Title

Leveraging Large-Truck Technology and Engineering to Realize Safety Gains:
Lane Departure Warning Systems

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Foreword

The mission of the AAA Foundation for Traffic Safety is to save lives through research and education. One of major focus areas is understanding how emerging technologies can affect traffic safety. Whereas the majority of our research into emerging technologies focuses on technologies found in the cars and light trucks driven by the general public, the research described in this report examines the issue from a different perspective: What role can advanced safety technologies for large trucks play in reducing crashes, injuries, and deaths on our roads?

This is one of four reports describing the results of a comprehensive study of the benefits and costs of several advanced safety technologies for large trucks. The focus of this report is on lane departure warning systems. This report should be a useful reference for Federal transportation agencies, the trucking industry, and developers and suppliers of advanced safety technologies. Companion reports presenting related research on automatic emergency braking systems, video-based onboard safety monitoring systems, and air disc brakes for large trucks are also available.

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About the Sponsor

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Founded in 1947, the AAA Foundation for Traffic Safety is a not-for-profit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies and other organizations or sources.

Table of Contents

List of Abbreviations and Acronyms

Acronym	**Definition**
AAAFTS	AAA Foundation for Traffic Safety
AIS	Abbreviated injury scale
AST	Advanced safety technology
BCA	Benefit-cost analysis
BCR	Benefit-cost ratio
CE	Cost-effectiveness
CEA	Cost-effectiveness analysis
CPI	Consumer price index
CUT	Combination unit truck
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GES	General Estimates System
GVWR	Gross vehicle weight rating
HOS	Hours-of-service
LDW	Lane departure warning
LTCCS	Large Truck Crash Causation Study
MAIS	Maximum abbreviated injury severity
MCMIS	Motor Carrier Management Information System
NHTSA	National Highway Traffic Safety Administration
NPV	Net present value
OEM	Original equipment manufacturer
OMB	Office of Management and Budget

PDO	Property damage only
PV	Present value
QALY	Quality adjusted life year
SUT	Single unit truck
VIUS	Vehicle inventory and use survey
VMT	Vehicle miles traveled
VSL	Value of statistical life

Executive Summary

In 2015, large trucks (trucks with a gross vehicle weight rating of more than 10,000 pounds) were involved in 414,958 crashes that resulted in 116,000 injuries and 4,067 fatalities (Federal Motor Carrier Safety Administration, 2016). The AAA Foundation for Traffic Safety identified the potential of several large-truck advanced safety technologies as promising countermeasures to reduce these crashes. Advanced safety technologies may use sensors or alerts to warn a driver of a possible collision, actively assume control of a vehicle in situations where a driver does not react to the threat of an imminent crash, or improve driver and fleet management (e.g., monitoring vehicle safety systems and drivers' hours-of-service status). Although some advanced safety technologies may be effective at preventing crashes, it is also important to know whether they are cost-effective, as this information may assist consumers in purchasing advanced safety technologies and/or government regulators in mandating their use.

The objective of this research was to provide scientifically-based estimates of the societal benefits and costs of advanced safety technologies in large trucks (i.e., the impacts a technology may have across the entire society if implemented) in order to (1) allow the Department of Transportation to make informed decisions related to potential regulations on advanced safety technologies, and (2) promote the adoption of cost-effective advanced safety technologies to motor carriers. To accomplish this objective, an in-depth literature synthesis of 14 advanced safety technologies was completed, an expert advisory panel informed cost and benefit estimations (based on the literature review and their experience and knowledge), and benefit-cost analyses were performed on selected advanced safety technologies. The advisory panel recommended the following four technologies for benefit-cost analyses: lane departure warning systems, automatic emergency braking systems, air disc brakes, and video-based onboard safety monitoring systems. This report presents the results related to lane departure warning systems. See other AAA Foundation reports for analyses of automatic emergency braking systems, air disc brakes, and onboard safety monitoring systems.

Overview of Lane Departure Warning Systems

Lane departure warning systems are vision-based, in-vehicle electronic systems that monitor the vehicle's position within a roadway. Based on lane line markings, the system warns a driver if the vehicle deviates or is about to unintentionally deviate outside the lane line. Lane departure warning systems are capable of providing direction-specific audible or haptic warnings depending on which way the vehicle is drifting. For example, an audible warning that sounds like rumble strips can be used for right side lane crossing. These warnings may also come from only the left-side (or right-side) speakers, depending on the direction of the lateral drift. It is important to note that if a turn signal is activated, the system will not issue an alert.

Efficacy and Costs Associated with Lane Departure Warning Systems

The literature review identified 13 studies that estimated the efficacy of large truck lane departure warning systems in reducing crashes. These studies found the efficacy of lane departure warning systems in preventing large-truck single-vehicle roadway departure, sideswipe, opposite sideswipe, and head-on crashes ranged from 13% to 53%. This wide range of efficacy was the result of variations in performance capabilities between different generations of systems, or not all relevant crash types were investigated in each study. Additionally, five documents provided costs associated with lane departure warning systems, identifying the costs of these systems as ranging from $301 to $2,000 per vehicle.

Expert Advisory Panel

An Expert Advisory Panel convened May 17, 2016, at the AAAFTS headquarters in Washington, D.C. This advisory panel consisted of six individuals representing various aspects of the industry, including representatives from a commercial motor vehicle carrier, a trucking insurance company, the Federal Motor Carrier Association (FMCSA), the National Highway Traffic Safety Administration (NHTSA), and an advanced safety technology vendor. The panel also included an industry safety consultant.

The purpose of this meeting was twofold: (1) to assist the research team in selecting technologies that require a benefit-cost analysis, and (2) to identify the appropriate efficacy rates and costs to be used in the benefit-cost analysis. Following this discussion, a benefit-cost analysis was recommended for lane departure warning systems, and upper- and lower-bound efficacy rates and costs were selected for lane departure warning systems.

For lane departure warning systems, the advisory panel recommended efficacy rates of 30% and 47.8% to reflect current performance capabilities of systems (instead of systems that were under development). This recommendation was based on current carrier conservative efficacy estimates, Pomerleau et al. (1999), and Hickman et al. (2013). Additionally, the panel recommended a cost of $1,000 per truck based on carrier feedback and information gathered from Orban et al. (2006), Houser et al. (2009), NorthAmerican Transportation Association (NTA; n.d.), and Hickman et al. (2013).

Benefit-Cost Analysis Methods

The benefit-cost analysis followed conventional methods used in similar studies (e.g., Hickman et al., 2013) to estimate the societal benefits and costs of implementing lane departure warning systems in the trucking industry. Societal benefits of lane departure warning systems associated with a reduction in crashes were compared to the costs of deploying the systems across the entire U.S. fleet of large trucks. The benefit and cost factors considered in this study are discussed below.

Benefit Factors:

- Medical-related costs
- Emergency response service costs
- Property damage

- Lost productivity
- Monetized value of pain, and the suffering and quality-of-life decrements experienced by families in a death or injury

Cost Factors:

- LDW system hardware purchase, installation, and financing costs
- LDW system maintenance costs
- LDW system replacement costs
- Costs associated with LDW system training for drivers and managers

To assess the impact lane departure warning systems could have on reducing crash rates (and the costs associated with the systems), national crash databases were used to identify the systems' target crash population. These crash databases included the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES). The FARS database was used to determine the number of fatal crashes and their associated fatalities and injuries, and the GES database was used as an estimation for injury and property damage only (PDO) crashes. The GES database also was used to estimate the number of injuries as a result of injury crashes. Queries were developed for relevant crash types and information was extracted for different vehicle types for a period of six years (2010 to 2015).

When filtering the GES and FARS crashes, the research team carefully considered the scenarios where lane departure warning systems may have prevented the crash. Specifically, only large-truck single-vehicle roadway departures and sideswipes, opposite direction sideswipes, and head-on crashes where the large truck struck another vehicle were selected as crashes potentially preventable by lane departure warning systems. Additionally, the research team used the following GES/FARS variables to further limit crashes that may have been prevented by LDW systems: pre-event movement, critical event, and first harmful event. Finally, all crashes that involved the use of alcohol or drugs by the large-truck driver were eliminated. The complete list of GES/FARS variables used may be found in Appendix B.

Two sets of benefit-cost analyses were performed for lane departure warning systems. The first set of analyses included retrofitting the entire U.S. fleet of large trucks. This approach assumed all new vehicles added to the fleet would be equipped with lane departure warning systems and old vehicles would be retrofitted. This analysis approach represented the scenario with the most benefits but also the highest costs. The second set of analyses used an annual incremental costs analysis approach. This approach assumed all new vehicles would be equipped with lane departure warning systems (starting in 2018) and did not include retrofitting old vehicles. Societal benefits were assessed over the life of the vehicle.

Additionally, for each analysis approach, an analysis was performed on different types of large trucks. The first analysis included all class 7 and 8 trucks (Gross Vehicle Weight Rating greater than 26,000 pounds). The second analysis was performed only using class 7 and 8 combination unit trucks. The third analysis was performed only using class 7 and 8 single unit trucks.

Finally, separate analyses were performed to account for the rate of monetary discount, in the present value, of the cost and benefits in any future year. Following guidance from the

Office of Management and Budget (OMB, 2003) analyses were performed using a 0%, 3%, and 7% discount rate.

Results: All Vehicles (New and Old) Equipped with Lane Departure Warning Systems

Lane departure warning systems were evaluated using a low and high efficacy rate (30% and 47.8%, respectively) and a low, average, and high cost ($500, $1,000, and $1,200, respectively[1]). Table 1 shows the benefit-cost ratios for lane departure warning systems when equipping all trucks (new and old). The analyses with a benefit-cost ratio greater than 1.00, which indicate that the benefits outweigh the costs, are highlighted. For example, the first row of results in Table 1 shows the results for all large trucks using a high efficacy rate for lane departure warning systems. When the costs of lane departure warning systems are average and the discount rate is 0%, the estimated benefits of lane departure warning systems are 2.3 times the estimated costs.

Table 1. Benefit-Cost Ratios for Lane Departure Warning Systems Installed on All Trucks by Vehicle Type, Efficacy Rate, Cost, and Discount Rate

	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks – High Efficacy	4.11	3.92	3.69	2.30	2.20	2.08	1.96	1.88	1.77
All Large Trucks – Low Efficacy	2.62	2.50	2.36	1.47	1.41	1.33	1.25	1.20	1.13
Only CUTs – High Efficacy	4.83	4.63	4.38	2.70	2.59	2.46	2.29	2.21	2.09
Only CUTs – Low Efficacy	3.08	2.96	2.79	1.72	1.66	1.57	1.46	1.41	1.33
Only SUTs – High Efficacy	2.74	2.60	2.43	1.55	1.47	1.37	1.32	1.25	1.17
Only SUTs – Low Efficacy	1.75	1.66	1.55	0.99	0.94	0.88	0.84	0.80	0.75

As lane departure warning was cost-effective in the majority of the analyses above when retrofitting the entire U.S. fleet of large trucks, raising the value of a statistical life (relative to the $9.4 million used in the main analyses) would only make these systems more cost-effective. Thus, only sensitivity analyses with a lower value of a statistical life are shown below (Table 2); results with a higher value of a statistical life are shown in Appendix C. Using a value of $5,304,000, the low-cost systems were found to be cost-effective regardless of efficacy rate, except for a 7% discount rate with only single-unit trucks. The average- and high-cost systems with a high efficacy rate were found to be cost-effective for all large trucks and combination unit trucks. The average-cost system with a low efficacy rate was also found to be cost-effective for only combination unit trucks when using a 0% or 3% discount rate.

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[1] As described in the body of the report, most published data showed the cost of lane departure warning systems was between $750 and $1,500. However, Ricardo et al. (2013) conducted a cost-weight analysis of lane departure warning systems and found significantly lower costs. Thus, the research team used the Ricardo et al. (2013) results as a lower-bound cost estimate.

Table 2. Sensitivity Analyses for Retrofitting the Entire U.S. Fleet of Large Trucks with Lane Departure Warning Systems and Using a $5,304,000 Value of a Statistical Life

	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks – High Efficacy	2.49	2.37	2.23	1.39	1.33	1.26	1.18	1.14	1.07
All Large Trucks – Low Efficacy	1.59	1.52	1.43	0.89	0.85	0.80	0.76	0.72	0.68
Only CUTs – High Efficacy	2.91	2.79	2.64	1.63	1.56	1.48	1.38	1.33	1.26
Only CUTs – Low Efficacy	1.86	1.78	1.68	1.04	1.00	0.95	0.88	0.85	0.80
Only SUTs – High Efficacy	1.68	1.60	1.49	0.95	0.90	0.84	0.81	0.77	0.72
Only SUTs – Low Efficacy	1.07	1.02	0.95	0.61	0.58	0.54	0.52	0.49	0.46

Results: Only New Vehicles Equipped with Lane Departure Warning Systems

Table 3 shows the benefit-cost ratios for lane departure warning systems when only equipping new trucks. As shown in Table 3, low-, average-, and high-cost systems were cost-effective for both the lower and upper efficacy rate with all truck types.

Table 3. Benefit-Cost Ratios for Lane Departure Warning Systems Installed on New Trucks Only by Vehicle Type, Efficacy Rate, Cost, and Discount Rate

	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks – High Efficacy	6.67	6.21	5.77	3.94	3.65	3.36	3.39	3.13	2.87
All Large Trucks – Low Efficacy	4.26	3.96	3.68	2.52	2.33	2.14	2.16	2.00	1.83
Only CUTs – High Efficacy	7.53	7.02	6.52	4.45	4.12	3.79	3.83	3.54	3.25
Only CUTs – Low Efficacy	4.81	4.48	4.16	2.84	2.63	2.42	2.44	2.26	2.07
Only SUTs – High Efficacy	4.83	4.50	4.18	2.85	2.64	2.43	2.45	2.27	2.08
Only SUTs – Low Efficacy	3.08	2.87	2.67	1.82	1.69	1.55	1.57	1.45	1.33

Table 4 shows the sensitivity analyses for only equipping new trucks with lane departure warning systems using the lower value of a statistical life. As shown in Table 4, only equipping new trucks with lane departure warning systems was cost-effective with the lower value of a statistical life regardless of efficacy rate for all large trucks and only combination unit trucks. The lower value of a statistical life resulted in cost-effective solutions for low- and average-cost systems with only sing unit trucks (except with a 7% discount rate). However, the high-cost systems were not cost-effective for only single unit trucks using the lower value of a statistical life.

Table 4. Sensitivity Analyses for Equipping All New Large Trucks with Lane Departure Warning Systems and Using a $5,304,000 Value of a Statistical Life

	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks – High Efficacy	4.04	3.76	3.49	2.39	2.21	2.03	2.05	1.89	1.74
All Large Trucks – Low Efficacy	2.58	2.40	2.23	1.52	1.41	1.30	1.31	1.21	1.11
Only CUTs – High Efficacy	4.54	4.23	3.93	2.69	2.48	2.29	2.31	2.13	1.96
Only CUTs – Low Efficacy	2.90	2.70	2.51	1.71	1.59	1.46	1.47	1.36	1.25
Only SUTs – High Efficacy	2.96	2.76	2.56	1.75	1.62	1.49	1.50	1.39	1.28
Only SUTs – Low Efficacy	1.89	1.76	1.64	1.12	1.03	0.95	0.96	0.89	0.81

Discussion

This report presents the scientifically-based estimates of the societal benefits and costs of lane departure warning systems installed on large trucks. The current study used efficacy rates from previously published research and identified crashes that may have been prevented through the deployment of a lane departure warning system. Crashes were identified using 2010 to 2015 GES and FARS data sets. Benefit-cost analyses were performed using varying efficacy rates (low and high), vehicle types (all large trucks, only combination unit trucks, and only single unit trucks), costs (low, average, and high), and discount rates (0%, 3%, and 7%).

The results strongly support the cost-effectiveness of lane departure warning systems for all large trucks. Regardless of cost and efficacy rate, lane departure warning systems were shown to be cost-effective given a $9.4 million value of a statistical life. These results were likely due to: (1) the relatively low cost of lane departure warning systems compared to other advanced safety technologies, and (2) the large number and high severity of the types of crashes that could be prevented with lane departure warning systems. As with the other advanced safety technologies, cost-effectiveness was higher when considering equipping only new large trucks as opposed to all large trucks including existing ones. However, these results suggest that equipping all large trucks (both retrofitting existing trucks and installing on new trucks) would be cost-effective provided the cost were not greater than the average cost considered here.

Limitations

Although the analyses used to assess the benefits and costs associated with lane departure warning systems were comprehensive, there were several limitations, including the following:

- It is possible the efficacy rates used in this study may not represent the current functionality/effectiveness of the current generation of lane departure warning systems. However, as the advisory panel consisted of experts with knowledge of current technology research, the efficacy rates recommended by the panel for use in the analysis should be consistent with the current generation of systems' efficacy rates.

- The technology costs used in this study may differ from current costs (costs typically decrease over time).
- This study used estimated crash, technology, and labor costs. It is possible that actual costs may differ and thus impact the cost-effectiveness of lane departure warning systems.
- The GES only included crashes that required a police accident report. However, lane departure warning systems may also prevent less severe crashes. Thus, these additional benefits are not accounted for in the benefit-cost analyses.
- The real-world effectiveness against different severity crashes may differ significantly. However, data limitations precluded the use of separate efficacy estimates for this study.
- These analyses did not account for reduced litigation costs associated with reduced crashes. These may be significant cost savings that were not integrated into the analyses.
- The failure to use data generated by lane departure warning systems (e.g., reports tracking alerts/activations) may result in missed driver coaching opportunities. Thus, maximum system efficacy may not be achieved.
- The efficacy of lane departure warning systems is dependent upon effective introduction, then initial and subsequent ongoing driver and management training.
- This study assumed all vehicle systems were functioning as intended. However, this is unlikely to be seen in the real world. Specifically, anti-lock brakes and foundation brakes have a direct impact on a vehicle's ability to avoid a crash. If they are poorly maintained, the actual efficacy rates may be lower than those used in the analyses reported here.

Introduction

In 2015, large trucks (trucks with a gross vehicle weight rating [GVWR] of more than 10,000 pounds) were involved in 414,958 crashes that resulted in 116,000 injuries and 4,067 fatalities (Federal Motor Carrier Safety Administration [FMCSA], 2016). Decades of research have shown that, historically, between 87% and 92% of all U.S. crashes have resulted from driver errors or risky behaviors. For example, the Large Truck Crash Causation Study (FMCSA, 2006) found that approximately 87% of all large-truck crashes were the result of risky driving behaviors or errors. Similarly, Treat et al. (1979) found that human factors (i.e., recognition errors, decision errors, performance errors, and critical non-performances) were determined to be the probable cause in 92.6% of all crashes, and Hendricks et al. (2001) found that driver behavioral errors contributed to or caused 717 out of the 723 crashes examined in their research. Risky driving behaviors and errors include excessive speed, violations of speed limits, excessive lateral acceleration on curves, unplanned lane departures, frequent hard braking, close following distances, lateral encroachment, failure to yield at intersections, distracted driving, and general disobedience of the rules of the road, among others.

The AAA Foundation for Traffic Safety (AAAFTS), which is recognized as an industry leader in traffic safety research, identified the potential of advanced safety technologies (ASTs) to mitigate risky driving behaviors or errors, which in turn may help prevent large-truck crashes. ASTs may use sensors or alerts to warn a driver of a possible collision. ASTs may also actively assume control of a vehicle in situations where a driver does not react to the threat of an imminent crash. In addition, ASTs include devices that improve driver and fleet management by, for example, monitoring vehicle safety systems and drivers' hours-of-service (HOS) status. There are a wide variety of ASTs available for large trucks, including the following:

- Forward collision warning
- Adaptive cruise control
- Automatic emergency braking systems
- Lane departure warning (LDW) systems
- Blind spot warning
- Electronic stability control
- Roll stability control
- Speed limiters
- Video-based onboard safety monitoring systems
- Kinematic-based onboard safety monitoring systems
- Vehicle-to-vehicle communication and large-truck platooning systems
- Electronic logging devices
- Air disc brakes
- Brake stroke monitoring systems

Project Objective

The objective of this research was to provide scientifically-based estimates of the societal benefits and costs of ASTs in large trucks. To accomplish this objective, an in-depth literature synthesis of 14 ASTs was completed, an expert advisory panel informed cost and benefit estimations for all ASTs, and a benefit-cost analysis (BCA) was performed on selected ASTs. The results of this study may be used by motor carriers and the Department of Transportation (DOT) to inform decisions related to the potential regulation and implementation of ASTs. These results may also be used to promote the adoption of cost-effective ASTs. Although the advisory panel recommended BCAs for four ASTs, this report only presents the information pertaining to LDW systems. Information about other ASTs are provided in separate AAAFTS reports.

Literature Review

The general approach taken for the literature synthesis was to identify relevant documents from the broader research literature and summarize the key information regarding the costs and benefits using a structured review format.

The major information sources for the literature review were (i) Transportation Research Information Services; (ii) U.S. government departments, such as the DOT; (iii) industry groups, such as the American Transportation Research Institute and the Owner-Operator Independent Drivers' Association; and (iv) academic journals (e.g., *Accident Analysis and Prevention* and the *Journal of Safety Research*).

All research obtained in the literature review was assessed to determine whether it contained the following detailed information: (i) a description of the LDW system features, (ii) a description of the vehicles examined, (iii) the estimated benefits of LDW systems (e.g., reduction in crashes or costs), and (iv) the estimated costs associated with LDW systems (e.g., purchase, installation, and/or maintenance). Literature that did not contain information about any of these fields was eliminated from further review. Additionally, only research pertaining to large trucks was considered. Literature that only discussed the costs and benefits of LDW systems on light vehicles was also eliminated from further review. Each relevant document was reviewed to identify the specific LDW system, vehicle type, study methodology, results related to benefits and costs, and study quality.

Some of the studies produced multiple reports, journal articles, and conference presentations (i.e., the same study was published in different journals, conference proceedings, etc.). Whenever possible, priority was given to a final report over journal articles and conference proceedings (which tend to provide less information). Typically, these secondary documents were removed from consideration or noted as duplicate works. In addition, the capabilities of the current generation of LDW systems may vary greatly compared to prior generations. Studies conducted after the year 2000 were given priority over research published before that.

Lane Departure Warning Systems

LDW systems are passive safety systems. Unlike active safety systems, passive ones simply alert the driver to a potential threat and do not assume control over any aspect of the vehicle. In other words, passive safety systems provide a warning to the driver, but the driver is not required to take any action as a result. These systems assist the driver by providing feedback and alerts regarding potential safety conflicts or unsafe driving behaviors.

LDW systems are vision-based, in-vehicle electronic systems that monitor the vehicle's position within a roadway. Based on lane line markings, the LDW system warns a driver if the vehicle deviates or is about to unintentionally deviate outside the lane line. LDW systems are capable of providing direction-specific audible or haptic warnings depending on which way the vehicle is drifting. For example, an audible warning that sounds like rumble strips can be used for right side lane crossing. These warnings may also come from only the left-side (or right-side) speakers, depending on the direction of the lateral drift. It is important to note that if a turn signal is activated, the LDW system will not issue an alert.

Crash Reductions Associated with Lane Departure Warning Systems

The literature review identified 13 studies that estimated the effectiveness of large-truck LDW systems in reducing crashes. These studies are described below.

Pomerleau et al. (1999) used national crash statistics and statistical modeling to evaluate driver behaviors in run-off-road crash scenarios. The authors found that 53% of all run-off-road crashes were applicable to LDW systems due to driver inattention or fatigue. Of these crashes, 63% could have been prevented with an LDW system. Their final estimation was that LDW systems could prevent 30% of all large-truck run-off-road crashes. This would eliminate 9,300 injuries and 96 fatalities each year.

De Ridder, Hogema, and Hoedemarker (2003) analyzed the results from an FOT designed to assess the effectiveness of LDW systems in the Netherlands. The FOT included 30 large trucks and one motorcoach. Three different vision-based LDW systems were installed on the 30 trucks (i.e., Safe-Trac system, Spurassistent, and Lane-Guard-Assistant), but a data acquisition system was only installed in six of these trucks. Results from the study showed that if all large trucks in the Netherlands were equipped with an LDW system, 10% of the injury crashes could be prevented. In addition, LDW systems had the potential to reduce 1.3% of the traffic congestion in the Netherlands through the reduction in crashes.

Orban, Hadden, Stark, and Brown (2006) conducted an independent evaluation of the Mack IVI FOT (Houser, Groeller, & Bishop, 2006). The Mack FOT (Houser et al., 2006) evaluated the effectiveness of LDW systems in improving the safety of large trucks. The FOT (Houser et al., 2006) included 22 instrumented trucks with 31 drivers over 12 months; however, data from only six drivers were used due to changes in the experimental design during the course of the study. In addition to the naturalistic data collected during the FOT, historical crash data from GES and FARS were analyzed, and survey data were collected from large-truck drivers, managers, and mechanics. The results indicated that LDW systems could reduce the crash scenarios related to rollovers and roadway departures by 31% on straight highways. On curved roadways, LDW systems reduced crash scenarios related to rollovers and roadway departures by 34%; however, this effect on curved roadways was not statistically significant, likely due to an insufficient sample size.

Visvikis, Smith, Pitcher, and Smith (2008) estimated the potential crash reductions related to LDW systems if all large trucks in Europe were equipped with them. They used published literature on the effectiveness and national crash statistics from Great Britain and Germany to estimate the number of crashes that may be related to LDW systems (i.e., head-on, sideswipe, road departure). The results indicated that LDW systems may prevent 48% of the fatal crashes, 36% of the serious injury crashes, and 20% of the minor injury crashes related to head-on collisions, road departures, and sideswipes.

Johnson (2008) included two separate analyses to estimate the safety benefits associated with LDW systems on large trucks. The first research effort included mining the LTCCS (FMCSA, 2006) data to identify the number of crashes that could be eliminated if all trucks were equipped with an LDW system. The results showed that LDW systems may prevent 7.2% to 8.2% of right-side road departures, 5.8% to 6.3% of left-side road departures, 11% to 12% of same direction sideswipes, and 17% to 18% of opposite direction sideswipes. The second research effort analyzed three years of carrier-owned crash data from eight commercial fleets. Johnson (2008) reviewed each crash and filtered crashes that would not have been impacted by LDW systems (e.g., mechanical failures, hit an overhead object, occurred in a parking lot, etc.). The results from this analysis indicated that LDW systems would prevent 0.8% to 6.2% of roadway departures and 1.38% to 21.7% of sideswipe/lane change crashes across the eight fleets. One limitation of this study was that the carriers did not provide a crash narrative for each crash (only a crash type and location were provided). Thus, the researcher was forced to make many assumptions to determine if a crash was related to an LDW system. For example, it would have been very difficult to verify if the crash was caused by the large truck (in the case of sideswipes and lane changes) or if the crash occurred as a result of an evasive maneuver.

Kingsley (2009) used crash data from the LTCCS (FMCSA, 2006) to estimate the potential reductions in crashes if all large trucks were equipped with one of nine ASTs (including LDW systems, forward collision warning systems, blind spot warning systems, drowsy driver detection, back-over crash prevention, night vision, tire pressure monitoring systems, roll stability control, and electronic stability control). Kingsley (2009) reviewed each of the 1,070 large-truck crashes in the LTCCS and identified all the crashes that could have been prevented with LDW systems. Results showed that LDW systems could have prevented 6.1% of all large-truck crashes included in the LTCCS (FMCSA, 2006).

Houser, Murray, Shackelford, Kreeb, and Dunn (2009) performed a carrier-level benefit-cost analysis of LDW systems for large trucks. The authors used the efficacy rates identified in the Mack IVI FOT (Houser et al., 2006) and collected effectiveness estimates from motor carriers. Houser et al. estimated that LDW systems would prevent between 23% and 53% of single-vehicle roadway departures (1,069 to 2,463 crashes), rollovers (627 to 1,307 crashes), same direction sideswipes (1,111 to 2,223 crashes), opposite direction sideswipes (997 to 1,992 crashes), and head-on crashes (59 to 118 crashes).

Kuehn, Hummel, and Bende (2011) analyzed 443 German truck crashes with insurance claims totaling over €15,000 (approximately $20,890). They estimated the percentage of these crashes that could have been prevented if the truck was equipped with one of six different ASTs (including automatic emergency braking, a turning assistant system, an intelligent rear view camera, LDW system, blind spot warning system, and electronic stability control). The authors extrapolated these results to 18,467 German insurance claims to estimate the potential safety benefits given a 100% penetration rate across all German trucks. The authors estimated that an LDW system could prevent 2% of all large-truck crashes (or 39% of all lane departure crashes).

Nodine et al. (2011) analyzed large truck naturalistic data from the Integrated Vehicle-based Safety Systems (IVBSS) FOT. The IVBSS FOT was designed to evaluate an integrated safety system that could prevent rear-end, lane-change, and road departure crashes for light and large trucks. The FOT included 18 large-truck drivers and 10 instrumented large trucks over 10 months. The final data set included 497,386 miles (87,730 miles where all safety systems were turned off, and 409,656 miles with all safety systems activated). The researchers reviewed naturalistic video data from a sample of 14,405 safety system alerts. Nodine et al. (2011) estimated LDW systems could eliminate 29% of opposite direction sideswipes and left-side road departures and 36% of the right-side road departures. There were insufficient data to determine the effects of LDW systems on same direction sideswipes.

Jermakian (2012) estimated the potential number of crashes, injuries, and fatalities that might be prevented with 100% adoption of five ASTs (including blind spot warning, automatic emergency braking, LDW system, electronic stability control, and roll stability control). The author used crash and injury data from the National Highway Traffic Safety Administration’s (NHTSA) General Estimates System (GES) and Fatality Analysis Reporting System (FARS) from 2004 to 2008, reviewing data from each crash and eliminating all crashes where an AST may have been ineffective (e.g., large truck was rear-ended, inclement weather, mechanical problems, off road crashes, a crash due to an evasive maneuver, etc.). The analyses found LDW systems could have prevented 3% of the large-truck single vehicle crashes and 10% of large-truck head-on, same-direction and opposite-direction sideswipe crashes. This reduction would prevent 9,000 to 10,000 large-truck crashes and 227 to 247 fatalities each year.

Hickman et al. (2013) used carrier-owned data to evaluate the efficacy and costs and benefits of three onboard safety systems (LDW systems, forward collision warning systems, and roll stability control). The authors collected three years of vehicle and crash data from 14 fleets. The final data set included 151,624 truck-years of operation, 13 billion vehicle miles traveled (VMT), and 88,112 crash records. These data were used to compare the crash rates of those trucks equipped with LDW systems compared to those trucks not equipped with LDW systems. Hickman et al. (2013) found that trucks equipped with LDW systems were involved in 47.8% fewer LDW-related crashes (e.g., sideswipes, opposite sideswipes, run off road, and head-on) compared to trucks not equipped with LDW systems.

Belzowski, Herter, Guan, and Murphy (2015) surveyed motor carriers that implemented various ASTs. Surveys were distributed to 537 U.S. motor carriers with 300 or more total vehicles, including at least 150 tractors. Sixty of these carriers completed the survey, and an additional 17 carriers only answered questions pertaining to the use of AST. In addition, the authors conducted more comprehensive interviews with six motor carriers, two technology vendors, and four DOT officials. Commercial fleets indicated that, on average, LDW systems prevented 14% of all large-truck crashes and 15% of all crash costs.

Finally, the technology vendor PeopleNet offers LDW systems from multiple vendors. PeopleNet (2016) claimed that fleets that use LDW systems reported a 75% reduction in lane departures over the course of 1.3 billion miles.

Lane Departure Warning System Costs

Several of the published documents summarized above included cost estimates for LDW systems. In 2006, Orban et al. (2006) reported the purchase price and installation of an LDW system was $750 to $1,500 per vehicle with a service life of five to seven years. In 2008, Visvikis et al. (2008) reported that LDW systems in Europe were estimated to cost €200 to €448 (i.e., $301.34 to $675.00 using the 2008 average exchange rate). In 2009, Houser et al. (2009) reported that an LDW system cost $1,000 to $1,500. Hickman et al. (2013) reported the average LDW cost (as reported by carriers) to be $1,000 per vehicle. These carriers also reported installation costs ranging from $0 to $250 per vehicle and driver training costs ranging from $0 to $100 per driver. Finally, the NorthAmerican Transportation Association (n.d.) estimated that LDW systems cost $1,000 to $2,000.

Literature Review Conclusions

The published literature was reviewed to identify the costs and benefits associated with large-truck LDW systems. Appendix A provides a summary of citations for LDW systems. The literature review identified 13 studies that estimated the efficacy of large-truck LDW systems in reducing crashes. These studies found the efficacy of LDW systems may prevent 13% to 53% of large-truck road departure, sideswipe, and head-on crashes. This wide range of efficacy may have been the result of variations in performance capabilities between different generations of LDW systems or because not all LDW-related crashes were investigated in each study. Additionally, five documents provided costs associated with LDW systems. The documents identified the costs of LDW systems as ranging from $301 to $2,000 per vehicle.

Methods

This section of the report provides an overview of the design and methods used to perform the BCAs.

Expert Advisory Panel

An Expert Advisory Panel convened on May 17, 2016, at AAAFTS headquarters in Washington, D.C. The advisory panel consisted of six individuals representing various aspects of the industry, including representatives from a commercial motor vehicle carrier, trucking insurance company, FMCSA, NHTSA, and an AST vendor, as well as an industry safety consultant.

The purpose of this meeting was twofold: (1) to assist the research team in selecting technologies that require a BCA, and (2) to identify the appropriate efficacy rates and costs to be used in the BCAs. Following this discussion, upper- and lower- bound efficacy rates and costs were selected for each of the four ASTs.

When determining the recommended efficacy rates and cost associated with LDW systems, the advisory panel prioritized recent research, real-world studies, generation of the technology, federal regulations, efficacy/cost estimates from the U.S. (due to differences in roadway infrastructure, safety culture, and crash rates), and crash reductions for specific crash types (compared to reductions for all large-truck crashes). Additionally, the Advisory Panel sought to be conservative in its efficacy estimates to avoid overestimating the potential benefits and cost-effectiveness of systems.

For LDW systems, the panel recommended efficacy rates of 30% and 47.8% to reflect current performance capabilities of LDW systems (instead of systems that were under development). This recommendation was based on current carrier conservative estimates, Pomerleau et al. (1999), and Hickman et al. (2013). Additionally, the panel recommended a cost of $1,000 per truck based on carrier feedback, Orban et al. (2006), Houser et al. (2009), NorthAmerican Transportation Association (n.d.), and Hickman et al. (2013).

Benefit-Cost Analysis Approach

The objective of deploying an AST is to reduce crashes and their associated fatalities and injuries. However, when faced with limited resources, industry stakeholders need to understand the positive and negative impacts associated with the deployment of each AST to make an informed decision. One tool often used to assist in the decision-making process is an economic analysis. An economic analysis is defined as “a systematic approach in determining the optimum use of scarce resources, involving comparison of two or more alternatives in achieving a specific objective under the given assumptions and constraints” (Business Dictionary, 2016). A BCA (a form of economic analysis) is the systematic process of calculating and comparing monetary benefits and costs for two purposes: (i) to determine if it is a sound investment (justification/feasibility), and (ii) to see how it compares with alternate projects (i.e., ranking/priority assignment; Transportation Economies Committee of the Transportation Research Board, n.d.). A cost-effectiveness analysis (CEA) is also a form of economic analysis where the benefits are not expressed in monetary gains, but in outcomes.

The process of an economic analysis involves relatively straightforward steps, as shown in Figure 1.

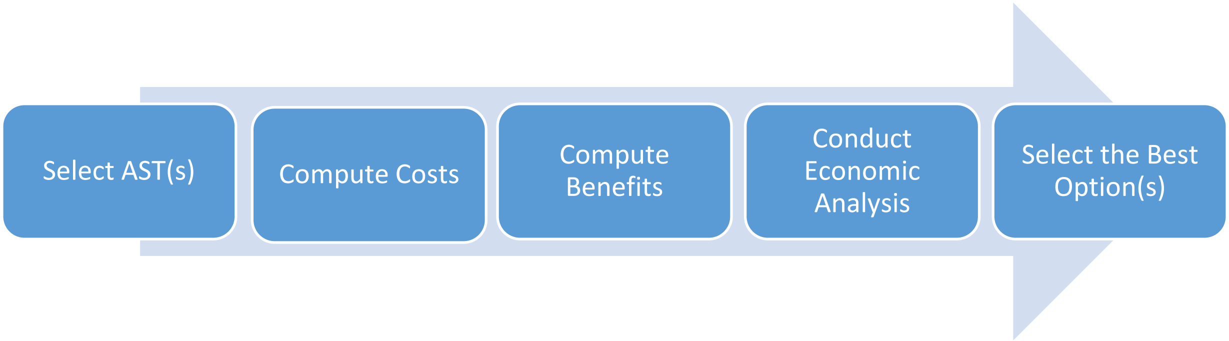

Figure 1. Economic analysis steps.

The associated AST deployment costs, benefits, and assumptions for each of the steps mentioned above are specific to the particular stakeholder group affected by the decision (i.e., carriers or society as a whole). Federal regulations require a societal BCA of an AST before any final decision is made (i.e., the impact of an AST-related regulation on all large trucks for which the regulation is being considered).

Societal benefits and costs are likely to differ from the benefits and costs for private carriers measured in the marketplace due to imperfections in analyses arising from: (i) external economies or diseconomies where actions by one party impose benefits or costs on other groups that are not compensated for in the marketplace, (ii) a monopoly power that distorts the relationship between marginal costs and market prices, and (iii) specific taxes or subsidies.

The present study focused on the evaluation of the expected societal costs and benefits originated by the deployment of LDW systems. This type of analysis is needed to evaluate the impact of new regulations through a regulatory analysis process (e.g., such as mandating a specific AST—in this case LDW systems—on trucks). Regulatory analysis requirements for the rulemaking process vary in terms of the regulating agency, rules the agency covers, and the "significant impact" of a proposed regulation. Currently, the most applied set of requirements includes those provided in Executive Order 12866 (1993), Executive Order 13563 (2011), and Office of Management and Budget (OMB) Circular A-4 (2003).

Executive Order 12866 (1993), *Regulatory Planning and Review*, requires "covered agencies" to conduct a regulatory analysis for "economically significant regulatory actions." Section 1 states,

> "In deciding whether and how to regulate, agencies should assess all costs and benefits of available regulatory alternatives, including the alternative of not regulating. Costs and benefits shall be understood to include both quantifiable measures (to the fullest extent that these can be usefully estimated) and qualitative measures of costs and benefits that are difficult to quantify, but nevertheless essential to consider. Further, in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefit." (Executive Order 12866, 1993) Section 1 (b) states that some costs and benefits are difficult to quantify, and agencies "should propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its cost." (Executive Order 12866, 1993)

A regulatory action is classified as significant if any of four parameters are met. In most cases, the trigger criterion is when an action will have an annual effect of $100 million on the economy or adversely affect the economy as a whole or certain sectors. For the present study, the research team conducted an economic analysis for LDW systems, which would independently affect the economy by $100 million.

Executive Order 13563 (2011) is supplemental and reaffirms the principles of Executive Order 12866 (1993). This directs agencies to propose or adopt regulations after conducting an analysis that shows the benefits justified the costs.

Circular A-4 (OMB, 2003) was designed "to assist analysts in the regulatory agencies by defining good regulatory analysis, called either 'regulatory analysis' or 'analysis' for brevity, and standardizing the way benefits and costs of Federal regulatory actions are measured and reported." (OMB, 2003) The circular specifies that "a good regulatory analysis should include the following three basic elements: (i) a statement of the need for the proposed action, (ii) an examination of alternative approaches, and (iii) an evaluation of the benefits and costs— quantitative and qualitative—of the proposed action and the main alternatives identified by the analysis." (OMB, 2003) With regard to analytical approaches, the circular states that BCAs provide a systematic framework for identifying and evaluating the likely outcomes of alternative regulatory choices and, when possible, a major rulemaking should be supported by both types of analysis.

To comply with Circular A-4 (2003) and Executive Orders 12866 (1993) and 13563 (2011), the OMB (2003) provides guidance on the steps that need to be completed, which include the following: (i) describe the need for the regulatory action, (ii) define the baseline alternative, (iii) select the analysis period, (iv) identify alternatives, (v) identify the consequences of regulatory alternatives, (vi) quantify and monetize costs and benefits, (vii) discount future benefits and costs, (ix) evaluate non-quantified and non-monetized benefits and costs, and (x) characterize uncertainty in benefits, costs, and net benefits.

NHTSA, the federal agency that governs new vehicle standards and also has the legal authority to mandate retrofitting of trucks, is in charge of completing the steps of the regulatory analysis process for the mandatory deployment of any AST. The present study completed the same steps described in Circular A-4 by using a formal economic analysis approach (OMB, 1992; 2003).

Conceptually, two options were formulated for the deployment of LDW systems. The first option assumed the agency did not issue any new rules regarding the adoption of LDW systems. These are the baselines against which costs and benefits were computed. The second option for LDW systems assumed rules were issued mandating the deployment of LDW systems. In addition, two sets of BCAs were performed for LDW systems. The first set of analyses assumed all large trucks would be equipped with LDW systems. In other words, these analyses assumed all new trucks would be equipped with LDW systems, and all old trucks would be retrofitted with LDW systems. The second set of analyses only assumed new trucks would be equipped with LDW systems. The following sections provide a brief description of the analysis period, technology and deployment costs, estimation of the target crash/injury base population, crash costs, identification of benefits as a reduction in crashes/injuries, discount rate, and expected economic indicators.

Analysis Period

According to the OMB (2003), the analysis period "should cover a period long enough to encompass all the important benefits and costs" (page 15). The time period should be long enough to consider the costs and most of the benefits in the project. Predicting the state of the art of LDW systems is, without doubt, a difficult task, especially taking into account the advancements made in the fields of connected and autonomous vehicles. There was consensus among the advisory panel that 20 years, with a 2018 base year, would be a reasonable analysis period. Selecting 2018 as the base year allowed for a lead implementation period of two years.

Technology and Deployment Costs

The costs associated with implementing LDW systems include all nonrecurring costs, such as the initial cost of the equipment and initial training, along with all recurring and operational costs, such as maintenance and additional training. These costs include everything that is needed to maintain the LDW system at operational levels. The cost of the installation and deployment of each LDW system per truck/driver per year is computed as:

$$CLDW_y = LDW_y + I_y + T_y + M_y$$

where $CLDW_y$ is the total cost of installation and deployment of LDW system per truck for year y; y is the year of the analysis period (0, 1, 2…n); LDW_y is the cost of the LDW system for year y; I_y is the initial installation cost of the LDW system for year y; T_y is the training cost for year y; and M_y is the maintenance cost for year y. It is important to note that some costs of the LDW system hardware are directly related to the number of trucks where the technology will be implemented, whereas other costs (e.g., training) are related to the number of drivers.

Technology Costs

The cost of the technology is usually the most significant cost in AST implementation. This holds true for LDW systems.

Different costs can be included in the computation of the technology costs: research and development, manufacturing setup for mass production, compliance and the marginal unit costs. For this report, the authors assumed these costs were built in to the initial cost of LDW systems (i.e., the technology provider allocated these costs over the life of the technology).

In general, three different approaches are used to identify the “real cost” of a new technology when considering a future regulation: a weight/cost teardown study, an optional equipment method, and an aftermarket computation. The weight/cost teardown study relies on experts to estimate how the technology is made, including the materials and labor involved, etc., to determine a variable cost for each piece of the AST, in this case the LDW system. A markup factor is applied for burden, fixed costs, etc. When there is not a weight/cost teardown study available, but the AST is already being sold as a stand-alone option on some vehicles, the optional equipment approach computes the “real cost of the technology” as the cost of the stand-alone option multiplied by a rule of thumb factor. Finally, the aftermarket equipment approach uses a subjective judgment based on how sophisticated the AST is, the number of competitors, and volumes produced to come up with the best price “estimation.”

When a weight cost analysis accounts for AST costs (i.e., research and development, corporate operations, marketing), the direct costs (materials and labor) are usually multiplied by a retail price equivalent. This formulation assumes the indirect cost of each technology is a fixed percentage of the AST, independent of the complexity of the technology. As a result, this analysis can underestimate the costs of less complex technologies and overestimate the cost of more complex ones. In addition, assumptions are made regarding the number of units produced by the industry when using a weight cost analysis. Thus, it is critical that the number of units for the base year of the BCA are similar to those used to compute the costs. After the literature review was completed, the research team found a weight cost analysis for LDW systems. A more detailed discussion of the cost components is discussed below.

In order to minimize the impact of the cost uncertainties, the research team used three costs: low, average, and high. The average costs were those recommended by the advisory panel and generally corresponded to the most representative cost provided by the industry. For example, the lower and higher costs (including installation) reported in published literature varied between $301 and $2,000. After careful consideration, the advisory panel recommended a cost of $1,000 as a base for the analysis. This cost was adopted as the average value. The lower cost was determined by the weight cost analysis, and the maximum cost corresponds to the maximum cost reported by the advisory panel.

The cost of LDW systems was related not only to the number of units produced, but also the manufacturer’s experience in producing the LDW system. Experience curves or learning curves can be used to estimate the potential reduction in costs as experience is gained in producing the technology. In general, one-factor learning curves are the most prevalent:

$$C_i = a\ x_i^{-b}$$

where C_i is the cost to produce the i^{th} unit, B is learning rate exponent, A is the coefficient (constant), and x_i is cumulative production or capacity through period i.

The curves represent the reduction in costs when a cumulative value of the production is reached. If a 92% learning curve is selected, it can be expected that costs are reduced 8% every time production is doubled.

Driver/Manager Training

Although training is not directly regulated, a BCA must identify all costs and benefits associated with a proposed alternative. Training the drivers and managers on the new technology's capabilities and how to use it is not only a reasonable assumption, but a cost that cannot be disregarded. The training required when deploying a new technology can be subdivided into initial and recurrent training. The initial training is applicable when the technology is installed on the truck. The recurrent training is conducted by the carrier each time there is a new driver or manager (or during a refresher training course). For this study, an initial training time (generally one hour) was assumed for LDW systems. Three factors influence the needed recurrent training in further years: the complexity of the LDW system, the driver attrition rate in the industry (assumed to be 100%), and the point at which the LDW system becomes integrated into basic safety training. To compute the technology and deployment cost for all trucks for year y, the costs were multiplied by the number of trucks where the LDW system will be installed/replaced and the number of drivers/managers who will receive training.

Truck Population

A critical part of any BCA is the identification of the number of vehicles where the technology will be implemented. The trucking industry is as diverse in operating characteristics as it is in the services it provides. Carriers are usually classified based on the size of the fleet, type of trucks, and type of operations and commodities they haul. There is not a unique classification system for trucks. In general, agencies classify trucks by the number of axles, their carrying capacity, or GVWR. The Federal Highway Administration's (FHWA's) Vehicle Inventory and Use Survey (VIUS) classifies trucks by their GVWR. As shown in Figure 2, this classification system includes eight classes ranging from 1 to 8.

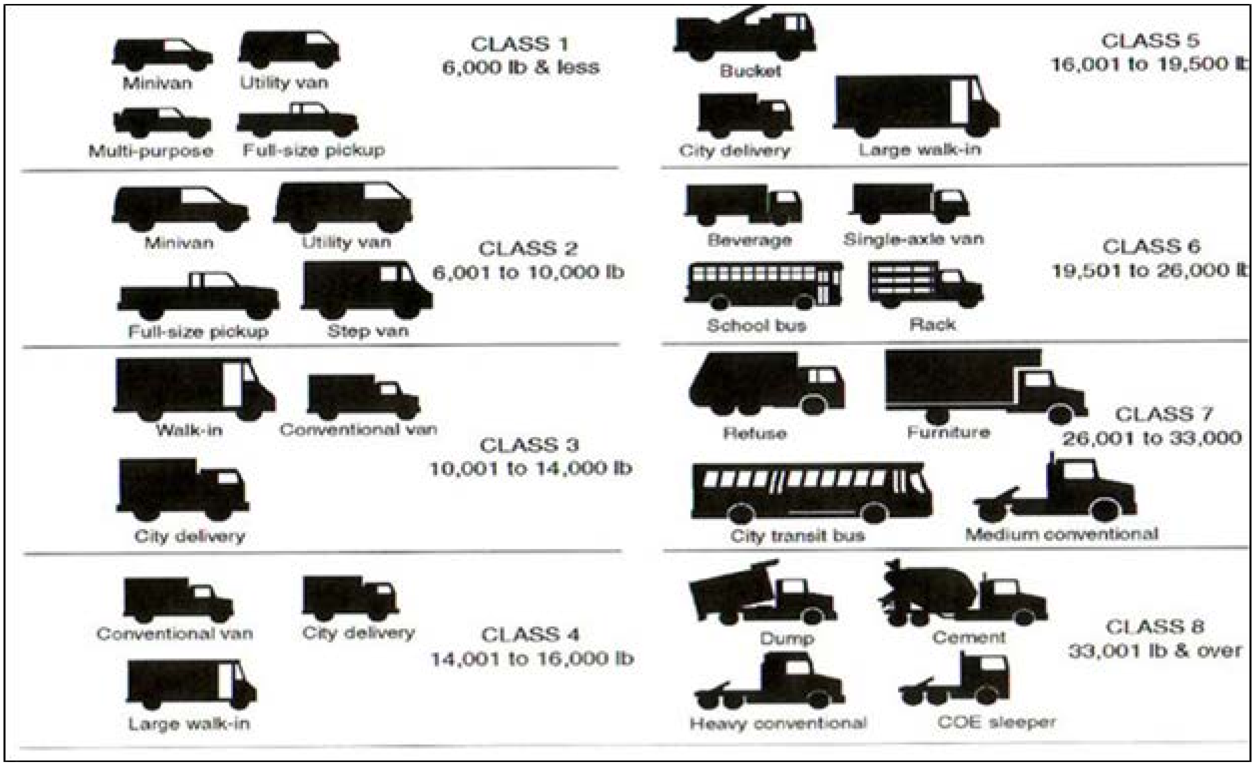

Figure 2. Truck classifications by gross vehicle weight.

Based on this classification, trucks also can be grouped as (i) "Light Duty" (class 1 and 2 vehicles), (ii) "Medium Duty" (class 3, 4, 5, and 6 trucks), and (iii) "Heavy Duty" (class 7 and 8 trucks). Per the recommendation of the advisory panel, the analyses in this study focus only on heavy duty trucks (i.e., class 7 and 8 truck-tractors and trailers) to match the vehicle populations found in previous studies identified in the literature review.

To identify the current and future truck target population, the research team relied on three sources of information: (i) the number of vehicles registered, (ii) the number of new vehicles that entered the market, and (iii) the number of vehicle miles traveled (VMT) per year for each vehicle category. FHWA's Office of Highway Policy Information regularly publishes Table VM1 (2014), which contains information regarding the number of vehicles registered and VMT for different types of vehicles. This table classifies vehicles as light vehicles, trucks, motorcycles, and buses. Trucks are further classified as single unit trucks (SUTs) and combination unit trucks (CUTs). SUTs include all class 3 to 8 single trucks with a GVWR of more than 10,000 pounds. CUTs include all class 7 and 8 trucks with a GVWR of more than 26,000 pounds that are designed to be used in combination with one or more trailers. Table 5 shows the number of registered vehicles, the total number of VMT, and the average annual VMT for SUTs and CUTs.

Table 5. Number of Registered Vehicles, VMT, and Average Annual VMT for SUTs and CUTs (adapted from Office of Highway Policy Information, 2014)

Year	Truck Single Unit 2 axle 6 tires or more			Combination Trucks		
	Registration	VMT (millions)	Average Annual VMT	Registration	VMT (millions)	Average Annual VMT
1990	4,487,000	51,901	11,567	1,709,000	94,341	55,202
1991	4,481,000	52,898	11,805	1,691,000	96,645	57,153
1992	4,370,000	53,874	12,328	1,675,000	99,510	59,409
1993	4,408,000	56,772	12,879	1,680,000	103,116	61,379
1994	4,906,000	61,284	12,492	1,681,000	108,932	64,802
1995	5,024,000	62,705	12,481	1,696,000	115,451	68,073
1996	5,266,000	64,072	12,167	1,747,000	118,899	68,059
1997	5,293,000	66,893	12,638	1,790,000	124,584	69,600
1998	5,414,000	67,894	12,540	1,831,000	128,159	69,994
1999	5,763,000	70,304	12,199	2,029,000	132,384	65,246
2000	5,926,000	70,500	11,897	2,097,000	135,020	64,387
2001	5,704,000	72,448	12,701	2,154,000	136,584	63,409
2002	5,651,000	75,866	13,425	2,277,000	138,737	60,930
2003	5,849,000	77,757	13,294	1,908,000	140,160	73,459
2004	6,161,000	78,441	12,732	2,010,000	142,370	70,831
2005	6,395,000	78,496	12,275	2,087,000	144,028	69,012
2006	6,649,000	80,344	12,084	2,170,000	142,169	65,516
2007	8,117,000	119,979	14,781	2,635,000	184,199	69,905
2008	8,228,000	126,855	15,417	2,585,000	183,826	71,113
2009	8,356,000	120,207	14,386	2,617,000	168,100	64,234
2010	8,217,000	110,738	13,477	2,553,000	175,789	68,856
2011	7,819,000	103,803	13,276	2,452,000	163,791	66,809
2012	8,190,000	105,605	12,894	2,469,000	163,602	66,262
2013	8,126,000	106,582	13,116	2,471,000	168,436	68,165
2014	8,329,000	109,301	13,123	2,577,000	169,830	65,897

As shown in Table 5, in 2014, there were 8,329,000 SUTs registered, which traveled a total of 109.3 billion miles, with an average of 13,123 miles per SUT. In the same year, there were 2,577,000 CUTs registered that traveled 169.8 billion miles, with an average per vehicle of 65,897 miles. Since 2010, the total VMT and the average number of miles per truck have experienced only small fluctuations, as shown in Figure 3. A closer look shows that the number of registered vehicles decreased after 2009 and it wasn’t until 2014 that the number reached levels similar to those in 2010.

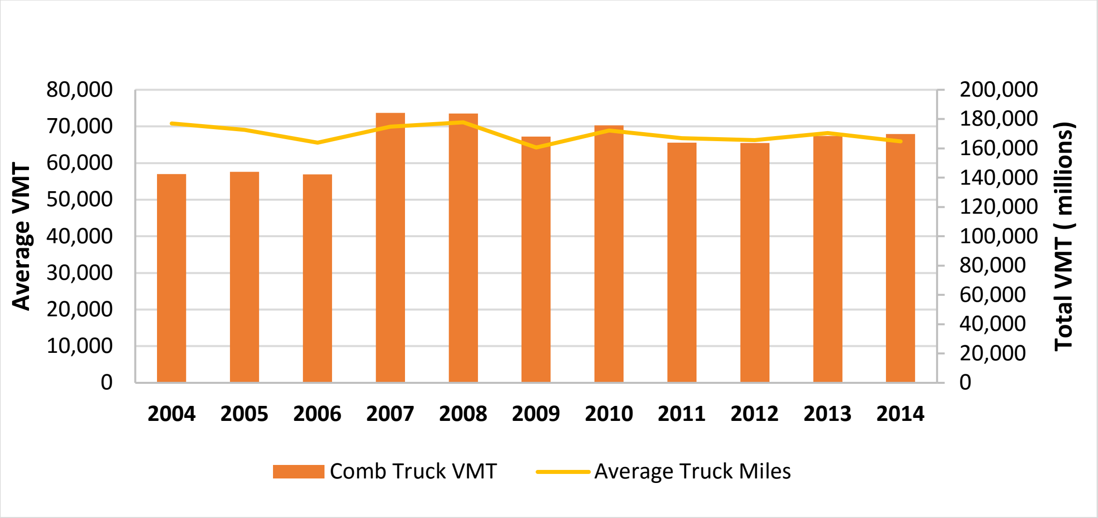

Figure 3. Total VMT (in millions) and average miles per CUT.

The number of miles traveled by each truck varies not only by the type of operation but also by the truck's age, with new trucks traveling the most. The VIUS provides the best estimate of the distribution of VMT based on the vehicle's age. The age of the trucks also varies by truck type and operation. Figures 4, 5 and 6 show the fraction of vehicles by age and type of operations. The highest percentage of CUT age in long-haul operations was 4 to 5 years, and the highest percentage of SUT age in long-haul operations was 11 to 12 years.

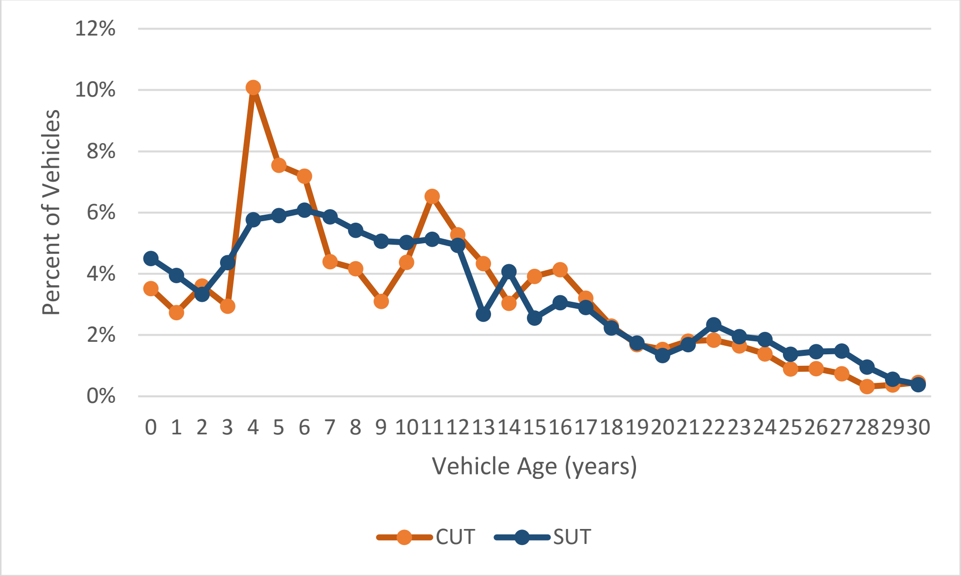

Figure 4. Percent of SUTs and CUTs by vehicle age.

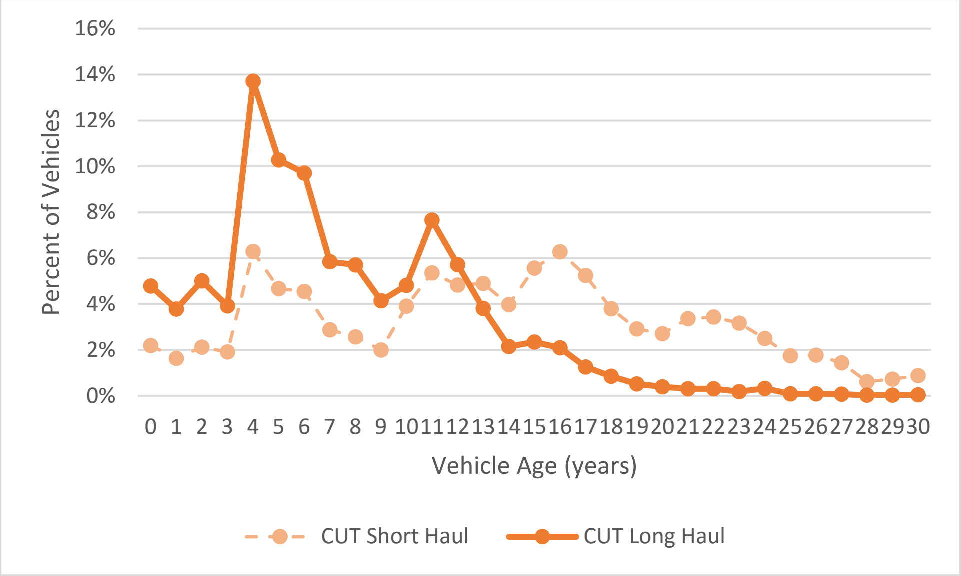

Figure 5. Percent of CUT age by operation type.

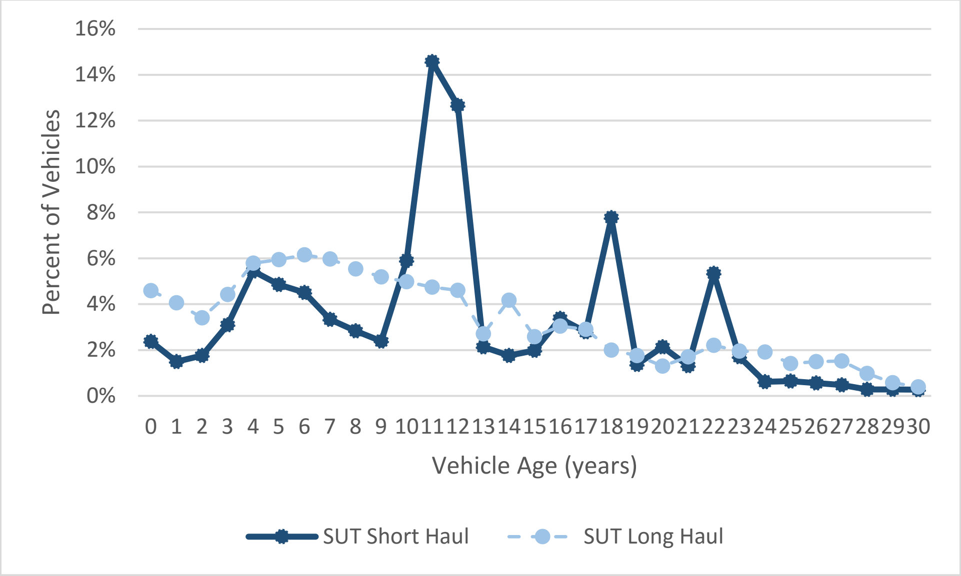

Figure 6. Percent of SUTs by operation.

Regarding future truck populations, the U.S. Energy Information Administration (2016) predicts an annual increase of 1.5% in the number of million VMT between 2016 and 2040 for trucks heavier than 10,000 pounds. Similarly, the American Trucking Associations' (2016) U.S. Freight Transportation Forecast to 2027 predicted that truck load volumes will grow 2% annually between 2016 and 2020 and then 1.6% per year until 2027. In addition to the number of vehicles registered, it is important to know the number of new trucks that will enter the market for each truck category. Table 6 shows the number of new trucks by GVWR that were sold in the U.S.

Table 6. New Retail Truck Sales by GVWR (Adapted from Davis, Diegel, & Boundy, 2016)

Year	New Retail Sales (Thousands)							
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
1990	3,451	1,097	21	27	5	38	85	121
1991	3,246	876	21	24	3	22	73	99
1992	3,608	1,021	26	26	4	28	73	119
1993	4,119	1,232	27	33	4	27	81	158
1994	4,527	1,506	35	44	4	20	98	186
1995	4,422	1,631	40	53	4	23	107	201
1996	4,829	1,690	52	59	7	19	104	170
1997	5,085	1,712	53	57	9	18	114	179
1998	5,263	2,036	102	43	25	32	115	209
1999	5,707	2,366	122	49	30	48	130	262
2000	5,965	2,421	117	47	29	51	123	212
2001	6,073	2,525	102	52	24	42	92	140
2002	6,068	2,565	80	38	24	45	69	146
2003	6,267	2,671	91	40	29	51	67	142
2004	6,458	2,796	107	47	36	70	75	203
2005	6,586	2,528	167	49	46	60	89	253
2006	6,136	2,438	150	50	49	70	91	284
2007	5,682	2,623	166	51	45	54	70	151
2008	4,358	1,888	135	36	40	39	49	133
2009	3,528	1,306	112	20	24	22	39	95
2010	4,245	1,513	161	12	31	29	38	107
2011	4,714	1,735	195	10	42	41	41	171
2012	5,164	1,811	223	9	55	40	47	195
2013	5,615	2,077	254	12	60	47	48	185
2014	6,209	2,275	264	13	67	52	54	220
2015	7,161	2,417	283	24	72	55	59	249

Classes 7 and 8 correspond to trucks heavier than 26,000 pounds, and the information does not differentiate between SUTs and CUTs. However, NHTSA estimates that on average, 80% of class 8 and 10% of class 7 trucks correspond to CUTs and the rest are SUTs. Since 2010, the number of new class 3 to 8 vehicles increased significantly, with an average of 47,800 new class 7 and 188,000 new class 8 trucks for the period 2010 to 2015. Dividing by the estimated proportion of class 7 and 8 CUTs, the average number of retail sales for CUTs has been 80,000 and 155,000 vehicles per year, respectively. However, since the beginning of 2016, it was predicted that heavy-truck demand in the previous years would begin to weaken (IHS Markit, 2016). Additionally, reductions between 29% and 39% on class 8 orders have been reported (Shedlock, 2016). Analysts point to an excessive number of new vehicles in stock, weakening pressure to replace older trucks, and a generally weak freight environment as potential reasons for this decline in sales.

Identify Safety Benefits as a Reduction in the Number of Crashes/Injuries/Fatalities

One of the main objectives in the study was to quantitatively evaluate the safety impact of ASTs (this report evaluates LDWs specifically). As described above, two options were formulated to assess the potential cost of LDW systems: no LDW system deployment and LDW system deployment. Circular A-4 requires a BCA and a CEA to evaluate the benefits and costs of the alternatives proposed. The BCA assigns a monetary value to the benefits and costs of the alternatives and uses economic indicators to evaluate the feasibility of implementing the specific alternative. The CEA, on the other hand, is expressed as a ratio where the denominator is a quantitative measure of the benefits and the numerator is the expected cost to be able to reach that benefit. For the BCA, the criterion is that the present and future value of the benefits must be greater than the present and future value of the costs. This can be expressed as the Net Value (benefit/costs greater than zero) or as a Benefit-Cost Ratio (BCR; benefit/cost greater than 1)

The CEA for vehicle safety is measured as equivalent fatalities or equivalent lives saved. The final goal is not only to justify the proposed alternative but to be able to select among different alternatives or proposed regulations to guarantee society the best allocation of the limited resources.

In the BCA, the safety benefits of LDW systems were computed as the difference in number of crashes/number of injury severity types (fatality equivalent) for both options (without mandatory LDW system deployment and with mandatory LDW system deployment) for each year over the period of the analysis:

$$AACC = \sum_{i,j} (N_{jio} - N_{ji1}) * CC_{ji}$$

where *AACC* was the average annual cost; j was the type of crash/injury the LDW system was expected to prevent; i was the severity of the crash or type of the injury; N_{ji0} was the number of crashes/injuries by severity i without mandatory LDW system deployment; N_{jiN} was the number of crashes/injuries by severity i with mandatory LDW system deployment; and CC_{ji} was the crash cost for crash type j and severity i. To identify the number of crashes that can be prevented by the deployment of LDW systems, the research team identified the types of crashes that were preventable by LDW systems and selected the efficacy rate of LDW systems.

Types of Crash/Crash Scenarios Preventable by Lane Departure Warning Systems

LDW systems have the capability of preventing only some types of crashes/crash scenarios. Specifically, the installation of an LDW system is expected to reduce large-truck single vehicle roadway departures, sideswipes, opposite sideswipes, and, to a much lesser extent, head-on collisions. In general, the crashes preventable by LDW systems exclude crashes when the driver is incapacitated or crashes due to vehicle malfunctions (e.g., faulty brakes). To identify the type and number of preventable crashes, the research team identified the different variables and pre-crash scenarios in different crash databases.

For this study, the advisory panel recommended that LDW systems only be considered effective at preventing large-truck single vehicle roadway departures, sideswipes, and opposite direction sideswipes crashes. Any future descriptions of crashes prevented by LDW systems refer to these crash types only. Thus, when indicating reduction in crashes for LDW systems, we are only referring to reduction in large-truck single vehicle roadway departures and sideswipes.

Crash Databases

When societal impacts are considered, the target population refers to the total number of reported crashes (i.e., by crash type, by crash severity, by injury severity) by vehicle type that can be affected by the deployment of LDW systems. To this end, national crash databases are used as a tool to identify the target population and its subgroups. These crash databases include the FARS, GES, and the Motor Carrier Management Information System (MCMIS). The FARS database is usually recommended to identify the total number of fatal crashes and fatalities. The GES database has the limitation that it is an estimation of nonfatal injury crashes and property damage only (PDO) crashes. The MCMIS database includes truck crashes that are reported to FMCSA by the states and has the limitation that, to be reported, the crash at a minimum needs to be a tow-away crash, involve a fatality, or cause an injury that results in transportation to a hospital.

The research team decided to use the FARS database to determine the number of fatal crashes and their associated fatalities and injuries, and the GES database as an estimation for injury and PDO crashes. The GES database was also used to estimate the number of injuries as a result of injury crashes. Queries were developed for LDW systems and information was extracted for different vehicle types for a period of six years (2010 to 2015; see Appendix B for the list of crash filtering criteria).

When filtering the GES and FARS crashes, the research team carefully considered the scenarios where LDW systems may have prevented the crash. Additionally, the research team used the following GES/FARS variables to further limit crashes that may have been prevented by LDW systems: pre-event movement, critical event, and first harmful event. Finally, all crashes that involved the use of alcohol or drugs by the large truck driver were eliminated.

The research team generated the two matrixes shown in Table 7 and Table 8. The GES and FARS used a vie-point KABCO severity scale to define the severity of injuries for all persons involved in a crash. Since many crashes have more than one injury, the worst severity was used to characterize the severity of the crash. Values for the KABCO scale are as follows: K = fatal; A = incapacitating injury; B = non-incapacitating injury; C = possible injury; O = no injury.

Table 7. Total Number of Crashes by Crash Type and Maximum Injury Severity (Example)

Body Type	Fatal Crashes	Injury Crashes	PDO Crashes
	X	X	X
	X	X	X
	X	X	X

Table 8. Number of Injured Persons for Each Crash Type and Injury Severity (Example)

Crash Type	Crashes	Police Reported Number of Persons Injured						
		K	A	B	C	O	U	PDO

The number of crashes and injuries shown in tables 7 and 8 corresponds to crashes that may be prevented by LDW systems if the efficacy rate is 100%. In order to realistically estimate the number of crashes that may be prevented by LDW system deployment, the LDW system efficacy rate must be considered.

Efficacy of Lane Departure Warning Systems

The efficacy rate of LDW systems corresponds to their capability to reduce the collision probability and/or severity of the crash types prevented with the technology. Efficacy is usually expressed as a percentage or reduction in number of crashes/fatalities/injuries, or as an expected crash rate (crashes per VMT). Independent of the method of measuring effectiveness, the efficacy rate is usually expressed as a range and not as a specific value. For the present study, the advisory panel selected an efficacy range. Thus, economic indicators will be presented for the lower and higher efficacy rates. It is important to note that most of the studies in the literature review did not differentiate the efficacy rate by the severity of the crash (fatal, different type of injuries, or property damage). To this end, the research team applied the same efficacy rate to fatal crashes, injury crashes, type of injuries, and PDO crashes. The authors note that real-world effectiveness against different severities of injuries may differ, but data limitations precluded development of separate efficacy estimates for LDW systems at the time of this study.

Expected Number of Crashes/Injuries/Fatalities Preventable by Lane Departure Warning Systems

The number of preventable crashes by crash type and injury severity for the base year was computed as:

$$N_{jibase(No\ LDW-LDW)} = \sum_{y}(N_{jiy}) * \frac{1}{y} * LDW_{effji} * (GR)_{bas}$$

where, N_{jibase} was the number of type j, category i crashes preventable by an LDW system for the base year; crash type j corresponds to the specific type of crash avoided by the technology; y was the number of years of crash data; N_{jiy} was the total number of type j, category i crashes preventable for year y by an LDW system; LDW_{effj} was the efficacy of an LDW system for crash j, category i; and GR_{bas} was a growth factor (if any) that was applied due to the lead time.

Change of Crash Frequency Over Time

It is generally accepted that there is a direct relationship between the exposure to traffic and the number of crashes. If all conditions remain equal, the number of crashes in a fleet population will increase if the number of vehicles or the mileage increases. However, it is also important to recognize that advancements in vehicle and road safety will reduce the number of crashes. Unfortunately, the latest statistics have shown an increase in the number of crashes despite those improvements and without an increase of the VMT. From 2004 to 2009, there were significant reductions in the number of crashes (likely due to the recession). During that period, large-truck fatal and injury crashes declined 33% and 37%, respectively. However, the situation reversed during the period 2010 to 2015 (when the economy improved), as shown in Table 9.

Table 9. Fatal, Injury, and PDO Crash Rates from 2010 to 2015 (Data from 2010-2015 GES)

	Fatal	Injury	PDO	VMT	Fatal rate	Injury rate	PDO rate
2010	3,271	56,000	207,000	286,527	1.14	19.54	72.24
2011	3,365	60,000	210,000	267,594	1.26	22.42	78.48
2012	3,486	73,000	241,000	269,207	1.29	27.12	89.52
2013	3,554	69,000	254,000	275,017	1.29	25.09	92.36
2014	3,424	82,000	326,000	279,132	1.23	29.38	116.79
2015	3,598	83,000	328,000	279,844	1.29	29.65	117.21

As a result of discussions with the advisory panel, a conservative approach (fewer crashes resulting in fewer benefits) was chosen. This approach, which assumed the number of crashes or the rate of crashes would remain constant at the 2004–2009 baseline average, would likely produce a conservative estimate of benefits. In other words, this approach provided lower cost-effectiveness estimates to reflect the LDW system possibilities with lower crash rates.

Crash Costs

Components of the societal or public cost of truck crashes included costs associated with property damage, increases or changes in emissions, and personal costs related to fatalities or injuries, medical costs, lost productivity due to injuries, and emergency services. The Value of Statistical Life (VSL) attempts to measure the value that consumers place on their lives as computed by the price that they are willing to pay to avoid death. Although VSL is a good indicator of the cost of a fatality, the reality is that most of the crashes involved only injury victims or no injuries at all. To estimate the cost of injuries and the different type of injuries, the same willing-to-pay studies can be used to estimate the quality adjusted life years (QALYs). This indicator uses a value of 1 for perfect health in a good year and a value of 0 when death occurs. These costs do not cover the unexpected costs that arise from the injury related to medical costs, legal costs, emergency services, congestion costs, emissions, and/or property damage. The deterioration of good health when someone suffers an injury is measured by estimating the QALYs. QALYs is a function of the VSL and has been used in previous studies, using an updated VSL value and the Employment Cost Index.

Regarding the VSL monetary value, the U.S. DOT annually publishes the *Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses* (USDOT, 2015). This document provides guidance on the revised VSL, indicates how the VSL needs adjustment, and determines how to account for uncertainties. Because it is expected that safety regulations affect a broad cross section of people, the U.S. DOT considers only a single nationwide VSL regardless of age, income, the mode of travel, or nature of risk. The latest Guidance, issued in 2015, establishes a VSL economic value of $9.4 million (base year 2014).

For this study, FMCSA provided the research team with new cost estimates (soon to be released) of crashes per victim and cost per crash per truck. These costs are in 2014 dollars with a VLS value of $9.4 million. To update the cost, NHTSA recommended using the consumer price index (CPI). This index represents changes of all goods and services purchased for consumption by urban households. To this effect, the Bureau of Labor Statistics provides the CPI inflation calculator that uses the average CPI for a given calendar year. The CPI ratio for 2015 to 2014 was 1. Thus, the values provided by FMCSA were considered the values to use in the BCA.

As shown in Table 10, the average cost of a fatal CUT crash was estimated as $11,313,000 (in 2014 dollars), $11,175,000 of which was the monetized QALY component. The remaining $138,000 comprised medical costs, emergency services, property damage, lost productivity from roadway congestion, environmental costs, and fuel consumption. Similarly, a CUT injury crash had an average cost of $540,000. This included a monetized QALY of $476,000, plus $64,000 for medical costs, emergency services, and property damage. These values correspond to an average number of 1.192 fatalities per fatal crash and an average number of 1.38 injuries per injury crash.

Table 10. Average Crash Cost by Crash Severity for CUTs

Severity	Average Cost
All	$383,000
Fatal	$11,313,000
Injury	$540,000
Unknown and No Injury	$117,000

In this study, the authors used the disaggregation of crash costs by severity, as the number of fatalities and injuries differed among the total crashes and the specific crash types (see Table 11). For example, the cost of an incapacitating or serious injury resulted in $52,100 in medical costs, $400 in emergency services, and $853,600 in QALY. Similar to the Maximum Abbreviated Injury Severity (MAIS) scale described below, the VSL fraction provided a coefficient to estimate (when multiplied by the VSL) the cost of an injury as a fraction of a fatality.

Table 11. Average CUT Crash Cost per Victim by Injury Severity

Severity	Medical Costs	Emergency Services	VSL Fraction	Monetized QALY
Fatality	$41,600	$1,300	1	$9,400,000
Incapacitating Injury	$52,100	$400	0.0908	$853,600
Non-incapacitating Injury	$18,000	$200	0.0298	$279,800
Possible Injury	$11,500	$200	0.0196	$184,400
Unknown and No Injury	$800	$100	0.0047	$43,800
Injury, Severity Unknown	$6,600	$200	0.0124	$117,000

Similarly, an injury crash results, on average, in $20,000 in property damage, $43,000 in lost productivity and roadway congestion, and $3,000 in environmental costs and fuel as shown in Table 12.

Table 12. Average Cost by Crash Severity for Property Damage, Lost Productivity and Roadway Congestion, and Environmental Costs and Fuel

Type of Crash	Property Damages	Lost Productivity Roadway Congestion	Environmental Cost and Fuel
All	$11,000	$14,000	$1,000
Fatal	$20,000	$43,000	$3,000
Injury	$20,000	$16,000	$1,000
Unknown and No Injury	$8,000	$13,000	$1,000

Expected Number of Equivalent Lives Saved

Circular A-4 (2003) states that when conducting a regulatory analysis, agencies should use both BCA and CEA. The computation of the number of lives saved by each AST constitutes an excellent tool to compare each AST's efficacy. The circular describes CEA as a way "to identify options that achieve the most effective use of the resources available without requiring monetization of all of relevant benefits or costs" (pp. 11). Nonfatal injuries as a result of crashes vary widely in severity and probability, but still result in losses of the quality of life and reduction of income. Thus, capturing the "value" of these injuries is essential to conducting a CEA. As mentioned before, the VSL attempts to capture the additional cost that individuals are willing to pay for improvements in safety (reduction of risks), that in aggregate reduce the number of fatalities by one.

To translate the different nonfatal injuries to "equivalent fatalities," the U.S. DOT rated each type of accidental injury on a scale of QALYs in comparison with the alternative of perfect health. Scores were then aggregated using the Abbreviated Injury Scale (AIS), and as a result, each MAIS is associated with a coefficient that can be applied to the VSL as a corresponding fraction of a fatality, as shown in Table 13 (Spicer & Miller, 2010). These values, expressed as a fraction of VSL, can be used to convert the number of injuries to equivalent fatalities.

Table 13. MAIS Scales/Fatality Fraction

MAIS Scale	Severity	Fraction of VSL
1	Minor	0.03
2	Moderate	0.047
3	Serious	0.105
4	Severe	0.266
5	Critical	0.593
6	Unsurvivable	1

KABCO and AIS Scales are not directly related (i.e., an injury observed and a reported crash could be more or less severe than originally reported). Thus, it was necessary to apply a KABCO/AIS Data Conversion Matrix to convert the number of injuries under the KABCO system to the MAIS number (Table 14).

Table 14. KABCO/MAIS Data Conversion Matrix

KABCO	O	C	B	A	K	U	Unknown if Injured
MAIS	No Injury	Possible Injury	Non-incapacitating	Incapacitating	Killed	Injury Severity Unknown	
0	0.9254	0.23437	0.08347	0.03437	0.000	0.21538	0.43676
1	0.07257	0.68946	0.76843	0.55449	0.000	0.62728	0.41739
2	0.0198	0.06391	0.10898	0.20908	0.000	0.10400	0.08872
3	0.00008	0.01071	0.03191	0.14437	0.000	0.03858	0.04817
4	0.0000	0.00142	0.0620	0.03986	0.000	0,00442	0.00617
5	0.00003	0.00013	0.00101	0.01783	0.000	0.01034	0.00279
Fatality	0.0000	0.000	0.000	0.000	1.000	0.000	0.000
Probability	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The usefulness of this matrix can be seen with crashes classified as non-incapacitating (i.e., KABCO scale "B"). Using the MAIS matrix reveals that only 8.3% of these crashes would be classified as MAIS 0 (i.e., no injury), and 76.8% of crashes would be classified as MAIS 1 (i.e., minor injury), 10.8% would be classified as MAIS 2, etc. Additionally, the total of MAIS 1 injuries was the sum of 7.257%, 68.946%, 76.843%, 55.449%, 62.728% and 41.739% of the total number of the O, C, B, A, and U categories, respectively. This study obtained the number of equivalent fatalities that may be prevented by the installation of LDW systems by multiplying the crashes by the relative fatality ratios shown in Table 13. This matrix also can be used to compute the crash costs by multiplying the relative fatality ratios per the VSL, and adding the cost of property damage, lost productivity from roadway congestion, and environmental cost and fuel. Although the authors calculated both of these values as a verification measure, the crash costs reported are those obtained from FMCSA, as previously noted (soon to be released).

Annual Incremental Cost Analysis

The standard practice described above assumes a constant rate of crashes over the analysis period reflecting the useful life of the LDW system/vehicle. The costs of crashes for each year are discounted to reflect the net present value (NPV) of those yearly benefits on the base year. Similarly, the cost of the installation, maintenance, and training are also discounted by the same factors. This discount factor is discussed in more detail below.

The period between when an LDW system is installed and when the crash may be prevented follows an empirical distribution that indicates the safety benefits can occur at any point during the vehicle's lifetime. If it can be assumed a constant number of vehicles experience a constant number of crashes, the previous methodology may be refined. To capture this lag on time, it can be assumed that the distribution of the VMT can be used as a proxy for the distribution of crashes (see Table 15). A survival probability may be used to represent a large number of vehicles across the population in question. As a result, the probability of the crash occurring will depend on the percent of miles traveled per each year of life multiplied by the survival probability. Furthermore, the cumulative percentage of VMT should be used when analyzing the number of vehicle life years. A more detailed description of this procedure can be found in Kirk (2009).

Table 15. Survival Probability and Annual VMT

Year	Total Annual Miles Traveled	Survivability	Weighted Miles Traveled	% Total Weighted Miles	Raw Discount Rate		Discount Rate	
					3%	7%	3%	7%
1	240,737	1	240,737	0.10	0.985329	0.966736	0.097713	0.09587
2	226,110	0.993	224,527.2	0.09	0.95663	0.903492	0.08848	0.083565
3	212,378	0.981	208,342.8	0.09	0.928767	0.844385	0.07971	0.072468
4	199,486	0.9642	192,344.4	0.08	0.901716	0.789145	0.071446	0.062527
5	187,381	0.9432	176,737.8	0.07	0.875452	0.737519	0.063737	0.053695
6	176,017	0.9181	161,601.2	0.07	0.849954	0.68927	0.056581	0.045884
7	165,346	0.8894	147,058.7	0.06	0.825198	0.644177	0.049989	0.039023
8	155,327	0.8575	133,192.9	0.05	0.801163	0.602035	0.043957	0.033032
9	145,919	0.823	120,091.3	0.05	0.777828	0.562649	0.038479	0.027834
10	137,085	0.786	107,748.8	0.04	0.755173	0.525841	0.033519	0.02334
11	128,789	0.7473	96,244.02	0.04	0.733178	0.49144	0.029068	0.019484
12	120,999	0.7071	85,558.39	0.04	0.711823	0.45929	0.025088	0.016187
13	113,683	0.666	75,712.88	0.03	0.69109	0.429243	0.021554	0.013388
14	106,813	0.6244	66,694.04	0.03	0.670961	0.401161	0.018434	0.011021
15	100,360	0.5826	58,469.74	0.02	0.651419	0.374917	0.01569	0.00903
16	94,300	0.5411	51,025.73	0.02	0.632445	0.35039	0.013294	0.007365
17	88,609	0.5003	44,331.08	0.02	0.614025	0.327467	0.011213	0.00598
18	83,263	0.4604	38,334.29	0.02	0.59614	0.306044	0.009414	0.004833
19	78,242	0.4217	32,994.65	0.01	0.578777	0.286022	0.007867	0.003888
20	73,526	0.3845	28,270.75	0.01	0.56192	0.267311	0.006544	0.003113
21	69,096	0.349	24,114.5	0.01	0.545553	0.249823	0.005419	0.002482
22	64,935	0.3152	20,467.51	0.01	0.529663	0.23348	0.004466	0.001969
23	61,026	0.2835	17,300.87	0.01	0.514236	0.218205	0.003665	0.001555
24	57,354	0.2537	14,550.71	0.01	0.499258	0.20393	0.002993	0.001222
25	53,905	0.226	12,182.53	0.01	0.484717	0.190589	0.002433	0.000956
26	50,664	0.2004	10,153.07	0.00	0.470599	0.17812	0.001968	0.000745
27	47,620	0.1769	8,423.978	0.00	0.456892	0.166468	0.001585	0.000578
28	44,759	0.1554	6,955.549	0.00	0.443584	0.155577	0.001271	0.000446

Year	Total Annual Miles Traveled	Survivability	Weighted Miles Traveled	% Total Weighted Miles	Raw Discount Rate		Discount Rate	
					3%	7%	3%	7%
29	42,072	0.1359	5,717.585	0.00	0.430665	0.145399	0.001014	0.000342
30	39,547	0.1183	4,678.41	0.00	0.418121	0.135887	0.000806	0.000262
31	37,175	0.1025	3,810.438	0.00	0.405943	0.126997	0.000637	0.000199
32	34,945	0.0884	3,089.138	0.00	0.394119	0.118689	0.000502	0.000151
33	32,851	0.0759	2,493.391	0.00	0.38264	0.110924	0.000393	0.000114
34	30,883	0.0649	2,004.307	0.00	0.371495	0.103668	0.000307	8.56E-05
35	29,033	0.0552	1,602.622	0.00	0.360675	0.096886	0.000238	6.4E-05
Total	3,530,235		2,427,562		0.35017		0.809473	0.642697

To determine the weighted discount factors, the authors multiplied the fraction of the weighted VMT that occurred in each year by the discount factors in that year. For example, the weighted discount factor for a vehicle 10 years old and a 3% discount rate was 0.0310. This was obtained by multiplying the fraction of total weighted VMT (0.04) by the proportion discount factor associated with a 3% discount rate at year 10 (0.7552). Figure 7 shows the plotted undiscounted and discounted distribution of the weighted VMT versus the vehicle age.

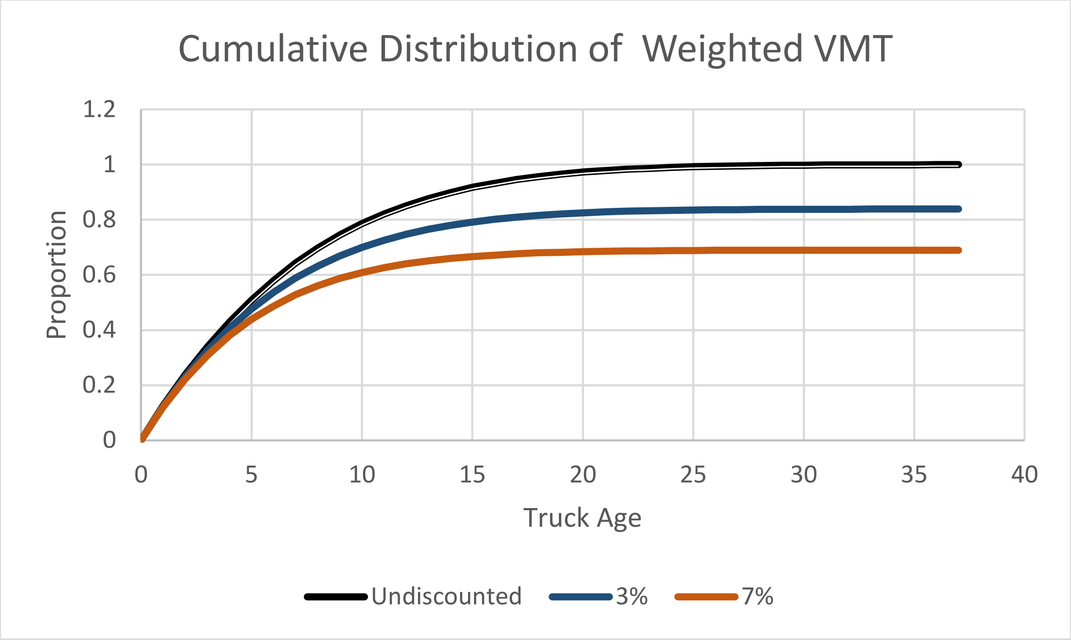

Figure 7. Distribution of weighted VMT by survival rate as a surrogate of probability of crash occurrence.

Figure 7 shows that the undiscounted distribution has a top value of 1 and the discounted distribution maximum value, or lifetime discount factor, was 0.809 for a 3% discount rate and 0.642 for a 7% discount rate. These discounts represent the lag between the investment and the return. Figure 7 also shows that all the undiscounted and discounted distributions flatten around 20 years. If a constant number of vehicles and crashes is assumed, this equals the linearized distribution for an analysis period of 20 years.

Benefit-Cost Analysis Measures

This section describes the BCA measures developed to compare the benefits and costs in implementing LDW systems, including NPV, BCR, and sensitivity analysis.

Discount Rate

The discount rate is the rate of discounts, in the present value (PV), of the cost and benefits in any future year. The discount rate is used to compute the PV of future costs and benefits using the following formula (OMB, 2003):

$$PV = \frac{P_y}{(1+r)^n}$$

where PV is the present value of the amount invested; P_y is the dollar value of the future amount in time y; r is the discount rate; and y is the year in which P_y is computed (0, 1, … n). The higher the discount rate, the lower the PV in future costs and benefits. A real discount rate of 7% will be used per OMB (2003) recommendations. The OMB (2003) also recommends conducting a sensitivity analysis to show the impact of discount rate variation (using 0%, 3%, and 7%).

Net Present Value

The NPV is the current value of all projected PV benefits minus the sum of all projected PV costs. If the NPV is greater than zero (“0”), it can be assumed that equipping the truck with an LDW system is a good alternative. The NPV was calculated as follows (OMB, 1992; Pearce et al. 2006):

$$NPV = \sum_{y=1}^{Y} \frac{(Benefits_y - Cost_y)}{(1+r)^y}$$

where $Benefits_y$ are the expected benefits for the year y and were computed as:

$$Benefits_y = Crash\ Costs_{y0} - Crash\ Costs_{y1}$$

$Crash\ Costs_{y0}$ were the expected crash costs for the year y without mandatory deployment of LDW systems, and $Crash\ Costs_{y1}$ were the expected crash costs for the year y with mandatory deployment of LDW systems. The crash costs will be divided by VSL. $Cost_y$ was the expected cost for the year y and was computed as:

$$Costy = Cost_{y1} - Cost_{yo}$$

where $Cost_{y1}$ is the expected total cost of installing and operating the LDW system for the year y with mandatory deployment; $Cost_{y0}$ is the expected total cost of installing and operating the LDW system for the year y without mandatory deployment; r is the discount rate; and y is the year in which C_y is computed (0, 1, …n).

Benefit–Cost Ratio

The BCR was calculated as the NPV of benefits divided by the NPV of costs. If the BCR exceeds "1," the benefits of installing the LDW system are higher than the costs incurred in buying, installing, and maintaining the LDW system. The BCR was calculated as follows (OMB, 2003):

$$BCR = \frac{\sum_{y=1}^{n} \frac{B_y}{(1+r)^n}}{\sum_{y=1}^{n} \frac{C_y}{(1+r)^n}}$$

where *BCR* is the BCR in implementing LDW systems over a period of analysis *n* assuming a rate of return *r*; B_y is the benefit associated with implementing LDW systems in year *y*; *Cy* is the cost associated with implementing LDW systems in year *y*; *r* is the discount rate; and *n* is the number of years for the analysis period.

Cost-Effectiveness Analysis

The cost-effectiveness (CE) was calculated as the total number of equivalent fatalities that would be avoided by the installation and deployment of LDW systems divided by the NPV of costs. The CE was calculated as follows (OMB, 2003):

$$CE = \frac{\sum_{y=1}^{n} \frac{NC_y *}{(1+r)^n}}{\sum_{y=1}^{n} \frac{EF_y}{(1+r)^n}}$$

where *CE* was the cost of each fatality prevented by implementing LDW systems over a period of analysis *n* and a rate of return *r*; *NCy* was the net cost associated with implementing LDW systems in year *y*; EF_y was the benefit associated with implementing LDW systems (in this case equivalent saved lives) in year *y; r* was the discount rate; and *n* was the number of years for the analysis period.

$NCost_y$ is the expected net cost for the year *y* and was computed as:

$$NCosty = Cost_{y1} - Cost_{yo} - Crash\ Cost_{-VSLy0} + Crash\ Cost_{-VSL1}$$

Crash Cost $_{-VSLy}$ was the crash cost minus the monetized VLS component.

Sensitivity Analysis

A sensitivity analysis was performed to examine how changes in the assumptions affected the outputs of the BCA or robustness of the results. The sensitivity analysis was conducted using $5,304,000 and $13,260,000 for low and high estimates of VSL values, and discount rates from 3% to 7% were applied.

Results

This section details the benefits and costs of LDW systems and the results of the BCA.

Technology and Deployment Costs per Truck

In a BCA, the costs associated with implementing LDW systems in each truck must include all the recurring and nonrecurring costs. Costs can also be subdivided into hardware, training, and maintenance. The hardware costs include the costs associated with installing the system in an in-service truck or the added cost to the value of a new truck. Additionally, the hardware may not have the same service life of the truck, which may necessitate replacing the hardware. The training costs refer to any kind of personnel training needed to ensure that the system is being used appropriately. The maintenance costs include annual costs required to keep the system operative. In general, the LDW system's normal maintenance costs are very small and may be covered in the routine maintenance of the truck.

As discussed in the literature review, the published literature estimated LDW system initial installation costs to range from $301 to $2,000 per truck. However, Ricardo Inc. (2013) identified much lower system costs in two large-truck LDW systems: Takata Safe TraK and Iteris/Bendix AutoVue. To conduct the study, the authors identified/computed all the elements that were needed to retrofit a truck with each LDW system. Ricardo Inc. (2013) also assumed a volume of 250,000 units per system and reported costs using 2012 dollars. Finally, the authors assumed all components were sold by a Tier 1 supplier to a vehicle original equipment manufacturer (OEM). To account for indirect costs (e.g., OEM engineering design and development cost, OEM tooling and factory capital costs, warranty recall cost and dealer markup), the OEM costs were multiplied for a Retail Price Equivalent factor of 1.42.

The consumer costs identified by Ricardo Inc. (2013) are shown in Table 16 and ranged from $195 to $285 per truck. Using the gross domestic product deflator, the 2015 equivalent cost for the LDW systems ranged from $200 to $292 per unit.

Table 16. Summary of Costs for LDW Systems (Ricardo Inc., 2013)

Components	***Takata Safe TraK***		***Iteris/Bendix AutoVue***	
	Without optional speaker	**With optional speaker**	**Without optional speaker**	**With optional speaker**
Camera Module	$103	$24	$103	$24
Control Module	N/A	$132	N/A	$132
Switch	$3	$3	$3	$3
Speakers	N/A	N/A	$13	$13
Brackets/Trim	$2	N/A	$2	N/A
Wiring and Electrical	$20	$20	$20	$20
Installation	$9	$9	$10	$10
Impact				
OEM Costs	$137	$188	$151	$201
Consumer Cost	$195	$267	$214	$285

However, Ricardo Inc. (2013) did not account for the labor required to install and calibrate the LDW systems. The research team estimated this would require an additional two hours of technician labor. The technician's time was computed using the 50th percentile salary from the Bureau of Labor Statistics (BLS; 2015), job category Large Truck and Mobile Equipment Service Technicians ($22.65 per hour in 2015). Fringe benefits and overhead costs (42% and 27%, respectively, based on the BLS' Employer Cost for Employee Compensation; BLS, 2016) were added to this hourly wage, resulting in a total cost per hour of $40. Thus, the research team estimated the 2015 total cost of each LDW system to be $366.71.

The results found in Ricardo Inc. (2013) and the published literature review were significantly different. Ricardo Inc. (2013) acknowledged the single service part quote obtained from a dealer may be more than 40 times that of the costs found. Furthermore, the authors also suggested the cost differences may be partially explained by the differences in "real volumes" of LDW system units produced in 2012 compared with the 250,000 annual volume units used in the study. Based on Ricardo Inc.'s (2013) results, the research team included a $500 lower-bound estimate of LDW systems, and used the advisory panel's $1,000 cost estimate as the average estimate of LDW systems.

For this study's societal BCA, the research team assumed the cost of the technology was incurred when the technology was installed or repaired, independently of the financial mechanism used by the carriers to acquire the technology. The service life of the technology was assumed to be 10 years with replacement costs equaling the cost of new technology.

The previous literature found that LDW system training time varied from 15 minutes to two hours. An average training time of one hour per driver was used in the BCAs. Based on previous studies (e.g., Hickman et al., 2013), this analysis assumed there was one driver per truck. The cost of the driver's time was computed using the 50th percentile driver salary from the BLS ($19.36 per hour for 2015; 2016) plus fringe and overhead costs. The fringe benefits were obtained from the Employer Cost for Employee Compensation (57%; 2016). The overhead cost was based on industry data gathered by Berwick and Farooq (2003).

During the course of this study, carriers mentioned that some drivers received training more often. The research team realized that some carriers may provide more frequent training, while other carriers may not train as often. To account for this potential difference, a sensitivity analysis was conducted to account for differences in training hours, driver retention rate, and discount rates (see Figure 8). This sensitivity analysis showed the impact on the total cost of LDW systems with an increase in the number of training hours from one hour per driver per year to one and a half and two hours per driver per year, driver retention rates of 200% and 50%, and different discount rates. The variability in these costs was not significant and was always less than the variability in equipment costs in LDW systems (i.e., low, average, and high).

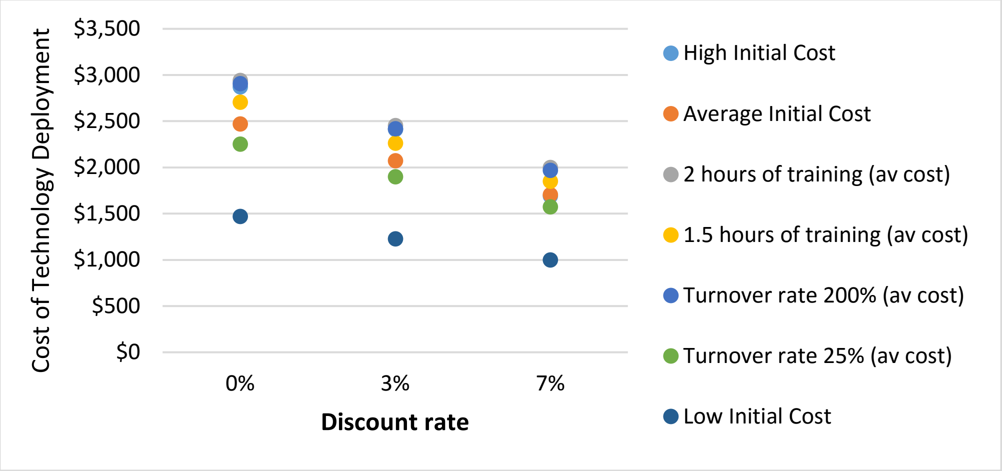

Figure 8. Impact of number of training hours and retention rates for different costs and LDW system discount rates.

Crash Target Population

The initial target population was the estimated number of large-truck single vehicle roadway departures, sideswipes, opposite sideswipes, and head-on crashes, and the associated fatalities and injuries that would be prevented if all large trucks were equipped with LDW systems. The research team used the 2010 to 2015 GES and the FARS databases to determine these numbers of rear-end crashes and injuries, which were computed as a six-year average from 2010 to 2015.

The six-year selection period was expected to capture some of the variations in crashes due to external factors, such as recession or market changes in the number of new trucks. However, as shown in Figure 9, there was a considerable variation in the number of crashes over the years. Data from 2015 showed a relative trend of returning to values achieved prior to 2013, but the 2015 values continued to be higher than those from 2010 and 2011. Thus, a six-year average represented a more conservative approach for the BCA.

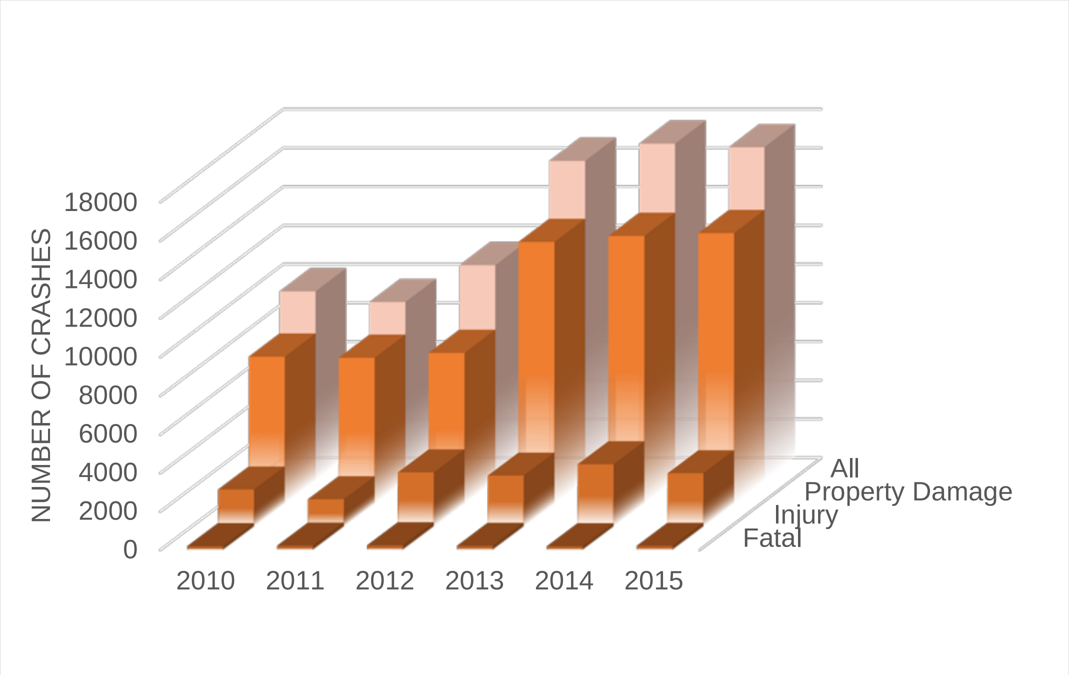

Figure 9. Number of large-truck crashes that may be prevented by LDW systems (Data from 2010 to 2015 GES and FARS).

As shown in Table 17 below, the installation of the large-truck LDW system has the potential to reduce an annual maximum of 13,558 crashes. Of those crashes, 1.61% correspond to fatal crashes, 18.38% to injury crashes, and 80% to PDO crashes. As a result of these crashes, LDW systems were associated with a maximum reduction of 245 fatalities and 2,854 injuries.

Table 17. Maximum Number of Crashes That May Be Preventable by Large Truck LDW Systems, by Severity (Data from 2010 to 2015 GES and FARS)

	Number of Crashes	Percent of Total Crashes
Fatal	219	1.61%
Injury	2,492	18.38%
PDO	10,847	80.00%
Total Crashes	13,558	100%

Effectiveness of Lane Departure Warning Systems

The efficacy rate of the LDW system corresponds to its capability to reduce the collision probability and/or severity of the crash types prevented with the technology. As discussed in the previous section, the advisory panel recommended lower- and upper-bound efficacy rates of 30% and 47.8%, respectively. Real-world efficacy may differ based on crash severity, but data limitations precluded separate efficacy estimates for LDW systems at this time.

Tables 18 and 19 below show the low, high, and maximum number of crashes and injuries that may be prevented by large-truck LDW systems. On average, large-truck LDW systems may prevent 66 to 103 fatal crashes, 748 to 1,171 injury crashes, and 3,254 to 5,098 property damage crashes each year. These crashes were associated with 74 to 115 fatalities, 103 to 162 suspected serious injuries, 366 to 573 suspected minor injuries, and 371 to 581 possible injuries.

Table 18. Average Number of Crashes by Efficacy Rate That May Be Prevented Each Year with a Large-Truck LDW System (Data from 2010 to 2015 GES and FARS)

Crash Severity	Number of Crashes		
	Low Efficacy (30%)	High Efficacy (47%)	Maximum Efficacy
Fatal	66	103	219
Injury	748	1,171	2,492
Property Damage	3,254	5,098	10,847
Total	4,067	6,372	13,558

Table 19. Average Number of Injuries by Efficacy Rate That May Be Prevented Each Year with a Large-Truck LDW System (Data from 2010 to 2015 GES and FARS)

Injury Severity	Number of Injuries		
	Low Efficacy (30%)	High Efficacy (47%)	Maximum Efficacy
Fatal Injury (K)	74	115	245
Suspected Serious Injuries (A)	103	162	345
Suspected Minor injury (B)	366	573	1,219
Possibly Injury (C)	371	581	1,235
Injury Severity Unknown	17	26	55

Equivalent Lives Saved

To estimate the number of fatal equivalents over six years for each of the efficacy rates, the average number of fatalities and injuries was converted from KABCO to MAIS as shown in Table 14 and multiplied by the MAIS matrix (see Table 13). As a result, the installation of an LDW system in a large truck may prevent 55 to 85 MAIS 1–5 fatal equivalents in addition to the 74 to 115 fatalities, for a total of 129 to 200 fatality equivalents prevented each year (Table 20).

Table 20. Number of Fatal Equivalents Per Year by Efficacy Rate for LDW Systems (Data from 2010 to 2015 GES and FARS)

	Low Efficacy (30%)		High Efficacy (47%)	
	MAIS	**Fatal Equivalent**	**MAIS**	**Fatal Equivalent**
Minor (MAIS 1)	1,086	33	1,701	51
Moderate (MAIS 2)	219	10	343	16
Serious (MAIS 3)	32	3	50	5
Severe (MAIS 4)	27	7	43	11
Critical (MAIS 5)	3	2	4	2
Unsurvivable (MAIS 6)	74	74	115	115
Total Fatal Equivalents		**129**		**200**

Cost of Crashes

Table 21 shows the annual costs of the crashes that may be prevented with LDW systems for each of the efficacy rates. The societal costs of crashes include medical and emergency costs, environmental and fuel costs, the cost of property damage, costs associated with lost productivity due to roadway congestion, and monetized QALY. In this study, the non-injury (i.e., lost productivity, congestion, and environmental) and injury (i.e., monetized QALY, medical, and emergency) costs were aggregated. To compute these costs, the research team used a procedure established by FMCSA and used in Hickman et al. (2013). This involved multiplying the costs provided by FMCSA (as described in the Methods chapter) by the number of crashes and number of injuries found in Table 18 and Table 19, respectively.

Table 21. Average Annual Cost of Crashes and Their Associated Injuries

	Low Efficacy (30%)	High Efficacy (47%)	100% Efficacy
Number of fatalities	74	115	245
Societal economic cost of crashworthiness	$25,683,283	$40,237,144	$85,610,945
Congestion, property damage and environmental savings	$104,098,988	$163,088,414	$346,996,625
Societal economic costs	$129,782,271	$203,325,558	$432,607,570
Monetized QALY	$1,244,446,032	$1,949,632,118	$4,148,153,442
Total monetized value per year	$1,374,228,303	$2,152,957,675	$4,580,761,011

Analysis Options

When implementing a new technology, several options can be analyzed. The first option includes retrofitting the entire U.S. fleet of large trucks. This approach assumes all new vehicles added to the fleet are equipped with the technology and that old vehicles are retrofitted. The second approach is what is known as an annual incremental costs analysis. This approach assumes that all new vehicles will be equipped with the technology in 2018 and does not include retrofitting old vehicles. Societal benefits are assessed over the life of the vehicle. One of the major drawbacks of this scheme is the fact that it assumes a constant number of vehicles and a constant number of crashes.

For each implementation option, an analysis was performed on different types of vehicle fleets. The first one included all class 7 and 8 trucks. The second analysis was performed only using class 7 and 8 CUTs. The third analysis was performed only using class 7 and 8 SUTs. Only the analyses for all class 7 and 8 trucks are shown below. The analyses for CUTs and SUTs are in Appendix C.

New and Old Large Trucks are Equipped with Lane Departure Warning Systems

This section describes the BCA, which assumed all large trucks (new and old) would be equipped with LDW systems. A BCA was conducted for two efficacy levels (low and high), three cost levels (low, average, and high), three vehicle classifications (SUTs and CUTs, SUTs, and CUTs), and three discount rates (0%, 3%, and 7%).

The assumptions used in this BCA include:

- Annual increase of 1.5% in the number of trucks,
- Annual increase of 1.5% in the number of drivers,
- One driver per truck,
- One hour of training per driver for the first 10 years followed by a 10% decrease per year, and
- A technology service life of 10 years with a replacement after year 10.

This BCA was conducted for an analysis period of 20 years. Typically, a lead time of two years is provided when regulating new technology on all large trucks. For the present study, the first year in the analysis period was the year 2018.

BCA Results for Retrofitting Entire U.S. Fleet of Large Trucks

Table 22 shows the BCA using the low efficacy rate (30%) for all large trucks equipped with LDW systems. For the lower efficacy rate, all three cost options were shown to be cost-effective. The low-cost estimate had BCRs ranging from 2.36 to 2.62 (net cost per fatality equivalent ranged from $3.07 million to $3.52 million). The average-cost estimate had BCRs ranging from 1.33 to 1.47 (net cost per fatality equivalent ranged from $6.27 million to $7.03 million). The high-cost estimate had BCRs ranging from 1.13 to 1.25 (net cost per fatality equivalent ranged from $7.55 million to $8.44 million). These results show that 1,412 to 2,573 fatality equivalents may be prevented over six years when all large trucks are equipped with a low efficacy LDW system.

Table 22. Results for Retrofitting the Entire U.S. Fleet of Large Trucks with LDW Systems: Low Efficacy (30%), by Cost and Discount Rate

Fleet CUT + SUT > 26,000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	2,573	1,942	1,412	2,573	1,942	1,412	2,573	1,942	1,412
Vehicle Costs	$8,231	$6,461	$4,962	$16,462	$12,922	$9,924	$19,754	$15,506	$11,909
Training Costs	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431
Total AST Cost	$10,484	$8,290	$6,393	$18,715	$14,750	$11,355	$22,007	$17,335	$13,340
Soc. Savings from Crashworthiness	$514	$388	$281	$514	$388	$281	$514	$388	$281
Congestion, PD and E S	$2,082	$1,572	$1,141	$2,082	$1,572	$1,141	$2,082	$1,572	$1,141
Total Societal Economic Savings	$2,596	$1,960	$1,422	$2,596	$1,960	$1,422	$2,596	$1,960	$1,422
VSL	$24,889	$18,790	$13,637	$24,889	$18,790	$13,637	$24,889	$18,790	$13,637
Total Monetized Savings	$27,485	$20,749	$15,060	$27,485	$20,749	$15,060	$27,485	$20,749	$15,060
Net Cost	$7,888	$6,330	$4,971	$16,119	$12,791	$9,933	$19,412	$15,375	$11,918
Net Cost per Fatal Equivalent	$3.07	$3.26	$3.52	$6.27	$6.59	$7.03	$7.55	$7.92	$8.44
Net Benefit	$17,001	$12,460	$8,666	$8,770	$5,999	$3,704	$5,477	$3,415	$1,719
Benefit Cost Ratio	**2.62**	**2.50**	**2.36**	**1.47**	**1.41**	**1.33**	**1.25**	**1.20**	**1.13**

Table 23 shows the BCA using a higher efficacy rate (47.8%) for all large trucks equipped with LDW systems. As shown in Table 23, the BCA results for the high efficacy were stronger. The low-cost option had BCRs ranging from 3.69 to 4.11 (cost per fatality equivalent ranged from $1.59 million to $1.88 million), the average cost estimate had BCRs ranging from 2.08 to 2.30 (cost per fatality equivalent ranged from $3.63 million to $4.13 million), and the high-cost estimates had BCRs ranging from 1.77 to 1.96 (cost per fatality equivalent ranged from $4.45 million to $5.02 million). The high efficacy LDW systems were shown to save between 2,212 and 4,031 lives over six years when all large trucks were equipped with an LDW system.

Table 23. Results for Retrofitting the Entire U.S. Fleet of Large Trucks with LDW Systems: High Efficacy (47%), by Cost and Discount Rate

Fleet CUT + SUT > 26000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	4,031	3,043	2,212	4,031	3,043	2,212	4031	3,043	2,212
Vehicle Costs	$8,231	$6,461	$4,962	$16,462	$12,922	$9,924	$19,754	$15,506	$11,909
Training Costs	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431
Total AST Cost	$10,484	$8,290	$6,393	$18,715	$14,750	$11,355	$22,007	$17,335	$13,340
Soc. Savings from Crashworthiness	$805	$608	$441	$805	$608	$441	$805	$608	$441
Congestion, PD and E S	$3,262	$2,462	$1,787	$3,262	$2,462	$1,787	$3,262	$2,462	$1,787
Total Societal Economic Savings	$4,067	$3,070	$2,228	$4,067	$3,070	$2,228	$4,067	$3,070	$2,228
VSL	$38,993	$29,437	$21,365	$38,993	$29,437	$21,365	$38,993	$29,437	$21,365
Total Monetized Savings	$43,059	$32,507	$23,593	$43,059	$32,507	$23,593	$43,059	$32,507	$23,593
Net Cost	$6,417	$5,220	$4,165	$14,648	$11,680	$9,127	$17,941	$14,265	$11,112
Net Cost per Fatal Equivalent	$1.59	$1.72	$1.88	$3.63	$3.84	$4.13	$4.45	$4.69	$5.02
Net Benefit	$32,575	$24,218	$17,200	$24,344	$17,757	$12,238	$21,052	$15,173	$10,253
Benefit-Cost Ratio	**4.11**	**3.92**	**3.69**	**2.30**	**2.20**	**2.08**	**1.96**	**1.88**	**1.77**

Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with Lane Departure Warning Systems

Sensitivity analyses were performed for all vehicle classifications and a $13,260,000 VSL and $5,304,000 VSL. As LDW systems were cost-effective in the majority of the analyses above, only the results with the lower VSL are provided below. The results with the higher VSL are shown in Appendix C. Table 24 shows the result using the low efficacy rate. The analyses with a BCR greater than 1.00 are highlighted. Using the low efficacy rate with a $5,304,000 VSL resulted in significantly lower BCRs. Only the low-cost option was cost-effective using the lower VSL in each of the vehicle classifications. Additionally, the average-cost estimate was only cost-effective for CUTs at a 0% or 3% discount rate. The high-cost estimate was not cost-effective.

Table 24. Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with LDW Systems with a $5,304,000 VSL: Low Efficacy (30%), by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	1.59	1.52	1.43	0.89	0.85	0.80	0.76	0.72	0.68
Only CUTs	1.86	1.78	1.68	1.04	1.00	0.95	0.88	0.85	0.80
Only SUTs	1.07	1.02	0.95	0.61	0.58	0.54	0.52	0.49	0.46

Table 25 shows the results using the high efficacy rate. The high efficacy rate with a $5,304,000 VSL resulted in a BCR greater than 1.00 for each of the cost estimates for all large trucks and only CUTs. However, LDW systems for SUTs were only cost-effective with the low-cost option.

Table 25. Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with LDW Systems with a $5,304,000 VSL: High Efficacy (47%), by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	2.49	2.37	2.23	1.39	1.33	1.26	1.18	1.14	1.07
Only CUTs	2.91	2.79	2.64	1.63	1.56	1.48	1.38	1.33	1.26
Only SUTs	1.68	1.60	1.49	0.95	0.90	0.84	0.81	0.77	0.72

Only New Large Trucks are Equipped with Lane Departure Warning Systems

For the incremental BCA, a constant number of vehicles per year was assumed (in this case 170,000 CUTs and 80,000 SUTs). These numbers were obtained by computing the average number of class 7 and 8 trucks sold in the U.S. Davis et al. (2016) found that 80% of class 8 and 10% of Class 7 trucks are CUTs and the remaining trucks are SUTs (see Table 26). The average number of new SUTs and CUTs that entered the market for the same analysis period as for the crash analysis was 81,000 and 15,500, respectively.

Table 26. Total Number of Large-Truck SUTs and CUTs Sold (thousands), 2010–2015

Year	GVWR Class 7	GVWR Class 8	SUT	CUT
2010	38	107	55.6	89.4
2011	41	171	71.1	140.9
2012	47	195	81.3	160.7
2013	48	185	80.2	152.8
2014	54	220	92.6	181.4
2015	59	249	102.9	205.1
Average			81	155

The total number of crashes that each of these vehicles will experience during their lifetime will equal the annual number of crashes computed for the previous analysis. However, the crashes may occur any time during the vehicle's lifetime, and it was assumed they followed the same distribution of the weighted average of VMT and survival rate. Thus, the crashes were discounted by applying a multiplicative factor of 0.8389 for a 3% discount rate and 0.6899 for a 7% rate. Since this analysis applied only to the new trucks entering the market, system replacement was assumed to occur when the truck reached the 50% weighted average lifetime VMT. This represented an increase in the vehicle cost of the technology of 7.4% (0% discount rate), 12% (3% discount rate), and 15% (7% discount rate). Results presented were for the calendar year replacement. In this study, the research team used the same CUT survival rates as the FMCSA electronic logging device mandate (Federal Motor Vehicle Safety Standards; Electronic Logging Devices).

The number of drivers receiving training will be proportional to the number of vehicles surviving. The number of drivers receiving training followed the same scenario as described above, where each surviving truck had a driver, but the percentage of drivers receiving training was reduced by 10% after year 10. The hourly cost per driver and the cost of the technology continued to be the same as described above. The major difference was that the crashes were reduced using the new accelerated discount factors.

BCA Results for Equipping Only New Trucks with Lane Departure Warning Systems

Table 27 shows the results for the low efficacy rate for all new large trucks (30%). Similar to the results for the results when deploying LDW systems across the entire U.S. fleet of large trucks, all three cost estimates were found to be cost-effective. The low-cost estimate was found to have BCRs ranging from 3.68 to 4.26 (net cost per fatality equivalent ranged from $1.50 million to $1.89 million); the average cost estimate was found to have BCRs ranging from 2.14 to 2.52 (net cost per fatality equivalent ranged from $3.24 million to $3.98 million); and the high-cost estimate was found to have BCRs ranging from 1.83 to 2.16 (net cost per fatality equivalent ranged from $3.93 million to $4.81 million). The low efficacy resulted in 83 to 129 equivalent lives saved over six years when all new large trucks were equipped with LDW systems.

Table 27. Results for Equipping All New Large Trucks with LDW Systems: Low Efficacy (30%), by Cost and Discount Rate

Fleet CUT + SUT > 26000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	129	104	83	129	104	83	129	104	83
Vehicle Costs	$223	$197	$173	$447	$395	$345	$536	$474	$414
Training Costs	$100	$83	$67	$100	$83	$67	$100	$83	$67
Total AST Cost	$323	$281	$240	$546	$478	$412	$636	$557	$481
Soc. Savings from Crashworthiness	$26	$21	$17	$26	$21	$17	$26	$21	$17
Congestion, PD and E S	$104	$84	$67	$104	$84	$67	$104	$84	$67
Total Societal Economic Savings	$130	$105	$83	$130	$105	$83	$130	$105	$83
VSL	$1,244	$1,007	$800	$1,244	$1,007	$800	$1,244	$1,007	$800
Total Monetized Savings	$1,374	$1,112	$883	$1,374	$1,112	$883	$1,374	$1,112	$883
Net Cost	$193	$176	$156	$416	$373	$329	$506	$452	$398
Net Cost per Fatal Equivalent	$1.50	$1.69	$1.89	$3.24	$3.58	$3.98	$3.93	$4.34	$4.81
Net Benefit	$1,051	$832	$643	$828	$634	$471	$739	$555	$402
Benefit-Cost Ratio	**4.26**	**3.96**	**3.68**	**2.52**	**2.33**	**2.14**	**2.16**	**2.00**	**1.83**

As shown in Table 28, all cost estimates were cost-effective at the high efficacy rate (47%) when all new large trucks (no retrofitting) were equipped with an LDW system. The low-cost estimate was found to have BCRs ranging from 5.77 to 6.67 (net cost per fatality equivalent ranged from $0.59 million to $0.84 million); the average-cost estimate was found to have BCRs ranging from 3.36 to 3.94 (net cost per fatality equivalent ranged from $1.70 million to $2.17 million); and the high-cost estimate was found to have BCRs ranging from 2.87 to 3.39 (net cost per fatality equivalent ranged from $2.14 million to $2.71 million). The high efficacy rate was found to save 130 to 202 equivalent lives over six years.

Table 28. Results for Equipping All New Large Trucks with LDW Systems: High Efficacy (47%), by Cost and Discount Rate

Fleet CUT + SUT > 26000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	202	163	130	202	163	130	202	163	130
Vehicle Costs	$223	$197	$173	$447	$395	$345	$536	$474	$414
Training Costs	$100	$83	$67	$100	$83	$67	$100	$83	$67
Total AST Cost	$323	$281	$240	$546	$478	$412	$636	$557	$481
Soc. Savings from Crashworthiness	$40	$33	$26	$40	$33	$26	$40	$33	$26
Congestion, PD and E S	$163	$132	$105	$163	$132	$105	$163	$132	$105
Total Societal Economic Savings	$203	$165	$131	$203	$165	$131	$203	$165	$131
VSL	$1,950	$1,578	$1,253	$1,950	$1,578	$1,253	$1,950	$1,578	$1,253
Total Monetized Savings	$2,153	$1,743	$1,384	$2,153	$1,743	$1,384	$2,153	$1,743	$1,384
Net Cost	$120	$116	$109	$343	$313	$282	$432	$392	$351
Net Cost per Fatal Equivalent	$0.59	$0.71	$0.84	$1.70	$1.92	$2.17	$2.14	$2.40	$2.71
Net Benefit	$1,830	$1,462	$1,144	$1,607	$1,265	$971	$1,517	$1,186	$902
Benefit-Cost Ratio	**6.67**	**6.21**	**5.77**	**3.94**	**3.65**	**3.36**	**3.39**	**3.13**	**2.87**

Sensitivity Analysis for Only Equipping New Trucks with Lane Departure Warning Systems

Similar to the analyses for equipping the entire U.S. fleet, sensitivity analyses were performed for all vehicle classifications and a $13,260,000 VSL and $5,304,000 VSL. Since all the results for equipping only new trucks with an LDW system had BCRs above 1.00, only the sensitivity analyses with the lowered VSL are shown below. The results with the higher VSL are shown in Appendix C. Table 29 shows the results using the low efficacy rate. The low efficacy rate with a $5,304,000 VSL resulted in cost-effective solutions for almost all of the cost estimates. The high-cost estimate was shown to not be cost-effective when only SUTs are equipped with LDW systems. Additionally, the average-cost estimate was not cost-effective, with a 7% discount rate when only SUTs are equipped with LDW systems.

Table 29. Sensitivity Analysis for Equipping All New Large Trucks with LDW Systems Using $5,304,000 VSL: Low Efficacy (30%), by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	2.58	2.40	2.23	1.52	1.41	1.30	1.31	1.21	1.11
Only CUTs	2.90	2.70	2.51	1.71	1.59	1.46	1.47	1.36	1.25
Only SUTs	1.89	1.76	1.64	1.12	1.03	0.95	0.96	0.89	0.81

As shown in Table 30, a $5,304,000 VSL and high efficacy resulted in all cost estimates being cost-effective.

Table 30. Sensitivity Analysis for Equipping All New Large Trucks with LDW Systems Using a $5,304,000 VSL: High Efficacy (47%) by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large trucks	4.04	3.76	3.49	2.39	2.21	2.03	2.05	1.89	1.74
Only CUTs	4.54	4.23	3.93	2.69	2.48	2.29	2.31	2.13	1.96
Only SUTs	2.96	2.76	2.56	1.75	1.62	1.49	1.50	1.39	1.28

Discussion

This study assessed scientifically-based estimates of the societal benefits and costs of LDW systems installed on large trucks. This study also assessed the societal benefits and costs of automatic emergency braking systems, video-based onboard safety monitoring, and air disc brakes; the assessment results of these ASTs are presented in separate AAAFTS reports. In addition to these ASTs, other ASTs were considered; however, the advisory panel selected ASTs that were not mandated, had empirical research evaluating the efficacy of the system, had an outdated BCA, or for which a BCA was not available. The current study used efficacy rates from previously published research and identified crashes that may have been prevented through the deployment of the AST. Crashes were identified using 2010 to 2015 GES and FARS data sets. BCAs were performed using varying efficacy rates (low and high), vehicle types (SUTs and CUTs, CUTs, and SUTs), costs (low, average, and high), and discount rates (0%, 3%, and 7%).

Lower and upper bound efficacy rates were used to estimate the benefits and costs associated with implementing LDW systems across the entire U.S. fleet of large trucks. This study found that an LDW system with 30% efficacy may prevent 4,067 total roadway departures, sideswipes, opposite sideswipes, and head-on crashes; 748 injury crashes (840 total injuries); and 66 fatal crashes (76 total lives) per year. An LDW system with a 47.8% efficacy may prevent 6,372 total roadway departure, sideswipes, opposite sideswipes, and head-on crashes; 1,171 injury crashes (1,316 total injuries); and 103 fatal crashes (115 total lives) each year.

The number of crashes that may be prevented with LDW systems were similar to some prior studies. Pomerleau et al. (1999) estimated that LDW systems could prevent 96 fatalities each year, similar to the 76 to 115 fatalities that may be prevented by LDW systems in this study. Additionally, Houser et al. (2009) estimated that LDW systems would prevent 23% to 53% of road departures, rollovers, sideswipes, and head-on crashes. Using these efficacy rates, Houser et al. (1999) estimated that LDW systems may prevent 3,863 to 8,103 total crashes each year (compared to 4,067 to 6,372 crashes found in this study). Thus, the number of crashes that may be prevented by LDW systems were in agreement with some of the prior literature.

Two sets of BCAs were conducted for LDW systems. Each set of analyses used a lower-bound efficacy rate (30%) and upper-bound efficacy rate (47.8%). The first set of BCAs estimated the cost-effectiveness of equipping all new and old large trucks with LDW systems. These analyses showed BCRs ranging from 1.13 to 4.11 (for all large trucks), 1.33 to 4.83 (if only CUTs were equipped), and 0.75 to 2.74 (if only SUTs were equipped). These analyses showed that every combination of cost (i.e., low, average, or high), efficacy rate (i.e., low or high), and discount rate (i.e., 0%, 3%, or 7%) produced a cost-effective solution when all new and old large trucks were equipped with a LDW system, or when all new and old CUTs were equipped with a LDW system. Only the low efficacy rate resulted in BCRs lower than 1.00 when considering equipping both new and existing SUTs with LDW systems.

The second set of BCAs estimated the cost-effectiveness of equipping only new vehicles with LDW systems. These analyses showed BCRs ranging from 1.83 to 6.67 (for all large trucks), 2.07 to 7.53 (if only CUTs were equipped), and 1.33 to 4.83 (if only SUTs were equipped).

Results indicated that equipping all new large trucks with LDW systems would be cost-effective given the costs and efficacy rates examined in this study.

These results show the benefits of LDW systems clearly outweigh the costs in almost all conditions. Additionally, these results support previous research that found LDW systems were a cost-effective solution for large trucks. In 2006, Orban et al. (2006) found LDW systems had societal BCRs ranging from 0.55 to 5.11 based on varying costs and efficacy rates. Houser et al. (2009) used the same effectiveness data as Orban et al. (2006) to calculate carrier-level BCAs. Although a societal BCA considers different costs compared to a carrier-level BCA, similar results were found (carrier BCRs from 1.37 to 6.55). Visvikis et al. (2008) used German crash data and found LDW systems had societal BCRs ranging from 0.18 to 6.56 for German large trucks. Abele et al. (2005) used data from the European Union and found large-truck LDW systems had societal BCRs ranging from 2.0 to 2.1. Finally, Hickman et al. (2013) found that LDW systems had societal BCRs ranging from 1.69 to 5.71. The results of all the previous studies are fairly consistent in showing that the benefit of LDW systems clearly outweighs the costs. The results from this study are remarkably consistent with the previous results.

LDW systems are easily retrofitted to old trucks. Although the results for only new vehicles produced higher BCRs, the analyses for all vehicles (old and new) resulted in estimated societal benefits that outweighed the associated costs. For example, if all large trucks were equipped with an LDW system, 4,031 equivalent lives could be saved (high efficacy, 0% discount). If only new large trucks were equipped with an LDW system, 202 equivalent lives could be saved (high efficacy, 0% discount). However, the net cost per fatality equivalent was much higher when equipping all large trucks with an LDW system ($3.63 million for the high efficacy, 0% discount) compared to only equipping new large trucks with an LDW system ($1.70 million for the high efficacy, 0% discount).

Conclusions

The results strongly support the cost-effectiveness of LDW systems for all large trucks. Regardless of cost and efficacy rate, LDW systems were shown to be cost-effective. These results were likely due to: (1) the relatively low cost of LDW systems compared to other ASTs, and (2) the large number/severity of roadway departures, sideswipes, opposite sideswipes, and head-on crashes that could be prevented with LDW systems. As with the other ASTs, cost-effectiveness was estimated to be higher when installing LDW systems only new large trucks. However, these results indicate that the societal benefits of installing LDW systems would outweigh the associated costs whether installed only on new large trucks or retrofitted to existing trucks as well.

Limitations

Although the analyses used to assess the benefit-costs associated with LDW systems were comprehensive, there were several limitations.

- It is possible the efficacy rates used in this study may not represent the current functionality/effectiveness of the current generation of LDW systems. However, as the advisory panel consisted of experts with knowledge of current technology research, the efficacy rates recommended by the Panel for use in this study should be consistent with current generation of systems' efficacy rates.

- The technology costs used in this study may differ from current costs (costs typically decrease over time).
- This study used estimated crash, technology, and labor costs. It is possible that actual costs may differ, and thus impact the cost-effectiveness of LDW systems.
- The GES only included crashes that required a police accident report. However, LDW systems may also prevent less severe crashes. Thus, these additional benefits are not accounted for in the BCAs.
- The real-world effectiveness against different severity crashes may differ significantly. However, data limitations precluded the use of separate efficacy estimates for this study.
- These analyses did not account for reduced litigation costs associated with reduced crashes. These may be significant costs savings that were not integrated into the analyses.
- The failure to use data generated by LDW systems (e.g., reports tracking alerts/activations) may result in missed driver coaching opportunities. Thus, maximum LDW system efficacy may not be achieved.
- The efficacy of LDW systems is dependent upon effective introduction, then initial and subsequent ongoing driver and management training.
- This study assumed all vehicle systems were functioning as intended. However, this is unlikely to be seen in the real world. Specifically, anti-lock brakes and foundation brakes have a direct impact on a vehicle's ability to avoid a crash. If they are poorly maintained, the actual efficacy rates may be lower than those used in this study.

References

Abele, J., Kerlen, C., Krueger, S., Baum, H., Geißler, T., Grawenhoff, S., Schneider, J., & Schulz, W. H. (2005). *Exploratory Study on the Potential Socioeconomic Impact of the Introduction of Intelligent Safety Systems in Road Vehicles.* Teltwo, Germany: VDI/VDE Innovation and Technik GmbH.

American Trucking Associations. (2016). *U.S. Freight Transportation Forecast to 2027.* Arlington, VA: American Trucking Associations.

Belzowski, B. M., Herter, J. J., Guan, A., & Murphy, S. (2015). *Deploying Safety Technologies in Commercial Vehicles: Market Study – February 2015.* Washington, D.C.: Intelligent Transportation Society of America.

Berwick, M., & Farooq, M. (2003). *Truck Costing Model for Transportation Managers.* Fargo, ND: Upper Great Plains Transportation Institute. Retrieved November 18, 2016 from http://www.mountain-plains.org/pubs/pdf/MPC03-152.pdf

Bureau of Labor Statistics. (2015). *Occupational Outlook Handbook, 2016-2017 Edition.* Washington, D.C.: Bureau of Labor Statistics, U.S. Department of Labor. Retrieved November 1, 2016 from https://www.bls.gov/ooh/installation-maintenance-and-repair/heavy-vehicle-and-mobile-equipment-service-technicians.htm

Bureau of Labor Statistics. (2016). *Occupational Employment and Wages, 2015.* Washington, D.C.: Bureau of Labor Statistics, U.S. Department of Labor. Retrieved November 1, 2016 from https://www.bls.gov/oes/current/oes533032.htm

Bureau of Labor Statistics. (2016). *Employer Costs for Employee Compensation – September 2016.* Washington, D.C.: Bureau of Labor Statistics, U.S. Department of Labor. Retrieved December 10, 2016 from https://www.bls.gov/news.release/pdf/ecec.pdf

Business Dictionary. (2016). *Economic analysis.* Retrieved from http://www.businessdictionary.com/definition/economic-analysis.html.

Davis, S.C., Diegel, S. W., & Boundy, R. G. (2016). *Transportation Energy Data Book: Edition 35.* Washington, D.C.: U.S. Department of Energy. Retrieved from http://www.cta.ornl.gov/data/tedb35/Edition35_Title_Pages.pdf

de Ridder, S. N., Hogema, J., Hoedemaeker, M. (2003). The Dutch Experience with Lane Departure Warning Systems: A Field Operational Test. *TNO Document TM-03-C048.*

Executive Order 12866, 3 C.F.R. (1993). Washington, D.C. Retrieved from http://www.whitehouse.gov/omb/inforeg/eo12866.pdf

Executive Order 13563, 3 C.F.R. (2011). Washington, D.C. Retrieved from https://www.whitehouse.gov/the-press-office/2011/01/18/executive-order-13563-improving-regulation-and-regulatory-review

Federal Motor Carrier Safety Administration. (2006). *Report to Congress on the Large Truck Crash Causation Study*. (Report No. MC-R/MC-RRA). Washington, D.C.: Federal Motor Carrier Safety Administration.

Federal Motor Carrier Safety Administration. (2016). *Large Truck and Bus Crash Facts 2014.* Washington, D.C.: Federal Motor Carrier Safety Administration.

Federal Motor Vehicle Safety Standards; Electronic Logging Devices, Final Rule, 49 CFR Parts 385, 386, 390, and 395.

Hendricks, D. L., Freedman, M., Zador, P. L., & Fell, J. C. (2001). *The Relative Frequency of Unsafe Driving Acts in Serious Traffic Crashes.* (Report No. DTNH22-94-C-05020). Washington, D.C.: National Highway Traffic Safety Administration.

Hickman, J. S., Geo, F., Camden, M. C., Medina, A., Hanowski, R. J., & Mabry, E. (2013). *Onboard Safety System Effectiveness Evaluation Final Report.* (Report No. FMCSA-RRT-12-012). Washington, D.C.: Federal Motor Carrier Safety Administration.

Houser, A., Groeller, C. J., Bishop, R. (2006). *Mack Intelligent Vehicle Initiative Field Operational Test Final Report.* (Report No. FMCSA-MCRR-06-007). Washington, D.C.: Federal Motor Carrier Safety Administration.

Houser, A., Murray, D., Shackelford, S., Kreeb, R., & Dunn, T. (2009). *Analysis of Benefits and Costs of Lane Departure Warning Systems for the Trucking Industry*. (Report No. FMCSA-RRT-09-022). Washington, D.C.: Federal Motor Carrier Safety Administration.

IHS Markit (2016, January). *U.S. commercial vehicle market expected to grow slightly in 2016, HIS says.* Retrieved November 1, 2016 from http://news.ihsmarkit.com/press-release/automotive/us-commercial-vehicle-market-expected-grow-slightly-2016-ihs-says

Jermakian, J. S. (2012). Crash avoidance potential of four large truck technologies. *Accident Analysis and Prevention, 49,* 338-346.

Johnson, S. L. (2008). *Human Factors Study of Driver Assistance Systems to Reduce Lane Departures and Side Collision Accidents.* Fayetteville, AR: Mack-Blackwell Rural Transportation Center.

Kingsley, K. J. (2009). *Evaluating crash avoidance countermeasures using data from FMCSA/NHTSA's Large Truck Crash Causation Study*. Proceedings of the 21nd International Technical Conference on Enhanced Safety of Vehicles, Stuttgart, Germany.

Kuehn, M., Hummel, T. & Bende, J. (2011). *Advanced driver assistance systems for trucks – benefit estimation from real-life accidents.* Proceedings of the 22nd International Technical Conference on Enhanced Safety of Vehicles, Washington, D.C.

Kirk, A. (2009). *An In-Service Analysis of Maintenance and Repair Expenses for the Anti-Lock Brake System and Underride Guard for Tractors and Trailers.* Washington, D.C.: National Center for Statistics and Analysis, National Highway Traffic Safety Administration.

NorthAmerican Transportation Association (n.d.). *Commercial Motor Vehicle Safety and Security Systems Technology: Lane Departure Warning Systems*. Retrieved April 14, 2016, from http://www.ntassoc.com/uploads/FileLinks/be1d5f8106d64e0198d776625e0f31aa/Lane%20Departure%20Warning%20Systems.pdf

Office of Highway Policy Information (2014). Roadway Extent, Characteristics, and Performance. Washington, D.C.: Federal Highway Administration. Retrieved from https://www.fhwa.dot.gov/policyinformation/statistics/

PeopleNet. (2016). *Lane Departure Notifications*. Retrieved April 14, 2016, from https://www.peoplenetonline.com/products/safety-compliance/safety-monitoring-alerts/

Office of Management and Budget. (1992). *Circular No. A-94 Revised*. Washington, D.C. Retrieved from https://www.whitehouse.gov/omb/circulars_a094

Office of Management and Budget (2003). *Circular A-4: Regulatory Analysis.* Washington, D.C. Retrieved from http://www.whitehouse.gov/omb/assets/regulatory_matters_pdf/a-4.pdf

Orban, J., Hadden, J., Stark, G., & Brown, V. (2006). *Evaluation of the Mack Intelligent Vehicle Initiative Field Operational Test.* (Report No. FMCSA-06-016).Washington, D.C.: Federal Motor Carrier Safety Administration.

Pearce, D., Atkinson, G., & Mourato, S. (2006). *Cost-Benefit Analysis and the Environment: Recent Developments*. Paris, France: OECD Publishing.

Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., McMillian, N., Brown, N., & Everson, J. (1999). *Run-off-Road Collision Avoidance Using IVHS Countermeasures.* (Report No. DOT HS 809 170). Washington, D.C.: National Highway Traffic Safety Administration.

Ricardo Inc. (2013. *Cost and Weight Analysis for CMB and LDWS for Heavy Trucks*. Washington, D.C.: National Highway Traffic Safety Administration.

Shedlock, M. (2016, May). *Class 8 truck orders plunge 39%; Large truck sales vs. recessions.* Retrieved November 1, 2016 from https://mishtalk.com/2016/05/05/class-8-truck-orders-plunge-39-large-truck-sales-vs-recessions/

Spicer, R.S., & Miller, T.R. (2010). *Uncertainty Analysis of Quality Adjusted Life Years Lost.* Washington, D.C.: National Highway Traffic Safety Administration.

Transportation Economics Committee of the Transportation Research Board. (n.d.). *Transportation benefit-cost analysis.* Retrieved from http://bca.transportationeconomics.org/.

Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E., Stansider, R. L., & Castellan, N. J. (2006). *Tri-Level Study of the Causes of Traffic Accidents: Final Report. (Volume I: Causal Factor Tabulations and Assessments; Volume II: Special Analyses).* (Report No. DOT HS 805 085). Washington, D.C.: National Highway Traffic Safety Administration.

U.S. Department of Transportation (2015). *Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses (2015).* Washington, D.C.: U.S. Department of Transportation. Retrieved May 25, 2016 from http://www.dot.gov/office-policy/transportation-policy/guidance-treatment-economic-value-statistical-life

U.S. Energy Information Administration (2016). *Annual Energy Outlook 2016.* Washington, D.C.: U.S. Energy Information Administration. Retrieved from http://www.eia.gov/outlooks/aeo/

Visvikis, C., Smith, T. L., Pitcher, M., & Smith, R. (2008). *Study on Lane Departure Warning and Lane Change Assistant Systems: Final Report*. Brussels, Belgium: European Commission.

Appendix A: Literature Review Summary Table

Citation	Title	AST	Effectiveness and/or cost
Kuehn, Hummel, & Bende (2011)	Advanced driver assistance systems for trucks: Benefit estimation from real-life accidents	LDW	• LDWs could reduce 2% of all large-truck crashes, or 39% of all large-truck lane-departure crashes.
Houser et al. (2009)	Analysis of benefits and costs of lane departure warning systems for the trucking industry	LDW	• LDWs could reduce 23% (from MACK FOT) of large-truck sideswipes, road departures, road departure rollovers, and head-ons. • Reduces 53% of these crashes (based on carrier estimates). • Purchase price = $1,000–$1,500. • Federal tax savings: $765–$866.40.
Jermakian (2012)	Crash avoidance potential of four large-truck technologies	LDW	• LDWs could prevent 3% of single vehicle crashes; could prevent 10% of head-ons, sideswipes, and opposite sideswipes.
Kingsley (2009)	Evaluating crash avoidance countermeasures using data from FMCSA/NHTSA's large truck crash causation study	LDW	• LDWs could reduce 6.1% of all crashes in the LTCSS.
Orban et al. (2006)	Evaluation of the Mack intelligent vehicle initiative field operational test	LDW	• Reduced scenarios leading to rollovers and road departures by 31% on straight roads. • Reduced scenarios leading to rollovers and road departures by 24% on curves (not statistically significant). • Installed LDW cost = $750–$1,500. • Service life = 5–7 years.

Citation	**Title**	**AST**	**Effectiveness and/or cost**
Johnson (2008)	Human factors study of driver assistance systems to reduce lane departures and side collision accidents	LDW	• Large Truck Crash Causation Study (LTCCS) analysis: crashes that may be prevented by LDW: 7.2%–8.2% of right side road departures, 5.8%–6.3% of left road departures, 11%–12% of same direction sideswipes, and 17%–18% of opposite sideswipes. • Fleet data analysis: crashes that may be prevented by LDW: 0.8%–6.2% of road departures and 1.38%–21.7% of sideswipes/lane change crashes.
Nodine et al. (2011)	Integrated vehicle-based safety systems heavy-truck field operational test independent evaluation	LDW into a clear lane (LDW-C) and occupied lane (LDW-I)	• LDW-I: insufficient data. • LCW-C: possible 29% reduction in opposite sideswipes and left-side road departures; 36% reduction in same-direction sideswipes/right-side road departures.
Hickman et al. (2013)	Onboard safety system effectiveness evaluation final report	LDW	• 47.8% reduction in large-truck sideswipes, opposite sideswipes, run off road, and head-on crashes. • Average cost: $1,000.
Pomerleau et al. (1999)	Run-off-road collision avoidance using IVHS countermeasures	LDW	• 30% of large-truck run-off road crashes could be prevented by LDW (9,300 crashes and 96 fatalities).
Visvikis et al. (2008)	Study on lane departure warning and lane change assistant systems	LDW	• EU-based estimations. • LDW could prevent 48% of fatalities, 36% of serious injuries, and 20% of minor injuries associated with large truck head-ons, road departures, and sideswipes. • Estimated costs: LDW = €200-€448. • May not be applicable to U.S. data as the roadway infrastructure and safety culture are different. Additionally, crash rates are likely not representative.

Citation	Title	AST	Effectiveness and/or cost
de Ridder, Hogema, & Hoedemarker (2003)	The Dutch experience with lane departure warning assistant systems: A field operational test	LDW	• 10% reduction in large-truck injury crashes with 100% penetration rate and 100% effectiveness at reducing related crashes. • May prevent 1.3% of traffic congestion in the Netherlands.
Belzowski et al. (2015)	Deploying safety technologies in commercial vehicles: Market study February 2015	LDW	• Carriers reported an average 14% reduction in crashes. • Carriers reported an average 15% reduction in crash costs.
NorthAmerican Transportation Association (n.d.)	Commercial motor vehicle safety and security systems technology: Lane departure warning systems	LDW	• Cost = $1,000 to $2,000 depending on the number of units purchased.
PeopleNet (2016)	Fleet safety monitoring and alerts	LDW	• 75% reduction in large-truck lane departures over 1.3 billion miles with PeopleNet LDW.

Appendix B: GES/FARS Crash Filtering Inclusion Variables

1. Vehicle Body Type
   a. 63: Single-Unit Straight Truck or Cab-Chassis (GVWR > 26,000 lbs)
   b. 64: Single-Unit Straight Truck or Cab-Chassis (GVWR unknown)
   c. 66: Truck-Tractor
   d. 68: Single-Unit Straight Truck (GVWR unknown)
   e. 72: Unknown if Single-Unit or Combination-Unit Heavy Truck (GVWR > 26,000 lbs)
   f. 78: Unknown Medium/Heavy Truck Type

2. Accident Type
   a. 1: Single Driver, Right Roadside Departure, Drive Off Road
   b. 2: Single Driver, Right Roadside Departure, Control/Traction Loss
   c. 6: Single Driver, Left Roadside Departure, Drive Off Road
   d. 7: Single Driver, Left Roadside Departure, Control/Traction Loss
   e. 44: Same Trafficway, Same Direction, Sideswipe/Angle, Straight Ahead on Left
   f. 45: Same Trafficway, Same Direction, Sideswipe/Angle, Straight Ahead on Left/Right
   g. 46: Same Trafficway, Same Direction, Sideswipe/Angle, Changing Lanes to the Right
   h. 47: Same Trafficway, Same Direction, Sideswipe/Angle, Changing Lanes to the Left
   i. 50: Same Trafficway, Opposite Direction, Head-on, Lateral Move (Left/Right)
   j. 64: Same Trafficway, Opposite Direction, Sideswipe/Angle, Lateral Move (Left/Right)

3. Pre-event Movement
   a. 1: Going Straight
   b. 2: Decelerating in Road
   c. 3: Accelerating in Road
   d. 14: Negotiating a Curve

4. Critical Event – Pre-crash
   a. 10: This Vehicle Traveling, Over the Lane Line on Left Side of Travel Lane
   b. 11: This Vehicle Traveling, Over the Lane Line on Right Side of Travel Lane
   c. 12: This Vehicle Traveling, Off the Edge of the Road on the Left Side
   d. 13: This Vehicle Traveling, Off the Edge of the Road on the Right Side

5. Police-Reported Alcohol Involvement
   a. 0: No (Alcohol Not Involved)

6. Police-Reported Drug Involvement
   a. 0: No (Drugs Not Involved)

7. Impairment at Time of Crash – Driver
    a. Removed 1: Ill/Blackout

8. First Harmful Event
    a. 1: Noncollision, Rollover/Overturn
    b. 12: Collision with Motor Vehicle in Transport, Motor Vehicle in Transport
    c. 14: Collision with Object not Fixed, Parked Motor Vehicle
    d. 17: Collision with Fixed Object, Boulder
    e. 19: Collision with Fixed Object, Building
    f. 20: Collision with Fixed Object, Impact Attenuator/Crash Cushion
    g. 21: Collision with Fixed Object, Bridge Pier or Support
    h. 23: Collision with Fixed Object, Bridge Rail
    i. 24: Collision with Fixed Object, Guardrail Face
    j. 25: Collision with Fixed Object, Concrete Traffic Barrier
    k. 26: Collision with Fixed Object, Other Traffic Barrier
    l. 30: Collision with Fixed Object, Utility Pole/Light Support
    m. 40: Collision with Fixed Object, Fire Hydrant
    n. 41: Collision with Fixed Object, Shrubbery
    o. 42: Collision with Fixed Object, Tree (Standing Only)
    p. 43: Collision with Fixed Object, Other Fixed Object
    q. 45: Collision with Object not Fixed, Working Motor Vehicle
    r. 46: Collision with Fixed Object, Traffic Signal Support
    s. 48: Collision with Fixed Object, Snow Bank
    t. 50: Collision with Fixed Object, Bridge Overhead Structure
    u. 52: Collision with Fixed Object, Guardrail End
    v. 53: Collision with Fixed Object, Mail Box
    w. 54: Collision With Motor Vehicle in Transport, Motor Vehicle in Transport Strikes or is Struck by Cargo, Persons or Objects Set in Motion From/by Another Motor Vehicle in Transport
    x. 55: Collision With Motor Vehicle in Transport, Motor Vehicle in Motion Outside the Trafficway
    y. 57: Collision with Fixed Object, Cable Barrier
    z. 58: Collision with Fixed Object, Ground
    aa. 59: Collision with Fixed Object, Traffic Sign Support
    bb. 99: Not Reported and Unknown, Unknown

Appendix C: Additional Analyses

Table 31. Results for Retrofitting the Entire U.S. Fleet of Large-Truck CUTs with LDW Systems by Low Efficacy (30%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	1,991	1,503	1,093	1,991	1,503	1,093	1,991	1,503	1,093
Vehicle Costs	$5,422	$4,237	$3,236	$10,844	$8,474	$6,473	$13,013	$10,169	$7,768
Training Costs	$1,424	$1,156	$905	$1,424	$1,156	$905	$1,424	$1,156	$905
Total AST Cost	$6,847	$5,393	$4,141	$12,269	$9,630	$7,378	$14,438	$11,325	$8,673
Soc. Savings from Crashworthiness	$383	$289	$210	$383	$289	$210	$383	$289	$210
Congestion, PD and E S	$1,494	$1,128	$819	$1,494	$1,128	$819	$1,494	$1,128	$819
Total Societal Economic Savings	$1,878	$1,417	$1,029	$1,878	$1,417	$1,029	$1,878	$1,417	$1,029
VSL	$19,238	$14,524	$10,541	$19,238	$14,524	$10,541	$19,238	$14,524	$10,541
Total Monetized Savings	$21,116	$15,941	$11,570	$21,116	$15,941	$11,570	$21,116	$15,941	$11,570
Net Cost	$4,969	$3,976	$3,113	$10,391	$8,213	$6,349	$12,560	$9,908	$7,644
Net Cost per Fatal Equivalent	$2.50	$2.64	$2.85	$5.22	$5.46	$5.81	$6.31	$6.59	$6.99
Net Benefit	$14,269	$10,548	$7,429	$8,847	$6,311	$4,192	$6,678	$4,616	$2,897
Benefit-Cost Ratio	**3.08**	**2.96**	**2.79**	**1.72**	**1.66**	**1.57**	**1.46**	**1.41**	**1.33**

Table 32. Results for Retrofitting the Entire U.S. Fleet of Large-Truck CUTs with LDW Systems by High Efficacy (47%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	3,120	2,355	1,712	3,120	2,355	1,712	3,120	2,355	1,712
Vehicle Costs	$5,422	$4,237	$3,236	$10,844	$8,474	$6,473	$13,013	$10,169	$7,768
Training Costs	$1,424	$1,156	$905	$1,424	$1,156	$905	$1,424	$1,156	$905
Total AST Cost	$6,847	$5,393	$4,141	$12,269	$9,630	$7,378	$14,438	$11,325	$8,673
Soc. Savings from Crashworthiness	$600	$453	$329	$600	$453	$329	$600	$453	$329
Congestion, PD and E S	$2,341	$1,767	$1,283	$2,341	$1,767	$1,283	$2,341	$1,767	$1,283
Total Societal Economic Savings	$2,941	$2,221	$1,612	$2,941	$2,221	$1,612	$2,941	$2,221	$1,612
VSL	$30,140	$22,754	$16,515	$30,140	$22,754	$16,515	$30,140	$22,754	$16,515
Total Monetized Savings	$33,082	$24,975	$18,126	$33,082	$24,975	$18,126	$33,082	$24,975	$18,126
Net Cost	$3,905	$3,173	$2,530	$9,327	$7,410	$5,766	$11,496	$9,104	$7,061
Net Cost per Fatal Equivalent	$1.25	$1.35	$1.48	$2.99	$3.15	$3.37	$3.69	$3.87	$4.12
Net Benefit	$26,235	$19,582	$13,985	$20,813	$15,345	$10,748	$18,644	$13,650	$9,454
Benefit-Cost Ratio	**4.83**	**4.63**	**4.38**	**2.70**	**2.59**	**2.46**	**2.29**	**2.21**	**2.09**

Table 33. Results for Retrofitting the Entire U.S. Fleet of Large-Truck SUTs with LDW Systems by Low Efficacy (30%), Cost, and Discount Rate

Fleet SUT	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
Equivalent Lives Saved	581	439	319	581	439	319	581	439	319
Vehicle Costs	$2,809	$2,224	$1,725	$5,617	$4,447	$3,451	$6,741	$5,337	$4,141
Training Costs	$829	$673	$526	$829	$673	$526	$829	$673	$526
Total AST Cost	$3,637	$2,896	$2,252	$6,446	$5,120	$3,977	$7,570	$6,010	$4,668
Soc. Savings from Crashworthiness	$131	$99	$72	$131	$99	$72	$131	$99	$72
Congestion, PD and E S	$588	$444	$322	$588	$444	$322	$588	$444	$322
Total Societal Economic Savings	$718	$542	$393	$718	$542	$393	$718	$542	$393
VSL	$5,651	$4,266	$3,096	$5,651	$4,266	$3,096	$5,651	$4,266	$3,096
Total Monetized Savings	$6,369	$4,808	$3,490	$6,369	$4,808	$3,490	$6,369	$4,808	$3,490
Net Cost	$2,919	$2,354	$1,859	$5,728	$4,578	$3,584	$6,851	$5,467	$4,274
Net Cost per Fatal Equivalent	$5.02	$5.36	$5.82	$9.85	$10.43	$11.23	$11.78	$12.45	$13.39
Net Benefit	$2,731	$1,912	$1,238	-$77	-$312	-$488	-$1,201	-$1,202	-$1,178
Benefit-Cost Ratio	**1.75**	**1.66**	**1.55**	**0.99**	**0.94**	**0.88**	**0.84**	**0.80**	**0.75**

Table 34. Results for Retrofitting the Entire U.S. Fleet of Large-Truck SUTs with LDW Systems by High Efficacy (47%), Cost, and Discount Rate

Fleet SUT	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
Equivalent Lives Saved	911	687	500	911	687	500	911	687	500
Vehicle Costs	$2,809	$2,224	$1,725	$5,617	$4,447	$3,451	$6,741	$5,337	$4,141
Training Costs	$829	$673	$526	$829	$673	$526	$829	$673	$526
Total AST Cost	$3,637	$2,896	$2,252	$6,446	$5,120	$3,977	$7,570	$6,010	$4,668
Soc. Savings from Crashworthiness	$204	$154	$112	$204	$154	$112	$204	$154	$112
Congestion, PD and E S	$921	$695	$504	$921	$695	$504	$921	$695	$504
Total Societal Economic Savings	$1,125	$849	$616	$1,125	$849	$616	$1,125	$849	$616
VSL	$8,852	$6,683	$4,851	$8,852	$6,683	$4,851	$8,852	$6,683	$4,851
Total Monetized Savings	$9,978	$7,533	$5,467	$9,978	$7,533	$5,467	$9,978	$7,533	$5,467
Net Cost	$2,512	$2,047	$1,636	$5,321	$4,271	$3,361	$6,444	$5,160	$4,051
Net Cost per Fatal Equivalent	$2.76	$2.98	$3.27	$5.84	$6.21	$6.72	$7.07	$7.50	$8.10
Net Benefit	$6,340	$4,636	$3,215	$3,531	$2,412	$1,489	$2,408	$1,523	$799
Benefit-Cost Ratio	**2.74**	**2.60**	**2.43**	**1.55**	**1.47**	**1.37**	**1.32**	**1.25**	**1.17**

Table 35. Sensitivity Analysis for Retrofitting the Entire Heavy Vehicle U.S. Fleet with LDW Systems using a $13,260,000 VSL by Low Efficacy (30%), Cost, and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All large trucks	3.60	3.43	3.23	2.01	1.93	1.82	1.71	1.64	1.55
Only CUTs	4.24	4.06	3.84	2.37	2.27	2.15	2.01	1.93	1.83
Only SUTs	2.39	2.26	2.11	1.35	1.28	1.20	1.15	1.09	1.02

Table 36. Sensitivity Analysis for Retrofitting the Entire Heavy Vehicle U.S. Fleet with LDW Systems using a $13,260,000 VSL by High Efficacy (47%), Cost, and Discount Rate

Fleet	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All large trucks	5.63	5.38	5.06	3.16	3.02	2.85	2.68	2.57	2.43
Only CUTs	6.64	6.36	6.01	3.71	3.56	3.38	3.15	3.03	2.87
Only SUTs	3.74	3.55	3.31	2.11	2.01	1.88	1.80	1.71	1.60

Table 37. Results for Equipping Only New CUTs with LDW Systems by Low Efficacy (30%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	100	81	64	100	81	64	100	81	64
Vehicle Costs	$152	$134	$117	$304	$268	$235	$364	$322	$282
Training Costs	$68	$57	$46	$68	$57	$46	$68	$57	$46
Total AST Cost	$220	$191	$163	$371	$325	$280	$432	$379	$327
Soc. Savings from Crashworthiness	$19	$16	$12	$19	$16	$12	$19	$16	$12
Congestion, PD and E S	$75	$60	$48	$75	$60	$48	$75	$60	$48
Total Societal Economic Savings	$94	$76	$60	$94	$76	$60	$94	$76	$60
VSL	$962	$779	$618	$962	$779	$618	$962	$779	$618
Total Monetized Savings	$1,056	$855	$679	$1,056	$855	$679	$1,056	$855	$679
Net Cost	$126	$115	$103	$278	$249	$220	$338	$303	$267
Net Cost per Fatal Equivalent	$1.26	$1.42	$1.61	$2.79	$3.09	$3.44	$3.40	$3.76	$4.17
Net Benefit	$836	$664	$515	$684	$530	$398	$624	$476	$351
Benefit-Cost Ratio	**4.81**	**4.48**	**4.16**	**2.84**	**2.63**	**2.42**	**2.44**	**2.26**	**2.07**

Table 38. Results for Equipping Only New CUTs with LDW Systems by High Efficacy (47%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	156	126	100	156	126	100	156	126	100
Vehicle Costs	$152	$134	$117	$304	$268	$235	$364	$322	$282
Training Costs	$68	$57	$46	$68	$57	$46	$68	$57	$46
Total AST Cost	$220	$191	$163	$371	$325	$280	$432	$379	$327
Soc. Savings from Crashworthiness	$30	$24	$19	$30	$24	$19	$30	$24	$19
Congestion, PD and E S	$117	$95	$75	$117	$95	$75	$117	$95	$75
Total Societal Economic Savings	$147	$119	$95	$147	$119	$95	$147	$119	$95
VSL	$1,507	$1,220	$969	$1,507	$1,220	$969	$1,507	$1,220	$969
Total Monetized Savings	$1,654	$1,339	$1,063	$1,654	$1,339	$1,063	$1,654	$1,339	$1,063
Net Cost	$73	$72	$69	$224	$206	$186	$285	$260	$233
Net Cost per Fatal Equivalent	$0.47	$0.57	$0.68	$1.44	$1.63	$1.85	$1.83	$2.06	$2.32
Net Benefit	$1,434	$1,148	$900	$1,283	$1,014	$783	$1,222	$960	$736
Benefit-Cost Ratio	**7.53**	**7.02**	**6.52**	**4.45**	**4.12**	**3.79**	**3.83**	**3.54**	**3.25**

Table 39. Results for Equipping Only New SUTs with LDW Systems by Low Efficacy (30%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	29	24	19	29	24	19	29	24	19
Vehicle Costs	$71	$63	$55	$143	$126	$110	$171	$152	$132
Training Costs	$32	$27	$22	$32	$27	$22	$32	$27	$22
Total AST Cost	$103	$90	$77	$175	$153	$132	$203	$178	$154
Soc. Savings from Crashworthiness	$7	$5	$4	$7	$5	$4	$7	$5	$4
Congestion, PD and E S	$29	$24	$19	$29	$24	$19	$29	$24	$19
Total Societal Economic Savings	$36	$29	$23	$36	$29	$23	$36	$29	$23
VSL	$283	$229	$182	$283	$229	$182	$283	$229	$182
Total Monetized Savings	$318	$258	$205	$318	$258	$205	$318	$258	$205
Net Cost	$67	$61	$54	$139	$124	$109	$167	$149	$131
Net Cost per Fatal Equivalent	$2.32	$2.58	$2.87	$4.78	$5.26	$5.83	$5.76	$6.34	$7.01
Net Benefit	$215	$168	$128	$144	$105	$73	$115	$80	$51
Benefit-Cost Ratio	**3.08**	**2.87**	**2.67**	**1.82**	**1.69**	**1.55**	**1.57**	**1.45**	**1.33**

Table 40. Results for Equipping Only New SUTs with LDW Systems by High Efficacy (47%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	46	37	29	46	37	29	46	37	29
Vehicle Costs	$71	$63	$55	$143	$126	$110	$171	$152	$132
Training Costs	$32	$27	$22	$32	$27	$22	$32	$27	$22
Total AST Cost	$103	$90	$77	$175	$153	$132	$203	$178	$154
Soc. Savings from Crashworthiness	$10	$8	$7	$10	$8	$7	$10	$8	$7
Congestion, PD and E S	$46	$37	$30	$46	$37	$30	$46	$37	$30
Total Societal Economic Savings	$56	$46	$36	$56	$46	$36	$56	$46	$36
VSL	$443	$358	$284	$443	$358	$284	$443	$358	$284
Total Monetized Savings	$499	$404	$321	$499	$404	$321	$499	$404	$321
Net Cost	$47	$44	$41	$119	$107	$96	$147	$133	$118
Net Cost per Fatal Equivalent	$1.03	$1.20	$1.39	$2.60	$2.91	$3.27	$3.23	$3.60	$4.03
Net Benefit	$396	$314	$244	$324	$251	$189	$296	$226	$167
Benefit-Cost Ratio	**4.83**	**4.50**	**4.18**	**2.85**	**2.64**	**2.43**	**2.45**	**2.27**	**2.08**

Table 41. Sensitivity Analysis for Equipping Only New Trucks with LDW Systems using a $13,260,000 VSL by Low Efficacy (30%), Cost, and Discount Rate

Fleet	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All large trucks	5.84	5.44	5.05	3.45	3.19	2.94	2.97	2.74	2.52
Only CUTs	6.61	6.15	5.72	3.91	3.61	3.33	3.36	3.10	2.85
Only SUTs	4.20	3.92	3.64	2.49	2.30	2.12	2.14	1.97	1.81

Table 42. Sensitivity Analysis for Equipping Only New Trucks with LDW Systems using a $13,260,000 VSL by High Efficacy (47%), Cost, and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All large trucks	9.15	8.52	7.91	5.41	5.00	4.60	4.65	4.29	3.94
Only CUTs	10.35	9.64	8.96	6.12	5.66	5.21	5.26	4.86	4.46
Only SUTs	6.59	6.14	5.70	3.89	3.60	3.32	3.35	3.09	2.84