

Field Relevance of the New Car Assessment Program Lane Departure Warning Confirmation Test

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ABSTRACT

The availability of active safety systems, such as Lane Departure Warning (LDW), has recently been added as a rating factor in the U.S. New Car Assessment Program (NCAP). The objective of this study is to determine the relevance of the NCAP LDW confirmation test to real-world road departure crashes. This study is based on data collected as part of supplemental crash reconstructions performed on 890 road departure collisions from the National Automotive Sampling System, Crashworthiness Data System (NASS/CDS). Scene diagrams and photographs were examined to determine the lane departure and lane marking characteristics not available in the original data. The results suggest that the LDW confirmation test captures many of the conditions observed in real-world road departures. For example, 40% of all single vehicle collisions in the dataset involved a drift-out-of-lane type of departures represented by the test. Also, the median total departure velocity for vehicles was 78.9 kph, which is close to the 72.4 kph (45 mph) specified in the LDW test. However, there are some aspects of real-world road departures not included in the test. For example, the test is performed in daylight yet nearly half of all road departure crashes (42%) occurred in the dark. Furthermore, the LDW test is only performed on straight road segments, which corresponds to 48% of real-world departures. The departure speed specified in the LDW test is 0.5 m/s (1.1 mph) whereas the mean lateral departure speed in real world crashes was 4.3 m/s (9.5 mph). Of the examined cases, the LDW test is applicable to approximately 23% of no maneuver road departures, which corresponds to 9% of all single vehicle collisions. Including dark lighting conditions and curved road segments would increase the applicability to 65% of no maneuver departures and 26% of all single vehicle collisions. These results can be applied to the design of future LDW performance tests.

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INTRODUCTION

Starting with the 2011 model year, the National Highway Traffic Safety Administration's (NHTSA) New Car Assessment Program (NCAP) started including the presence of active safety systems on the vehicle's Monroney label alongside the vehicle's star safety rating. One of these active safety systems is Lane Departure Warning (LDW). LDW systems aim to alert the driver through visual, auditory, and/or haptic means if an unintended lane departure is probable. Most LDW systems available on the market today utilize forward facing cameras to track the vehicle position between lane lines or other road features.

To determine the availability of LDW on new passenger vehicles for the NCAP, NHTSA conducts a confirmation test on a laboratory test track. The test is conducted on a straight road segment with in combinations of three line styles and two departure sides (left and right) [1]. The test vehicle leaves the lane at a relatively a low lateral departure velocity.

Each of the 6 combination of line style and departure side is repeated for 5 trials, making 30 total trials in the test. Table 1 shows the test matrix for the LDW confirmation test. The test is performed on a dry, level paved surface in daylight at a constant speed of 72.4 kph (45 mph) with a single highway lane marking. Tests are run starting at both ends of the segment to create left and right departures. The departures are induced manually by a test driver steering the vehicle after the start of the test to induce a nominal lateral departure velocity of 0.5 m/s. Lateral velocities for each trial must be between 0.1 m/s and 0.6 m/s to be deemed acceptable. The vehicle passes the test if a warning is delivered after the vehicle is within 0.75 m (2.5 ft) of crossing the lane line and before the vehicle has exceeded 0.3 m (1.0 ft) past the lane line. The overall system passes the test if warnings are effectively delivered 3 of 5 (60%) of trials for each configuration and 20 of 30 of all trials (66%). Vehicle forward speed must be kept within 2 kph of the 72.4 kph

target speed during the entire test. The vehicle yaw rate must not exceed 1.0 degrees/s.

Table 1. Test Matrix for NCAP LDW Confirmation Test.
Tests are run on a straight road segment at a low lateral departure velocity [1].

Line Type	Departure Direction	Number of Trials
White Solid	Left	5
	Right	5
Yellow Dashed	Left	5
	Right	5
Botts Dots	Left	5
	Right	5
TOTAL	-	30

Three types of lane markings are used in the confirmation test: 1) a white solid line, 2) a yellow dashed line, and 3) raised traffic markers, also known as Bott's Dots. Bott's Dots have been adopted in some states, such as California, as an alternative to painted lane markings. They are raised markers that are circular or square that adhere directly to the pavement. They can be retro-reflective or non-reflective. The Bott's Dots marking, while limited to certain localities, is considered difficult to accurately track for most vision-based LDW systems [1].

These test conditions were selected in order to evaluate LDW systems on passenger vehicles. An ideal test would be representative of the environments the systems are likely to encounter in the field. One prominent source of data used to characterize road departure collisions is historical crash databases [2, 3, 4]. These databases usually contain information aggregated from police accident reports and may be supplemented by professional investigators who collect additional information. However, these traditional data sources do not have many data elements that are of importance to an LDW confirmation test, such as lane marking availability and departure velocities. Also, the focus in traditional databases is on the vehicle after it leaves the road. However, of greater interest in evaluating LDW performance are vehicle movements from the point of lane departure to when the vehicle departs the road. This study presents data from a unique crash database that contains supplemental reconstructions focusing on lane departure collisions that were not used in the design of the LDW confirmation test.

OBJECTIVE

The objective of this study is to quantify the road, environmental, and vehicle characteristics in road departure collisions and assess the applicability of the NCAP LDW confirmation test to real-world serious road departure conditions.

METHODOLOGY

DATA SOURCE

Crashes in this study were extracted from a special subset of road departure collisions from the National Automotive Sampling System, Crashworthiness Data System (NASS/CDS). NASS/CDS is a nationally representative sample of in-depth crash investigations performed in the U.S. Crash investigation teams located in urban, suburban, and rural locations throughout the country collect information about highway traffic collisions. In order to be selected for investigation, crashes must involve at least one passenger vehicle and result in at least one vehicle towed from the scene due to damage. Investigations consist of photographing and diagraming the crash scene, conducting interviews with those involved, retrieving medical and police records, and documenting damage to vehicles. One challenge to using NASS/CDS for road departure collision studies is that the primary focus of this database is on vehicle and restraint crash performance. NASS/CDS contains little information on the roadway or roadside and no information on the speed or angle of road departure.

In the subset of NASS/CDS cases examined in this study, researchers reconstructed the speed and departure angles, which were not contained in the original NASS/CDS cases. These additional reconstructions were performed under the National Cooperative Highway Research Program (NCHRP) Project 17-22 titled "Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes" [5]. The reconstructions were performed by collecting additional information from the original crash scenes, photographs, and scene diagrams. The NCHRP Project 17-22 performed detailed reconstructions on 890 cases from NASS/CDS years 1997 to 2001 and 2004. In order to be included in the NCHRP 17-22 study, the crash involved a single passenger vehicle on a road with a speed limit above 45 mph (72.4 kph). One central focus of the 17-22 project was to reconstruct the speed and angle of the vehicle at the point of road departure. This type of data is not available in traditional crash databases, such as NASS/CDS.

EXAMINATION OF SCENE PHOTOGRAPHS

Missing from almost all traditional crash databases, including NCHRP 17-22, is the availability of lane markings in collisions. The current study extends the NCHRP 17-22 dataset to add detailed information on the availability and style of lane markings. Scene photographs taken by the crash investigator were utilized to assess the availability of road markings. Two independent reviewers analyzed the 890 cases in the NCHRP 17-22 database. For each case, the reviewers assessed the lane markings based upon the scene diagram prepared by the investigator, the case summary text, and all of the crash scene photographs available for each case. The reviewers first identified the original travel lane of the vehicle



before it left its lane. The reviewers then determined the side of the first lane departure (right or left), if there was a road marking delineating the edge of that lane, and the style of the road marking (e.g. dashed, double solid). The same information was recorded pertaining to the lane or road boundary on the opposite side of the first departure. The result was the details of the road marking style on both sides of the vehicle's travel lane prior to the departure. Examining the lane markings at the point of the first lane departure, opposed to where the vehicle ultimately left the road, is important because the point of lane departure is where the sensors of the LDW system will need to track the vehicle's position on the road.

Another unique data element collected from examination of the scene diagrams was the lateral movements of the vehicle during the departure event. Often, traditional crash databases have no information on what side of the road the vehicle first departed the roadway. Part of the supplemental investigations performed in the NCHRP 17-22 project was to determine the side of the road that the vehicle first departed. In many road departure collisions the vehicle does not just simply depart the lane and continue off the roadway, but instead may have multiple departures. For example, a vehicle may depart its lane to the right, the driver will overcorrect, and send the vehicle across its original travel lane to the left. From examination of the scene photographs and diagrams, the sequence of lane departures was determined in addition to the final road departure side.

In most crashes, the determination of lane markings and departure sides is straightforward. However, reviewers interpreted some cases differently, which led to different results from each reviewer. Agreement between the two reviewers on individual assessments (e.g. which side of the lane did the vehicle depart? What was the lane color on the side of the first departure?) was between 89% and 97%. An analogous situation often arises in independent review of medical studies. For instance, two doctors will be asked to diagnose an ailment from x-ray film. A measure for assessing observer variability often used in medical studies is the kappa statistic [6]. The kappa statistic determines what proportion of agreement between observers is above chance alone. A kappa statistic of 0 represents only chance agreement between two reviewers and a statistic of 1 represents perfect agreement. For assessments in the current study, the kappa statistic ranged from 0.77 to 0.89. In medical studies, kappa statistics in this range would be considered substantial to almost perfect agreement [7]. In crashes where there was no agreement between reviewers on one or more items (215 out of 890 case), a third member of research team reviewed the case to determine the departure and lane marking characteristics.

STATISTICAL ANALYSIS

In order to create a representative sample of all collisions that occurred in the U.S., each collision investigated in NASS/CDS is assigned a weighting factor that correspond to

the number of similar collisions that occurred during the sampling period. NASS/CDS uses a complex, stratified survey design, which is not a simple random sample. For example, crashes that involve newer vehicles and hospitalization of occupants are sampled more often than non-injury cases. As a result, case weights can vary from 1 to above 50,000. Because the NCHRP 17-22 database is a small sample of NASS/CDS (890 cases of 27,000 total cases investigated during the study time frame), cases with large weights can have large influence on statistical analyses. To decrease the bias introduced by extreme weighting factors, cases with weighting factors greater than 5,000 were excluded from the analysis [8]. From the 890 cases, 14 cases had weights above 5,000 and one case had a case weight of zero, leaving 875 cases. These 14 cases omitted (1.6% of the 890 total cases) corresponded to a disproportionately high 44% of the total case weights.

All statistical analysis was performed using the software SAS (version 9.2, SAS Institute, Cary N.C.). When statistical tests were performed, variance was estimated using methods that account for the complex survey design of the sample using Taylor series linearization. Traditional variance estimation methods will underestimate variance in complex survey designs.

RESULTS

TARGET ROAD DEPARTURE SCENARIOS

Road departure collisions can include a wide variety of scenarios and LDW will be applicable in only some of these scenarios. LDW systems are most effective in cases that were the result of a vehicle drifting outside of its travel lane. In road departures primarily caused by control loss or vehicle failure, for example, LDW may have little or no effect. The first task in this analysis was to determine the set of collisions where LDW systems could be expected to be effective in mitigating or preventing road departure.

Of the 495,319 weighted cases (n=875) in the NCHRP 17-22 database, 278,548 collisions involved a single vehicle (n=869). Each single vehicle collision was assigned a road departure scenario. These scenarios were determined using pre-crash variables in NASS/CDS, including the critical pre-crash event, pre-crash vehicle movement, and accident type. The goal was to aggregate similar collisions by their pre-crash scenarios. [Table 2](#) shows the distribution of road departure scenarios for all the single vehicle collisions in NCHRP 17-22 and the corresponding years of NASS/CDS, for comparison. The no maneuver scenario includes crashes with little or no input from the driver prior to the critical event of leaving the lane or road (i.e. the driver drifted off the road). The control loss scenario included crashes where the vehicle lost control, then departed the roadway. The avoidance maneuver scenario was a road departure caused by the driver avoiding a previous critical event, such as a slower

Table 2. Road Departure Scenarios in Single Vehicle Collisions from NCHRP 17-22 and NASS/CDS 1997-2001 and 2004.

Scenario	NCHRP 17-22			NASS/CDS 1997-2001 + 2004		
	N	Weighted	%	N	Weighted	%
No Maneuver	509	141,151	51%	5,095	2,432,026	48%
Control Loss	200	87,254	31%	2,539	1,393,015	27%
Avoidance Maneuver	111	42,430	15%	957	674,029	13%
Not a Departure	0	0	0%	295	222,013	4%
Vehicle Failure	31	5,886	2%	272	182,116	4%
Traffic Maneuver	16	1,661	1%	263	134,933	3%
Other/Unknown	2	165	0.1%	95	68,648	1.3%
No Driver	0	0	0%	9	11,663	0.2%
Total	869	278,548	100%	9,525	5,118,444	100%

vehicle in its lane. Some collisions were not departures, such as impacts with objects or animals on the roadway. Still other departures occurred due to disabling vehicle failure, while performing another traffic maneuver (e.g. turning at an intersection), or did not fall into any other category. The no maneuver scenario, which accounted for 51% of collisions in the NCHRP 17-22 dataset, is the scenario in which LDW is thought to be most effective in preventing or mitigating collisions.

The distribution of scenarios appears to be similar between the 17-22 dataset and the entire set of NASS/CDS cases. A Roa-Scott Chi-Squared test is used to test whether two variables are dependent on each other. This Chi-Squared test was used to determine if the distribution of scenarios is different between NCHRP 17-22 and the entire NASS/CDS population from the same time frame. The null hypothesis is that the distributions are similar. The resulting test has a p-value of 0.1895, which suggests that the distribution of scenarios is similar between both sets. The Roa-Scott test is similar to the traditional Pearson's Chi-Square test but corrects for the complex survey design of the sample. This result also confirms that dropping cases in the NCHRP 17-22 dataset with extreme case weights did not affect the extent to which the dataset represents the entire population.

LDW systems will also only function on surfaces where lane markings are available, i.e. roads that are paved. Table 3 shows the distribution of surface type for no maneuver road departure collisions. The majority, 91%, occurred on paved roads, while the remaining 9% occurred on gravel, dirt, or other road surfaces.

Table 3. Distribution of Surface Type for No Maneuver Road Departure Collision in NCHRP 17-22

Surface Type	N	Frequency	%
Paved	470	127,931	91%
Gravel/Slag	19	7,668	5%
Dirt	11	3,869	3%
Other	9	1,684	1%
Total	509	141,151	100%

Also due to lane marking issues, crashes where the critical event occurs within an intersection may not be applicable to LDW systems. Lane markings prior to and inside of intersections can be complex and inconsistent. Not all LDW system may be able to consistently track the vehicle's position within the lane in or around intersections. Table 4 shows the relationship to junctions of no maneuver road departure collisions that occurred on paved roads. The majority of collisions occurred on non-intersection/-interchange locations.

Table 4. Relationship to Junctions in No Maneuver Road Departure Collisions on Paved Roads

Crash Location	N	Frequency	%
Non-intersection/interchange	417	110,944	86%
Interchange Related	34	14,854	11%
Intersection Related	18	3,966	3%
Driveway Related	1	59	0.05%
Total	470	129,823	100%

The remaining analysis will focus on the 110,944 collisions (40% of weighted crashes, n=417) that had a pre-crash scenario of no maneuver, occurred on a paved road, and did not occur in or around an interchange or intersection. These collisions are the majority of collisions where LDW is thought to be most effective. Table 5 shows the number of lanes and traffic flow patterns for target road departure collisions. Almost two-thirds (63%) of roads were undivided 2-lane roads with two-way traffic, which are often U.S. or state route roads. The next most frequent road configuration was 2-lane roads with one-way traffic, such as an interstate with a divided median.

ROAD AND ENVIRONMENT CONDITIONS

Table 6 summarizes the general characteristics of the target scenario of no maneuver road departure collisions. For comparison, frequencies are also shown for single vehicle collisions from NASS/CDS years 1997 to 2001 and 2004.