Leveraging Safe Drivers' Takeover Data to Improve Pedestrian-AEB Systems

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I. INTRODUCTION

Pedestrian Autonomous Emergency Braking (P-AEB) systems are important for reducing pedestrian injuries in vehicle collisions by automatically applying the brakes [1]. P-AEB systems rely on thresholds, to initiate braking based on factors such as distance, relative velocity, and time-to-collision (TTC) [2][3]. However, establishing thresholds that reflect human-like decision-making for balancing pedestrian injury mitigation and driving comfort remains a significant challenge. Human drivers possess a refined ability to assess collision risks while operating vehicles [4]. In this study, this capability is exemplified by safe drivers in autonomous vehicles, who monitor the driving environment and intervene when necessary to prevent collisions. When faced with imminent danger, safe drivers often take over control or apply brakes, demonstrating an intuitive perception of risk. Analysing these takeover behaviours can help establish more representative P-AEB thresholds—ones that align better with human judgment in safety-critical scenarios where decisions are aimed at mitigating pedestrian injury. This study leveraged safe drivers' takeover data to refine P-AEB activation strategies and thresholds in pedestrian-vehicle conflict scenarios.

II. METHODS

Safe Drivers' Takeover Data Collection

This study utilised a real-world autonomous vehicle (AV) testing database, which was obtained through a collaborative project. Each AV was monitored by one or two safe drivers who were responsible for intervening when necessary to prevent collisions, especially during pedestrian-vehicle interactions (Fig. 1). Takeover typically occurred when: (1) the perception module failed to identify pedestrians, (2) pedestrians suddenly changed their trajectory, or (3) pedestrians emerged unexpectedly from occluded areas. Each takeover event was logged in the data control system, capturing vehicle and pedestrian speed, position, and the surrounding environment at the moment of takeover. We selected classical unobstructed pedestrian-vehicle interaction scenarios and included only cases where the vehicle speed at takeover was between 10km/h and 45km/h.

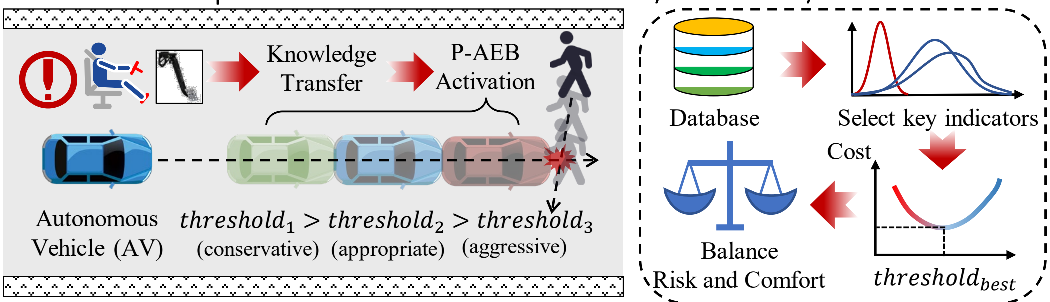

Fig. 1. Safety drive takeover data collection and analysis.

Key Indicators and Threshold of P-AEB Activation

In P-AEB testing standards, key activation variables include TTC and distance, both with longitudinal and lateral components. To evaluate robustness, we analysed their distributions at the moment of safe drivers' takeover, where P-AEB should ideally activate or provide earlier warnings. Kernel smoothing was applied to compare the 95% confidence intervals (CI) lengths, with shorter CI indicating greater robustness. After identifying key variables, determining activation threshold is important, as it directly affects the false positive rate (FPR) and false negative rate (FNR). Instead of quantifying exact error rates, we designed a risk cost function (Eq. 1) that incorporates FPR and FNR cost coefficients. The relationship between takeover samples and proposed thresholds was evaluated using Euclidean distance, with threshold obtained by minimising this function (Eq. 2).

$$R(\theta) = \alpha_{FN} P(FN|\theta) + \beta_{FP} P(FP|\theta) \quad (1)$$

$$P(F|\theta) = \sum_{x_i \in X} d^2(x_i, x_i*), x_i* = \begin{cases} min(x_i, \theta), if\ F = FN \\ max(x_i, \theta), if\ F = FP \end{cases}, \quad \vartheta = \text{argmin}_{\theta \in (\theta_{lower},\ \theta_{upper})} R(\theta) \quad (2)$$

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Where $R(\theta)$ is risk cost function and $P(F|\theta)$ represents the false negative/positive rate cost function at threshold θ. α_{FN} and β_{FP} are the cost coefficients and ϑ denotes the optimized threshold.

III. INITIAL FINDINGS

A total of 95 cases were selected for analysis and we removed outliers using the 3σ criterion. Figure 2a shows data points of vehicle-pedestrian distances and TTCs in longitudinal and lateral directions at the moment of safe drivers' takeover. Notably, no collisions occurred after safe drivers' takeover, as 95% of pedestrians had not intruded into the vehicle's path at the moment of takeover. Distributions of $Distance_{lateral}$ and $TTC_{long.}$ are noticeably more concentrated suggesting that P-AEB testing should prioritise these indicators (Fig. 2b).

Figure 2c presents the thresholds derived from the risk cost function. As an example, with $\alpha_{FN} = 0.7$ and $\beta_{FP} = 0.3$, where false negatives are less acceptable than false positives, the derived thresholds are 2.74m for $Distance_{lateral}$ and 1.14s for $TTC_{long.}$. P-AEB activation should require both indicators to simultaneously fall within their respective thresholds. Activation thresholds vary with false negative and positive preferences, shaping activation patterns and impacting pedestrian injury severity in collisions (Fig. 2d). The equilibrium point serves as a baseline reference for setting the P-AEB activation threshold, reflecting experienced driver behaviours aimed at mitigating pedestrian injury. ($\vartheta_{lateral\ dis.} = 2.40\ m, \vartheta_{longitudinal\ ttc} = 0.92\ s$).

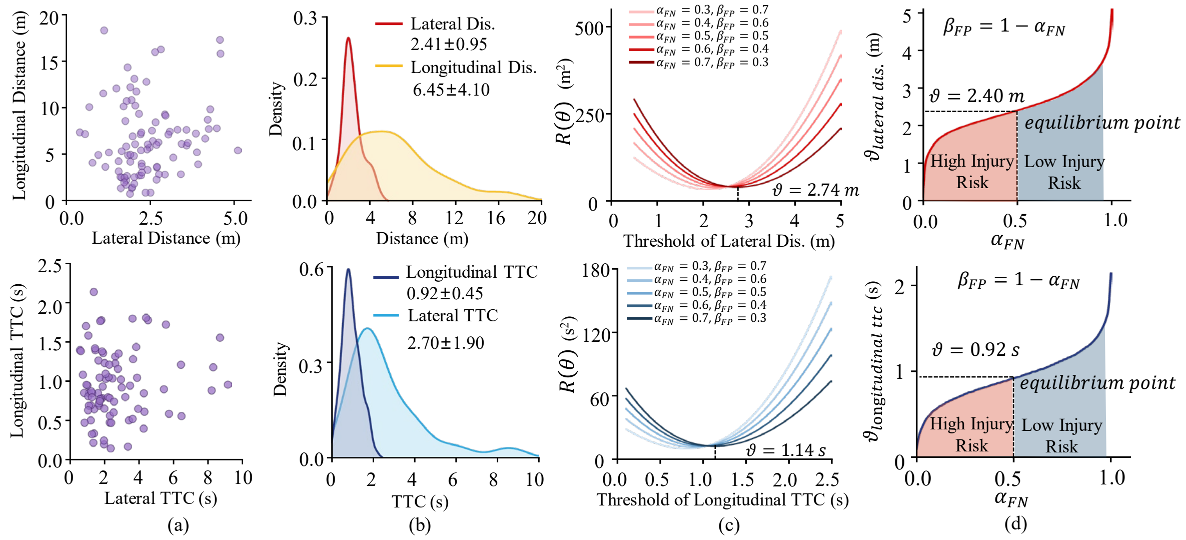

Fig. 2. (a) Data points of pedestrian-AV distance and TTC at safe drivers' takeover moments; (b) Distribution of distance and TTC at safe drivers' takeover moments; (c) Risk curve cluster; (d) Variation in activation thresholds.

IV. DISCUSSION

The study analysed P-AEB activation thresholds using 95 safe drivers' takeover events in safety-critical scenarios, focusing on lateral distance and longitudinal TTC distributions at takeover moments. Results identified these indicators as most robust variables due to their concentrated distributions. Thresholds derived by minimising a risk cost function across a range of cost coefficients provide a flexible baseline for P-AEB calibration. The equilibrium threshold (lateral distance: 2.40 m; longitudinal TTC: 0.92 s) represents safe drivers' decisions prioritising safety. Given the similarity between safe drivers' takeover and P-AEB responsibilities in critical pedestrian scenarios, takeover data can inform threshold calibration. Adjusting the cost coefficient upwards to align system responses more closely with normal driver preferences needs further investigation.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] Li Q *et al., Accid Anal Prev*, 2025.

[2] IIHS, Pedestrian Automatic Emergency Braking Test Protocol Version IV, 2024.

[3] Abdel-Aty M *et al., Accid Anal Prev*, 2022.

[4] Qin D *et al.*, *IRCOBI*, 2023.