Collaborative Sciences Center for ROAD SAFETY

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Driver impairment detection & safety enhancement through comprehensive volatility analysis

Collaboration: University of Tennessee, Knoxville & University of North Carolina, Chapel Hill

February 22, 2021

R20 Project Team

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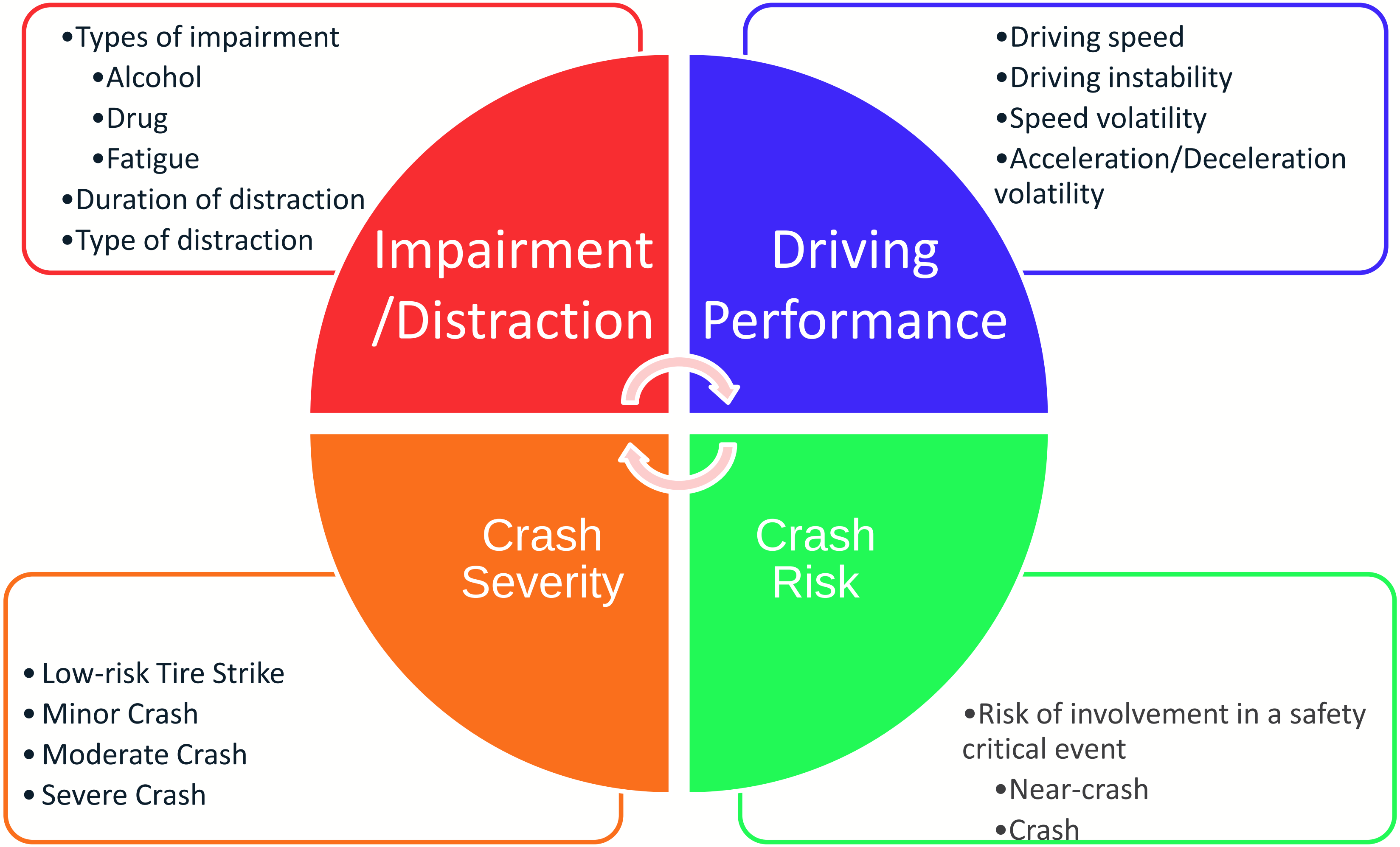
Introduction: Safe Systems

- Creating new knowledge to advance transportation safety through a systems-based approach
- Distraction & impairment can substantially lower driver performance
  - Limit drivers’ attention to driving tasks
  - Increase reaction time
  - Increase driver workload
- Distracted & impaired driving contribute to ~35% of all transportation-related deaths
  - In 2016: 10,497 fatalities had distracted & impaired driving as main contributors



This project explores the association of impairment & distraction on crash risk & severity

Research objectives

- Develop a systems framework to integrate & analyze driver biometrics, vehicle kinematics, & roadway/environment data
- Conduct in-depth analysis of impairment & distracted driving using detailed Naturalistic Driving Study (NDS-SHRP 2) data
- Quantify instantaneous crash risk by real-time monitoring of driver biometrics, vehicular movements, & instability in driving using AI techniques
- Demonstrate collection & processing of driver biometric, vehicle, & roadway surroundings data using experimentation in simulated & naturalistic settings

Related publications-Research to Practice

1. Arvin, R., Khattak, A. J. & Qi, H (2021). Safety critical event prediction through unified analysis of driver & vehicle volatilities: Application of deep learning methods. Forthcoming in *Accident Analysis & Prevention.*

2. Arvin, R., & Khattak, A. J. (2020). Driving impairments & duration of distractions: assessing crash risk by harnessing microscopic naturalistic driving data. *Accident Analysis & Prevention*, *146*, 105733.

3. Arvin, R., Kamrani, M., & Khattak, A. J (2019). The role of pre-crash driving instability in contributing to crash intensity using naturalistic driving data. *Accident Analysis & Prevention*, 132, 105226.

4. Borhani, S., Arvin, R., Khattak, A., Wang, M., Zhao, X. Predicting Drivers' Reaction Time in Unexpected Lane Departure Situations Using Brainwave Signals: Application of Machine Learning Techniques. Transportation Research Board 100th Annual Meeting for presentation, Washington, D.C., 2021.

5. Jerome, Z. Arvin, R., & Khattak, A. Why are Most Drivers Not Recognizing Impending Single-Vehicle Collisions & Does this Influence Event Outcomes? Transportation Research Board 100th Annual Meeting for presentation, Washington, D.C., 2021.

Related Publications-that have appeared in AAP

Accident Analysis and Prevention 146 (2020) 105733

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Driving impairments and duration of distractions: Assessing crash risk by harnessing microscopic naturalistic driving data

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ARTICLE INFO

Keywords:
Crash risk
Impaired driving
Naturalistic driving
SHRP2
Distracted driving
Microscopic data

ABSTRACT

Distracted and impaired driving is a key contributing factor in crashes, leading to about 35% of all transportation related deaths in recent years. Along these lines, cognitive issues like inattentiveness can further increase the chances of crash involvement. Despite its prevalence and importance, little is known about how the duration of these distractions is associated with critical events, such as crashes or near-crashes. With new sensors and increasing computational resources, it is possible to monitor drivers, vehicle performance, and roadway features to extract useful information, e.g., eyes off the road, indicating distraction and inattention. Using high-resolution microscopic SHRP2 naturalistic driving data, this study conducts in-depth analysis of both impairments and distractions. The data has more than 2 million seconds of observations in 7394 baselines (no event), 1228 near-crashes, and 617 crashes. The event data was processed and linked with driver behavior and roadway factors. The intervals of distracted driving during the period of observation (15 seconds) were extracted; next, rigorous fixed and random parameter logistic regression models of crash/near-crash risk were estimated. The results reveal that alcohol and drug impairment is associated with a substantial increase in crash/near-crash event involvement of 34%, and the highest correlations with crash risk include duration of distraction through dialing on a cellphone, texting while driving, and reaching for an object. Using detailed pre-crash data from instrumented vehicles, the study contributes by quantifying crash risk vis-à-vis detailed driving impairment and information on secondary task involvement, and discusses the implications of the results.

IF = 3.655
(for 2019)

Accident Analysis and Prevention 132 (2019) 105226

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

The role of pre-crash driving instability in contributing to crash intensity using naturalistic driving data

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ARTICLE INFO

Keywords:
Volatility
Vehicle stability
Path analysis
Naturalistic driving study
SHRP2
Random parameter
Ordered probit

ABSTRACT

While the cost of crashes exceeds $1 Trillion a year in the U.S. alone, the availability of high-resolution naturalistic driving data provides an opportunity for researchers to conduct an in-depth analysis of crash contributing factors, and design appropriate interventions. Although police-reported crash data provides information on crashes, this study takes advantage of the SHRP2 Naturalistic Driving Study (NDS) which is a unique dataset that allows new insights due to detailed information on driver behavior in normal, pre-crash, and near-crash situations, in addition to trip and vehicle performance characteristics. This paper investigates the role of pre-crash driving instability, or driving volatility, in crash intensity (measured on a 4-point scale from a tire-strike to an injury crash) by analyzing microscopic vehicle kinematic data. NDS data are used to investigate not only the vehicle movements in space but also the instability of vehicles prior to the crash and their contribution to crash intensity using path analysis. A subset of the data containing 617 crash events with around 0.18 million temporal trajectories are analyzed. To quantify driving instability, microscopic variations or volatility in vehicular movements before a crash are analyzed. Specifically, nine measures of pre-crash driving volatility are calculated and used to explain crash intensity. While most of the measures are significantly correlated with crash intensity, substantial positive correlations are observed for two measures representing speed and deceleration volatilities. Modeling results of the fixed and random parameter probit models revealed that volatility is one of the leading factors increasing the probability of a severe crash. Additionally, the speed prior to a crash is highly correlated with intensity outcomes, as expected. Interestingly, distracted and aggressive driving are highly correlated with driving volatility and have substantial indirect effects on crash intensity. With volatile driving serving as a leading indicator of crash intensity, given the crashes analyzed in this study, early warnings and alerts for the subject vehicle driver and proximate vehicles can be helpful when volatile behavior is observed.

A third paper is under production in AAP

Framework for impairment & distraction association with driving performance

Study Highlights

Overall goal:

- Role of impairment/distraction on driving performance (instability in driving) & crash intensity (severity)

Framework:

- Systems-based path analysis for how a system of predictors correlates with multiple dependent variables

Data

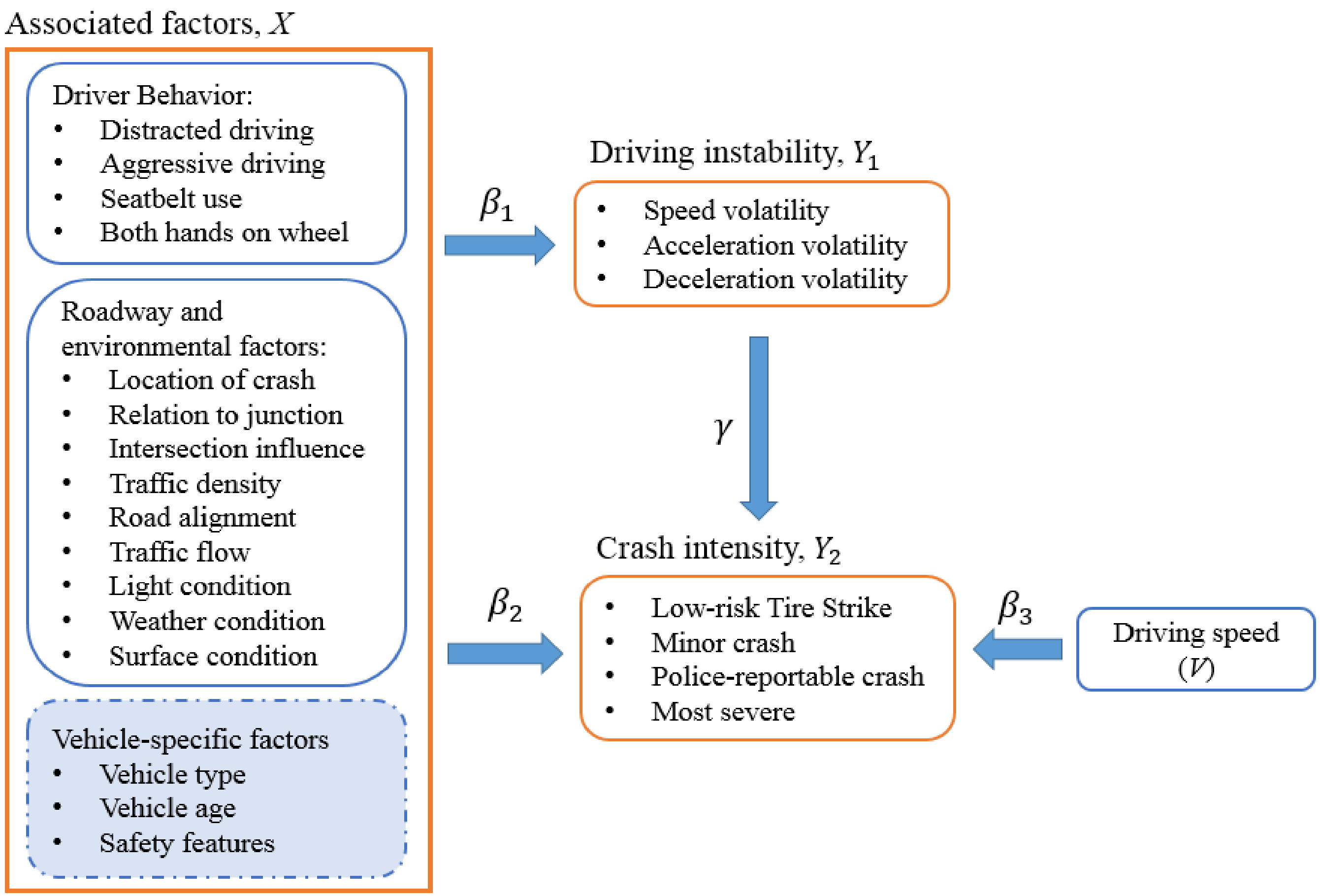
- SHRP 2 NDS data contains:
  - Crash severity (Dependent Variable)
  - Distraction & impairment; secondary tasks based on gaze
  - Vehicle kinematics before, during, & after crash
  - Driver behavior
  - Driver instability (Dependent Variable)
  - Roadway/environmental factors

- **Key results**
  - Distracted & aggressive driving increase instability in driving
  - Distraction directly & indirectly increases crash intensity
  - Instability in driving is strongly associated with crash intensity

System dynamics framework

Research questions:

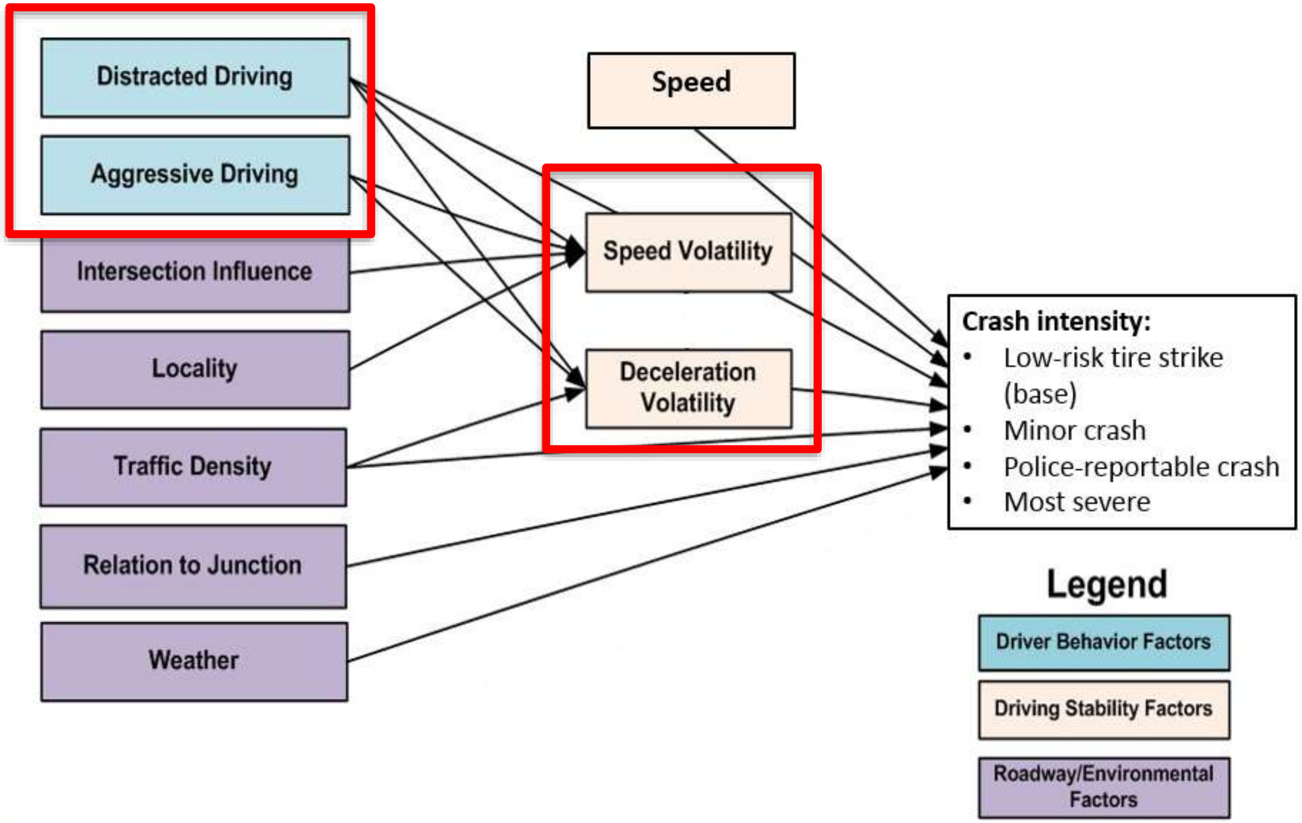
- How is distracted & impaired driving related to instability in driving performance?
- What is the direct & indirect role of distraction & impairment on crash severity?



Final model - Pathway diagram

Distraction & aggressive driving:

- Increase driving instability
- Directly & indirectly increase chances of involvement in a severe crash



Summary

- Analyzed high resolution naturalistic driving data with information on distraction/impairment, driver behavior, vehicle kinematics, & severity of crashes

- Developed a system dynamics pathway diagram to explore
  - Role of impairment/distraction on driving performance (instability in driving)
  - Quantified direct and indirect associations of distraction and impairment on crash intensity (severity)

- Driving volatility is used as a proxy of driving instability

- Distracted & aggressive driving increase driving instability

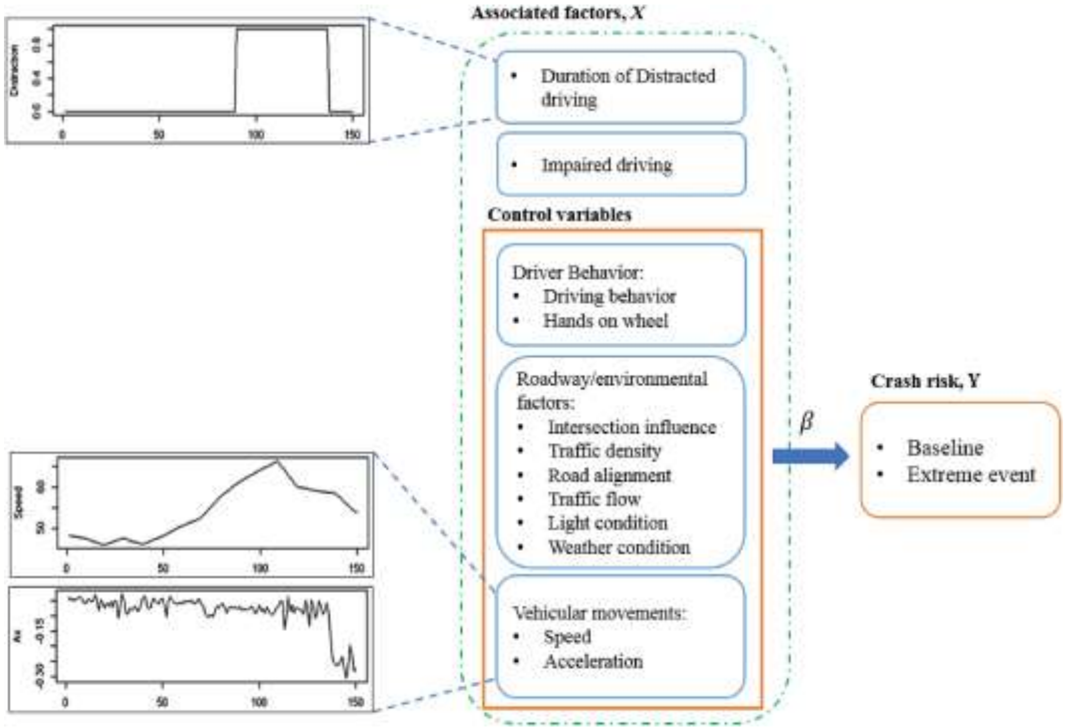
- Distraction directly & indirectly (through driving instability) increases crash intensity

Inference-based assessment of impairment & distraction on crash risk

Overall framework

- SHRP 2 NDS data
  - Baseline-non-event driving (N=7394)
  - Near-crash (N=1228)
  - Crash (N=617)

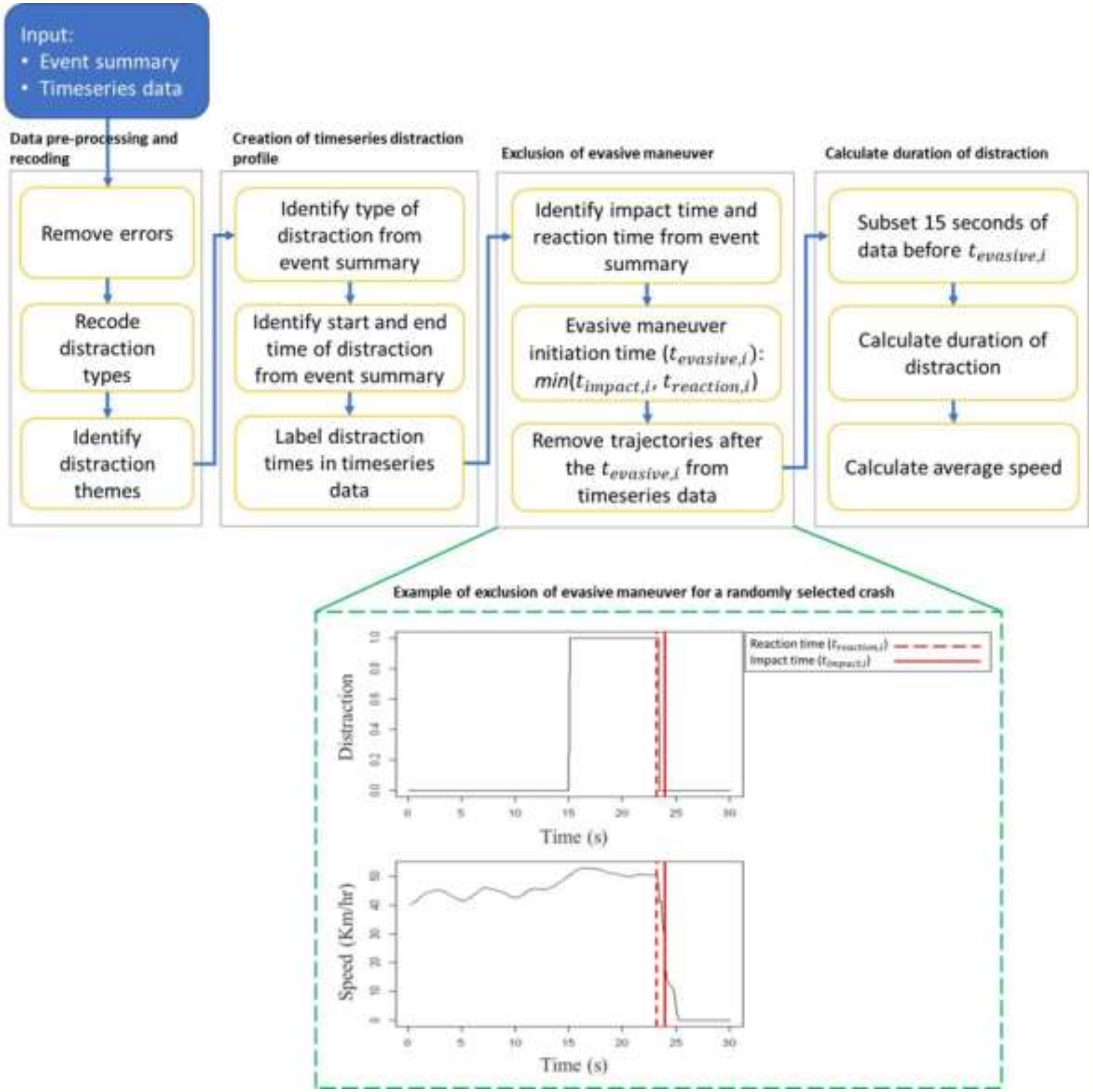
- Available data
  - 15 sec. of observations for each event
  - Instantaneous vehicle kinematics
  - Driver distraction profile



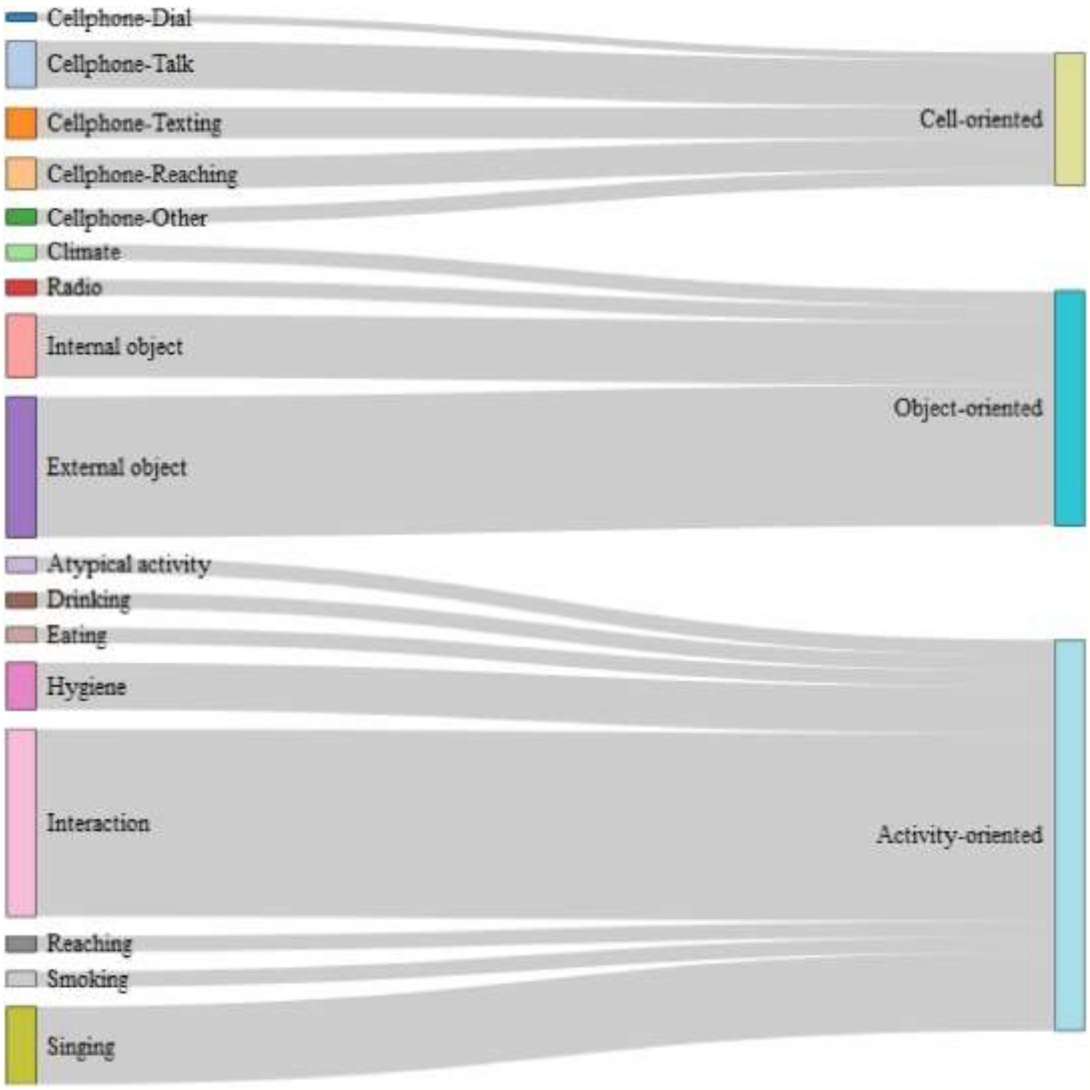
Key results

- Longer distraction duration → Higher probability of involvement in safety-critical event
- Substantial variation in how duration of different distraction types (e.g., mobile-phone, radio control) associate with crash risk

Data processing framework



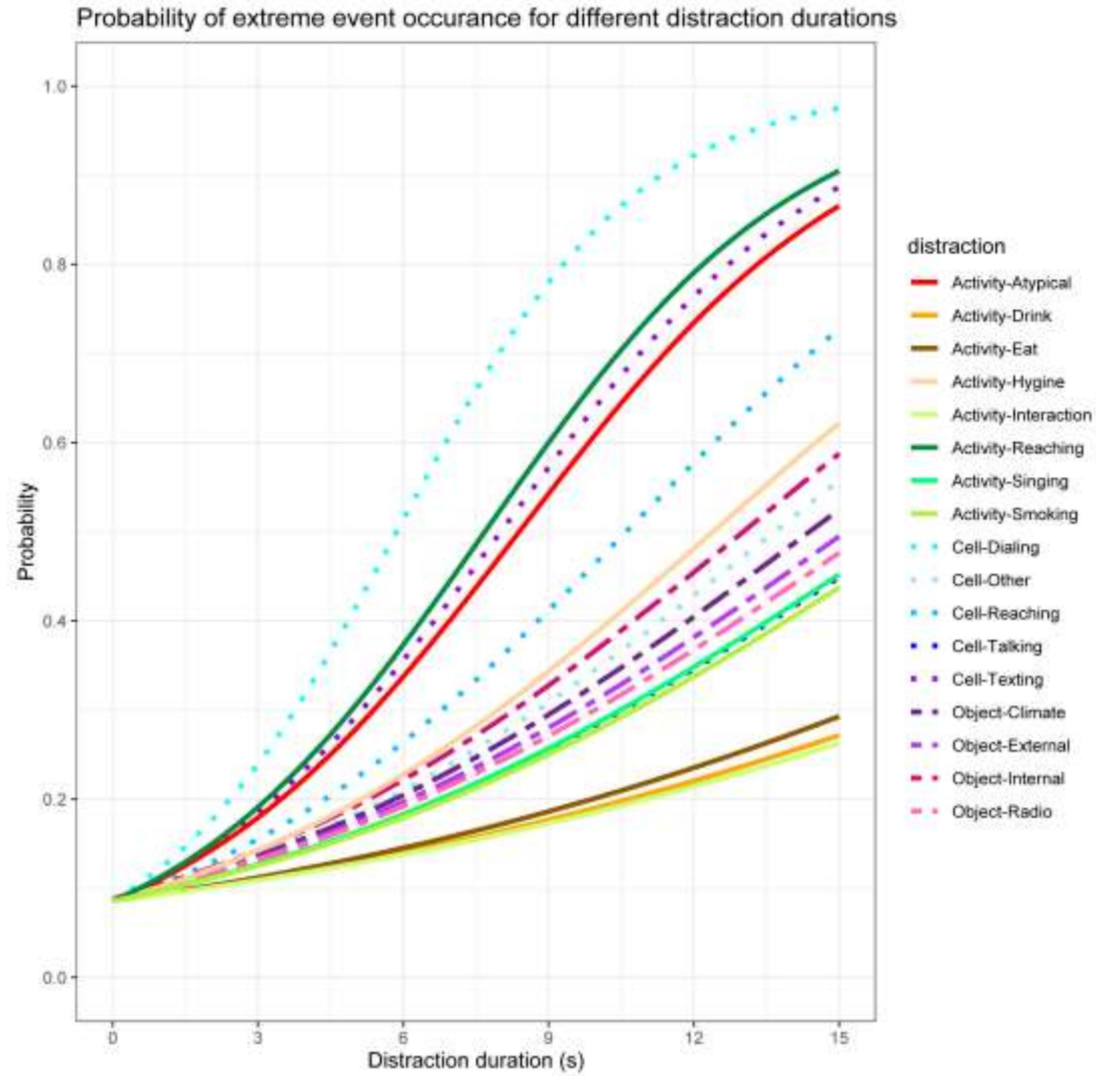
Categorization of secondary tasks during driving



Role of distraction duration in crash risk

- Probability of crash/near-crash events with increasing duration of distraction for different types of secondary tasks

- This increase varies substantially among different distraction types



Summary

- Develop a systems framework to analyze driver biometrics (gaze), distractions, vehicle, and roadway/environment factors

- Analysis of how duration of distraction and impairment relate to safety-critical events using naturalistic data
  - Classified secondary tasks performed by drivers prior to crash or near-crash
  - Longer distraction durations, especially by cellphones, substantially increase crash risk
  - Alcohol & drug impairment also substantially increase crash risk

- Use of inference information from this study can be used to design safer systems in the future

Safety critical event prediction through unified analysis of driver & vehicle volatilities: AI Application

Study Highlights

Overall goal:

- Real-time prediction of critical event occurrence using vehicle kinematics & driver distraction profile

Framework:

- System dynamics-based AI for how volatility in driving and distraction can be leading predictors for crash risk

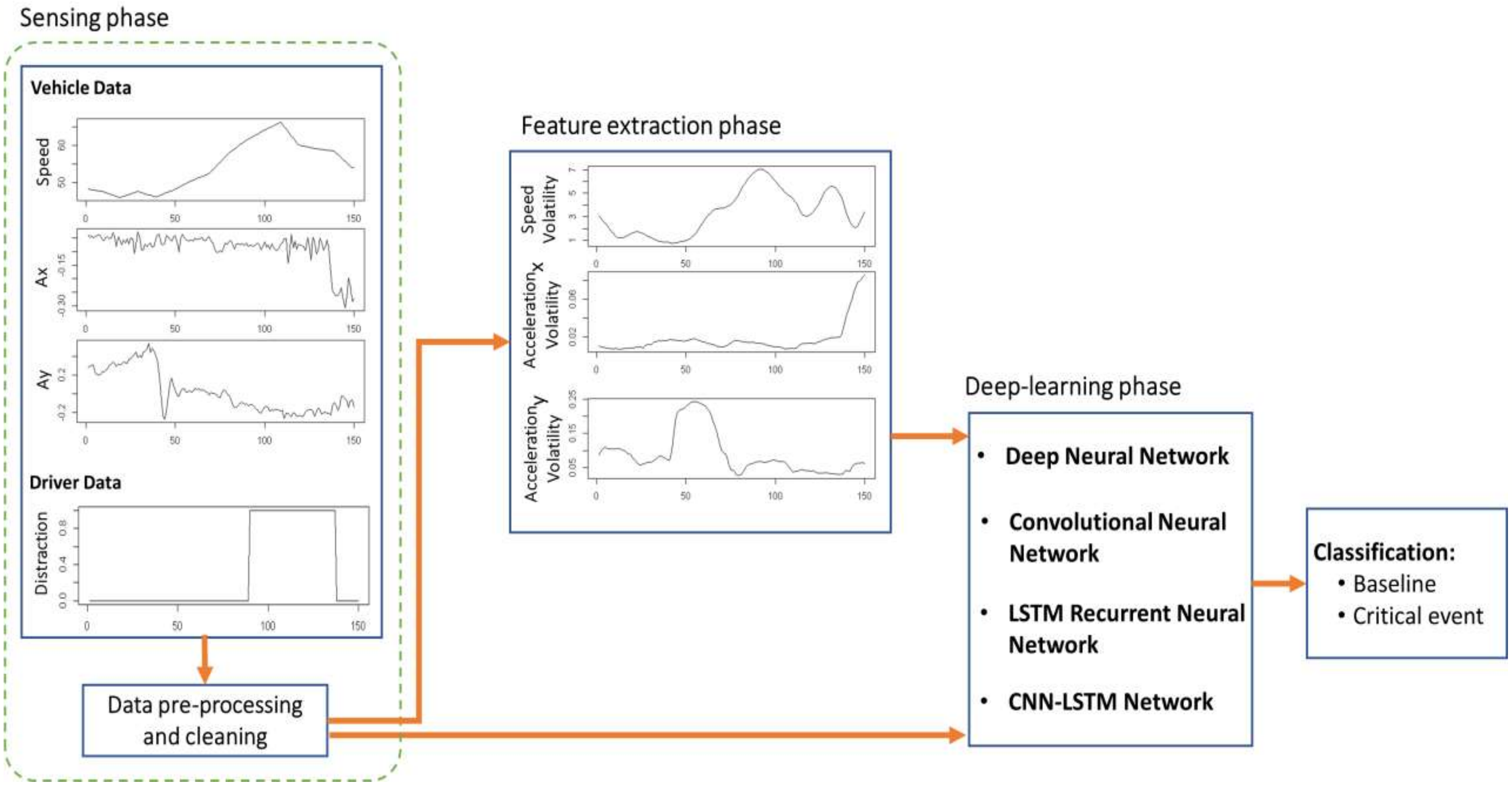
Data:

- SHRP2 Naturalistic Driving Data
  - 1,925 critical events & 7,566 baselines
    - 15 seconds of observations for each event
    - Instantaneous vehicle kinematics
    - Driver distraction profile

Key results:

- AI method confirms higher driving volatility & distraction are associated with higher crash risk
- 1 Dimensional Convolutional Neural Network-Long Short Term Memory (1D-CNN-LSTM) model predicts 73% of extreme events correctly
- Very low false-alarm rate in non-event driving (0.57%)

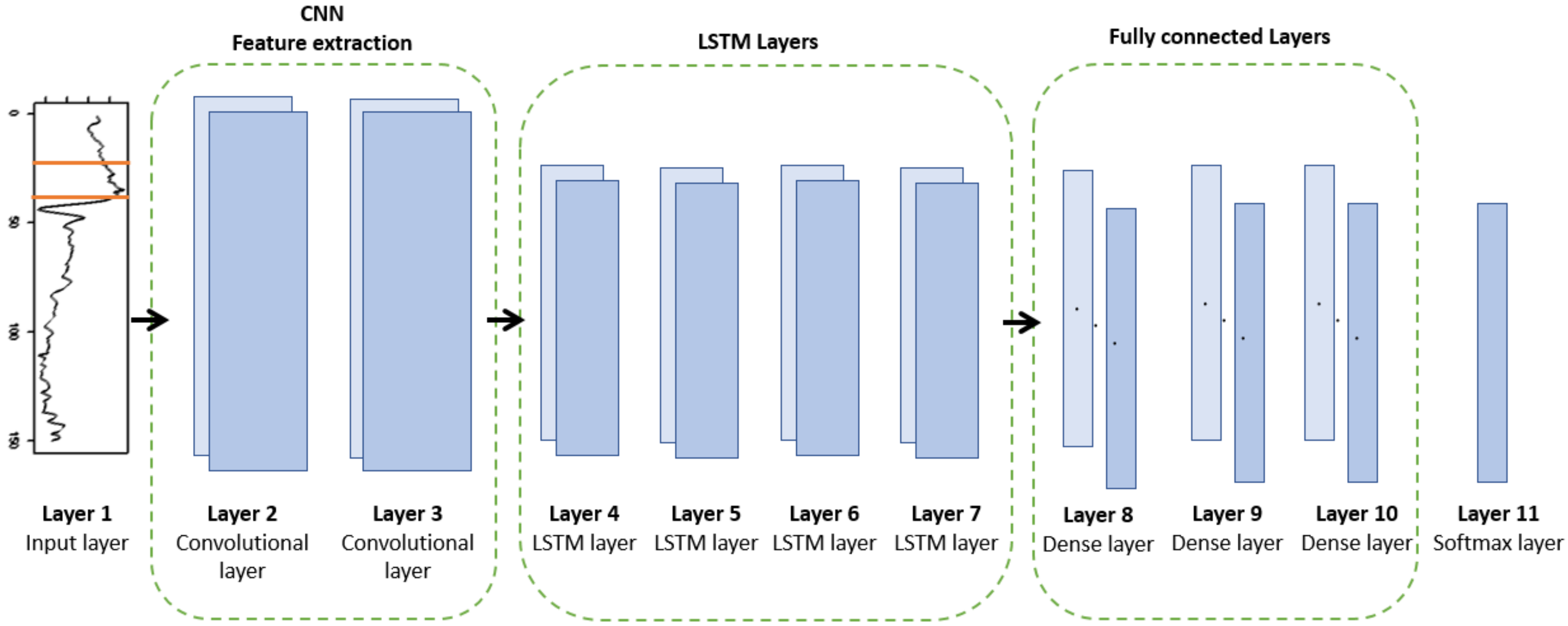
Conceptual framework



Deep learning structure to capture time dependency

Input:
For each event 15 seconds of
- Distraction profile
- Speed
- Acceleration
- Speed volatility
- Acceleration volatility

Output:
- Baseline
- Crash/near-crash



Performance of AI models

Highlights:

- Correctly predicts 73.4% of safety critical events with the precision of 95.7%
- Very low false-alarm rate in non-event driving (0.57%)

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

$$Precision_c = \frac{TP_c}{TP_c + FP_c}$$

$$Recall_c = \frac{TP_c}{TP_c + FN_c}$$

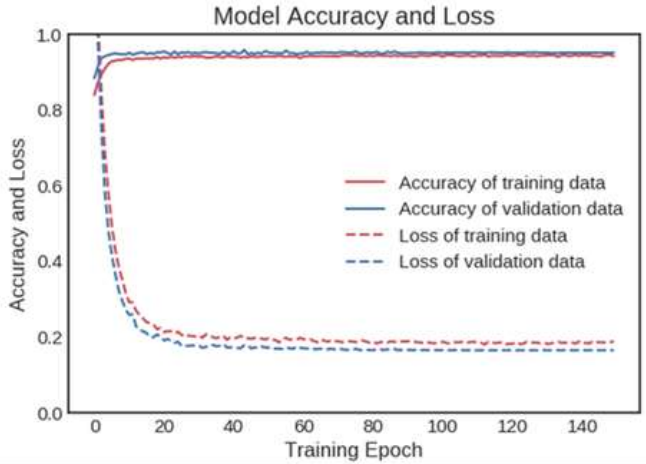
$$F_1 = \sum_i 2 * w_i \frac{Precision_i * Recall_i}{Precision_i + Recall_i}$$

		Classification	
		Positive	Negative
Condition	+	True Positive	False Negative
	-	False Positive	True Negative

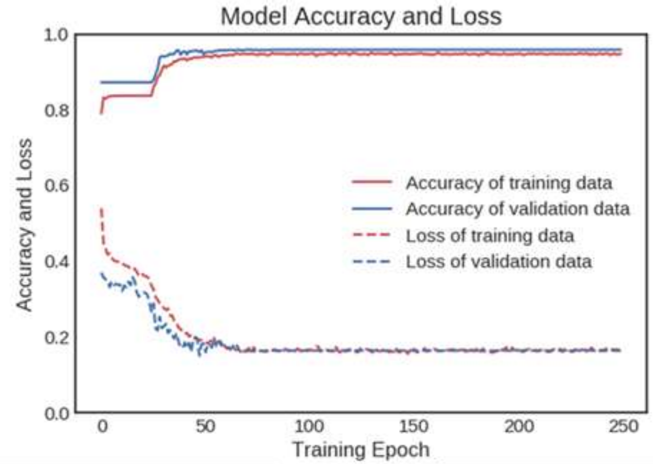
Performance		Train Data				Test Data			
		DNN	1D-CNN	LSTM	1DCNN-LSTM	DNN	1D-CNN	LSTM	1DCNN-LSTM
Test time (millisecond)		-	-	-	-	0.181	0.194	19.65	0.345
Overall	*Accuracy*	0.9446	0.9502	94.62	**96.1912**	92.10	94.54	94.32	**95.4648**
	Loss	0.18	0.16	0.16	**0.15**	0.24	0.18	0.18	**0.16**
	AUC	0.9472	0.95412	0.9536	**0.9836**	0.9085	0.9535	0.9371	**0.9626**
Baseline	*Precision*	0.9470	0.9489	0.9458	**0.9686**	0.9426	0.9440	0.9461	**0.9563**
	Recall	0.9956	0.9992	0.9949	**0.9987**	0.9913	0.9941	0.9899	**0.9943**
	F1-Score	0.9707	0.9734	0.9697	**0.9834**	0.9663	0.9685	0.9675	**0.9749**
CNC	*Precision*	0.9674	0.9943	0.9615	**0.9606**	0.9267	0.9517	0.9193	**0.9567**
	Recall	0.6988	0.7090	0.6915	**0.8107**	0.6171	0.6547	0.6701	**0.7340**
	F1-Score	0.8114	0.8278	0.8045	**0.8793**	0.7409	0.7758	0.7751	**0.8307**

Accuracy & loss for the training & validation datasets

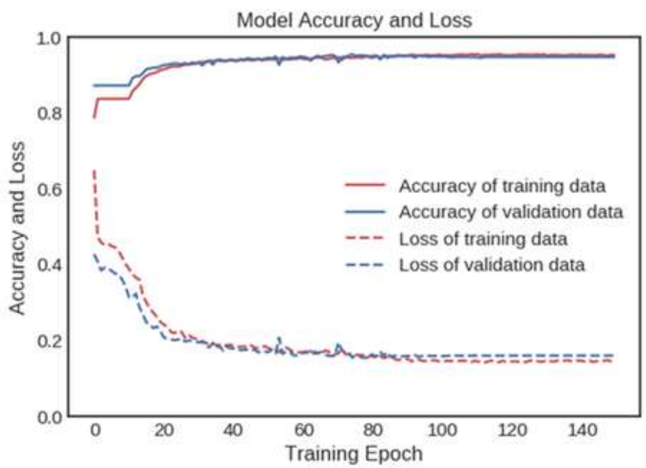
Model convergence implies that overfitting is not a problem



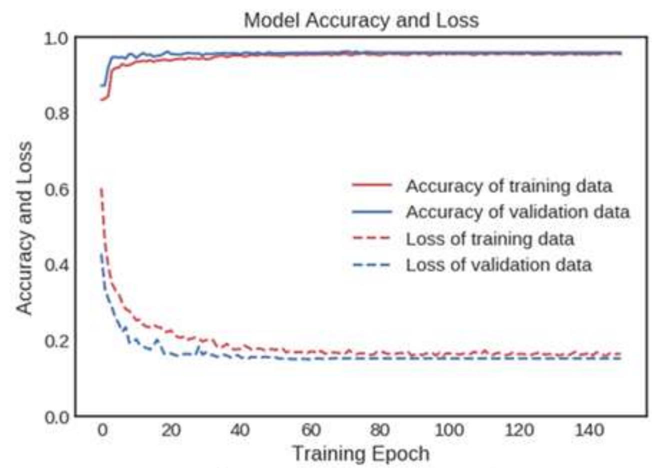
DNN



1D-CNN



LSTM



1DCNN-LSTM

Summary

- Quantified instantaneous crash risk by real-time monitoring of driver and vehicular movements using AI techniques

- AI-based model shows:
  - Successful prediction of safety-critical events using naturalistic streaming data
  - Low false alarm rates in non-event driving

- Can use model to predict hazards by monitoring driver biometrics

- Distraction and driving volatility can be leading indicators for crash prediction

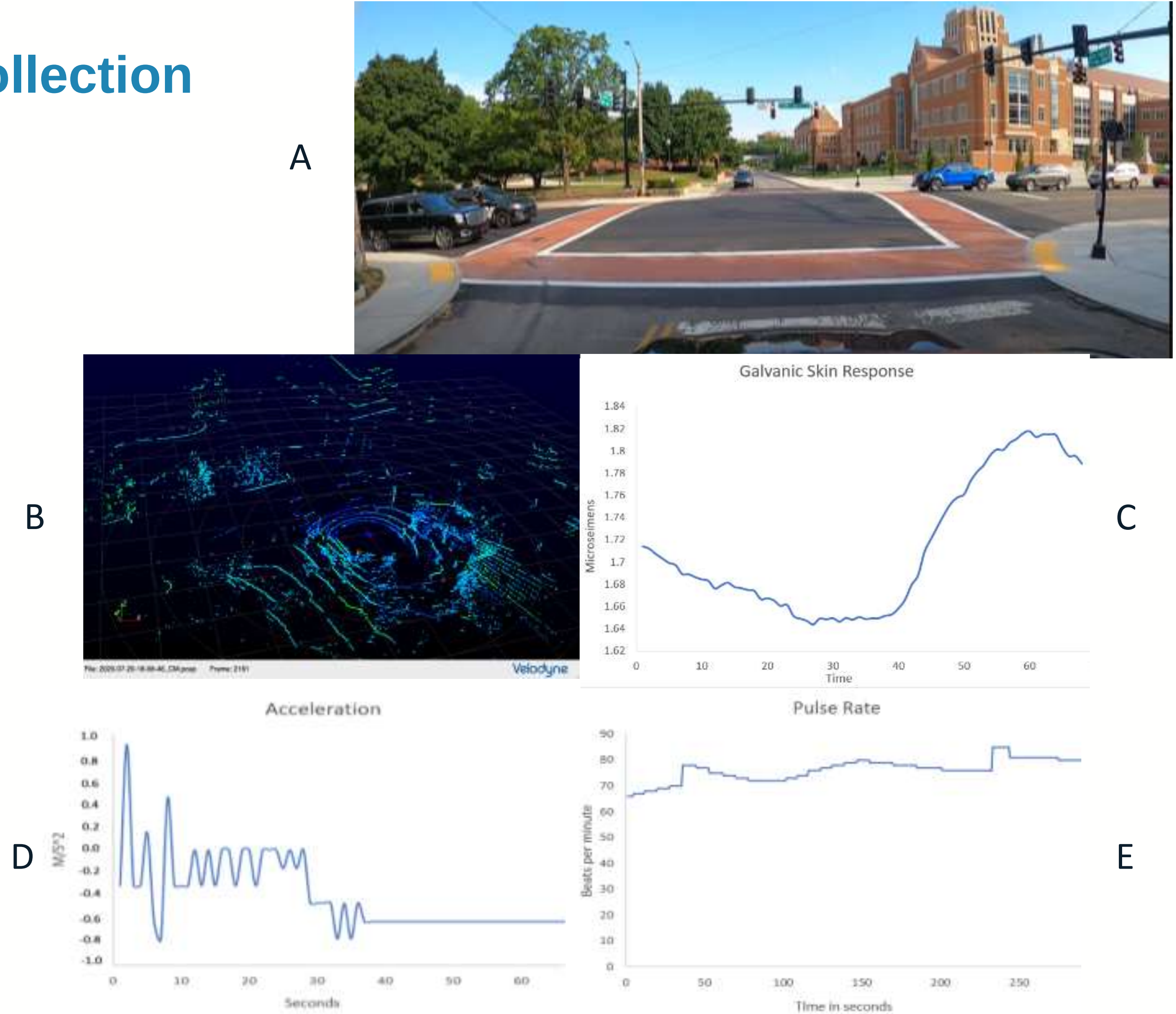
Driving experimentation in simulated & naturalistic settings

Data collection set up: On-going

- Biometric sensors record data in naturalistic driving to monitor driver's physiological response to changes in cognitive load while driving, including:
  - Galvanic Skin Response (GSR)
  - Electrocardiogram (EKG)
  - Electromyographic (EMG)

- Simultaneously, vehicle dynamics data are collected with an advanced driver assistance system (ADAS)

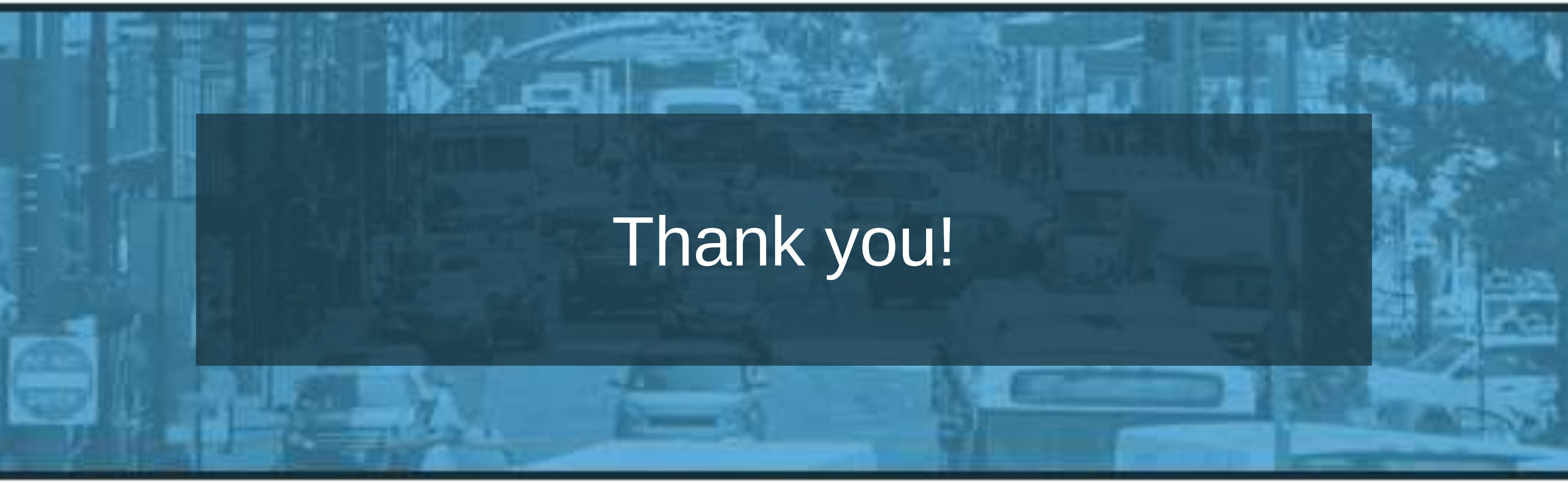
Data collection



a) Camera data, b) LiDAR point cloud, c) Galvanic Skin Response & vehicle acceleration, d) Acceleration data, e) Pulse rate recorded

Overall

- Developed a systems framework to integrate driver biometrics, vehicle kinematics, & roadway/environment data
- Inference-based analysis of role of impairment & distracted driving on crash risk using naturalistic driving
- Predictive AI techniques to foretell crash risk in real-time by using streaming naturalistic data of driver gaze and vehicle kinematics
- Demonstrated collection & processing of driver biometric, vehicle, & roadway surroundings data using experimentation in simulated & naturalistic settings
- Suggest the use of distraction and volatility information as leading predictors to improve crash prediction and driver safety



Thank you!