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Analysis of Contributing Factors in Crashes Involving Electric Vehicles and Vehicles with Automated Features

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16. Abstract			
Most light-duty vehicle (LDV) crashes occur due to human error. The National Highway Safety Administration (NHTSA) reports that eight percent of fatal crashes in 2018 were distraction-affected crashes, while close to ninety-four percent of all crashes occur in part due to human error. Crash avoidance features could reduce both the frequency and severity of light and heavy-duty vehicle crashes, primarily caused by distracted driving behaviors and/or human error by assisting in maintaining control or issuing alerts if a potentially dangerous situation is detected. As the automobile industry transitions to partial vehicle automation, newer crash avoidance technologies are beginning to appear more frequently in non-luxury vehicles such as the Honda Accord and Mazda CX-9. Additionally, the market penetration of electric vehicles (EVs) is increasing, in turn increasing the weight and size of vehicles on the road. However, the patterns and characteristics of crashes involving EVs or vehicles automated features have not been explored in much detail. This project develops a replicable, open, deployable model that can: 1) assess the distribution of crashes with automated features across factors such as weather conditions, vehicle speed, crash severity, pre-crash movement, facility type, and time of day, 2) estimate the relationship between contributing factors and the severity of crashes involving vehicles with automated features using regression analysis, and 3) assess the patterns and characteristics of crashes involving EVs.			
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Problem Statement

According to the National Highway Traffic Safety Administration (NHTSA), 39,345 people died in motor vehicle traffic crashes in the United States in 2024 (NHTSA, 2025) . Compared to a decade ago, traffic deaths in 2024 increased by 20%, with an average of 108 fatalities per day (NHTSA, 2025). Human error plays a significant role in crashes; with approximately 94% of all crashes occurring in part or due to human error (NHTSA, 2015). NHTSA highlights several key risky driving behaviors attributable to human error (NHTSA, 2024). For instance, speeding resulted in 11,775 deaths in 2023 and contributed to 29% of all traffic fatalities in 2023. Distracted driving claimed 3,275 lives in 2023, while 12,429 people died due to alcohol-impaired driving in the same year.

Advanced crash avoidance features offer the potential to mitigate both the frequency and severity of crashes for light and heavy-duty vehicles (Harper et al., 2016; Khan et al., 2019). These technologies can help maintain vehicle control or provide warnings in potentially hazardous situations, helping to mitigate or prevent crashes primarily arising from distracted driving and/or human error. This paper utilizes summary incident report data from the Standing General Order issued by NHTSA to assess the distribution of crashes involving Automated driving System (ADS)-equipped vehicles across different contributing factors (e.g., pre-crash speed, roadway types, and lighting conditions) and estimates the relationship between these contributing factors and the severity of crashes involving ADS-equipped vehicles using statistical analysis.

Data and Methods

For this study, the summary incident report data reported to the NHTSA under the General Order is utilized. Three CSV files are available for download: one for incidents involving ADS-equipped vehicles, one for incidents involving ADAS-equipped vehicles, and one containing other reports where the system type (ADS or Level 2 ADAS) was not reported. The primary analysis of this paper uses the ADS-equipped vehicles' data files. Each record in the data files represents a reported incident and includes numerous columns detailing various aspects of the incident and the involved vehicle. For crashes that meet the reporting requirements of the General Order, multiple reports may be submitted for a single incident. These can include an initial report, a 10-day follow-up, and any subsequent updates. Additionally, multiple entities, such as the vehicle manufacturer, system developer/supplier, and vehicle operator, may be required to report the same crash. As a result, a single incident may have multiple reports from different entities. Therefore, the overall number of reports submitted does not directly correspond to the total number of incidents and should not be used as a safety metric in the data files.

To ensure data integrity and avoid duplication, a thorough data cleaning process was conducted. The first step was to remove duplicated versions of a single incident submitted by one entity. The "Report ID" column contains a unique identifier generated by NHTSA to track initial and updated reports for a given incident. The "Report Version" column indicates the version of each incident report, with new versions created and sequentially numbered by the portal whenever a reporting entity updates a previously filed report. By grouping the data by "Report ID" and selecting the highest "Report Version" within each group, only the latest version of each incident report was retained. This approach ensured that the dataset included only the most current information for each incident, thereby enhancing the reliability and relevance of the subsequent analysis. The second step involves removing duplicate records when an incident is reported by multiple entities. The "Same Incident ID" column, a unique identifier generated by NHTSA, links reports filed by different entities regarding the same incident. The "Same Vehicle ID" column serves as a unique identifier for each vehicle involved in an incident, as the full VIN is not publicly disclosed by NHTSA. If a unique "Same Incident ID" has multiple records with different "Same Vehicle ID" entries, this indicates the involvement of multiple vehicles in the same incident. By identifying and retaining only one unique record for each combination of "Same Incident ID", "Same Vehicle ID," and other relevant incident characteristics, the approach ensures that each distinct vehicle involved in an incident is represented only once if reported by multiple entities, with other incident characteristics used to confirm that the records indeed pertain to the same incident. After the entire data cleaning process, 671 records of incidents involving ADS-equipped vehicles were retained. The distribution of injury severity is as follows: No Injuries Reported (575), Minor (56), Moderate (12), Serious (5), Unknown or Null (23).

Results

Distribution of Incidents Involving ADS Vehicles Across Different Factors

To gain a deeper understanding of the conditions under which crashes involving ADS-equipped vehicles occur, the distribution of these incidents is analyzed across several factors, including pre-crash speed, pre-crash movement of the subject vehicle, pre-crash movement of the crash partner, weather condition, lighting condition, roadway types, and time of day. Fig. 1 illustrates the pre-crash speed distribution in crashes involving ADS-equipped vehicles and reveals that the majority of crashes occurred at lower speeds (0-10 MPH) and incidents at higher speeds are less frequent. Fig. 2 shows the weather condition distribution in crashes involving an ADS-equipped vehicle. Most crashes occurred during clear weather conditions, with significantly fewer incidents happening during cloudy, or adverse weather including rainy, thundering, and snowy conditions. This makes sense as most AV testing occurs in regions with dry and/or mild weather conditions.

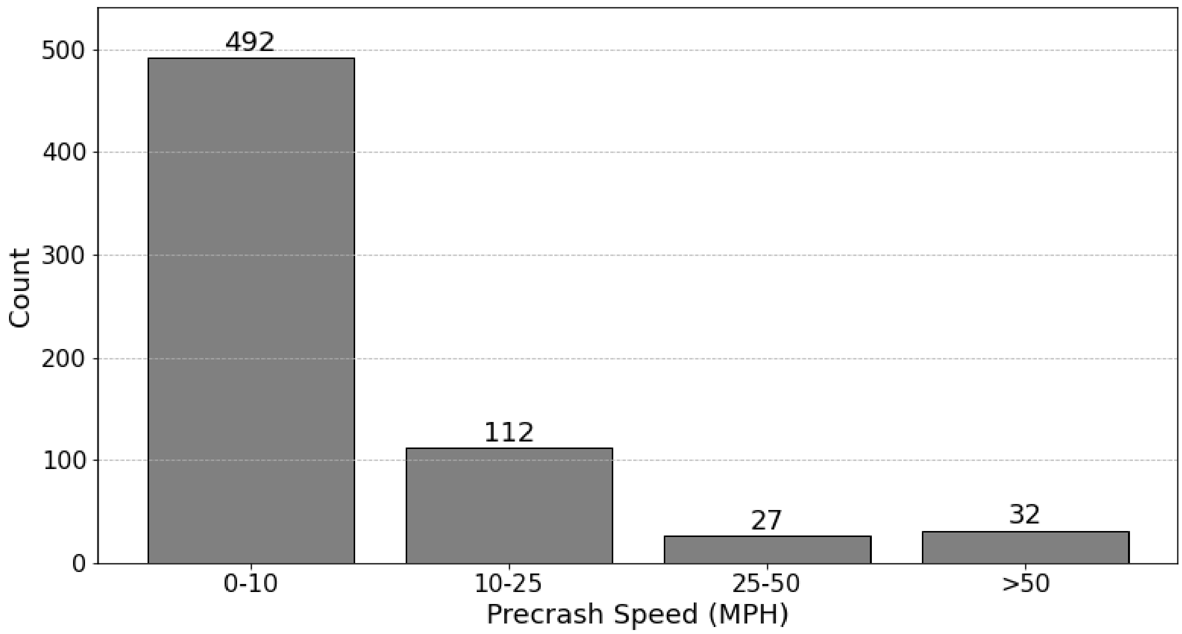


Fig. 1 Pre-crash Speed (MPH) Distribution in Crashes Involving an ADS-equipped Vehicle

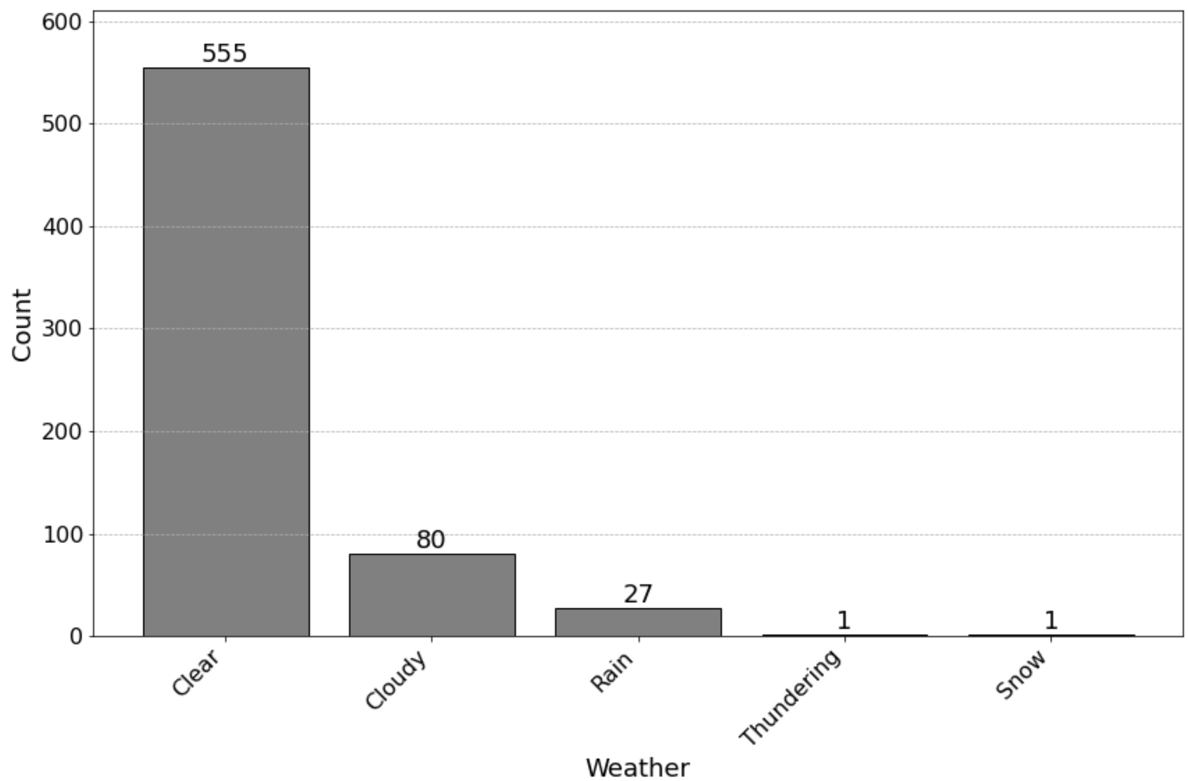


Fig. 2 Weather Condition Distribution in Crashes Involving an ADS-equipped Vehicle

Fig. 3 shows the location distribution and illustrates that crashes involving ADS-equipped vehicles predominantly occur on streets or at intersections, with fewer incidents on highways, in parking lots, and very few in traffic circles. Fig. 4 shows the lighting condition distribution and illustrates that the majority of crashes occur during daylight, followed by dark and lighted conditions. Crashes during dawn/dusk conditions as well as dark and unlighted conditions are relatively rare.

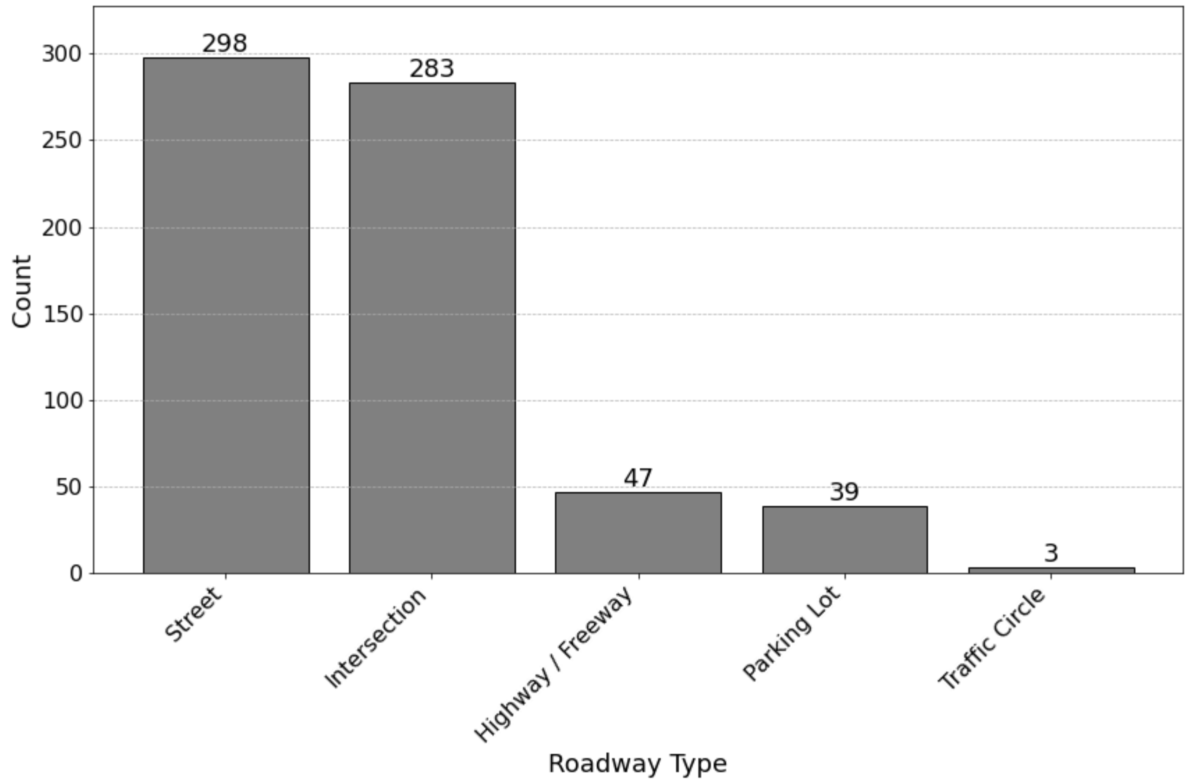


Fig. 3 Distribution of Location in Crashes Involving an ADS-equipped Vehicle

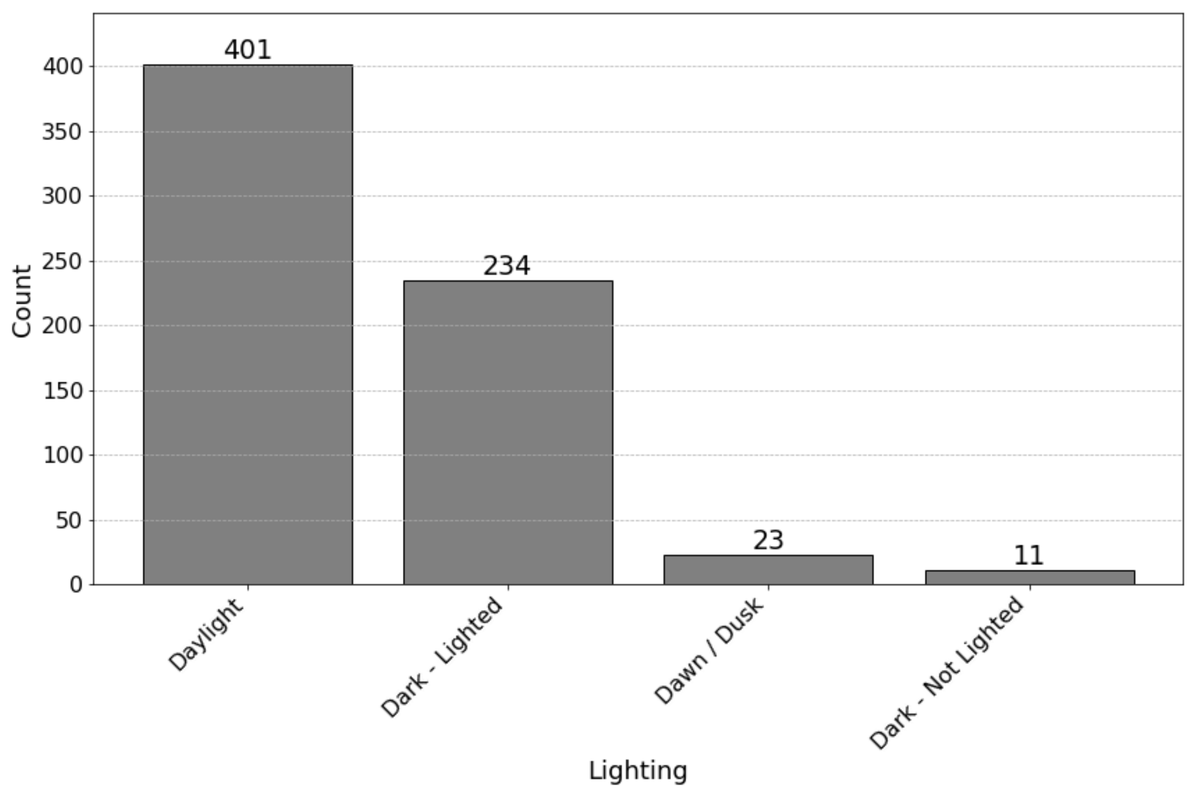


Fig. 4 Lighting Condition Distribution in Crashes Involving an ADS-equipped Vehicle

Fig. 5 shows the hour of the day distribution and reveals that crashes are more frequent in the afternoon, with a noticeable drop during the early morning hours (4-6 AM). Fig.6 highlights that the most common pre-crash movements of both the subject vehicle and crash partner are "Moving Straight or Passing" and "Stopped/Parking/Backing" while other movements are less frequent.

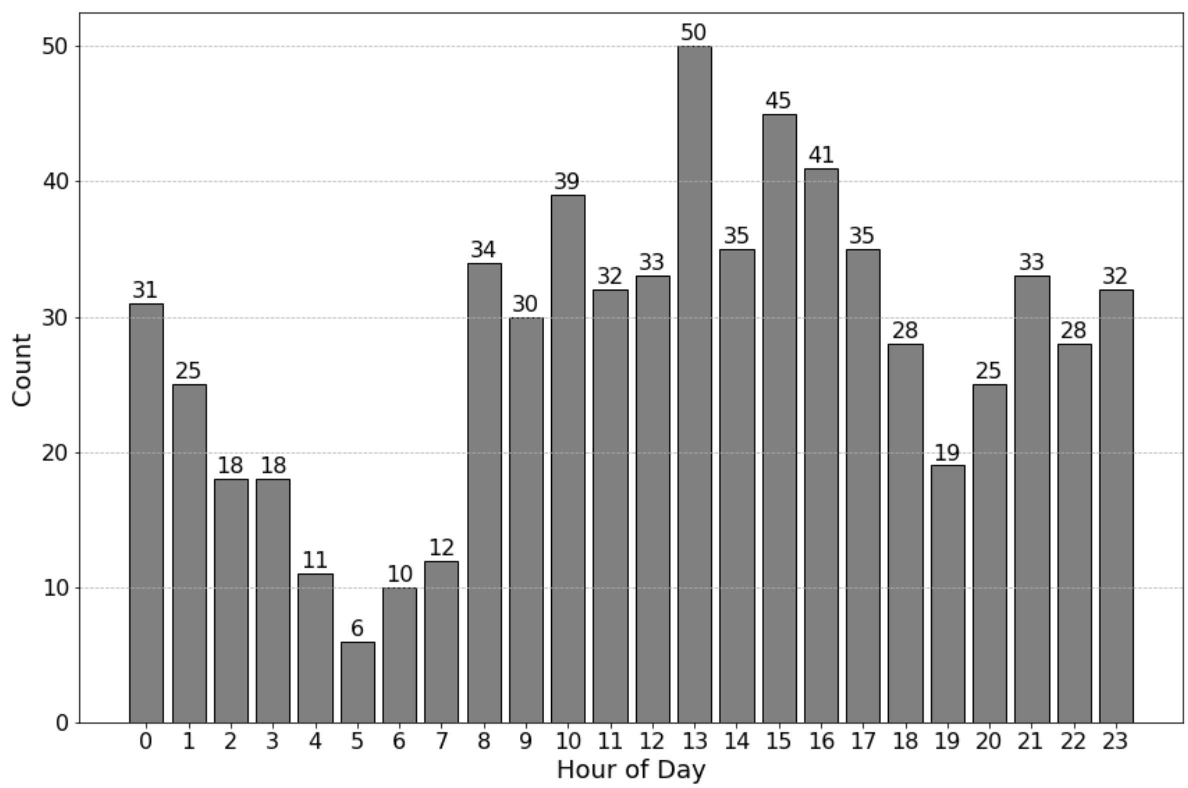
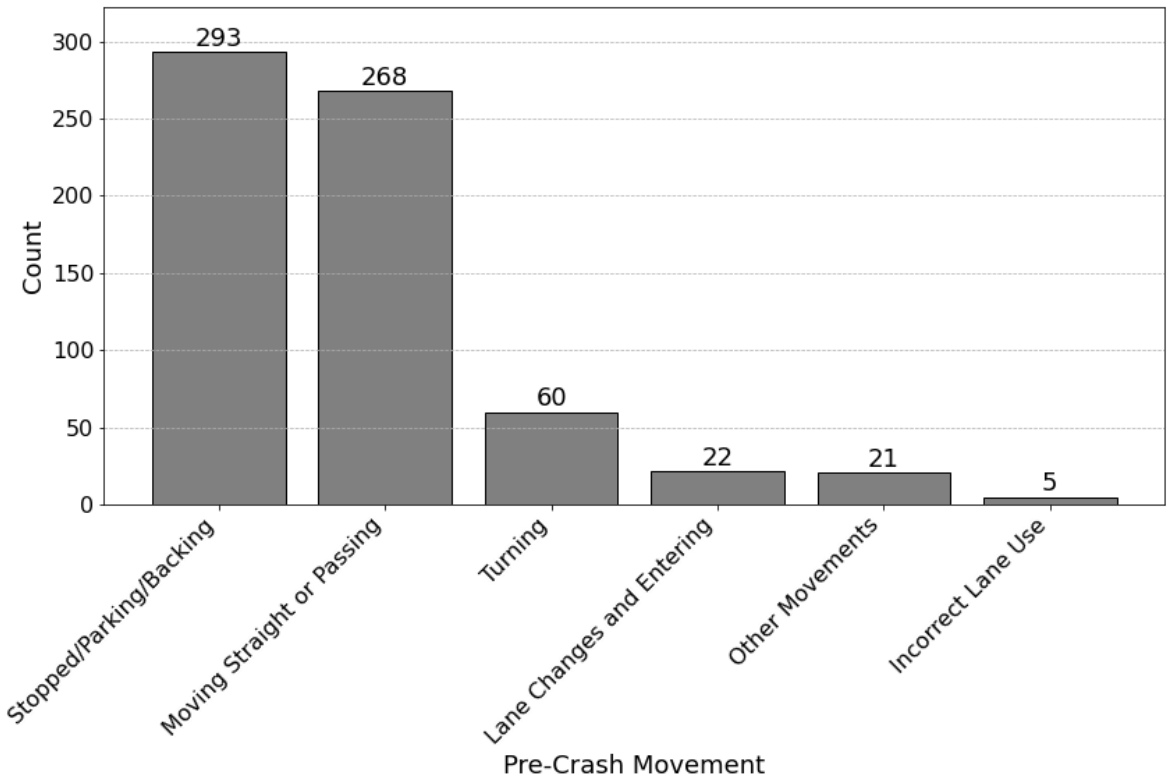
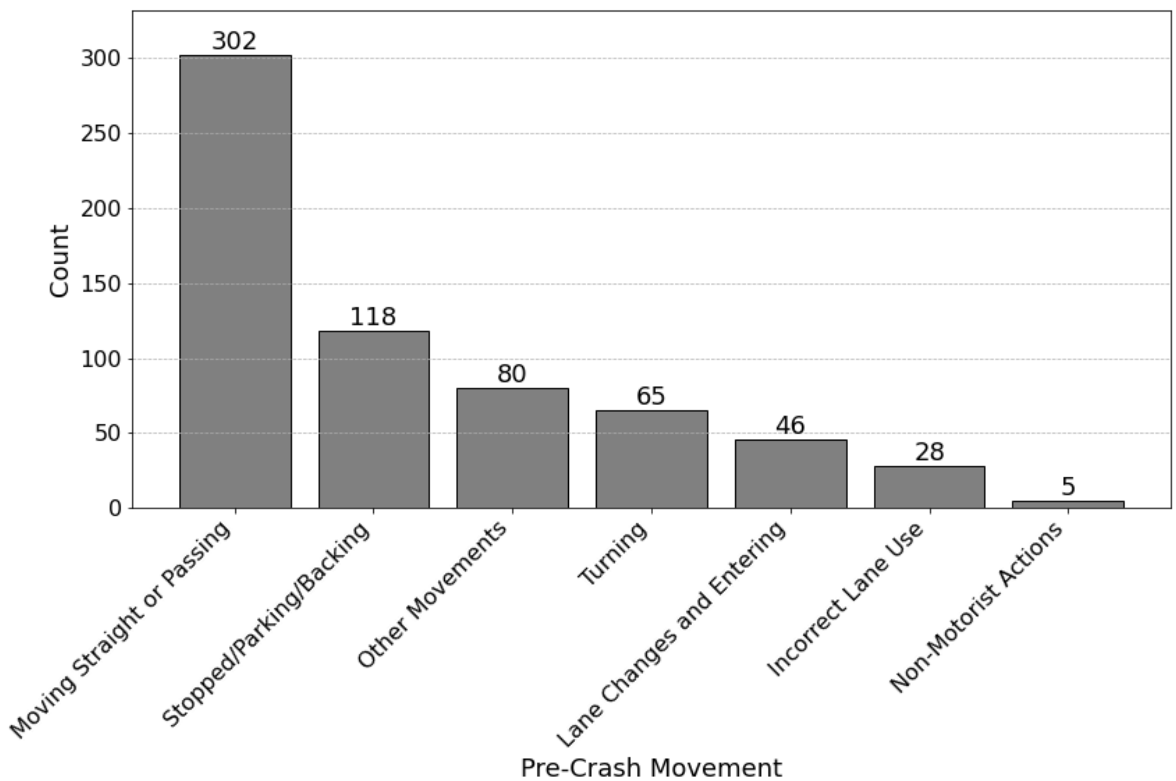


Fig. 5 Time of day Distribution in Crashes Involving an ADS-equipped Vehicle



(a) Pre-Crash Movement Distribution of the Subject Vehicle



(b) Pre-Crash Movement Distribution of the Crash Partner

Fig. 6 Pre-crash Movement Distribution in Crashes Involving an ADS-equipped Vehicle

The factors shown in these figures likely exhibit intricate interdependencies, complicating the establishment of straightforward causal connections. To delve deeper into these associations, Fig. 7, 8 and 9 present two-way plots exploring the interactions between intuitively correlated factor pairs. Fig. 7 examines the relationship between pre-crash speeds and roadway types. Fig. 8 investigates the links between lighting conditions and times of day. Fig. 9 displays the relationship between pre-crash speeds and the subject vehicle's pre-crash movements.

Fig. 7 shows the percentage of crashes with different pre-crash speeds relative to each roadway type, offering insights into how speed distributions vary across different locations where incidents occurred. The majority of crashes on streets, intersections, and parking lots occur at lower speeds (0-10 MPH), as indicated by the darkest shading in the lowest speed category. Notably, approximately 65.9% of crashes on highways involve speeds greater than 50 MPH, highlighting a significant proportion of high-speed incidents on this roadway type.

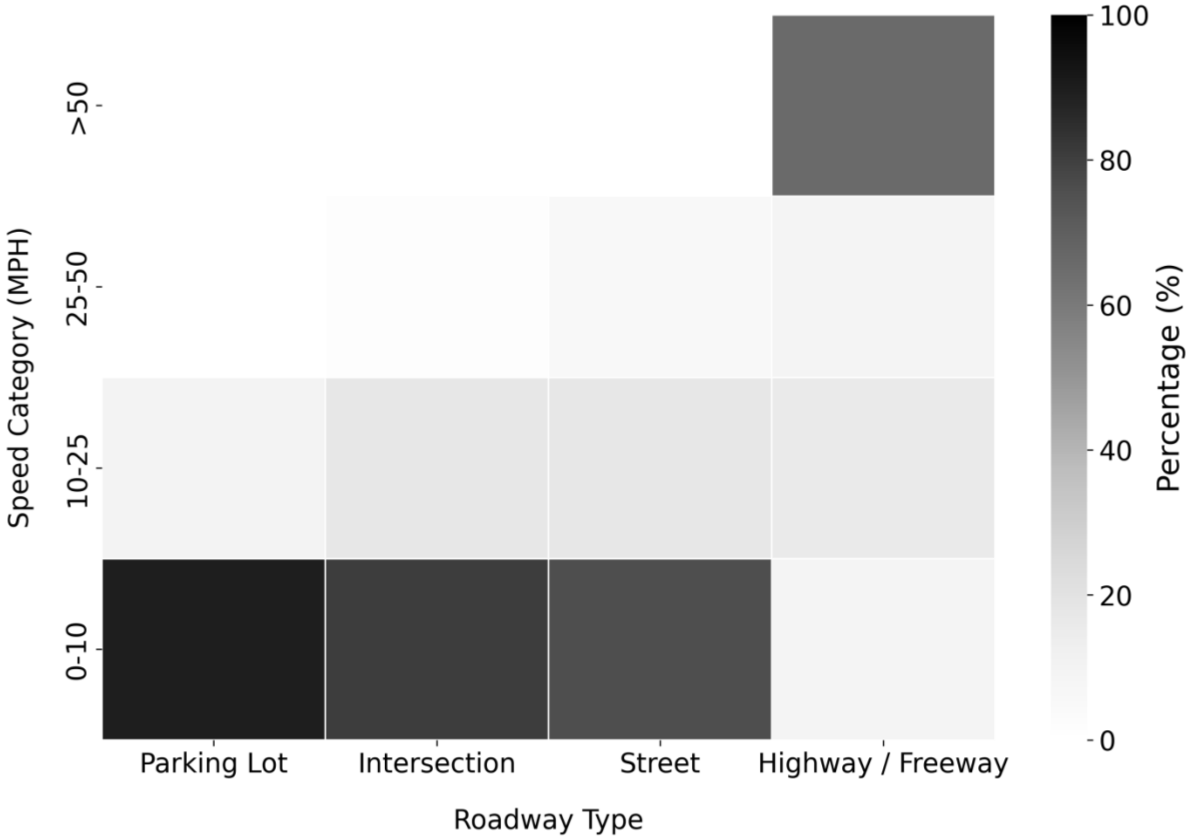


Fig. 7 Correlation between Pre-Crash Speed and Roadway Type

Fig. 8 illustrates the percentage distribution of crashes across different times of day relative to lighting conditions, acknowledging the inherent correlation between lighting and time. As expected, the majority of crashes under daylight conditions occurred during the morning and afternoon, which corresponds to periods of natural light. In dark conditions, crashes predominantly occurred during the evening and late night. Specifically, dark-unlighted conditions were more strongly associated with crashes in the late night, while dark-lighted conditions were more prevalent in the evening.

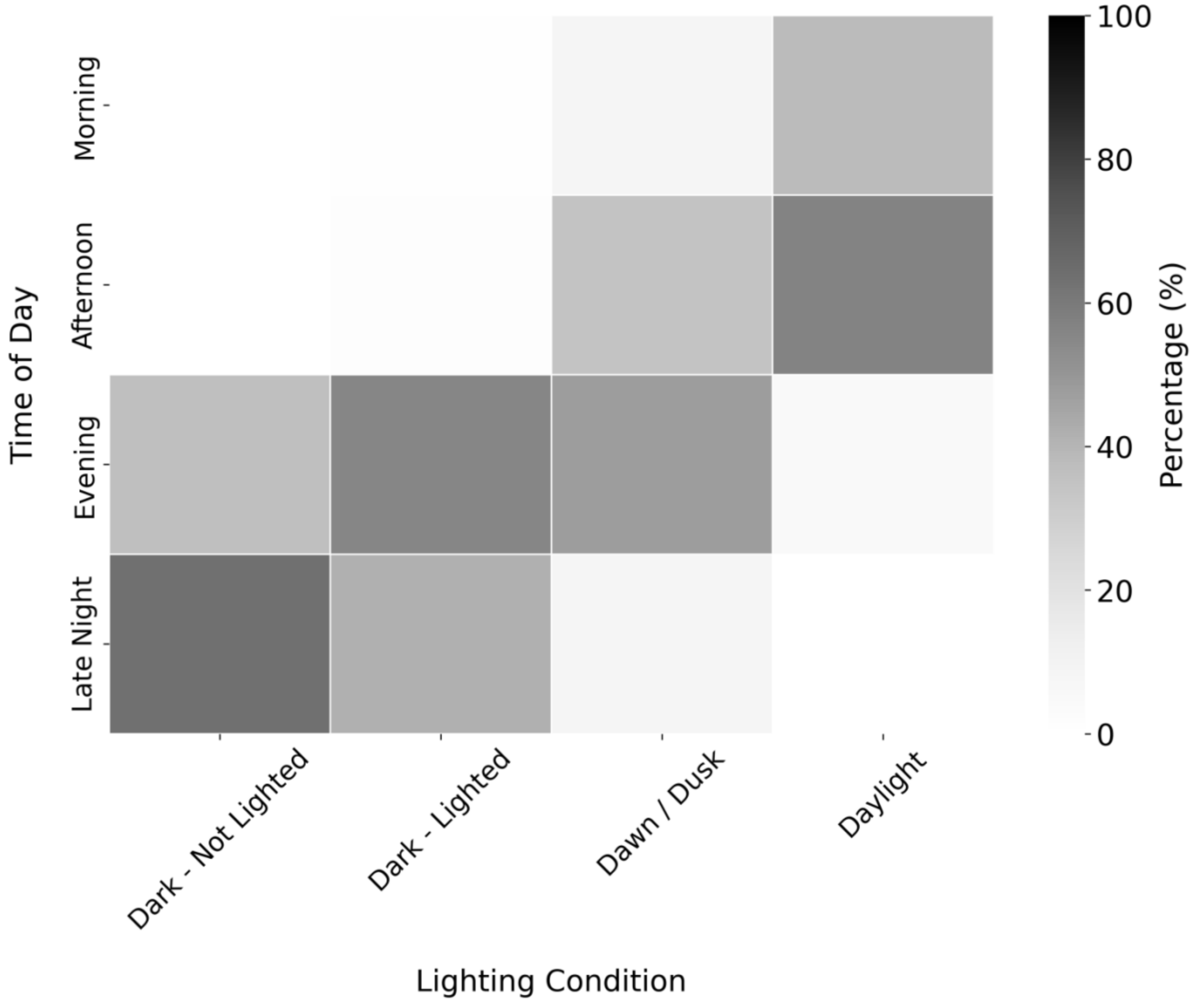


Fig. 8 Correlation Between Lighting Condition and Time of Day

Fig.9 illustrates the percentage distribution of crashes across different pre-crash speeds relative to pre-crash movement of the subject vehicle. The darkest shading is observed in the 0-10 MPH category, indicating that the majority of crashes across all roadway types occur at lower speeds. Notably, the " Stopped / Parking / Backing" category shows a particularly high concentration of incidents at the lowest speed range (0-10 MPH), reflecting the nature of these movements, which typically occur at minimal speeds. "Turning" also predominantly occurs at 0-10 MPH, but the percentage is not as high as in the "Stopped/Parking/Backing" category. In contrast, the "Moving Straight or Passing" and "Lane Changes and Entering" categories exhibit a more even distribution across the speed ranges, with incidents occurring across all speed categories, including higher speeds. Overall, these patterns align with expectations, as different types of vehicle movements naturally correspond to different speed profiles, underscoring the logical relationship between pre-crash movements and the speeds at which incidents occur.

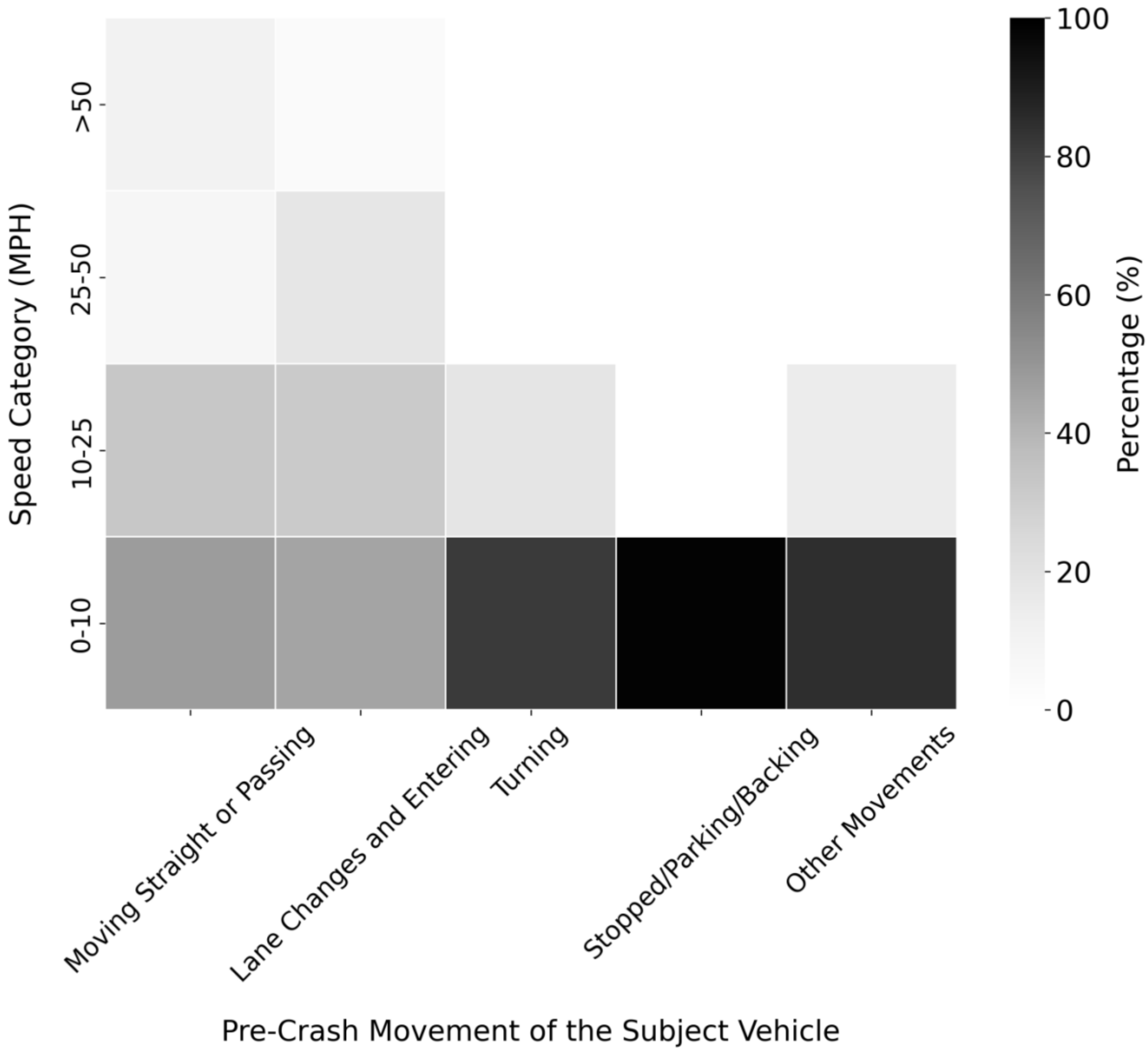


Fig. 9 Correlation Between Pre-Crash Speed and Pre-Crash Movement of Subject Vehicle

Relationship Between Severity of Injury and Different Factors

The previous sub-section summarizes the distribution of incident involving ADS-equipped vehicles across different factors of interest. This section focuses on comparing different levels of injury severity and understanding how these factors are related to it. Analyzing the safety implications of ADS in vehicular incidents provides valuable insights into their effectiveness in enhancing road safety. Fig.10 illustrates the distribution of injury severity in incidents involving vehicles equipped with automated features, which includes all incidents involving vehicles with ADS or ADAS. It also shows the proportion of these incidents that specifically involve ADS-equipped vehicles. The dataset consists of 908 records of incidents involving vehicles with automated features, of which 648 involve ADS-equipped vehicles. The 648 ADS-equipped vehicles incidents correspond to 671 records after data cleaning illustrated in the Method section, with 23 records containing unknown or null values excluded from the analysis. The results show that 83% of incidents resulting in no injuries involve ADS-equipped vehicles, highlighting a high level of safety in these incidents. No fatalities were reported for incidents involving ADS-equipped vehicles, underscoring the safety of ADS-equipped vehicles in preventing fatal outcomes. The proportion of ADS-equipped vehicles involved decreases as the severity of injuries increases. This trend suggests that ADS technology may contribute to reducing the severity of injuries in vehicle incidents. A chi-squared test was performed to evaluate the independence of injury severity distributions between incidents involving ADS-equipped vehicles and non-ADS-equipped vehicles. The resulting p-value is smaller than 1e-10, indicating a statistically significant difference in the distributions. This makes it statistically true that the proportion of ADS involvement decreases as the severity of injuries increases.

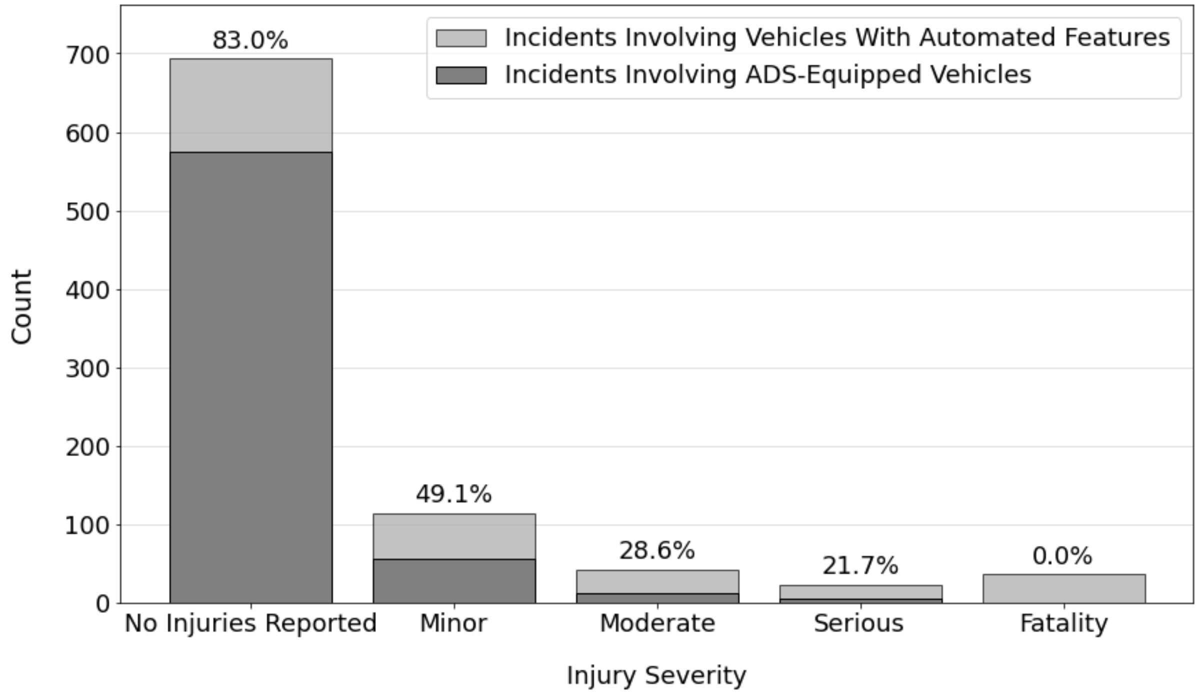


Fig. 10 Injury Severity Distribution in Crashes Involving an ADS-equipped Vehicle

Note: The percentages on the chart indicate the proportion of incidents involving ADS-equipped vehicles relative to all incidents involving vehicles with automated features (including both ADS and ADAS) across different injury severity categories.

To further analyze how different factors of interest are correlated to injury severity, the distributions for each injury level category ('No Injuries Reported', 'Minor Injuries Reported', '>= Moderate Injuries Reported') are calculated in terms of the selected factors of interest for incidents involving ADS-equipped vehicles. The respective population proportions are shown in Table 1. A Chi-Squared test for independence between the three populations was conducted for each factor of interest. The resulting p-values for each grouping are also tabulated in Table 1.

The relationship between pre-crash speed and injury severity indicates that higher speeds are more likely to result in moderate or more severe injuries. Specifically, 11.76% of incidents involving moderate or more severe injuries occur at speeds greater than 50 miles per hour (MPH), compared to only 1.79% for minor injuries and 4.93% for no injuries at the same speed. Similarly, at moderate speeds (10-25 MPH), 41.18% of incidents result in moderate or more severe injuries, which is significantly higher than the 16.07% for minor injuries and 16.55% for no injuries. Conversely, lower speeds (0-10 MPH) are predominantly associated with less severe outcomes, with 74.47% of incidents at these speeds resulting in no injuries and 78.57% leading to minor injuries. This suggests that both moderate (10-25 MPH) and high speeds (>50 MPH) are more likely to lead to severe injuries, whereas lower speeds generally mitigate the severity of injuries. The p-value of 0.0747 indicates a moderate level of statistical significance, suggesting that pre-crash speed does influence injury severity, though the relationship is not highly statistically significant. The location (Roadway Type) where the crash occurs significantly impacts injury severity (p-value = 0.0129). Most incidents occurred at intersections or on streets. However, among incidents resulting in moderate or more severe injuries, 17.65% occurred on highways/freeways, in stark contrast to 3.57% for minor injuries and 6.79% for no injuries. Conversely, parking lots are associated with a higher percentage of no injuries and minor injuries. Given the positive correlation between high speeds and highways, and the positive correlation between low speed and parking lots, as shown in Fig. 7, the trend is further supported that incidents causing moderate or more severe injuries are more positively correlated with high speeds on highways, while incidents resulting in no or minor injuries are more positively correlated with low speeds in parking lots.

Lighting conditions also significantly correlate with the severity of injuries. In incidents with moderate or more severe injuries, the proportion of those occurring in dark and unlighted conditions is 11.76%, whereas this proportion drops to 0.00% for minor injuries and 1.22% for no injuries. Conversely, incidents occurring in daylight account for 59.69% of incidents resulting in no injuries and 71.43% of incidents resulting in minor injuries, while they only account for 47.06% of moderate or more severe injuries. This underscores the importance of visibility in influencing the severity of injuries. Regarding the time of day when incidents occur, late night incidents represent a larger proportion of incidents causing moderate or more severe injuries (29.41%) compared to minor injuries (5.36%) and no injuries (16.38%). Conversely, only 5.88% of incidents resulting in moderate or severe injuries occur in the morning, while 32.14% of minor injuries and 23.34% of no injuries happen at that time. Despite these trends, the highest percentage of incidents across all injury severity categories occurs in the afternoon. Similarly, as shown in Fig. 8, the positive correlation between daylight and morning further supports the conclusion that daylight conditions in the morning are more likely to result in minor or no injuries. Although late-night and dark, unlighted conditions are more positively correlated with moderate or more severe injuries compared to less severe injuries, they do not show a strong positive correlation with crashes in general, as shown in Fig. 8.

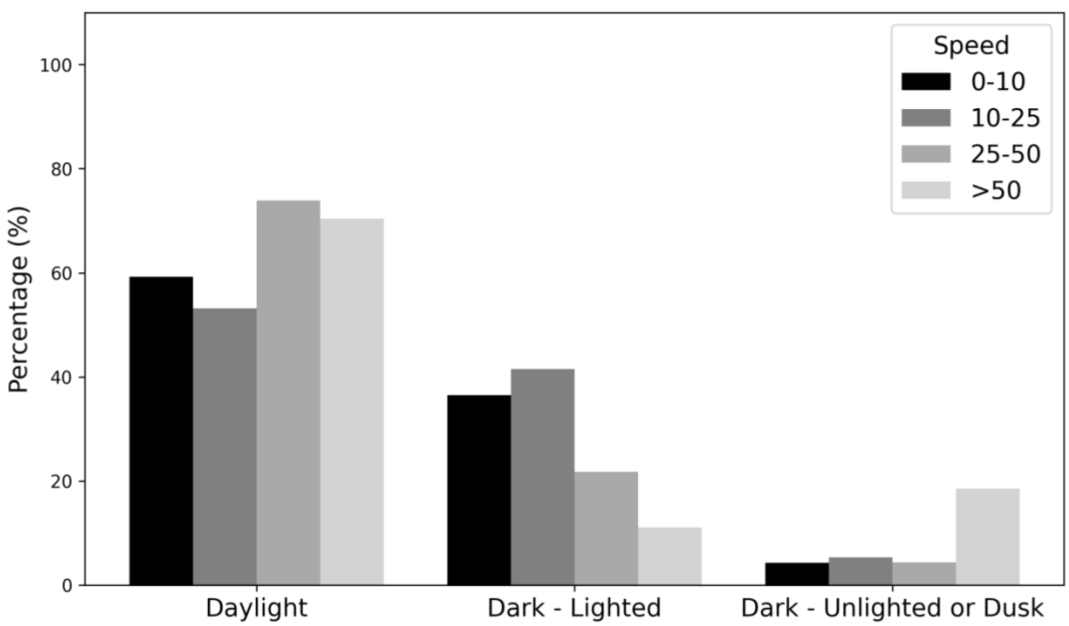
The pre-crash movement of the subject vehicle is also crucial in determining injury severity. A significant proportion (70.59%) of moderate or more severe injuries occur when the pre-crash movement involves moving straight or passing, compared to 46.43% for minor injuries and 38.74% for no injuries. Conversely, stopping, parking, or backing are more frequently connected with no injuries (46.07%), highlighting that these movements usually cause less damage. This pattern holds statistical significance with a p-value of 0.0076. The pre-crash movement of the crash partner also significantly impacts injury outcomes, particularly when involving non-motorist actions. These actions, such as pedestrian or cyclist movements, are often associated with higher injury severity, which is supported by a compellingly low p-value. Weather conditions, although analyzed, do not show a significant correlation with injury severity, as indicated by a large p-value (0.3531).

Table 1 Injury Severity Characteristics in Crashes Involving an ADS-equipped Vehicle

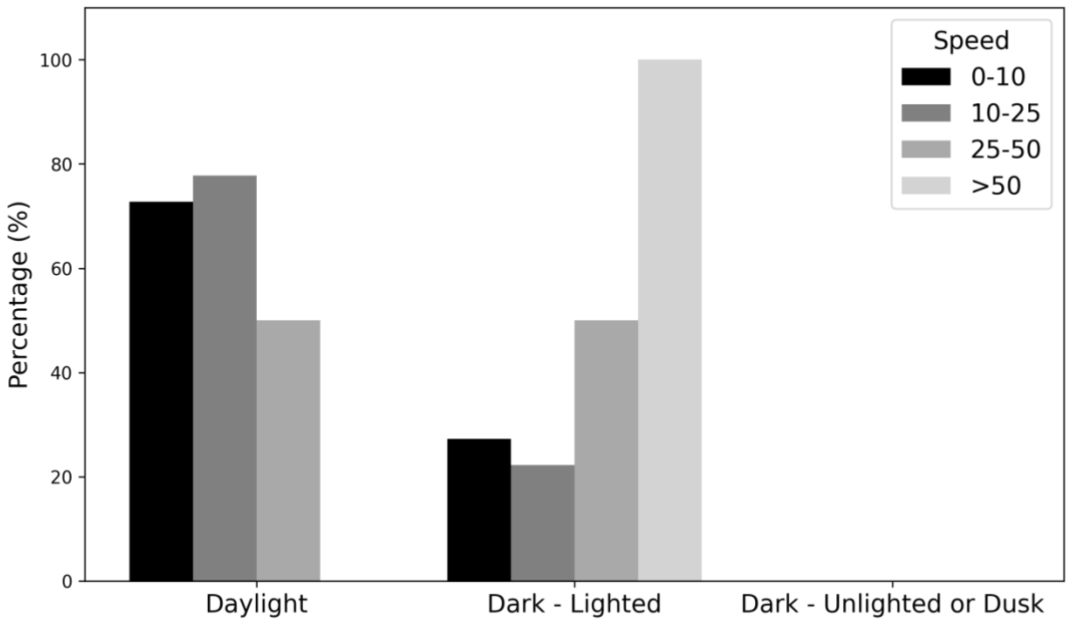
	Status	**>= Moderate Injuries Reported (%)**	**Minor Injuries Reported (%)**	**No Injuries Reported (%)**	***P-value***
Pre-Crash Speed (MPH)	0-10	41.18	78.57	74.47	0.0747
	10-25	41.18	16.07	16.55	
	25-50	5.88	3.57	4.05	
	>50	11.76	1.79	4.93	
Roadway Type	Highway / Freeway	17.65	3.57	6.79	0.0129
	Intersection	41.18	50	40.94	
	Parking Lot	0	1.79	6.62	
	Street	35.29	44.64	45.3	
	Traffic Circle	5.88	0	0.35	
Lighting Condition	Daylight	47.06	71.43	59.69	0.0046
	Dark - Lighted	35.29	28.57	35.25	
	Dark - Not Lighted	11.76	0	1.22	
	Dawn / Dusk	5.88	0	3.84	
Time of a Day	Late Night	29.41	5.36	16.38	0.1173
	Morning	5.88	32.14	23.34	

	Afternoon	41.18	37.5	35.71	
	Evening	23.53	25	24.56	
Pre-Crash Movement of the Subject Vehicle	Moving Straight or Passing	70.59	46.43	38.74	
	Lane Changes and Entering	5.88	1.79	3.49	
	Turning	0	19.64	8.2	
	Stopped/Parking/Backing	17.65	26.79	46.07	0.0076
	Incorrect Lane Use	0	0	0.87	
	Other Movements	5.88	5.36	2.62	
Pre-Crash Movement of the Crash Partner	Moving Straight or Passing	52.94	69.09	43.64	
	Lane Changes and Entering	11.76	3.64	7.64	
	Turning	5.88	14.55	9.82	
	Stopped/Parking/Backing	5.88	3.64	20.73	2.38E-06
	Incorrect Lane Use	5.88	1.82	4.55	
	Non-Motorist Actions	11.76	0	0.55	
	Other Movements	5.88	7.27	13.09	
Weather	Adverse	0	0	4.92	
	Clear	88.24	91.07	83.13	0.3531
	Cloudy	11.76	8.93	11.95	

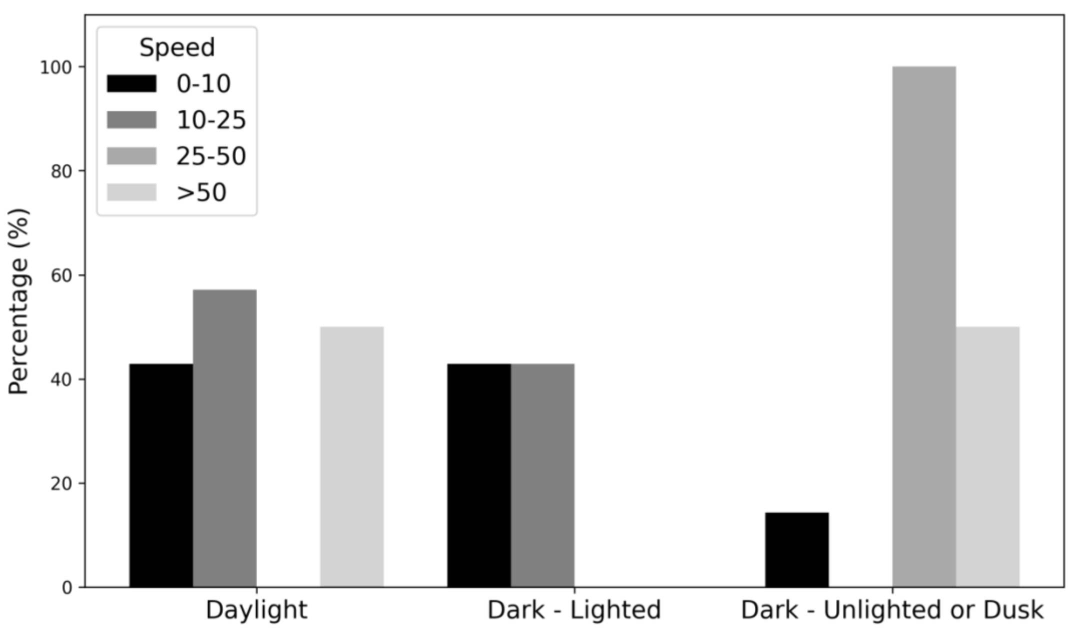
To further capture potential variations in these relationships across different injury severity levels, a more detailed correlation analysis was conducted for factor pairs that do not have intuitive connections. The crash distribution under different lighting conditions across different pre-crash speeds (MPH) is shown in Fig.11. Based on observation, as injury severity increases, the distribution of incidents becomes more concentrated in dark conditions. This shift in lighting condition distribution with rising injury severity corresponds to the results presented in Table 1, reinforcing the observed trends. Crashes resulting in moderate or more severe injuries occur in dark lighting conditions and at high pre-crash speeds. This indicates a positive correlation between high pre-crash speeds and dark, unlighted or dusk conditions at this injury category. The analysis reveals a compounded relationship, as shown in Table 1, where both dark (unlighted) or dusk conditions and high pre-crash speeds are individually correlated with moderate or more severe injuries. These findings further uncover that these factors are not just independently correlated with severe injuries, but their combination significantly intensifies the likelihood of moderate or more severe injuries, demonstrating a compounded correlation.



(a) Lighting Condition Distribution Relative to Pre-Crash Speed in Crashes with No Injuries Reported



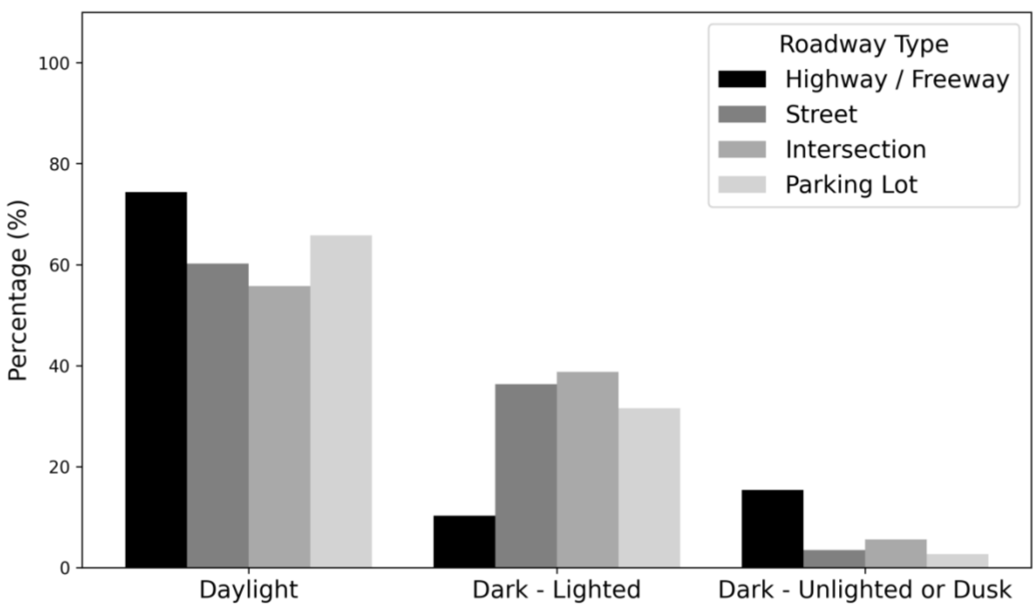
(b) Lighting Condition Distribution Relative to Pre-Crash Speed in Crashes with Minor Injuries Reported



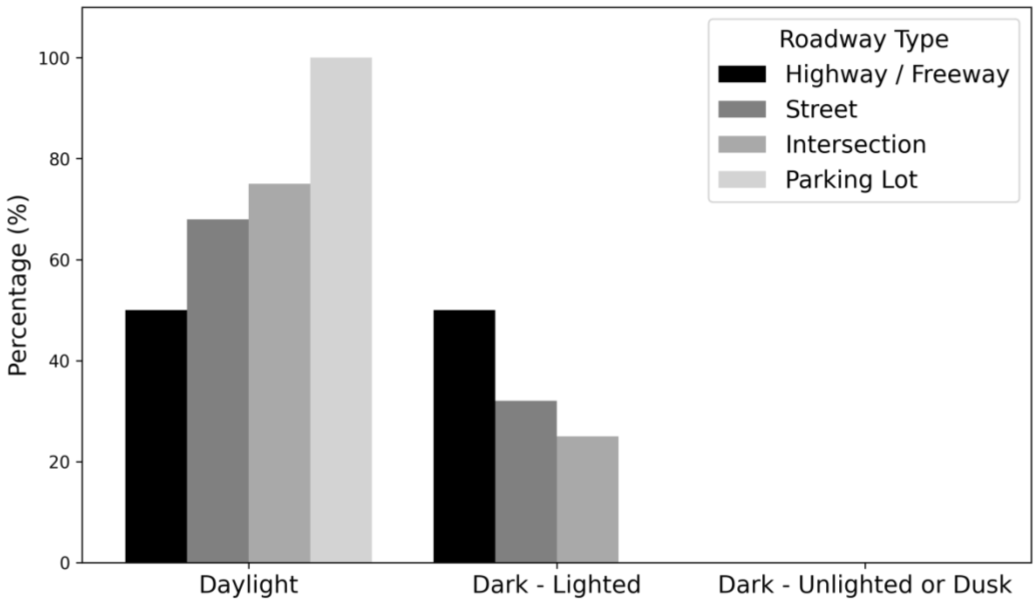
(c) Lighting Condition Distribution Relative to Pre-Crash Speed in Crashes with Moderate or More Severe Injuries Reported

Fig.11 Comparison of the Distribution of Lighting Condition Relative to Pre-Crash Speed Across Crashes Resulting in Varying Levels of Injury Severity

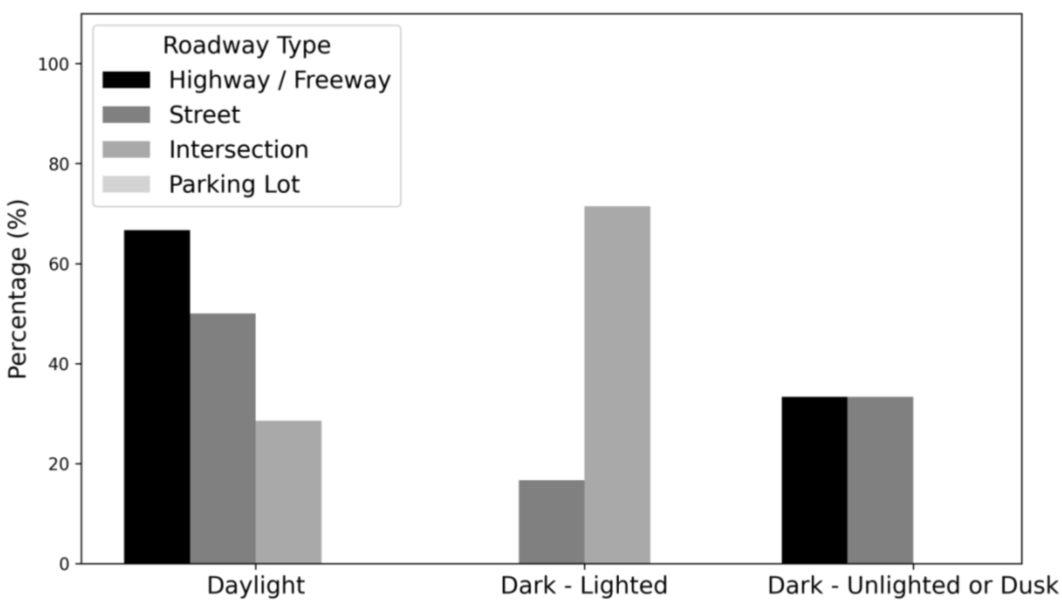
Fig. 12 provides a detailed breakdown of the proportions of different lighting conditions across various roadway types. It illustrates the percentage distribution of incidents occurring under each lighting condition within locations defined by roadway type. Beyond the already observed trend that incidents occur more frequently under dark conditions and less under daylight as injury severity increases, it has also been discovered that incidents resulting in moderate or more severe injuries show a strong correlation with intersections under dark-lighted conditions. Furthermore, the percentage of incidents on highways and streets under dark, unlighted, or dusk conditions is higher for moderate or more severe injuries compared to those resulting in no or minor injuries. These findings suggest a moderately compounded relationship between dark conditions and non-parking lot roadway types, contributing to the likelihood of moderate or more severe injuries.



(a) Lighting Condition Distribution Relative to Roadway Type in Crashes with No Injuries Reported



(b) Lighting Condition Distribution Relative to Roadway Type in Crashes with Minor Injuries Reported



(c) Distribution of Lighting Condition Relative to Roadway Type in Crashes with Moderate or More Severe Injuries Reported

Fig.12 Comparison of Lighting Condition Distribution Relative to Roadway Type Across Crashes Resulting in Varying Levels of Injury Severity

Logistic Regression Analysis

A multivariate logistic regression analysis was conducted to examine the factors and interactions among covariates that influence the severity of injuries in incidents involving ADS-equipped vehicles. The covariates are detailed in Table 2. A positive coefficient indicates that as the value of the predictor increases, the likelihood (odds) of a specific injury severity also increases. Conversely, a negative coefficient signifies that an increase in the predictor value decreases the odds of injury severity. The analysis of the factors influencing injury severity reveals several key insights, which align closely with the results outlined in Table 1.

An increase in injury severity is observed as pre-crash speed increases. Lower pre-crash speeds (0-10 MPH) are positively associated with no injuries and minor injuries but are negatively correlated with moderate or more severe injuries. Conversely, speeds between 10-25 MPH and over 50 MPH show a trend where higher speeds are more correlated with moderate and severe injuries. Adverse weather, associated only with no injuries in Table 1, remains positively correlated with the absence of injuries. Both clear and cloudy weather exhibit a slight positive correlation with minor, moderate or more severe injuries. Dark, unlighted conditions are strongly associated with moderate or more severe injuries compared to other lighting conditions, but daylight and dark-lighted conditions are negatively correlated to moderate or mode severe injuries and show a strong correlation with minor or no injuries. This highlights the critical role of visibility in crash severity, with well-lighted conditions potentially reducing injury severity. Time of day also significantly impacts injury outcomes, with late-night crashes associated with more severe injuries and morning crashes linked to minor injuries, suggesting that factors like driver fatigue and reduced visibility at night contribute to more severe outcomes. The pre-crash movements of both the subject vehicle and the crash partner reveal notable patterns. The subject vehicle’s movements such as stopping or parking are strong predictors of less severe injuries, whereas moving straight is a significant indicator of more severe injuries. Lane changes and turning maneuvers exhibit mixed correlations with injury severity. Notably, non-motorist actions by the crash partner, such as those involving pedestrians or cyclists, are strong predictors of severe injuries, highlighting the heightened risk for vulnerable road users in these incidents. Regarding feature importance, the top three factors most strongly associated with moderate or more severe injuries are: Non-Motorist Actions by the crash partner (coefficient: 1.108), Dark-Not Lighted conditions (coefficient: 0.632), and late-night time of day (coefficient: 0.564). These values highlight the significant impact of vulnerable road users, poor visibility, and nighttime driving on injury severity in ADS vehicle crashes.

The intercept values suggest that when all predictor variables are set to zero, the "No Injuries" outcome is the most likely, with a positive log-odds of 2.300. In contrast, "Minor Injuries" and ">= Moderate Injuries" have lower baseline probabilities, indicated by their negative intercepts of -1.461 and -0.839, respectively. This implies that under the baseline conditions (all predictors at zero), "No Injuries" is more probable compared to the other two outcomes.

Table 2 Logistic Regression Analysis of Factors Influencing Injury Severity

Features		**Coefficients**		
		No Injuries	**Minor Injuries**	**>=Moderate Injuries**
Intercept		2.300	-1.461	-0.839
Pre-Crash Speed (MPH)	0-10	0.189	0.211	-0.399
	10-25	-0.128	-0.254	0.382
	25-50	-0.007	0.116	-0.109
	>50	-0.038	-0.1	0.139
Weather	Adverse	0.709	-0.417	-0.292
	Clear	-0.45	0.231	0.218
	Cloudy	-0.244	0.158	0.086
Lighting Conditions	Daylight	-0.078	0.487	-0.409
	Dark - Lighted	0.082	0.282	-0.365
	Dark - Not Lighted	-0.372	-0.261	0.632
	Dawn / Dusk	0.382	-0.535	0.153
Roadway Types	Highway / Freeway	0.117	-0.149	0.033
	Intersection	0.232	0.128	-0.361
	Parking Lot	0.346	-0.037	-0.309

	Street	0.099	0.282	-0.381
Time of a Day	Late Night	0.182	-0.746	0.564
	Morning	0.031	0.514	-0.545
	Afternoon	-0.063	-0.001	0.064
	Evening	-0.135	0.207	-0.072
Pre-Crash Movement of the Subject Vehicle	Moving Straight or Passing	-0.258	-0.003	0.261
	Lane Changes and Entering	0.137	-0.245	0.108
	Turning	-0.006	0.522	-0.516
	Stopped/Parking/Backing	0.481	-0.421	-0.06
	Other Movements	-0.476	0.232	0.244
Pre-Crash Movement of the Crash Partner	Moving Straight or Passing	-0.443	0.541	-0.098
	Lane Changes and Entering	0.166	-0.275	0.108
	Turning	-0.114	0.445	-0.331
	Stopped/Parking/Backing	0.586	-0.4	-0.186
	Incorrect Lane Use	0.142	-0.132	-0.01
	Non-Motorist Actions	-0.824	-0.284	1.108
	Other Movements	0.502	0.078	-0.58

This analysis closely aligns with the findings in Table 1, reinforcing the observed patterns in injury severity. The results offer valuable insights into how various factors contribute to differing levels of injury severity in crashes involving ADS-equipped vehicles. This comprehensive analysis highlights the significant variations in injury severity and underscores the importance of considering these factors in studies related to road safety and ADS technology.

Discussion

The study conducted an exploratory analysis of crash data involving ADS-equipped vehicles, utilizing summary incident reports from the Standing General Order of NHTSA. To ensure the reliability of the findings, the data underwent extensive preprocessing to clean and standardize the information. Logistic regression was employed to identify factors contributing to different levels of injury severity, providing valuable insights into the conditions and circumstances that contribute to incidents involving ADS-equipped vehicles. This analysis helps to uncover underlying causes and patterns associated with these crashes.

The analysis indicates that incidents involving ADS-equipped vehicles, regardless of injury severity, frequently occur at low speeds, in clear weather, on streets or at intersections, during daylight or in the afternoon, and when vehicles are either stopped, backing, or moving straight. These findings suggest that ADS-equipped vehicles are often involved in typical urban driving scenarios, where low speeds and frequent stops are common due to traffic signals and other urban features. However, without comprehensive travel data (such as total miles driven, number of trips, or distances traveled) for ADS vehicles under various conditions, it is challenging to fully understand these patterns. The absence of such data creates a research gap, making it difficult to assess the true risk associated with different driving scenarios. Future studies should aim to collect and analyze travel data to better contextualize these findings.

Regarding injury severity, the analysis reveals that as the severity of injury increases, the proportion of incidents involving ADS-equipped vehicles relative to those involving vehicles with automated features (ADS + ADAS) decreases significantly. This inverse relationship is statistically supported by a chi-squared test, which shows a very low p-value, indicating a strong association between the type of automated features and the severity of injuries in incidents. One possible explanation for this finding is that ADS-equipped vehicles, being fully autonomous, may be better equipped to handle driving situations safely, thereby reducing the likelihood of severe injuries. The advanced sensors and decision-making algorithms in ADS may allow these vehicles to avoid or mitigate crashes more effectively compared to scenarios where human judgment plays a role. In contrast, vehicles equipped with ADAS (which assist but do not replace the driver) rely on human intervention, which can vary in effectiveness depending on the situation. This suggests that fully autonomous ADS technology could potentially enhance safety by reducing the severity of crashes.

Analyzing the distribution of injury severity reveals significant variations based on multiple factors. Incidents that occur under dark, unlighted conditions, late at night, at high speeds on highways or freeways, during straight or passing movements, and those involving non-motorist crash partners (such as pedestrians or cyclists) are particularly likely to result in moderate or more severe injuries compared to minor or no injuries. These conditions inherently involve higher risks: low visibility at night, higher speeds, and the presence of vulnerable road users all contribute to the increased likelihood of severe outcomes. Logistic regression analysis further highlights that late-night crashes and dark, unlighted conditions–two highly correlated factors–along with non-motorist crash partners, are more critical predictors of moderate or more severe injuries than factors like roadway type (such as highways), pre-crash speed (10-25 MPH or over 50 MPH), or the action of moving straight. The heightened risk in these scenarios may be due to reduced visibility, driver fatigue, and the lack of protective infrastructure for non-motorists, which can amplify the severity of incidents. In contrast, incidents occurring in the morning with daylight, in parking lots, during backing or when stopped, and at low speeds are more associated with no injury or minor injuries. These conditions generally involve lower risks: better visibility during daylight, reduced speed, and the controlled environment of parking lots contribute to the lower likelihood of severe injuries. Additionally, the slow maneuvers typical in these settings, such as backing and stopping, allow for more system response time and less impact force, which reduces injury severity.

Interestingly, adverse weather conditions, including snowy and rainy weather, were found to be strong predictors for incidents resulting in no injuries. The data showed that all incidents under adverse weather conditions led to no injuries. This could be because drivers (or the ADS systems) might exercise more caution during adverse weather, driving at lower speeds and maintaining greater distance from other vehicles, which can prevent serious crashes. However, the chi-squared test indicated that weather and injury severity are not statistically correlated. This suggests that while adverse weather may influence driving behavior and reduce injury likelihood, it does not have a consistent impact on injury severity across all incidents. Despite the differences between incidents leading to moderate or more severe injuries and those causing minor or no injuries, most crashes—regardless of injury severity—still follow the overall trend: they tend to occur at low speeds, in clear weather, on streets or at intersections, during daylight or the afternoon, and when vehicles are either stopped, backing, or moving straight. These factors dominate across all levels of injury severity, although there are percentage differences in their impact depending on the specific injury outcomes.

Overall, these findings provide valuable insights into the specific contexts in which ADS-equipped vehicles incidents occur, highlighting the importance of understanding various driving scenarios to better assess the associated risks. The study's analysis sheds light on the patterns and factors that contribute to crash severity, offering a foundation for further research and potential safety improvements in ADS technology. However, a significant limitation of this study is the limited dataset, particularly in terms of incidents causing moderate or more severe injuries. The scarcity of such data makes it challenging to draw definitive conclusions about the factors contributing to more severe outcomes. By addressing the current gaps in data, particularly regarding travel patterns, conditions, and more comprehensive incident reporting, future studies can provide a more robust understanding of the factors contributing to crash severity in ADS vehicles.

Future Work

Remaining tasks from this project include assessing the patterns and characteristics of crashes involving electric vehicles (EVs), which will be completed with our Year 3 project.

Project Outputs

- In February 2025, project PI Corey Harper presented a seminar titled "Advancing Towards a Smarter and More Sustainable Transportation System" at Johns Hopkins University.
- In January 2025, project PI Corey Harper presented a paper at the Transportation Research Board 104th Annual Meeting titled "Estimating the Cost and Benefits of and Number of Lives Saved by Crash Avoidance Technologies"
- In November 2024, project PI Corey Harper presented a seminar titled "Advancing Towards a Smarter and More Sustainable Transportation System" at University of Maryland.
- In November 2024, project PI Corey Harper participated in the Safety21 Deployment Partner Consortium Symposium.
- In November 2024, project PI Corey Harper presented a seminar titled "Advancing Towards a Smarter and More Sustainable Transportation System" at University of Michigan.

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