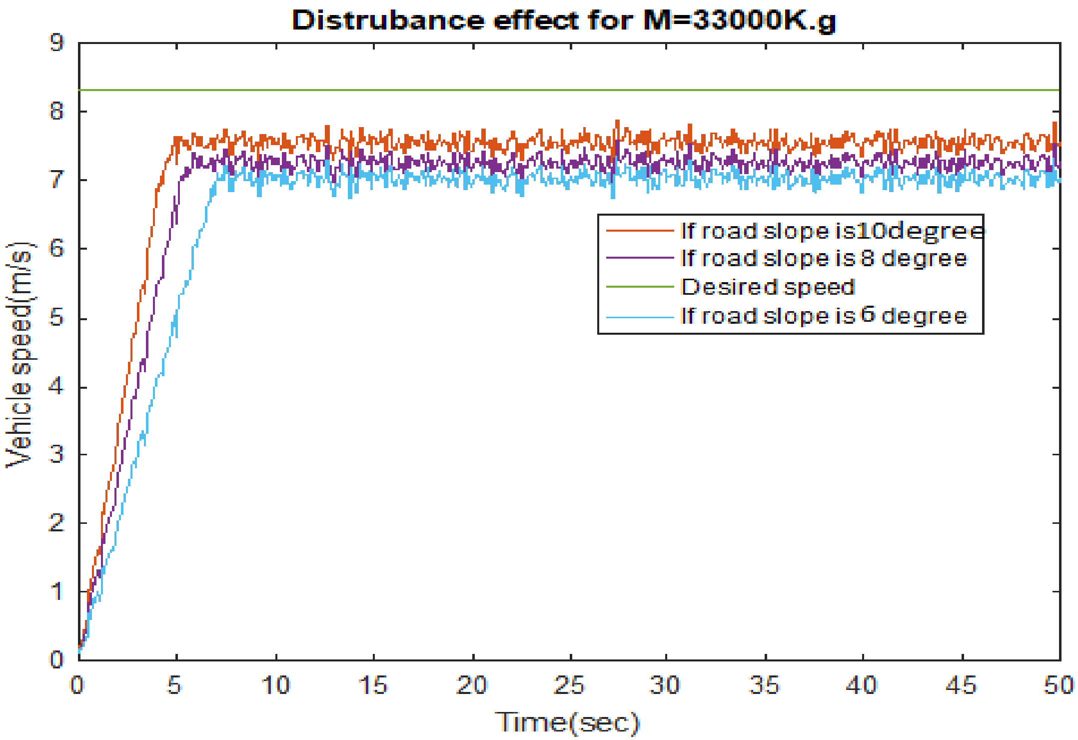




The filling ratio value of a chamber is increase if the vehicle mass or road slope increase or the reverse is true for the vehicle mass M≤330000K.g.

The Effect of disturbance on system response





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

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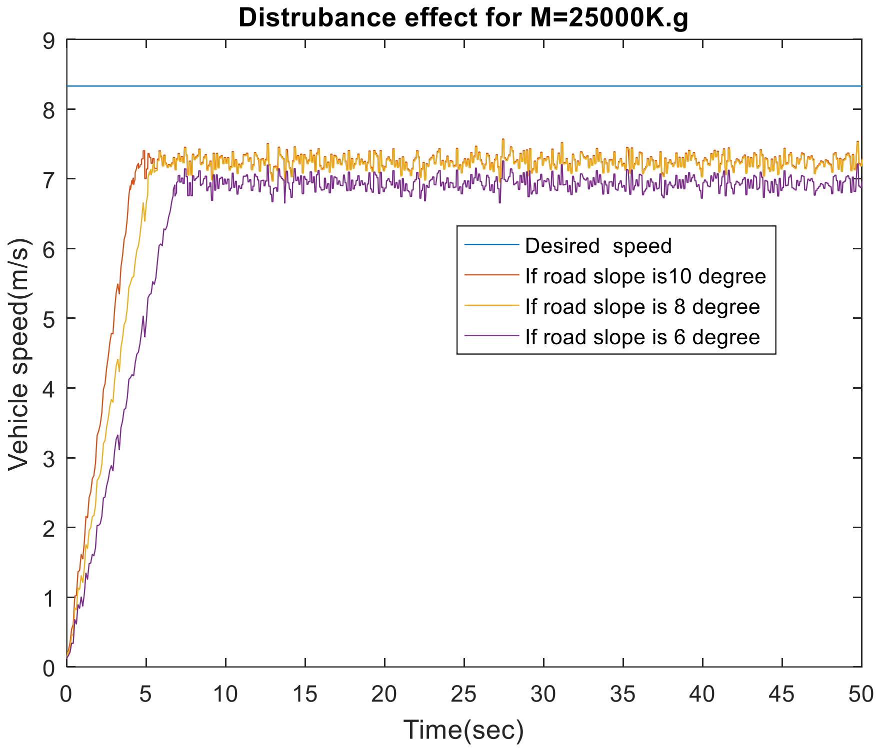

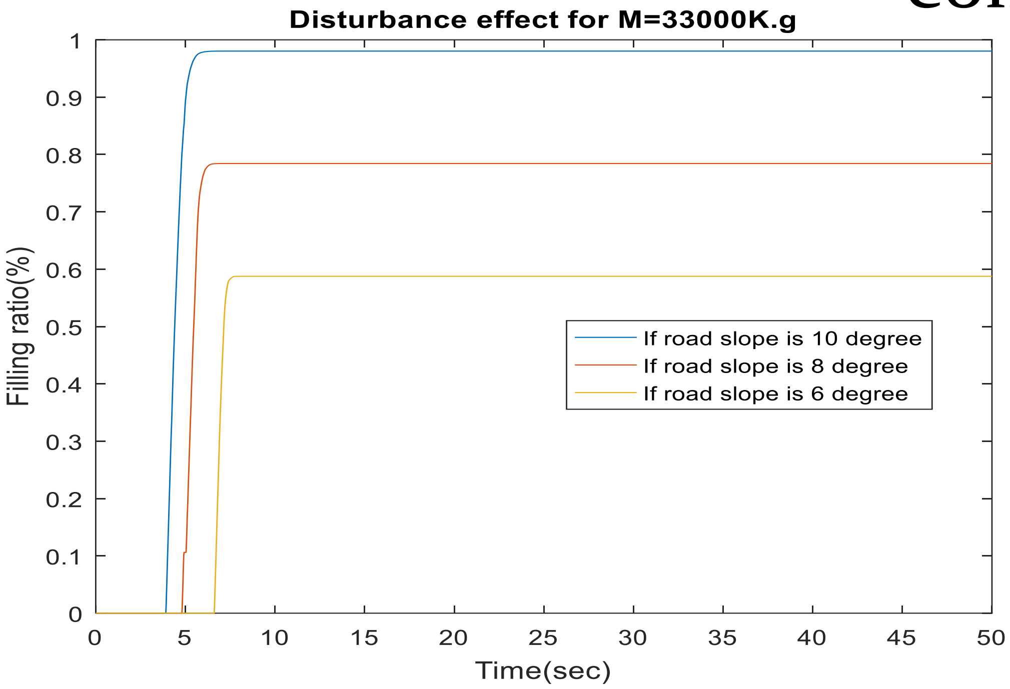

- It indicates the filling ratio of the retarder under disturbance has small incremental value 0.0002, 0.0004 and 0.0006 for road slope 10^0,$8^0$and 6^0 respectively.
- Due to the vibration effect the valve couldn’t fully closed and filling ratio also increase and the speed is decrease.

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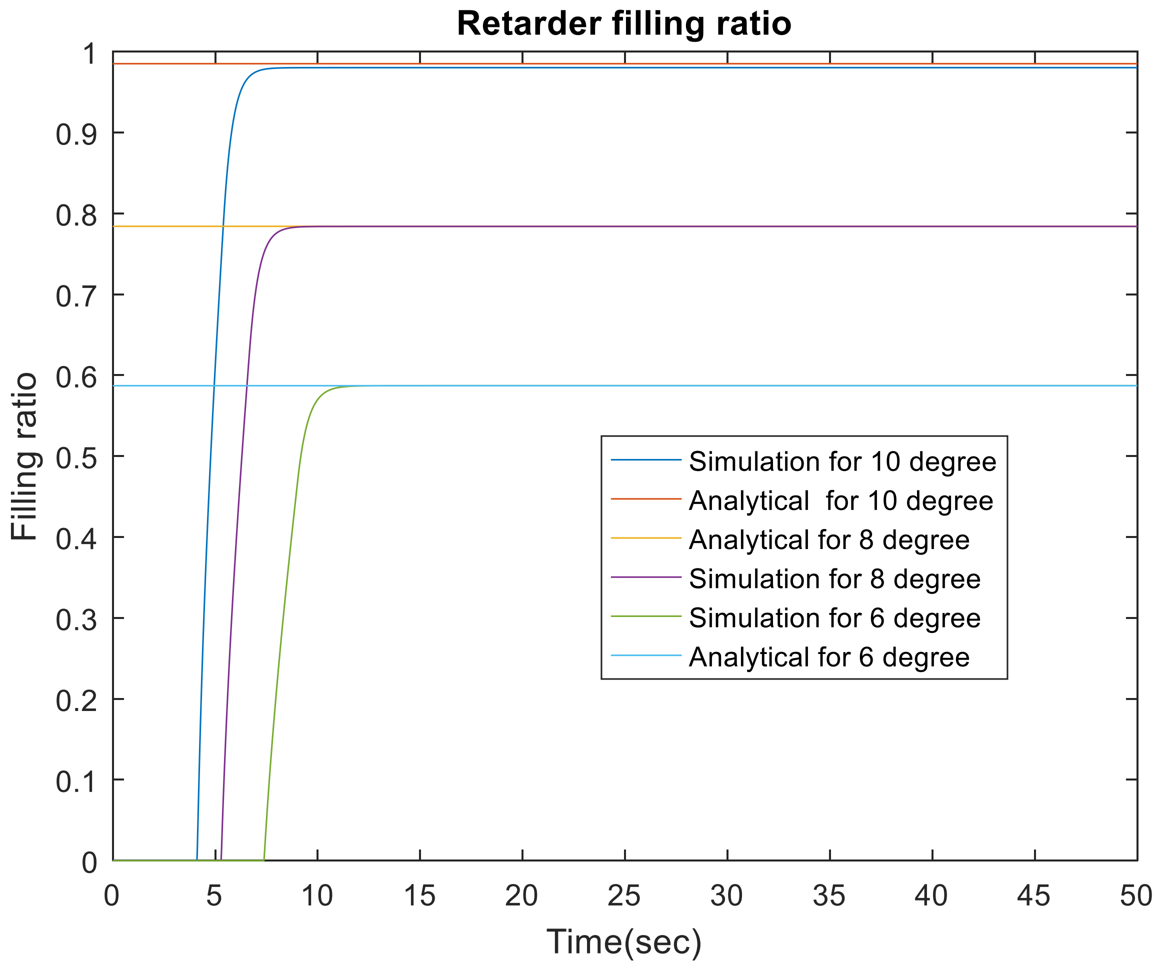
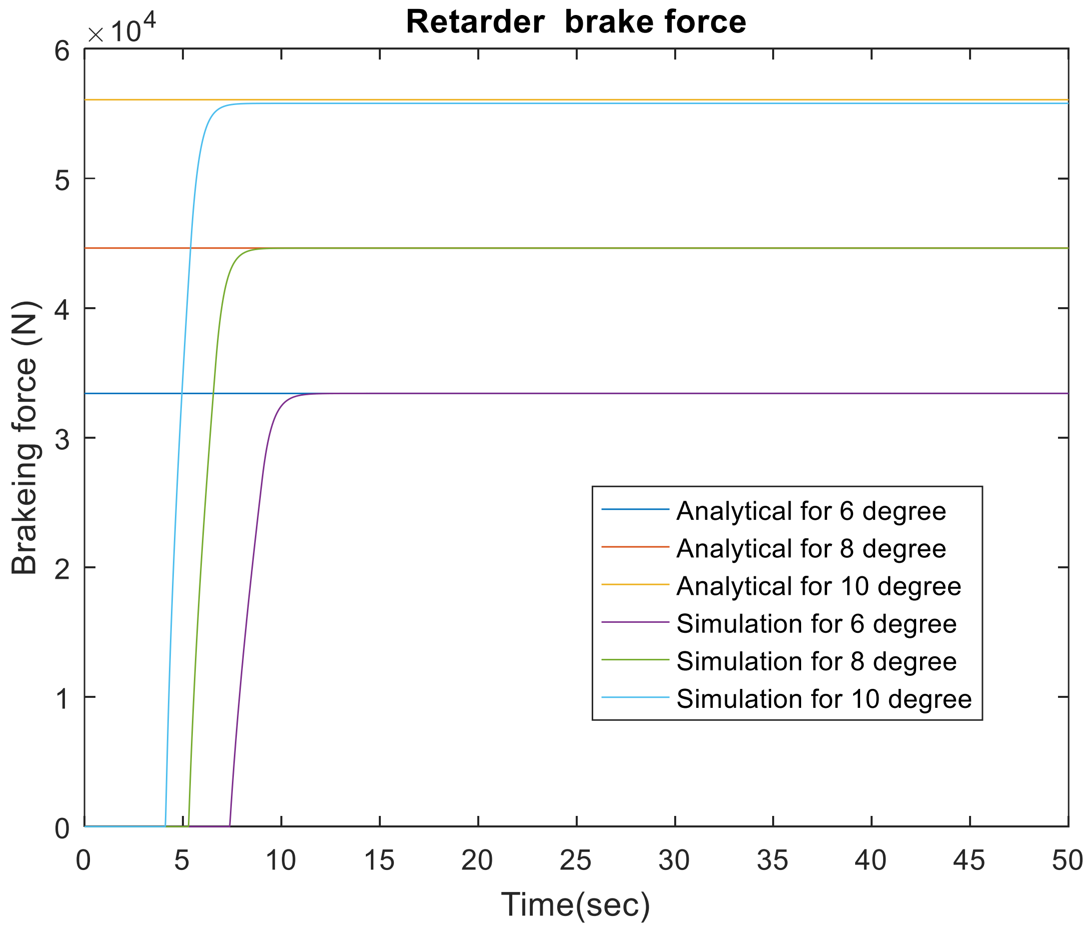
Comparison the result





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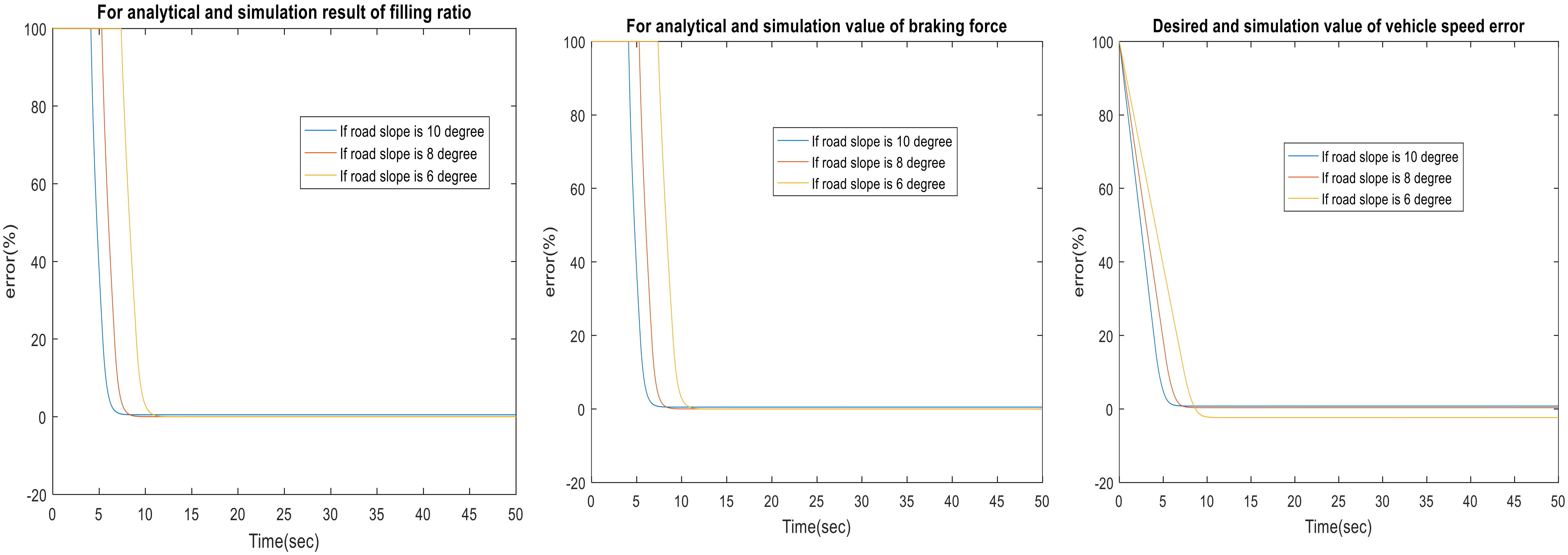

The result shows very small steady state error between analytical and simulation for a vehicle mass M=33000K.g

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 untile $V_{actual} > 8.33\ m/s$.
- 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!