Integrated Assessment of Passing Maneuvers Based on Road and Vehicle Characteristics

Paper 311

Stergios Mavromatis
National Technical University of Athens
stemavro@central.ntua.gr

Two-Lane Rural Roads

Background

- High proportion of severe crashes
- Overtaking maneuvers are among the most critical safety issues
- Head-on collisions frequently associated with failed passing attempts
- Safe passing requires adequate visibility and vehicle performance

Key Question

- How do vehicle dynamics and roadway geometry jointly influence Passing Sight Distance (PSD)?

Why Revisit PSD?

Limitations of Existing Standards

- US AASHTO (2018)
  - Fixed acceleration assumptions
  - Fixed speed differential (ΔV = 19 km/h))
  - Simplified vehicle behavior
- German RAL (2012)
  - Standardized PSD values (e.g. 600 m)

AASHTO, 2018		
Design Speed (km/h)	**Passed Vehicle Speed (km/h)**	**PSD (m)**
80	61	245
90	71	280
100	81	320
110	91	355

Reality

- Different vehicle performances
- Different horsepower levels
- Variable grades
- Dynamic acceleration behavior

Research Gap

Current PSD methodologies:

✓ Consider geometry

✓ Consider safety margins

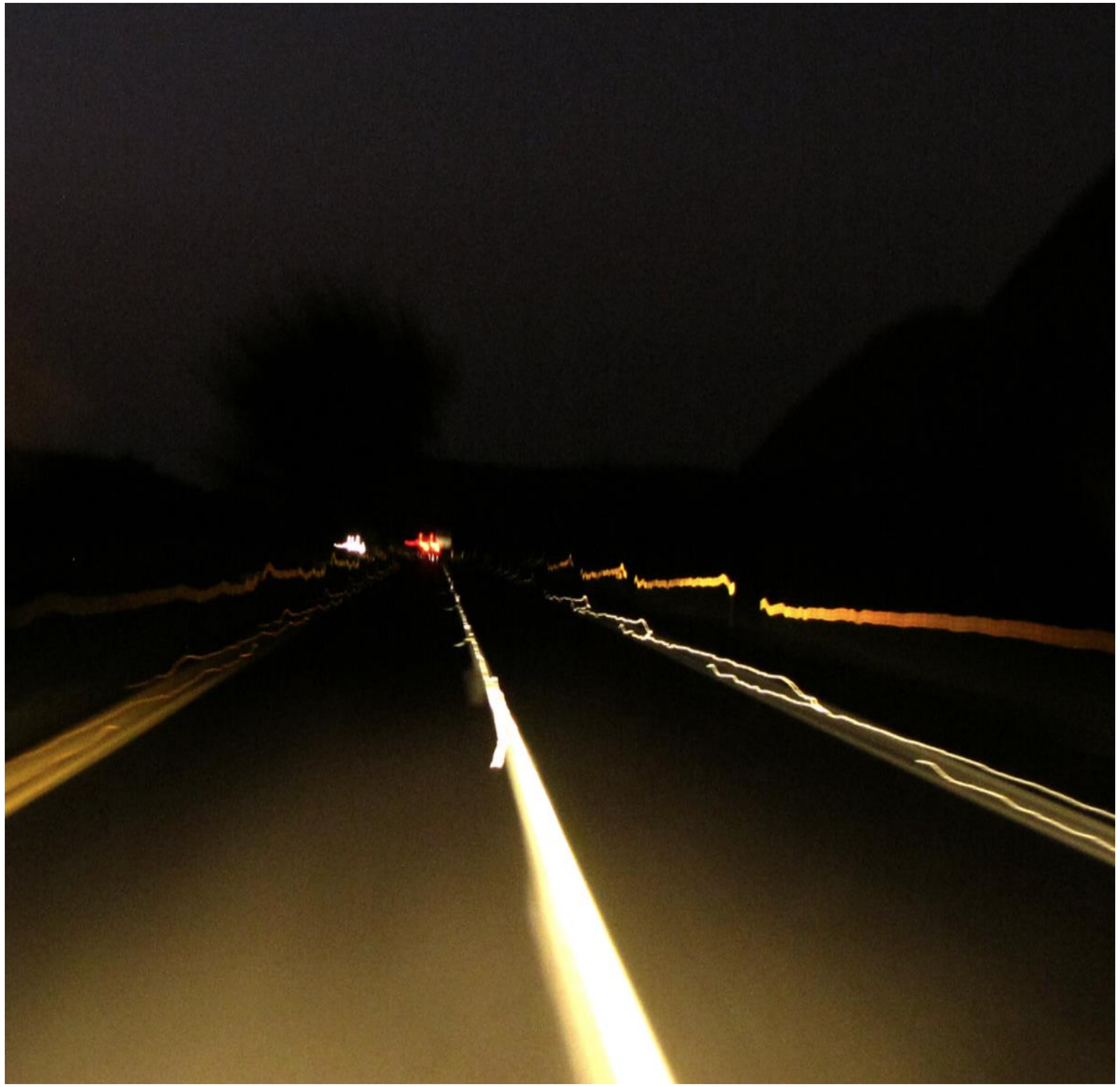
✗ Limited consideration of vehicle dynamics

✗ Limited consideration of grade effects

✗ Static representation of overtaking process

Need

Integrated road–vehicle approach for PSD assessment



Study Objective

Main Objective

Investigate the **interaction** between:

- Posted speed
- Passed vehicle speed
- Vehicle horsepower
- Roadway grade

and quantify their impact on:

Passing Sight Distance

using a **validated vehicle dynamics model**

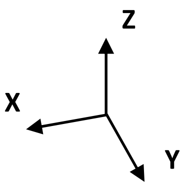
Methodology

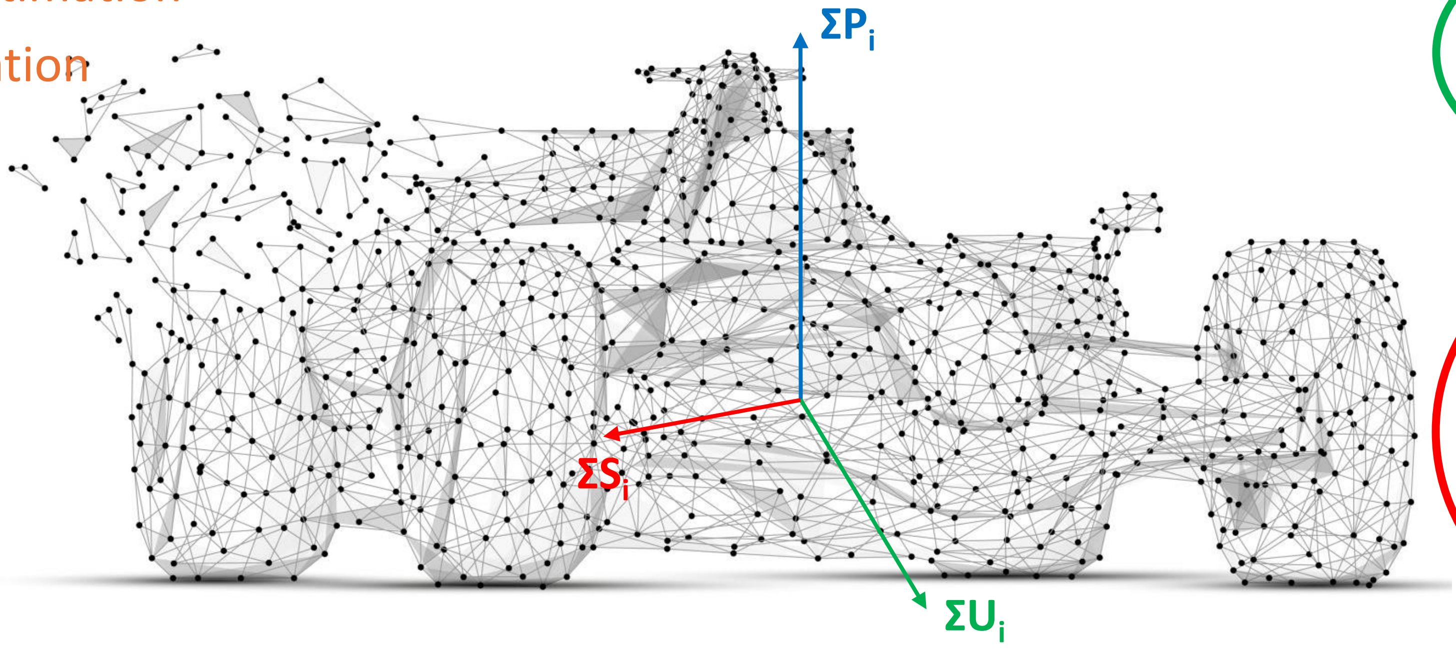
Two-Step Approach

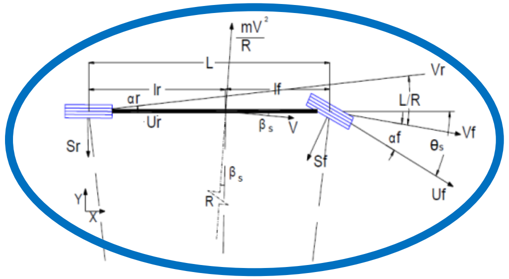
Vehicle Dynamics Model

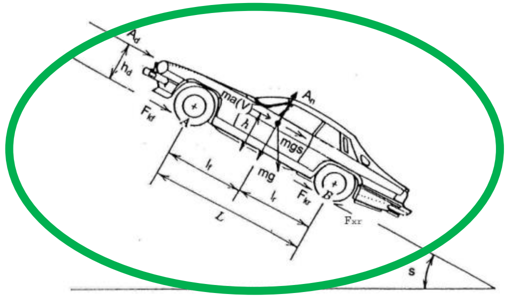
Core Characteristics

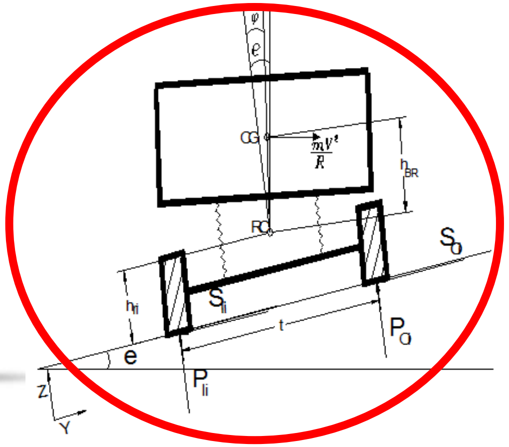
- 3D vehicle representation
- Four-wheel model
- Tire-road interaction
- Tractive effort estimation
- Variable acceleration











Acceleration treated

as **Dynamic Variable**

not constant

Tractive Force Concept

Available Tractive Force

$$F_x = 745.60 \cdot P/V \cdot n/100$$

where:
P = horsepower (hp)
V = speed (m/sec)
n = horsepower utilization factor

Key points

- During tractive motion, the vehicle continues to accelerate up to dV/dt = 0
- The acceleration rate decreases as vehicle speed increases
- Friction-Limited Region (n < 100%)
    - Vehicle performance is limited by available tire–road friction
    - Any additional power or tractive effort results in wheel skidding
- Power-Limited Region (n = 100%)
    - Change from friction-limited to power-limited operation
    - Skid risk is no longer the governing constraint
    - Vehicle continues to gain speed, but acceleration decreases more rapidly

Acceleration Determination

Vehicle's instant acceleration, expressed as a function of vehicle's instant speed as well as driven distance, thus delivering the following differential equation

$$a(v) = \partial V/\partial d \cdot v$$

where:
α(v): acceleration (m/sec^2)
V: speed (m/sec)
d: distance (m)

PSD Assessment Framework

Vehicles Considered

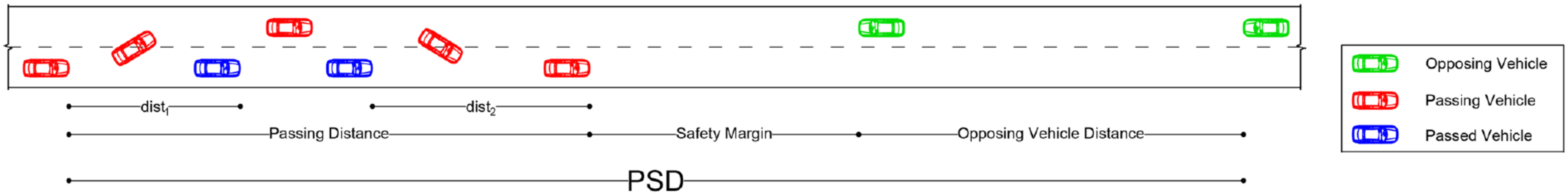
- Passing vehicle
- Passed vehicle
- Opposing vehicle

Assumptions

- Free-flow conditions
- Solely passing vehicle accelerates
- Opposing vehicle travels at V_{posted}
- Passed vehicle travels at $V_{posted} - \Delta V$
- Poor friction pavement $f_{avail} = 0.50$

PSD Components

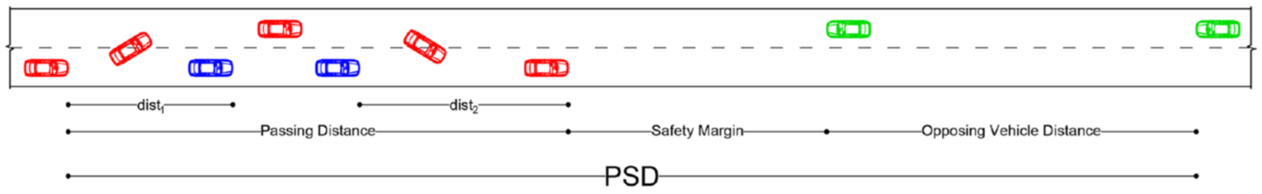
- Initial headway ($dist_1$) = 15 m
- Final headway ($dist_2$) = 30 m
- Fixed safety margin = 100 m

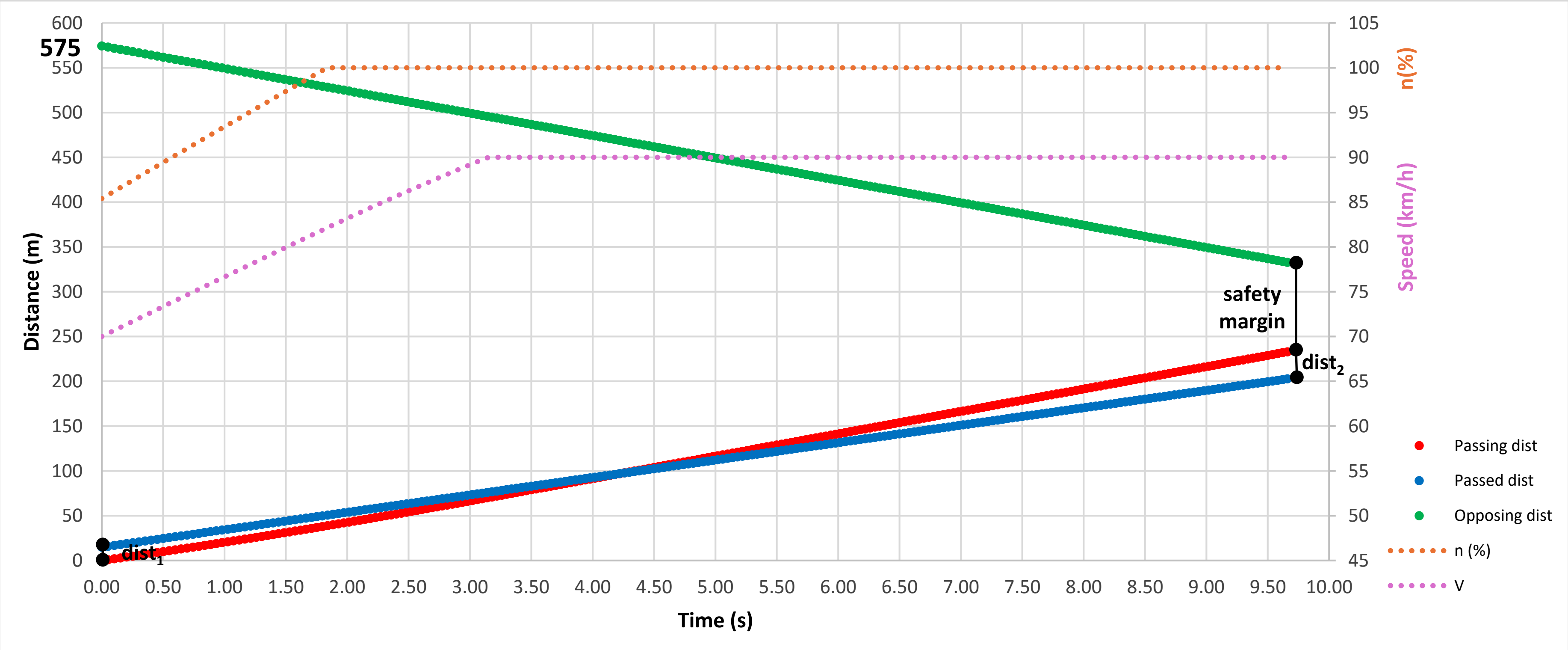


Example Passing Manoeuvre

Example Scenario

- Posted speed = 90 km/h
- Passed vehicle speed = 70 km/h
- ΔV = 20 km/h
- Grade = 4%
- Power = 120 hp





Result

- PSD ≈ 575 m

Simulation Database

Parameter Ranges

- 162 PSD observations

Variable	Range
Posted Speed (V_{posted})	80 km/h – 110 km/h
Passed Vehicle Speed (V_o)	70 km/h – 100 km/h
Horsepower (hp)	80 hp – 120 hp
Grade (s)	1 % – 6 %

Statistical Modelling

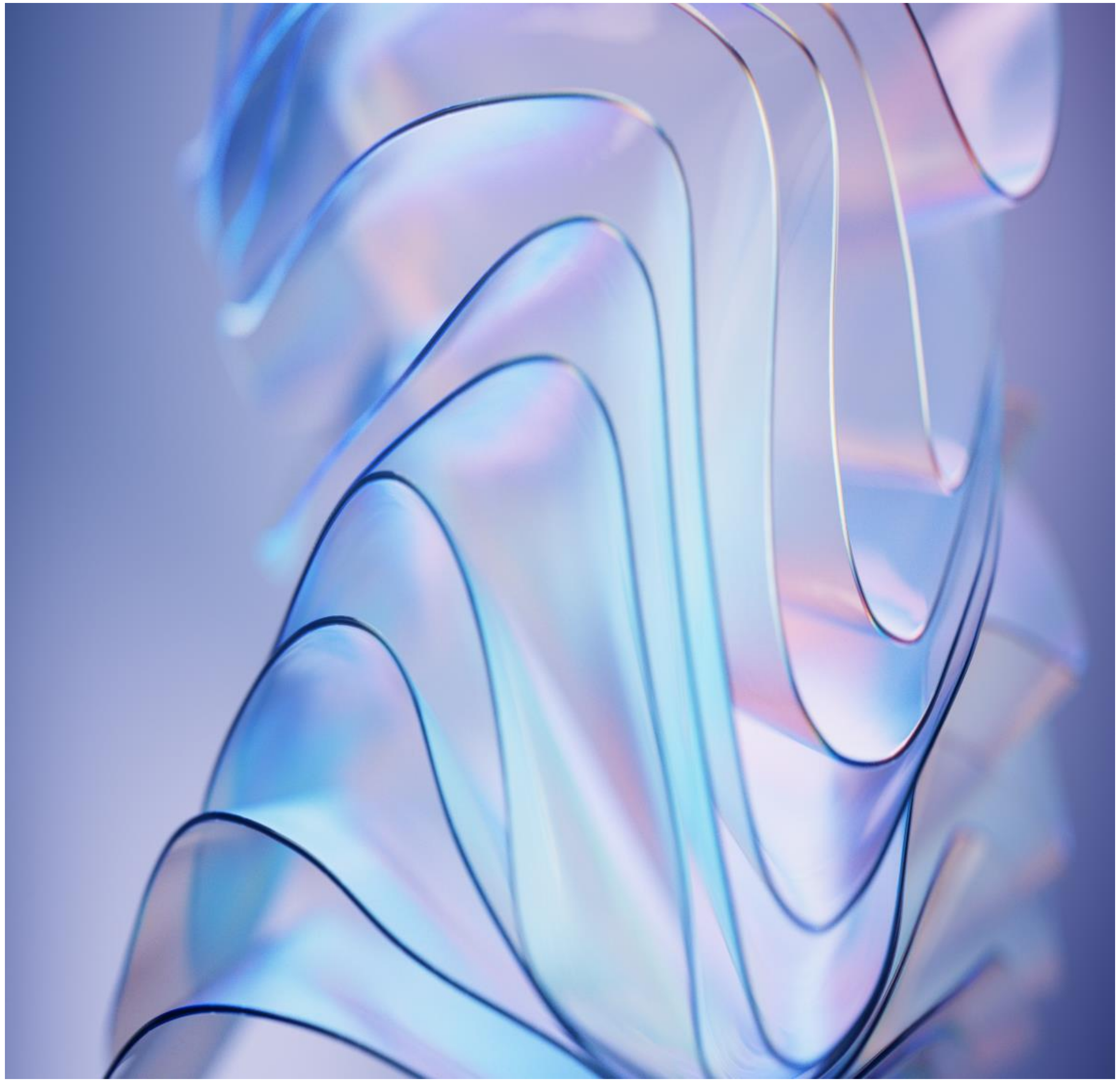
Lognormal Regression

$$\log(\mathrm{PSD_i}) = \sum \beta_i \cdot X_i + \varepsilon_i$$

Descriptive data analysis revealed nonlinear association of PSD vs examined variables

Purpose:

- Reduce computational burden
- Provide practical engineering tool
- Preserve physical relationships



Final PSD Equation

Output Model

$$\log(\mathbf{PSD}) = 14.8757 - 2.4750\ \log(\mathbf{V_{posted}}) + 14.3207\ \mathbf{hp}^{-1} + 0.000194\ \mathbf{s}^3 + 0.0364\ \mathbf{V_0}$$

Parameter	B	Std. Error	t-value	p-value	VIF
(Intercept)	14.876	0.2942	50.5636	<0.001	-
log (V_{posted})	-2.475	0.072	-34.3889	<0.001	1.86
hp^{-1}	14.321	3.1961	4.4807	<0.001	1.08
s^3	$1.94\ 10^{-4}$	0.000072	2.6993	0.0077	1.06
V_0	$3.64\ 10^{-2}$	0.0008	48.4234	<0.001	1.79

Adjusted R^2	0.936	df	4

Interpretation

- Outstanding explanatory capability
- No multicollinearity concerns

Sensitivity Analysis

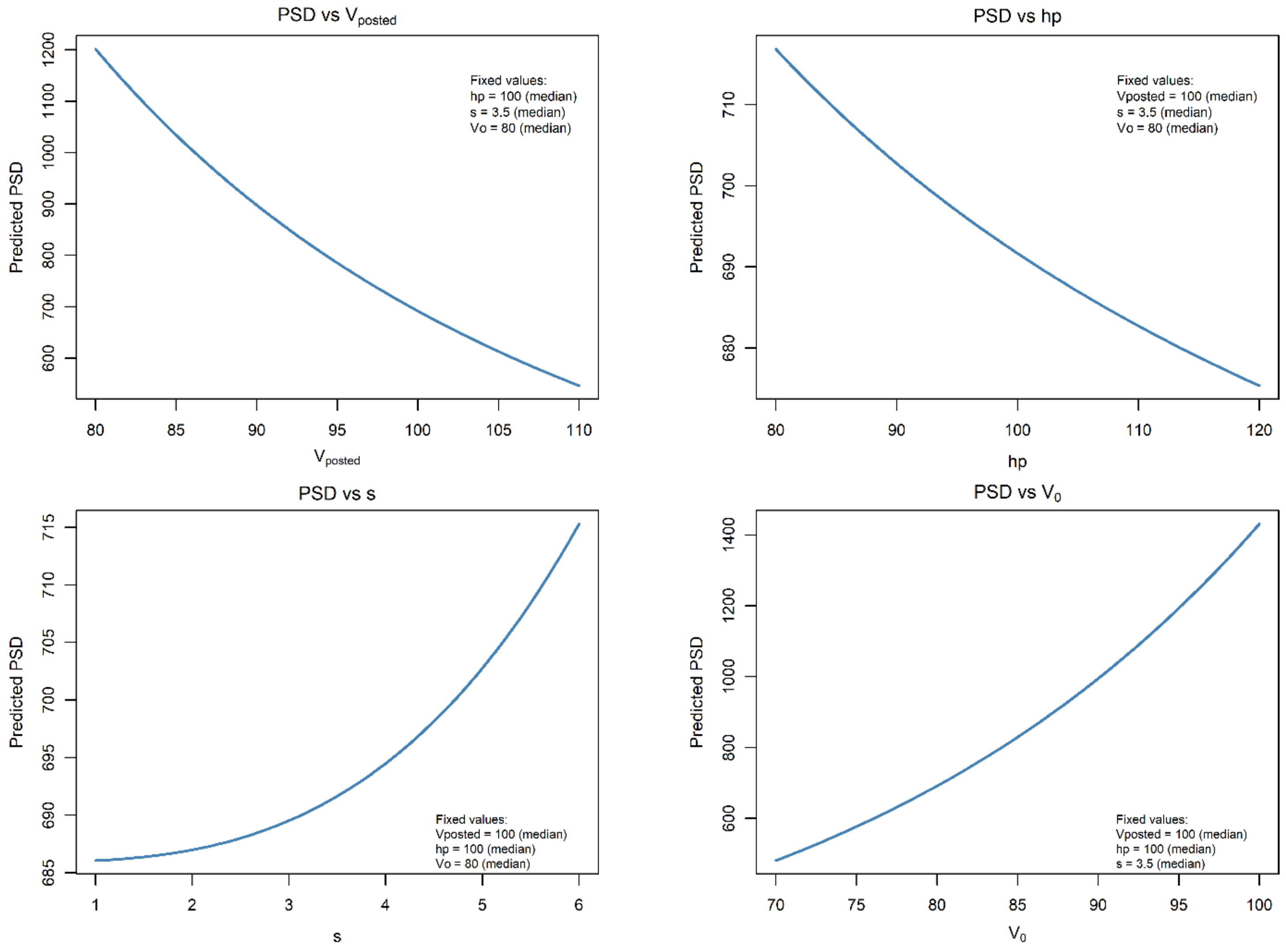
Approach

- One variable varied
- Others fixed at median value

V_{posted} = 100 km/h
hp = 100
s = 3.5%
V_o = 80 km/h

Strongest Predictors:

$V_o - V_{posted}$



Conclusions & Future Research

Conclusions

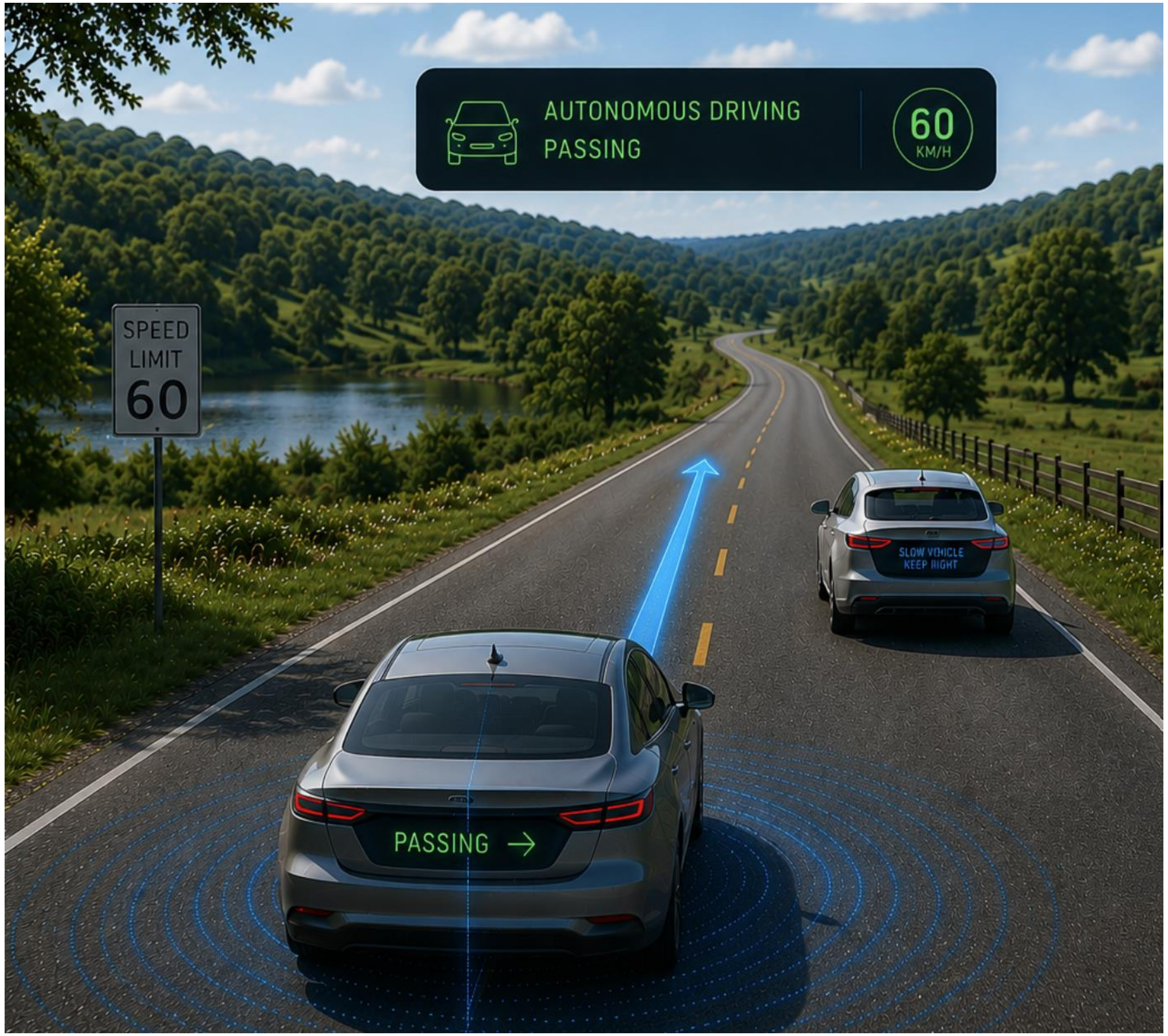
- Speed-related variables dominate PSD
- Grade effects become critical at steep slopes
- Horsepower contributes meaningfully
- Lognormal model predicts PSD accurately

Future Work

- Real-world passing validation
- Horizontal and vertical curvature effects
- Heavy vehicles and SUVs
- ADAS integration
- V2V and V2I applications

Long-Term Vision

- Real-time passing assistance systems based on dynamic PSD estimation



Integrated Assessment of Passing Maneuvers Based on Road and Vehicle Characteristics

Paper 311

Stergios Mavromatis
National Technical University of Athens
stemavro@central.ntua.gr