

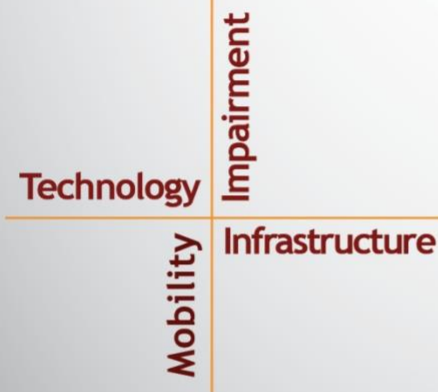
NSTSCCE

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In-depth Analysis of Crash Risk Associated with Eyes-off-road Duration by Road Control Type and Intersection Type

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EXECUTIVE SUMMARY

This study quantified the odds ratios (ORs) associated with eyes-off-road (EOR) durations on different road control and intersection types using the Second Strategic Highway Research Program Naturalistic Data Study (SHRP 2 NDS) dataset. The motivation of this project was to provide support for driver state monitoring systems (DMSs) regarding alert timer settings when drivers look away from the road. The main research questions addressed are: (1) Should there be a different DMS alert timer setting on controlled access roads vs. uncontrolled access roads? And (2) Should there be a different alert timer setting on intersections vs. non-intersections? It is not surprising that the longer drivers look away, the higher the resulting ORs. There are considerable differences for specific road types and intersection types as summarized below:

- Safety impacts of EOR by road control type:
 - Drivers on uncontrolled access roads tended to have longer glances away from the road compared with drivers on controlled access roads.
 - The relative risk (ORs) of EOR events on both crashes of severity 1, 2, and 3, and safety-critical events (SCEs; crashes/near-crashes) for uncontrolled access roads was higher than for controlled access roads.
 - **A lower DMS alert timer setting might be needed on uncontrolled access roads.**
- Safety impacts of EOR by intersection type:
 - The prevalence of events with long single EOR glances (i.e., > 2 s) was relatively low for turning samples.
 - The ORs associated with EOR were the highest for turning at intersections.
 - **A lower DMS timer alert setting is recommended for turning at intersections.**
- A series of varying alert timer thresholds based on single longest EOR duration were evaluated to capture the changing point of the ORs more accurately.
 - **2.7 s and 3.7 s of a single EOR glance were the two changing points regarding the ORs and may potentially be considered as thresholds for the DMS alert timer setting.**
- The proposed alert rate is a representative indicator for false alarm rate, which needs to be considered while setting the alert timer since there is a tradeoff between sensitivity and specificity.
 - **The alert rate was 1 alert per 11 minutes when the threshold was 2.7 s, and 1 alert per 40 minutes when the threshold was 3.7 s.**
- The study also evaluated the influence of different time windows, EOR metrics, and crash severity, with the following main findings.
 - A 6 s window was more informative compared to a 15 s window.
 - ORs by using single longest EOR were much higher than using total EOR and percentage of EOR.
 - ORs for more severe crashes tended to be higher.

Overall, this study suggests that different DMS alert timer settings are needed for different road geometrical characteristics. For uncontrolled access roads, a timer with a lower threshold is recommended, and a higher threshold is recommended for controlled access roads. For intersections, a zero tolerance for vision interruption is ideal. But practically, a relative lower threshold is recommended at intersections compared with non-intersection related segments. This finding could provide critical information for advanced driver assistance system development and driver behavior education programs.

Despite the extensive exploration of the ORs associated with EOR duration in the SHRP 2 NDS data, there are still some limitations and suggested future work. (1) A limited sample size was obtained, especially for turning, due to breaking down turns by intersection type. Going straight at intersections and turning at intersections were combined as intersection-related due to the similarity in locality. However, going straight is similar to a straight segment in some ways, and needs to be further investigated. (2) The non-linear relationship between $\text{logit}(P_{\text{crash}})$ and EOR duration was explored, as shown in [Appendix E](#), but more work is needed to reveal a definitive pattern. (3) Field experiments and tests are needed to give guidelines about timer settings on advanced driving assistance system DMSs. (4) The ORs associated with EOR glances under other road features, such as divided vs. undivided roads and straight vs. curved roads, are also worth investigating.

TABLE OF CONTENTS

LIST OF FIGURES	v
LIST OF TABLES	vii
CHAPTER 1. BACKGROUND.....	1
CHAPTER 2. DATA AND METHODOLOGY	5
DATA PREPRATION.....	5
<i>Glance Data Preparation</i>	<i>5</i>
<i>Definition of Road Type.....</i>	<i>7</i>
<i>Definition of Maneuver Type</i>	<i>8</i>
WEIGHT-ADJUST CALCULATION	9
CHAPTER 3. RESULTS.....	11
EYEGLANCE PATTERN EXPLORATORY.....	11
ORs ASSOCIATED WITH EOR DURATION BY CONTROL TYPE	13
<i>ORs From Crashes with Severity 1, 2, and 3</i>	<i>14</i>
<i>ORs From All Crashes and Near-crashes</i>	<i>15</i>
ORs ASSOCIATED WITH EOR DURATION BY INTERSECTION TYPE	18
<i>ORs From All Crash Types</i>	<i>18</i>
<i>ORs From Selected Crashes with Varying EOR Thresholds</i>	<i>21</i>
<i>Rewighted ORs With Varying EOR Threshold.....</i>	<i>22</i>
ALERT RATE ESTIMATION	24
CHAPTER 4. RESULTS AND DISCUSSION.....	27
SUMMARY OF RESULTS.....	27
DISCUSSION.....	28
REFERENCES.....	31
APPENDIX A. ORs OF THREE EOR METRICS BY CONTROL TYPE (15 S WINDOW).....	33
APPENDIX B. SAMPLE SIZE AND ORS.....	37
APPENDIX C. CRUDE ORs OF NINE COMBINED CRASH CATEGORIES	43
APPENDIX D. LOGISTIC REGRESSION MODEL	49
APPENDIX E. NON-LINEAR MODEL FIT OF THE SINGLE LONGEST EOR DURATION	51

LIST OF FIGURES

Figure 1. Chart. Sequential eyeglance within a 25 s window for two crash drivers.	1
Figure 2. Flow chart. Illustration of analysis framework.	3
Figure 3. Diagram. Illustration of glance locations (Hallmark et al., 2015).	5
Figure 4. Diagram. Illustration of analysis window for SCEs (6s and 15s).	7
Figure 5. Diagram. Illustration of relation to junction (intersections) (Virginia Tech Transportation Institute, 2015).	8
Figure 6. Diagram. Illustration of weight-adjusted ORs calculation.	10
Figure 7. Histogram. Distribution of the single longest EORs by event type.	11
Figure 8. Bar chart. Comparison of the single longest EORs by road control type.	12
Figure 9. Bar chart. Comparison of the single longest EORs by maneuver type.	12
Figure 10. Bar charts. Comparison of ORs by road control type of crashes with severity 1, 2, and 3 only (6 s window).	15
Figure 11. Bar charts. Comparison of ORs by road control type for all SCEs (crashes and near-crashes; 6 s window).	17
Figure 12. Bar chart. Comparison of prevalence of the single longest EOR > 2 s by control type (6 s window).	18
Figure 13. Bar charts. Comparison of ORs associated with single longest EOR glances by maneuver type.	19
Figure 14. Bar charts. Proportion of events with long EORs by event type and maneuver type within uncontrolled access roads (6 s window).	20
Figure 15. Line chart. Comparison of ORs based on selected crashes by maneuver type and single longest EOR threshold.	22
Figure 16. Comparison of reweighted ORs based on matched crashes by maneuver type and single longest EOR threshold.	23
Figure 17. Line chart. Comparison of alert rate in baselines by varying timer threshold and intersection type.	25
Figure 18. Bar charts. Comparison of ORs by road control type of crashes with severity 1, 2, and 3 only (15 s window).	34
Figure 19. Bar chart. Comparison of ORs by road control type of all SCEs (crashes and near-crashes; 15 s window).	36
Figure 20. Line charts. Comparison of crude ORs by intersection type (similar group).	44
Figure 21. Line charts. Comparison of crude ORs by intersection type (higher ORs in intersection).	45
Figure 22. Line charts. Comparison of crude ORs by intersection type (higher ORs in straight segment).	47

Figure 23. Diagram. Illustration of crash configuration. 47
Figure 24. Diagrams. GAM output by road control type..... 52

LIST OF TABLES

Table 1. SHRP 2 Eyeglance category and count with available window¹.....	6
Table 2. Weight of different crash categories.....	10
Table 3. Definitions of crash severity.	13
Table 4. Sample size of matched crash types by intersection type.	22
Table 5. Hypothetical example of alert rate calculation.....	25
Table 6. Descriptive statistics of single EOR duration by three categories based on the first and the last eyeglance status.	26
Table 7. Sample size and ORs for crash severities 1, 2, 3 by control type (total EOR, 6 s window).....	37
Table 8. Sample size and ORs for crash severities 1, 2, 3 by control type (single longest EOR, 6 s window).....	37
Table 9. Sample size and ORs for crash severities 1, 2, 3 by control type (% EOR, 6 s window).....	38
Table 10. Sample size and ORs for all SCEs by control type (total EOR, 6 s window)	38
Table 11. Sample size and ORs for all SCEs by control type (single longest EOR, 6 s window).....	39
Table 12. Sample size and ORs for all SCEs by control type (% EOR, 6 s window).	39
Table 13. Sample size and ORs for crash 123 by maneuver type (single longest EOR, 6 s window).....	40
Table 14. Sample size and ORs for all SCEs by maneuver type (single longest EOR, 6s window).....	40
Table 15. Estimated ORs and corresponding confidence intervals of selected crashes by intersection type within uncontrolled access roads.....	41
Table 16. Reweighted ORs of the matched crashes by intersection type within uncontrolled access roads.....	47

LIST OF ABBREVIATIONS AND SYMBOLS

ADAS	advanced driver assistance systems
DMS	driver monitoring system
EOR	eyes-off-road
OR	odds ratio
SCE	safety-critical event
SHRP 2 NDS	Second Strategic Highway Research Program Naturalistic Driving Study

CHAPTER 1. BACKGROUND

Scanning the driving environment is an important element of safe driving behavior. To prevent extended eyes-off-road (EOR) periods, many advanced driver assistance systems (ADAS) have driver monitoring systems (DMSs) that alert the driver when their EOR time has reached a certain threshold, reminding them to return their eyes to the forward roadway. The longer drivers have their eyes off the forward roadway, the riskier the secondary activity becomes (Klauer et al., 2006), as the driver's attention is not continuously, but only intermittently, directed to the road. The interruption of vision will increase the uncertainty of awareness about the driving situation until it exceeds a threshold (Senders et al., 1967).

The complexity of the driving environment impacts a driver's ability to gather information and gain sufficient awareness of their situation. Uncontrolled access roadways tend to have more walking and biking and turning motor vehicles as they travel through or turn from one route to another. As a result, drivers on controlled access roads may be able to afford more and safer EOR time compared to drivers in uncontrolled access scenarios. An example of sequential eyeglance of two drivers within a 25 s window is compared on controlled access roads vs. uncontrolled access roads in Figure 1.

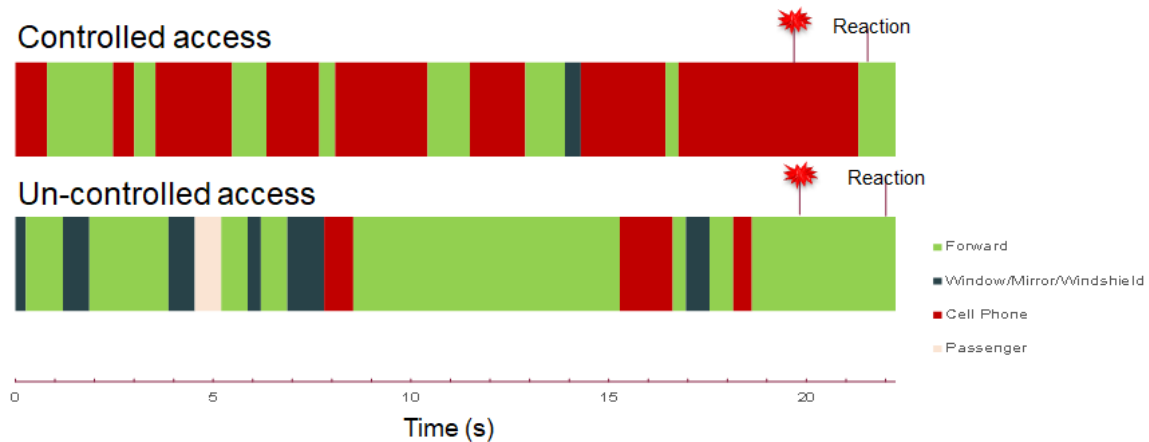


Figure 1. Chart. Sequential eyeglance within a 25 s window for two crash drivers.

Both drivers experienced crashes and the data covers the 20 s prior to and the 5 s after the crash. The crash in the example at the top of the figure occurred on the controlled access road, while the bottom crash happened on the uncontrolled access road. Different colors represent different eyeglance statuses. As the figure shows, both drivers engaged in cell use while driving, and the duration and frequency of cell use on the controlled access sample was much greater than on the uncontrolled access sample.

Eyeglance measures—such as the total EOR duration, the average EOR duration, the single longest EOR duration, and number of EORs—are promising diagnostic metrics for quantifying driver distraction. Glance location sequences and allocations could also be used as an indicator to describe the glance patterns (Xu et al., 2023). It is not surprising that drivers may modulate their behavior based on surrounding environments, but there are very few studies to quantify the

impact of different environmental factors. Huisinigh et al. (2015) observed drivers at controlled intersections and found that secondary behaviors were more frequent among drivers in stopped vehicles than among drivers in moving vehicles. Similarly, three analyses of video recordings of daily driving found that drivers made phone calls and interacted with their cellphone more often when the vehicle was stopped compared with when it was moving, especially at higher speeds (Farmer et al., 2015; Funkhouser & Sayer, 2012; Metz et al., 2014). Kidd et al. (2015) conducted a pilot study wherein they recorded data via roadside observers standing at different roadway features (straightway, controlled intersections, and roundabouts). Data collection was improved by using the same roadway corridor to minimize the effect of other factors (Kidd et al., 2016). Their study showed that drivers may attempt to reduce driving performance impairments and increased risk by engaging in secondary behaviors more often in less demanding situations like when the vehicle is stopped and less often in more demanding roadway situations like a roundabout. Tivesten and Dozza (2014) investigated the impact of driving context (e.g., turning maneuvers, presence of lead or oncoming vehicles, vehicle speed etc.) on drivers' glance behavior, and showed that drivers indeed spent more time looking at the road and had a lower proportion of long EOR durations in complex driving contexts such as when turning and when lead or oncoming vehicles were present. Yuan et al. (2018) used a Hidden Markov Model to identify different driving scenarios (urban, rural, and motorway) and predict drivers' EOR durations with simulator data.

In summary, existing research has explored the impact of road features on drivers' behavior and distraction engagement; however, there is still a gap in quantifying the odds ratios (ORs) associated with EOR duration by different road control type and intersection type. This study thoroughly evaluates the risk of EOR on uncontrolled access roads, especially intersection and intersection-related roads, as compared to the risk on controlled access roads. The findings can provide support for the alert timer setting on DMSs. False alarm rates are also evaluated under different timer thresholds.

This study used Second Strategic Highway Research Program Naturalistic Driving Study (SHRP 2 NDS) data to:

- Explore eyeglance patterns on controlled roads vs. uncontrolled roads;
- On uncontrolled roads: (1) calculate the risk associated with eyeglance compared among three different maneuver types (i.e., turning at an intersection, going straight through an intersection, and driving on a straight segment); (2) re-calculate the weighted risk by considering the yearly functional loss, which factors in ADAS effectiveness and crash statistics; and (3) estimate the alert rate for normal drivers based on baseline samples under different DMS alert timer settings.

The analysis framework is illustrated in Figure 2:

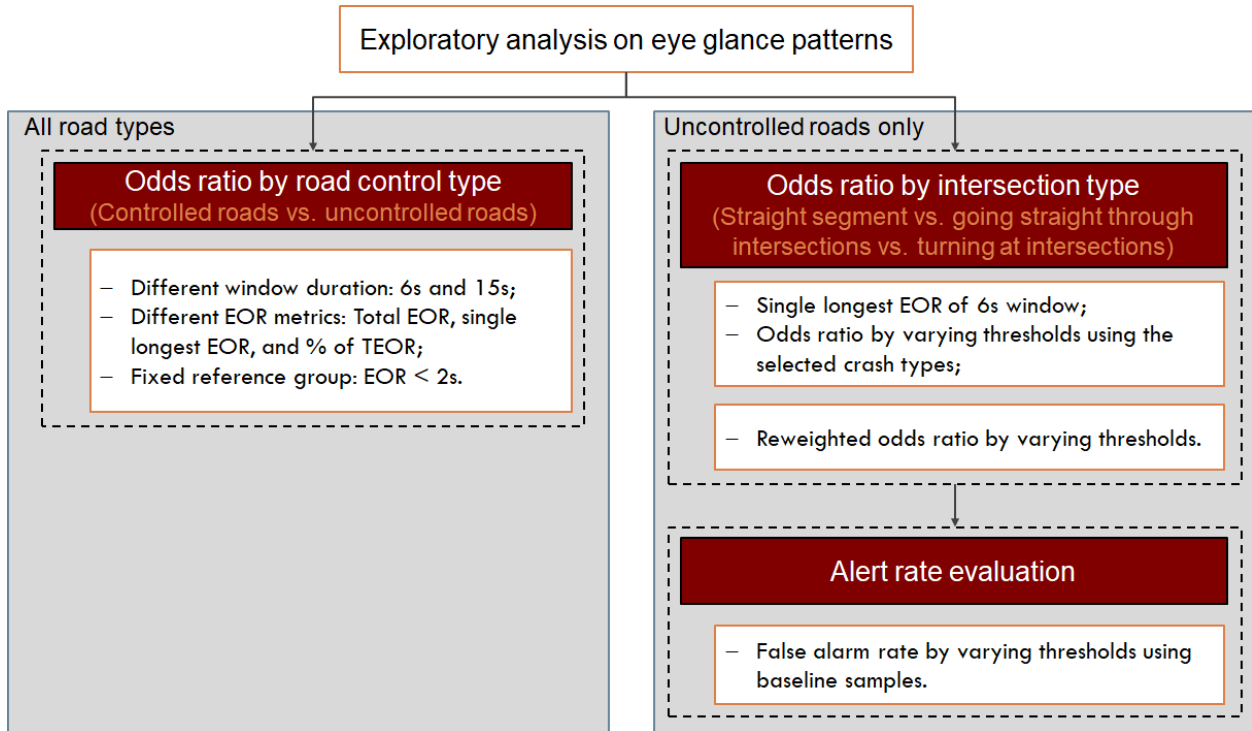


Figure 2. Flow chart. Illustration of analysis framework.

The findings could provide critical information for ADAS development and driver behavior education programs.

CHAPTER 2. DATA AND METHODOLOGY

This study uses SHRP 2 NDS data to evaluate eyeglance behaviors by different road control types (i.e., controlled vs. uncontrolled) and different intersection types on uncontrolled roads (i.e., intersection-related vs. straight segment) in safety-critical events (SCEs; i.e., crashes/near-crashes) as compared to baselines (periods of normal driving). Data preparation and key analytical methods, including weight-adjustment, are introduced in this section.

DATA PREPARATION

Glance Data Preparation

Data reductionists conducted a thorough face video review in order to code SHRP 2 eyeglance locations, which represent practical areas of glance locations, as shown in Figure 3. The video data was collected at 15 Hz, and hence every second includes 15 frames. The eyeglance data for SCEs is available in 30 s clips consisting of the period 20 s prior to and 10 s after the SCE. Eyeglance data is available for baselines in 20 s clips. In total, there are 21 types of eyeglance locations coded, including forward, instrument cluster, center stack, and rearview mirror, among others (see Table 1 for a full list). Note that certain glance locations, including “over the shoulder,” “no eyes visible,” and “other,” were determined based on the judgment of experienced data reductionists. Potential distractions were determined by examining both the driver’s face view and the view over the driver’s right shoulder, which shows hands on/off the steering wheel. Distractions were identified when drivers took their eyes off the forward roadway. Examples of eyeglance locations under distraction are passenger, interior object, cell phone, iPod, portable media device, etc.



Figure 3. Diagram. Illustration of glance locations (Hallmark et al., 2015).

This study focused on two categories of combined eyeglance locations: eyes-on-road and EOR, the locations of which as well as the corresponding duration (in hours) are shown in Table 1. All transitional eyeglance locations were processed to be the same as the previous glance location. Data coded as any of the following were excluded from the analysis: (1) No eyes visible, (2) No video, (3) No driver, (4) No eyes visible, and (5) Others. Over 99% of reduced eyeglance epochs were kept after this process. Within the analysis window, there are 120.57 hours of eyeglance data that have been reduced, with over three quarters coded as “Forward.”

Table 1. SHRP 2 Eyeglance category and count with available window¹.

EOR Category	Eyeglance Location	Duration (hour)
On road	Forward	92.13
	Instrument Cluster	1.10
	Rearview Mirror	1.94
	Right Window/Mirror	1.43
	Right Windshield	4.50
	Left Window/Mirror	4.02
	Left Windshield	2.32
Off road	Center Stack	0.87
	Over-the-Shoulder (left or right)	0.33
	Passenger	0.38
	iPod	0.01
	Interior Object	1.43
	Portable Media Device	0.01
	Cell Phone	2.37
Change to the nearest previous eyeglance location	Transition	6.95
Exclude from the analysis	Eyes Closed	0.10
	No Driver	0.02
	No Eyes Visible - Eyes are Off-Road	0.01
	No Eyes Visible - Glance Location Unknown	0.61
	No Video	0.01
	Other	0.06
Total		120.57

¹Available window indicates 30 s for SCEs and 20 s for baselines.

Three eyeglance metrics were extracted for each sample: total EOR duration, average EOR duration, and single longest EOR duration. Note that the calculation of average EOR duration required the total number of EOR occurrences; i.e., how many times the driver looked away during the selected window.

Time Window Setting (6 s and 15 s)

Although 20 s clips for baselines and 30 s clips for SCEs are available in the SHRP 2 dataset, this study tested two different windows of 6 s and 15 s. For baselines, the duration relative to the end of the sample was used, while the EOR epochs were split 5 s/14 s prior to the precipitating timestamp, and 1 s after for SCEs, as shown in Figure 4. The benefit of using the window in this manner is that the nearby eyeglances are potentially more strongly associated with the occurrence of SCEs. Some previous analyses also used a 6 s window (Klauer et al., 2010). As a result, the short 6 s window was selected. Meanwhile, an additional analysis was calculated for 15 s, given that more eyeglance data was available, and the longer window tended to be able to keep a long EOR glance uncropped. Additionally, 15 s is a useful human factors metric given SAE International’s 15 s rule for task duration (Green, 1999; SAE International, 2004), and will provide a useful comparison of how risk increases over this time period as total EOR increases.

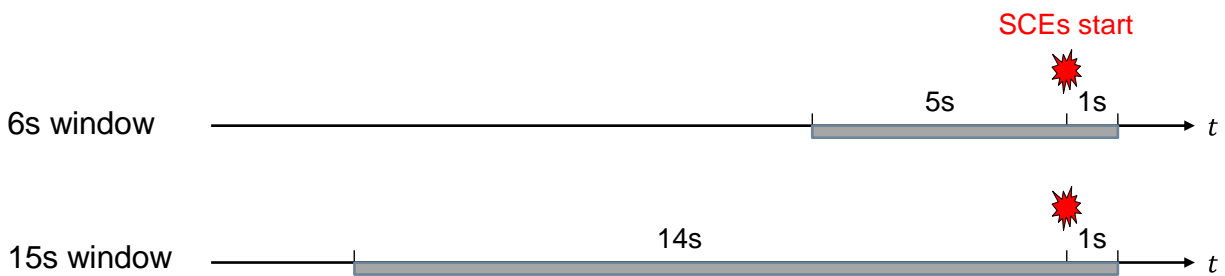


Figure 4. Diagram. Illustration of analysis window for SCEs (6s and 15s).

Definition of Road Type

Road type is defined from two perspectives: control type and divided type.

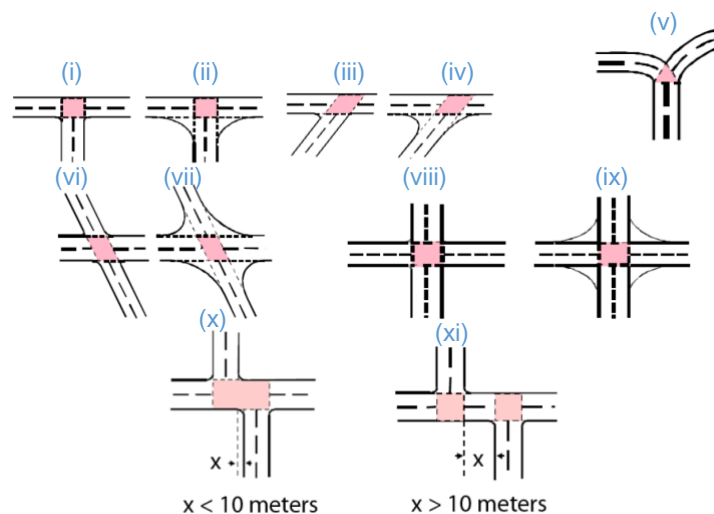
Control type is described by “locality,” which includes the surroundings that influence or may influence the flow of traffic at the start of the precipitating event. Practically, when the locality type is “Interstate/Bypass/Divided Highway with no traffic signals,” the control type is defined as “controlled access road,” which means that all traffic flow is regulated. Otherwise, the control type is “uncontrolled access road” such as “Urban,” “Business/Industrial,” “Bypass/Divided Highway with traffic signals,” “Moderate Residential,” etc. Overall, 7,757 events occurred on controlled access roads, and 20,747 events occurred on uncontrolled access roads.

Divided type describes the roadway design, including the presence or lack of a median, present at the start of the precipitating event. If the event occurred at an intersection, the condition just prior to the intersection was recorded. There are five divided types: “Divided (median strip or barrier)” (12,130 events), “Not divided – simple 2-way trafficway” (12,012 events), “Not divided center 2-way left turn lane” (2,152 events), “One-way traffic” (1,096 events), and “No lanes” (1,114 events). This study focused on the first three divided types. Events on roads with “No lanes” and “One-way traffic” were excluded from the analysis.

Definition of Maneuver Type

On uncontrolled access roads, maneuver type is defined jointly by the following three variables to further explore the ORs with respect to its relationship with intersections (as shown in Figure 5).

- **Pre-incident maneuver:** This represents the last type of driving action or maneuver that the subject vehicle driver engaged in or was engaging in just prior to or at the time of the Precipitating Event, beginning anywhere from about 2–6 s before the Precipitating Event. This variable is independent of the driver's engagement in secondary tasks and the Precipitating Event but should be determined after the Precipitating Event is defined. It is a vehicle kinematic measure, which means that it is based on what the vehicle does (movement and position of the vehicle), not on what the driver is doing inside the vehicle. For baselines, this is the action or driving maneuver that the subject vehicle driver is engaging in or was engaged in for the last 2–6 s of the baseline epoch prior to the baseline anchor point (Event Start), which occurs 1 s before the end of the baseline event. Some pre-incident maneuver types are going straight with constant speed; decelerating in traffic lane; negotiating a curve; changing lanes; turning left or right etc.
- **Relation to junction:** This is the spatial relation of the subject vehicle to a junction at the time of the start of the Precipitating Event. A junction is defined as a point in space where two or more roads or trafficways with different travel speeds or directions of travel meet, as illustrated by the shaded area in Figure 5. Note that (i)–(ix) in the figure are single junctions, while (x)–(xi) are two junctions next to each other. If the distance between two adjacent junctions is less than 10 meters, then they are combined together and considered as one junction; otherwise, if the distance is greater than 10 meters, then they are treated as two individual junctions. If the incident occurs off of the roadway, the relation to junction is determined by the point of departure.



Note: the shaded areas are coded “intersection.”

Figure 5. Diagram. Illustration of relation to junction (intersections) (Virginia Tech Transportation Institute, 2015).

- **Intersection influence:** A judgment call was made as to whether the subject vehicle's safe movement, travel path, and travel speed were under the influence of an intersection at the time of the event (at any time between Event Start through Event End). This could include the subject or other involved vehicle(s) accelerating or decelerating in relation to an intersection or intersecting trafficway, accelerating or decelerating prior to a turn onto a new roadway or into a parking lot or driveway, waiting in a queue of traffic, moving between through lanes and turn lanes or through lanes and acceleration/deceleration lanes, yielding to oncoming or cross traffic, etc. Note that a "Yes" option can be coded here, even if Relation to Junction is Non-junction, if the vehicle(s) are too far from the intersection to code Relation to Junction categories but are still being influenced in a manner described here by an intersection (e.g., a longer queue of traffic at a signal, or a long process of deceleration prior to a turn).

There are three maneuver types:

- 1) **Turning at intersection:** If the pre-incident maneuver is “Turning left” or “Turning right” AND relation to junction is “Intersection” or “Intersection-related.”
- 2) **Going straight at intersection:** If the pre-incident maneuver is “Decelerating in traffic lane” or “Going straight, accelerating” or “Going straight, constant speed” AND the relation to junction is “Intersection” or “Intersection-related.”
- 3) **Straight segment:** if the pre-incident maneuver is “Decelerating in traffic lane” or “Going straight, accelerating” or “Going straight, constant speed” AND relation to junction is “Non-junction” AND intersection influence is “No.”

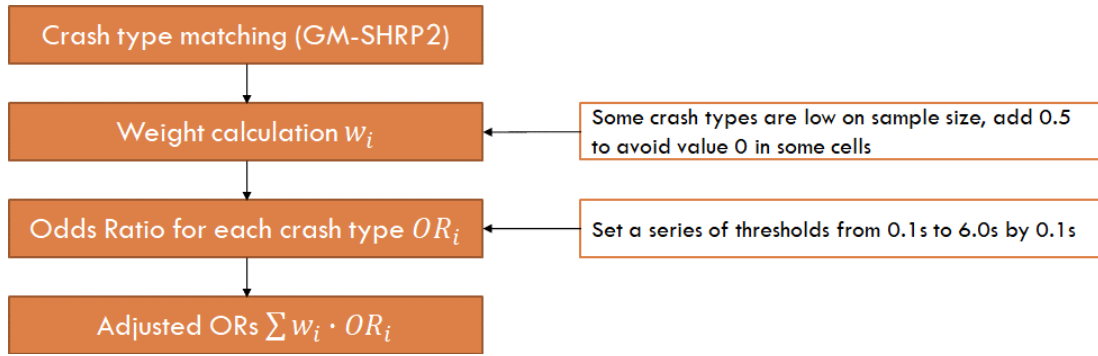
Based on this definition, the total sample sizes are:

- Turning at intersection = 817
- Going straight at intersection = 4,164
- Straight segment = 5,488

Note that the first two groups were combined as “intersection-related” for certain circumstances due to the limited size of turning samples.

WEIGHT-ADJUST CALCULATION

There was a discrepancy between the SHRP 2 NDS crash composition and the target crash composition. Crash types among different maneuver types could also vary substantially—for example, more rear-end striking, sideswipe, and animal-related maneuver types tend to occur on straight segments while intersections tend to have more road departures in addition to rear-end striking. In addition, different ADAS functions are designed to prevent/mitigate certain types of crashes. For example, Forward Collision Warning targets rear-end crashes while Lane Departure Warning is more likely to target run-off roads crashes. As such, a weight-adjusted method was employed to control the differences in crash compositions and ADAS effectiveness across maneuver types. Figure 6 illustrates the method used to adjust crash composition.



Where w_i : weight of crash type i
 OR_i : crude OR associated with EOR for crash type i
 Adjusted OR: weighted OR associated with EOR for all crash types

Figure 6. Diagram. Illustration of weight-adjusted ORs calculation.

Therefore, the SHRP 2 NDS data was adjusted by using a weight based on the ADAS’s effectiveness. The details are omitted in this report, as they are proprietary information, but the final weights of nine selected crashes are shown in Table 2.

Table 2. Weight of different crash categories.

	Combined Crash Category	Crash Type Description – Less Specific	Percentage
1	Road departure	Road departure (end)	22.6%
		Road departure (left or right)	
2	Rear End	Rear-End Striking	14.2%
3	Sideswipe, opposite Direction	Opposite direction (head-on or sideswipe)	13.9%
4	Vulnerable Road Users	Pedestrian-related	23.8%
		Animal-related	
		Pedalcyclist-related	
5	Straight Crossing Paths	Straight crossing path	8.4%
6	Left/Right Turn Across Path	Turn into path (opposite direction)	5.5%
7	Left/Right Turn into Path	Turn into path (same direction)	2.1%
8	Left Turn Across Path (opposite direction)	Turn across path	6.4%
9	Lane Change	Sideswipe, same direction (left or right)	3.0%
	Total		100%

CHAPTER 3. RESULTS

This section contains the following: (1) an exploration of eyeglance patterns by different road control type and maneuver type, (2) a comparison of the ORs associated with EOR duration by road control type, (3) a comparison of the ORs associated with EOR duration by intersection type, (4) a re-calculation of the weight-adjusted ORs by considering ADAS's effectiveness on different intersection types, and (5) an estimation of the alert rate for normal drivers under different time settings.

EYEGLANCER PATTERN EXPLORATORY

EOR characteristics were compared among different event types, road control types, and maneuver types by using the single longest EOR glance. Only samples with non-zero EOR glances were selected and evaluated. The distribution of the non-zero single longest EORs of three event types is compared in Figure 7, which shows that the histogram of crash has long tails compared to baselines.

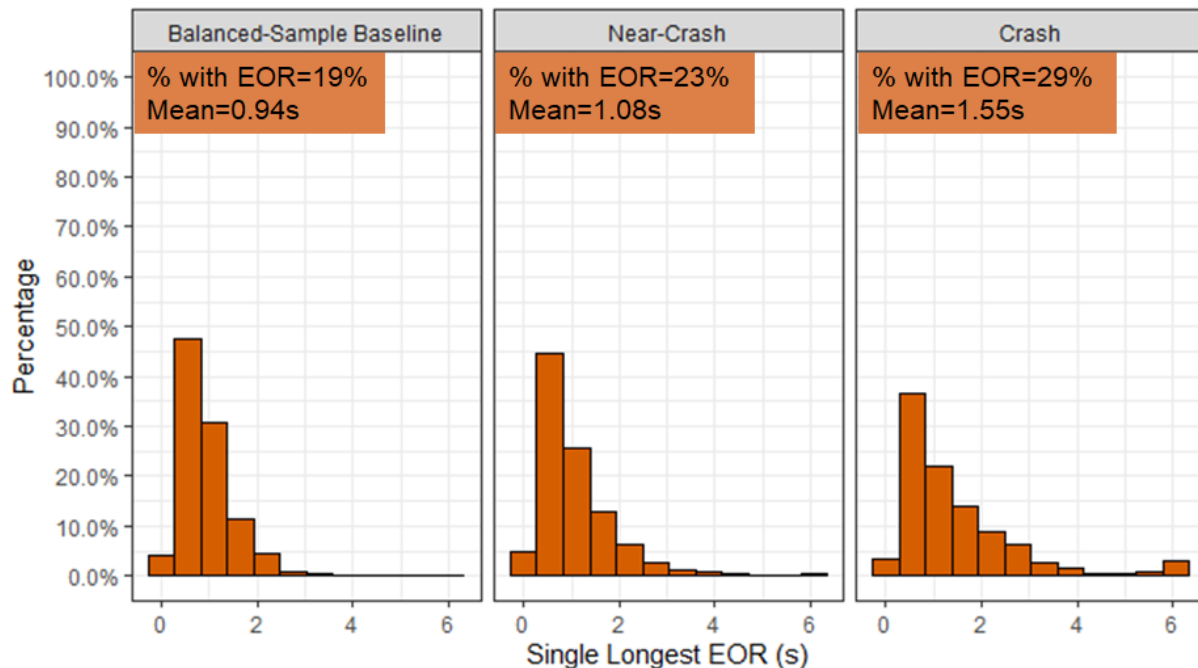


Figure 7. Histogram. Distribution of the single longest EORs by event type.

The proportion of these samples with EORs are 19%, 23%, and 29% for baselines, near-crashes, and crashes, and the corresponding average value of the single longest EORs are 0.94 s, 1.08 s, and 1.55 s. This indicates that drivers with crash occurrences tended to look away from the road substantially longer than those with occurrences of near-crashes and than drivers in baselines. Drivers in baseline samples looked away less often and their EOR glance was the shortest among the three event types.

The average single longest EOR duration by road control type is shown in Figure 8.

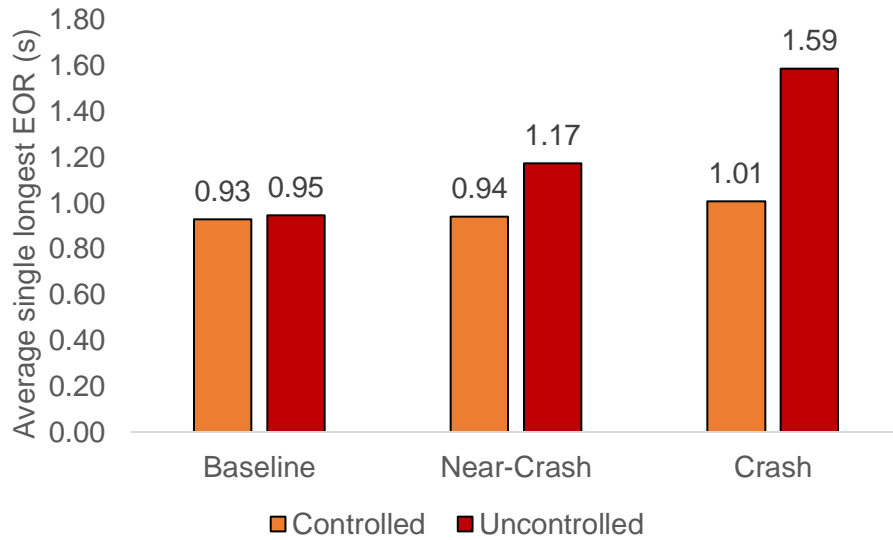


Figure 8. Bar chart. Comparison of the single longest EORs by road control type.

Overall, crashes had longer EOR durations than near-crashes, while baselines had the shortest EOR durations. Within baselines, there was almost no difference between controlled and uncontrolled access roads, while the EOR duration for crashes and near-crashes was substantially higher on uncontrolled access roads than on controlled access roads. **This implies that drivers engaged in shorter single longest EOR glances on controlled access roads (t-test = -7.80, p-value < 0.001).**

The average single longest EORs by intersection type were compared, and are shown in Figure 9.

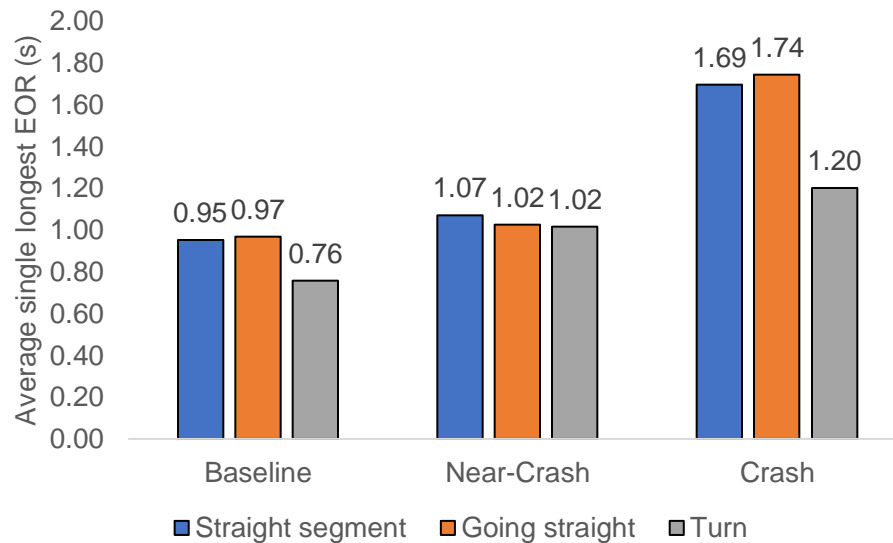


Figure 9. Bar chart. Comparison of the single longest EORs by maneuver type.

Similarly to road control type results, crashes had longer EORs than near-crashes, and baselines had the shortest EORs. As for intersection type, going straight at intersections had similar EORs as straight segments, while **turning at intersections had considerably shorter EORs** compared with the former two conditions. Lower EORs in baselines for turning samples implies that drivers adjusted their eyeglance behavior to look away less while turning at intersections, and lower EORs in crashes for turning samples implies that drivers turning at intersections can't afford greater EOR durations compared to drivers going straight at intersections and drivers on straight segments. However, note the event type is statistically significant ($F_{2, 1,955} = 41.0$, p-value < 0.001) while maneuver type is not ($F_{2, 1,955} = 0.294$, p-value = 0.745).

ORS ASSOCIATED WITH EOR DURATION BY CONTROL TYPE

In this section, all crash types were used to estimate the ORs associated with EOR duration. Two levels of SCEs (i.e., crashes with severity 1, 2, and 3 only, and all crashes and near-crashes combined) were analyzed. The definitions of crash severity are presented in Table 3.

Table 3. Definitions of crash severity.

Crash Severity	Definition
1	Any crash that includes an airbag deployment, any known injury of driver, pedal cyclist, or pedestrian; a vehicle rollover, a high Delta-V—i.e., a kinematic metric (Hankey et al., 2016)—; or vehicle damage requiring towing.
2	Not a level 1 crash, and a minimum of approximately \$1,500 worth of damage as estimated from video.
3	Not a level 1 or 2 crash, the vehicle makes physical contact with another object or departs the road but sustains only minimal or no damage.
4	Tire strike.

We considered two levels of SCEs because more severe SCEs are the main interest of the study; however, more severe crashes are rare events and suffer from insufficient sample size after being broken down by road control type and intersection type. As such, we combined certain groups for some analyses. Three EOR metrics of two time-windows (6 s and 15 s) were used to calculate the ORs associated with EOR. Overall findings are as follows:

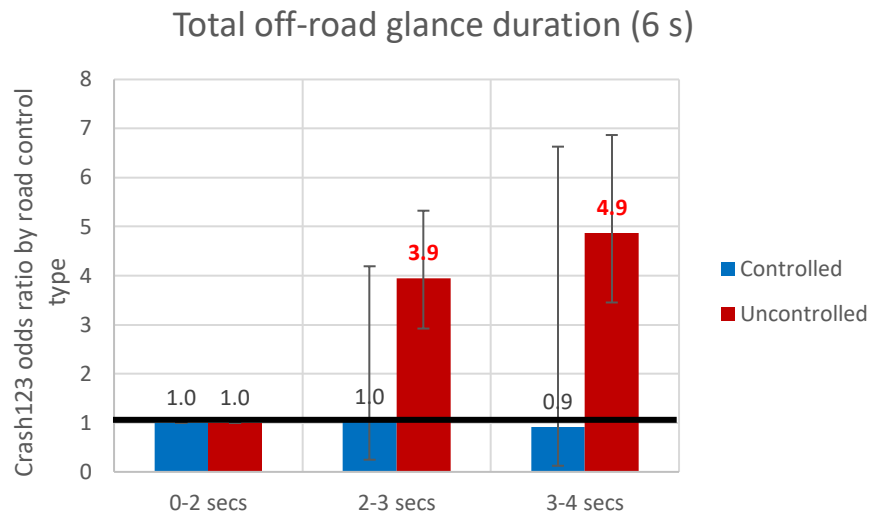
- In general, the magnitude of ORs was lower in the 15 s window than in the 6 s window, but the overall pattern was consistent.
- Single longest EOR duration is a representative indicator of ORs rather than total EOR duration and percentage of EOR duration, as described below.

Therefore, only results from the 6 s window by control type are provided. Results from the 15 s window can be found in Figure 18 and Figure 19 in [Appendix A](#). Also, only ORs of the single longest EOR by intersection type are compared in this report, as the 6 s window tended to capture more relevant EOR glances for SCEs.

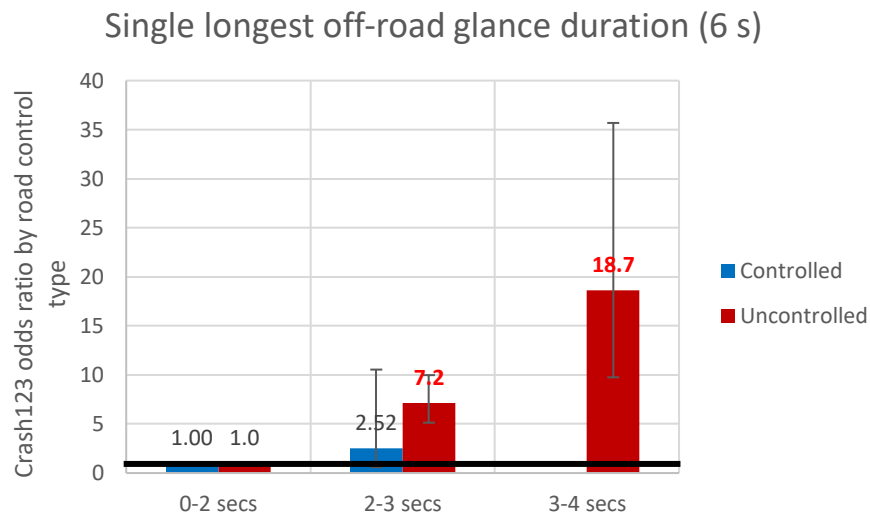
ORs From Crashes with Severity 1, 2, and 3

Comparisons of ORs across three metrics by control type within a 6 s window of crashes with severities 1, 2, and 3 only are shown in Figure 10 below and in Table 7–Table 9 in [Appendix B](#).

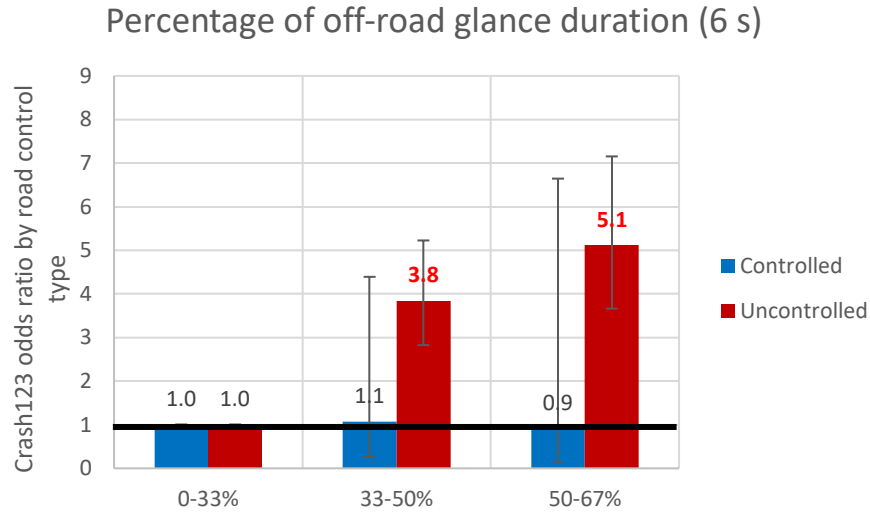
Note: error bars represent 95% confidence intervals. If the lower bar is greater than 1, which is indicated by the black horizontal line in the plot, the ORs are significantly higher than the reference group (i.e., the first cluster in the bar plots); if the upper bar is less than 1, this indicates the ORs are significantly lower than the reference group. The statistically significant results are highlighted as red/bold texts in the figure. The same is true for the bar plots below.



(a) Total EOR glance



(b) Single longest EOR glance



(c) Percentage of EOR glance

Figure 10. Bar charts. Comparison of ORs by road control type of crashes with severity 1, 2, and 3 only (6 s window).

Some relevant observations about the findings are:

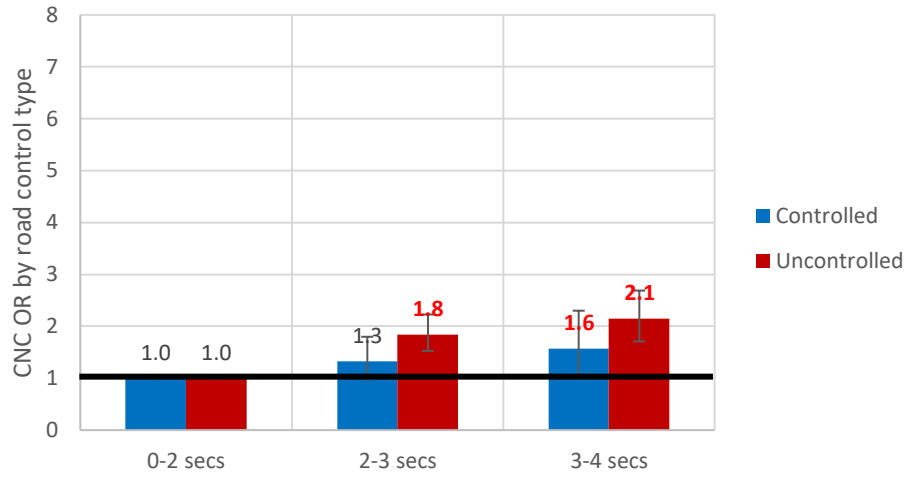
- The longer the EOR duration, the higher the ORs for all three metrics.
- With the same EOR duration range, the ORs for uncontrolled access roads are substantially higher than for the controlled access roads.
- For the magnitude of the ORs, the total EOR duration and the percentage of the EOR duration are approximately the same, due to the fact that the window is 6 s; as a result, a 33–50% result is equivalent to 2–3 s in total EOR.
- The single longest EOR glance duration has much higher ORs than the other two metrics. This is because the total EOR duration could be much longer than the single longest EOR glance duration, resulting in much larger ORs for the same group (i.e., total EOR 2–3 s vs. single longest EOR glance 2–3 s).

ORs From All Crashes and Near-crashes

All SCEs were considered in this analysis to increase sample size, especially for the longer EOR duration group. The results are shown in Figure 11 and the corresponding tables are

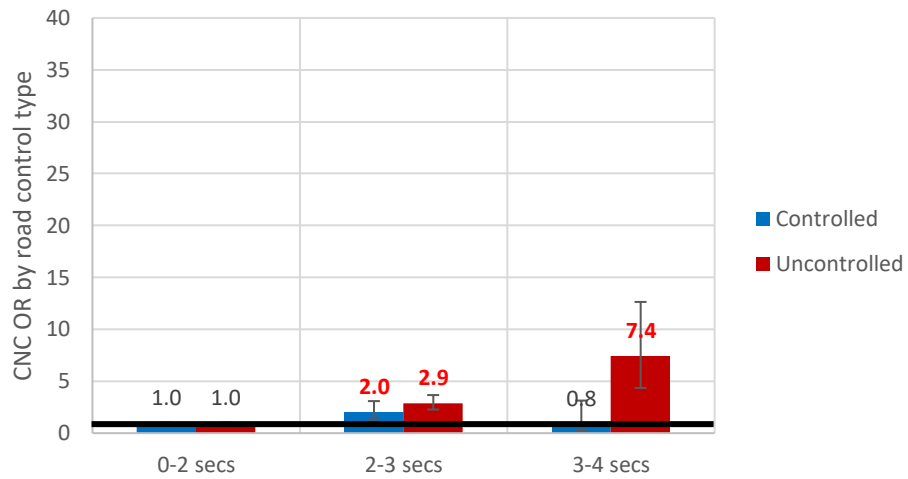
Table 10–Table 12 in [Appendix B](#).

Total off-road glance duration (6 s)

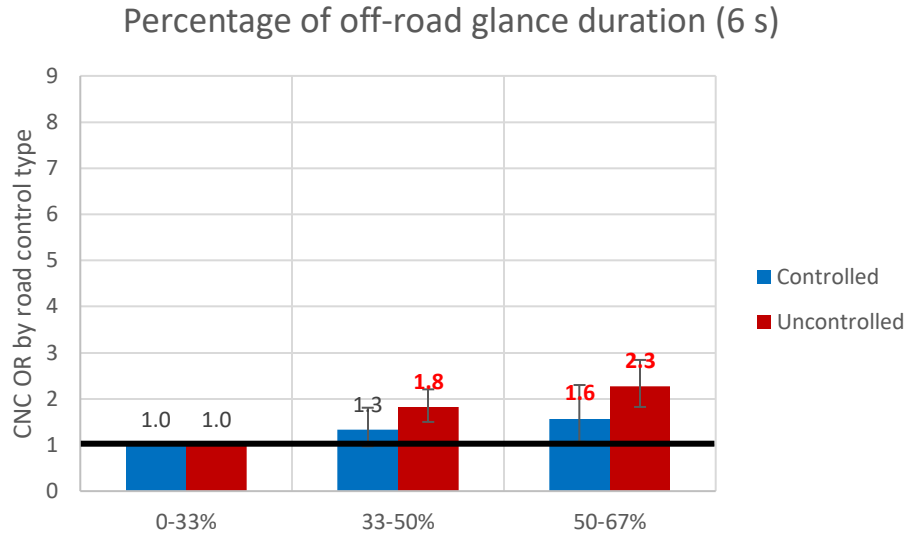


(a) Total EOR glance duration

Single longest off-road glance duration (6 s)



(b) Single longest EOR glance duration



(c) Percentage of EOR glance duration

Figure 11. Bar charts. Comparison of ORs by road control type for all SCEs (crashes and near-crashes; 6 s window).

The findings are summarized as follows:

- Overall, the pattern found for severity 1, 2, and 3 crashes still holds for SCEs. That is, the ORs within the same EOR range are higher for uncontrolled access roads than for controlled access roads; the single longest EOR has a higher OR than total EOR and percentage of EOR.
- Comparing the results of all SCEs with severity 1, 2, and 3 only, the magnitude of the ORs is substantially lower for all SCEs. This is because SCEs contain all severities of crashes and near-crashes, which makes them less extreme than crashes with severity 1, 2, and 3 only.

The prevalence of events with the single longest EOR duration greater than 2 s by control type is illustrated in Figure 12.

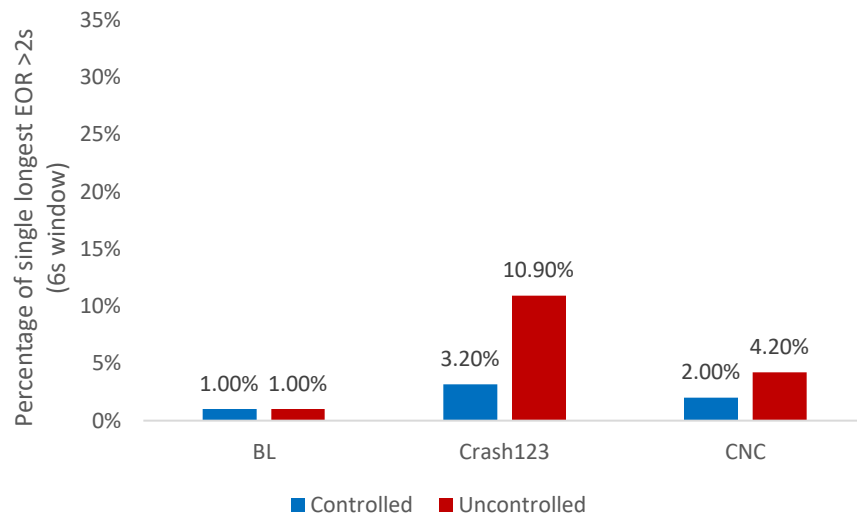


Figure 12. Bar chart. Comparison of prevalence of the single longest EOR > 2 s by control type (6 s window).

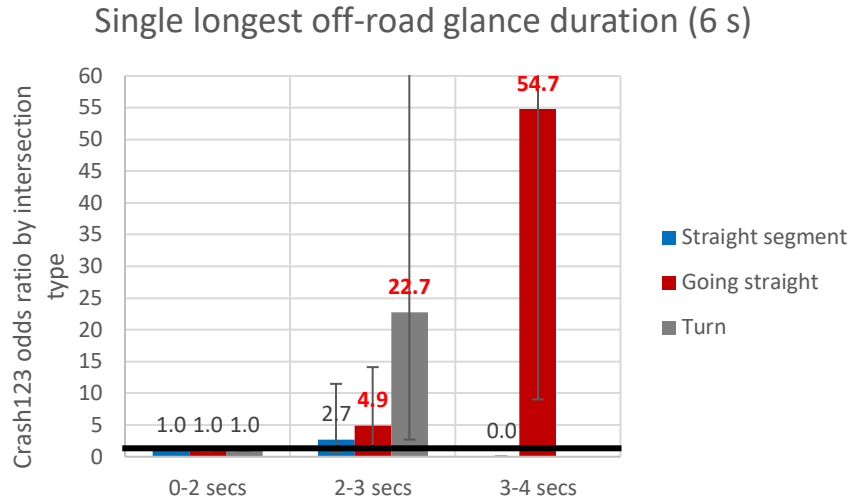
The above figure shows that, overall, fewer drivers on controlled access roads looked away more than 2 s compared to drivers on uncontrolled access roads, especially for crashes with severity 1, 2, and 3. However, for baselines, the prevalence was approximately the same for controlled and uncontrolled access roads. We can infer that, with same EOR duration, uncontrolled access roads are more likely to have severe crashes. That is, drivers on uncontrolled access roads cannot afford long EOR glances.

ORS ASSOCIATED WITH EOR DURATION BY INTERSECTION TYPE

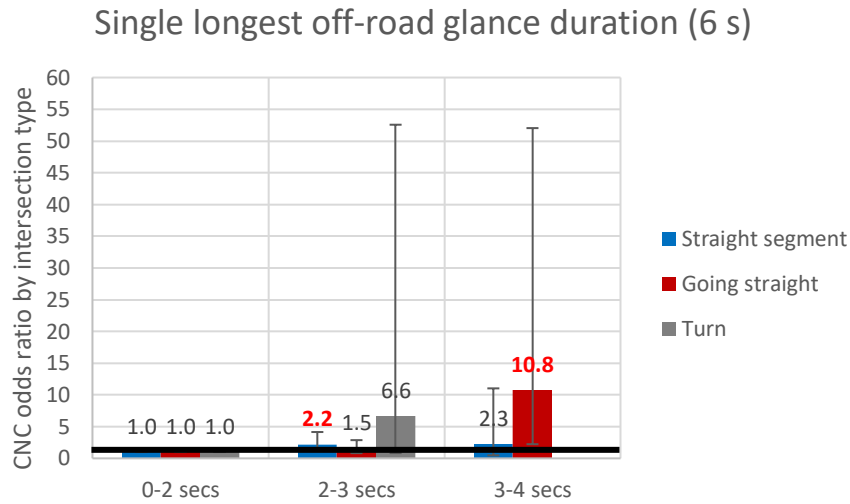
The ORs associated with EOR duration at intersections are of main interest for this study. This section focuses on the different intersection types on uncontrolled access roads. Three approaches were adapted to investigate the ORs associated with EOR duration on uncontrolled access roads: (1) calculate ORs of all crash types with preset thresholds (i.e., 2 s and 3 s); (2) calculate ORs with selected crash types only and a series of thresholds; (3) calculate the weighted average to adjust the SHRP 2 crash composition towards the target crash composition.

ORs From All Crash Types

Based on the previous section, the single longest EOR glance is a promising indicator of EOR-related ORs. Hence, only the results of the single longest EOR by different maneuver types under a 6 s window are presented (Figure 13 below and Table 13–Table 14 in [Appendix B](#)).



(a) Crashes with severity 1, 2, 3 (6 s window)



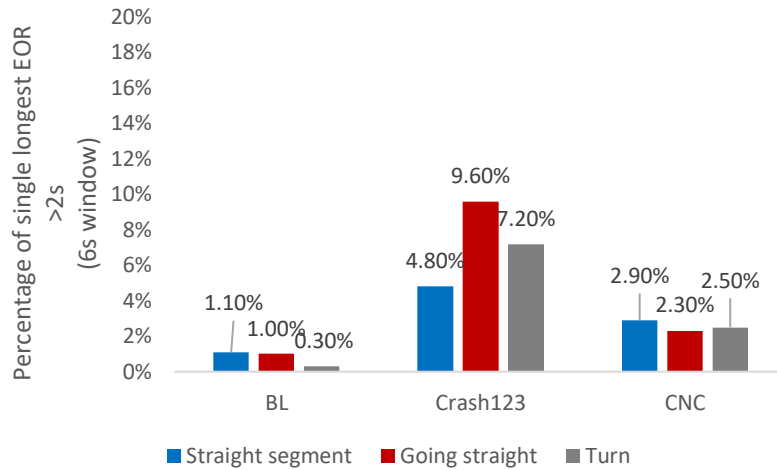
(b) All SCEs (6 s window)

Figure 13. Bar charts. Comparison of ORs associated with single longest EOR glances by maneuver type.

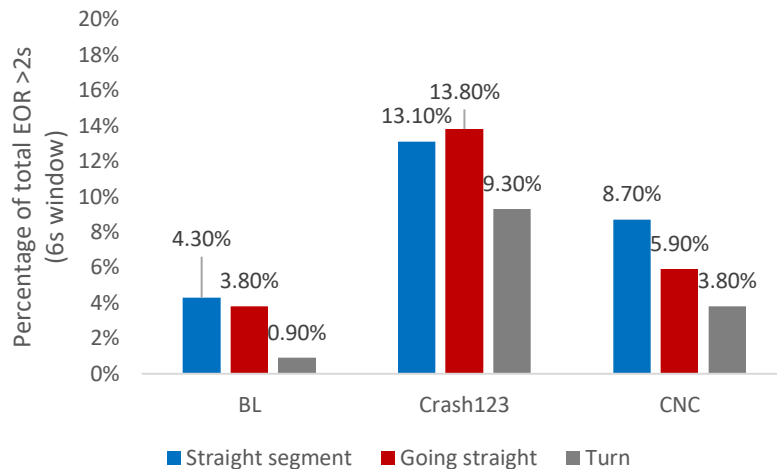
The findings are as follows:

- Overall, the ORs associated with EOR duration are the highest for turning at intersections, followed by going straight at intersections, and driving on a straight segment. This implies that with the same duration of single longest EOR, EOR behavior is much riskier while turning at an intersection.
- The ORs are approximately the same for going straight at intersections and driving on a straight segment when the single longest EOR glance is less than 3 s. However, once the duration of this glance exceeds 3 s, the ORs for going straight at intersection increase substantially, while driving on straight segments stays at the same level.

Note that there are very few samples with single longest EOR glances or total EOR duration greater than 2 s, as shown in Figure 14.



(a) Prevalence of events with the single longest EOR > 2 s



(b) Prevalence of events with the total EOR > 2 s

Figure 14. Bar charts. Proportion of events with long EORs by event type and maneuver type within uncontrolled access roads (6 s window).

Consequently, there are even fewer samples that contain a single longest EOR greater than 3 s, especially for turning and straight segments. The percentage of baselines during turning with long single EOR glances (i.e., > 2 s) was only 0.3% while crashes with severity 1, 2, and 3 accounted for 7.2%. This indicates that most drivers adapted their behavior to look away from the road less while turning to ensure safety. Meanwhile, although drivers on straight segments tended not to conduct long single EOR glances, their total EOR duration tended to be longer than

on straight segments and turning at intersections. On the other hand, under baseline scenarios, drivers tended not to have long single EOR glances or long total EOR durations.

ORs From Selected Crashes with Varying EOR Thresholds

Certain types of crashes of interest were selected by using the incident type in SHRP 2 data. This variable describes the type of conflict(s) that the subject vehicle has with other objects, such as rear-end striking, rear-end struck, run-off-road, etc. Based on the particular interest of this study (i.e., not of interest, or can be prevented if designed ADAS functions effectively), the following incident types were kept in the final analysis:

- Backing, fixed object
- Pedalcyclist-related
- Pedestrian-related
- Rear-end, struck
- Road departure (end)
- Sideswipe, same direction (left or right)
- Straight crossing path
- Turn across path
- Turn into path (opposite direction)
- Turn into path (same direction)
- The animal size is big when the crash is animal-related such as deer.
- Other

The following incident types were excluded from the analysis:

- Backing into traffic
- Opposite direction (head-on or sideswipe)
- Rear-end, striking
- Road departure (left or right)
- The animal size is small when the crash is animal-related (e.g., a squirrel, rabbit, raccoon or other small animal)
- Unknown

Figure 15 below compares the ORs associated with the duration of the single longest EOR on intersections and straight segments. Note that both turning at intersections and going straight at intersections were combined into “intersection” due to their small sample size in turning events. The range of the single longest EOR is from 0.1 s to 4.0 s with increments of 0.1 second. Note that all the uncontrolled access samples were divided into two groups: greater than the threshold group (comparison group) vs. less than or equal to the threshold group (reference group). Therefore, the interpretation was compared to the reference group: the OR of the same duration in the comparison group is larger if the ORs are > 1 or smaller if the ORs are < 1 .

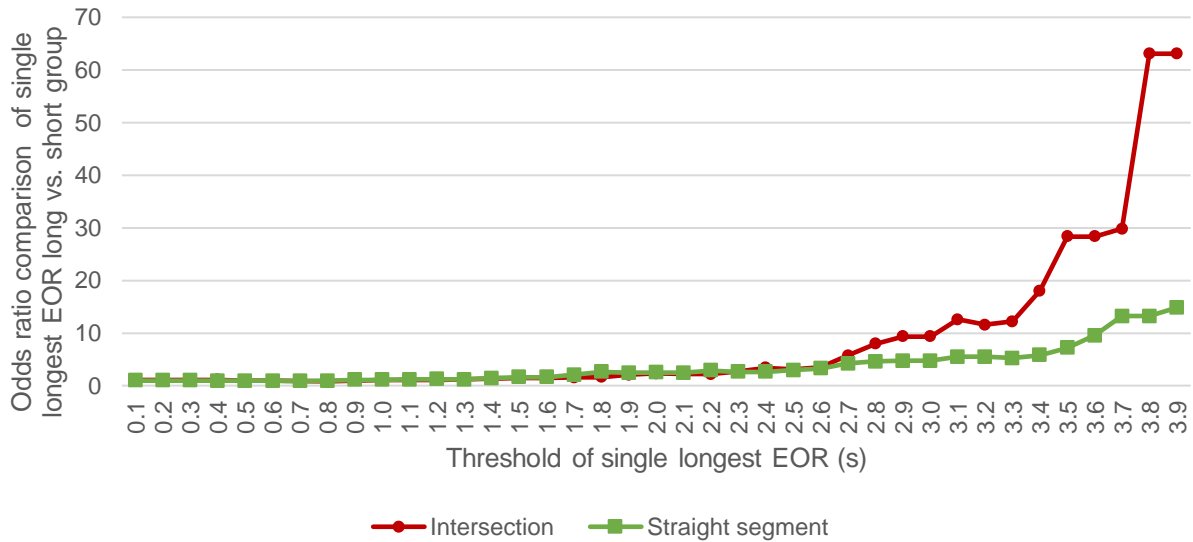


Figure 15. Line chart. Comparison of ORs based on selected crashes by maneuver type and single longest EOR threshold.

The main findings are as follows:

- The ORs kept increasing for both intersection types as the single longest EOR glances increased.
- The ORs of intersections increased much faster than that of straight segments after the single longest EOR glances became greater than 2.7 s, which implies the ORs rose considerably at intersections if the driver looked away more than 2.7 s, and the risk skyrocketed after 3.7 s.
- The confidence intervals were too wide to demonstrate in Figure 15, which was mostly due to the small sample size issue. The detailed confidence intervals are provided in Table 15.

Reweighted ORs With Varying EOR Threshold

This reweighted ORs analysis combined all SCEs in the SHRP 2 NDS dataset. The overall sample size (including all SCEs and baselines) was low for certain crash types and intersection types, as shown in Table 4.

Table 4. Sample size of matched crash types by intersection type.

Matched crash type	Straight segment	Turn	Going straight
Road departure	31	257	29
Rear End	214	37	374
Opposite Direction	19	2	4
Vulnerable Road Users	187	30	58

Matched crash type	Straight segment	Turn	Going straight
Straight Crossing Paths	2	3	58
Left/Right Turn Across Path	3	7	88
Left/Right Turn into Path	5	25	77
Left Turn Across Path (opposite direction)	3	6	94
Lane Change	64	32	82
Baseline	4,376	316	2,812

As shown in table Table 4 above, “straight segment” and “turn” samples were combined into an “intersection” category. Still, the sample size for certain cells was as low as zero after breaking samples into event types and different EOR duration thresholds. During the ORs calculation, 0.5 was added to each cell to avoid errors caused by zeroes in the numerator or denominator. However, this did not distort the final conclusions. This is because when the sample size is large, the impact of adding 0.5 is negligible, and when the sample size is extremely low or zero, adding 0.5 to each cell only guarantees a non-invalid output; the confidence interval is extremely wide and not misleading for purposes of interpretation. We added 0.5 because the low sample size was not consistent across different intersection types for the same crash type. For example, “opposite direction” had a low sample size for turning at intersections, but there were a decent number of samples of traveling in straight segments. Simply removing this crash type was not advisable because (1) the summation of all the weights should be 100% and excluding any crash types would make this impossible and (2) we wanted to maximize the use of the available data.

The comparison of reweighted ORs between intersections and straight segments is shown in Figure 16 below and Table 16 in the [Appendix C](#).

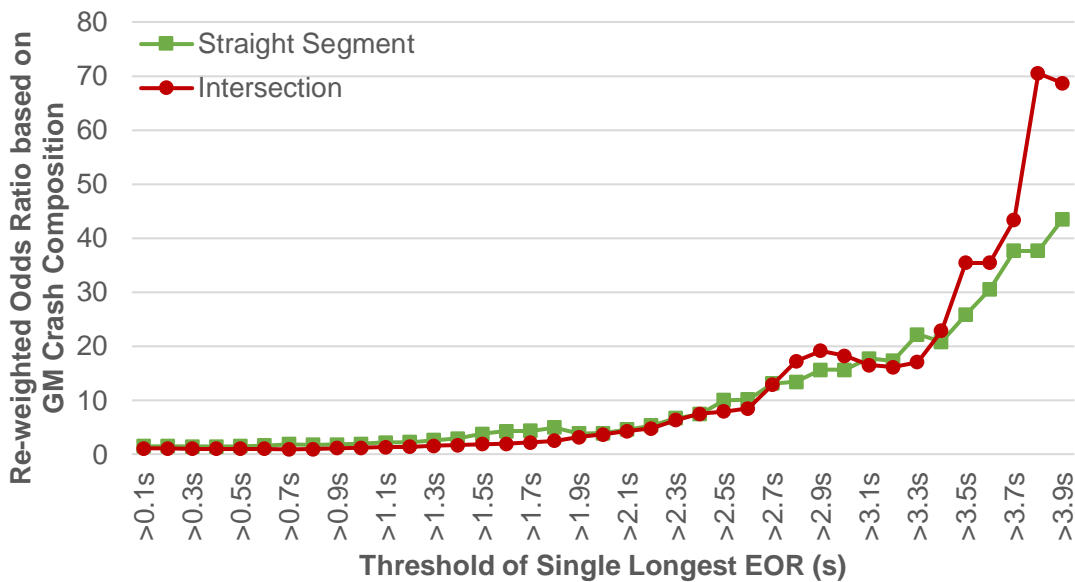


Figure 16. Comparison of reweighted ORs based on matched crashes by maneuver type and single longest EOR threshold.

The main findings are summarized as following:

- Overall, the ORs kept increasing when the single longest EOR glances were longer for both intersection types.
- The ORs increased considerably when the threshold was 1.6 s regardless of intersection type.
- The gap between intersections and straight segments was much smaller until the threshold reached 3.6 s compared to the ORs of selected crashes.

This phenomenon was investigated by checking the crude ORs of nine individual matched crash types, as shown in Figure 20–Figure 23 in [Appendix C](#). Three crash types had higher ORs for intersections: sideswipe-opposite direction, rear-end, and vulnerable road users. Three crash types had higher ORs for straight segments: straight crossing paths, left/right turn across path, and left/right turn into path. The remaining three crash types had approximately the same ORs between intersections and straight segments containing a left turn across path (opposite direction), road departure, and lane change. The resulting mixture of all these patterns generated the smaller gap between intersections and straight segments for the reweighted ORs compared with the ORs from the selected crash types.

ALERT RATE ESTIMATION

ORs can measure the crash risk associated with EOR duration. The results presented in the previous section confirmed that the longer the driver looked away, the higher the risk of an SCE. Selecting an appropriate ADAS DWS alert timer setting is crucial, since there is a trade-off between preventing long EOR glances and causing too many false alarms. Therefore, the alert rate was evaluated by varying the timer for baseline samples on uncontrolled access roads. Two maneuver types were assessed with 3,142 intersection-related events, and 4,389 straight segment events. The window used the maximum available data (i.e., 20 s), such that long EOR glances were less likely to be cropped by the preset window.

The alert rate was calculated using the following steps:

1. Collect all the single EOR glances of baselines only for intersections and straight segments.
2. Set threshold for the alert timer d .
3. Count the number of EOR glances N_i that exceed the preset threshold d_i .
4. Estimate the total window T_i by assuming a 20 s duration for each sample.
5. Calculate the corresponding alert rate per hour: $r_i = \frac{N_i}{T_i} \times 3,600$.

A hypothetical example is illustrated in Table 5.

Table 5. Hypothetical example of alert rate calculation.

Sequential EOR duration (s)							The number of alerts		Total duration (s)
Sample	EOR1	EOR2	EOR3	EOR4	EOR5	EOR6	Threshold = 1.5 s	Threshold = 3.0 s	
1	0.5	1.2					0	0	20.1
2	3.3						1	1	20.0
3	2.1	0.8	1.2	1.5	2.5		3	0	20.1
4	2.5						1	0	19.9
5	0.8	1.9	1.4				1	0	20.0
Total							6	1	100.1
Alert rate							215.7	36.0	

A series of thresholds for the timer setting ranging from 0.1 s to 6.0 s were evaluated by intersection type. The corresponding alert rates of baselines equivalent to the false alarm rate are shown in Figure 17.

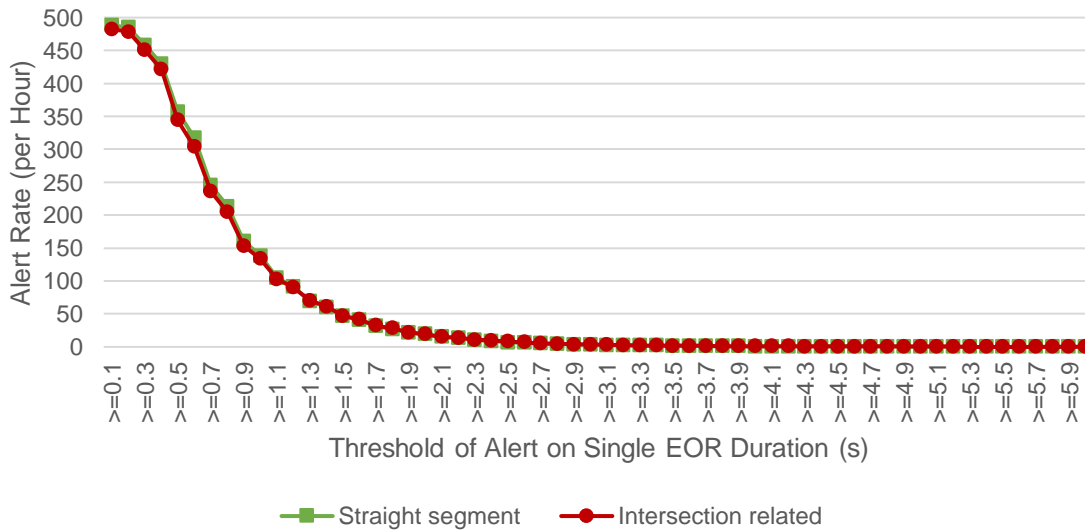


Figure 17. Line chart. Comparison of alert rate in baselines by varying timer threshold and intersection type.

The main findings are:

- Overall, the higher the threshold, the lower the alert rate for both intersections and straight segments. For example, the alert rate was one alert per minute when the threshold was 1.4 s, and the alert rate dropped to one alert per 3 minutes when the threshold was 2.0 s. The alert rates were one per 18 minutes and one per 35 minutes for thresholds of 3.0 s and 3.5 s.

- There was no obvious difference between intersections and straight segments with the maximum difference in percentage of hourly alert rate being 4.3%.

Ideally, the eyeglance data for a whole trip should be used for the analysis instead of a 20 s window. The concern was that some of the long EOR glances might be chopped at the beginning and/or at the end of the 20 s window. The severity of the problem was evaluated as shown in Table 6.

Table 6. Descriptive statistics of single EOR duration by three categories based on the first and the last eyeglance status.

Category	Average EOR (s)	Maximum EOR (s)
Samples with the first eyeglance as EOR	0.747	5.741
Samples with the last eyeglance as EOR	0.699	5.072
Samples with neither the first nor the last eyeglance as EOR	0.855	9.944

Overall, there are 7,531 baseline samples. Among these samples, 799 events had the first eyeglance status as EOR within a 20 s window, while 921 events had their last eyeglance status as EOR, accounting for 11% and 12% of samples, correspondingly. The average and the single longest EOR duration of these two types of samples were compared with samples without EOR glances being cropped. The rest of the events neither started nor ended with EOR glances; i.e., these events started and ended with eyes-on-road glances within the 20 s window. This illustrated that cropped cases had shorter EOR durations compared to uncropped cases, especially in cases with long EOR durations. In addition, it is possible that long EOR glances were not captured in all scenarios, but based on the qualitative analysis, the problem was not severe. Therefore, the calculated alert rate is determined to be a valid estimation of false alert rates under certain thresholds.

CHAPTER 4. RESULTS AND DISCUSSION

SUMMARY OF RESULTS

This study quantified the ORs associated with EOR durations on different road control types and intersection types by using SHRP 2 NDS data. It is not surprising that the longer drivers looked away, the higher the ORs. However, there were considerable differences for specific road types and intersection types, as summarized below:

- For different road control types:
 - The prevalence of events with long single EOR glances (i.e., > 2 s) was approximately the same under baselines between controlled access and uncontrolled access roads, but substantially fewer drivers with long single EOR glances on controlled access roads experienced SCEs, especially crashes of severity 1, 2, and 3.
 - With the same EOR duration range, the ORs for uncontrolled access roads were substantially higher than for controlled access roads.
 - These findings imply that drivers tend to look away more on uncontrolled access roads, and the risk on those roads is higher compared to controlled access roads. Therefore, a lower DWS alert timer might be beneficial on uncontrolled access roads.
- For different intersection types:
 - The prevalence of events with long single EOR glances as well as long total EOR durations of greater than 2 s was extremely low for turning samples. This indicates that most drivers adapted their behavior to look away from the road less while turning to ensure safety.
 - The ORs associated with EOR were the highest for turning at intersections, followed by going straight at intersections, then driving on straight segments. This implies that for the same duration of single longest EOR, SCE risk is much higher while turning at intersections.
 - The ORs rose quickly for turning samples when drivers conducted long single glances greater than 2 s, and this value skyrocketed for going straight at intersections when drivers conducted long single glances greater than 3 s.
 - This implies that most drivers could adjust their eyegance behavior and tended to look away less while turning at intersections. In addition, the ORs were very sensitive to single EOR duration for turning. Therefore, a lower DWS alert timer is recommended for turning at intersections.
- A series of varying timer thresholds based on single longest EOR duration was evaluated to capture the changing point of the ORs more accurately.
 - With the selected crash types, the ORs for intersections was similar to the straight segments when the single longest EOR glances were less than 2.7 s. Beyond that, the ORs increased much more quickly on intersections. Another changing point for intersections was 3.7 s, with a steep rise when drivers glanced away from the

road longer than 3.7s. This confirms that a lower timer is recommended for intersections, and establishes that 2.7 s and 3.7 s are two thresholds for single EOR durations.

- With the re-weighted ORs, the overall pattern still holds that the ORs were higher for intersections than for straight segments, and that the thresholds were at approximately 2.7 s and 3.7 s. However, the gap between these two intersection types was much smaller for the re-weighted ORs. The reason for this is that the crash compositions were considerably different on intersections compared with straight segments and there were various patterns in terms of crash type and intersection type. The mixture of all these patterns generated a smaller gap.
- The proposed alert rate is a representative indicator for a false alarm rate, which needs to be considered while setting the DWS alert timer.
 - Overall, the higher the threshold, the lower alert rate for both intersections and straight segments.
 - The alert rate was one alert per 11 minutes at a threshold of 2.7 s and one alert per 40 minutes at a threshold of 3.7 s.
- Different windows, EOR metrics, and different crash severities were compared:
 - A 6 s window seems to capture more relevant SCE-related EOR glances compared to a 15 s window.
 - In general, the single longest EOR is a representative EOR indicator since it has much higher ORs than total EOR duration and percentage of EOR duration.
 - More severe crashes generate higher ORs.

DISCUSSION

Scanning the driving environment is an important element of safe driving behavior. It is well-accepted that the longer the driver has their eyes off the forward roadway, the riskier the associated secondary activity becomes. However, in the real world, a driver's attention is not continuously, but only intermittently, directed to the road. The interruption of vision will increase the uncertainty of awareness about the driving situation and the crash risk associated with the vision interruption increases substantially once the interruption duration exceeds a threshold. The complexity of the driving environment impacts a driver's ability to gather information and gain sufficient awareness. This poses a crucial challenge for ADAS DMSs, which are supposed to ensure that drivers keep their eyes on the road while using automated assistance features by generating alerts for EOR instances. It is helpful to quantify the ORs associated with EOR glances by different road geometrical characteristics to provide information for ADAS developers. More specifically, this study focuses on two types of road characteristics: road control type, and whether or not an intersection is present. In addition, since there is a tradeoff between the detection rate and false alarm rate, the DWS alert rate was also evaluated with baseline samples by varying the alert timer's threshold.

The results showed that drivers tended to look away longer on uncontrolled access roads, and that uncontrolled roads had higher ORs compared to the controlled access roads. As for different intersection types, most drivers could adjust their eyeglance behavior and tended to look away less when turning at intersections. The ORs were considerably higher for turning samples compared to straight segments. Overall, this study suggests that different DMS alert timer settings are needed for different road geometrical characteristics. For uncontrolled access roads, a timer with a lower threshold is recommended, and a higher threshold is recommended for controlled access roads. For intersections, a zero tolerance for vision interruption would be ideal. But practically, a relative lower threshold is recommended at intersections compared with non-intersection related segments. The ORs start rising when drivers look away more than 2 s, which is consistent with previous studies (Dingus et al., 1989; Kircher & Ahlström, 2009; Liang et al., 2014; Sodhi et al., 2002), and substantially increases once drivers look away from the road more than 3 s. The results from varying thresholds show that 2.7 s and 3.7 s are two main “changing points” in terms of ORs for intersections. The ORs on non-intersections show a much gentler change, where the changing point is 3.7 s, and the ORs are less than 10 when the single glance is less than 3.0 s. Drivers are expected to receive an alert every 11 minutes if the timer is set at 2.7 s, and 1 alert per 40 minutes if the timer is set at 3.7 s.

The results of this project suggest that being attentive is essential for safe driving, and, accordingly, various timer lengths on different road types are necessary for ADAS DMSs to alert most effectively. This finding could provide critical information for ADAS development and driver behavior education programs.

Despite the extensive exploration on the ORs associated with EOR duration in SHRP 2 NDS data, there are still some limitations and suggested future work. (1) A limited sample size was obtained, especially for turning, due to breaking down turns by intersection type. Going straight at intersections and turning at intersections were combined as intersection-related due to the similarity in locality. However, going straight is similar to a straight segment in some ways, and needs to be further investigated. (2) The non-linear relationship between $\text{logit}(P_{\text{crash}})$ and EOR duration was explored, as shown in [Appendix E](#), but more work is needed to reveal a definitive pattern. (3) Field experiments and tests are needed to give guidelines about timer settings on ADAS DMSs. (4) The ORs associated with EOR glances under other road features, such as divided vs. undivided roads and straight vs. curved roads, is also worth investigating.

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APPENDIX A. ORs OF THREE EOR METRICS BY CONTROL TYPE (15 S WINDOW)

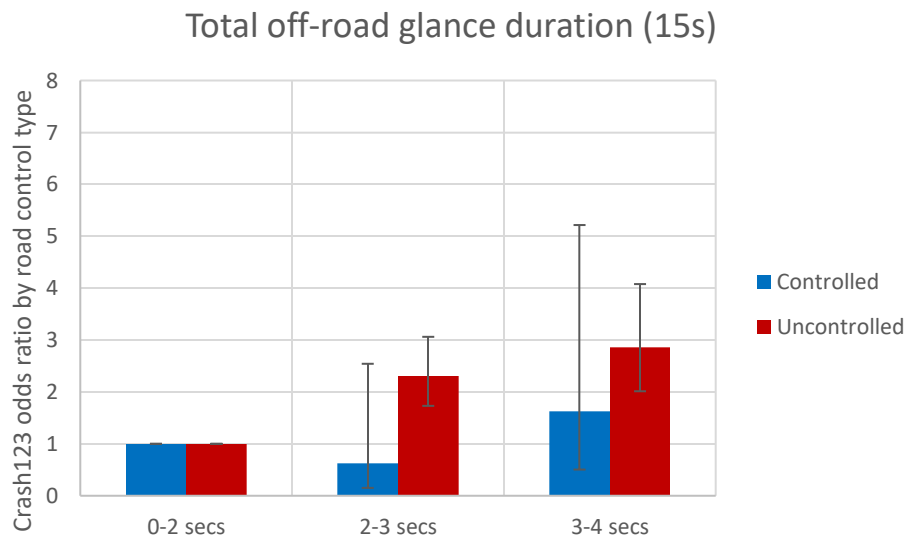
The ORs associated with EOR instances within a 15 s window are shown in Figure 17 for crashes with severity 1, 2, and 3. Figure 18 shows the ORs for all SCEs. Comparing ORs within a 15 s window:

- Overall, the ORs within the same EOR range are higher for uncontrolled access roads than for controlled access roads.
- The ORs of all SCEs are smaller than those of crashes with severity of 1, 2, and 3 only.

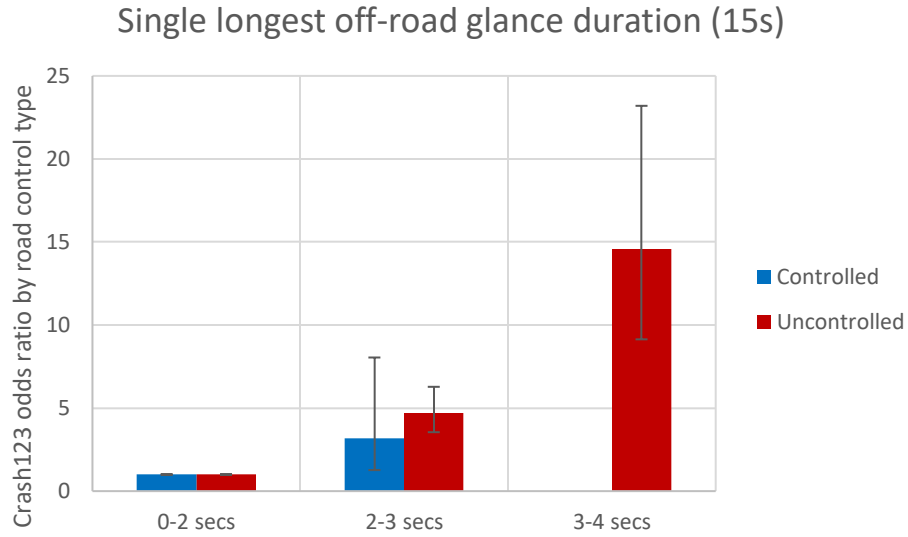
Comparing the results with the 6 s window:

- In general, the magnitude of the ORs is lower in a 15 s window than in a 6 s window. This implies that the shorter window may be capable of capturing the most relevant EOR glances.
- The percentage of EOR glances does not follow the same pattern as the total EOR glances for the 15 s window. This is because for the 6 s windows, 33% and 50% of EOR glances match 2 s and 3 s; however, this number changes to 5 s and 7.5 s for the 15 s window. As such, the ORs rose substantially.
- Most of the patterns for the 6 s window still hold for the 15 s window, with the exception of the single longest EOR glances. The ORs are higher on controlled access roads in the 15 s window than the ORs on uncontrolled access roads in the 6 s window.

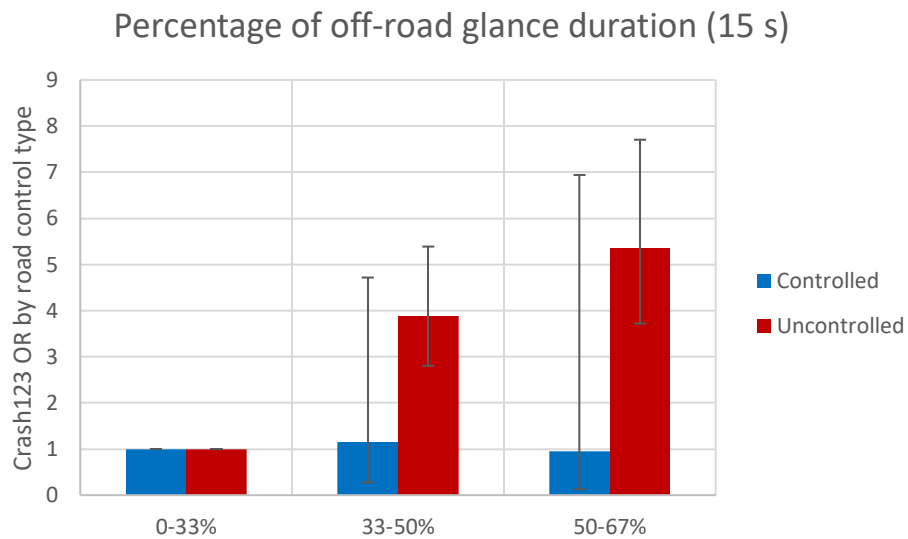
Crashes With Severity 1, 2, and 3



(a) Total EOR glance



(b) Single longest EOR glance

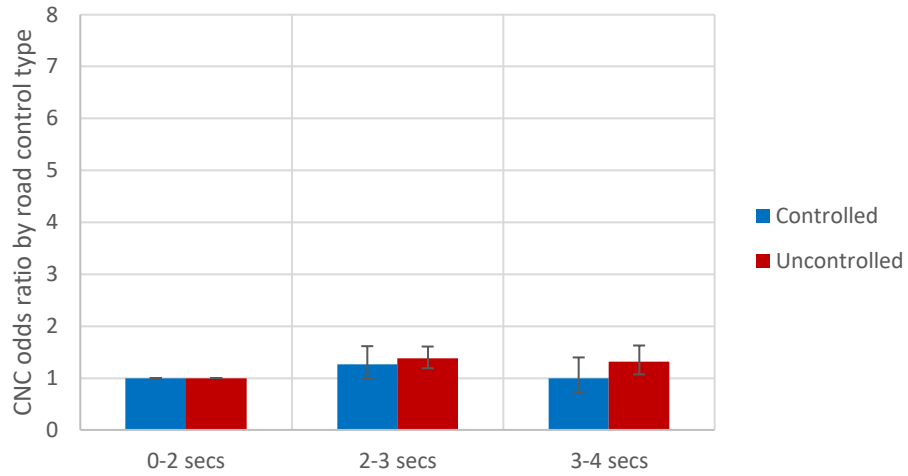


(c) Percentage of EOR glance

Figure 18. Bar charts. Comparison of ORs by road control type of crashes with severity 1, 2, and 3 only (15 s window).

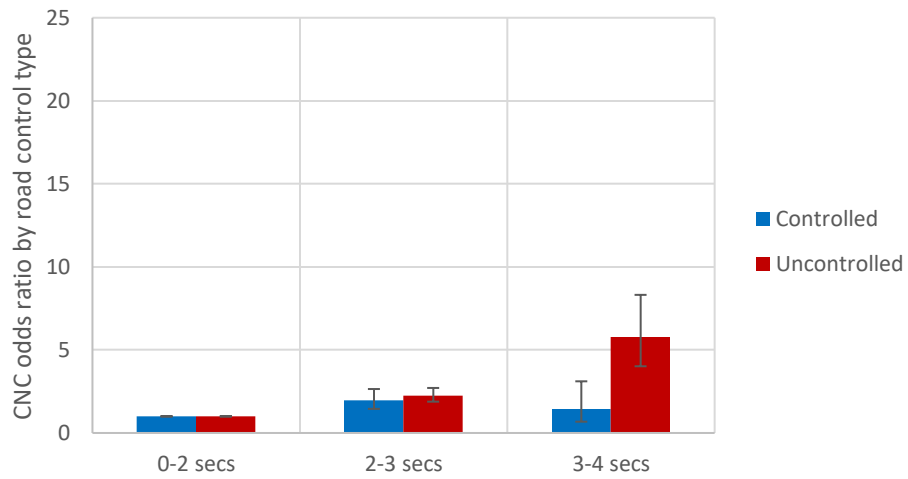
SCEs – Crashes and Near-crashes

Total off-road glance duration (15s)

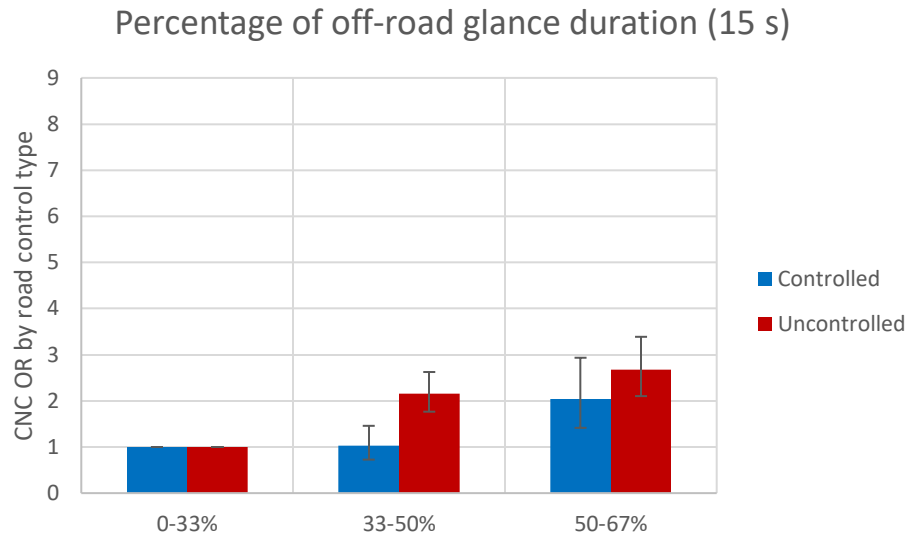


(a) Total EOR glance

Single longest off-road glance duration (15s)



(b) Single longest EOR glance



(c) Percentage of EOR glance

Figure 19. Bar chart. Comparison of ORs by road control type of all SCEs (crashes and near-crashes; 15 s window).

APPENDIX B. SAMPLE SIZE AND ORS

Table 7. Sample size and ORs for crash severities 1, 2, 3 by control type (total EOR, 6 s window).

Controlled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	5,084	86	1.00	1.00	1.00
2–3 seconds	116	2	1.02	0.25	4.19
3–4 seconds	65	1	0.91	0.12	6.63
Others	67	5			
Percentage of events with total EOR > 2 s	4.7%	8.5%	–	–	–
Uncontrolled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	13,985	753	1.00	1.00	1.00
2–3 seconds	259	55	3.94	2.92	5.32
3–4 seconds	164	43	4.87	3.45	6.87
Others	145	64			
Percentage of events with total EOR > 2 s	3.9%	17.7%	–	–	–

Note: A dash (–) indicates not applicable.

Note regarding the following tables:

- “Others” have no estimates and confidence intervals since they are not of interest. The frequency count is kept for calculating the “Percentage of events with total EOR > 2 s.” The same is true for all tables below.
- Text in bold represents statistical significance at level 0.05. The same is true for all tables below.

Table 8. Sample size and ORs for crash severities 1, 2, 3 by control type (single longest EOR, 6 s window).

Controlled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	5,278	91	1.00	1.00	1.00
2–3 seconds	46	2	2.52	0.60	10.55
3–4 seconds	8	0	–	–	–
Others	0	1			
Percentage of events with single longest EOR > 2 s	1.0%	3.2%	–	–	–
Uncontrolled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	14,405	815	1.00	1.00	1.00
2–3 seconds	126	51	7.15	5.13	9.98
3–4 seconds	18	19	18.66	9.75	35.68

Controlled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
Others	4	30			
Percentage of events with single longest EOR > 2 s	1.0%	10.9%	–	–	–

Table 9. Sample size and ORs for crash severities 1, 2, 3 by control type (% EOR, 6 s window).

Controlled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–33%	5,095	86	1.00	1.00	1.00
33%–50%	111	2	1.07	0.26	4.39
50–67%	65	1	0.91	0.13	6.64
Others	61	5			
Percentage of events with %EOR > 33%	4.4%	8.5%	–	–	–
Uncontrolled	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–33%	14,003	758	1.00	1.00	1.00
33%–50%	250	52	3.84	2.83	5.23
50–67%	166	46	5.12	3.66	7.15
Others	134	59			
Percentage of events with %EOR > 33%	3.8%	17.2%	–	–	–

Table 10. Sample size and ORs for all SCEs by control type (total EOR, 6 s window)

Controlled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	5,084	2,244	1.00	1.00	1.00
2–3 seconds	116	68	1.33	0.98	1.80
3–4 seconds	65	45	1.57	1.07	2.30
Others	67	68			
Percentage of events with total EOR > 2 s	4.7%	7.5%	–	–	–
Uncontrolled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	13,985	5,649	1.00	1.00	1.00
2–3 seconds	259	193	1.84	1.53	2.23
3–4 seconds	164	142	2.14	1.71	2.69
Others	145	210			
Percentage of events with total EOR > 2 s	3.9%	8.8%	–	–	–

Table 11. Sample size and ORs for all SCEs by control type (single longest EOR, 6 s window).

Controlled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	5,278	2,377	1.00	1.00	1.00
2–3 seconds	46	42	2.03	1.33	3.09
3–4 seconds	8	3	0.83	0.22	3.14
Others	0	3			
Percentage of events with single longest EOR > 2 s	1.0%	2.0%	–	–	–
Uncontrolled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	14,405	5,932	1.00	1.00	1.00
2–3 seconds	126	150	2.89	2.28	3.67
3–4 seconds	18	55	7.42	4.35	12.64
Others	4	57			
Percentage of events with single longest EOR > 2 s	1.0%	4.2%	–	–	–

Table 12. Sample size and ORs for all SCEs by control type (% EOR, 6 s window).

Controlled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	5,095	2,250	1.00	1.00	1.00
2–3 seconds	111	65	1.33	0.97	1.81
3–4 seconds	65	45	1.57	1.07	2.30
Others	61	65			
Percentage of events with %EOR > 33%	4.4%	7.2%	–	–	–
Uncontrolled	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	14,003	5,665	1.00	1.00	1.00
2–3 seconds	250	184	1.82	1.50	2.21
3–4 seconds	166	153	2.28	1.83	2.84
Others	134	192			
Percentage of events with %EOR > 33%	3.8%	8.5%	–	–	–

Table 13. Sample size and ORs for crash 123 by maneuver type (single longest EOR, 6 s window).

Straight segment	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	4,816	80	1.00	1.00	1.00
2–3 seconds	44	2	2.74	0.65	11.48
3–4 seconds	7	0	0.00		
Others	1	2			
Percentage of events with single longest EOR > 2 s	1.1%	4.8%	–	–	–
Going straight	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	3,102	85	1.00	1.00	1.00
2–3 seconds	30	4	4.87	1.68	14.12
3–4 seconds	2	3	54.74	9.03	331.87
Others	0	2			
Percentage of events with single longest EOR > 2 s	1.0%	9.6%	–	–	–
Turn	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	341	90	1.00	1.00	1.00
2–3 seconds	1	6	22.73	2.70	191.24
3–4 seconds	0	1	–	–	–
Others	0	0			
Percentage of events with single longest EOR > 2 s	0.3%	7.2%	–	–	–

Table 14. Sample size and ORs for all SCEs by maneuver type (single longest EOR, 6s window).

Straight segment	Baseline	Crash 123	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	4,816	602	1.00	1.00	1.00
2–3 seconds	44	12	2.18	1.15	4.15
3–4 seconds	7	2	2.29	0.47	11.03
Others	1	4			
Percentage of events with single longest EOR > 2 s	1.1%	2.9%	–	–	–
Going straight	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	3,102	1,006	1.00	1.00	1.00
2–3 seconds	30	15	1.54	0.83	2.88
3–4 seconds	2	7	10.79	2.24	52.03

Others	0	2			
Percentage of events with single longest EOR > 2 s	1.0%	2.3%	–	–	–
Turn	Baseline	CNC	Estimate	95% Lower CI	95% Upper CI
0–2 seconds	341	463	1.00	1.00	1.00
2–3 seconds	1	9	6.63	0.84	52.57
3–4 seconds	0	3	–	–	–
Others	0	0			
Percentage of events with single longest EOR >2s	0.3%	2.5%	–	–	–

Table 15. Estimated ORs and corresponding confidence intervals of selected crashes by intersection type within uncontrolled access roads.

Threshold of single longest EOR (s)	Intersection			Straight Segment		
	Estimate	95% CI Lower Bound	95% CI Upper Bound	Estimate	95% CI Lower Bound	95% CI Upper Bound
> 0.1 s	1.116	0.914	1.363	0.980	0.714	1.345
> 0.2 s	1.112	0.911	1.359	0.996	0.726	1.367
> 0.3 s	1.093	0.894	1.336	0.966	0.703	1.327
> 0.4 s	1.109	0.906	1.357	0.892	0.647	1.231
> 0.5 s	0.997	0.811	1.227	0.901	0.650	1.248
> 0.6 s	0.957	0.774	1.183	0.893	0.641	1.246
> 0.7 s	0.870	0.695	1.091	0.863	0.608	1.224
> 0.8 s	0.873	0.691	1.103	0.908	0.635	1.298
> 0.9 s	0.996	0.777	1.277	1.091	0.754	1.577
> 1 s	1.033	0.796	1.341	1.098	0.746	1.614
> 1.1 s	1.049	0.794	1.386	1.190	0.790	1.791
> 1.2 s	1.091	0.818	1.455	1.237	0.812	1.884
> 1.3 s	1.180	0.863	1.615	1.162	0.727	1.858
> 1.4 s	1.281	0.926	1.773	1.391	0.867	2.231
> 1.5 s	1.435	1.015	2.030	1.597	0.972	2.624
> 1.6 s	1.426	0.990	2.052	1.589	0.934	2.703
> 1.7 s	1.529	1.034	2.260	2.048	1.193	3.515
> 1.8 s	1.587	1.049	2.401	2.628	1.517	4.552
> 1.9 s	2.027	1.298	3.166	2.444	1.327	4.502
> 2 s	2.298	1.439	3.670	2.524	1.338	4.759
> 2.1 s	2.242	1.326	3.791	2.420	1.181	4.956
> 2.2 s	2.207	1.267	3.846	2.855	1.382	5.900
> 2.3 s	2.729	1.460	5.103	2.634	1.117	6.214
> 2.4 s	3.358	1.733	6.506	2.643	1.052	6.643

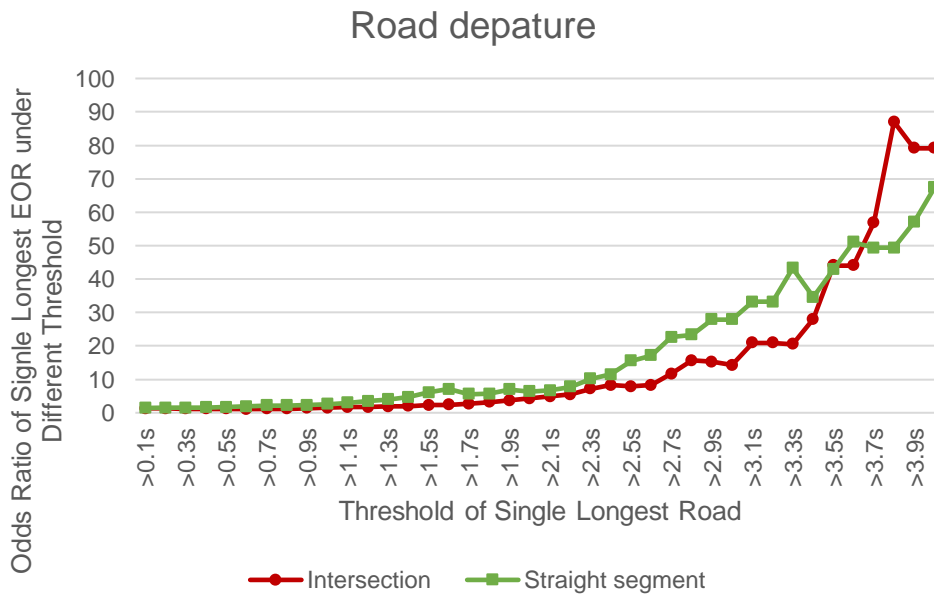
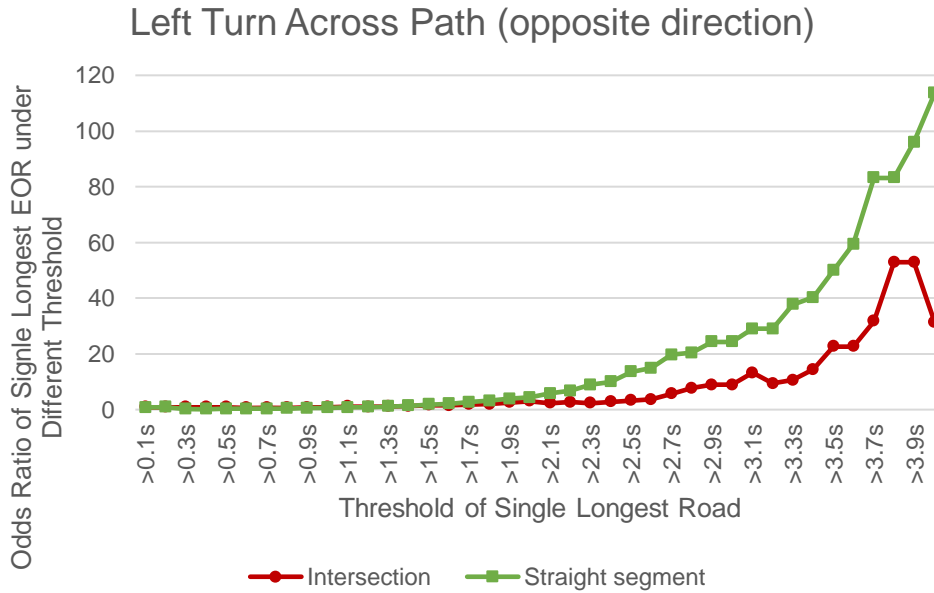
Threshold of single longest EOR (s)	Intersection			Straight Segment		
	Estimate	95% CI Lower Bound	95% CI Upper Bound	Estimate	95% CI Lower Bound	95% CI Upper Bound
> 2.5 s	3.088	1.490	6.401	2.966	1.074	8.188
> 2.6 s	3.435	1.637	7.209	3.251	1.167	9.057
> 2.7 s	5.702	2.520	12.899	4.216	1.467	12.117
> 2.8 s	7.950	3.298	19.167	4.587	1.592	13.213
> 2.9 s	9.344	3.741	23.340	4.741	1.481	15.183
> 3 s	9.344	3.741	23.340	4.741	1.481	15.183
> 3.1 s	12.563	4.478	35.243	5.488	1.676	17.966
> 3.2 s	11.541	4.057	32.833	5.488	1.676	17.966
> 3.3 s	12.219	4.058	36.792	5.210	1.327	20.452
> 3.4 s	18.003	5.289	61.281	5.765	1.449	22.932
> 3.5 s	28.367	6.558	122.712	7.205	1.737	29.879
> 3.6 s	28.367	6.558	122.712	9.503	2.174	41.532
> 3.7 s	29.785	5.127	173.046	13.177	2.703	64.241
> 3.8 s	63.084	6.481	614.013	13.177	2.703	64.241
> 3.9 s	63.084	6.481	614.013	14.826	2.907	75.621

Note: text in bold indicates statistical significance at level 0.05.

APPENDIX C. CRUDE ORS OF NINE COMBINED CRASH CATEGORIES

The ORs associated with the single longest EOR have three different patterns, which becomes apparent when comparing intersections and straight segments: (1) approximately the same ORs, (2) higher ORs on intersection segments, and (3) higher ORs on straight segments.

(1) Approximately the same ORs



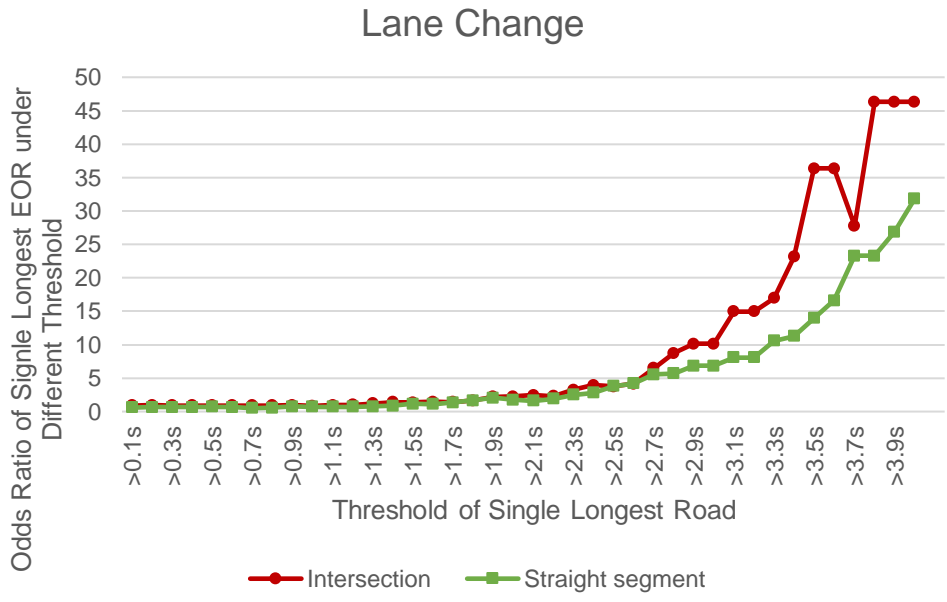
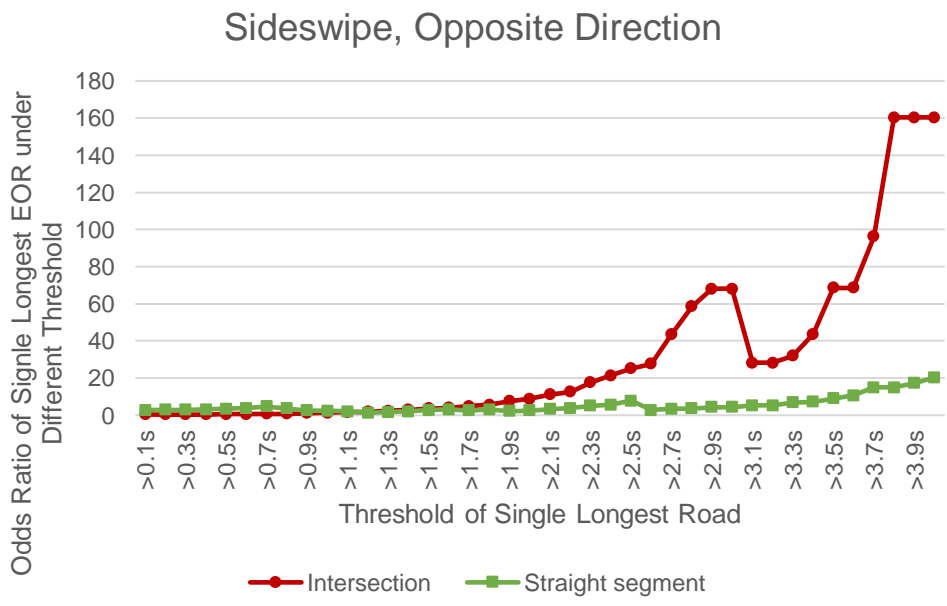


Figure 20. Line charts. Comparison of crude ORs by intersection type (similar group).

(2) Higher ORs on intersections



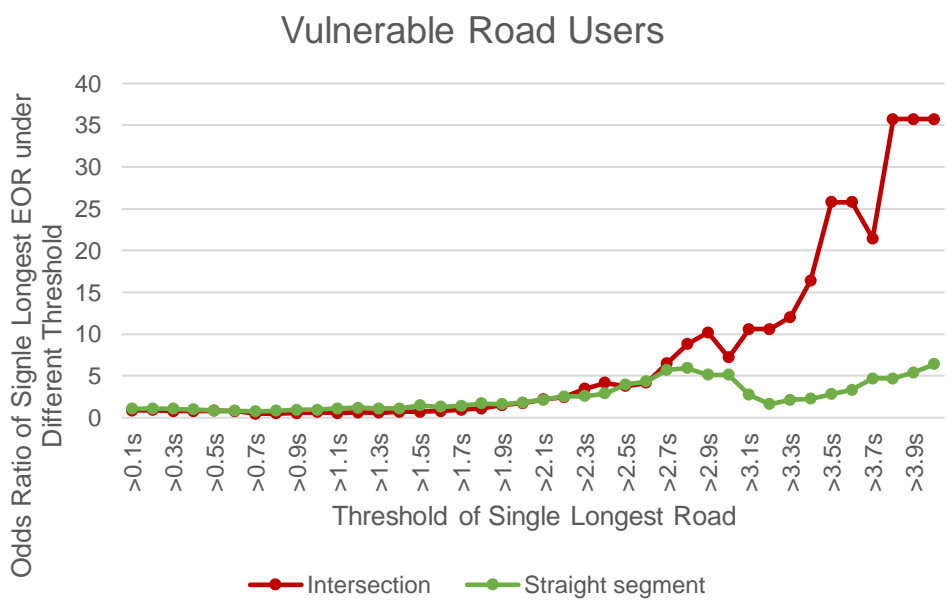
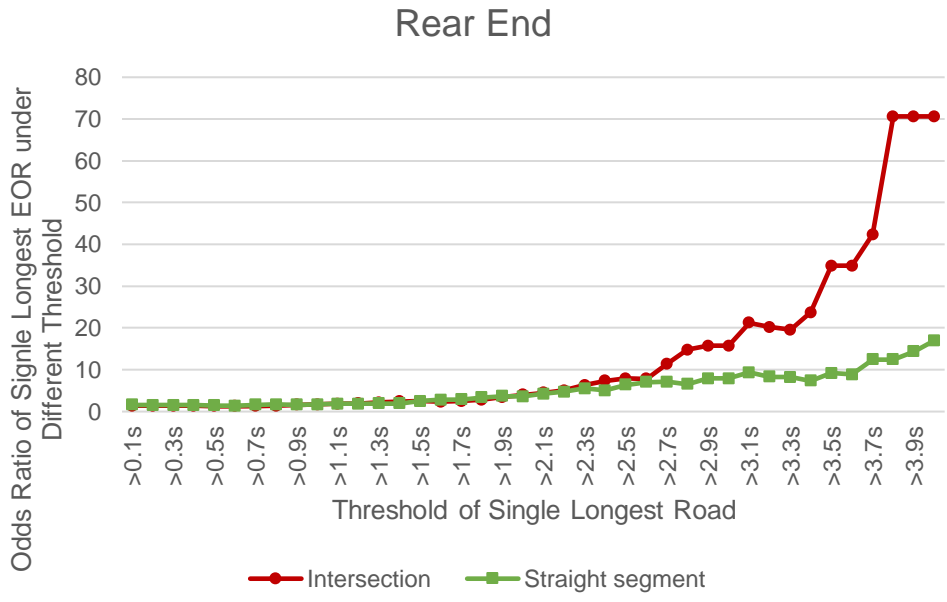
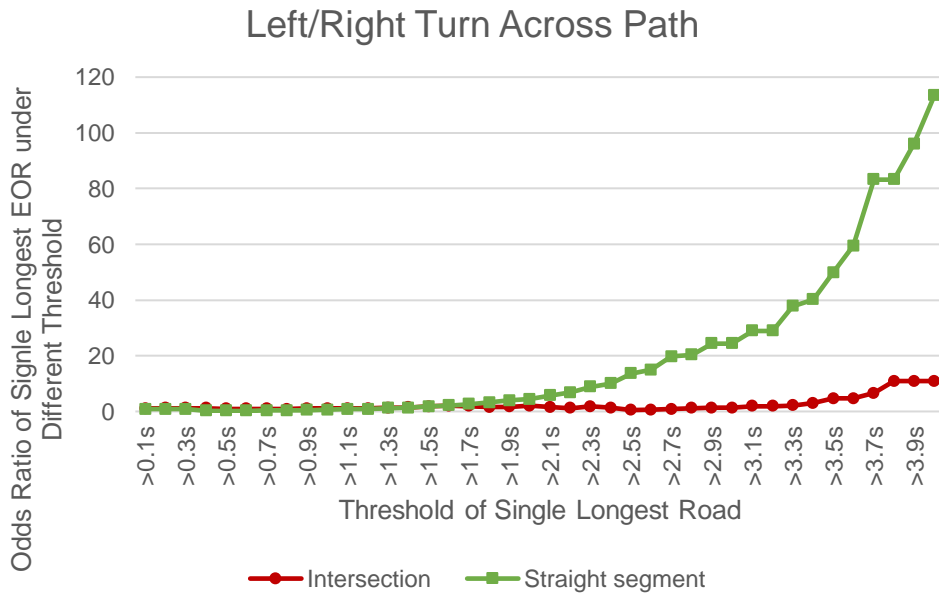
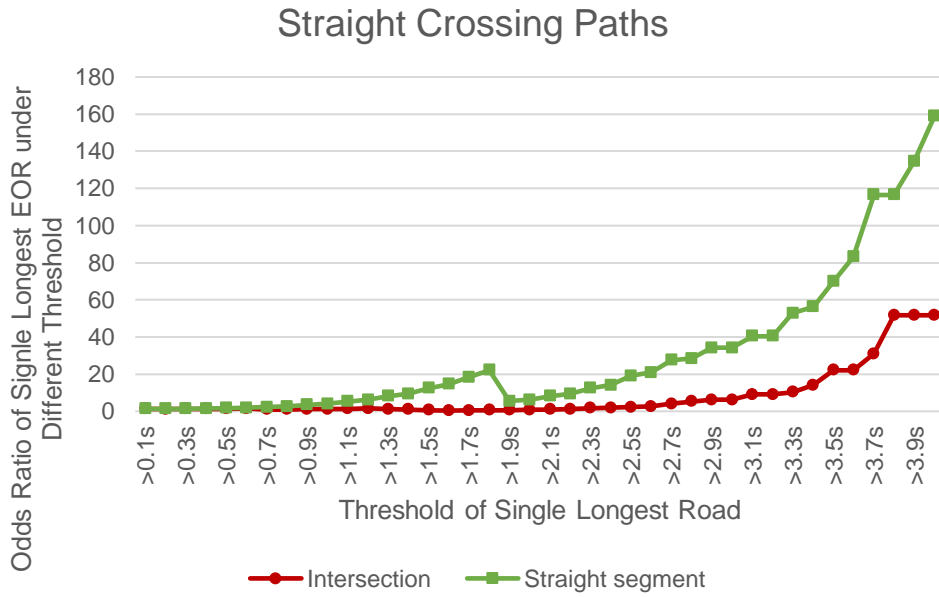


Figure 21. Line charts. Comparison of crude ORs by intersection type (higher ORs in intersection).

(3) Higher ORs on straight segments



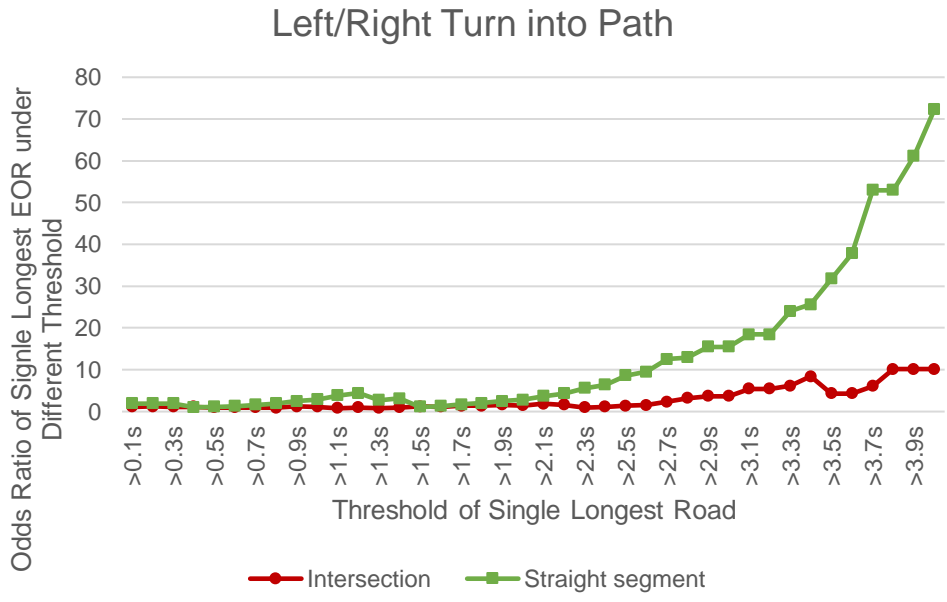


Figure 22. Line charts. Comparison of crude ORs by intersection type (higher ORs in straight segment).

Note that the difference among turn across path, turn into path, and straight paths might be subtle. The diagram below illustrates the configuration of these three crash types.

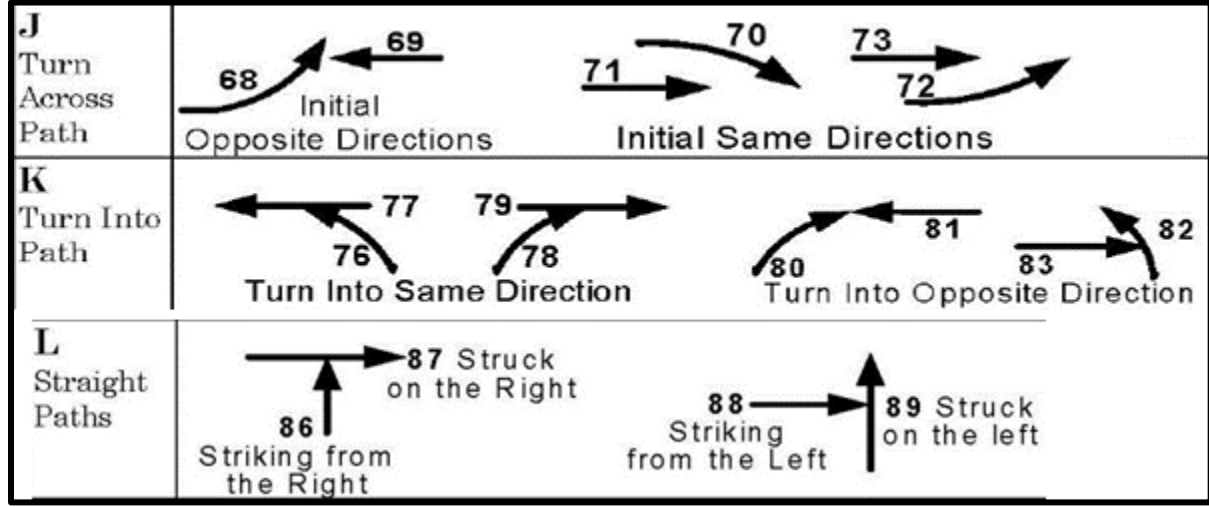


Figure 23. Diagram. Illustration of crash configuration.

Table 16. Reweighted ORs of the matched crashes by intersection type within uncontrolled access roads.

Threshold of the Single Longest EOR	Intersection	Straight Segment
> 0.1 s	1.026	1.463
> 0.2 s	1.020	1.476

Threshold of the Single Longest EOR	Intersection	Straight Segment
> 0.3 s	0.992	1.438
> 0.4 s	1.005	1.410
> 0.5 s	0.978	1.473
> 0.6 s	0.962	1.582
> 0.7 s	0.878	1.839
> 0.8 s	0.920	1.753
> 0.9 s	1.090	1.757
> 1 s	1.193	1.901
> 1.1 s	1.301	2.129
> 1.2 s	1.370	2.234
> 1.3 s	1.520	2.563
> 1.4 s	1.658	2.919
> 1.5 s	1.852	3.767
> 1.6 s	1.912	4.277
> 1.7 s	2.180	4.317
> 1.8 s	2.483	4.930
> 1.9 s	3.147	3.831
> 2 s	3.653	3.869
> 2.1 s	4.248	4.571
> 2.2 s	4.720	5.310
> 2.3 s	6.295	6.678
> 2.4 s	7.434	7.398
> 2.5 s	7.880	9.964
> 2.6 s	8.447	10.130
> 2.7 s	12.839	13.069
> 2.8 s	17.209	13.397
> 2.9 s	19.108	15.579
> 3 s	18.173	15.579
> 3.1 s	16.491	17.691
> 3.2 s	16.104	17.283
> 3.3 s	17.052	22.171
> 3.4 s	22.840	20.808
> 3.5 s	35.391	25.819
> 3.6 s	35.391	30.462
> 3.7 s	43.352	37.656
> 3.8 s	70.484	37.656
> 3.9 s	68.705	43.459
> 4 s	67.340	51.372

APPENDIX D. LOGISTIC REGRESSION MODEL

A logistic regression model can be used to model the probability of dichotomous outcome variables such as pass/fail, win/lose, alive/dead, or healthy/sick. In the model, the log-odds (the logarithm of the odds) for the value labeled 1 is a linear combination of one or more independent variables (predictors); the independent variables can each be a binary variable (two classes, coded by an indicator variable) or a continuous variable (any real value). Mathematically, logistic regression estimates a multiple linear regression function defined as:

$$\text{logit}(p) = \log\left(\frac{P(y^{(i)} = 1)}{1 - P(y^{(i)} = 1)}\right) = \beta_0 + \beta_1 \cdot x_1^{(i)} + \dots + \beta_p \cdot x_p^{(i)}$$

Therefore,

$$P(y^{(i)} = 1) = \frac{1}{1 + \exp(-(\beta_0 + \beta_1 \cdot x_1^{(i)} + \dots + \beta_p \cdot x_p^{(i)}))}$$

The log function is called *odds*, which is the probability of an event divided by the probability of no event. The formula above represents the log odds. If we compare what happens when increasing one unit of a feature value, the ratio of the two predictions is as follows:

$$\frac{\text{odds}_{x_j+1}}{\text{odds}_{x_j}} = \frac{\exp(\beta_0 + \beta_1 x_1 + \dots + \beta_j(x_j + 1) + \dots + \beta_p x_p)}{\exp(\beta_0 + \beta_1 x_1 + \dots + \beta_j x_j + \dots + \beta_p x_p)} = \exp(\beta_j)$$

Therefore, a change in a feature by one unit changes the ORs by a factor of $\exp(\beta_j)$.

The covariates can be different types, and their interpretations are as follows:

- **Numerical variables:** One unit in a numerical variable. The estimated odds change by a factor of $\exp(\beta_j)$.
- **Binary categorical variable:** One of the two values of the feature is the reference category. Changing the feature x_j from the reference category to the other category changes the estimated odds by a factor of $\exp(\beta_j)$.
- **Categorical variable with more than two categories:** One solution to deal with multiple categories is one-hot-encoding, meaning that each category has its own column. In that case, only L-1 columns for a categorical feature with L categories are needed, otherwise the category is over-parameterized. The Lth category is then the reference category. Other encoding methods can be used to build contrast in linear regression. The interpretation for each category is then equivalent to the interpretation of binary features.
- **Intercept β_0 :** When all numerical features are 0 and the categorical features are at the reference category, the estimated odds are $\exp(\beta_0)$. The interpretation of the intercept is usually not relevant.

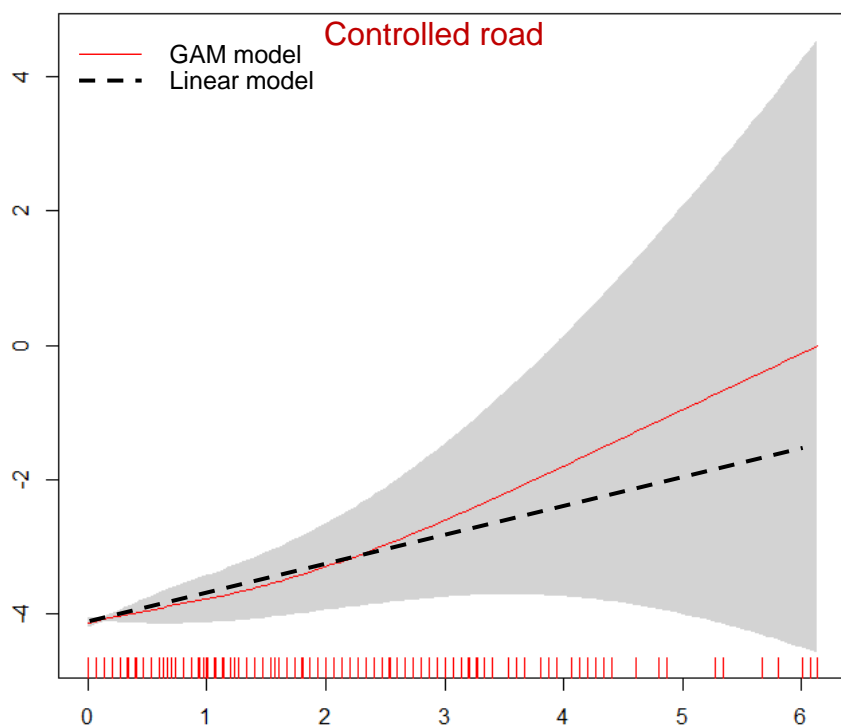
In this study, a logistic regression method was used to quantify the ORs associated with EOR duration.

APPENDIX E. NON-LINEAR MODEL FIT OF THE SINGLE LONGEST EOR DURATION

The logistic model has a linear assumption between the independent variable (i.e., EOR duration) and the dependent variable (i.e., safety outcomes). That is, there is a uniform increase in ORs for each unit increase in EOR duration. However, this assumption can be violated under some circumstances. For example, the impact of a 1 s increase in looking away from the road from 1 s to 2 s could be substantially different than the risk increase from 3 s to 4 s. Therefore, a Generalized Additive Model (GAM) was employed to incorporate the possible non-linear relationship between the EOR duration and ORs.

The formula of the GAM is $\log \frac{p}{1-p} = \beta_0 + f(EOR)$ instead of $\log \frac{p}{1-p} = \beta_0 + \beta_1 EOR$ in logistic model. This $f(\cdot)$ is a general function that could be linear or non-linear, which allows greater flexibility in evaluating the association between the EOR duration and the safety outcomes.

The overall pattern of the GAM model and logistic model is consistent, as shown in Figure 23. But the ORs increased much faster for the GAM model once the single longest EOR duration exceeded 3.0 s for both controlled access roads and uncontrolled access roads. For example, the ORs would increase 1.54 times for a 1 s increase in the single longest EOR duration on controlled access roads based on the logistic model. The value was 1.22 for the GAM model when the driver looked away 0.5 s and rose to 4.06 when the driver looked away for 3.0 s. For the logistic model, the increase in ORs is constant (i.e., 1.54 times per 1 s increase in EOR duration) while the increase is exponential for GAM mode—this can better reflect the actual risk associated with EOR duration.



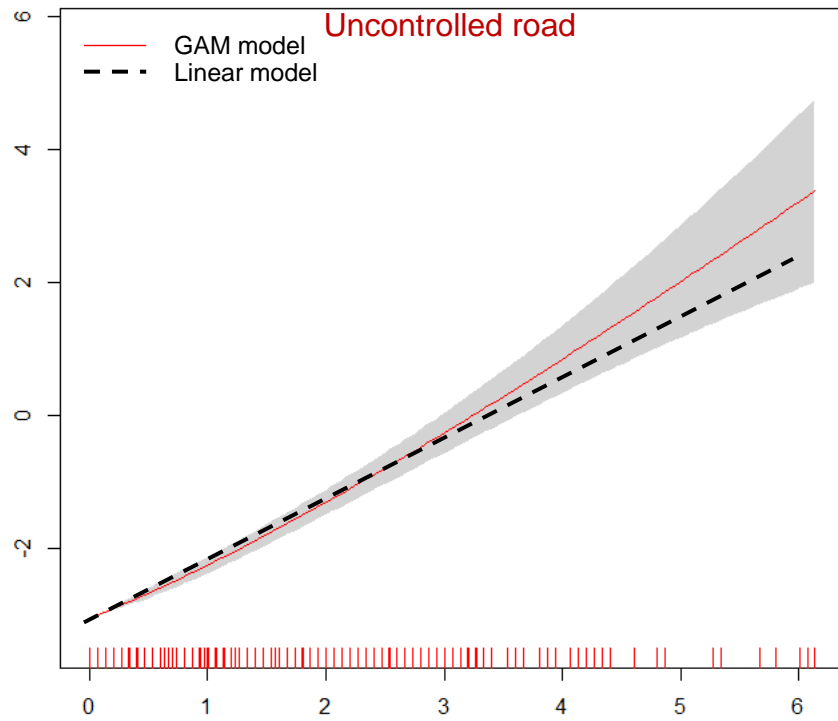


Figure 24. Diagrams. GAM output by road control type.