MASTER THESIS

Modelling and Simulation of ISEAUTO Self-driving Vehicle Dynamics

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THESIS AIM

Research object: ISEAUTO self-driving vehicle.

Thesis tasks:

- Theoretical study of vehicle dynamics.
- Creating of a dynamics model of ISEAUTO in Matlab and Simulink environments.
- Making practical measurements and comparison of received results.

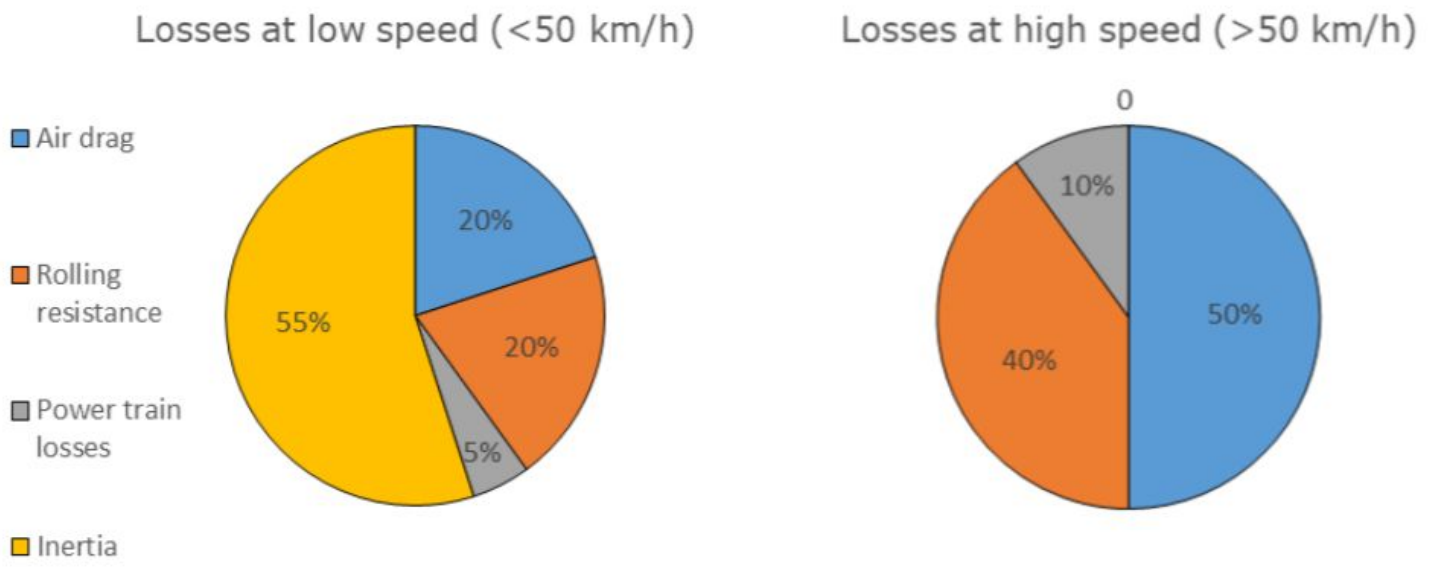
ISEAUTO TECHNICAL PARAMETERS

- Capacity: 4 + 2 passengers
- Speed: 10 km/h, max 50 km/h
- Main motor: 47 kW
- Unloaded mass: 1160 Kg

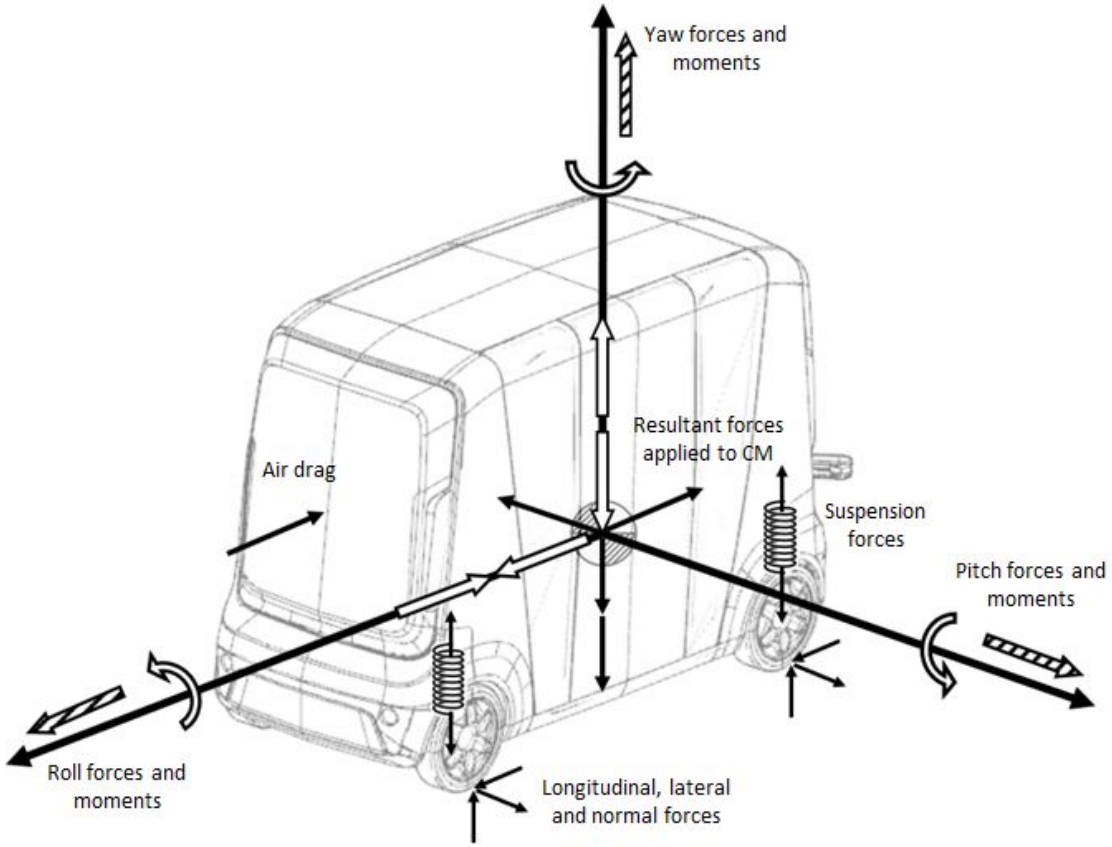
Dimensions:

- Height: 2,4 m
- Length: 3,6 m
- Width: 1,5 m
- Wheelbase: 2,55 m

TYPICAL LOSSES OF VEHICLE MOVEMENT

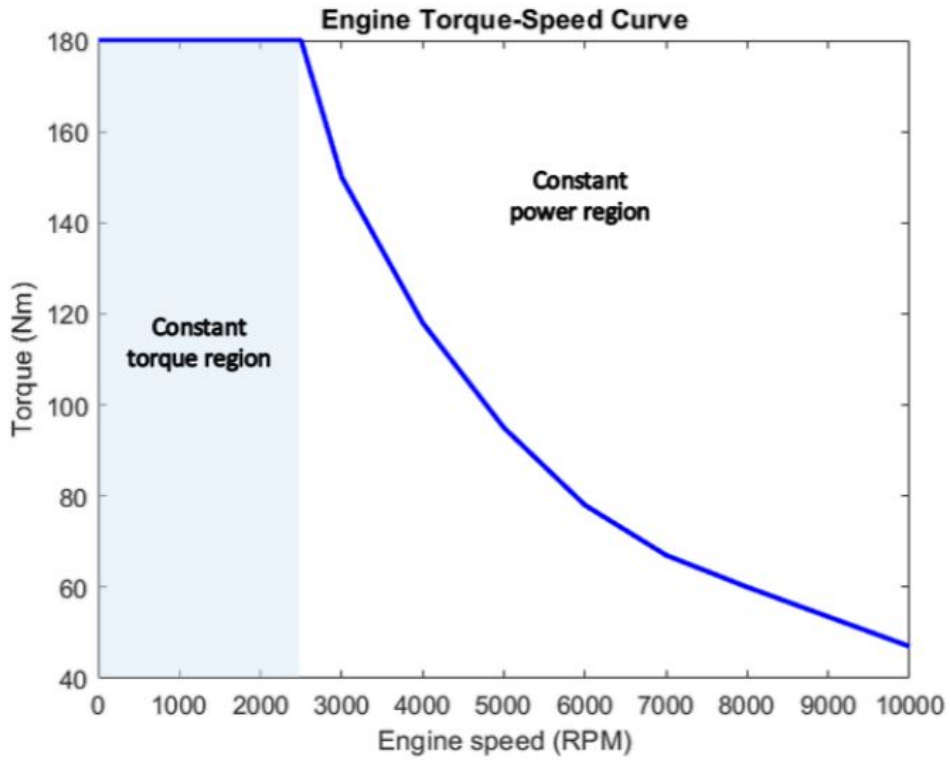


DYNAMIC MODEL OF THE ISEAUTO



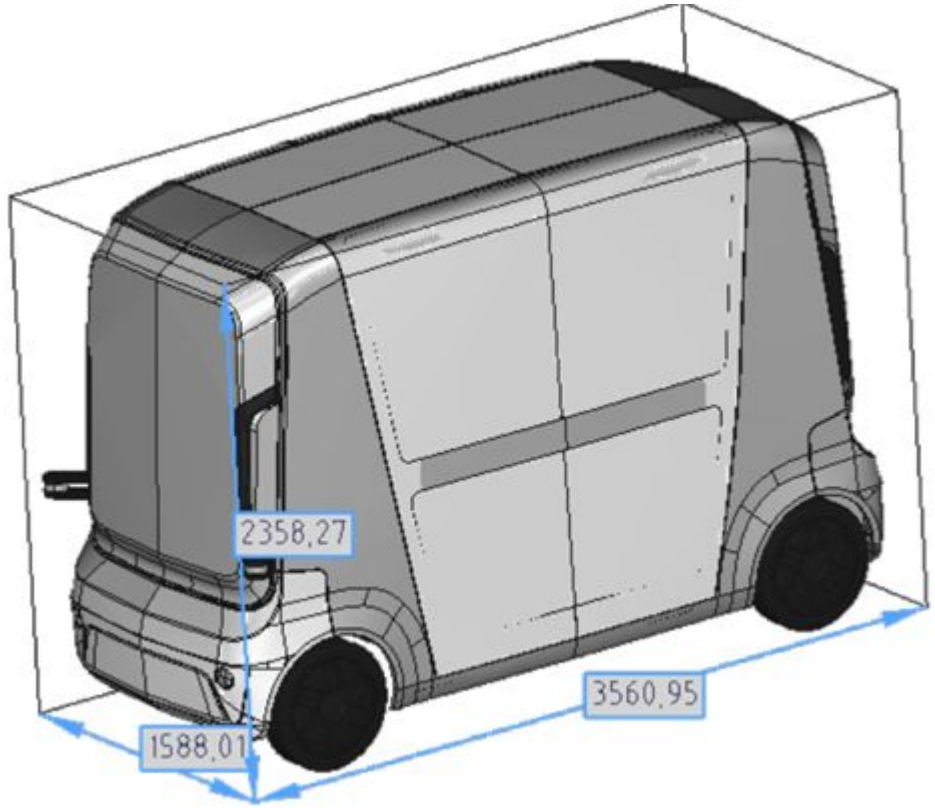
MOTOR

- Torque output.
- Rotor speed of rotation.
- Motor inertia.
- Throttle rate.



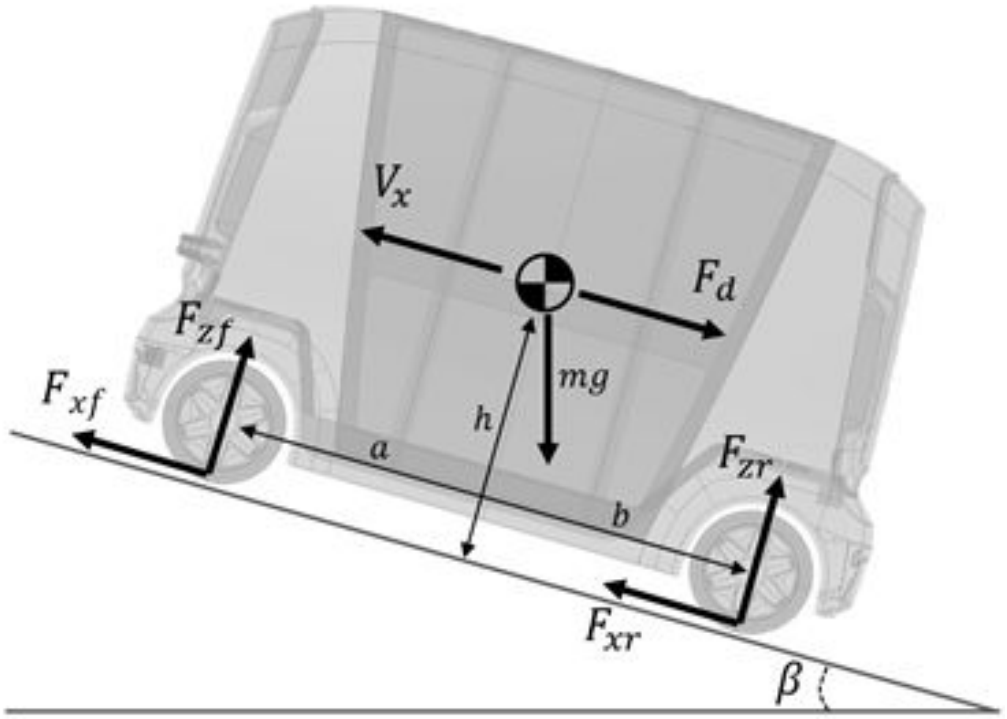
MASS DISTRIBUTION

System	Mass, kg	Coordinates of CG
Vehicle shell	550	[1220,0,1540]
Motor, gearbox and differential	90	[2550,0,350]
Batteries	250	[1420,0,150]
Steering unit	60	[0,0,350]
Cargo (passengers)	0-400	[1550,0,870]
Forward axle	100	[0,0,0]
Rear axle	120	[2550,0,0]



BODY DYNAMICS

- Longitudinal and normal forces of wheels.
- Location of vehicle CM.
- Distance between axles.
- Surface inclination.
- Drag force.

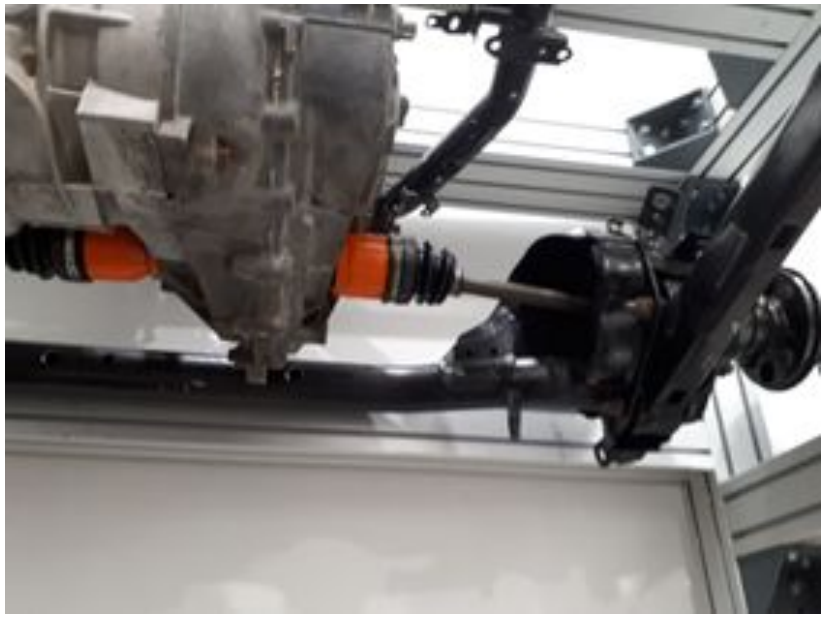


TRANSMISSION AND DIFFERENTIAL

- Gear ratio.
- Transmission efficiency.
- Differential efficiency.
- Transmission parts inertia.
- Differential parts inertia.

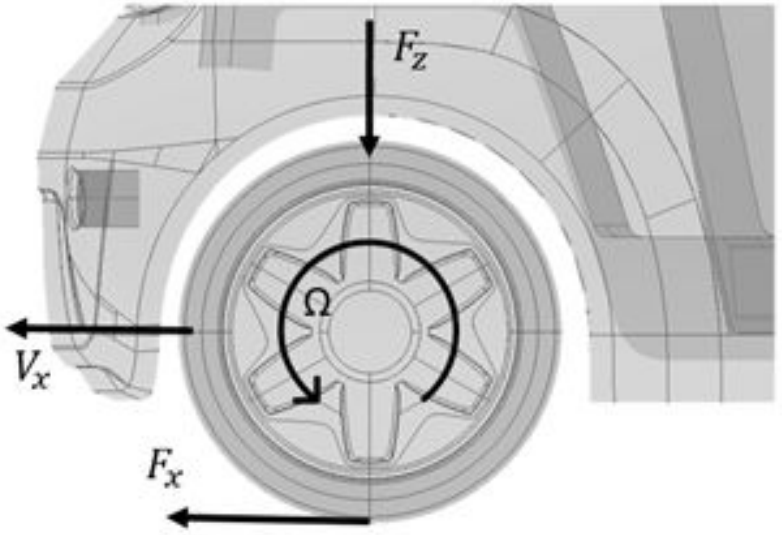
FORWARD AND REAR AXLES

- Drive shafts efficiency.
- Drive shafts inertia.
- Suspension stiffness.



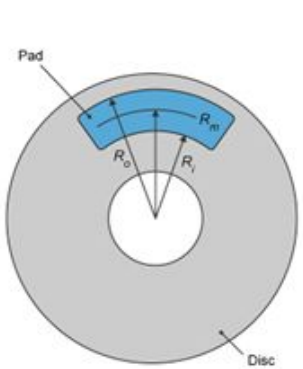
TIRE DYNAMICS

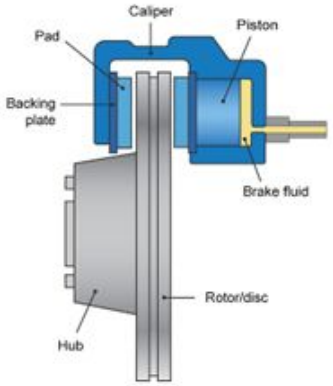
- Wheel parameters.
- Loading ratio.
- Slip ratio.
- Type of surface.
- Rolling resistance.



FRONT AND REAR BRAKING SYSTEMS

- Geometrical parameters of a disc brake (front axle).
- Geometrical parameters of a drum brake (rear axle).
- Braking pressure.
- Friction coefficients.





MATLAB CODE

```
%% Parameters
inclination_deg= 0; %%[deg]
wind_vel= 0; %%[m/s]

%% mass and center of mass
mass_shell=550; %%[kg]
mass_motor=90; %%[kg]
mass_batteries= 250; %%[kg]
mass_steering= 60; %%[kg]
mass_axleFwd=100; %%[kg]
mass_axleAft=120; %%[kg]
mass_passangers=400; %%[kg] 400

coord_shell = [1220,0,1540]; %%[x;y;z]
coord_motor = [2550,0,350]; %%[x;y;z]
coord_batteries = [1420,0,150]; %%[x;y;z]
coord_steering = [0,0,350]; %%[x;y;z]
coord_axleFwd = [0,0,0]; %%[x;y;z]
coord_axleAft = [2550,0,0]; %%[x;y;z]
coord_passangers = [1550,0,870]; %%[x;y;z]
%% Vehicle parameters
drag_coeff= 0.7; %%
front_area = 3.6; %%m2
%% Tire parameters (dry surface)
frontTire_mass =7;
frontTire_fitD = 381; %%tire fit diameter [mm]
frontTire_H = 94;  %%tire profile height [mm]
frontTire_W = 145; %%tire width [mm]

rearTire_mass =10;
rearTire_fitD = 381; %%tire fit diameter [mm]
rearTire_H = 96;  %%tire profile height [mm]
rearTire_W = 175; %%tire width [mm]

load_coeff= 0.85 %% 0.85-0.9 for diagonal tires, 0.8-0.85
for radial tires

surface= 'dry';%% dry/wet/snow/ice

roll_resist = 0.0062;
```

```
CG_height = coord_cm(3); %%mm
front_axle= coord_cm(1); %%mm
rear_axle= coord_axleAft(1)-coord_cm(1); %%mm

frontTire_R  =  frontTire_fitD/2+  frontTire_H;    %%outer
tire radius [mm]
rearTire_R = rearTire_fitD/2+ rearTire_H;   %%outer tire
radius [mm]

front_tire_R_static=
0.5*frontTire_fitD+frontTire_H*load_coeff    %%    static
radius, mm
rear_tire_R_static=
0.5*rearTire_fitD+rearTire_H*load_coeff %% static radius,
mm

switch surface
    case 'dry'
        tire_b= 10; tire_c= 1.9; tire_d= 1; tire_e= 0.97;
    case 'wet'
        tire_b= 12; tire_c= 2.3; tire_d= 0.82; tire_e= 1;
    case 'snow'
        tire_b= 5; tire_c= 2; tire_d= 0.3; tire_e= 1;
    case 'ice'
        tire_b= 4; tire_c= 2; tire_d= 0.1; tire_e= 1;
end

frontTire_inertia=
1/2*rearTire_mass*((frontTire_R/1000)^2+(frontTire_fitD)
/1000^2) ; %% inertia of front tire, N*m
rearTire_inertia=
1/2*frontTire_mass*((rearTire_R/1000)^2+(rearTire_fitD)/
1000^2) ; %% inertia of rear tire, N*m

veh_length= 3560; l= veh_length/1000;
veh_width = 2358; w= veh_width/1000;
veh_height = 1588; h= veh_height/1000;
m= mass_total;
```

MATLAB VARIABLES

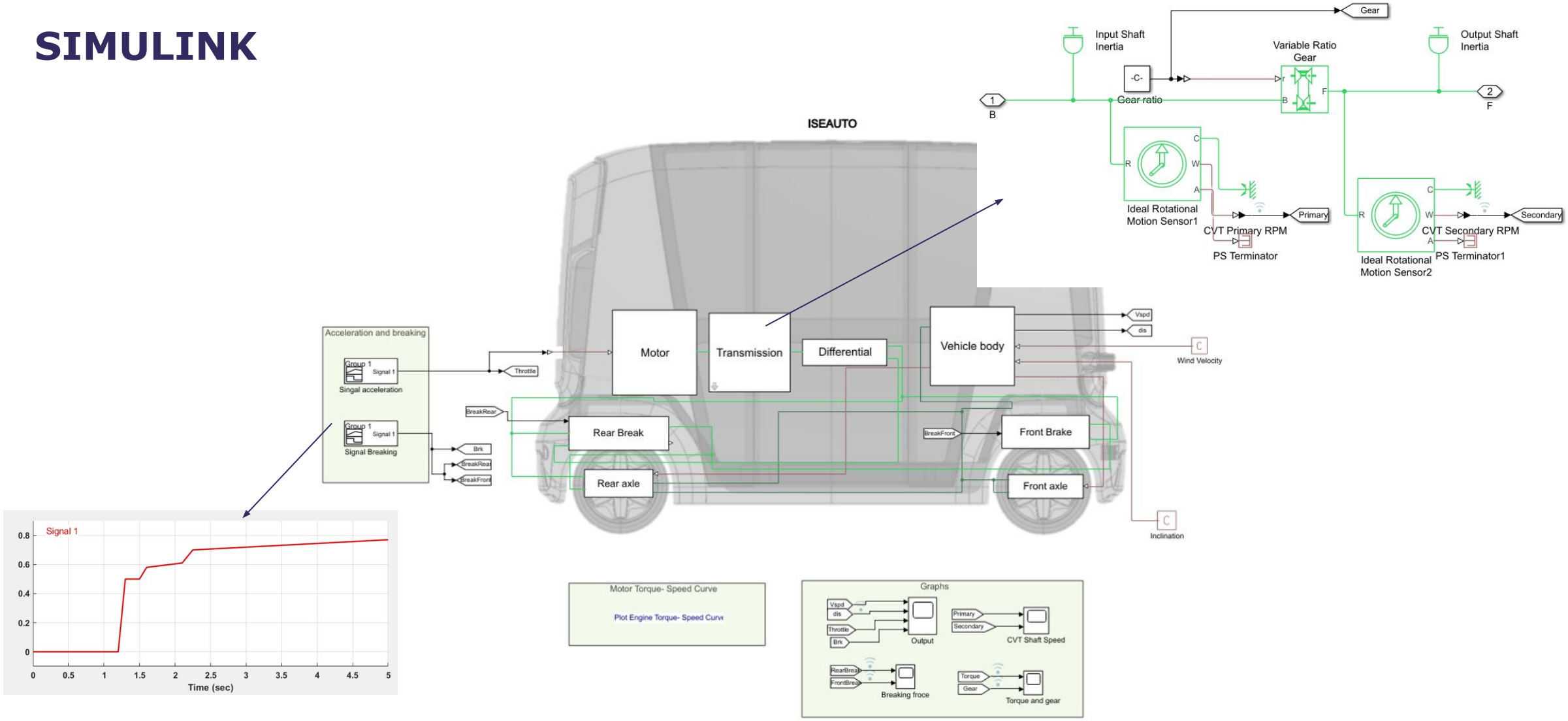
Name	Value
act_R_rearBR	100
Angle_left_wh...	15
Angle_right_w...	17
Angle_steering	16
ans	6
BreakingPress...	0
CG_height	850.9934
coloumb_fricti...	0.3000
contFriction_c...	0.3000
coord_axleAft	[2550,0,0]
coord_axleFwd	[0,0,0]
coord_batteri...	[1420,0,150]
coord_cm	[1.4447e+03,0,85...
coord_motor	[2550,0,350]
coord_passan...	[1550,0,870]
coord_shell	[1220,0,1540]
coord_steering	[0,0,350]
cylD_rearBR	19.1000
cylinder_bore...	10
d_sprinf_fwd	0.0100
D_sprinf_fwd	0.0860
d_sprinf_rear	0.0110
D_sprinf_rear	0.0970
diff_eff	0.9200
differential_In...	0.0361
drag_coeff	0.7000
dram_R_rearBR	150
engine_Inertia	0.0120
front_area	3.6000
front_axle	1.4447e+03
front_tire_R_st...	270.4000
FrontAxle_Ine...	0.1380
frontTire_fitD	381
frontTire_H	94

Name	Value
frontTire_H	94
frontTire_inertia	0.4066
frontTire_mass	7
frontTire_R	284.5000
frontTire_W	145
gear1_d	170
gear1_Inertia	0.0578
gear1_m	8
gear2_d	50
gear2_Inertia	0.0016
gear2_m	2.5000
gear3_d	90
gear3_Inertia	0.0071
gear3_m	3.5000
gear4_d	50
gear4_Inertia	0.0016
gear4_m	2.5000
gearbox_Inertia	0.0680
GearRatio	6.0660
h	1.5880
I_x	791.3240
I_y	1.4985e+03
I_z	1.8005e+03
inclination_deg	0
inclination_rad	0
inertia_axleAft	146.6020
inertia_axleFwd	208.7164
inertia_batteries	305.4209
inertia_motor	109.9515
inertia_passang...	4.4351
inertia_shell	1.7326e+03
inertia_steering	73.3010
input_shaft_iner...	0.0050
input_shaft_mass	3.5000

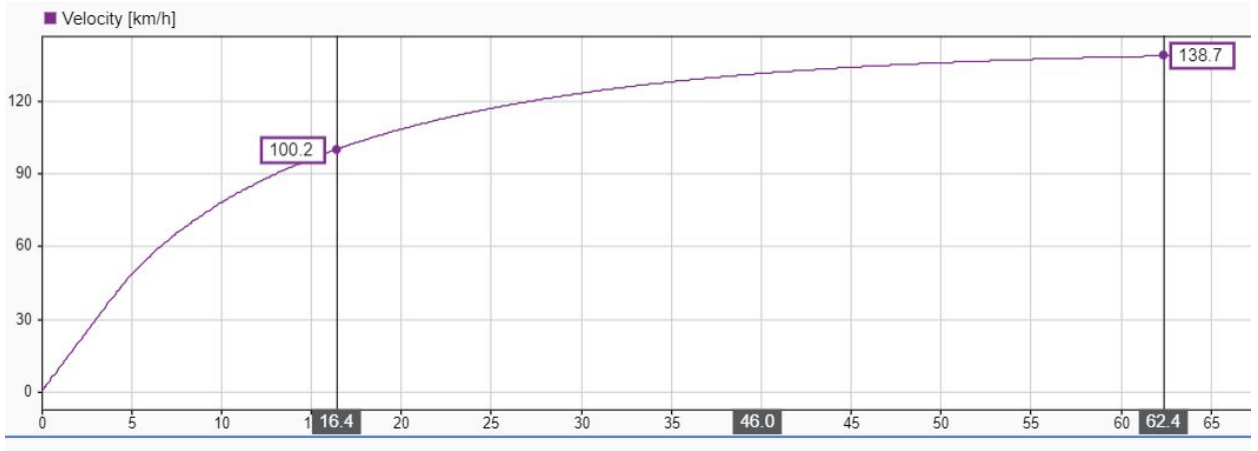
Name	Value
input_shaft_mass	3.5000
I	3.5600
I_aft	-1.1053e+03
I_fwd	1.4447e+03
load_coeff	0.8500
logsout_cvtMod...	*1x1 Dataset*
m	1510
m1	3.5000
m2	3.2000
mass_axleAft	120
mass_axleFwd	100
mass_batteries	250
mass_motor	90
mass_passangers	400
mass_shell	550
mass_steering	60
mass_total	1510
massLoad_axle...	855.4902
massLoad_axleF...	654.5098
maxBreakingPre...	1.0800e+10
maxForce_rearBR	1.2378e+07
mr1	0.8000
mr2	0.7000
Num_coils_fwd	5
Num_coils_rear	5
num_pads_front...	2
output_shaft_in...	0.0341
output_shaft_m...	3.2000
pad_R_frontBR	150
pin_angle_rearBR	15
pin_loc_rearBR	125
pitch_inertia	2.7897e+03
rear_axle	1.1053e+03
rear_tire_R_static	272.1000

Name	Value
pin_loc_rearBR	125
pitch_inertia	2.7897e+03
rear_axle	1.1053e+03
rear_tire_R_static	272.1000
RearAxle_Inertia	0.1380
rearTire_fitD	381
rearTire_H	96
rearTire_inertia	0.2886
rearTire_mass	10
rearTire_R	286.5000
rearTire_W	175
roll_resist	0.0062
rpmVector	[1;2000;2500;300...
Shear_modulus	11500000
shoe_angle_rear...	5
shoe_span_rear...	120
simlog_cvtMod...	*1x1 Node*
speedVector	*70x1 double*
static_friction_c...	0.3000
stiffenes_fwd	770.9000
stiffenes_rear	1.2648e+03
surface	'dry'
tire_b	10
tire_c	1.9000
tire_d	1
tire_e	0.9700
torqueVector	[50;50;50;50;30;1...
trans_eff	0.8500
veh_height	1588
veh_length	3560
veh_width	2358
vehicle_mass	1110
viscFriction_coe...	0.0100
w	2.3580
wind_vel	0

SIMULINK

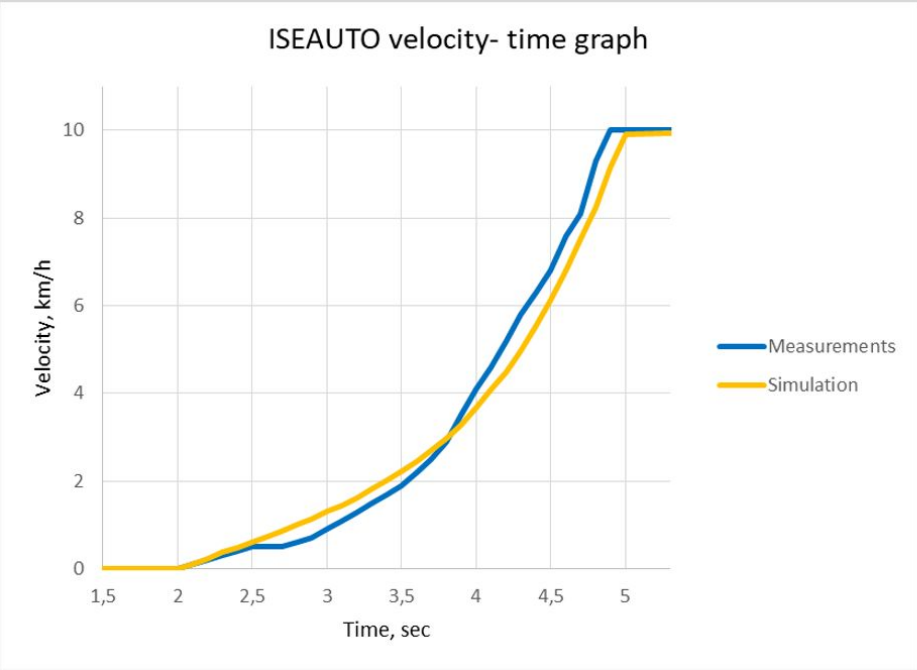

ISEAUTO
Acceleration and breaking
Group 1
Signal 1
Singal acceleration
Signal Breaking
Throttle
Brk
BreakRear
BreakFront
Motor
Transmission
Differential
Vehicle body
Rear Break
Rear axle
Front Brake
Front axle
Vspd
dis
Wind Velocity
Inclination
Input Shaft Inertia
Variable Ratio Gear
Output Shaft Inertia
Gear
-C-
Gear ratio
Ideal Rotational Motion Sensor1
CVT Primary RPM
PS Terminator
Primary
Ideal Rotational Motion Sensor2
CVT Secondary RPM
PS Terminator1
Secondary
Signal 1
Time (sec)
Motor Torque- Speed Curve
Plot Engine Torque- Speed Curve
Graphs
Output
CVT Shaft Speed
Breaking froce
Torque and gear

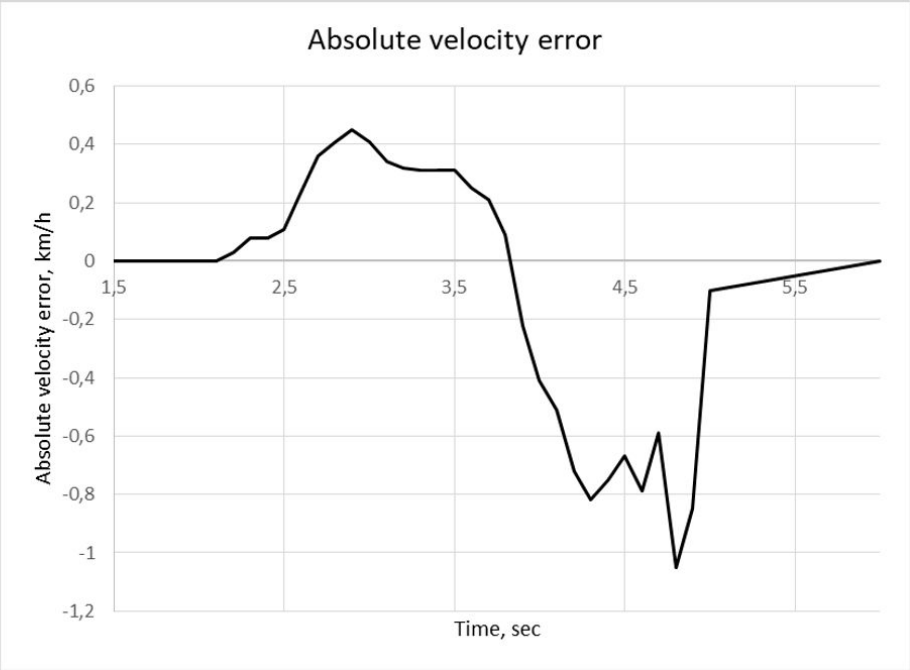
PRACTICAL VERIFICATION



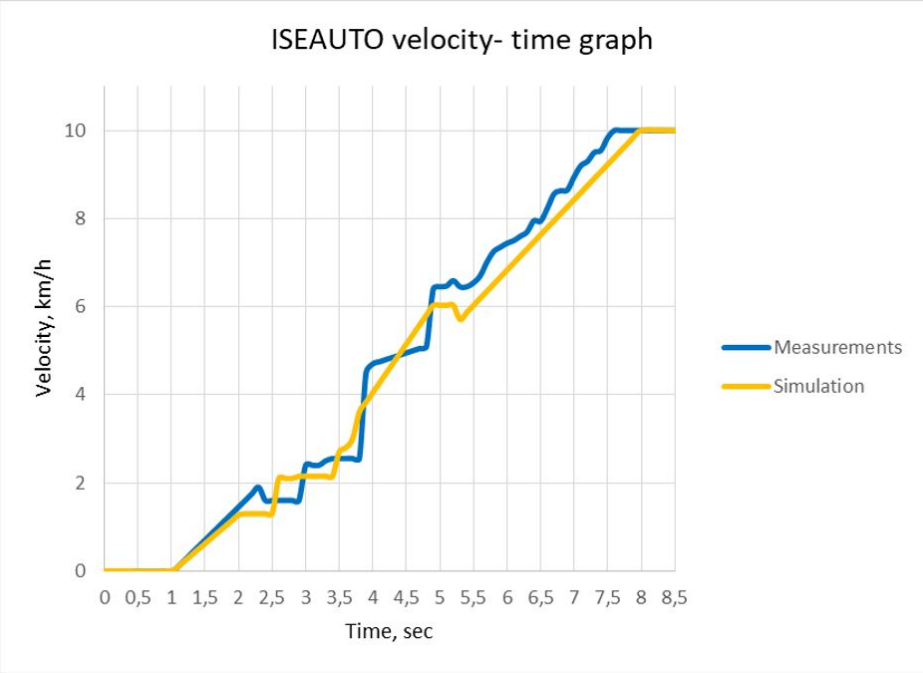
Parameter	Manufacturer data	Simulation	Error
Maximum speed, km/h	130	138	5,80%
Acceleration time to 100 km/h, s	15,9	16,4	3,14%

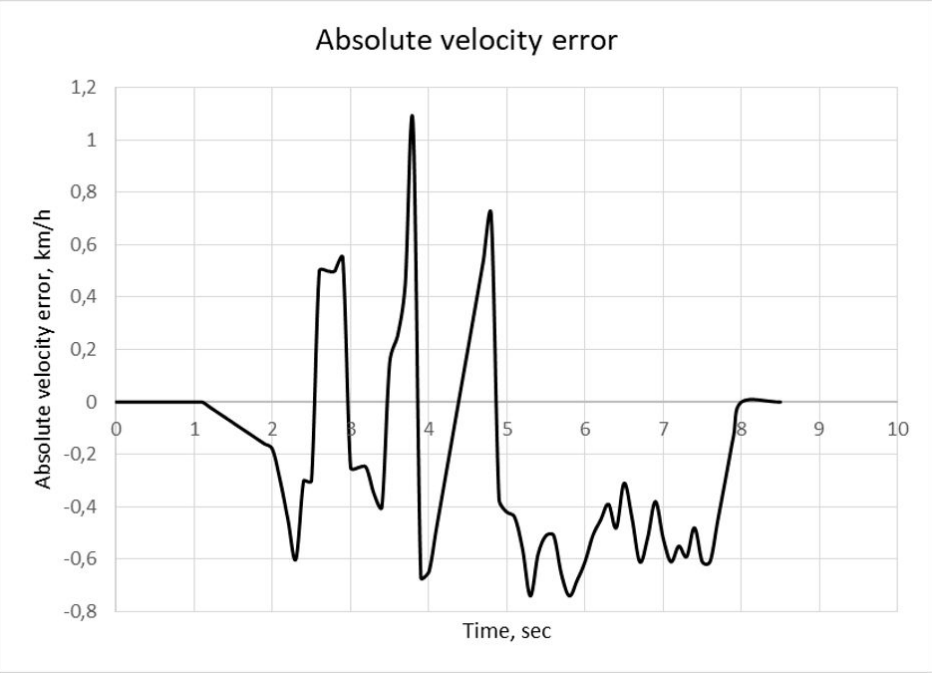
PRACTICAL VERIFICATION



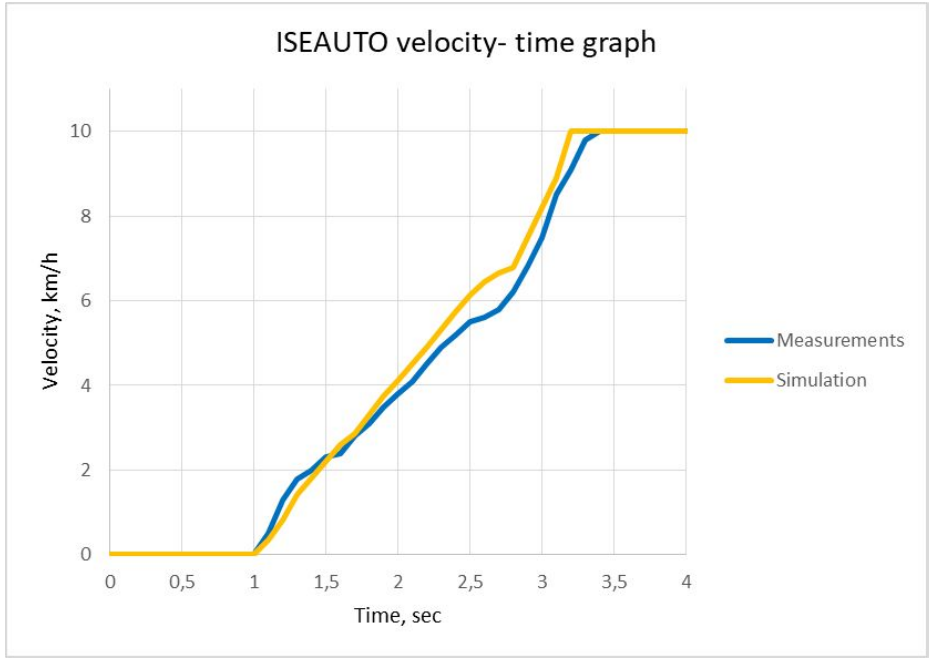


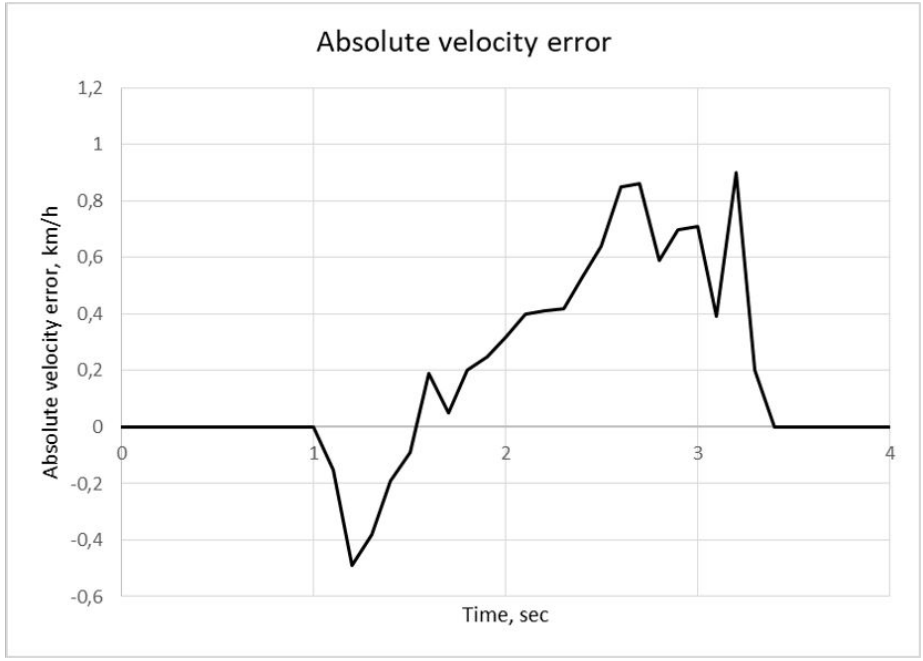
PRACTICAL VERIFICATION





PRACTICAL VERIFICATION





PRACTICAL VERIFICATION

Practical stopping time, sec	Simulation stopping time, sec
1,2	0,8
0,96	
0,84	
0,82	
0,76	

SUMMARY

- Developed dynamics model considers main ISEAUTO parameters and its structural and drive elements.
- Simulation was successfully verified.

Developed model can be used for the following purposes:

- Analysis of linear motion of ISEAUTO and prediction its behaviour at any time;
- Trace a change in driving dynamics in case of replacing any components;
- Optimization of autonomous driving to reduce losses and increase safety.

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