Title

Leveraging Large-Truck Technology and Engineering to Realize Safety Gains:
Video-Based Onboard Safety Monitoring 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 video-based onboard safety monitoring 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, lane departure warning 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.

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List of Abbreviations and Acronyms

Acronym	**Definition**
AAAFTS	American Automobile Association 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
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
OSM	Onboard safety monitoring

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 an advanced safety 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 for all advanced safety technologies (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 analysis: video-based onboard safety monitoring systems, lane departure warning systems, automatic emergency braking systems, and air disc brakes. This report presents the results related to video-based onboard safety monitoring systems. See other AAA Foundation reports for analyses of automatic emergency braking systems, lane departure warning systems, and air disc brakes.

Overview of Video-Based Onboard Safety Monitoring Systems

Video-based onboard safety monitoring systems incorporate in-vehicle video technology that records the environment surrounding the vehicle, as well as the driver's behavior and performance. These types of systems typically have at least one camera but usually have two. One camera records the forward roadway and shows what the driver can see through the front windshield. The second camera faces and records the driver, showing how they behave behind the wheel and respond to driving situations. Some video-based onboard safety monitoring systems incorporate additional cameras. Additional camera feeds may include a rear camera that shows what is behind the vehicle, and rear-facing left-and right-side cameras that show the lanes adjacent to the vehicle.

Video-based onboard safety monitoring systems also capture driver kinematic performance through vehicle telematics. Some of the driving behaviors that these systems can measure and record include speeding, hard braking, rapid acceleration, quick cornering, seat belt use, turn signal use, driver distraction, following distance (if the vehicle is equipped with forward radar), and lane departures (if the vehicle is equipped with a lane departure warning system). This combination of visual and kinematic data provides a wealth of video and vehicle information to pinpoint problems and safe and unsafe behaviors. Most video-based onboard safety monitoring systems continuously monitor the driver whenever the vehicle is on. When a specific threshold is exceeded (e.g., a hard-braking event that exceeds 0.3 g), the system automatically saves a predefined amount of data (e.g., 30 seconds prior to the event and 60 seconds after the event) to the memory card. These safety events in the memory card are used in driver coaching and feedback sessions.

Efficacy and Costs Associated with Video-Based Onboard Safety Monitoring Systems

The literature review only identified two empirical studies that evaluated crash reductions associated with video-based onboard safety monitoring systems. However, eight case studies were found on technology vendor websites. The empirical studies found video-based onboard safety monitoring systems may have prevented 38.1% to 52.2% of large-truck safety-critical events, 20% of large-truck fatal crashes, and 35.5% of large-truck injury crashes. The case studies found that 44% to 86% of safety-critical events may be prevented, and 61% to 80% of crashes may be prevented with video-based onboard safety monitoring systems. No published documents provided costs associated with video-based onboard safety monitoring systems. However, one technology provider shared detailed cost data. These costs are listed below.

- Hardware: $300-$600 (per system)
- Installation: $0-$150 (per system)
- Monthly service fee: $20-$60 (per system)
- Training costs included
- Free integration with other Advanced safety technologies
- Coaching
    - Averages 10 minutes per driver
    - During first two months, approximately 25% of drivers receive coaching
    - After one to two months, only 1% of drivers require coaching
    - On average, one manager is responsible for coaching 75 drivers

Expert Advisory Panel

An Expert Advisory Panel convened May 17, 2016, at the AAA Foundation for Traffic Safety 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, the National Highway Traffic Safety Administration, 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 analyses. Following this discussion, a benefit-cost analysis was recommended for video-based onboard safety monitoring systems, and upper- and lower-bound efficacy rates and costs were selected for video-based onboard safety monitoring systems.

For video-based onboard safety monitoring systems, the advisory panel recommended efficacy rates of 20% and 52.2% to reflect current performance capabilities of video-based onboard safety monitoring systems (instead of systems that were under development). This recommendation was based on current carrier conservative efficacy estimates, Hickman and Hanowski (2012), and Soccolich and Hickman (2014). Additionally, the panel recommended the cost described above for use in the benefit-cost analysis.

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 video-based onboard safety monitoring systems in the trucking industry. Societal benefits of video-based onboard safety monitoring systems associated with a reduction in crashes were compared to the costs of deploying video-based onboard safety monitoring 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:

- Video-based onboard safety monitoring systems' hardware purchase, installation, and financing costs
- Video-based onboard safety monitoring systems' maintenance costs
- Video-based onboard safety monitoring systems' replacement costs
- Costs associated with video-based onboard safety monitoring systems training for drivers and managers
- Costs associated with coaching drivers

To assess the impact video-based onboard safety monitoring systems could have on reducing crash rates (and the costs associated with the systems), national crash databases were used to identify video-based onboard safety monitoring systems' target 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 crashes. The GES database also was used to estimate the number of injuries as a result of injury crashes. Queries were developed for video-based onboard safety monitoring systems 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 video-based onboard safety monitoring systems may have prevented the crash. Whereas other advanced safety technologies prevent specific crash types, video-based onboard safety monitoring systems are applicable to many different crashes, as long as the large-truck driver could have done something to prevent or mitigate the crash. Thus, all large-truck crashes that resulted from an error by the driver of the large truck were included. The research team used the same GES/FARS filtering criteria found in Soccolich and Hickman (2014). The complete list of GES/FARS variables is located in Appendix B.

Two sets of benefit-cost analyses were performed for video-based onboard safety monitoring 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 video-based onboard safety monitoring 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 video-based onboard safety monitoring 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 large trucks (gross vehicle weight rating greater than 10,000 pounds). The second analysis was performed only using class 7 and 8 combination unit trucks (CUTs). The third analysis was performed only using single unit trucks (SUTs) with gross vehicle weight rating greater than 10,000 pounds.

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 Video-Based Onboard Safety Monitoring Systems

Video-based onboard safety monitoring systems were evaluated using a low and high efficacy rate (20% and 52.2%, respectively) and a low, average, and high hardware cost ($350, $525, and $750, respectively). Additionally, monthly service fees and driver coaching costs were incorporated into each analysis. Table 1 shows the benefit-cost ratios for video-based onboard safety monitoring 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 video-based onboard safety monitoring systems. When the costs of video-based onboard safety monitoring systems are equal to the average cost used in the analysis and the discount rate is 0%, the estimated benefits of video-based onboard safety monitoring systems are 4.51 times the estimated costs. However, when the costs of video-based onboard safety monitoring systems are high and the discount rate is 7%, the estimated benefits of video-based onboard safety monitoring systems are 3.13 times the estimated costs.

Table 1. Benefit-Cost Ratios for Video-Based Onboard Safety Monitoring 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	7.90	7.82	7.73	4.51	4.51	4.49	3.13	3.13	3.13
All Large Trucks – Low Efficacy	3.03	3.00	2.96	1.73	1.73	1.72	1.20	1.20	1.20
Only CUTs – High Efficacy	8.62	8.54	8.45	4.93	4.92	4.91	3.42	3.43	3.43
Only CUTs – Low Efficacy	3.30	3.27	3.24	1.89	1.89	1.88	1.31	1.31	1.31
Only SUTs – High Efficacy	6.63	6.56	6.48	3.78	3.77	3.76	2.62	2.63	2.62
Only SUTs – Low Efficacy	2.54	2.51	2.48	1.45	1.45	1.44	1.01	1.01	1.01

Sensitivity analyses were performed with a higher value of a statistical life ($13,260,000) and with a lower value ($5,304,000). As video-based onboard safety monitoring systems were cost-effective in all of the analyses above when installing the systems in the entire U.S. fleet for all trucks and for both single-unit trucks and combination-unit trucks individually, using a higher value of a statistical life in the calculations would only make these systems more cost-effective. Thus, only the results with the lower value of a statistical life are shown below (Table 2). The results with the higher value are shown in Appendix C. Using the $5,304,000 value of a statistical life, video-based onboard safety monitoring systems were still cost-effective, regardless of vehicle classification or system cost, when the high efficacy rate was used in analyses. However, only the low- and average-cost systems were cost-effective using the lower efficacy rate and lower value of a statistical life (the average-cost system was no longer cost-effective for single unit trucks).

Table 2. Sensitivity Analyses for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based Onboard Safety Monitoring 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	4.94	4.90	4.84	2.83	2.82	2.81	1.96	1.96	1.96
All Large Trucks – Low Efficacy	1.89	1.88	1.85	1.08	1.08	1.08	0.75	0.75	0.75
Only CUTs – High Efficacy	5.37	5.32	5.26	3.07	3.07	3.06	2.13	2.13	2.14
Only CUTs – Low Efficacy	2.06	2.04	2.02	1.18	1.18	1.17	0.82	0.82	0.82
Only SUTs – High Efficacy	4.20	4.16	4.10	2.40	2.39	2.38	1.66	1.66	1.66
Only SUTs – Low Efficacy	1.61	1.59	1.57	0.92	0.92	0.91	0.64	0.64	0.64

Results: Only New Large Trucks Equipped with Video-Based Onboard Safety Monitoring Systems

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

Table 3. Benefit-Cost Ratios for Video-Based Onboard Safety Monitoring 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	9.64	10.17	10.74	5.47	5.85	6.27	3.79	4.08	4.39
All Large Trucks – Low Efficacy	3.69	3.90	4.11	2.09	2.24	2.40	1.45	1.56	1.68
Only CUTs – High Efficacy	9.84	10.39	10.97	5.58	5.98	6.40	3.87	4.17	4.48
Only CUTs – Low Efficacy	3.77	3.98	4.20	2.14	2.29	2.45	1.48	1.60	1.72
Only SUTs – High Efficacy	9.19	9.71	10.24	5.21	5.58	5.98	3.62	3.89	4.19
Only SUTs – Low Efficacy	3.52	3.72	3.92	2.00	2.14	2.29	1.39	1.49	1.60

Table 4 shows the sensitivity analyses for only equipping new trucks with video-based onboard safety monitoring systems using the lower value of a statistical life. The results with the higher value are shown in Appendix C. As shown in Table 4, the high efficacy rate still resulted in cost-effective solutions for all cost estimates, regardless of vehicle classification, when using the lower value of a statistical life. The lower efficacy rate also resulted in cost-effective solutions for the low- and average-cost video-based onboard safety monitoring systems with the lower value of a statistical life. However, the high-cost video-based onboard safety monitoring system was only cost-effective at a 7% discount rate when the analysis used both the lower efficacy rate and the lower value of a statistical life.

Table 4. Sensitivity Analyses for Equipping All New Large Trucks with Video-Based Onboard Safety Monitoring 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	6.03	6.37	6.72	3.42	3.66	3.92	2.37	2.55	2.75
All Large Trucks – Low Efficacy	2.31	2.44	2.58	1.31	1.40	1.50	0.91	0.98	1.05
Only CUTs – High Efficacy	6.13	6.48	6.83	3.48	3.72	3.99	2.41	2.60	2.79
Only CUTs – Low Efficacy	2.35	2.48	2.62	1.33	1.43	1.53	0.92	0.99	1.07
Only SUTs – High Efficacy	5.83	6.15	6.49	3.30	3.54	3.79	2.29	2.47	2.65
Only SUTs – Low Efficacy	2.23	2.36	2.49	1.27	1.36	1.45	0.88	0.94	1.02

Discussion

This report presents the scientifically-based estimates of the societal benefits and costs of video-based onboard safety monitoring 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 video-based onboard safety monitoring system. Crashes were identified using 2010 to 2015 GES and FARS data sets. Benefit-cost analyses were performed using varying efficacy rates, vehicle types, system costs, and discount rates (0%, 3%, and 7%).

This project was the first to perform empirical-based benefit-cost analyses on video-based onboard safety monitoring systems. Video-based onboard safety monitoring systems were shown to be cost-effective regardless of their cost and efficacy (within the ranges of cost and efficacy considered) when analyses were performed using a $9.4 million value of a statistical life. Video-based onboard safety monitoring systems were found to have a high benefit-cost ratio of 10.17 when new large trucks were equipped with the technology (with a 3% discount rate). The benefit-cost ratio was even higher when only new combination-unit trucks were equipped with the systems. Despite the significant costs associated with driver coaching, the results of this study suggest that the societal benefit of equipping large trucks with video-based onboard safety monitoring systems, expressed in economic terms, substantially outweigh the associated costs.

Limitations

Although the analyses used to assess the benefits and costs associated with video-based onboard safety monitoring 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 video-based onboard safety monitoring systems. However, the advisory panel consisted of experts with knowledge of current technology research, and as such, the efficacy rates recommended by the panel 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 video-based onboard safety monitoring systems.
- The GES database only included crashes that required a police accident report. However, video-based onboard safety monitoring systems may also prevent less severe crashes. Thus, these additional benefits are not accounted for in the benefit-cost analyses.
- The real-world effectiveness of the systems 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 or driver exonerations. These may be significant cost savings that were not integrated into the analyses.
- The efficacy of video-based onboard safety monitoring relies on carrier management following driver coaching protocols. These protocols include using the data generated by the video-based onboard safety monitoring system for driver coaching. System efficacy and reductions in crashes outlined in this project may not be achieved if coaching protocols are not adhered to.

- The efficacy of video-based onboard safety monitoring 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. For example, 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 achieved may be lower than those used in this study.

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 systems
- Blind spot warning
- Electronic stability control
- Roll stability control
- Speed limiters
- Video-based onboard safety monitoring (OSM) systems
- Kinematic-based OSM 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. This report presents information pertaining to video-based OSM systems. Information about other ASTs examined in this study 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 video-based OSM system features, (ii) a description of the vehicles examined, (iii) the estimated benefits of video-based OSM systems (e.g., reduction in crashes or costs), and (iv) the estimated costs associated with video-based OSM 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 video-based OSM systems on light vehicles was also eliminated from further review. Each relevant document was reviewed to identify the specific video-based OSM 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.). Where 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 video-based OSM systems may vary greatly compared to prior generations. Studies conducted after the year 2000 were given priority over research published before then.

Video-Based Onboard Safety Monitoring Systems

Driver OSM systems incorporate in-vehicle recording technology that can continuously measure and record the driver's performance. Some of the capabilities of OSM systems include the following (Camden, Hickman, & Hanowski, 2015):

- Continuous recording of driver behavior and/or "flagging" a safety-related event
- Saving safety-related event videos for post-trip review (only for video-based OSM systems)
- Integration into a fleet's existing back-office software
- Providing managers with real-time alerts of safety-related events via email and/or text messages

- Providing drivers with immediate in-cab feedback via a visual, auditory, or haptic alert
- Wireless or manual data retrieval

Given these criteria, systems that included some of these features but were only used for crash reconstruction (i.e., similar to a "black box") were not included in this study, as they were not viewed as safety technologies. OSM systems that included immediate feedback and/or a back-office coaching program that proactively attempted to reduce risky driving behaviors were considered safety technologies.

Video-based OSM systems incorporate in-vehicle video technology that records the environment surrounding the vehicle, as well as the driver's behavior and performance. These types of systems typically have at least one camera but usually have two. One camera records the forward roadway and shows what the driver can see through the front windshield. The second camera faces and records the driver and shows how they behave behind the wheel and respond to driving situations. Some video-based OSM systems incorporate additional cameras. Additional camera feeds may include a rear camera that shows what is behind the vehicle, and rear-facing left-and right-side cameras that show the lanes adjacent to the vehicle.

Video-based OSM systems also capture driver kinematic performance through vehicle telematics. They record driving data from the vehicle's sensors or network. Some of the driving behaviors that these systems can measure and record include speeding, hard braking, rapid acceleration, quick cornering, seat belt use, turn signal use, driver distraction, following distance (if the vehicle is equipped with forward radar), and lane departures (if the vehicle is equipped with a lane departure warning system). This combination of visual and kinematic data provides a wealth of video and vehicle information to pinpoint problems and safe and unsafe behaviors. Most video-based OSM systems continuously monitor the driver whenever the vehicle is on. When a specific threshold is exceeded (e.g., a hard-braking event that exceeds 0.3 g), the system automatically saves a predefined amount of data (e.g., 30 seconds prior to the event and 60 seconds after the event) to the memory card. These safety events in the memory card are used in driver coaching and feedback sessions. Additionally, some video-based OSM systems have wireless capabilities that allow daily wireless transfers of the saved safety events to a driver's manager.

Crash Reductions Associated with Video-Based Onboard Safety Monitoring Systems

The literature review only identified two empirical studies that evaluated crash reductions associated with video-based OSM systems. However, eight case studies were found on technology vendor websites. The total 10 studies are summarized below. Only those systems that included driver coaching and/or feedback were included in the literature review.

Hickman and Hanowski (2010) evaluated the safety benefits of a video-based OSM system in two large truck fleets. They found the combination of an OSM system with driver feedback and coaching resulted in a 52.2% reduction in SCEs per 10,000 miles. Furthermore, the most severe SCEs were reduced by 59.1%. Results also showed the in-cab feedback light alone or coaching sessions that did not include a review of the video(s) were insufficient to significantly reduce the mean rate of safety-related events. Finally, the study found that drivers with the most severe safety-related events (i.e., DriveCam Program event score greater than 3) reaped the most benefits from the combination of data pulled from the OSM system and driver feedback and coaching.

Soccolich and Hickman (2014) modeled the potential safety benefits of video-based OSM systems on all large trucks in the U.S. by comparing the safety benefits found in Hickman and Hanowski (2010) to the large-truck crashes in GES. The study found that a video-based OSM system paired with driver coaching could prevent an average of 727 fatal truck and bus crashes (20.5% of the total fatal crashes) and save 801 lives (20.0% of the total fatalities), reduce an estimated 25,000 truck and bus injury crashes (35.2% of the total injury crashes), and eliminate approximately 39,000 injuries (35.5% of the total injuries) each year.

Lytx® (formerly DriveCam®) provided five case studies on its website regarding the crash reductions associated with the DriveCam® program (a video-based OSM system). AmeriGas installed the DriveCam® program in its entire large-truck fleet, which consists of 3,000 trucks hauling hazardous materials (Lytx®, 2016a). AmeriGas reported the DriveCam® program reduced its crashes and safety-related events by 55%. In a second case study, Cargo Transporters, a large for-hire commercial motor carrier, reported reductions in rear-end crashes; however, specific numbers were not provided (Lytx®, 2016b). A third case study reviewed the effects of the DriveCam® program at Cox Petroleum Transport (Lytx®, 2016c). After implementing the DriveCam® program on 100 tractor-tankers, Cox Petroleum Transport had an 80% reduction in at-fault crashes in the first year. Several years later, Cox Petroleum Transport only had two at-fault crashes in 14 million miles traveled. The fourth case study reported the results of Monarch Beverage Co.'s success with the DriveCam® program (Lytx®, 2016d). The DriveCam® program helped Monarch Beverage reduce the number of SCEs per month from 358 to 50 (an 86% reduction) in only a few months. The final case study examined the effectiveness of the DriveCam® program at Salmon Companies (Lytx®, 2016e). Salmon Companies implemented DriveCam® on 225 large trucks that traveled an average of 14 million miles per month. They found the DriveCam® program reduced their drivers' risky driving behaviors by 44% in six months.

SmartDrive® also provided three case studies on its website on the crash reduction from its SmartDrive® program. The first case study reviewed the safety benefits of the SmartDrive® program at Reynolds Catering (SmartDrive®, 2013a). Reynolds Catering installed SmartDrive® in its entire fleet of 180 large trucks. The fleet experienced a 61% reduction in crashes. A second case study assessed the safety benefits of SmartDrive® at Verst Group Logistics (SmartDrive®, 2013b). Verst Group Logistics reported a downward trend in crashes with the SmartDrive® program (no percentage provided) and zero DOT-reportable crashes in 2012 (no percentage change provided). The final case study was from West Horsely Dairy (SmartDrive®, 2013c). West Horsely Dairy installed SmartDrive® on its entire fleet and experienced a 66% reduction in crashes.

Video-Based Onboard Safety Monitoring System Costs

The purchase price for video-based OSM systems was not found in the published literature. However, Hickman and Hanowski (2010) estimated that video-based OSM systems cost less than $1,000 per vehicle. A number of the case studies did provide some cost data in savings related to driver exonerations, reduced litigation costs, crash costs, and fuel economy. The authors of this report contacted four video-based OSM system technology providers. Only one of these vendors eventually provided detailed cost data. These costs include:

- Hardware: $300–$600 (per system)
- Installation: $0–$150 (per system)
- Monthly Service Fee: $20–$60
- Training costs included
- Free integration with other ASTs
- Coaching
  - Averages 10 minutes per driver
  - During first two months, approximately 25% of drivers receive coaching
  - After one to two months, only 1% of drivers require coaching
  - On average, one manager is responsible for coaching 75 drivers

Literature Review Conclusions

The published literature was reviewed to identify the costs and benefits associated with large-truck video-based OSM systems. Appendix A provides a summary of citations for video-based OSM systems. The literature review only identified two empirical studies that estimated the efficacy of large-truck video-based OSM systems in reducing crashes. However, eight case studies were found on technology vendor websites. The empirical studies found video-based OSM systems may prevent 38.1% to 52.2% of large-truck safety critical events (SCEs), 20% of large-truck fatal crashes, and 35.5% of large-truck injury crashes. The case studies found that 44% to 86% of SCEs may be prevented and 61% to 80% of crashes may be prevented with video-based OSM systems. Additionally, cost data were obtained from one video-based OSM system vendor. This vendor indicated the costs of video-based OSM systems ranged from $300 to $750 (including installation) with monthly service fees ranging from $20 to $60 per truck.

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 video-based OSM 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 crash 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 video-based OSM systems, the advisory panel recommended using efficacy rates of 20% (low) and 52.2% (high) to reflect current performance capabilities of video-based OSM systems (as opposed to systems that were under development). This recommendation was based on current carrier conservative efficacy estimates, Hickman and Hanowski (2012), and Soccolich and Hickman (2014). Additionally, the panel recommended a hardware cost of $525 (including installation) and a $40 monthly service fee per truck based on information supplied by a video-based OSM system vendor and carrier feedback.

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.

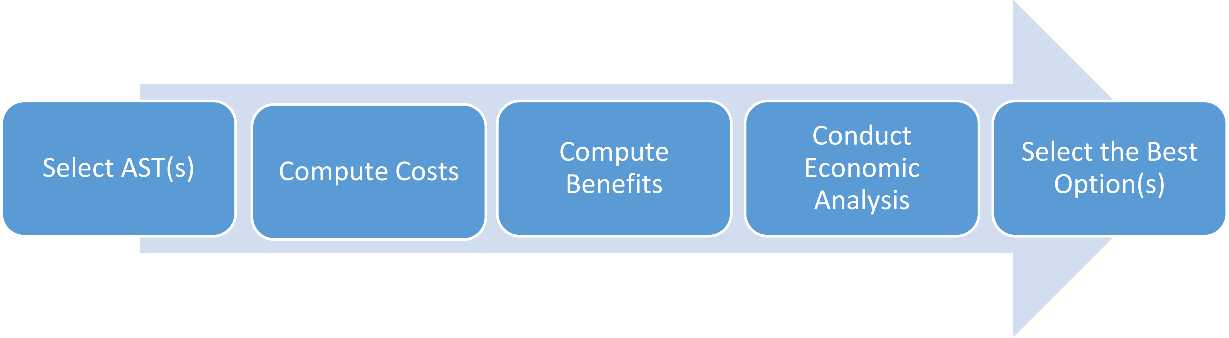

Figure 1. Economic analysis steps.

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 video-based OSM 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 video-based OSM 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 video-based OSM 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 different 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 video-based OSM systems. The first option assumed that the agency did not issue any new rules regarding the adoption of video-based OSM systems. These are the baselines against which costs and benefits were computed. The second option for video-based OSM systems assumed rules were issued mandating their deployment. In addition, two sets of BCAs were performed for video-based OSM systems. The first set of analyses assumed all large trucks would be equipped with video-based OSM systems. In other words, these analyses assumed all new trucks would be equipped with video-based OSM systems, and all old trucks would be retrofitted. The second set of analyses only assumed new trucks would be equipped with video-based OSM 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 video-based OSM 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 video-based OSM 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 video-based OSM system at operational levels, including a monthly service fee or time for coaching sessions. The cost of the installation and deployment of each video-based OSM system per truck/driver per year is computed as:

$$COSM_y = OSM_y + I_y + T_y + M_y$$

where $COSM_y$ is the total cost of installation and deployment of video-based OSM system per truck for year y; y is the year of the analysis period (0, 1, 2…n); OSM_y is the cost of the video-based OSM system for year y; I_y is the initial installation cost of the video-based OSM 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 video-based OSM system hardware are directly related to the number of trucks where the technology will be implemented, whereas other costs (e.g., training and driver coaching costs) are related to the number of drivers.

Technology Costs

The cost of the technology is usually the most significant cost in AST implementation. However, this did not hold true for video-based OSM systems. This was due to a combination of factors, such as the relatively initial low cost of the technology, and the monthly fees that are recurrent each year the truck is operative with the system functioning.

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 video-based OSM systems (i.e., the technology provider allocated these costs over the life of the technology).

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 represented the average for the range of costs provided by the video-based OSM system vendor. For example, in the case of video-based OSM systems, the lower and higher costs (including installation) reported by the technology vendor varied between $300 and $750. The monthly service fee ranged from $20 to $60. After careful consideration, the advisory panel recommended a video-based OSM system hardware value of $525 (including installation) and a $40 monthly service fee as a base for the analysis. This cost was adopted as the average value. The lower and upper costs were determined by the lower and upper costs, respectively, provided by the technology vendor.

The cost of video-based OSM systems was related not only to the number of units produced, but also the manufacturer's experience in producing the video-based OSM 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 the 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 the training 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 video-based OSM systems. Three factors influence the needed recurrent training in further years: the complexity of video-based OSM systems, the driver attrition rate in the industry (assumed to be 100%), and the point at which the video-based OSM 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 video-based OSM 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.

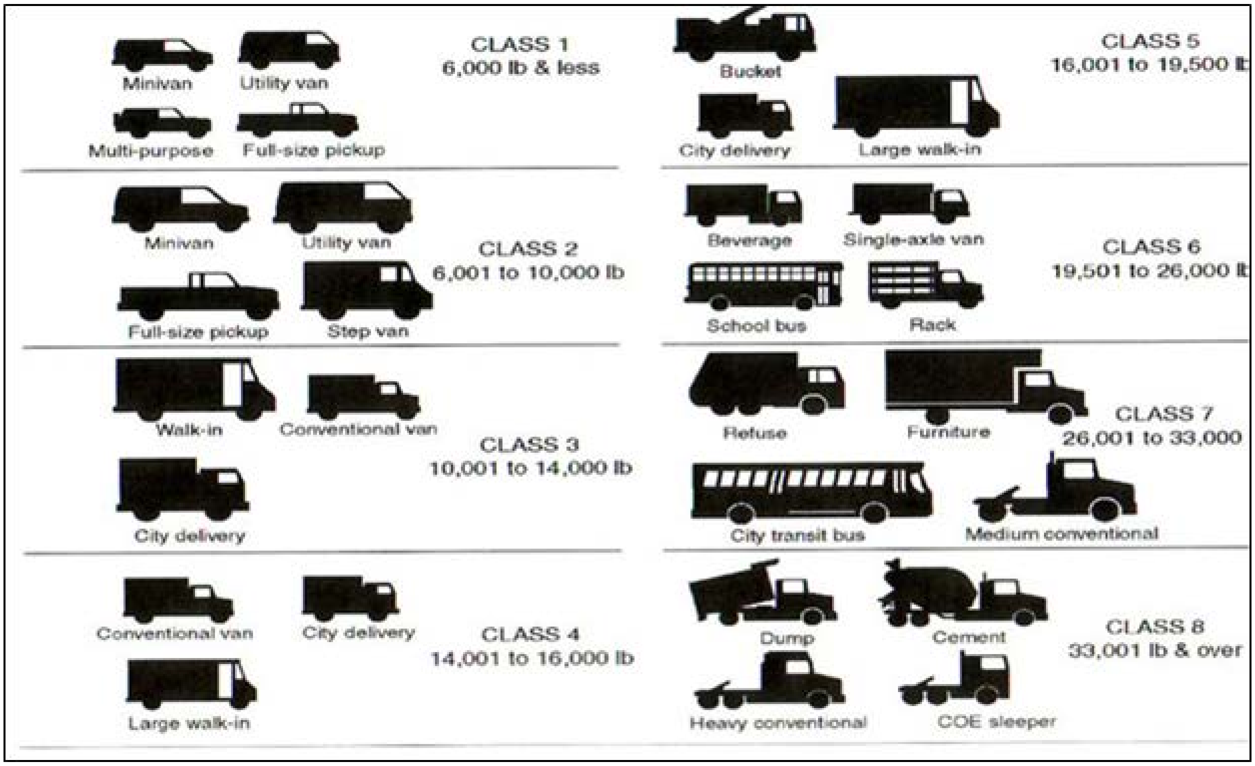

Figure 2. Truck classifications by gross vehicle weight.

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 all medium and large trucks (excluding buses) with a GVWR greater than 10,000 pounds to match the vehicle populations used in Soccolich and Hickman (2014).

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 GWVR 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 number of miles per SUT of 13,123. 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.

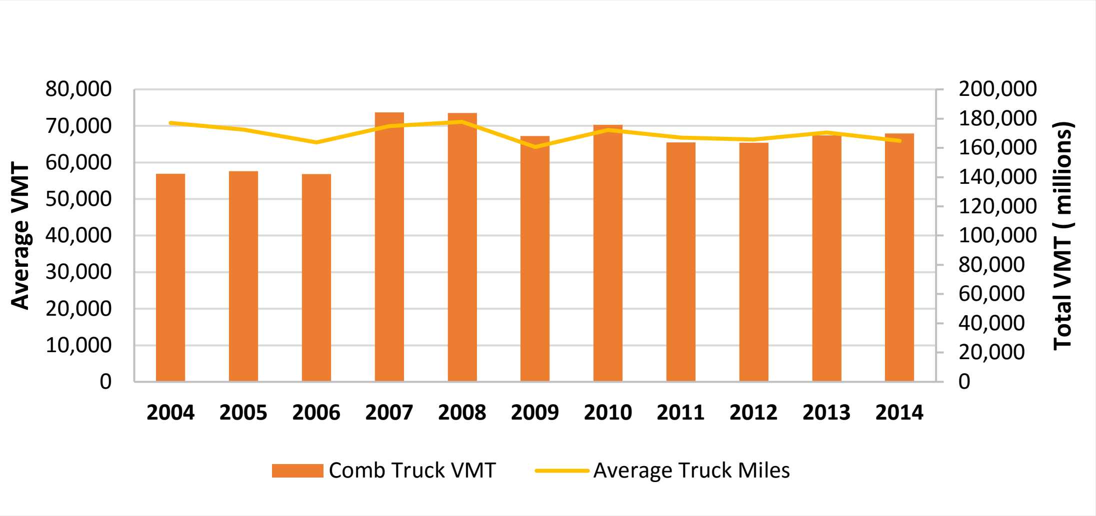

Figure 3. Total VMT (in millions) and average miles per CUT.

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 age of the vehicle. 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.

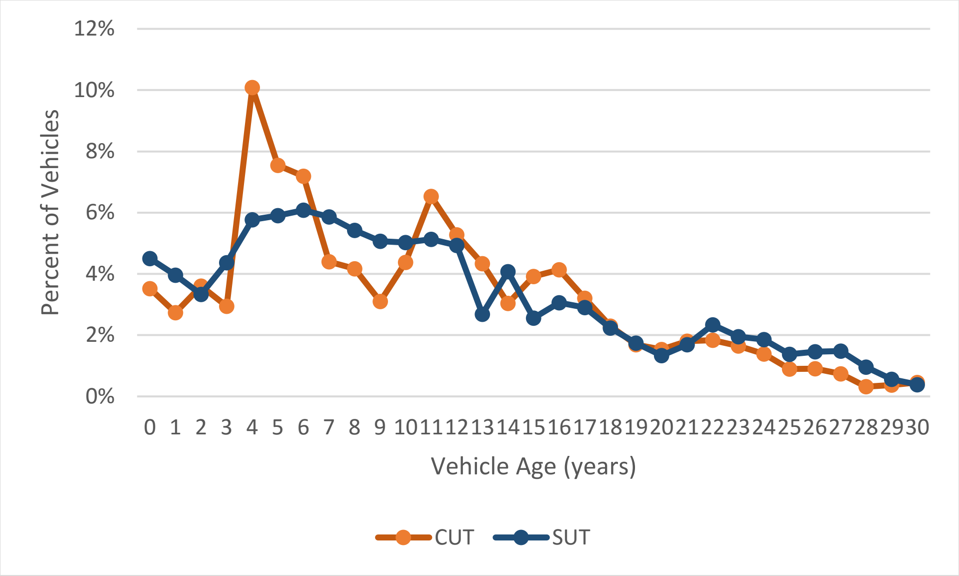

Figure 4. Percent of SUTs and CUTs by vehicle age.

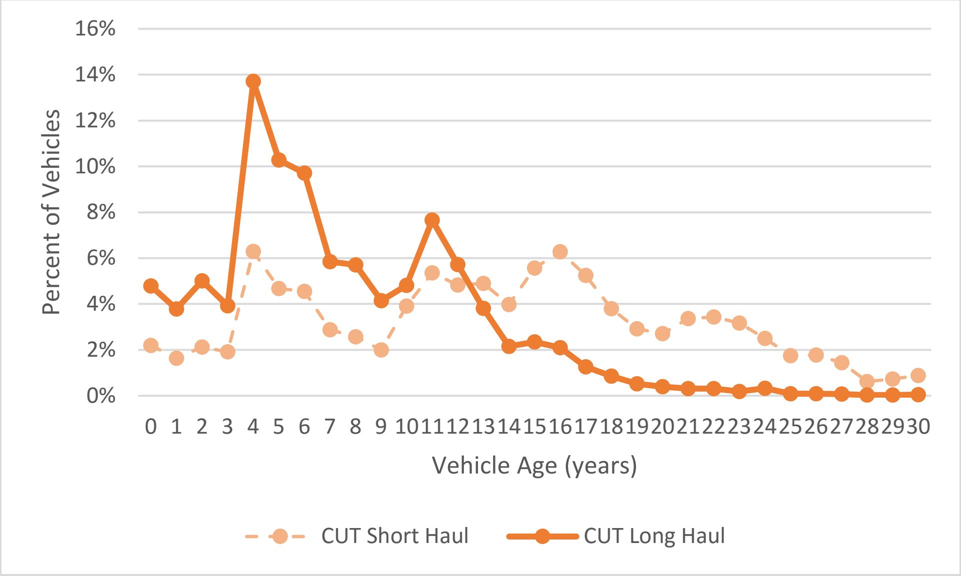

Figure 5. Percent of CUT age by operation type.

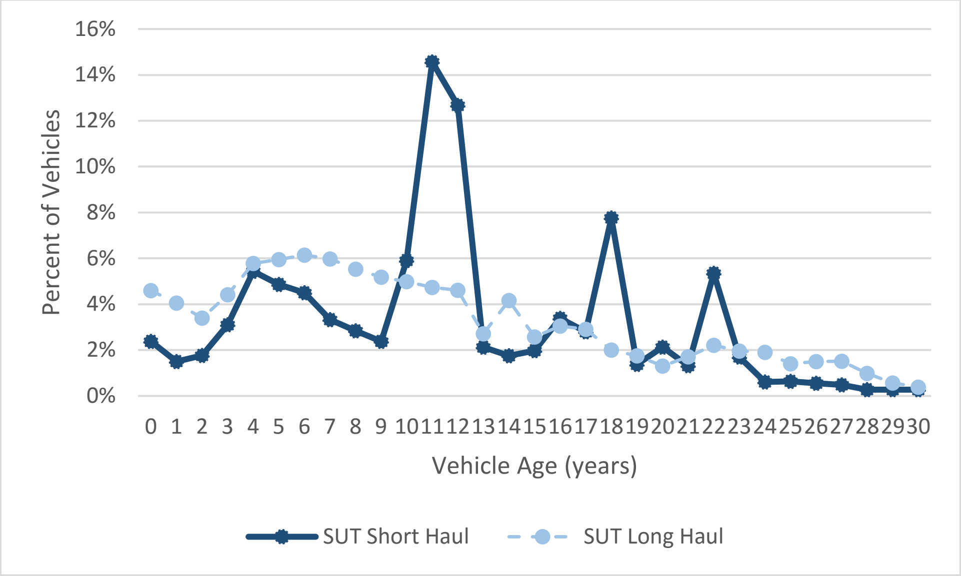

Figure 6. Percent of SUTs by operation.

Regarding future truck populations, the U.S. Energy Information Administration (2016) predicts an annual increase of 1.5% in the number of 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 (Cullen, 2014; 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

As described above, two options were formulated to assess the potential cost of video-based OSM systems: no video-based OSM system deployment and video-based OSM 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 those benefits. 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 video-based OSM systems were computed as the difference in number of crashes/number of injury severity types (fatality equivalent) for both options (without mandatory video-based OSM system deployment and with mandatory video-based OSM 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 video-based OSM 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 video-based OSM system deployment; N_{jiN} was the number of crashes/injuries by severity *i* with mandatory video-based OSM 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 video-based OSM systems, the research team identified the types of crashes that were preventable by video-based OSM systems and selected the efficacy rate of video-based OSM systems.

Types of Crash/Crash Scenarios Preventable by Video-Based Onboard Safety Monitoring Systems

Video-based OSM systems have the capability to prevent only some types of crashes/crash scenarios. Specifically, the installation of a video-based OSM system is expected to reduce preventable large-truck crashes that occurred due to an error by the large-truck driver. In general, the crashes preventable by video-based OSM systems exclude crashes when the driver is incapacitated or crashes due to vehicle malfunctioning (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 video-based OSM systems only be considered effective at preventing large-truck crashes that likely occurred due to an error or behavior of the large-truck driver. Any future descriptions of crashes prevented by video-based OSM systems refer back to these crash types only.

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 video-based OSM 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. It 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 video-based OSM 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 video-based OSM systems may have prevented the crash. Whereas other ASTs prevent specific crash types, video-based OSM systems are applicable to many different crashes, as long as the large-truck driver could have done something to prevent or mitigate the crash. Thus, all large-truck preventable crashes that resulted from an error of the large-truck driver were included. The research team used the same GES/FARS filtering criteria found in Soccolich and Hickman (2014). The complete list of GES/FARS variables is located in Appendix B.

The research team generated the two matrixes shown in Table 7 and Table 8. The GES and FARS used a five-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. 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 Table 7 and Table 8 corresponds to crashes that may be prevented by video-based OSM systems if the efficacy rate is 100%. In order to realistically estimate the number of crashes that may be prevented by video-based OSM system deployment, the video-based OSM system efficacy rate must be considered.

Efficacy of Video-Based Onboard Safety Monitoring Systems

The efficacy rate of video-based OSM 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 the 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 video-based OSM systems at the time of this study.

Expected Number of Crashes/Injuries/Fatalities Preventable by Video-Based Onboard Safety Monitoring Systems

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

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

where, N_{jibase} was the number of type *j,* category *i* crashes preventable by a video-based OSM 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 a video-based OSM system; OSM_{effj} was the efficacy of a video-based OSM 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 as 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 was chosen. This approach, which assumed 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 yielded lower cost-effectiveness estimates to reflect the video-based OSM system benefits with the systems acting on a lower baseline crash rate.

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 damages, 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 Cost Per Victim Per Severity Type

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	$279conbs,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 video-based OSM 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 video-based OSM 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 a video-based OSM 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.

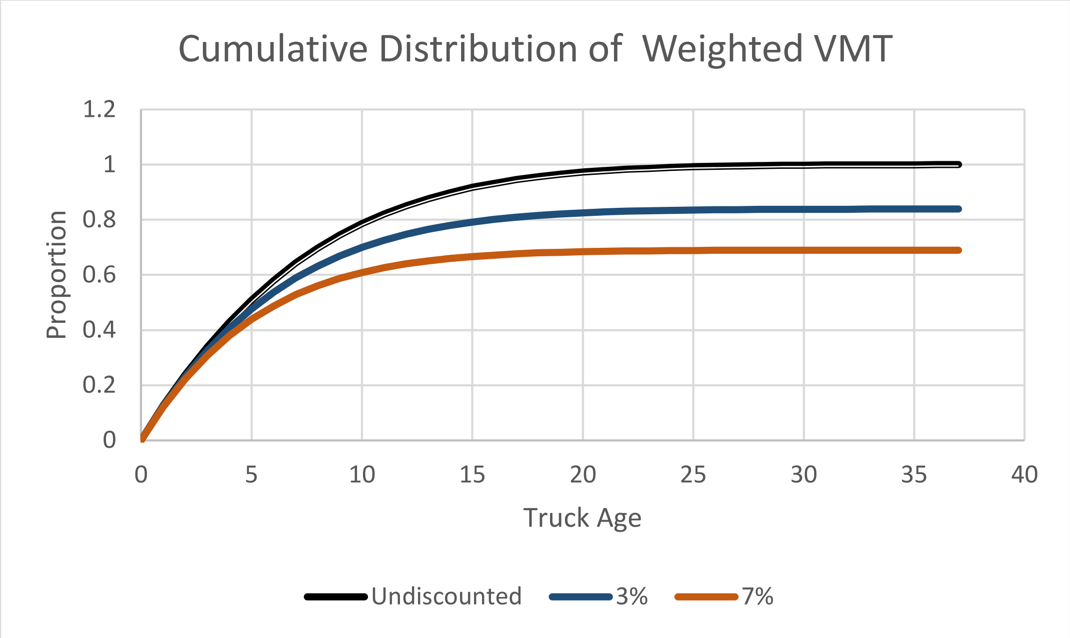

Figure 7. Distribution of weighted VMT by survival rate as a surrogate of probability of crash occurrence.

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 video-based OSM 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 a video-based OSM 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 video-based OSM systems, and $Crash\ Costs_{y1}$ were the expected crash costs for the year y with mandatory deployment of video-based OSM 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 video-based OSM system for the year y with mandatory deployment; $Cost_{y0}$ is the expected total cost of installing and operating the video-based OSM 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 video-based OSM system are higher than the costs incurred in buying, installing, and maintaining the video-based OSM 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 video-based OSM systems over a period of analysis n assuming a rate of return r; B_y is the benefit associated with implementing video-based OSM systems in year y; Cy is the cost associated with implementing video-based OSM 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 video-based OSM 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 video-based OSM systems over a period of analysis n and a rate or return r; NCy was the net cost associated with implementing video-based OSM systems in year y; EF_y was the benefit associated with implementing video-based OSM 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 video-based OSM systems and the results of the BCA.

Technology and Deployment Costs Per Truck

In a BCA, the costs associated with implementing video-based OSM 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 video-based OSM system's normal maintenance costs are very small and may be covered in the routine maintenance of the truck. Additionally, video-based OSM systems have costs associated with monthly service fees and driver coaching. The driver coaching costs, in particular, were found to be a substantial cost.

As discussed above, the initial cost of video-based OSM systems can be divided into hardware and installation costs. The costs of the system hardware ranged from $300 to $600 plus installation costs ranging from $50 to $150 per vehicle. However, many carriers install the system themselves to avoid the installation cost. According to video-based OSM system providers, self-installation was a preferred option, especially among larger carriers. In this study, the total hardware costs for video-based OSM systems ranged from $350 ($300 minimum hardware cost plus $50 minimum cost of installation) to $750 ($600 maximum hardware costs plus $150 maximum cost installation). The average hardware cost was $525 ($450 average hardware cost plus $75 average cost of the installation). Additionally, the monthly fee for video-based OSM system service ranged from $20 to $60. This translates to an annual cost equivalent of $240 to $720 per truck.

According to video-based OSM system providers, approximately 25% of drivers receive coaching after the installation of the system. This is reduced dramatically after the first or second month where only 1% to 2% of the drivers receive coaching. For the purpose of this analysis, it was assumed that 25% of drivers received one coaching session per week for the first month or one coaching session per driver per month. By the second month, 10% of drivers received one coaching session per week. Following the second month, only 2% of drivers received a coaching session each week. Thus, every driver averaged one coaching session during the first month after installation, 0.4 coaching sessions during the second month, and 0.88 (44 weeks * 0.02) coaching sessions per month for every subsequent month. This totals 2.28 coaching sessions per driver per year. Previous research (Hickman & Hanowski, 2010) found coaching sessions lasted 10 minutes. This study assumed coaching sessions lasted 20 minutes to account for lost time. Thus, each driver averaged 0.76 hours of coaching per year. This time was multiplied by the cost per hour per driver plus the cost per hour per manager. A safety manager's salary was found to be $43.51 per hour, which corresponded to the 75th percentile of the driver salary in job category 53-3032 from Occupational Employment Statistics (BLS, 2016), multiplied by fringe benefits and overhead. The fringe benefits were obtained from the Employer Cost for Employee Compensation (BLS, 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 video-based OSM systems with an increase in the number of training hours from one hour per driver per year to one and a half to two hours per driver per year, driver retention rates of 200% and 50%, and different discount rates. Unlike other ASTs, the equipment costs were relatively low for video-based OSM systems. Thus, there was a greater impact on variability in training. For example, a sensitivity analysis including the average hardware cost of $525, a discount rate of 0%, a service life of 10 years (with one replacement), and the cost for one, one and a half, or two hours of training per driver resulted in a total cost per truck of $1,521, $1,757 and $1,993. The analysis using the upper bound cost estimate ($750) with one hour of training resulted in a total cost per truck of $1,970 (approximately equal to the average price system with two hours of training). However, it is important to remember that the highest cost for video-based OSM systems was the monthly service fee and driver coaching.

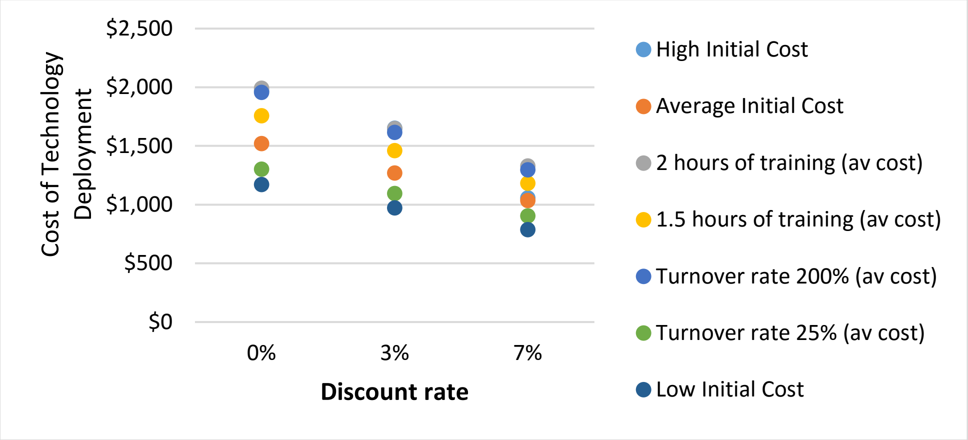

Figure 8. Impact of number of training hours and retention rates for different costs and video-based OSM system discount rates.

Crash Target Population

The initial target population was the estimated number of large-truck preventable crashes related to an error or behavior of the large-truck driver, and the associated fatalities and injuries that would be prevented if all large trucks were equipped with video-based OSM systems. The research team used the 2010 to 2015 GES and the FARS databases to determine these numbers of 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.

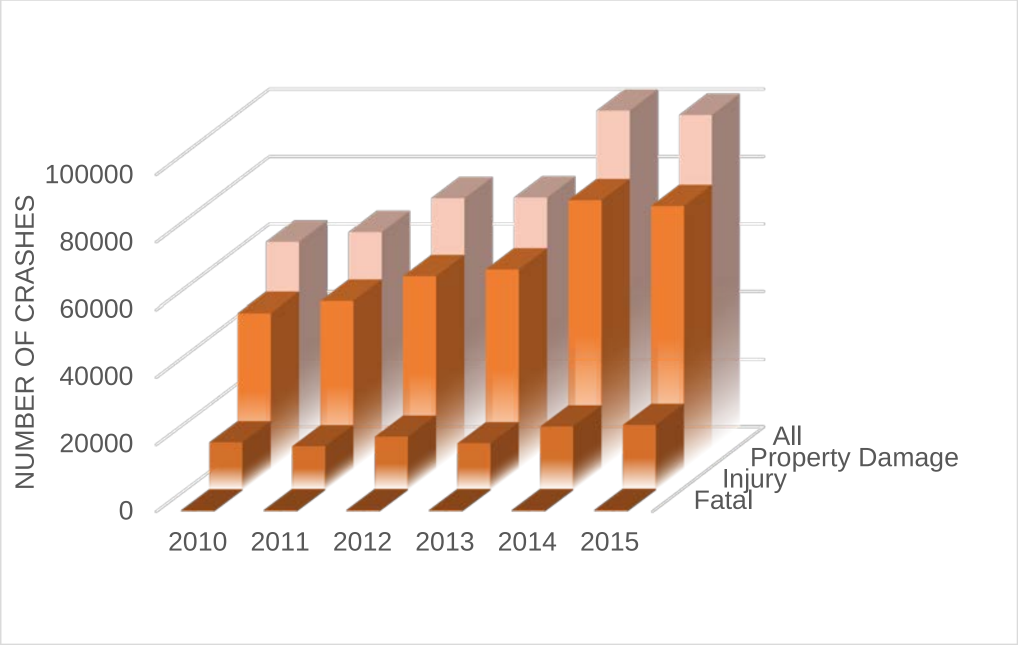

Figure 9. Number of large-truck crashes that may be prevented by video-based OSM systems (Data from 2010 to 2015 GES and FARS).

As shown in Table 16 below, the installation of the large-truck video-based OSM system has the potential to reduce an annual maximum of 121,154 crashes. Of those crashes, 0.42% correspond to fatal crashes, 19.56% to injury crashes, and 80.02% to PDO crashes. As a result of these crashes, video-based OSM systems were associated with a maximum reduction of 561 fatalities and 33,971 injuries.

Table 16. Maximum Number of Crashes That May Be Preventable by Large Truck Video-Based OSM Systems, by Severity (Data from 2010 to 2015 GES and FARS)

	Number of Crashes	Percent of Total Crashes
Fatal	511	0.42%
Injury	23,700	19.56%
PDO	96,943	80.02%
Total Crashes	121,154	100%

Effectiveness of Video-Based Onboard Safety Monitoring Systems

The efficacy rate of the video-based OSM 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 20% and 52.2%, respectively. Real-world efficacy may differ based on crash severity, but data limitations precluded separate efficacy estimates for video-based OSM systems at this time.

Table 17 and Table 18 below show the low, high, and maximum number of crashes and injuries that may be prevented by large-truck video-based OSM systems. On average, large-truck video-based OSM systems may prevent 66 to 103 fatal crashes, 782 to 1,225 injury crashes, and 3,220 to 5,045 property damage crashes each year. These crashes were associated with 76 to 115 fatalities, 103 to 162 suspected serious injuries, 366 to 573 suspected minor injuries, and 371 to 581 possible injuries.

Table 17. Average Number of Crashes by Efficacy Rate That May Be Prevented Each Year with a Large-Truck Video-Based OSM System (Data from 2010 to 2015 GES and FARS)

Crash Severity	Number of Crashes		
	Low Efficacy (20%)	High Efficacy (52%)	Maximum Efficacy
Fatal	102	267	511
Injury	4,740	12,371	23,700
Property Damage	19,389	50,604	96,943
Total	24,231	63,243	121,154

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

Injury Severity	Number of Injuries		
	Low Efficacy (20%)	High Efficacy (52%)	Maximum Efficacy
Fatal Injury (K)	112	293	561
Suspected Serious Injuries (A)	682	1,780	3,409
Suspected Minor injury (B)	2,287	5,970	11,436
Possibly Injury (C)	3,565	9,304	17,824
Injury Severity Unknown	260	679	1,301

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 a video-based OSM system in a large truck may prevent 373 to 975 MAIS 1–5 fatal equivalents in addition to the 112 to 293 fatalities, for a total of 485 to 1,268 fatality equivalents prevented each year (Table 19).

Table 19. Number of Fatal Equivalents Per Year by Efficacy Rate for Video-Based OSM Systems (Data From 2010 to 2015 GES and FARS)

	Low Efficacy (20%)		High Efficacy (52%)	
	MAIS	**Fatal Equivalent**	**MAIS**	**Fatal Equivalent**
Minor (MAIS 1)	7,540	226	19,678	590
Moderate (MAIS 2)	1,411	66	3,682	173
Serious (MAIS 3)	223	23	581	61
Severe (MAIS 4)	175	47	457	122
Critical (MAIS 5)	19	11	49	29
Unsurvivable (MAIS 6)	112	112	293	293
Total Fatal Equivalents		**485**		**1,268**

Cost of Crashes

Table 20 shows the annual costs of the crashes that may be prevented with video-based OSM 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 17 and Table 18, respectively.

Table 20. Average Annual Cost of Crashes and Their Associated Injuries

	Low Efficacy (20%)	High Efficacy (52%)	100% Efficacy
Number of fatalities	112	293	561
Societal economic cost of crashworthiness	$160,445,701	$418,763,279	$802,228,504
Congestion, property damage and environmental savings	$610,833,811	$1,594,276,247	$3,054,169,055
Societal economic costs	$771,279,512	$2,013,039,526	$3,856,397,559
Monetized QALY	$4,654,842,688	$12,149,139,416	$23,274,213,441
Total monetized value per year	$5,426,122,200	$14,162,178,942	$27,130,611,000

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 large trucks with a GVWR greater than 10,000 pounds. The second analysis was performed only using class 7 and 8 CUTs. The third analysis was performed only using SUTs with a GVWR greater than 10,000 pounds. Only the analyses for all large trucks are shown below. The analyses for CUTs and SUTs are in Appendix C.

New and Old Large Trucks are Equipped with Video-Based Onboard Safety Monitoring Systems

This section describes the BCA, which assumed all large trucks (new and old) would be equipped with video-based OSM 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 21 shows the BCA using the low efficacy rate (20%) for all large trucks equipped with video-based OSM systems. For the lower efficacy rate, all cost estimates were shown to be cost-effective with the potential to save between 5,333 and 9,717 equivalent lives over six years when all large trucks are equipped with video-based OSM systems. The low-cost estimate had BCRs ranging from 2.96 to 3.03 (net cost per fatality equivalent ranged from $2.10 million to $2.18 million). The average cost estimate had BCRs ranging from 1.72 to 1.73 (net cost per fatality equivalent ranged from $4.87 million to $4.89 million). The high-cost estimate had a BCR of 1.20 (net cost per fatality equivalent ranged from $7.70 million to $7.72 million).

Table 21. Results for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based OSM Systems: Low Efficacy (20%), by Cost and Discount Rate

Fleet CUT + SUT > 10,000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	9,717	7,336	5,333	9,717	7,336	5,333	9,717	7,336	5,333
Vehicle Costs	$5,762	$4,523	$3,473	$8,642	$6,784	$5,210	$12,346	$9,691	$7,443
Training Costs	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431
Total AST Cost	$35,871	$27,337	$20,080	$62,762	$47,462	$34,548	$90,475	$68,233	$49,512
Soc. Savings from Crashworthiness	$3,209	$2,423	$1,758	$3,209	$2,423	$1,758	$3,209	$2,423	$1,758
Congestion, PD and E S	$12,217	$9,223	$6,694	$12,217	$9,223	$6,694	$12,217	$9,223	$6,694
Total Societal Economic Savings	$15,426	$11,646	$8,452	$15,426	$11,646	$8,452	$15,426	$11,646	$8,452
VSL	$93,097	$70,283	$51,010	$93,097	$70,283	$51,010	$93,097	$70,283	$51,010
Total Monetized Savings	$108,522	$81,929	$59,462	$108,522	$81,929	$59,462	$108,522	$81,929	$59,462
Net Cost	$20,445	$15,692	$11,628	$47,336	$35,817	$26,096	$75,050	$56,588	$41,060
Net Cost per Fatal Equivalent	$2.10	$2.14	$2.18	$4.87	$4.88	$4.89	$7.72	$7.71	$7.70
Net Benefit	$72,651	$54,592	$39,382	$45,761	$34,467	$24,914	$18,047	$13,696	$9,950
Benefit-Cost Ratio	**3.03**	**3.00**	**2.96**	**1.73**	**1.73**	**1.72**	**1.20**	**1.20**	**1.20**

Table 22 shows the BCA using a higher efficacy rate (52.2%) for all large trucks equipped with video-based OSM systems. The high efficacy resulted in all cost estimates being cost-effective with the potential to save 13,920 to 25,361 equivalent lives over six years when all large trucks are equipped with a video-based OSM system. The low-cost estimate had BCRs that ranged from 7.73 to 7.90 (net costs per fatality equivalent were $0). The average cost estimate had BCRs that ranged from 4.49 to 4.51 (net cost per fatality equivalent ranged from $0.89 million to $0.90 million). The high-cost estimate had a BCR of 3.13 (net cost per fatality equivalent ranged from $1.97 million to $1.98 million).

Table 22. Results for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based OSM Systems: High Efficacy (52%), by Cost and Discount Rate

Fleet CUT + SUT > 10,000 pounds	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	25,361	19,147	13,920	25,361	19,147	13,920	25,361	19,147	13,920
Vehicle Costs	$5,762	$4,523	$3,473	$8,642	$6,784	$5,210	$12,346	$9,691	$7,443
Training Costs	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431	$2,253	$1,829	$1,431
Total AST Cost	$35,871	$27,337	$20,080	$62,762	$47,462	$34,548	$90,475	$68,233	$49,512
Soc. Savings from Crashworthiness	$8,375	$6,323	$4,589	$8,375	$6,323	$4,589	$8,375	$6,323	$4,589
Congestion, PD and E S	$31,886	$24,072	$17,471	$31,886	$24,072	$17,471	$31,886	$24,072	$17,471
Total Societal Economic Savings	$40,261	$30,395	$22,060	$40,261	$30,395	$22,060	$40,261	$30,395	$22,060
VSL	$242,983	$183,440	$133,137	$242,983	$183,440	$133,137	$242,983	$183,440	$133,137
Total Monetized Savings	$283,244	$213,835	$155,197	$283,244	$213,835	$155,197	$283,244	$213,835	$155,197
Net Cost	-$4,390	-$3,058	-$1,980	$22,501	$17,067	$12,488	$50,215	$37,838	$27,452
Net Cost per Fatal Equivalent	-0.17	-0.16	-0.14	0.89	0.89	0.90	1.98	1.98	1.97
Net Benefit	$247,373	$186,497	$135,117	$220,482	$166,372	$120,649	$192,768	$145,601	$105,684
Benefit-Cost Ratio	**7.90**	**7.82**	**7.73**	**4.51**	**4.51**	**4.49**	**3.13**	**3.13**	**3.13**

Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based Onboard Safety Monitoring Systems

Sensitivity analyses were performed for all vehicle classifications and a $13,260,000 VSL and $5,304,000 VSL. As video-based OSM systems were cost-effective in each 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 23 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. The average-cost estimate was only cost-effective for all large trucks and CUTs. The high-cost estimate was not cost-effective.

Table 23. Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based OSM Systems with a $5,304,000 VSL: Low Efficacy (20%) by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	1.89	1.88	1.85	1.08	1.08	1.08	0.75	0.75	0.75
Only CUTs	2.06	2.04	2.02	1.18	1.18	1.17	0.82	0.82	0.82
Only SUTs	1.61	1.59	1.57	0.92	0.92	0.91	0.64	0.64	0.64

Table 24 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, regardless of vehicle classification.

Table 24. Sensitivity Analysis for Retrofitting the Entire U.S. Fleet of Large Trucks with Video-Based OSM Systems with a $5,304,000 VSL: High Efficacy (52%) by Cost and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	4.94	4.90	4.84	2.83	2.82	2.81	1.96	1.96	1.96
Only CUTs	5.37	5.32	5.26	3.07	3.07	3.06	2.13	2.13	2.14
Only SUTs	4.20	4.16	4.10	2.40	2.39	2.38	1.66	1.66	1.66

Only New Large Trucks are Equipped with Video-Based Onboard Safety Monitoring 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 25). The average numbers of new SUTs and CUTs that entered the market for the same analysis period as the crash analysis were 81,000 and 15,500, respectively.

Table 25. 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 Video-Based Onboard Safety Monitoring Systems

Table 26 shows the results for the low efficacy rate for all new large trucks (20%). Similar to the results when deploying video-based OSM systems across the entire U.S. fleet of large trucks, all three cost estimates were shown to be cost-effective. Specifically, the low-cost estimate had BCRs from 3.69 to 4.11 (net cost per equivalent fatality ranged from $1.13 million to $1.44 million); the average cost estimate had BCRs from 2.09 to 2.40 (cost per fatality equivalent ranged from $3.07 million to $3.75 million); and the high-cost estimate had BCRs from 1.45 to 1.68 (net cost per fatality equivalent ranging from $5.06 million to $6.10 million). If all new large trucks are equipped with a video-based OSM system, 312 to 486 equivalent lives could be saved over six years with the low efficacy.

Table 26. Results for Equipping All New Large Trucks with Video-Based OSM Systems: Low Efficacy (20%), by Cost and Discount Rate

Fleet CUT + SUT > 10,000 pounds	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
Equivalent Lives Saved	486	393	312	486	393	312	486	393	312
Vehicle Costs	$156	$138	$121	$234	$207	$181	$335	$296	$259
Training Costs	$100	$83	$67	$100	$83	$67	$100	$83	$67
Total AST Cost	$1,470	$1,127	$848	$2,591	$1,959	$1,453	$3,735	$2,811	$2,075
Soc. Savings from Crashworthiness	$160	$130	$103	$160	$130	$103	$160	$130	$103
Congestion, PD and E S	$611	$494	$393	$611	$494	$393	$611	$494	$393
Total Societal Economic Savings	$771	$624	$496	$771	$624	$496	$771	$624	$496
VSL	$4,655	$3,768	$2,992	$4,655	$3,768	$2,992	$4,655	$3,768	$2,992
Total Monetized Savings	$5,426	$4,392	$3,487	$5,426	$4,392	$3,487	$5,426	$4,392	$3,487
Net Cost	$698	$502	$352	$1,820	$1,335	$957	$2,964	$2,187	$1,579
Net Cost per Fatal Equivalent	$1.44	$1.28	$1.13	$3.75	$3.39	$3.07	$6.10	$5.56	$5.06
Net Benefit	$3,956	$3,266	$2,640	$2,835	$2,433	$2,035	$1,691	$1,581	$1,412
Benefit-Cost Ratio	**3.69**	**3.90**	**4.11**	**2.09**	**2.24**	**2.40**	**1.45**	**1.56**	**1.68**

As shown in Table 27, all three cost estimates were cost-effective at the high efficacy rate (52.2%) when all new large trucks (no retrofitting) were equipped with a video-based OSM system. The low-cost estimate had BCRs ranging from 9.64 to 10.74 (net cost per fatality equivalent was $0); the average-cost estimate had BCRs ranging from 5.47 to 6.27 (net cost per fatality equivalent ranged from $0.20 million to $0.46 million); and the high-cost estimate had BCRs ranging from 3.79 to 4.39 (net cost per fatality equivalent ranged from $0.96 million to $1.36 million). A high efficacy increased the number of equivalent lives saved over six years to 815 to 1,268 when all new large trucks are equipped with a video-based OSM system.

Table 27. Results for Equipping All New Large Trucks with Video-Based OSM Systems, High Efficacy (52%), by Cost and Discount Rate

Fleet CUT + SUT > 10,000 pounds	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
Equivalent Lives Saved	1,268	1,026	815	1,268	1,026	815	1,268	1,026	815
Vehicle Costs	$156	$138	$121	$234	$207	$181	$335	$296	$259
Training Costs	$100	$83	$67	$100	$83	$67	$100	$83	$67
Total AST Cost	$1,470	$1,127	$848	$2,591	$1,959	$1,453	$3,735	$2,811	$2,075
Soc. Savings from Crashworthiness	$419	$339	$269	$419	$339	$269	$419	$339	$269
Congestion, PD and E S	$1,594	$1,291	$1,025	$1,594	$1,291	$1,025	$1,594	$1,291	$1,025
Total Societal Economic Savings	$2,013	$1,630	$1,294	$2,013	$1,630	$1,294	$2,013	$1,630	$1,294
VSL	$12,149	$9,834	$7,808	$12,149	$9,834	$7,808	$12,149	$9,834	$7,808
Total Monetized Savings	$14,162	$11,464	$9,102	$14,162	$11,464	$9,102	$14,162	$11,464	$9,102
Net Cost	-$543	-$503	-$446	$578	$329	$159	$1,722	$1,181	$781
Net Cost per Fatal Equivalent	-$0.43	-$0.49	-$0.55	$0.46	$0.32	$0.20	$1.36	$1.15	$0.96
Net Benefit	$12,692	$10,337	$8,254	$11,571	$9,505	$7,649	$10,427	$8,653	$7,027
Benefit-Cost Ratio	**9.64**	**10.17**	**10.74**	**5.47**	**5.85**	**6.27**	**3.79**	**4.08**	**4.39**

Sensitivity Analysis for Only Equipping New Trucks with Video-Based Onboard Safety Monitoring 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 a video-based OSM 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 28 shows the result using the low efficacy rate. The low- and average-cost options were found to be cost-effective using the lower VSL in each of the vehicle classifications. However, the high-cost estimate was only cost-effective at the 7% discount rate.

Table 28. Sensitivity Analysis for Equipping All New Large Trucks with Video-Based OSM Systems Using $5,304,000 VSL: Low Efficacy (20%), by Cost and Discount Rates

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	2.31	2.44	2.58	1.31	1.40	1.50	0.91	0.98	1.05
Only CUTs	2.35	2.48	2.62	1.33	1.43	1.53	0.92	0.99	1.07
Only SUTs	2.23	2.36	2.49	1.27	1.36	1.45	0.88	0.94	1.02

As shown in Table 29, a $5,304,000 VSL and high efficacy resulted in all three cost estimates being cost-effective.

Table 29. Sensitivity Analysis for Equipping All New Large Trucks with Video-Based OSM Systems Using a $5,304,000 VSL: High Efficacy (52%), by Cost and Discount Rates

Fleet	Low Cost			Average Cost			High Cost		
	0%	3%	7%	0%	3%	7%	0%	3%	7%
All Large Trucks	6.03	6.37	6.72	3.42	3.66	3.92	2.37	2.55	2.75
Only CUTs	6.13	6.48	6.83	3.48	3.72	3.99	2.41	2.60	2.79
Only SUTs	5.83	6.15	6.49	3.30	3.54	3.79	2.29	2.47	2.65

Discussion

This study assessed scientifically-based estimates of the societal benefits and costs of video-based OSM systems installed on large trucks. This study also assessed the societal benefits and costs of automatic emergency braking systems, lane departure warning systems, 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 (in this case, video-based OSM systems). 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%).

Unlike the other ASTs, the crash target population for video-based OSM systems was much larger. Whereas the other ASTs prevented specific crash types, video-based OSM systems are applicable to many different crashes, as long as the large-truck driver could have done something to prevent or mitigate the crash. With this in mind, this study found that a video-based OSM system with 20% efficacy may prevent 24,231 total crashes, 4,740 injury crashes (6,534 total injuries), and 102 fatal crashes (112 total lives) per year. A video-based OSM system with a 52.2% efficacy may prevent 63,243 total crashes, 12,371 injury crashes (17,054 total injuries), and 267 fatal crashes (293 total lives) each year.

Although there were many case studies available via technology vendor websites, only one empirical study was found that estimated the number of crashes that may be prevented with video-based OSM systems. Soccolich and Hickman (2014) used efficacy data from Hickman and Hanowski (2010) to estimate the number of injury and fatal crashes that may be prevented with video-based OSM systems. Soccolich and Hickman (2014) found that video-based OSM systems could prevent 39,000 injuries and 801 fatalities. Despite using the same crash filtering criteria as Soccolich and Hickman (2014), this study found video-based OSM systems could prevent fewer serious crashes. These discrepancies were likely the result of methodological differences between the two studies. Soccolich and Hickman extrapolated the proportion of unweighted GES crashes to FMCSA's Commercial Motor Vehicle Facts, whereas this study used the weighted crash counts to obtain a national estimate of PDO and injury crashes. The authors believed the GES crash weights would provide a more realistic estimate of crashes. Additionally, Soccolich used the GES data set to obtain fatality estimates, whereas the FARS data set was used in the current study for fatality estimates. From the authors' experience, GES fatality numbers may not provide an accurate crash estimate, especially for large-truck crashes. Conversely, FARS provides exact fatal crash counts (not estimates based on a sample). Given these differences, the authors believed the estimated number of crashes identified in this report provided a conservative estimate.

Two sets of BCAs were conducted for video-based OSM systems. Each set of analyses used a lower-bound efficacy rate (20%) and upper-bound efficacy rate (52.2%). Video-based OSM systems have a complex cost structure. Whereas the costs associated with other ASTs is primarily from the hardware, the majority of the costs for video-based OSM systems come from the monthly service fee and driver coaching. This cost difference is evident in using the discount rates (especially the 7% discount rate).

The first set of BCAs estimated the cost-effectiveness of equipping all new and old large trucks with video-based OSM systems. These analyses showed BCRs ranging from 1.20 to 7.90 (for all large trucks), 1.31 to 8.62 (if only CUTs were equipped), and 1.01 to 6.63 (if only SUTs were equipped). These analyses showed that every combination of cost (i.e., low, average, or high), vehicle type (i.e., all large trucks, only CUTs, or only SUTs), 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 video-based OSM systems.

The second set of BCAs estimated the cost-effectiveness of equipping only new vehicles with video-based OSM systems. These analyses showed BCRs ranging from 1.45 to 10.74 (for all large trucks), 1.48 to 4.20 (if only CUTs were equipped), and 1.39 to 10.24 (if only SUTs were equipped). Similar to the first set of analyses, all cost estimates were shown to be cost-effective, regardless of efficacy rate.

The literature review did not identify any prior published BCAs for video-based OSM systems. Thus, it is not possible to compare the results of these analyses with others. However, these analyses clearly showed that video-based OSM systems were cost-effective, regardless of cost. In fact, these analyses showed that video-based OSM systems were the most cost-effective of the four ASTs analyzed for this project. They may be even more cost-effective for carriers than presented here given that these analyses did not account for reduced litigation costs and driver exonerations. These costs can be significant, and many fleets indicate that video-based OSM systems are incredibly valuable to prove a driver was not at fault in a crash.

While this study found video-based OSM systems were cost-effective, the efficacy of these systems relies on management following the driver-coaching protocol. As the major benefits of these systems lies in driver training, if drivers do not receive coaching or feedback, the systems' effectiveness will drastically decrease.

Conclusions

Video-based OSM systems were shown to be the most cost-effective AST in this study. Regardless of cost and efficacy rate, video-based OSM systems were shown to be cost-effective. Video-based OSM systems were found to have a high BCR of 10.74 when new large trucks were equipped with the technology. Despite the significant costs associated with driver coaching, the results of this study suggest that the societal benefit of equipping large trucks with video-based OSM systems, expressed in economic terms, substantially outweigh the associated costs.

Limitations

Although the analyses used to assess the benefit-costs associated with video-based OSM 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 video-based OSM systems. However, the advisory panel consisted of experts with knowledge of current technology research, and as such, the efficacy rates selected by the panel should be consistent with the current generation of systems' efficacy rates.
- The technology costs used in this study may differ from current costs (with costs typically decreasing 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 video-based OSM systems.
- The GES only included crashes that required a police accident report. However, video-based OSM 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 or driver exonerations. These may be significant cost savings that were not integrated into the analyses.
- The efficacy of video-based OSM relies on carrier management following driver coaching protocols. These protocols include using the data generated by the video-based OSM system for driver coaching. System efficacy and reductions in crashes outlined in this project may not be achieved if coaching protocols are not adhered to.
- The efficacy of video-based OSM 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. For example, 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 efficacy rates used in this study would be reduced.

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Appendix A: Literature Review Summary Table

Citation	Title	AST	Effectiveness and/or cost
Hickman & Hanowski (2010)	Evaluating the safety benefits of a low-cost driving behavior management system in commercial vehicle operations	Video-based OSM	• 38.1%–52.2% reduction in large-truck SCEs. • 44.4%–59.1% reduction in severe SCEs. • Coaching with video reduced severe SCEs by 75.5%.
Soccolich & Hickman (2014)	Potential reduction in large-truck and bus traffic fatalities and injuries using Lytx's DriveCam program	Video-based OSM	• DriveCam® could prevent 20.5% of large-truck fatal crashes resulting in a 20.0% reduction of fatalities. • Prevents 35.2% of large-truck injury crashes and prevents 35.5% of injuries.
Lytx (2016a)	AmeriGas: Turning hazardous fuel delivery into a safer operation for AmeriGas	Video-based OSM	• SCEs, including crashes, were reduced by 55%.
Lytx (2016b)	Cargo Transporters: Cargo Transporters reduced litigation using DriveCam fleet video recorders	Video-based OSM	• Carrier saw reductions in tailgating and rear-end crashes (no specific percentage of reduction mentioned). • Carrier experienced a positive ROI after two crashes. In both cases, the driver was exonerated, resulting in reduced litigation costs. • These two crashes saved the carrier between $50K and $100K each.
Lytx (2016b)	Cox: Cox Petroleum Transport sees significant results from DriveCam program	Video-based OSM	• At-fault crashes reduced by 80% during the first year of deployment (2008–2009). • Experienced only two at-fault crashes over 14 million miles in 2011. • Helped to exonerate drivers (no cost savings mentioned).

Citation	**Title**	**AST**	**Effectiveness and/or cost**
Lytx (2016b)	Monarch Beverage: Safeguarding drivers and protecting profits with DriveCam	Video-based OSM	• Company experienced a reduction in SCEs from 358/month to 50/month. This was an 86% reduction of SCEs in only a few months. • Helped to exonerate drivers (no cost savings mentioned).
Lytx (2016b)	Salmon Companies: Largest mail contractor in U.S. experiences a 44% reduction in risky driver behavior with DriveCam	Video-based OSM	• Risky driving behaviors were reduced by 44%. • SCEs were reduced by 22% over the last 90 days.
SmartDrive (2013)	Case Study: Reynolds: Video safety system from SmartDrive reduces collision and cuts insurance costs for Reynolds	Video-based OSM	• Crashes reduced by 61%. • Weekly minor damage costs reduced by 50%. • Reduced annual insurance premiums by $385,000.
SmartDrive (2013)	Case Study: Verst Group Logistics: Preventing the “big one”	Video-based OSM	• Allowed the fleet to avoid $20K–$30K in litigation costs • Downward trend in claims (no specific percentage given). • Achieved a 0 DOT-reportable crash rate in 2012 (no specific percentage given).
SmartDrive (2013)	Case Study: West Horsley Dairy: West Horsley Dairy ties SmartDrive to safety incentive program, reduces claims by 66%	Video-based OSM	• Claims reduced by 66%.

Appendix B: GES/FARS Crash Filtering Inclusion Variables

1. Vehicle Body Type
    a. 60: Step Van
    b. 61: Single-Unit Straight Truck or Cab-Chassis (10,000 lbs < GVWR ≤ 19,500 lbs)
    c. 62: Single-Unit Straight Truck (19,500 lbs < GVWR ≤ 26,000 lbs)
    d. 63: Single-Unit Straight Truck or Cab-Chassis(GVWR > 26,000 lbs)
    e. 64: Single-Unit Straight Truck or Cab-Chassis(GVWR unknown)
    f. 66: Truck-Tractor
    g. 67: Medium/Heavy Pickup (GVWR > 10,000 lbs)
    h. 71: Unknown if Single-Unit or Combination-Unit Medium Truck (10,000 lbs < GVWR < 26,000 lbs)
    i. 72: Unknown if Single-Unit or Combination-Unit Heavy Truck (GVWR > 26,000 lbs)
    j. 78: Unknown Medium/Heavy Truck Type
    k. 79: Unknown Truck Type (Light/Medium/Heavy)
2. Removed Accident Types
    a. 21: Same Trafficway, Same Direction, Rear End, Stopped, Straight
    b. 22: Same Trafficway, Same Direction, Rear End, Stopped, Left
    c. 23: Same Trafficway, Same Direction, Rear End, Stopped, Right
    d. 25: Same Trafficway, Same Direction, Rear End, Slower, Going Straight
    e. 26: Same Trafficway, Same Direction, Rear End, Slower, Going Left
    f. 27: Same Trafficway, Same Direction, Rear End, Slower, Going Right
    g. 29: Same Trafficway, Same Direction, Rear End, Decelerating, Going Straight
    h. 30: Same Trafficway, Same Direction, Rear End, Decelerating, Going Left
    i. 31: Same Trafficway, Same Direction, Rear End, Decelerating, Going Right
    j. 35: Same Trafficway, Same Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    k. 37: Same Trafficway, Same Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    l. 39: Same Trafficway, Same Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    m. 41: Same Trafficway, Same Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    n. 45: Same Trafficway, Same Direction, Sideswipe/Angle, Straight Ahead on Left/Right
    o. 55: Same Trafficway, Opposite Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    p. 57: Same Trafficway, Opposite Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    q. 59: Same Trafficway, Opposite Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    r. 61: Same Trafficway, Opposite Direction, Forward Impact, This Vehicle is Impacted by Frontal Area of Another Vehicle
    s. 65: Same Trafficway, Opposite Direction, Sideswipe/Angle, Lateral Move

    (Going Straight)
    t. 69: Changing Trafficway, Vehicle Turning, Turn Across Path, Initial Opposite Directions (Going Straight)
    u. 71: Changing Trafficway, Vehicle Turning, Turn Across Path, Initial Same Directions (Going Straight)
    v. 73: Changing Trafficway, Vehicle Turning, Turn Across Path, Initial Same Directions (Going Straight)
    w. 77: Changing Trafficway, Vehicle Turning, Turn into Path, Turn into Same Direction (Going Straight)
    x. 79: Changing Trafficway, Vehicle Turning, Turn into Path, Turn into Same Direction (Going Straight)
    y. 81: Changing Trafficway, Vehicle Turning, Turn into Path, Turn into Opposite Directions (Going Straight)
    z. 83: Changing Trafficway, Vehicle Turning, Turn into Path, Turn into Opposite Directions (Going Straight)
    aa. 93: Miscellaneous, Backing, etc., Other Vehicle or Object
3. Critical Event – Pre-crash
    a. 6: This Vehicle Loss of Control Due to: Traveling Too Fast for Conditions
    b. 8: This Vehicle Loss of Control Due to: Other Cause of Control Loss
    c. 9: This Vehicle Loss of Control Due to: Unknown Cause of Control Loss
    d. 10: This Vehicle Traveling: Over the Lane Line on the Left Side of Travel Lane
    e. 11: This Vehicle Traveling: Over the Lane Line on the Right Side of Travel Lane
    f. 12: This Vehicle Traveling: Off the Edge of the Road on the Left Side
    g. 13: This Vehicle Traveling: Off the Edge of the Road on the Right Side
    h. 14: This Vehicle Traveling: End Departure
    i. 15: This Vehicle Traveling: Turning Left at Junction
    j. 16: This Vehicle Traveling: Turning Right at Junction
    k. 17: This Vehicle Traveling: Crossing Over (Passing Through) Intersection
    l. 18: This Vehicle Traveling: This Vehicle Decelerating
    m. 19: This Vehicle Traveling: Unknown Travel Direction
    n. 50: Other Motor Vehicle in Lane, Other Vehicle Stopped
    o. 51: Other Motor Vehicle in Lane, Traveling in Same Direction with Lower Steady Speed
    p. 52: Other Motor Vehicle in Lane, Traveling in Same Direction while Decelerating
    q. 53: Other Motor Vehicle in Lane, Traveling in Same Direction with Higher Speed
    r. 54: Other Motor Vehicle in Lane, Traveling in Opposite Direction
    s. 55: Other Motor Vehicle in Lane, In Crossover
    t. 56: Other Motor Vehicle in Lane, Backing
    u. 59: Other Motor Vehicle in Lane, Unknown Travel Direction of the Other Motor Vehicle in Lane
    v. 80: Pedestrian, Pedalcyclist, or Other Non-Motorist, Pedestrian in Road
    w. 81: Pedestrian, Pedalcyclist, or Other Non-Motorist, Pedestrian Approaching Road
    x. 82: Pedestrian, Pedalcyclist, or Other Non-Motorist, Pedestrian Unknown Location

y. 83: Pedestrian, Pedalcyclist, or Other Non-Motorist, Pedalcyclist/Other Non-Motorist in Road
z. 84: Pedestrian, Pedalcyclist, or Other Non-Motorist, Pedalcyclist/Other Non-Motorist Approaching Road
aa. 85: Pedestrian, Pedalcyclist, or Other Non-Motorist,, Pedalcyclist/Other Non-Motorist Unknown Location

Appendix C: Additional Analyses

Table 30. Results for Retrofitting the Entire U.S. Fleet of Large-Truck CUTs with Video-Based OSM Systems by Low Efficacy (20%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	6,846	5,169	3,758	6,846	5,169	3,758	6,846	5,169	3,758
Vehicle Costs	$3,796	$2,966	$2,266	$5,693	$4,449	$3,398	$8,133	$6,356	$4,855
Training Costs	$1,424	$1,156	$905	$1,424	$1,156	$905	$1,424	$1,156	$905
Total AST Cost	$22,831	$17,389	$12,764	$39,908	$30,166	$21,946	$57,527	$43,366	$31,451
Soc. Savings from Crashworthiness	$2,171	$1,639	$1,189	$2,171	$1,639	$1,189	$2,171	$1,639	$1,189
Congestion, PD and E S	$7,982	$6,026	$4,374	$7,982	$6,026	$4,374	$7,982	$6,026	$4,374
Total Societal Economic Savings	$10,153	$7,665	$5,563	$10,153	$7,665	$5,563	$10,153	$7,665	$5,563
VSL	$65,236	$49,250	$35,744	$65,236	$49,250	$35,744	$65,236	$49,250	$35,744
Total Monetized Savings	$75,389	$56,915	$41,308	$75,389	$56,915	$41,308	$75,389	$56,915	$41,308
Net Cost	$12,678	$9,724	$7,201	$29,755	$22,501	$16,383	$47,374	$35,701	$25,888
Net Cost per Fatal Equivalent	1.85	1.88	1.92	4.35	4.35	4.36	6.92	6.91	6.89
Net Benefit	$52,558	$39,525	$28,543	$35,481	$26,749	$19,362	$17,862	$13,549	$9,857
Benefit-Cost Ratio	**3.30**	**3.27**	**3.24**	**1.89**	**1.89**	**1.88**	**1.31**	**1.31**	**1.31**

Table 31. Results for Retrofitting the Entire U.S. Fleet of Large-Truck CUTs with Video-Based OSM Systems by High Efficacy (52%), Cost, and Discount Rate

Fleet CUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	17,869	13,490	9,807	17,869	13,490	9,807	17,869	13,490	9,807
Vehicle Costs	$3,796	$2,966	$2,266	$5,693	$4,449	$3,398	$8,133	$6,356	$4,855
Training Costs	$1,424	$1,156	$905	$1,424	$1,156	$905	$1,424	$1,156	$905
Total AST Cost	$22,831	$17,389	$12,764	$39,908	$30,166	$21,946	$57,527	$43,366	$31,451
Soc. Savings from Crashworthiness	$5,666	$4,277	$3,104	$5,666	$4,277	$3,104	$5,666	$4,277	$3,104
Congestion, PD and E S	$20,834	$15,728	$11,415	$20,834	$15,728	$11,415	$20,834	$15,728	$11,415
Total Societal Economic Savings	$26,500	$20,006	$14,520	$26,500	$20,006	$14,520	$26,500	$20,006	$14,520
VSL	$170,266	$128,542	$93,293	$170,266	$128,542	$93,293	$170,266	$128,542	$93,293
Total Monetized Savings	$196,765	$148,548	$107,813	$196,765	$148,548	$107,813	$196,765	$148,548	$107,813
Net Cost	-$3,669	-$2,616	-$1,756	$13,408	$10,160	$7,426	$31,027	$23,360	$16,931
Net Cost per Fatal Equivalent	-$0.21	-$0.19	-$0.18	$0.75	$0.75	$0.76	$1.74	$1.73	$1.73
Net Benefit	$173,934	$131,158	$95,049	$156,858	$118,382	$85,867	$139,238	$105,182	$76,362
Benefit-Cost Ratio	**8.62**	**8.54**	**8.45**	**4.93**	**4.92**	**4.91**	**3.42**	**3.43**	**3.43**

Table 32. Results for Retrofitting the Entire U.S. Fleet of Large-Truck SUTs with Video-Based OSM Systems by Low Efficacy (20%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	2,871	2,167	1,576	2,871	2,167	1,576	2,871	2,167	1,576
Vehicle Costs	$1,966	$1,557	$1,208	$2,949	$2,335	$1,812	$4,213	$3,336	$2,588
Training Costs	$829	$673	$526	$829	$673	$526	$829	$673	$526
Total AST Cost	$13,040	$9,948	$7,316	$22,854	$17,296	$12,602	$32,949	$24,867	$18,061
Soc. Savings from Crashworthiness	$1,038	$784	$569	$1,038	$784	$569	$1,038	$784	$569
Congestion, PD and E S	$4,234	$3,197	$2,320	$4,234	$3,197	$2,320	$4,234	$3,197	$2,320
Total Societal Economic Savings	$5,272	$3,980	$2,889	$5,272	$3,980	$2,889	$5,272	$3,980	$2,889
VSL	$27,861	$21,034	$15,266	$27,861	$21,034	$15,266	$27,861	$21,034	$15,266
Total Monetized Savings	$33,133	$25,014	$18,155	$33,133	$25,014	$18,155	$33,133	$25,014	$18,155
Net Cost	$7,768	$5,967	$4,427	$17,582	$13,316	$9,713	$27,676	$20,887	$15,172
Net Cost per Fatal Equivalent	$2.71	$2.75	$2.81	$6.12	$6.14	$6.16	$9.64	$9.64	$9.63
Net Benefit	$20,093	$15,066	$10,839	$10,279	$7,718	$5,553	$185	$147	$93
Benefit-Cost Ratio	**2.54**	**2.51**	**2.48**	**1.45**	**1.45**	**1.44**	**1.01**	**1.01**	**1.01**

Table 33. Results for Retrofitting the Entire U.S. Fleet of Large-Truck SUTs with Video-Based OSM Systems by High Efficacy (52%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	7,493	5657	4112	7,493	5,657	4,112	7,493	5,657	4,112
Vehicle Costs	$1,966	$1,557	$1,208	$2,949	$2,335	$1,812	$4,213	$3,336	$2,588
Training Costs	$829	$673	$526	$829	$673	$526	$829	$673	$526
Total AST Cost	$13,040	$9,948	$7,316	$22,854	$17,296	$12,602	$32,949	$24,867	$18,061
Soc. Savings from Crashworthiness	$2,709	$2,045	$1,485	$2,709	$2,045	$1,485	$2,709	$2,045	$1,485
Congestion, PD and E S	$11,052	$8,344	$6,056	$11,052	$8,344	$6,056	$11,052	$8,344	$6,056
Total Societal Economic Savings	$13,761	$10,389	$7,540	$13,761	$10,389	$7,540	$13,761	$10,389	$7,540
VSL	$72,717	$54,898	$39,844	$72,717	$54,898	$39,844	$72,717	$54,898	$39,844
Total Monetized Savings	$86,478	$65,287	$47,384	$86,478	$65,287	$47,384	$86,478	$65,287	$47,384
Net Cost	-$721	-$441	-$224	$9,093	$6,907	$5,062	$19,187	$14,478	$10,521
Net Cost per Fatal Equivalent	-$0.10	-$0.08	-$0.05	$1.21	$1.22	$1.23	$2.56	$2.56	$2.56
Net Benefit	$73,438	$55,339	$40,068	$63,624	$47,990	$34,782	$53,530	$40,420	$29,323
Benefit-Cost Ratio	**6.63**	**6.56**	**6.48**	**3.78**	**3.77**	**3.76**	**2.62**	**2.63**	**2.62**

Table 34. Sensitivity Analysis for Retrofitting the Entire Heavy Vehicle U.S. Fleet with Video-Based OSM Systems using a $13,260,000 VSL by Low Efficacy (20%), Cost, and Discount Rate

Fleet	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All Large Trucks	4.09	4.05	4.00	2.34	2.33	2.33	1.62	1.62	1.62
Only CUTs	4.48	4.44	4.39	2.56	2.56	2.55	1.78	1.78	1.78
Only SUTs	3.42	3.38	3.34	1.95	1.95	1.94	1.35	1.35	1.35

Table 35. Sensitivity Analysis for Retrofitting the Entire Heavy Vehicle U.S. Fleet with Video-Based OSM Systems using a $13,260,000 VSL by High Efficacy (52%), Cost, and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All Large Trucks	10.68	10.58	10.45	6.10	6.09	6.07	4.23	4.24	4.24
Only CUTs	11.68	11.58	11.45	6.68	6.67	6.66	4.64	4.64	4.65
Only SUTs	8.92	8.83	8.71	5.09	5.08	5.06	3.53	3.53	3.53

Table 36. Results for Equipping Only New CUTs with Video-Based OSM Systems by Low Efficacy (20%), Cost, and Discount Rate

Fleet CUT	Low Cost			Average Cost			High Cost		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	342	277	220	342	277	220	342	277	220
Vehicle Costs	$106	$94	$82	$159	$141	$123	$228	$201	$176
Training Costs	$68	$57	$46	$68	$57	$46	$68	$57	$46
Total AST Cost	$999	$766	$576	$1,762	$1,332	$988	$2,540	$1,911	$1,411
Soc. Savings from Crashworthiness	$109	$88	$70	$109	$88	$70	$109	$88	$70
Congestion, PD and E S	$399	$323	$257	$399	$323	$257	$399	$323	$257
Total Societal Economic Savings	$508	$411	$326	$508	$411	$326	$508	$411	$326
VSL	$3,262	$2,640	$2,096	$3,262	$2,640	$2,096	$3,262	$2,640	$2,096
Total Monetized Savings	$3,769	$3,051	$2,423	$3,769	$3,051	$2,423	$3,769	$3,051	$2,423
Net Cost	$492	$355	$250	$1,254	$921	$662	$2,032	$1,501	$1,085
Net Cost per Fatal Equivalent	$1.44	$1.28	$1.14	$3.66	$3.32	$3.01	$5.94	$5.42	$4.93
Net Benefit	$2,770	$2,285	$1,846	$2,007	$1,719	$1,435	$1,229	$1,140	$1,012
Benefit-Cost Ratio	**3.77**	**3.98**	**4.20**	**2.14**	**2.29**	**2.45**	**1.48**	**1.60**	**1.72**

Table 37. Results for Equipping Only New CUTs with Video-Based OSM Systems by High Efficacy (52%), Cost, and Discount Rate

Fleet CUT	Low Cost			Average Cost			High Cost		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	893	723	574	893	723	574	893	723	574
Vehicle Costs	$106	$94	$82	$159	$141	$123	$228	$201	$176
Training Costs	$68	$57	$46	$68	$57	$46	$68	$57	$46
Total AST Cost	$999	$766	$576	$1,762	$1,332	$988	$2,540	$1,911	$1,411
Soc. Savings from Crashworthiness	$283	$229	$182	$283	$229	$182	$283	$229	$182
Congestion, PD and E S	$1,042	$843	$669	$1,042	$843	$669	$1,042	$843	$669
Total Societal Economic Savings	$1,325	$1,073	$852	$1,325	$1,073	$852	$1,325	$1,073	$852
VSL	$8,513	$6,891	$5,471	$8,513	$6,891	$5,471	$8,513	$6,891	$5,471
Total Monetized Savings	$9,838	$7,964	$6,323	$9,838	$7,964	$6,323	$9,838	$7,964	$6,323
Net Cost	-$326	-$306	-$275	$437	$260	$136	$1,215	$839	$559
Net Cost per Fatal Equivalent	-$0.36	-$0.42	-$0.48	$0.49	$0.36	$0.24	$1.36	$1.16	$0.97
Net Benefit	$8,839	$7,198	$5,747	$8,076	$6,632	$5,335	$7,298	$6,052	$4,912
Benefit-Cost Ratio	**9.84**	**10.39**	**10.97**	**5.58**	**5.98**	**6.40**	**3.87**	**4.17**	**4.48**

Table 38. Results for Equipping Only New SUTs with Video-Based OSM Systems by Low Efficacy (20%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	144	116	92	144	116	92	144	116	92
Vehicle Costs	$50	$44	$39	$75	$66	$58	$107	$95	$83
Training Costs	$32	$27	$22	$32	$27	$22	$32	$27	$22
Total AST Cost	$470	$361	$271	$829	$627	$465	$1,195	$900	$664
Soc. Savings from Crashworthiness	$52	$42	$33	$52	$42	$33	$52	$42	$33
Congestion, PD and E S	$212	$171	$136	$212	$171	$136	$212	$171	$136
Total Societal Economic Savings	$264	$213	$169	$264	$213	$169	$264	$213	$169
VSL	$1,393	$1,128	$895	$1,393	$1,128	$895	$1,393	$1,128	$895
Total Monetized Savings	$1,657	$1,341	$1,065	$1,657	$1,341	$1,065	$1,657	$1,341	$1,065
Net Cost	$207	$147	$102	$566	$413	$295	$932	$686	$495
Net Cost per Fatal Equivalent	$1.44	$1.27	$1.10	$3.94	$3.56	$3.20	$6.49	$5.90	$5.36
Net Benefit	$1,186	$980	$793	$827	$714	$600	$461	$442	$401
Benefit-Cost Ratio	**3.52**	**3.72**	**3.92**	**2.00**	**2.14**	**2.29**	**1.39**	**1.49**	**1.60**

Table 39. Results for Equipping Only New SUTs with Video-Based OSM Systems by High Efficacy (52%), Cost, and Discount Rate

Fleet SUT	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
Equivalent Lives Saved	375	303	241	375	303	241	375	303	241
Vehicle Costs	$50	$44	$39	$75	$66	$58	$107	$95	$83
Training Costs	$32	$27	$22	$32	$27	$22	$32	$27	$22
Total AST Cost	$470	$361	$271	$829	$627	$465	$1,195	$900	$664
Soc. Savings from Crashworthiness	$135	$110	$87	$135	$110	$87	$135	$110	$87
Congestion, PD and E S	$553	$447	$355	$553	$447	$355	$553	$447	$355
Total Societal Economic Savings	$688	$557	$442	$688	$557	$442	$688	$557	$442
VSL	$3,636	$2,943	$2,337	$3,636	$2,943	$2,337	$3,636	$2,943	$2,337
Total Monetized Savings	$4,324	$3,500	$2,779	$4,324	$3,500	$2,779	$4,324	$3,500	$2,779
Net Cost	-$218	-$196	-$171	$141	$70	$23	$507	$343	$222
Net Cost per Fatal Equivalent	-$0.58	-$0.65	-$0.71	$0.38	$0.23	$0.09	$1.35	$1.13	$0.92
Net Benefit	$3,854	$3,140	$2,508	$3,495	$2,873	$2,314	$3,129	$2,601	$2,115
Benefit-Cost Ratio	**9.19**	**9.71**	**10.24**	**5.21**	**5.58**	**5.98**	**3.62**	**3.89**	**4.19**

Table 40. Sensitivity Analysis for Equipping Only New Trucks with Video-Based OSM Systems using a $13,260,000 VSL by Low Efficacy (20%), Cost, and Discount Rate

Fleet	**Low Cost**			**Average Cost**			**High Cost**		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All Large Trucks	4.99	5.27	5.56	2.83	3.03	3.25	1.96	2.11	2.27
Only CUTs	5.11	5.40	5.70	2.90	3.10	3.32	2.01	2.16	2.33
Only SUTs	4.74	5.00	5.28	2.69	2.88	3.08	1.86	2.01	2.16

Table 41. Sensitivity Analysis for Equipping Only New Trucks with Video-Based OSM Systems using a $13,260,000 VSL by High Efficacy (52%), Cost, and Discount Rate

Fleet	Low Cost			Average Cost			High Cost		
	0%	**3%**	**7%**	**0%**	**3%**	**7%**	**0%**	**3%**	**7%**
All Large Trucks	13.03	13.76	14.52	7.39	7.91	8.47	5.13	5.51	5.93
Only CUTs	13.34	14.09	14.87	7.57	8.10	8.67	5.25	5.65	6.07
Only SUTs	12.37	13.06	13.78	7.01	7.51	8.04	4.87	5.23	5.63