

Overtaking Decision Model for Cyclists Considering Interaction with Rear-Approaching Vehicles

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This paper proposes a hierarchical overtaking behavior model for cyclists that explicitly considers the psychological pressure—termed the "interference effect"—exerted by rear approaching vehicles. Accurately predicting non-motorized traffic participant behavior in mixed-traffic environments is essential for constructing microscopic traffic digital twin simulations, evaluating advanced driver assistance systems (ADAS), and ensuring the safety of autonomous vehicles operating on narrow urban roads. However, conventional microscopic behavior models typically treat surrounding entities merely as static or dynamic physical obstacles based solely on forward relative distance and speed. Consequently, they fail to represent human-like decision shifts caused by dynamic threats approaching from behind, leading to a significant disparity between simulated trajectories and real-world human interaction.

To capture the underlying cognitive mechanisms, we conducted controlled cycling simulator experiments involving various traffic scenarios with approaching rear vehicles. Through detailed motion analysis, we observed that cyclists consistently perform a series of distinct physical preparatory behaviors prior to initiating a lane change for overtaking. These physical cues include an intentional reduction in velocity, head rotation for rearward safety checking, and subtle bicycle yaw angle fluctuations caused by gaze movement. Based on these empirical observations, we formulated the overtaking decision process into a two-phase hierarchical structure: Phase 1 for Intention Estimation ($X_1 \in \{0,1\}$) and Phase 2 for Execution Decision ($X_2 \in \{0,1\}$).

In Phase 1, a dynamic Long Short-Term Memory (LSTM) network was developed to estimate the latent intention (X_t) from the time-series history of physical preparatory behaviors. The model incorporates time-series physical signals $y_{\text{turn}} = [\text{yaw}_{\text{CS}}, \text{roll}_{\text{CS}}, \text{yaw}_{\text{Head}}, a_{\text{CS}}]^T$ alongside front environmental factors $u_1 = [1, D_{\text{Front}}, v_{\text{rel_Front}}]^T$:

$$P(X_t = 1) = \text{LSTM}(u_{1,1:t}, y_{\text{turn},1:t}, \hat{X}_{t-1})$$

The proposed LSTM model achieved an overall classification accuracy of 89.8%, significantly outperforming a static Logistic Regression Model (LRM) based solely on front physical factors (65.8%). While the baseline LRM generated frequent false positives by over-reacting to simple physical proximity, the proposed LSTM effectively captured the temporal context of human hesitation and physical preparation, thereby reducing detection timing errors from -1.71 s to -1.10 s and correctly identifying non-intention states during follow-riding.

In Phase 2, a static LRM evaluates the final Go/No-Go execution decision at the decision timing by balancing the motivation to overtake against safety constraints. The execution probability is calculated using an integrated feature vector $\phi_2 = [u_1^T, u_2^T]^T$, where $u_2 = [D_{\text{Rear}}, v_{\text{rel_Rear}}]^T$ represents rear vehicle states:

$$P(X_2 = 1 | \phi_2) = \frac{1}{1 + \exp(-\eta_2^T \phi_2)}$$

Multivariate logistic regression analysis revealed that the distance to the rear vehicle D_{Rear} is the statistically dominant factor influencing the final decision, showing a highly significant positive coefficient ($\eta_{2,D_{\text{Rear}}} = +0.351, p = 2.14 \times 10^{-5}$). This statistical evidence demonstrates that cyclists prioritize the rear physical safety margin over relative approach speed when deciding whether to execute an overtaking maneuver. To quantitatively validate the necessity of incorporating rear threats, we conducted a comparative evaluation against a conventional baseline model trained exclusively in an environment without rear vehicles. As shown in Fig. 1, applying this baseline model (Front only) to scenarios with rear vehicle pressure resulted in a severe 71.0% misclassification rate for "No-Go" cases as "Go" (overall accuracy: 65.8%). This indicates that models ignoring rear threats generate dangerously aggressive lane-changing maneuvers in simulation environments. In contrast, the proposed model (Front + Rear) achieved an overall accuracy of 92.6% by properly predicting safe waiting behavior ("No-Go"). These findings quantitatively prove the existence of the interference effect, where rear threats distort intrinsic decision criteria, underscoring that interaction-aware modeling is indispensable for realistic microscopic traffic simulations.

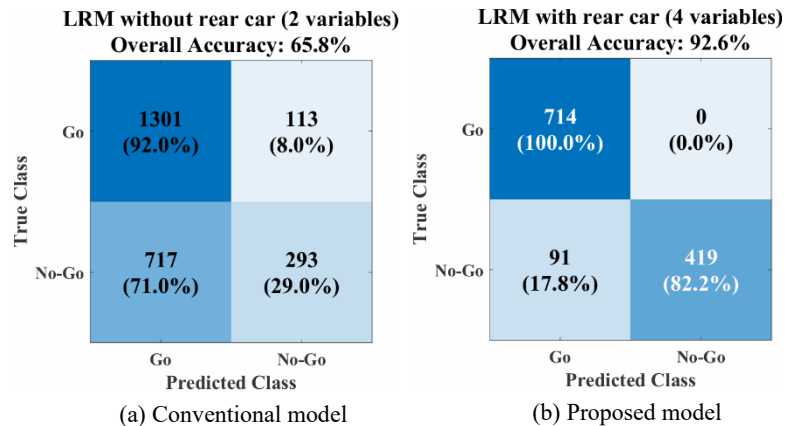


Fig. 1: Comparison of Go/No-Go prediction accuracy. (a) Conventional model (without rear car), (b) Proposed model (with rear car).