

Research Report Summary



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Defining Safety-Critical Scenarios for Simulation-Based Automated Vehicle Evaluation

Simulation-based design is essential for an efficient safety verification and deployment of automated vehicles (AVs). Test scenarios are the core of simulation-based AV safety evaluation. Existing AV crash data, especially crash sequence data, is helpful for identifying unique crash progression and dynamics, which would support the rendering of challenging crash scenarios in simulation-based testing.

Research Objective

The objective of this study is to investigate the patterns of AV crash sequences and discuss potential uses of crash sequences in scenario design for AV safety testing.

Data and Methods

Sequences of events were extracted from 168 California AV Collision Reports' text narratives and analyzed using sequence analysis methods. The reports were from 2015-2019, with AV operating in automatic mode at the time of the crash or automation was disengaged just prior to crash.

Following a procedure of "text narratives -> short phrases -> labels" we converged to a set of 35 labels for the encoding of 497

events, which made up the 168 AV crash sequences.

AV crash sequence analysis focused on identifying patterns from these three aspects: 1) most frequent events and event transitions; 2) disengagements' role in AV crash sequences; and 3) characterization of AV crash sequences.

Most Frequent Subsequences

AV crash sequences ended with AV hit by a second-party road user: 92%. AV stopped and was hit by a second-party road user: 40%. Disengagement: 24%. AV hit by a second-party road user following disengagement: 19%.

	AV disengaged		
	[-> DG]	[DG ->]	
AV decelerates [D1 ->]	44%	51%	[-> X21] 2 nd party hits AV
2 nd party decelerates [D2 ->]	100%	10%	[-> X12] AV hits 2 nd party
2 nd party makes left turn [ML2 ->]	31%	7%	[-> X10] AV hits objects
3 rd party makes left turn [ML3 ->]	33%	7%	[-> MR1] AV merges right
AV merges right [MR1 ->]	43%	5%	[-> D1] AV decelerates
2 nd party merges right [MR2 ->]	17%	5%	[-> ML2] 2 nd party merges left
3 rd party merges right [MR3 ->]	50%	5%	[-> V2] 2 nd party runs stop sign/red light
2 nd party passes AV from left [PL2 ->]	15%	2%	[-> B1] AV backs up
AV stops [S1 ->]	1%	2%	[-> L2] 2 nd party makes left turn
2 nd party runs stop sign/red light [V2 ->]	20%	2%	[-> ML1] AV merges left
AV yields [Y ->]	27%	2%	[-> MR2] 2 nd party merges right

Figure 1. Disengagement transitions

Disengagement Transitions

Transitions to and from disengagements (DG) were obtained from the sequence transition matrix (Figure 1).

Sequence Groups

Cluster analysis resulted in crash sequences being clustered into 7 groups (Illustrated in Figure 2).

- Group 1 “Disengage-Deceleration”
- Group 2 “Hesitation”
- Group 3 “Stop”

- Group 4 “Yield”
- Group 5 “Hit Others”
- Group 6 “Left Turn”
- Group 7 “Moving-Unexpected”

Associations with Other Crash Attributes

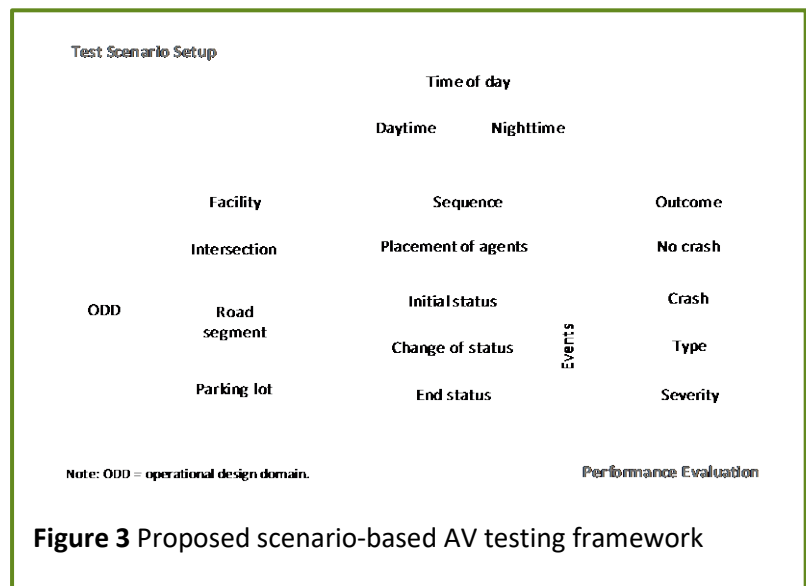
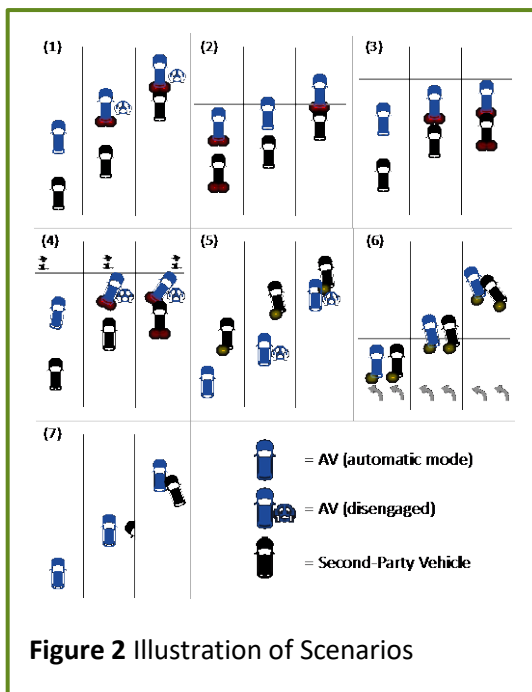
Cross-tabulation analysis was carried out between sequence types and crash injury severity, manner of collision, facility type, time of day, and year.

AV crash sequence groups were significantly associated with variables measuring crash

outcomes and describing environmental conditions, indicating that scenarios described by combinations of event sequences and environmental condition variables can lead to various crash outcomes.

Scenario-Based AV Safety Testing Framework

A scenario-based AV safety testing framework was developed with the sequence of events embedded as a core component (shown in Figure 3).



Impacts

By supporting the safety evaluation of automated vehicles, this research can hasten the development and deployment of AVs and turn the widely expected societal benefits of AV into reality.