Modeling Perception Performance in Traffic Simulation

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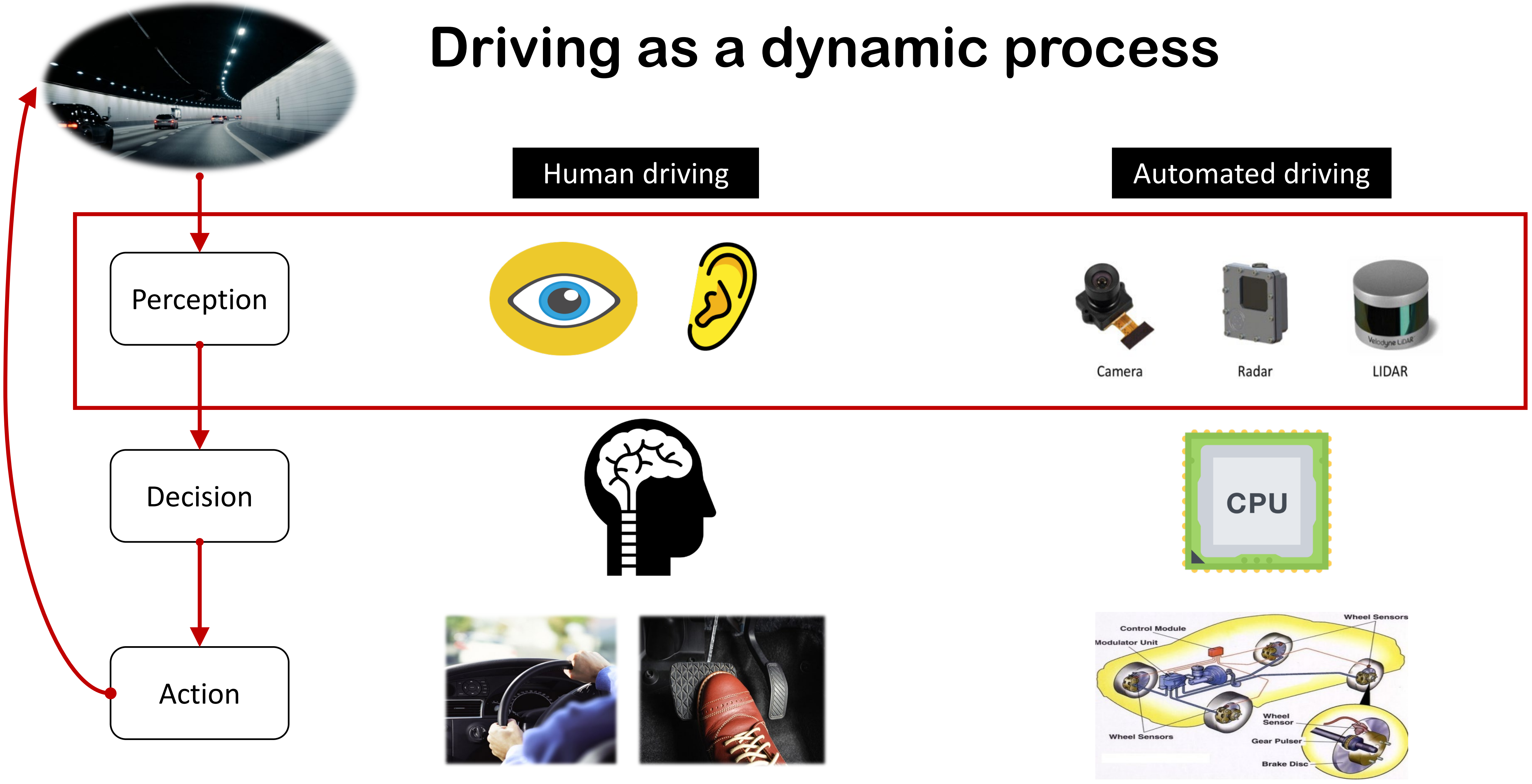
Background

- Automated driving systems (ADS) are expected.
- Road authorities concern of traffic performance.
- Microscopic traffic simulation tools need to be made ready to assess mixed traffic with automated driving.
- Microscopic models for automated driving are developed based on expectations with limited possibility for validation.

Driving as a dynamic process



Problem

- The perception is essential for the driving activity → situational awareness.

- In previous simulation experiments the perception is oversimplified[(1)]

    - Implicit modeling of perception.
    - Perfect perception / no perception errors.
    - Little / no difference in perception between automated and human driving.

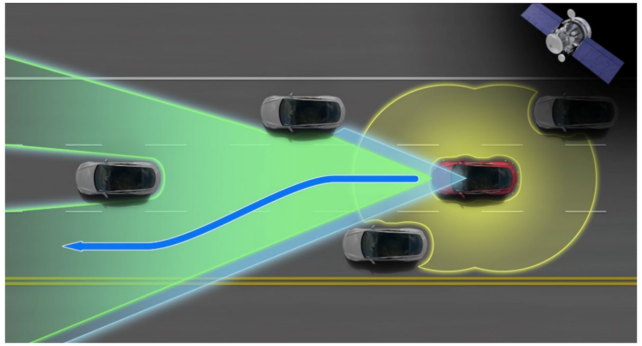
(1) Postigo et al. 2021, Effects on Traffic Performance Due to Heterogeneity of Automated Vehicles on Motorways : A Microscopic Simulation Study

Aim

- Develop a model that explicitly deals with the perception which ensures consistency and transparency about assumptions.

- Describe differences in **perception performance** for the types of perception expected in mixed traffic.

Vehicle perception

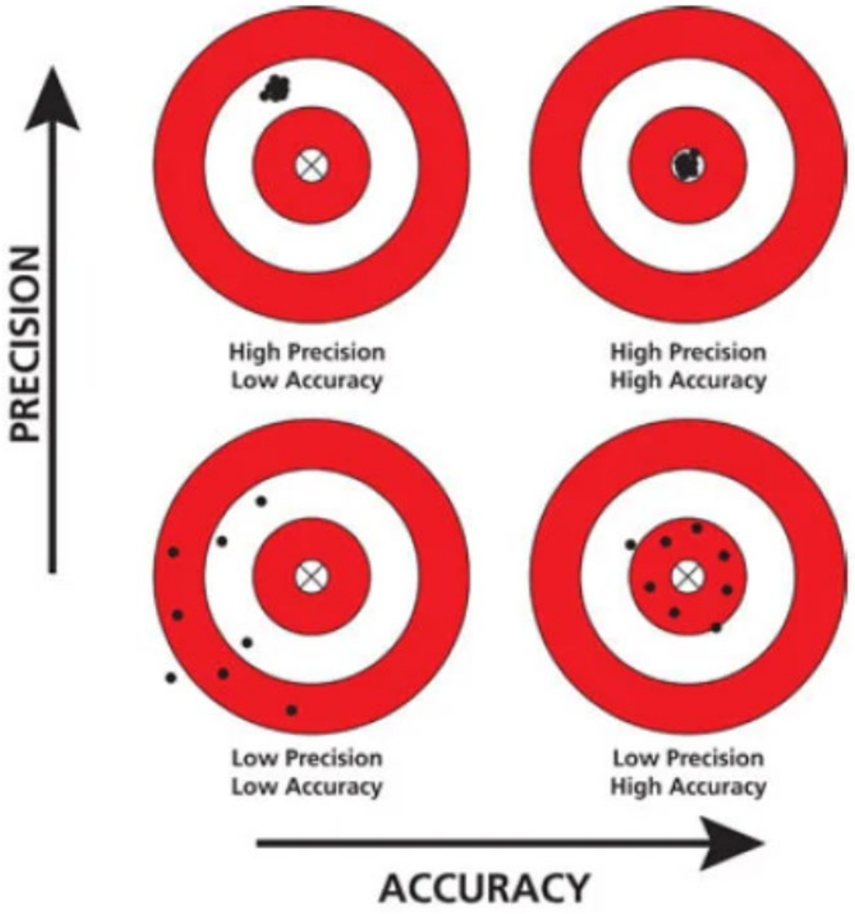


- How is the information obtained/what are the sensing capabilities?
  - Type of perception – e.g., sensors, v2x.
  - Accuracy - Precision - Range
- Which vehicles/objects can be perceived?
- What information can be known?
  - Position - Speed - Intentions
- When is the information obtained?
  - Delay

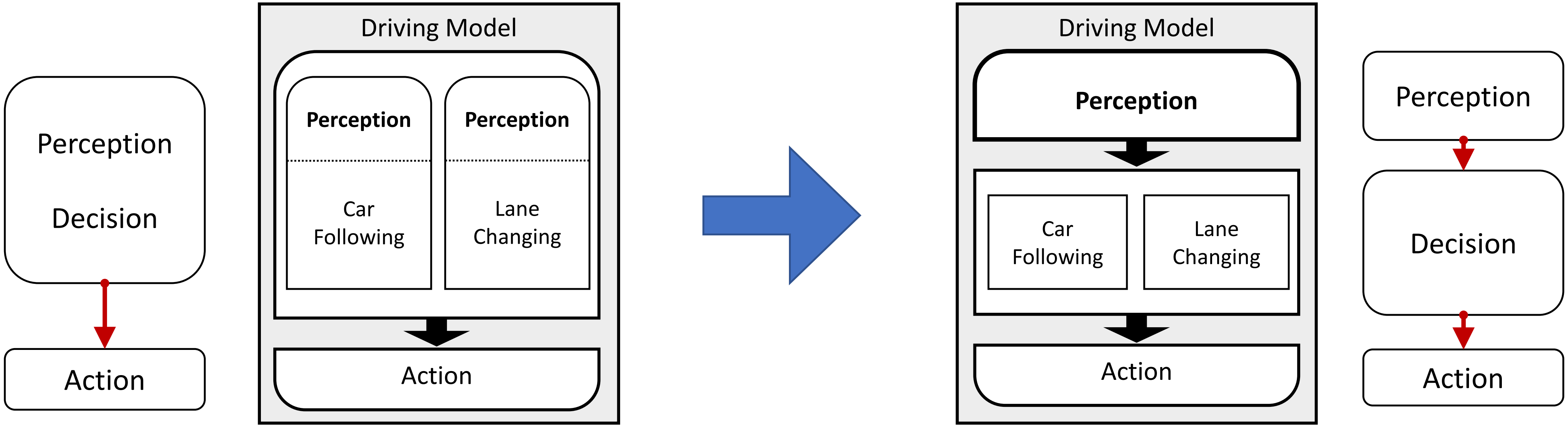
Perception performance

Four dimension to characterize the perception performance:

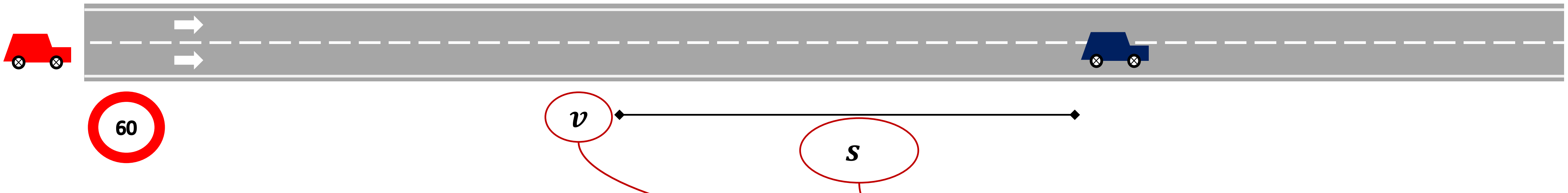
- Accuracy
- Precision
- Detection speed – Delay
- Range



Change in microscopic driving model



Example current approach – following regime



Perception

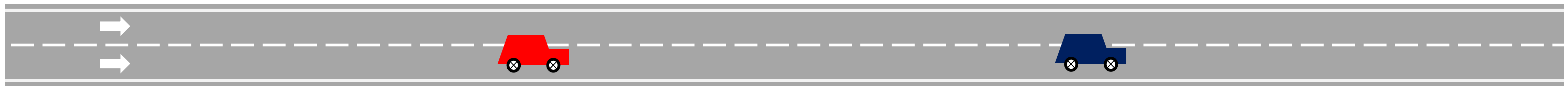
Decision

→ e.g., optimal velocity model
$a = f(s, v)$

$$v_{opt} = \frac{s}{T} \qquad a = \frac{v_{opt} - v}{\tau}$$

Action → a

Proposed approach – following regime



v s → s, v

Perception → Decision → Action

Perception Model

$$\hat{s} = f(s, \epsilon)$$
$$\hat{v} = f(v, \epsilon)$$

$$\epsilon = (\mu, \sigma)$$

Precision

Accuracy

Decision: $a = f(s, v)$ → $v_{opt} = \frac{\hat{s}}{T}$ $\quad$ $\boldsymbol{a} = \frac{\boldsymbol{v_{opt}} - \hat{\boldsymbol{v}}}{\boldsymbol{\tau}}$

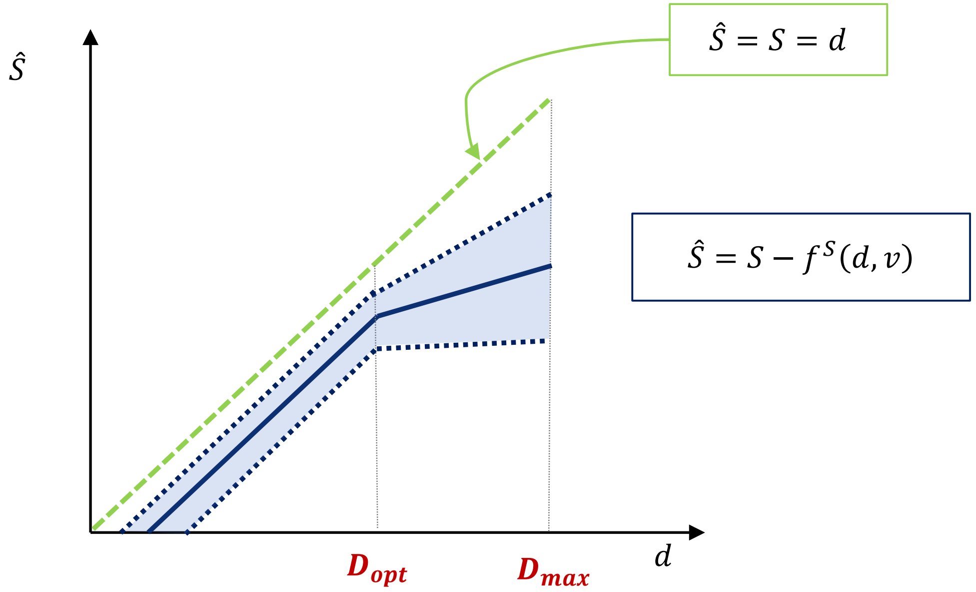
Action: a

Error function - $\boldsymbol{f^{\Omega}(d,v)}$

$$\boldsymbol{f^{\Omega}(d,v)} = \varepsilon^{\Omega}(d) + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$

accuracy — $\varepsilon^{\Omega}(d)$

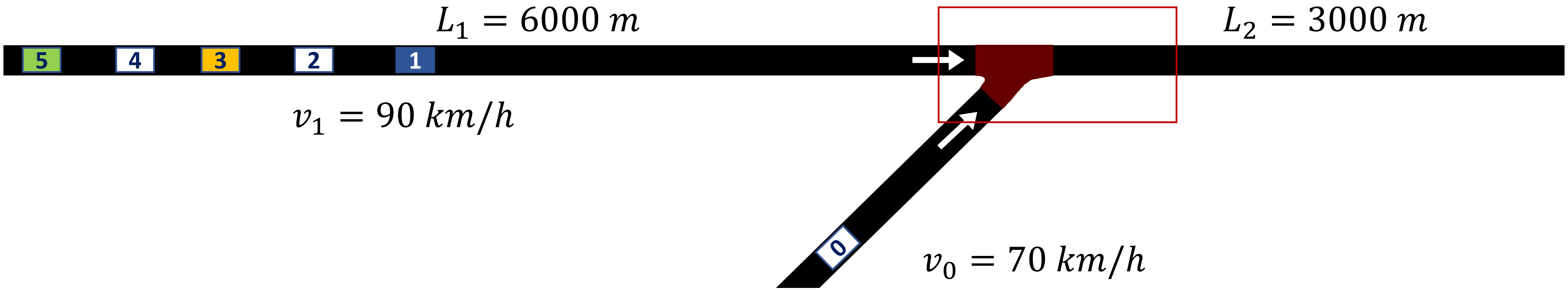
precision — $W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$



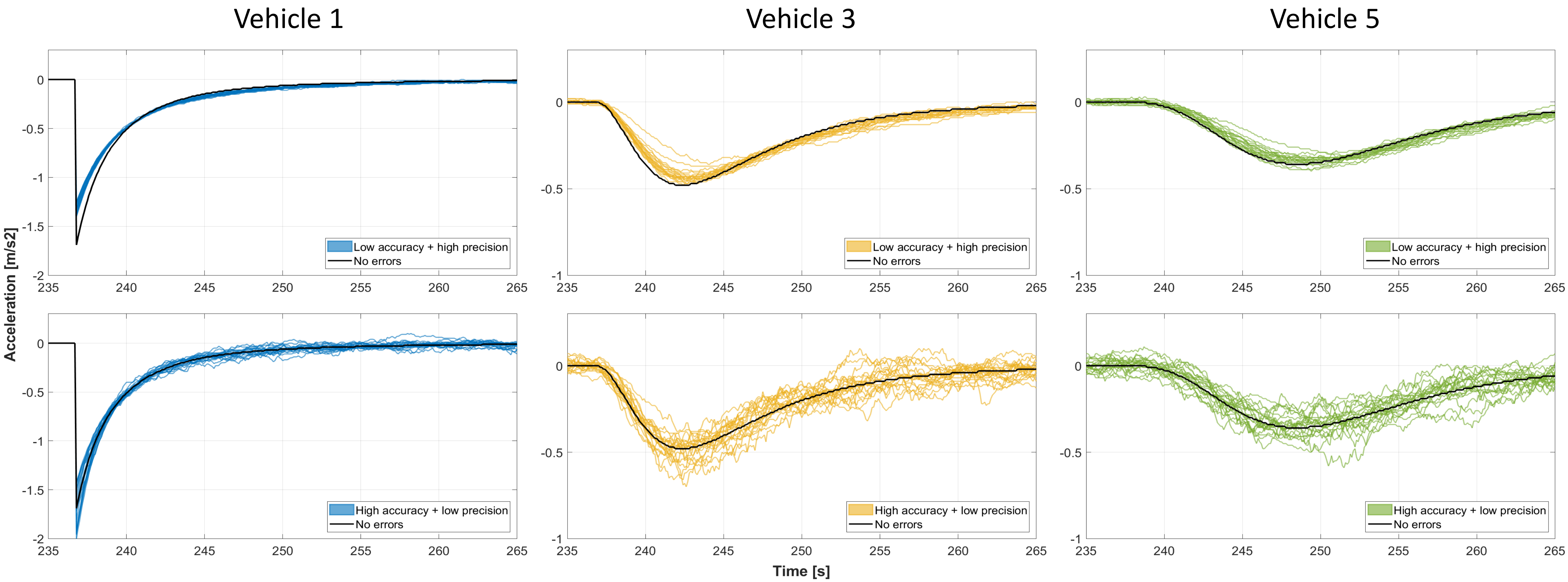
S : Front space gap or space headway
d : Distance
v : Speed

Simulation experiment

Base scenario	Scenario 1	Scenario 2
No errors	Low accuracy + high precision	High accuracy + low precision



Simulation results



Conclusions and future work

- Conclusions
  - Results show that perception errors affect the acceleration response and thereby the traffic flow dynamics.
  - Improved transparency for microscopic traffic simulation.
  - Enable explicit assumptions for different types of perception.
  - Improved consistency on the level of detail for different types of perception.
  - Improved modeling of mixed traffic in different driving conditions.

- Future work
  - Implement perception errors for other submodels.
  - Evaluate perception errors in a realistic simulation experiment.

Thanks for your attention!

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Accuracy (i)

$$f^{\Omega}(d,v) = \boldsymbol{\varepsilon^{\Omega}(d)} + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$

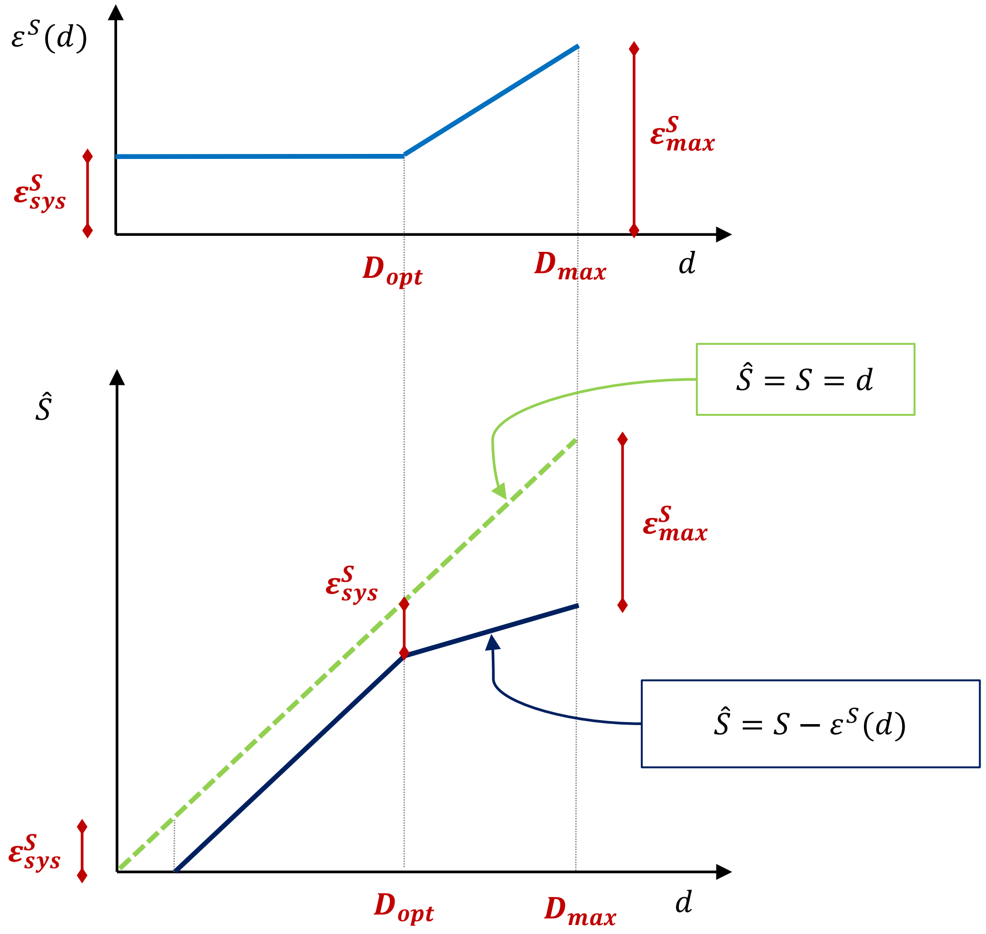
$\boldsymbol{\varepsilon^{\Omega}(d)}$ - *Parameters :*

$\varepsilon^{\Omega}_{sys}$: Systematic, persistent or minimum error

$\varepsilon^{\Omega}_{max}$: Error at maximum detection range

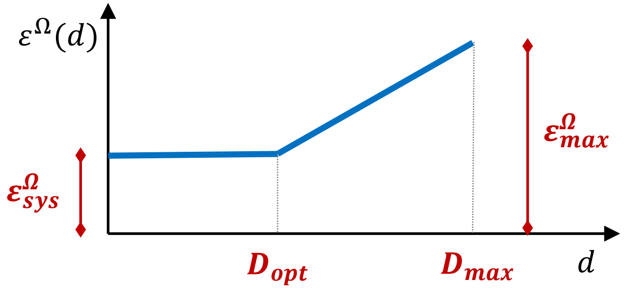
D_{opt} : Optimal operational range

D_{max} : Maximum detection range

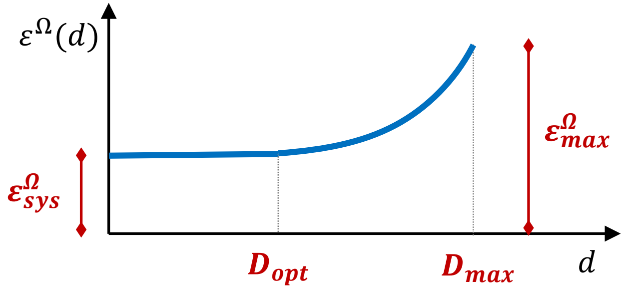


Accuracy (ii)

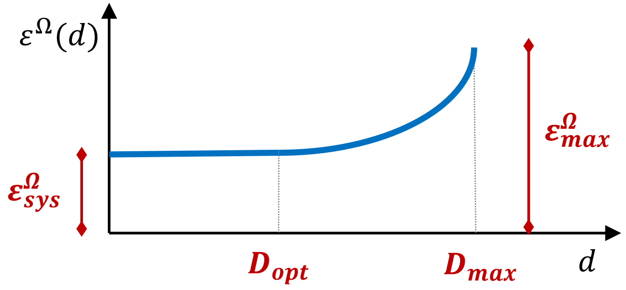
$$f^{\Omega}(d,v) = \boldsymbol{\varepsilon^{\Omega}(d)} + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$



linear



quadratic



ellipse

Precision (i)

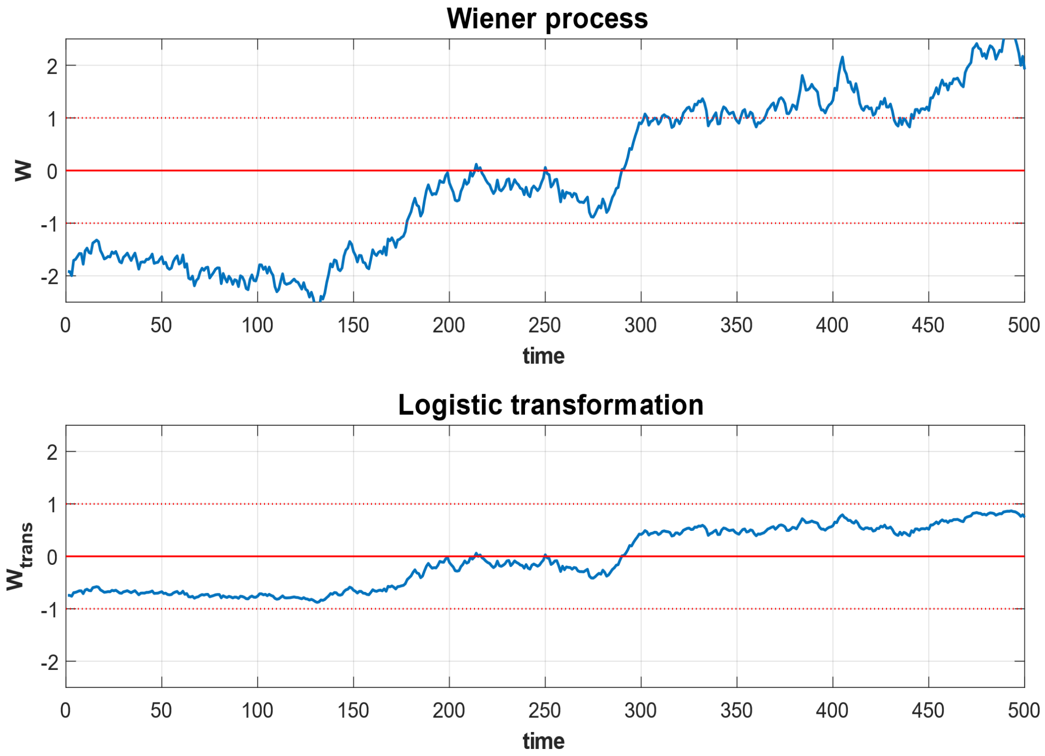
$$f^{\Omega}(d,v) = \boldsymbol{\varepsilon}^{\boldsymbol{\Omega}}(\boldsymbol{d}) + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$

$$\boldsymbol{W_{trans}} \in [-\mathbf{1}, \mathbf{1}]$$

$$\boldsymbol{W_{trans}} = \frac{\mathbf{2}}{\mathbf{1} + \mathbf{exp}(-\boldsymbol{W})} - \mathbf{1}$$

$$W(t+\Delta t) = \begin{cases} \eta, & initial \\ \exp\left(-\frac{\Delta t}{\tau}\right) * W(t) + \eta\sqrt{\frac{2\Delta t}{\tau}}, & otherwise \end{cases}$$

$\eta \in N(0,1)$
τ: Time-window correlation



Precision (ii)

$$f^{\Omega}(d,v) = \boldsymbol{\varepsilon}^{\boldsymbol{\Omega}}(\boldsymbol{d}) + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$

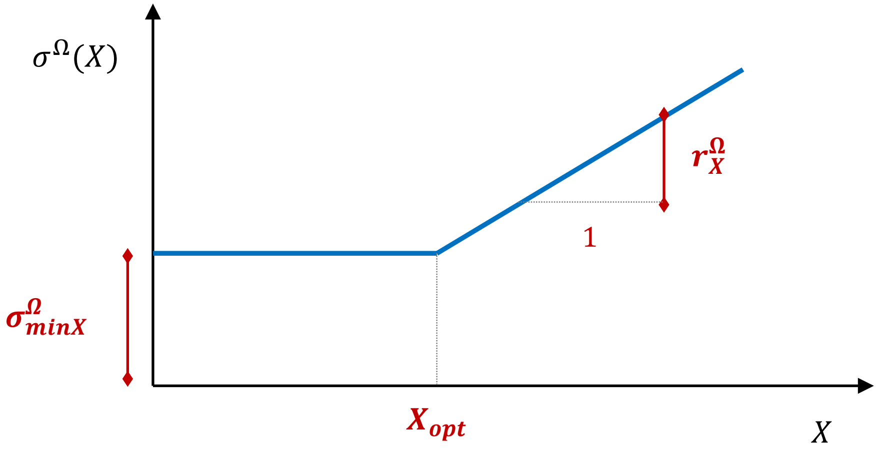
$$\mathrm{X} = \{d, v\}$$

$\boldsymbol{\sigma}^{\boldsymbol{\Omega}}(\boldsymbol{X})$ - *Parameters :*

σ^{Ω}_{minX} : Minimum variation or noise

r^{Ω}_{X} : variation increase rate

X_{opt} : Optimal operational range

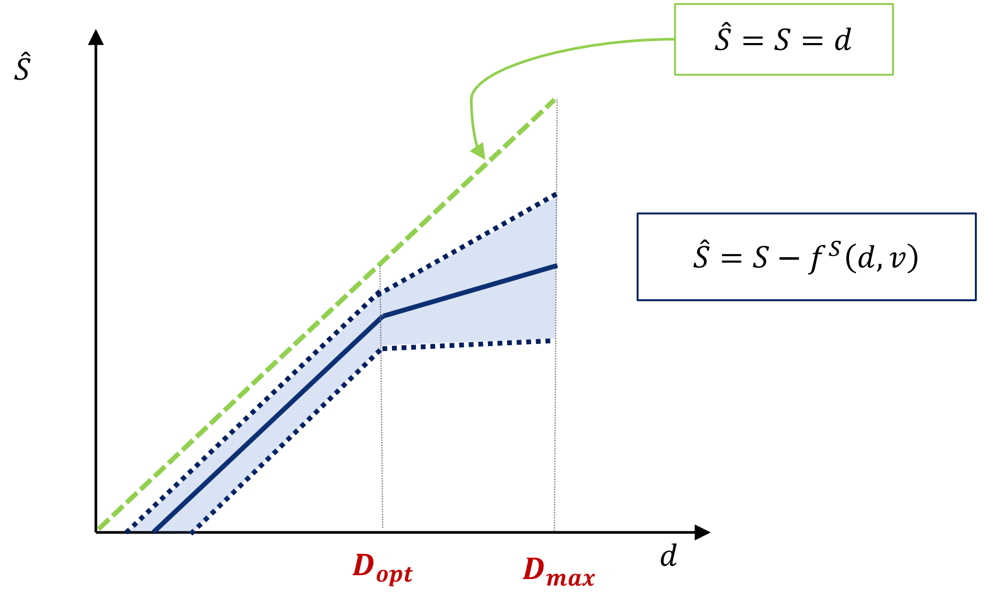


Accuracy and precision

Parameters :

$\varepsilon^{\Omega}_{sys}$	: Systematic, persistent or minimum error
$\varepsilon^{\Omega}_{max}$	: Error at maximum detection range
D_{opt}	: Optimal operational range
D_{max}	: Maximum detection range
σ^{Ω}_{minD}	: Minimum distance variation or noise
r^{Ω}_{d}	: Distance variation increase rate
σ^{Ω}_{minV}	: Minimum speed variation or noise
r^{Ω}_{v}	: Speed variation increase rate
V_{opt}	: Optimal operational speed
τ	: Time-window variation correlation

$$f^{\Omega}(d,v) = \varepsilon^{\Omega}(d) + W_{trans} * (\sigma^{\Omega}(d) + \sigma^{\Omega}(v))$$

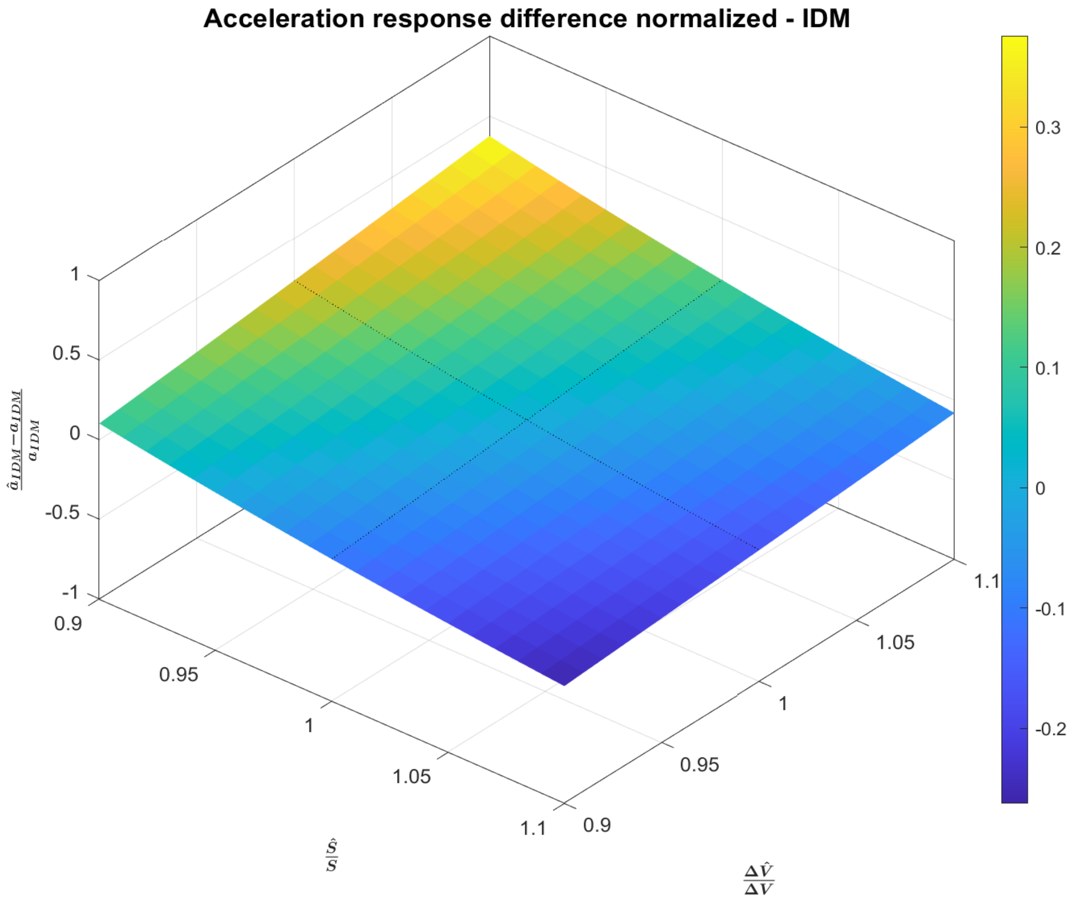


Intelligent driver model (IDM) sensibility

$$\dot{v} = a \cdot \left(1 - \left(\frac{v}{V_o}\right)^{\delta} - \left(\frac{S^*}{S}\right)^{2}\right)$$

$$S^* = So + \max\left\{\left(0, vT + \frac{v\Delta v}{2\sqrt{ab}}\right)\right\}$$

a = 1 m/s2
S = 65 m
v = 25 m/s
Vo = 25 m/s
Delta V = 5.55 m/s



Change in fundamental diagram (IDM)

Vo = 19.45 m/s

$$S = Se(v) = \frac{so + vT}{\sqrt{1 - \left(\frac{v}{Vo}\right)^{\delta}}}$$

$$\rho = \frac{1}{S}$$

$$Q = \rho * V$$