**Project Title:** Risk-Aware Warning and Control for Interactive Traffic Safety

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**Center Name:** Safety21 National University Transportation Center for Promoting Safety

**Research Priority:** Promoting Safety

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**Project Partners:**

- PennDOT
- RISS, Carnegie Mellon University

**Research Project Funding:** $195,372.00

**Project Start and End Date:** 07-01-2023 to 06-30-2024

**Project Description:**

This project aims to pioneer a risk-aware control methodology tailored for ego vehicles operating in freeway driving scenarios, such as ramp merging and lane changing. The dynamic nature of these situations, characterized by intricate interactions, demands a meticulous approach due to uncertainties stemming from various sources' human factors, sensor-based stochasticity, and contextual information such as road geometry and vehicle types. For instance, in the context of an ego vehicle performing a ramp merge, it is vital to consider not only the distance between vehicles on the main road but also their speed, intent to yield, and overall traffic observations. This understanding is crucial, as attempting to merge into a gap within a truck platoon might be riskier than with non-truck vehicles. In this highly interactive and uncertain environment, the safety of human drivers heavily relies on Advanced Driver Assistance Systems (ADAS) for accurate risk perception, even when an immediate collision is not imminent.  Our primary objective is to develop a comprehensive risk assessment tool capable of quantifying the diverse risk factors influencing ego vehicles within multi-vehicle interactions. This tool can significantly enhance overall safety, whether a human driver is utilizing active ADAS or opting for full automation by the controller. Seamlessly integrating with existing ADAS, this tool can alert drivers to potential dangers when risk assessment exceeds a certain threshold and can take necessary preventive actions to avert collisions. Building upon our prior research in safety-critical autonomous driving, our goal is to seamlessly integrate the proposed novel risk management toolbox with ADAS/safety controller development, culminating in a distinctive interaction-aware framework for ego vehicles.  We propose the application of Conditional Value at Risk (CVaR) to quantify the cumulative risk that autonomous vehicles face during interactions with surrounding vehicles. This approach accounts for stochasticity arising from human drivers, uncertainty from sensor inputs, and contextual information such as road geometry and vehicle types. CVaR, a robust risk management tool, provides a quantitative measure of potential losses beyond a specified confidence level, helping identify tail risks, compare strategies, and facilitate informed decisions in risk management and analysis. For human-driven vehicles, this risk management tool acts as a verification layer for existing ADAS, mitigating possible unsafe actions by reckless or distracted drivers. For fully autonomous vehicles, this tool can be seamlessly integrated with safety-critical controllers, such as our pre-existing Control Barrier Function (CBF)-based safe controllers, to obtain formally provable safety guarantees. Notably, these safe controllers have demonstrated remarkable performance in initial collision avoidance scenarios, and subsequent efforts will focus on developing risk-aware CBF-based controllers, followed by validation through simulation and real-world vehicle testing.  To validate our approach, we will conduct a rigorous testing phase in simulation and the real world by using a 1/10th scale autonomous race car. The significance of this approach is twofold: first, its implementation in existing ADAS can convey to drivers the comprehensive risk associated with desired actions within the current interactive environment; second, for fully autonomous vehicles, it offers interpretable risk-aware behavior with formally proven safety guarantees, enhancing overall operational safety.

**Outputs:**

a. Identify the various sources of uncertainty and contextual information that should be considered in risk evaluation. b. Develop a Conditional Value at Risk (CVaR)-based comprehensive risk evaluation toolbox for interaction-intensive scenarios. c. Refine the comprehensive risk evaluation toolbox to handle multi-vehicle interactions. d. Develop risk-aware ADAS/safe controllers by integrating the comprehensive risk evaluation toolbox into ADAS/CBF-based safe controllers. e. Improve and analyze the risk-aware ADAS/safe controllers' robustness to sensor inputs and human error. f. Test the risk-aware ADAS/safe controllers in the freeway driving domain with a focus on entrance ramp behaviors but including also freeway distance keeping and lane changing.

**Outcomes/Impacts:**

Outcomes

- Creation of a risk management toolbox that can be integrated to existing ADAS/safe controllers with significant safety benefits via driver assistance and inclusion in autonomous driving algorithms
- Validation of the system in simulation and on-road driving via a 1/10th scale autonomous race car
- Documentation of the results in a form appropriate for hand-off to a partner capable of full-scale deployment

Impacts/Metrics

- Achieve 98% safe interaction with neighboring drivers in entrance ramp, distance keeping, and lane changing maneuvers under uncertainty
- Achieve risk-aware but efficient driving response to such maneuvers