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## A Novel Adaptive Driver Sensitivity Framework Significantly Improves Traffic Stability and Safety of Autonomous Vehicles.



### 1 INTRODUCTION & AIM

- Autonomous vehicles require adaptive driver behavior.
- Existing OV/FVD models assume constant sensitivity.
- This work develops dynamic headway- and velocity-dependent sensitivity.

**Aim:**  
To design driver sensitivity functions that improve traffic stability and collision avoidance in autonomous traffic systems.

### 2 RESEARCH GAP & NOVELTY

- Research Gap**
- Existing models assume constant sensitivity.
  - Produce unrealistic acceleration/ deceleration.
  - Show larger unstable traffic regions.

#### Novelty of This Work

- Dynamic headway-dependent sensitivity
- Taillight-adapting velocity sensitivity
- New neutral stability conditions
- Reduced unstable traffic regions
- Improved autonomous traffic stability
- Enhanced collision avoidance capability

### 3 MODEL FORMULATION

#### 3.1 Case I – Headway-Based Sensitivity

Driver action depends on the preceding headway gap.

Governing equation:

$$\frac{dv_n(t)}{dt} = a [V(\Delta x_n(t)) - v_n(t)] + \lambda(\Delta x_n(t))\Delta v_n \quad (1)$$

where  $v_n$ : speed of  $n^{\text{th}}$  vehicle,  $a$ : sensitivity,

$V(\Delta x_n)$ : optimal velocity,  $\Delta x_n = x_{n+1} - x_n$ ,

$\Delta v_n = v_{n+1} - v_n$ .

Sensitivity function (headway dependent):

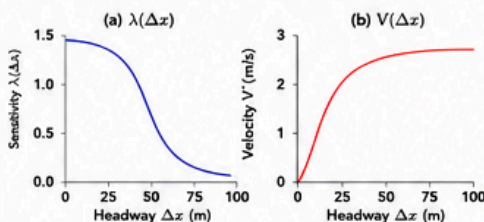
$$\lambda(\Delta x_n(t)) = \lambda_{\min} + \frac{\lambda_{\max} - \lambda_{\min}}{1 + e^{\alpha(\Delta x - h_c)}} \quad (2)$$

Optimal velocity function (OV):

$$V(\Delta x_n) = \frac{v_{\max}}{2} [\tanh(\Delta x_n - h_c) + \tanh(h_c)] \quad (3)$$

where  $h_c$ : safety distance,  $v_{\max}$ : maximum velocity.

Figure 1: Headway-based sensitivity  $\lambda(\Delta x)$  and OV  $V(\Delta x)$



- Properties:
- $\lambda$  is high for small headway (prevent collision).
  - $\lambda$  decreases as headway increases.
  - Ensures smooth and realistic traffic behavior.

#### 3.2 Case II – Velocity Difference (Taillight) Sensitivity

Sensitivity adapts to the velocity difference via taillight signals.

Governing equation:

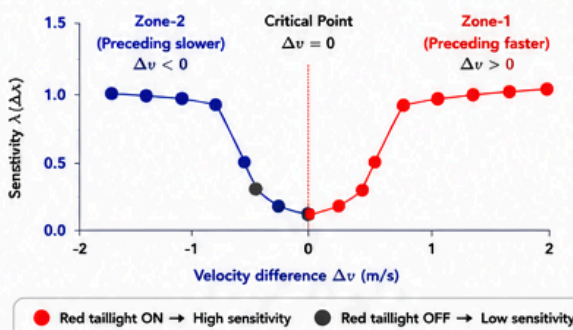
$$\frac{dv_n(t)}{dt} = a [V(\Delta x_n(t)) - v_n(t)] + \lambda(\Delta v_n(t))\Delta v_n \quad (4)$$

Improved sensitivity function:

$$\lambda(\Delta v_n(t)) = \begin{cases} \lambda_{\max}^D - (\lambda_{\max}^D - \lambda_{\min}^*) \cdot \text{Sech}[4 \cdot \Delta v_n(t)], & \Delta v_n(t) \leq 0 \\ \lambda_{\max}^A + (\lambda_{\max}^A - \lambda_{\min}^*) \cdot (-\text{Sech}[4 \cdot \Delta v_n(t)]), & 0 \leq \Delta v_n(t) < 2 \end{cases} \quad (5)$$

where  $\lambda_{\min}^*$ : lower limit,  $\lambda_{\max}^D$ : upper limit (deceleration),  
 $\lambda_{\max}^A$ : upper limit (acceleration).

Figure 2: Taillight-adapting sensitivity  $\lambda(\Delta v)$



### 4 METHODOLOGY



#### Model & Simulation Setup

- Periodic (cyclic) boundary condition
- Number of vehicles:  $N = 100$
- Road length:  $L = 2000$  m
- Safety distance:  $h_c = 2$  m
- Maximum velocity:  $v_{\max} = 30$  m/s
- Time step:  $\Delta t = 0.1$  s
- Initial condition: uniform spacing, equal velocity

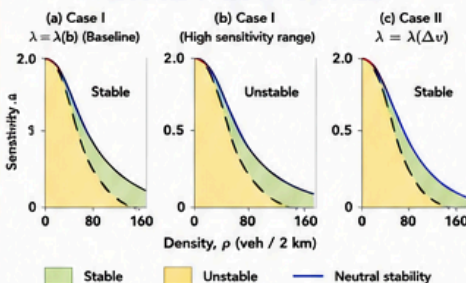
### 5 LINEAR STABILITY ANALYSIS

Linear stability of the homogeneous traffic flow leads to the neutral stability condition:

$$au = 2 [V'(b) - \lambda(u)] \quad (6)$$

where  $b$ : equilibrium headway,  $u$ : perturbation wave number.

Figure 3: Stability regions in the  $(\rho, a)$  plane

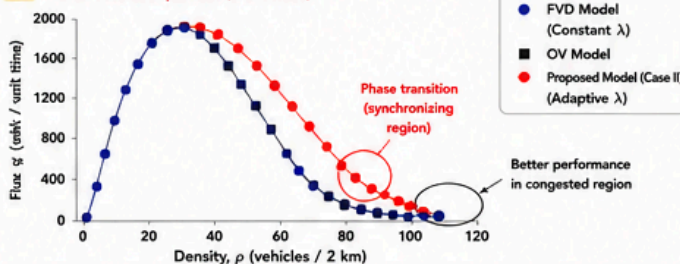


#### Implications:

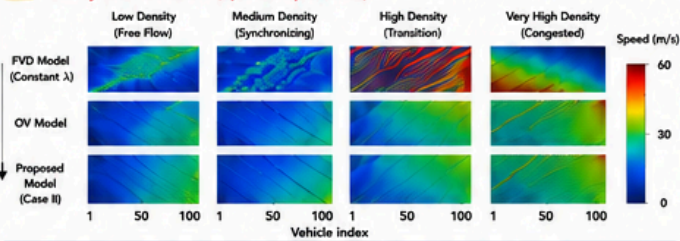
- Case I shifts instability toward lower-density regions.
- Case II substantially reduces unstable regions.
- Stability improves as adaptive sensitivity increases.

### 6 NUMERICAL SIMULATION & RESULTS

#### 6.1 Traffic Flux Comparison (2 km road)



#### 6.2 Density Wave Evolution (Spatiotemporal Plot)



The proposed model produces smoother waves and effectively suppresses stop-and-go oscillations across all traffic densities.

### 7 CONCLUSION

- A novel adaptive driver sensitivity framework based on headway and velocity difference is proposed.
- It significantly improves traffic stability compared with conventional models.
- It reduces unrealistic acceleration and deceleration and suppresses stop-and-go waves.
- It reduces collision risk and improves congestion performance.
- It provides the foundation for next-generation intelligent transportation systems.

### 8 FUTURE WORK

- Extend the model to multi-lane heterogeneous traffic.
- Incorporate lane-changing and overtaking behavior.
- Develop adaptive and learning-based sensitivity estimation for real-time AV control.
- Integrate with connected vehicle (V2V/V2I) communication systems.
- Experimental validation using real-world traffic data and AV platforms.

### 9 ACKNOWLEDGEMENTS

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### 10 KEY FINDINGS

- Smaller unstable region than FVD.
- Suppressed stop-and-go oscillations.
- Improved traffic flow in synchronized and congested regimes.
- Enhanced collision avoidance and vehicle safety.
- More realistic driver behavior.
- Supports safer autonomous traffic systems.

### 11 REFERENCES

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