

Benefit Estimation of a Lane Departure Warning System using ASSTREET

Shin Tanaka and Tsutomu Mochida
Toyota Motor Corporation

Masami Aga
Toyota Motor North America, Inc.

Jun Tajima
Advanced Solutions Technology JAPAN

ABSTRACT

It is known that the collisions caused by lane departure events account for range of percentages among the countries studied. To help prevent such collisions, the Lane Departure Warning (LDW) system has started to be introduced in production vehicles, but there is little research on its benefits and limitations so far. In this paper we performed an in-depth analysis of the collisions and driver-related essential variables for the lane-departure collision scenarios and demonstrated the benefit estimation process. The benefit of the LDW system is estimated by comparing lane departure events when the vehicle has no LDW, and how they change with the addition of LDW. The event without LDW was modeled in 5 phases: (1) before departure, (2) starting of the departure, (3) departed the lane, (4) at the impact with an object, and, (5) after the impact. "An extensive analysis was conducted of traffic crash data compiled by the Institute for Traffic Accident Research and Data Analysis (ITARDA). The results of this analysis were used to create models of each phase of an LDW event. The Advanced Safety System & Traffic REaltime Evaluation Tool (ASSTREET), which is based on Monte-Carlo Simulation, was then used to simulate a variety of collision types. The results of these simulations were validated by comparing the distributions of fatality, serious injury, minor injury and no injury that they generated to crash statistics for Japan. Then, the effect of the LDW system was added to the lane departure events. The drivers' response delay to the LDW and the possible reactions were measured in a driving simulator test. The comparison between events with and without LDW clearly shows which cases could be prevented by the use of LDW and the ones that could not be avoided, thereby, providing us with important guidelines to improve the system performance.

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INTRODUCTION

Single vehicle collisions and head-on collisions tend to result in fatalities and serious injuries ⁽¹⁾. Several advanced safety systems have been developed to help prevent such accidents, one of the most promising of which is the Electronic Stability Control (ESC). The efficiency of pre-crash system (PCS) was proven using analysis of traffic collision statistics ⁽²⁾, and ESC has become standard from the 2012 model year light vehicles ⁽³⁾ in the United States.

However, it was also shown that ESC may be effective for collisions caused by human errors in the vehicle operation, but not so effective for those caused by the driver's

misrecognitions or misjudgments ⁽⁴⁾. To improve this scenario, Lane Departure Warning (LDW) systems have been developed by both car manufacturers and system suppliers. Although these systems are now becoming available in production vehicles, they are only available in a limited number of models.

Currently, there is limited research on its benefits and limitations of LDW systems. NHTSA (National Highway Traffic Safety Administration) published reports that analyzed the result of field operational tests using LDW equipped vehicles ^{(5),(6)}. Though the research was beneficial to know the characteristics of the system and the level of

effectiveness in the real world, it was insufficient to measure specification differences.

This paper presents a study of a benefit estimation method, using the crash data analysis in Japan. The benefit was measured by comparing the number of collisions and casualties when no LDW was equipped, with the collisions when LDW was equipped. To do this, we relied on the simulation tool ASSTREET (Advanced Safety System & Traffic REaltime Evaluation Tool).

ASSTREET is a tool developed to reproduce traffic flow and accidents and to evaluate active safety systems. It considers road environment, driving behavior models and vehicle maneuvers, including changes resulting from the activation of a system. As depicted in Fig. 1, ASSTREET allows the driver behind the wheel of each vehicle to perceive, recognize, make judgments about the surrounding traffic environment, and finally generate driving actions. ASSTREET was first applied to a Pre-Collision Safety System (PCS) to estimate the benefit of such system (7). In our analysis, we reproduced the traffic collisions due to lane departure using ASSTREET, and then the effect of LDW was added to those collisions.

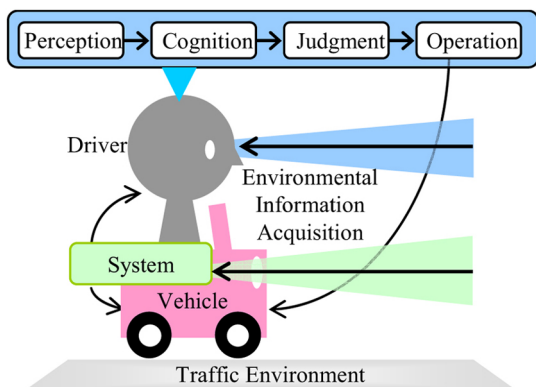


Figure 1. ASSTREET (Advanced Safety System & Traffic REaltime Evaluation Tool)

TRAFFIC COLLISION DATA IN JAPAN

First, we will briefly explain the crash data used in this study. The data was mainly extracted from the Institute of Traffic Accident Research and Data Analysis (ITARDA) reports.

ITARDA accumulates two kinds of data. The first is general crash statistics. In Japan, there are about 800,000 casualty-involved crashes every year. The police reports the information related to the crash, which is registered by ITARDA. In 2008, single-vehicle crashes (excluding those that involve pedestrians or cyclists) accounted for about 23,000 cases, and head-on crashes were about 17,000. This database was used for our study. However, this alone was not sufficient, since the driving behavior before the crash was not described.

The second dataset utilized was a compilation of detailed data of each crash, similar to the NASS-CDS (National Automotive Sampling System, Crashworthiness Data System) data in the United States. About 300 cases every year are recorded for a detailed analysis by ITARDA. ITARDA report 2007(8) analyzed LDW relevant cases from 1996 through 2003. As shown in Table 1, it extracted 167 cases where drivers unintentionally left their lanes. The result indicates that most of those cases resulted in single vehicle road departure and head-on collisions. In addition, in 2009, the ITARDA report analyzed 240 cases of lane departure crashes while negotiating curves that occurred from 1995 through 2007(9). Both reports provided the detailed level necessary for this analysis.

Table 1. Composition of lane departure crashes in in-depth data analysis (Source: ITARDA report 2007)

Manner of collision	Cases / Total
Single vehicle	128 / 513
Head-on	29 / 142
Sideswipe, opposite direction	2 / 12
Sideswipe, same direction	0 / 15
Rear-end	3 / 297
Other car to vehicle	5 / 1,021
Car to pedestrian	0 / 211
Total	167 / 2,211

SCHEME FOR LDW BENEFIT ESTIMATION

Figure 2 depicts the structure followed in the benefit estimation of the LDW system. The procedure consists of the following three steps.

Step 1: Reproduction of lane departure collisions

Step 2: Addition of LDW effect into collisions reproduced in Step 1

Step 3: Comparison of number of collisions and casualties resulted in both, Step 1 and Step 2

In the following sections, we will explain these three steps.

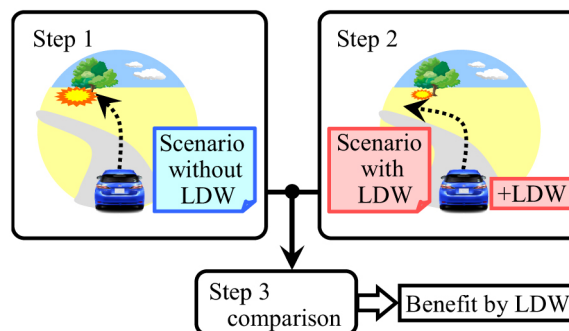


Figure 2. LDW benefit estimation structure

STEP 1: REPRODUCTION OF LANE DEPARTURE COLLISIONS

In this step we will explain in details the process carried out to simulate accurately the lane departure collisions. The process of the lane departure collision, from running normally on the road until after the collision, was divided into 5 phases as listed below (Fig. 3).

- Phase 1: Before departure
- Phase 2: Starting departure
- Phase 3: Running off the lane
- Phase 4: Impact
- Phase 5: Post-impact

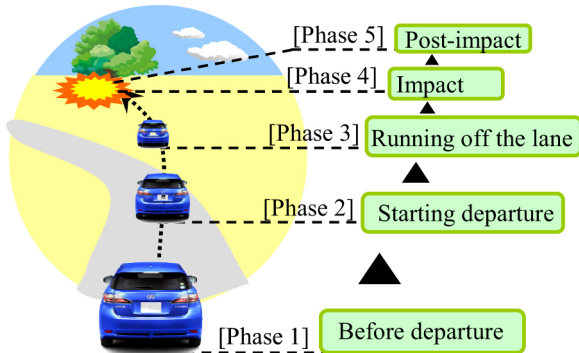


Figure 3. Lane departure sequence

To accurately simulate the collisions, the scenario for each phase was reconstructed based on the actual crash data, obtained from the ITARDA reports. In the following sections, we will explain the main characteristics of each phase that were considered in the simulation.

PHASE 1: BEFORE DEPARTURE

This phase is when the vehicle is driving normally on its lane, before the departure starts. Here, the shape of the road is an important factor. Fig.4 shows the roadway alignment distribution analyzed from the data of ITARDA report 2007⁽⁸⁾. It indicates that during half of collisions the vehicles departed from a straight road and for remaining half the vehicles departed from a curved road. Curve left and curve right road crashes were almost the same ratio. The ITARDA report 2009⁽⁹⁾ shows that road departure frequency is evenly distributed for road curvatures with a radius under 100 m, and that it gradually decreases as the curve radius increases (Fig. 5). It shows that although it is almost uniformly distributed in less than 100m range, the cases are gradually reduced as the curve radius is increased. From the data, we obtained the relationship between curve radius and travel speed before departure, as shown in Fig. 6. It is clear that speed is dependent on road curvature to some extent but its distribution at each radius value is wide.

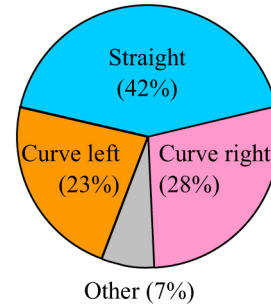
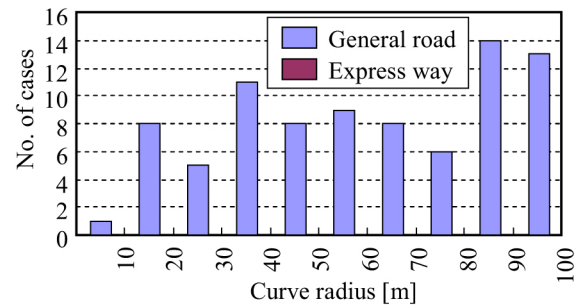
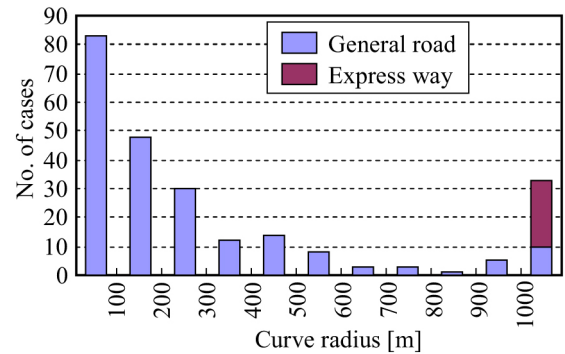


Figure 4. Roadway alignment distribution (Source: ITARDA report 2007)



(a). Less than 100 m



(b). More than 100m

Figure 5. Road curvature distribution (Source: ITARDA report 2009)

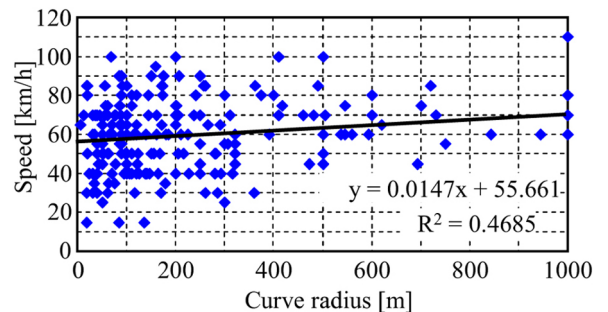


Figure 6. Relationship between curve radius and travel speed before departure (Source: ITARDA report 2009)

PHASE 2: STARTING DEPARTURE

This phase begins at the instant when the vehicle leaves the lane. Vehicle speed and departure angle are the most important factors in this phase. Fig. 7 and Fig. 8 show the distribution of the vehicle speed and departure angle respectively, as reported by ITARDA⁽⁸⁾. Fig. 7 shows that the majority of the cases are concentrated around 30 to 60 km/h. With respect to the departure angle, from Fig. 8 it can be seen that for most of the crashes it was of less than 10 degrees, regardless of the side of the departure. Fig. 8 also indicates that the cases of the left side departure and those of the right side departure were almost even. The report further analyzes the relationship between vehicle speed and departure angle, as shown in Fig. 9. The figure shows that both have poor correlation. This conclusion is a very important result because it affects the simulation.

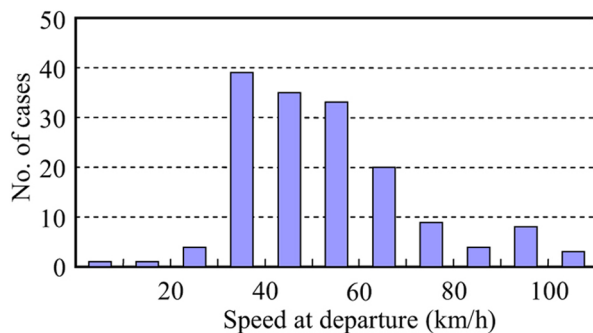


Figure 7. Vehicle speed distribution (Source: ITARDA report 2007)

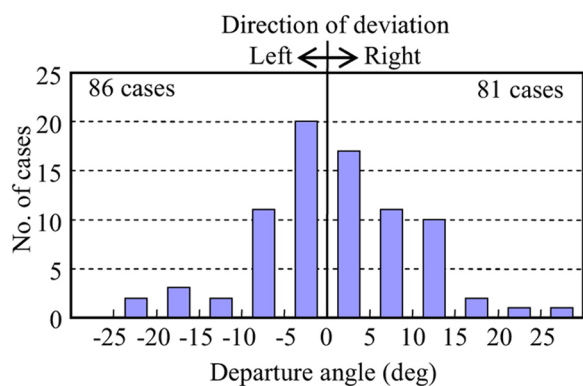


Figure 8. Departure angle distribution (Source: ITARDA report 2007)

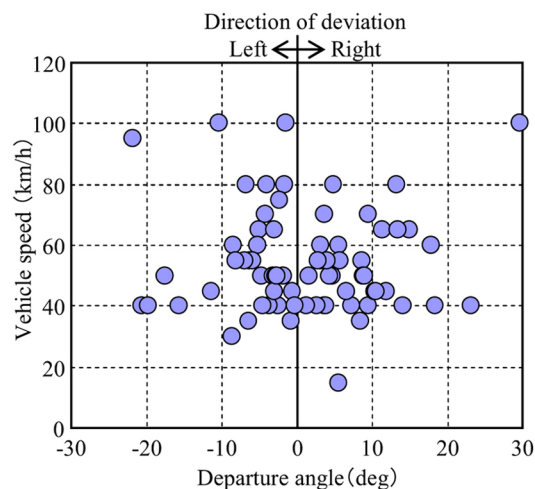


Figure 9. Relationship between vehicle speed and departure angle (Source: ITARDA report 2007)

PHASE 3: RUNNING OFF THE LANE

This phase starts when the vehicle has completely left the lane, until the instants just before the impact. The most important factor is the action of the driver. The ITARDA report⁽⁸⁾ summarized the attempted driver actions, as shown in Table 2. It is reported that, excluding cases where the driver action was not reported or unknown, about 80% of the drivers performed no avoiding maneuver. The remaining 20% tried to steer, brake or both. Due to the missing data, it was difficult to accurately reflect the driver behavior in simulation. Therefore, to simplify the scenario, we assumed that when the vehicle without LDW, No crash avoidance maneuvered.

Table 2. Composition of avoiding maneuvers (Source: ITARDA report 2007)

Avoiding maneuver	Cases	(Ratio)
No avoiding maneuver	118	(80%)
Steering	15	(11%)
Braking	10	(6%)
Steering + braking	4	(3%)
Unknown	20	(-)
Total	167	

PHASE 4: IMPACT

Whether drivers could avoid the colliding object depends on whether the object is located next to the road or in the adjacent lane. The lateral and longitudinal distance from the departure point was available for 84 out of the 167 cases were used to build model. The origin of the distances is defined as the crossing point of either side of the lane marking of the subject vehicle's lane and the locus of the front outer wheel of the vehicle. Both distances were used to identify their