# Hysteresis Phenomenon in Traffic Safety Analysis

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## Introduction

### Hysteresis in Traffic Analysis

- Hysteresis Phenomenon: a delay recovery from disturbances in traffic characteristics
- Categories:
  - Macroscopic: traffic flow
  - Microscopic: vehicle speed and acceleration
- Causes:
  - Diverse driver populations
  - Driver behaviours from aggressive to cautious
  - Drivers relaxation and anticipation
- Impact:
  - A strong correlation between hysteresis and string instability
  - Intensify traffic oscillations, thereby negatively impacting traffic safety and efficiency
- Manifestation: Hysteresis loop (clockwise or counterclockwise)
- Quantification:
  - Macroscopic: the average flow differentials during the deceleration and acceleration phases in stop-and-go traffic
  - Microscopic: the average spacing difference between the acceleration and deceleration phases

### Traffic Safety Analysis

- Indicators to evaluate traffic safety:
  - Temporal proximity indicators
  - Distance-based indicators
  - Deceleration-based indicators
- Time-to-collision (TTC): the ratio of spacing to relative speed between a pair of consecutive vehicles

## Does the hysteresis phenomenon occur in traffic safety Analysis?

Research Objectives:

- Identification of safety hysteresis at microscopic and macroscopic scales
- Development of Hysteresis Intensity (HI) to quantify the safety hysteresis
- Examination of the impact of acceleration and deceleration on safety HI

## Dataset and Preliminary

- Dataset: Next Generation Simulation (NGSIM) Vehicle Trajectories Data.
- Traffic Safety Evaluation: Time-to-collision (TTC),

$$TTC_n = \begin{cases} \dfrac{x_{n-1} - x_n - l_{n-1}}{v_n - v_{n-1}}, & \text{if } v_n > v_{n-1} \\ \infty, & \text{otherwise} \end{cases} = \begin{cases} \dfrac{s_n}{\Delta v_n}, & \text{if } v_n > v_{n-1} \\ \infty, & \text{otherwise} \end{cases} \quad (1)$$

where $x_{n-1}$ and $x_n$ denote the positions of the leading vehicle $(n-1)$ and the following vehicle $n$, respectively; $l_{n-1}$ refers to the length of vehicle $(n-1)$; $v_{n-1}$ and $v_n$ are the velocities of vehicle $(n-1)$ and vehicle $n$, respectively; $s_n$ refers to the spacing between vehicle $n$ and its preceding vehicle $(n-1)$.

- Fundamental Metrics of Traffic Flow: for an arbitrary region, denoted as $R$, to assess the key fundamental metrics of macroscopic traffic flow. These include traffic density ($k_R$), traffic flow ($q_R$), and average speed ($v_R$), derived as follows

$$k_R = \frac{\sum_{i=1}^{n} t_i}{|R|} \approx \frac{1}{\bar{s}_R};\ q_R = \frac{\sum_{i=1}^{n} d_i}{|R|} \approx \frac{1}{\bar{h}_R};\ v_R = \frac{q_R}{k_R} \quad (2)$$

where $t_i$ and $d_i$ represent the time and distance for vehicle $i$ traveled inside $R$, respectively; $|R|$ indicates the area of region $|R|$; $\bar{s}_R$ and $\bar{h}_R$ refers to the average spacing and headway in region $R$.

- Simulation Setting: Intelligent Driver Model (IDM),

$$\dot{v}_n = a\left[1 - \left(\frac{v_n}{v_0}\right)^{\delta} - \left(\frac{s_0 + v_n T + \frac{v_n \Delta v_n}{2\sqrt{ab}}}{s_n}\right)^2\right] \quad (3)$$

## Microscopic Safety Hysteresis Analysis

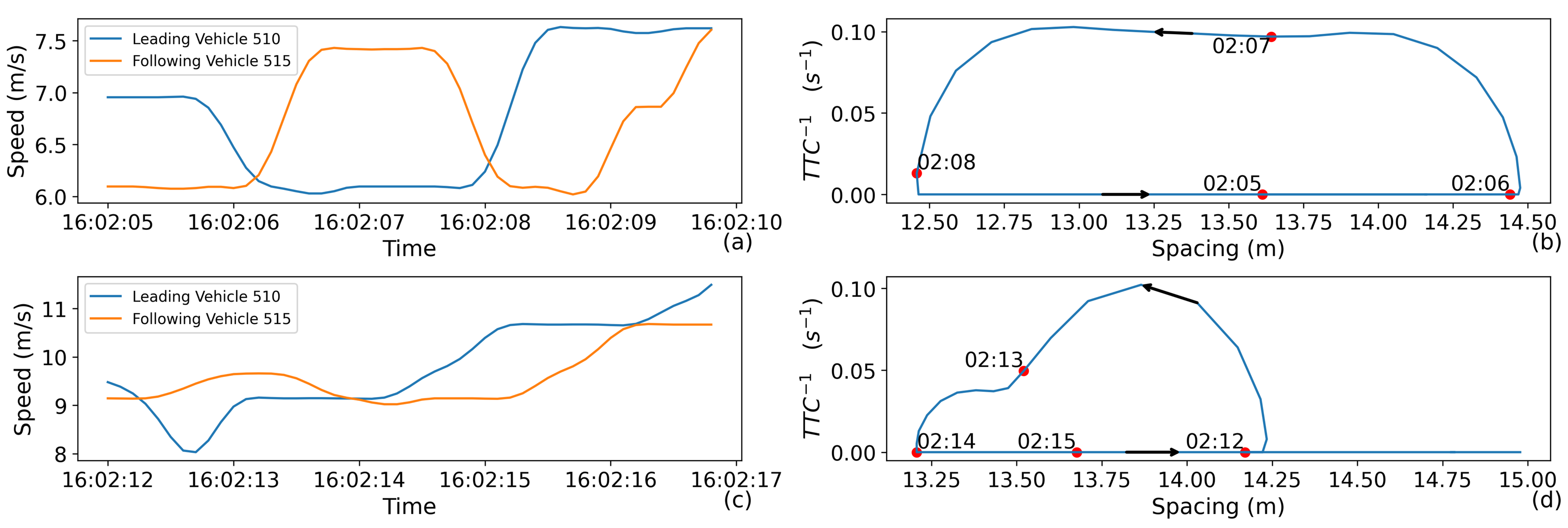


Figure 1. Microscopic safety hysteresis phenomena for vehicle 510 and 515 on I-80 lane 2

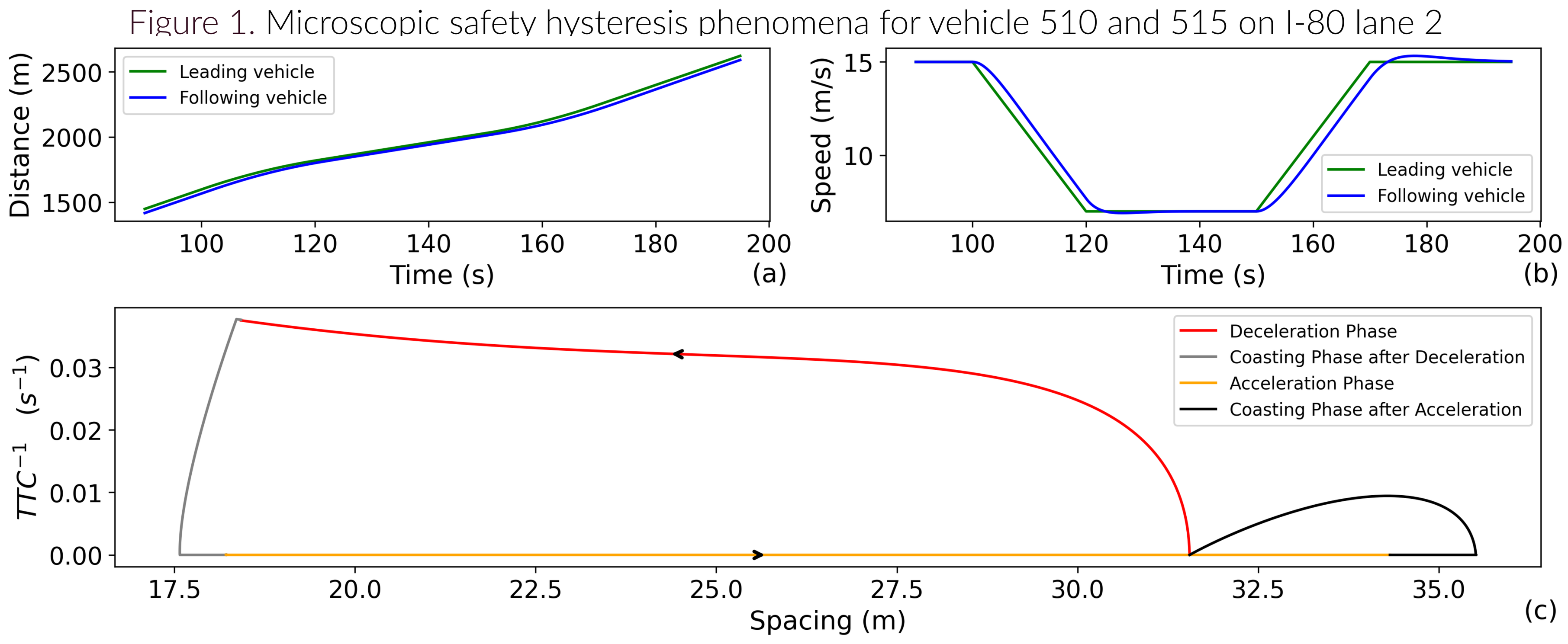


Figure 2. Microscopic safety hysteresis in simulation environment

Quantification of microscopic safety hysteresis, i.e., microscopic safety HI:

$$I_s = \frac{|A|}{\Delta s_A} \quad (4)$$

where $|A|$ indicates the area of the micro hysteresis loop $A$ and $\Delta s_A$ represents the spacing span of this hysteresis loop.

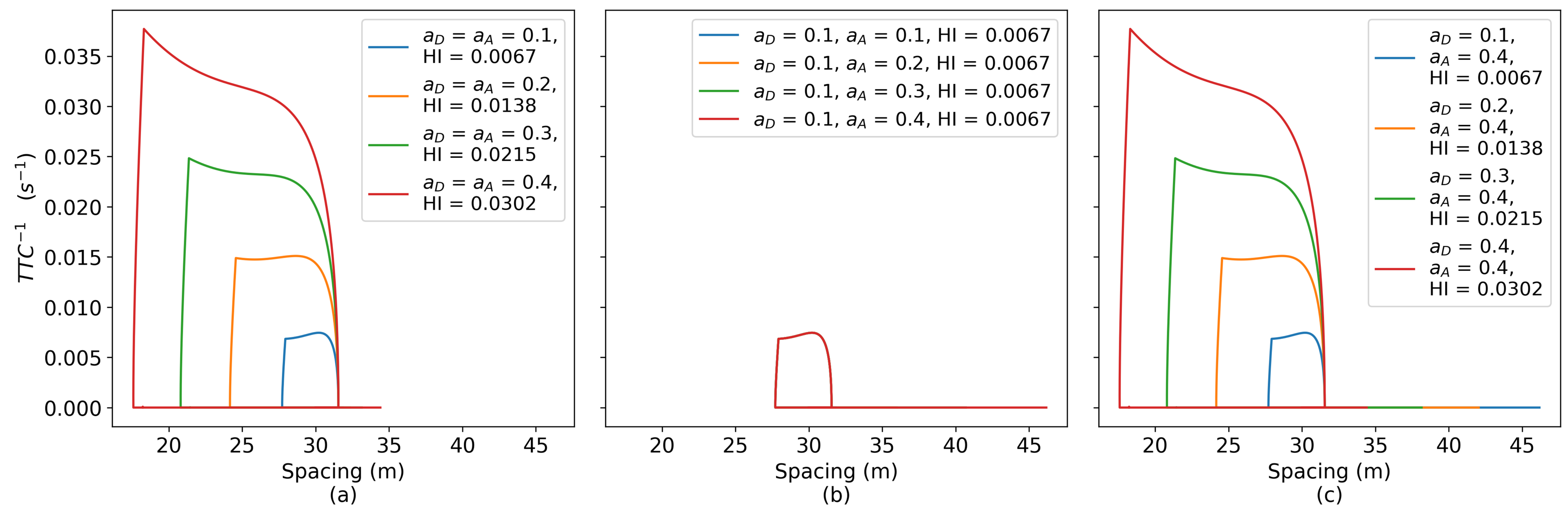


Figure 3. Effect of acceleration on microscopic safety hysteresis

## Macroscopic Safety Hysteresis Analysis

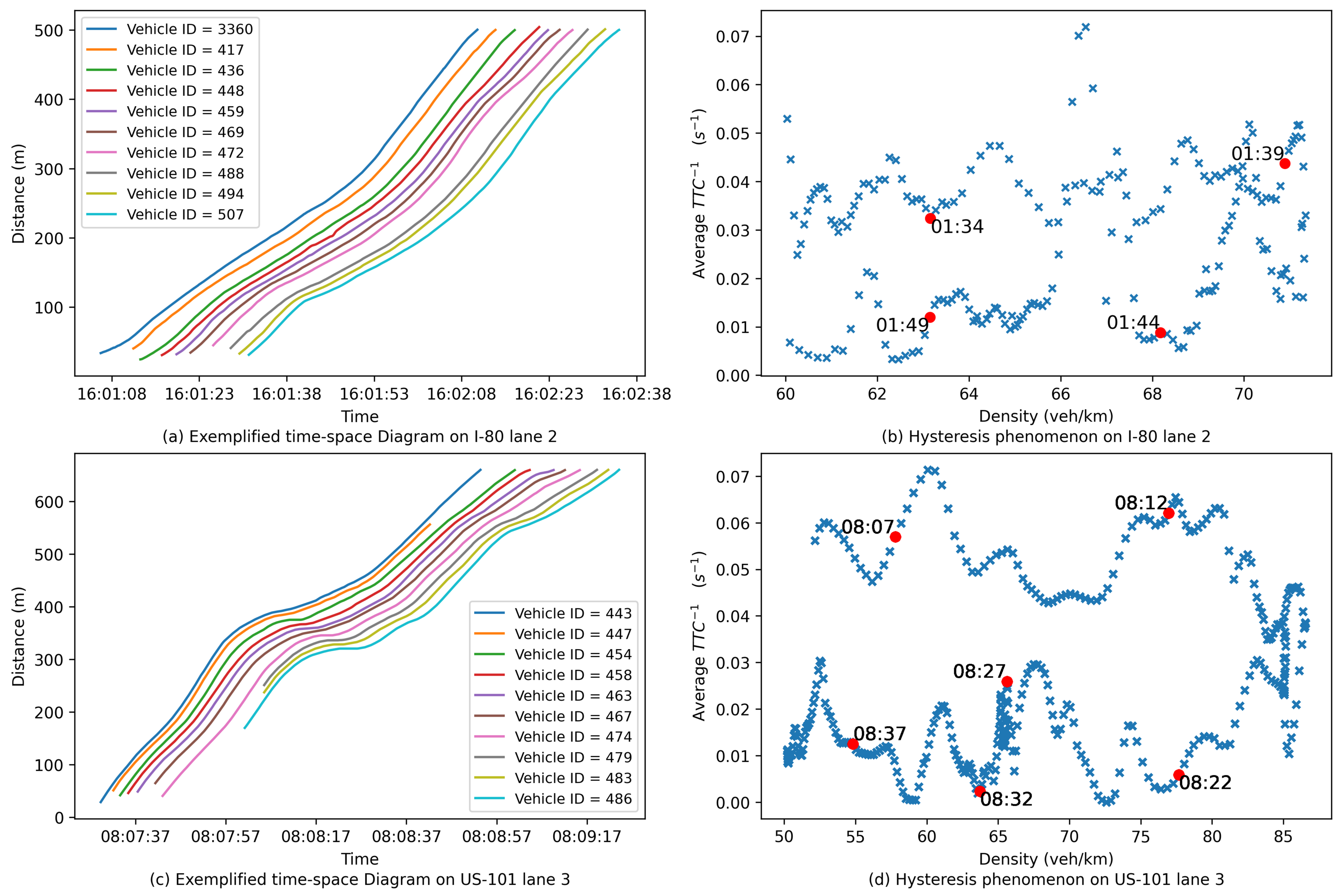


Figure 4. Macroscopic safety hysteresis phenomena on I-80 lane 2 and US-101 lane 3

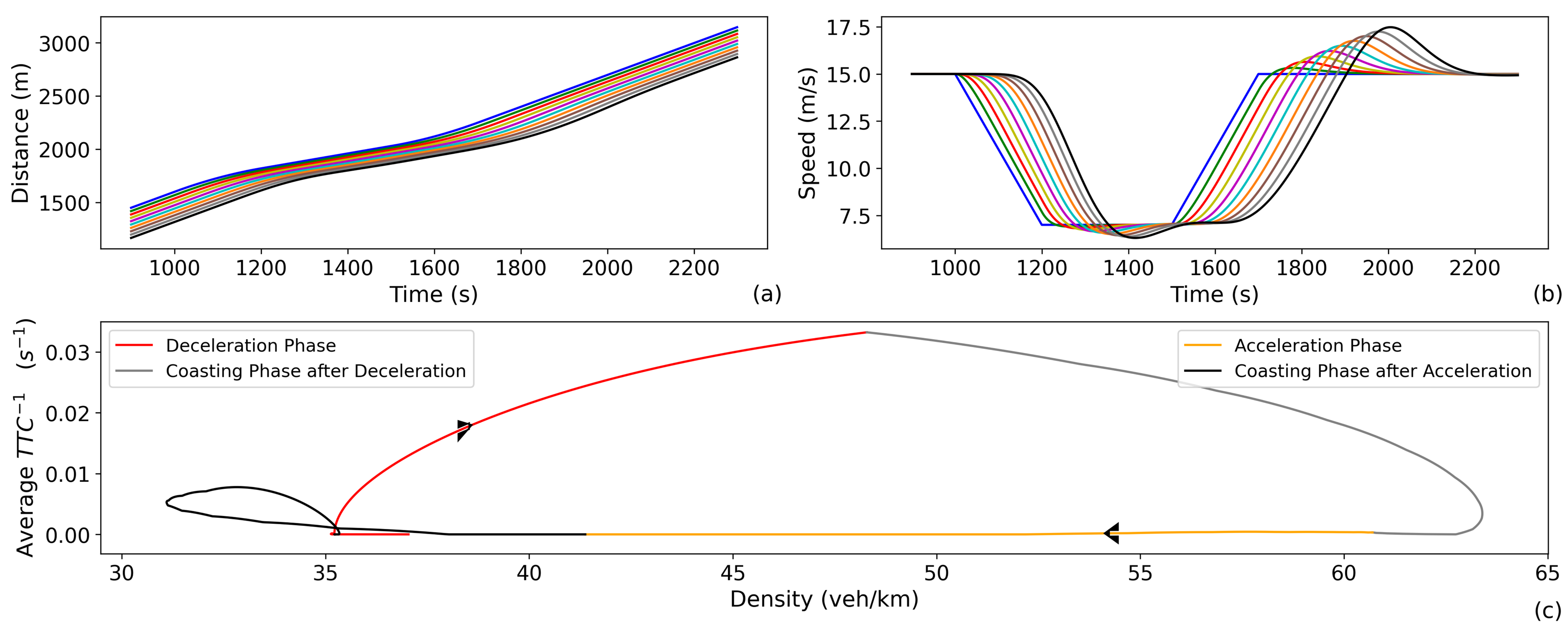


Figure 5. Macroscopic safety hysteresis in simulation environment

Quantification of macroscopic safety hysteresis, i.e., macroscopic safety HI:

$$\mathbb{I}_s = \frac{|\mathbb{A}|}{\Delta k_{\mathbb{A}}} \quad (5)$$

where $|\mathbb{A}|$ indicates the area of the hysteresis loop $\mathbb{A}$ and $\Delta k_{\mathbb{A}}$ represents the density span of this hysteresis loop.

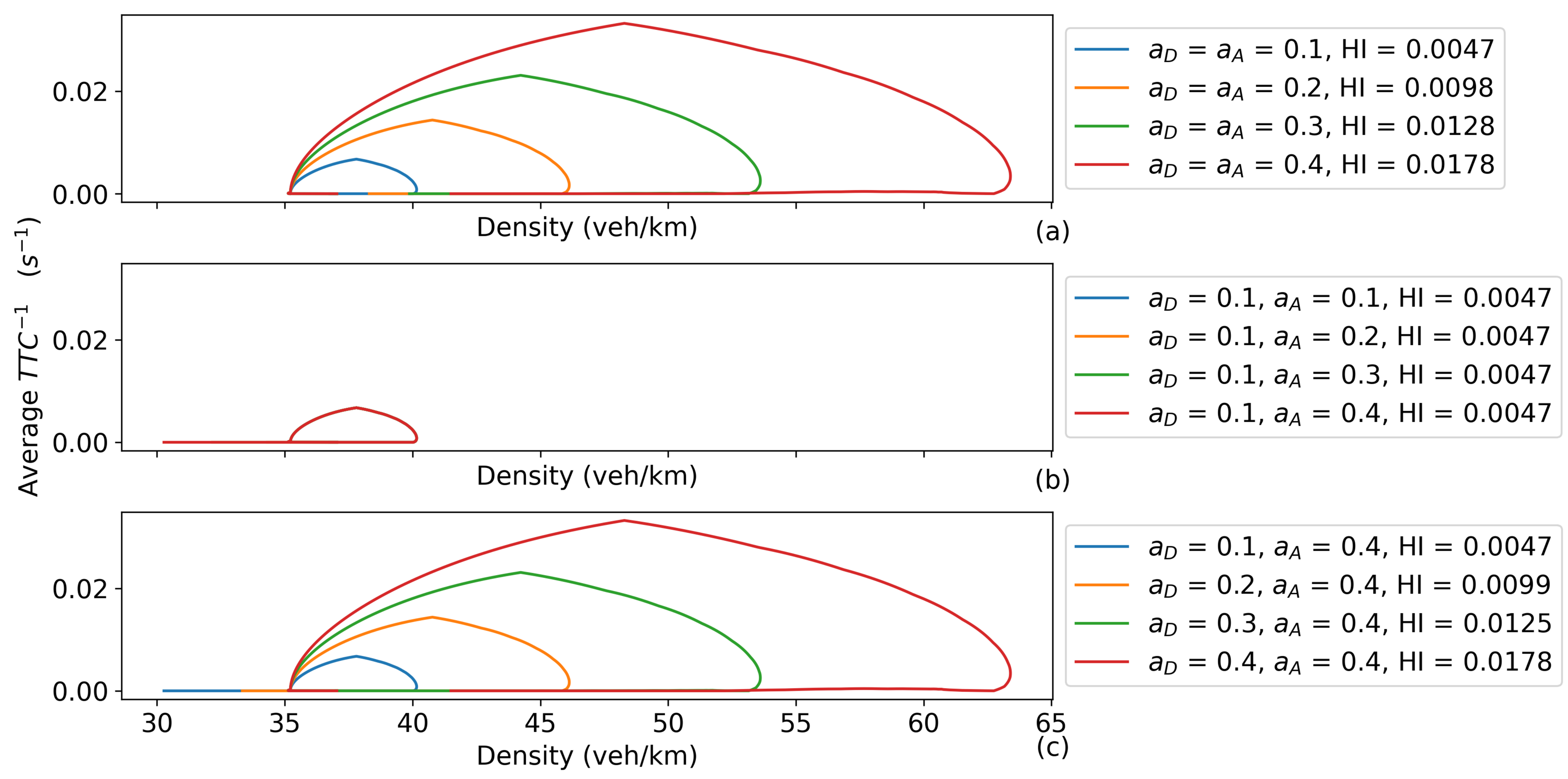


Figure 6. Effect of acceleration on macroscopic safety hysteresis

## Conclusion

- Our analysis uncovers distinct safety hysteresis loops: a counterclockwise loop at the microscopic level and a clockwise loop at the macroscopic level
- To effectively measure these phenomena, we introduced specific metrics: the microscopic safety Hysteresis Intensity (HI) and the macroscopic safety HI
- Higher deceleration rates markedly increase the safety HI, signifying more hazardous traffic conditions, whereas acceleration has a marginal effect.