Side Object Detection Systems Evaluation
Final Evaluation Report

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16. Abstract

Nearly 46 percent of bus accidents across the United States each year occur on the left or right side of the bus. These collisions result in property damage, and they can negatively impact on revenue operations and public perception. The first commercially available side collision warning system for transit buses entered the market in 2004. The system is designed to help bus operators navigate tight maneuvers at speeds below 15mph and with lane changes at speeds greater than 15mph. This report presents the findings of a federally sponsored, independent evaluation of the system. The evaluation aimed to address three key goals: (1) to assess operator usability and acceptance of the technology; (2) to assess the return on investment of the technology; and (3) to identify lessons learned and other information that would be useful to agencies considering deployment of this technology or similar technologies.

The evaluation team worked with three participating agencies to gather a wide range of data through interviews, surveys, focus groups, interviews, site visits and observations, collision records, and cost data. The findings indicated that operators were optimistic about the potential of a side-impact collision warning device and that SODS was useful in certain situations and that it had in fact prevented collisions, in particular those that involved detecting an object in the operator's blind spot. However, operators did not find the system usable in its current design, particularly with regard to the quality and frequency of visual and audible alerts. Additionally, the return on investment analysis indicated that the early-adopters of this technology are not likely to experience a return on investment within 12 years, the typical life of a bus. However, agencies investing in this type of technology in the future may not face the same institutional challenges as the early-adopters or may have different collision characteristics, and thus may see a sooner return on their investment.

These institutional issues can be significant if not properly accounted for prior to system deployment. All transit agency stakeholders—operations, maintenance, training, safety, and claims—must have a clear understanding of the technology capabilities and its limitations. Inconsistency in system installation resulted in varying operational characteristics among the different bus models and influenced operators' perceptions of system reliability. Additionally incomplete training and system activation prior to all affected operators being trained led many operators to incorrectly understand the technology, system operation, and system limitations. Similarly, incomplete maintenance staff training led to improper troubleshooting and testing of the technology. Agencies considering SODS or similar safety devices for their transit fleet should first consider the lessons learned experienced by these agencies.

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ABBREVIATIONS

AVL	Automatic Vehicle Location
BIFA	Buses Involved in Fatal Accidents
BLS	Bureau of Labor Statistics
CCTV	Closed-Circuit Television
EODS	Enhanced Object Detection System
FOT	Field Operational Test
FTA	Federal Transit Administration
GCRTA	Greater Cleveland Regional Transit Authority
ITS	Intelligent Transportation Systems
ITS JPO	Intelligent Transportation Systems Joint Program Office
IVBSS	Integrated Vehicle Based Safety System
LCA/BSD	Lane Change Assist and Blind Spot Detection
LED	Light Emitting Diode
NABI	North American Bus Industries
NTD	National Transit Database
ODS	Object Detection System
OEM	Original Equipment Manufacturer
ROI	Return on Investment
SODS	Side Object Detection System
USDOT	United States Department of Transportation
UTA	Utah Transit Authority
WMATA	Washington Metropolitan Area Transit Authority

EXECUTIVE SUMMARY

INTRODUCTION

This report presents the findings of a federally sponsored, independent evaluation of the only side object collision warning system that is currently commercially available for transit buses. The system entered the market in 2004, and was the result of a 6-year partnership between the Federal Transit Administration (FTA), the transit industry, researchers, and private vendors, all working together to support development and study of a side object detection system for transit buses. The system eventually developed was designed to help operators navigate tight maneuvers at speeds below 15mph and with lane changes at speeds greater than 15mph, ultimately reducing the occurrence of side collisions. The system detects nearby objects through ultrasonic transmitters and receivers installed on the outside of the bus, and the system alerts operators to potential hazards through a combination of visual and audible alerts.

The study aims to help the United States Department of Transportation (USDOT) determine whether to further support development and deployment of side object detection systems (SODS) and to provide information that will help transit agencies make important decisions about purchasing this and similar on-board technologies for their fleets. With this in mind, the evaluation aimed to address three key goals:

(1) To assess operator usability and acceptance of the technology.

(2) To assess the return on investment of the technology.

(3) To identify lessons learned and other information that would be useful to agencies considering deployment of this technology or similar technologies.

What follows is a summary of the findings of the study according to the key evaluation goals, followed by conclusions and recommendations regarding the future of this technology and other similar bus technologies.

OVERVIEW OF EVALUATION APPROACH

The Federal Transit Administration (FTA) and the evaluation team elected to partner with three transit agencies, each of which had a significant number of units in hand or planned for deployment in the near future. The three agencies included in the study were:

- The Washington Metropolitan Area Transit Authority (WMATA) in Washington, DC.
- The Greater Cleveland Regional Transit Authority (GCRTA) in Cleveland, Ohio.
- The Utah Transit Authority (UTA) in Salt Lake City, Utah.

The evaluation team worked with these three participating agencies to gather a wide range of data and information for the evaluation. For the operator acceptance portion of the evaluation, the team obtained feedback from operators through a variety of means including surveys, focus groups, interviews, and site visits and observations. For the return on investment analysis, a wide range of data was used including collision records, costs associated with side object collisions, and costs associated with SODS installation and maintenance. Some costs were estimated through discussions with agency staff due to lack of data. To document institutional issues that can affect successful deployment, information was gathered through direct dialogue with each agency regarding institutional issues.

SUMMARY OF FINDINGS

A summary of the findings of each of the evaluation goals are presented below.

Summary of Operator Acceptance Findings

Operators were optimistic about the potential of a side-impact collision warning device, even though these types of collisions are not a critical concern to them relative to other collision types. They reported that SODS was useful to certain situations and had prevented collisions, particularly those that involved detecting an object in the operator's blind spot.

However, operators did not find the system usable in its current design, particularly with regard to the quality and frequency of visual and audible alerts. Among the suggestions to improve the design of the system were changing the sound to be less annoying and moving the visual alerts to a better position (e.g., on the dashboard or front windshield). Operators also complained about the consistency with which the system functioned, partly because of true maintenance issues and partly because of uncertainties in understanding the system's capabilities.

Summary of Return on Investment Findings

The results of this study indicate that, based on the current state of SODS deployment in the United States, the early-adopters of this technology are not likely to experience a return on investment within 12 years, the typical life of a bus.

Agencies investing in this type of technology in the future may not face the same challenges as the early-adopters, and thus would likely see a better return on their investment. However, given the current cost of the device and the current expected benefit of the device (based on collision data and cost data from the three agencies participating in this study), it does not appear that an agency would see a positive return on investment within the life of the unit even if the institutional issues faced by the early-adopters were overcome.

There are scenarios, however, under which an agency could expect to see a positive return on investment. For example, an agency could expect to see a positive return on investment if the cost of the device were less expensive ($1,650 instead of $2,000). Another scenario for which the return on investment could be positive is if the agency's SODS-relevant collision rate is higher than the average rate for the three agencies presented here. If the agency's collision rate is about 15 percent higher (at 0.614 collisions per 100,000 VMT) then the agency would see a positive ROI.[1] Alternatively the agency could strategically deploy SODS only on routes that have a high incidence of side collisions. A final scenario for which the return on investment would be positive is if the sensor reliability is actually higher than what it was assumed to be in this study. If a typical bus only needs to have one sensor replacement over the life of the bus this would also result in a positive ROI for the agency.

It should be noted that the Federal Transit Administration (FTA) conducted an Integrated Vehicle-Based Safety Systems (IVBSS) Business Case Analysis that showed a positive benefit-

[1] These scenarios are based on a system efficacy of 0.9 (SODS-utilization factor of 0.95 and system uptime of 95%) and a discount rate of 3%.

cost ratio for SODS (of 1.43).[2] It is important to point out the differences between that analysis and the analysis presented here. One reason for this discrepancy is that the business case analysis defined SODS in a generic sense while this study looked at a very specific technology already on the market. The IVBSS study defined SODS as a system that monitors the entire length of the bus (all the way to the rear bumper), while the system under study in this evaluation only covers the front half of the bus. Also the business case analysis primarily relied on national databases (i.e., the National Transit Database [NTD], and the Buses Involved in Fatal Accidents [BIFA] database) for estimating the number of side collisions, while this analysis includes a review of detailed collision data from three agencies that participated in this study.

Summary of Institutional Issues Findings

The institutional issues can be significant if not properly accounted for prior to system deployment. All transit agency stakeholders—operations, maintenance, training, safety, and claims—must have a clear understanding of the technology capabilities and its limitations. Inconsistency in system installation resulted in varying operational characteristics among the different bus models. This influenced the operators' perceptions of system reliability. Accordingly, proper factory installation and testing is critical to the successful deployment of a technology. This creates the basis for correct system operation and, ultimately, operator acceptance.

Effective training programs promote operator understanding and teach drivers how the technology can improve their driving safety. However, incomplete training and system activation prior to all affected operators being trained led many operators to incorrectly understand the technology, system operation, and system limitations. Similarly, incomplete maintenance staff training led to improper troubleshooting and testing of the technology. These matters further exacerbated operator perception of system unreliability.

CONCLUSIONS AND RECOMMENDATIONS

An important question to ask at the conclusion of this study is whether or not there is a future for this technology or other similar bus technologies. Through discussion with transit agencies, it appears that there remains significant interest in this type of system. Furthermore, nearly every individual that the evaluation team spoke with throughout the course of the study (including operators) felt that the system had potential despite any complaints they may have had. Most, however, felt that the system -- as it currently exists and within the conditions and environment in which it is currently being used -- is not addressing their needs.

Agencies investing in this type of technology in the future may not face the same challenges as the early-adopters, and thus would likely see a better return on their investment. Certainly a better return on investment (ROI) could be achieved if system modifications were put into place and if the institutional issues faced by the early-adopters were overcome.

Although the results of this study indicate that there is not an acceptable return on investment with the current system, they do indicate that a positive ROI could be achieved under different circumstances such as a lower device purchase price or a higher side collision rate. In addition to this, the return on investment analysis as presented here only takes into account the direct costs of collisions to transit agencies in the form of bus repair costs and claims costs. Beyond these direct costs, there other costs associated with collisions such as personal injury and

[2] Travis Dunn, Richard Laver, Douglas Skorupski, Deborah Zyrowski (2007). Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses; Federal Transit Administration.

incident-related traffic congestion, costs, which if quantified, could significantly increase the "cost" of a collision. In other words, there is the possibility that SODS contributes to policy goals of reducing transportation injuries and congestion, even if it does not "pay for itself" in strictly financial terms.

Recommendations for Agencies Considering Deployment of SODS or Similar Technologies

Agencies interested in investing in a technology such as SODS should first be fully aware of the challenges that they may face in introducing such a technology into their fleet. It is critical that agencies:

- Work with the original equipment manufacturer (OEM) to ensure that the technology is properly installed. This includes considering involvement of the product supplier in the factory and acceptance testing processes.
- Properly educate all within the agency about the technology (from maintenance staff and their managers, to operators and their managers, to training staff). It is important to provide information on why the agency made the decision to invest in the technology, how the system works, what the system can and cannot do for a bus operator, and how to know if the system is working properly (so that operators can report system failures to maintenance staff in a prompt manner).
- Properly maintain the system and encourage information sharing between garages as they learn through experience how to troubleshoot and maintain the system. Proper maintenance should include routine system testing to identify component failures promptly to avoid creating distrust among operators about the system.
- Encourage and ensure "buy in" for the technology at all levels within the agency.

Furthermore, before making the decision to invest in an in-vehicle safety technology, it is useful for agencies to consider their operating environment as well as the nature of the collisions that the agency most commonly experiences. For example, this particular system would only be a meaningful or practical investment for an agency that has routes with tight turns and narrow operating conditions (since the system helps with tight maneuvers at lower speeds), or for an agency that has routes requiring high-speed lane changes (since the system helps with lane-changing at higher speeds).

Recommendations for Future Research in this Area

Future studies in the area of collision warning systems for transit buses should give consideration to issues that arose out of this study, including further exploration into questions such as: *Is ultrasonic the most appropriate sensing technology for this application or is there now a better technology? What is the optimal placement of sensors? What is the optimal placement of the visual displays and what is the best combination of audible and visual alerts for the operator?* More details about each of these questions are described below.

Sensing Technology

The sensing technology itself is important as it drives the accuracy of the system and the number of missed readings and false positives that operators will experience. It also drives what the system is able to detect. Many operators that the evaluation team spoke with were disappointed that the system did not detect pedestrians. This is a major consideration when selecting the most appropriate sensing technologies for future systems. In terms of accuracy with the existing system, one agency believes that it may be experiencing a problem with false alarms due to interference in the sensors, which the agency suspects results from hard water build-up in the sensors caused by the bus wash. Also, it is known that compressed air from the air brakes can cause false readings. False readings can be just as damaging as missed readings since they can result in distrust among operators, which can lead to inattention to the alerts or disabling of the device. Although it is not clear whether a better technological approach exists, it is clear that this current system has challenges. Further studies should be conducted to confirm the best sensor housing and best sensor placement for the existing system. Also consideration should be given to whether there are now other technologies better suited for this type of system.

Placement of the Sensors

There are a number of issues with the sensor locations that should be further explored. Sensor placement on buses is not always consistent (within or between agencies). This is important because the placement of the sensors affects the “field of view” of the sensors and the zone of object detection. In some cases the varying sensor placement is due to limitations presented by the bus design itself (e.g., one model of bus may not accommodate identical sensor placement to another model), but in many cases it is simply the result of inconsistent installation by the OEM, who may have limited knowledge of the system and the importance of proper placement. As many agencies work with multiple OEMs, varying sensor placement across their fleet is highly likely if the agency chooses to invest in SODS fleetwide.

Based on responses from the surveyed operators and on-board observations, the current sensor configuration does not appear to have coverage far enough back on the bus to provide timely warning to operators in lane-change situations or to provide coverage of all blind spots when making tight turns.

Moving forward, it would be desirable if the supplier of this technology or of any future technologies were more actively involved in working with the OEM to ensure that sensors are installed in a consistent fashion. It may also be advisable to involve the product supplier in the acceptance testing. Finally, additional research is needed to confirm the most appropriate sensor placement.

Placement of the Visual Displays

Additional consideration should be given to the placement of the visual displays. Many operators reported that they were not pleased with the current placement. Some felt that modifications as simple as making the height adjustable would accommodate the challenge of varying operator heights while others thought the placement was poor altogether. As with the placement of the sensors, display placement varied within and between agencies. The intent of the system design was to display a visual warning that would be visible to operators through their peripheral vision while practicing safe driving habits (e.g., the curbside display was intended to be in their peripheral vision when looking toward the curb when making a tight right turn). It appears that more research is needed in determining the optimal display placement and the range of adjustments needed to accommodate the variations in the anthropomorphic bus operator workforce.

Design of the Audible and Visual Alerts

Additional consideration should be given to the design of the audible and visual alerts. As with prior studies, there was a perception by some operators that the two flash rates (i.e., slow and fast) were difficult to distinguish, distracting, and perhaps unnecessary. In terms of the audible, some operators found the chime to be too loud (passengers could hear it, which bothered many operators). Some commented that they would like the frequency or pitch of the chime to be changed. Others suggested that the sound level of the audible alert be adjustable. Although there were many divergent opinions on this topic, a number of operators felt strongly that the system would be more effective for them if it provided an audible warning even at speeds below 15 mph. The operators felt that the lights alone were not enough, especially with many side collisions occurring at slower speeds (e.g., while making a tight right turn, or while merging back into traffic after a service stop). Interestingly enough, in WMATA's initial test of the device, they did have the audible alert at low speeds and operators asked that this be changed due to the frequency of alarms and the interference with being able to hear the stop-request. This area should be further studied.

Overall Recommendations

Future research is needed to determine how to deploy side object detection systems in a cost-effective manner for the transit industry. In addition to addressing a multitude of institutional issues, the current system design needs to be reconsidered. Further modification to the current system is one option. Another option is to adapt one or more technologies that already exist for personal automobiles and heavy vehicles to the unique conditions of transit operations. However, a key challenge to improving the design of the system is the size of the transit market. In comparison to the passenger car and heavy truck markets, the transit industry represents a significantly smaller market with unique needs, thus limiting interest among potential suppliers.

1 INTRODUCTION

1.1 OVERVIEW

Nearly 46 percent of bus accidents occur on the left or right side of the bus, compared with 25 percent occurring at the front of the bus and 19 percent occurring at the rear of the bus.[3] Reported property damage costs range from $3,660 per incident for sideswipe collisions to nearly $13,085 for collisions with fixed objects. These numbers present a good case for side collision warning systems and side object detection systems to reduce fixed object and sideswipe collisions, increase safety, and save money. These collisions impact the availability of buses for revenue operations, add to the cost of providing transit services, and can have a negative affect on public perception of transit.

For these reasons, in 1998 the Federal Transit Administration (FTA) began working with the transit industry, researchers, and private vendors to support development and study of a side object detection system (SODS) for transit buses. As a result of this work, the first commercially available system entered the market in 2004. Recognizing the potential benefit of side object detection and warning systems and also recognizing that the transit industry is more inclined to adopt technologies if they have access to information on the expected return on investment and safety benefits, the FTA elected to undertake an evaluation of this system. This document presents the findings of that independent evaluation. The study aims to help the United States Department of Transportation (USDOT) determine whether to further support development and deployment of side object detection systems, and to provide information that will help transit agencies in making important decisions about purchasing this and similar on-board technologies for their fleets.

In 2007 the FTA conducted a business case analysis looking at the viability of the range of options for integrated collision avoidance systems for transit buses. This was conducted as part of the USDOT's Integrated Vehicle Based Safety Systems (IVBSS) Initiative.[4] The objective of the study was to evaluate the business case for (or against) the development of various safety systems and the adoption of those systems by transit bus operators in the United States. The purpose of the study was to determine whether transit-based versions of these systems would warrant further investment in additional operational tests, demonstrations, and evaluations.

The transit IVBSS business case study defined SODS in a generic sense as a system that would monitor the entire length of the bus (all the way to the rear bumper), while the system under study in this evaluation is a very specific technology already on the market that only covers the front half of the bus. Also the business case analysis primarily relied on national databases (i.e., the National Transit Database [NTD], and the Buses Involved in Fatal Accidents [BIFA] database) for estimating the number of side collisions, while this analysis includes a review of much more detailed collision data from three specific agencies that participated in this study.

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[3] Taken from Statement of Work for Side Object Detection Evaluation received from the FTA 4/23/04. Source cites Federal Transit Administration's (FTA) 2002 National Transit Database (NTD).

[4] Travis Dunn, Richard Laver, Douglas Skorupski, Deborah Zyrowski (2007). Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses; Federal Transit Administration.

The benefit-cost analysis conducted as part of the transit IVBSS business case analysis indicated that SODS (and combinations of systems containing SODS) were the only bus safety systems that had a benefit-cost ratio greater than one. The findings of the industry outreach indicated that technology awareness was generally high for staff with responsibilities relating either to bus vehicle engineering or fleet safety, but that awareness was generally low outside of these key agency functions. Of those who were aware of the technologies' existence, the vast majority were not aware of the specific systems available (e.g., object detection versus collision warning) or of their differing capabilities. Virtually all expressed interest in the technology as a means of improving bus service safety, although many wanted to see concrete evidence of positive impacts before investing. The positive outlook for side object detection systems resulting from the business case study further demonstrated the need for a study documenting the return on investment of these types of systems.

1.2 SUMMARY OF RESEARCH OBJECTIVES

This evaluation aimed to address three key goals: (1) to assess operator usability and acceptance of SODS, (2) to assess the return on investment (ROI) of SODS, and (3) to identify lessons learned and other information that would be useful to agencies considering deployment of SODS or similar technologies in the future.

1.3 ORGANIZATION OF THE REPORT

The remainder of this report is structured as follows:

- **Section 2 – Side Collision Warning Systems.** Provides background information on what technologies exist for the transit industry as well as for the automotive industry and the trucking industry.
- **Section 3 – Participating Agencies.** Provides background information on which agencies participated in this study, how the agencies were selected, and how SODS was deployed at each agency.
- **Section 4 – Evaluation Methodology.** Summarizes the overall evaluation approach for the study.
- **Section 5 – Operator Acceptance - Data Collection Approach and Findings.** Provides details about the data collection approach for the operator acceptance portion of the evaluation and findings of the focus groups, surveys, and one-on-one interviews with operators.
- **Section 6 - Framework for Determining the Return on Investment.** Provides details about the data collection approach for the return on investment portion of the evaluation.
- **Section 7 – Return on Investment Calculation and Findings.** Provides details of the return on investment calculation as well as the findings of the study in terms of return on investment.
- **Section 8 – Institutional Issues - Approach and Findings.** Provides details about how institutional issues were gathered and provides a summary of what types of issues may play a role in future deployments of SODS or other similar technologies.
- **Section 9 – Summary and Conclusions.** Summarizes the major findings of the evaluation and states the major conclusions and recommendations drawn from the findings.

2 SIDE COLLISION WARNING SYSTEMS

In order to understand the context in which SODS was developed and functions, it is useful to examine technologies that currently exist to detect objects as well as to examine how these technologies already have been applied to assist operators of personal automobiles, heavy trucks, and transit buses. This chapter provides an overview of available technologies for object detection, presents a summary of object detection technologies currently available for personal automobiles and heavy trucks, and then provides a description of the technology under study in this evaluation.

2.1 TECHNOLOGIES FOR OBJECT DETECTION

A wide range of technologies have been developed to address the challenges of vehicle side object detection. Most products that are currently available use ultrasonic audio waves, microwave radar, or infrared lasers to detect objects, although some newer systems utilize computer vision (computer interpretation of a video feed) to detect objects. These technologies can be characterized by their strengths and weaknesses in terms of expense, environmental tolerance (i.e., how well the technology performs during inclement weather such as heavy rain, snow, or wind), and other factors. A summary of the strengths and weaknesses of the various detection technologies is presented in Table 2-1.

Table 2-1. Summary of Detection Technologies.[5]

	Technology			
	Ultrasonic	Radar	Infrared Laser	Computer Vision
Strengths	**Accuracy, Price**	**Accuracy, Environmental tolerance, low profile installation.**	**Accuracy**	**Ability to distinguish pedestrians from other objects.**
Weaknesses	**Weather, irregular surfaces, limited range, does not reliably detect pedestrians.***	**N/A**	**Weather, required processing power.**	**Weather, required processing power, several frames required for identification.**

**** Although ultrasonic sensors may sometimes detect pedestrians, they do not do so reliably since the detection is dependent on factors such as the clothing the pedestrian is wearing. For example, if the pedestrian was wearing clothing made of a synthetic fiber such as nylon, he or she might be detected, but if the pedestrian was wearing clothing made of a natural fiber such as cotton, he or she may not be detected.***

N/A = Not Applicable

Ultrasonic Object Detection Systems[6]

Ultrasonic object detection systems emit an ultrasonic (>20,000 Hz) sound wave. The sound wave reflects off of “hard objects” such as vehicles, and back to a receiver.[7] Based on this

[5] Fanping Bu, Ching-Yao Chan, California PATH Program, University of California at Berkeley, IEEE, *Pedestrian Detection in Transit Bus Application: Sensing Technologies and Safety Solutions*.
[6] Ibid.
[7] Ibid.

reflected signal, an ultrasonic object detection system can determine the presence, distance, and relative speed of objects within its range.

There are two basic types of ultrasonic sensors. Pulse ultrasonic sensors determine the presence and distance of objects by measuring the "flight time" (the elapsed time between emission and detection) of a reflected ultrasonic sound pulse. Continuous wave ultrasonic sensors output a wave at a steady frequency and use the Doppler principle to detect a moving object's speed.

Ultrasonic sensors can accurately and reliably measure the distance to cylindrical or perpendicular surfaces. However, when reflected from an angled wall or corner (such as the corner of a bus), ultrasonic range-finding becomes less reliable because of the varying flight time of the reflected signal. In addition, environmental conditions (e.g., temperature, pressure, humidity, wind, rain) can negatively affect the performance of ultrasonic object detection systems.

SODS, the system specifically under consideration in this evaluation, uses a form of ultrasonic detection. The specifics of this system are presented in Section 2.3.

***Microwave Radar Object Detection Systems*[8]**

Microwave radar object detection systems function much like ultrasonic systems. However, microwave radar systems emit an electromagnetic signal (300MHz-300GHz) instead of a sound wave. The presence, distance, and relative speed of nearby objects are determined by analysis of the reflected signal.

Radar sensors provide accurate measurements of object distance and speed without the complex signal processing required by computer vision systems. One benefit to radar is that it is not affected by environmental conditions such as rain, fog, poor visibility, dust, or snow. When installed on a vehicle, radar technology can be concealed behind radar transparent material, resulting in an unaltered exterior appearance.

***Infrared Laser Object Detection Systems*[9]**

Infrared laser object detection systems emit infrared laser pulses and detect their reflections from objects. Similar to ultrasonic and microwave radar detection systems, infrared laser detection systems measure the time-of-flight of emitted pulses. Infrared laser object detection systems can determine the presence, distance, and speed of nearby objects. Object distance, and angle can be determined with a high degree of accuracy.

Because infrared laser technology relies upon optical sensors, infrared laser detection system performance can be affected by weather condition like fog or snow. Infrared laser object detection systems also require more processing power than ultrasonic or microwave radar object detection systems.

***Computer Vision Object Detection Systems*[10]**

Computer vision object detection systems use video camera(s) and advanced signal processing to determine the presence of objects. There are two basic types of computer vision object detection systems. Motion-based systems interpret the differences from one frame to the next

[8] Ibid.
[9] Ibid.
[10] Ibid.

to determine object motion. Shape-based systems rely on shape characteristics to identify objects, especially pedestrians. Similar to ultrasonic and infrared laser object detection systems, computer vision object detection systems can be affected by environmental conditions, especially those that affect visibility (e.g., fog, snow, darkness). Computer vision object detection systems require significantly more processing power to interpret the video data than other technologies.

2.2 EXISTING OBJECT DETECTION SYSTEMS FOR TRANSIT AND OTHER PLATFORMS

There are a variety of side collision detection and warning systems already on the market and there are many others that are currently being explored through the USDOT's IVBSS Initiative, which is establishing partnerships with the automotive and commercial vehicle industries to accelerate the introduction of integrated vehicle-based safety systems (front, rear, and side warnings) into vehicles.[11] However, most of the systems that exist and that are under development have been designed for the automotive and trucking industries and focus on highway applications. Without significant modification, these systems are not likely to be suitable for transit buses that typically operate in urban and suburban environments. A recent effort exploring a prototype integrated collision warning system for transit buses collected data that demonstrated that the transit operation environment involves complex scenarios that are not addressed by the existing commercial collision warning systems.[12]

2.2.1 Applications for Personal Automobiles

There are a number of personal automobiles on the market that are available equipped with systems to warn operators about the presence of objects in their blind spots. The various automotive manufacturers use detection technologies and warning systems ranging from a gentle seat vibration, to a flashing icon of a vehicle, to a flashing light. Below is a description of some of the technologies that are currently available.

General Motors (Vehicle to Vehicle Technology and Radar)[13]

Select General Motors (GM) vehicles are equipped with a side object detection system. The system includes an antenna, a computer chip, and global positioning system technology, and has the ability to detect other vehicles equipped with the same technology. When the system detects the presence of a vehicle in the driver's blind spot, it alerts the driver by displaying a steady amber light in the side mirror (Figure 2-1). If the turn signal is activated and a vehicle is detected, the driver is notified of this potential danger via a flashing amber light along with a gentle seat vibration on the side of the detected vehicle.

Figure 2-1. GM System.

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[11] U.S. Department of Transportation, Research and Innovative Technologies Administration, "Integrated Vehicle-Based Safety Systems" Web site. <http://www.its.dot.gov/ivbss/> (accessed 7/22/2008).

[12] University of California PATH, Carnegie Mellon University Robotics Institute, *Integrated Collision Warning System Final Evaluation Report,* (May 2006).

[13] GM Safety Initiatives Web site: http://www.gm.com/explore/technology/news/2007/tech_veh2veh_060107.jsp (accessed 1/14/2008). A Car Place Web site: http://www.acarplace.com/brands/gm/vehicle-to-vehicle.html (accessed 1/14/2008).

A different system, the GM Side Blind Zone Alert System™, is available as an option on limited models. This system uses radar to detect vehicles in operators' blind spots. The detection zone, measured from the side-view mirrors, extends approximately 11.48 ft. to the side and 16.4 ft. back. When the system detects a vehicle, it illuminates an "alert symbol" on the side-view mirror. The system only detects moving objects.

Volvo Car Corporation (Computer Vision)[14]

Select Volvo Car Corporation vehicles are equipped with a Blind Spot Information System™ that utilizes digital camera technology to identify vehicles present in the area alongside and offset to the rear behind the vehicle. Digital cameras mounted on the side mirrors on each side of the vehicle capture multiple frames each second and then compare the frames to determine when a vehicle has moved into the monitored zone, an area 31.7 ft. long and 9.8 ft. wide (Figure 2-2). When a vehicle is detected as entering the warning zone, the system activates a yellow warning light beside the side mirror on the side where the vehicle is present.

Figure 2-2. Volvo Car's Blind Spot Information System.

The Volvo system is designed to identify moving objects including cars and motorcycles. It is also designed to work in both daylight and night conditions; however, it does not function well in situations with low visibility.

Mercedes-Benz DISTRONIC Plus Blind Spot Assist (Microwave Radar)[15]

S- and CL-Class Mercedes-Benz vehicles can be equipped with DISTRONIC PLUS™ sensors (Figure 2-3) that monitor vehicle blind spots. The radar-based system makes use of six short-range radar sensors to monitor blind spots to the side and rear of the vehicle. If a vehicle is detected when the turn signal is activated, the system illuminates a red warning symbol on the side-view mirror. If the attempted lane change continues, the warning symbol flashes and an audible warning sounds.

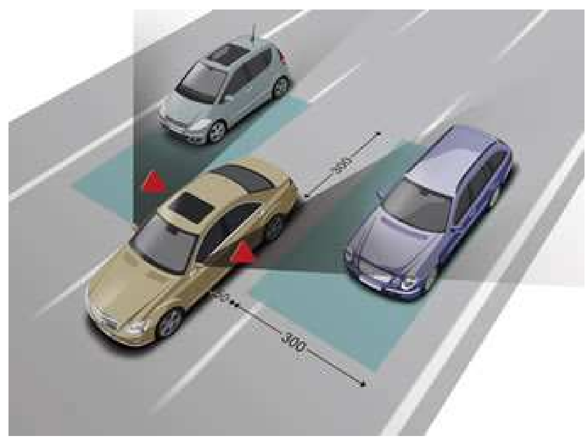

Figure 2-3. DISTRONIC Plus Blind Spot Assist.

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[14] Ford Motor Company Web site, press release: http://media.ford.com/newsroom/feature_display.cfm?release=17040 (accessed 2/6/2008). National Roads and Motorists' Association Web site: http://www.mynrma.com.au/cps/rde/xchg/mynrma/hs.xsl/blis.htm (accessed 2/6/2008).

[15] Mercedes Benz Website: http://www.emercedesbenz.com/Sep07/28_Blind_Spot_Assist_Now_Available_On_S_Class_And_CL_Class_Models.html (accessed 4/29/2008).

Audi (Microwave Radar)[16]

Select Audi vehicles are equipped with a radar-based, lane-change warning system. The system, known as the Audi Side Assist™, identifies objects in the vehicle's blind spot as well as those objects that might not be visible in the rearview mirror. When a vehicle enters the system's range of vision, a yellow vertical light strip illuminates on the corresponding side-view mirror. The driver will also receive a warning (the light strip will flash) if there is a vehicle in a neighboring lane when the turn signal is activated, indicating an intention to change lanes. The lane-change assistant has two 24 GHz radar sensors integrated into the vehicle's bumper with a range of 164 ft. The system is designed to function regardless of the weather conditions and is in operation whenever the vehicle is traveling over 35 mph.

2.2.2 Applications for Heavy Vehicles

There are also a number of systems that have been developed especially for heavy vehicles and many others are being explored as part of the USDOT IVBSS Initiative.

Eagle Eye Object Detection System (Ultrasonic)[17]

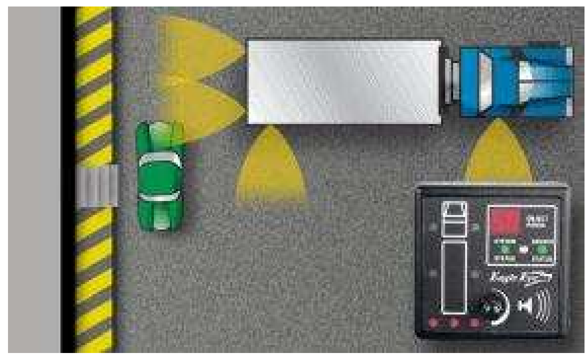

Figure 2-4. Eagle Eye Object Detection System.

The Eagle Eye™ object detection system manufactured by Transportation Safety Technologies, Inc. is an aftermarket system comprised of up to seven ultrasonic side and rear sensors along with a driver alert module (Figure 2-4). The side sensors have a 6 ft. wide by 8 ft. deep field of vision and the rear sensors have a 10 ft. x 10 ft. field of vision. The sensors can be custom-mounted to be positioned according to the operator's needs to address areas of poor visibility around the vehicle. The driver alert module can be installed in or on the dashboard and displays a diagram of the truck as well as the activated sensors. The driver alert module displays a yellow warning light when an object is detected and a flashing red light when an object is detected within 5 ft. The driver alert module also beeps once when it detects an object, then twice more if the object is detected within 5 ft. of the vehicle. The system can be programmed to sound alerts only in specific situations (e.g., warnings from side sensors could be set to generate an alert only when the turn signal is on).

SideEyes (Infrared Laser)[18]

The SideEyes™ infrared laser side object detection system is manufactured by Trico Electronics (Figure 2-5). The system is self-contained within a specialized side-view mirror.

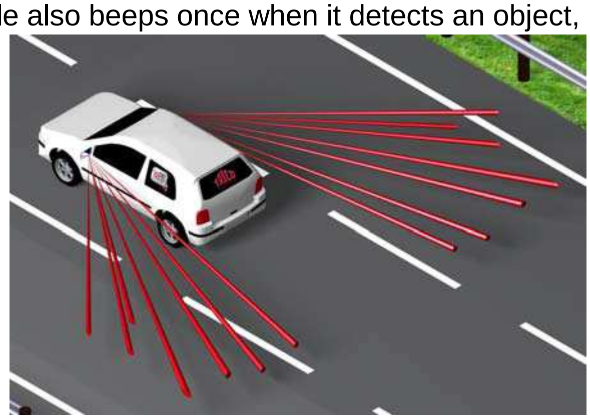

Figure 2-5. SideEyes.

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[16] ThomasNet Industrial Newsroom® Website: http://news.thomasnet.com/companystory/526916 (accessed 2/6/2008).

[17] Transportation Safety Technologies Website: http://www.tst-eagleeye.com/ (accessed 4/29/2008).

[18] Trico Electronics Web site: http://www.sideeyes.com/heavyduty.cfm (accessed 4/29/2008).

SideEyes detects objects in a vehicle's blind spot using an infrared laser and sensor within an adjustable range of up to 25 ft. If an object is detected, the system illuminates a red warning light on the side mirror. The system is available in both OEM and after-market platforms.

Eaton VORAD Blind Spotter (Microwave Radar)[19]

The Eaton VORAD Blind Spotter™ is an aftermarket system composed of a 5.8GHz radar sensor and a driver display and warning module. The radar sensor has an area of detection 10 ft. deep by 15 ft. wide with a 120 degree field of vision. The driver warning module displays a red warning light when an object is detected. When the turn signal is engaged, the driver warning module sounds an audible warning signal. The small driver warning module (1 in. x 2 in. x 2.25 in., or 2.5 cm x 5 cm x 5.7 cm) is typically mounted on the windshield pillar opposite the driver (Figure 2-6). A typical installation consists of one sensor and one warning module. However, up to four sensors can be linked to communicate with the warning module. Warning modules and sensors can be installed on either or both sides of the vehicle.[20]

MobilEye Lane Change Assist and Blind Spot Detection (Computer Vision)[21]

The MobilEye Lane Change Assist and Blind Spot Detection™ system is a computer vision system that detects objects in a vehicle's blind spot using an image sensor. The sensor is mounted within a custom side-view mirror and has a range of 160 ft. The system software processes the captured images and warns the driver if it is not safe to change lanes. The system detects approaching vehicles, determines their range and relative speed, and provides a warning signal based upon the calculated time to collision. The system differentiates between vehicles in adjacent lanes and those that are two or more lanes away. The system functions during day or night, but can be impacted by environmental factors such as snow or fog. If the system determines that it is not functioning properly it shuts off automatically and notifies the driver.

Figure 2-6. Eaton VORAD Blind Spotter.

MobilEye Pedestrian Protection (Computer Vision)[22]

The MobilEye Pedestrian Protection System™ identifies pedestrians from a video camera feed (Figure 2-7). The system software identifies moving and stationary pedestrians and determines their distance, angular position, and (for front-mounted systems) their crossing speed. The monocular video feed can operate in the visible spectrum, near-infrared, or far-infrared (night

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[19] Eaton Corporation Web site: http://www.roadranger.com/Roadranger/productssolutions/collisionwarningsystems/blindspottersideradar/index.htm (accessed 4/29/2008).

[20] Eaton Road Ranger Installation Guide, Collision Warning System, Side Object Detection, October 2007. http://www.roadranger.com/ecm/idcplg?IdcService=GET_FILE&dID=139577 (accessed 4/29/2008).

[21] MobileEye Lane Change Assist and Blind Spot Detection Fact Sheet: http://www.mobileye.com (accessed 4/29/2008).

[22] MobileEye Pedestrian Protection Fact Sheet: http://path.berkeley.edu/~cychan/Research_and_Presentation/Pedestrian_Detection_TO5200/Sensors_Information/Mobileye_Peds.pdf (acessed 4/29/2008).

vision). If the system determines that the pedestrian and vehicle are on a collision path, the system sounds an audible warning. The pedestrian protection system can also be linked to emergency braking systems.

Figure 2-7. MobileEye Pedestrian Protection.

The system is typically forward-facing; however it can incorporate rear- and side-facing cameras for up to 360 degree awareness. The system can be configured for long range (230 ft.) detection with a 20 degree field of view or short range (100 ft.) detection with a 48 degree field of view.[23]

2.2.3 Applications for Transit Buses

The only commercially available system for transit buses at this time is the system that is under study in this independent evaluation. This side object detection system, referred to as "SODS" throughout the remainder of this document, was developed in 2003 following a series of field operational tests on two prior generations of the system. The system is described in further detail in the following section.

Other collision warning systems for transit are at the research and development stages, including a prototype for a side collision warning system that was developed by Carnegie Mellon University's Robotics Institute and the University of California PATH Program.[24] The system makes use of laser scanners for object detection and is capable of detecting objects up to 165 ft. from the bus. Current plans do not include the commercialization of this system as the hardware configuration is cost prohibitive.

2.3 THE SIDE OBJECT DETECTION SYSTEM UNDER STUDY IN THIS REPORT

2.3.1 Field Operational Tests that Led to Development of Current System[25,26]

The FTA, with support from the USDOT's Intelligent Transportation System (ITS) Joint Program Office (JPO), first began exploring technologies to reduce side collisions nearly a decade ago. In 1999, FTA initiated a partnership with the Pennsylvania Department of Transportation (including the Port Authority of Allegheny County) and various research organizations and technology providers, including Carnegie Mellon University, to investigate technologies to reduce the number of side collisions involving transit buses. The goal of this partnership was to develop and test side-mounted object detection systems. Work began with design, installation, testing, and evaluation of the first generation system—Gen1 Transit IVI Side ODS—from 1999 to 2001. This first system used off-the-shelf proximity detection technologies that had previously proven useful for the trucking industry.

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[23] MobileEye Web site: http://www.mobileye-vision.com/default.asp?PageID=220 (accessed 4/29/2008).

[24] University of California PATH, Carnegie Mellon University Robotics Institute (May 2006). Integrated Collision Warning System Final Evaluation Report.

[25] Luglio, T. J. (2003). Final Evaluation Report-Revised, Side Collision Warning System Operational Test Evaluation, Transportation Resource Associates for the Pennsylvania Department of Transportation, Project No. 99-06.

[26] Tate, W. H., Orben, J. E., Clark, H. M., & Luglio, T. J. (2003). Evaluation Report: Driver Experience with the Enhanced Object Detection System for Transit Buses. USDOT Final Report.

The system was installed on 100 full-sized transit buses operating in normal revenue service at the Port Authority's East Liberty Division. The field test was carried out over a 9-month period in 2001. This initial evaluation was designed to determine whether a system such as this could result in a reduction in collisions and whether it was economically viable to install the system on the entire Port Authority fleet. While a reduction in accidents and associated claims was noted during the field operational test (FOT) period, it was difficult to establish a cause and effect relationship, except perhaps for the evidence that the presence of the system increased operators' awareness.

Based on feedback from this evaluation, a second generation system was developed, the Enhanced Object Detection System (EODS) or Gen2, the forerunner of the current SODS technology. This second generation system was subject of a five-vehicle aftermarket FOT conducted in 2003, again in partnership with the Port Authority. Findings from this 100-day study with five operators led to a final small-scale study that was conducted that same year with a slightly modified system. Again five buses were included in the study, but this final study involved an OEM-installed system rather than an aftermarket system.

2.3.1.1 Findings of Field Operational Tests of Previous Systems

The previous system was very similar to the current system. As with the current system, it used a combination of visual (flashing or solid lights) and audible (a double chime) cues to warn the operator of the presence of an object. The primary difference between the systems is that the current system has only one detection distance (6 ft.) when the bus is traveling at speeds between 15 and 45 mph, whereas the previous system had three levels of sensitivity that resulted in different visual alerts (at distances of 8 ft., 4 ft., and 2 ft.). Another difference is that an audible warning previously accompanied the visual warning at speeds below 15 mph, whereas the audible warning has since been removed at these speeds due to feedback from operators.

In terms of feedback on this second generation system, operators reported that they generally felt that the lights were easy to see and to distinguish from other bus displays, although two operators did report that the lights were too bright at night. There was a perception by some operators that the two flash rates (i.e., slow and fast) were difficult to distinguish, distracting, and perhaps unnecessary. No changes were made as a result of these comments. Operators felt that the "chime" (the audible alert) was easy to hear in various conditions and easy to distinguish from other sounds. Some operators felt that the chime should distinguish between the left and right sides of the bus although this suggestion was not implemented.

In general, operators seemed to understand that the role of the system was to assist their judgment, although there was some feeling that the ideal system presented in the training was a disappointment in the real world. Operators reported that they used the chime to "double-check" for vehicles on the left side of the bus when changing lanes on highways and used the lights when making right turns in the city. One operator reported that in tight situations, it was hard to know how to use the information the system provided (i.e., how to prioritize information from both sides of the bus and know what to do operationally). It was not clear in such a situation whether the system really provided any information beyond what was already obvious. Operators' ratings of the lights improved over time (specifically appreciation for rapidly versus slowly flashing lights), perhaps because the operators learned to use the lights or to ignore them as they wished. Operators' ratings of the audible alert declined over time, as operators realized that the chimes were difficult to ignore and did not always provide useful information in situations where they expected that they would be helpful (e.g., cars overtaking the bus when driving on a freeway).

Operators perceived that the system did not decrease stress or fatigue and that it may in fact have increased workload, although this does not necessarily mean they avoided using it. While operators usually did not find the lights distracting, some did find the audible distracting. Second, operators perceived a high rate of false alarms when the chime rang. Operators perceived false alarms to be a problem in three ways:

- Actual false alarms – no object is causing an alarm (positive false alarm)
- Irrelevant false alarms – flashing is so constant that the alarm becomes irrelevant
- False negatives – an object is not detected which should have been

This perception led them to feel the system was not reliable; this is especially true of the lights due to their frequency of activation.

In addition to false alarms, many operators perceived that system warnings were not timely enough, especially when a vehicle was approaching "from the rear of the bus to pass at a high relative speed and passes to the front of the bus before the warning light came on, rendering the warning too little and too late… While this is not a function of system error, it was of concern to the operators because as a practical matter they felt the sensors could not act quickly enough to meet their needs in some situations in which a vehicle was approaching from the rear at a high relative speed… Several operators who had complained of this perceived shortcoming understood and accepted this explanation, but that did nothing to help them gain confidence. The problem was not that they would, for this reason, distrust the chime when it sounded. The problem was that they did not trust it always to sound when there was an object in their blind spot. To them, this represented a gap in the alert system that otherwise would have provided a double check on what they were observing in their mirrors".[27]

Most operators felt that the system would not help them avoid accidents and this feeling increased over time. Two operators felt EODS had helped them avoid an accident. Three reported that it had prevented an evasive maneuver. "Most drivers place little overall value on the EODS in its current form" due in part to the rate of false alarms.

2.3.2 Current System

This study focuses on the only commercially-available side object detection system for transit buses at this time. The current system was developed based on feedback from operators on previous generations of the system tested with the Port Authority. As with the earlier versions, the current system was designed to help operators avoid side object collisions. Specifically it was designed to help operators with tight maneuvers at slower speeds (to reduce collisions with fixed objects such as parked cars, signposts, or poles), and with blind spots while changing lanes at higher speeds (to reduce side-swipe collisions).

2.3.2.1 System Components

The system consists of six ultrasonic transmitters and receivers that detect the distance between the bus and nearby objects (the location of the six sensors is shown in Figure 2-8). These sensors emit sound waves that register a reading with the sensor when they bounce off of solid objects. A central controller interprets the ultrasonic range data.

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[27] Tate, W. H., Orben, J. E., Clark, H. M., & Luglio, T. J. (2003). Evaluation Report: Driver Experience with the Enhanced Object Detection System for Transit Buses. USDOT Final Report.

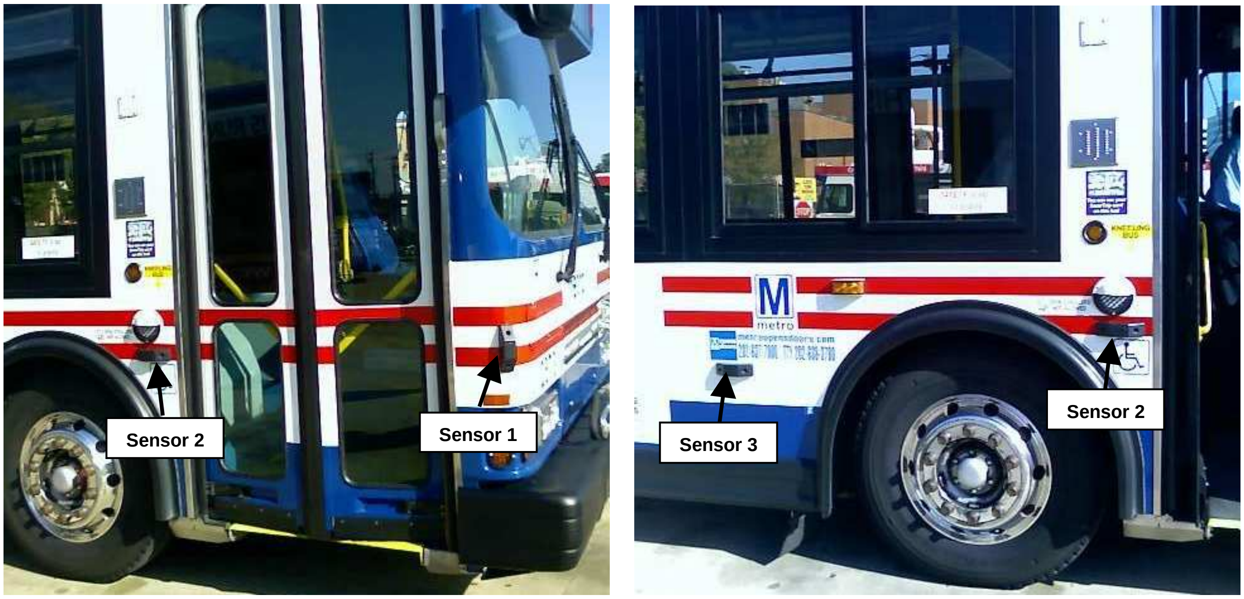

Figure 2-8. Sensor Locations on Outside of Bus.

2.3.2.2 Operator Interface

The interface is the means by which the operators interact with the system. Thus, the interface is the source of information about the world which the system provides and the operator must interpret. The SODS interface is composed of three LED displays along with a speaker that audibly alerts the operator when the system detects a potential hazard. Figure 2-9 shows a representative view of the display locations on a bus and a photograph of the street-side LED display.

Each LED display consists of a blue indicator light that conveys to the operator that the system is on, and three small yellow warning lights that warn the operator when objects are detected. The displays are designed to be positioned such that they are in the operator's peripheral vision when they are practicing safe driving habits. For example, the curbside display is intended to be in their peripheral vision when looking toward the curb when making a tight right turn. Therefore, operators are not expected to monitor a display by actively checking it or looking at it directly. Rather, operators are expected to drive normally, following safe driving procedures, and the LED displays provide information that augments the information they perceive directly from the world.

The audible alert speaker is located above the operator. It is a double-chime sound that is different from other audible indicators on the bus.

2.3.2.3 System Modes

In order for the system to help operators with tight maneuvers at slower speeds, and with blind spots at higher speeds, it must consider a number of factors including the speed at which the bus is traveling, the activation of the turn signal, the distance of the object from the bus, and the location of the object relative to the bus (e.g., whether the object is adjacent to the front or rear of the bus). These factors together determine the current system mode, which then prescribes which sensors should be operable as well as what the detection distance should be for each sensor. The system has four distinct modes: Stopped, Urban Slow, Urban Fast, and Highway. These modes are described below.

Figure 2-9. Mounting Locations of LED Displays.

Stopped Mode and Urban Slow Mode. Stopped mode occurs when the vehicle is stopped and Urban Slow mode applies when the vehicle is traveling at speeds below 15 mph. During these modes, all six detectors are activated and the detector distance is set to 4 ft. Note that the system does not have an audible alert in these modes. (Prior versions of the system had an audible alert in the Urban Slow mode, but this feature was removed due to feedback from operators). The detection zones during these modes are depicted in Figure 2-10. During these modes of operation, the system is designed to help avoid side collisions while making tight maneuvers (e.g., when pulling into or away from a stop or when making a tight turn). To do this, SODS classifies detected objects according to their distance from the detector and provides feedback to the operator based on the severity of the threat:

- Objects greater than 4 ft. away are ignored. The reason for this is that there are typically a good deal of objects within close range of the bus when it is making a tight maneuver and the system would not be helpful to the operator if it warned of every object within a wide range of the bus.
- Objects 3 to 4 ft. from the detector are considered a low threat and result in a slow flash on the LED warning.
- Objects 2 to 3 ft. from the detector are considered a moderate threat and result in a fast flash on the LED warning.
- Objects less than 2 ft. from the detector are considered a high threat and result in a continuous warning light.

Urban Fast Mode. Urban Fast mode applies when the vehicle is traveling between 15 and 45 mph and one of the turn signals is activated. In this mode the system only detects objects near the sensors on the side of the vehicle for which the turn signal is activated (Figure 2-11). In this mode there is no distinction for distance. Any objects detected within 6 ft. of a detector (on the side of the vehicle with the turn signal on) will result in a solid yellow light on the LED display as well as an audible warning. Note that the front sensors are not utilized in this mode.

Highway Mode. Highway mode applies when a vehicle is traveling over 45 mph and one of the turn signals is activated. The operation is identical to Urban Fast mode, except that the detection distance is increased to 8 ft.

Table 2-2 summarizes how SODS functions at different operating speeds.

Table 2-2. Summary of How SODS Works at Different Speeds.

	Below 15 mph (Stopped and Urban Slow Modes)	Above 15 mph (Urban Fast and Highway Modes)
Helps with…	**Determining how close the bus is to a fixed object (pole, parked car)**	**Detecting moving vehicles in blind spots while making lane changes (note sensors are only activated when turn signal is activated)**
Sensor range	**Detects objects within 4 ft of any of the 6 sensors**	**Detects objects within 6 ft. of sensors on side of bus with turn signal activation when bus is traveling below 45 mph** **Detects objects within 8 ft. of sensors on side of bus with turn signal activation when bus is traveling above 45 mph**
Audible cues	**No audible alert**	**Audible alert**
Visual cues	**Solid light at 4 ft., slow flash at 3 ft., fast flash at 2 ft.**	**Solid light**

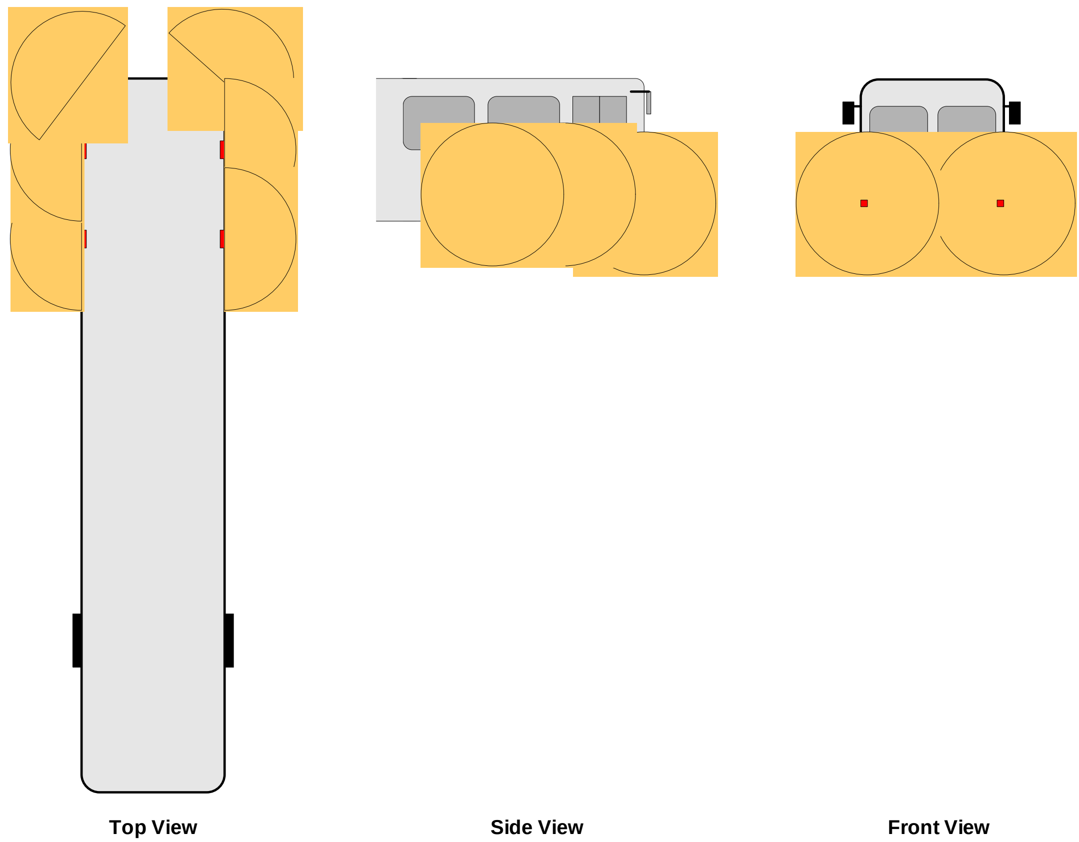

Figure 2-10. SODS Detection Zones during Stopped and Urban Slow Modes.

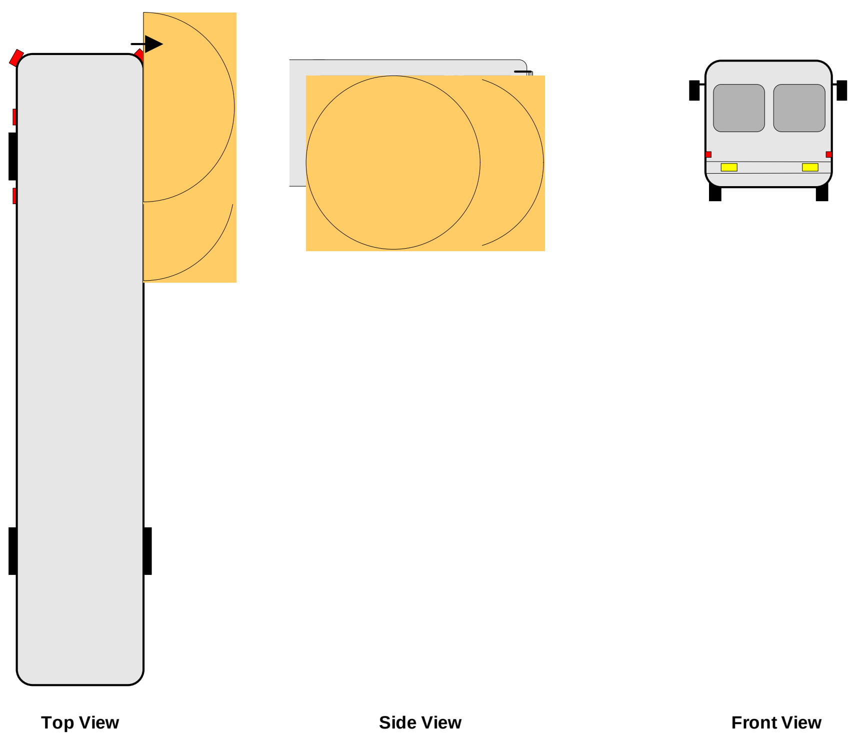

Figure 2-11. SODS Detection Zones during Urban Fast and Highway Modes.

2.3.2.4 Design Limitations of the System

As with any system, the effectiveness of SODS is constrained by the type of technology used and its inherent limitations, as well as by the configuration of the system itself (e.g., sensor placement, etc.). There are certain design limitations of the system that the reader should be aware of in order to understand the context of this study and the findings. What follows are the key limitations of the system. Due to these limitations, SODS is not able to prevent all object collision types. This is an important consideration when assessing how bus operators, maintenance staff, and others perceive the behavior of the system.

These limitations are discussed in further detail, along with recommendations of the evaluation team in terms of future design considerations, in Section 8.3.1.

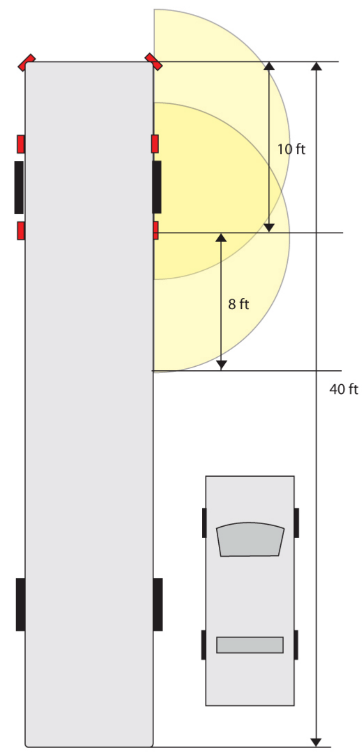

Figure 2-12. Sensor Coverage along the Length of the Bus.

Pedestrians

Pedestrians are certainly a concern for transit bus operators. Due to the type of sensing that SODS uses, however, the system is not capable of reliably detecting the presence of pedestrians and was not designed for this purpose. Ultrasonic technologies rely on receiving a recognizable echo reflected from hard objects, and soft objects such as pedestrians absorb sound energy and may not return a detectable echo to the system.

Speed Differentials Between Vehicles

The system does not warn of vehicles passing the bus at high speeds. Specifically, the system will not detect passing vehicles when the speed differential between the bus and the passing vehicle is greater than 15mph. This is by design (at a speed differential of 15 mph, the passing vehicle is traveling 22 ft/sec faster than the bus, meaning that the vehicle will pass the bus in approximately 2 seconds, and any attempts to warn the operator would arrive too late), but is an element of the design that can cause distrust among operators if they are not properly trained on the system. This is discussed further in Section 5.3.1, *Perception of System Detection Capabilities and Reliability*.

Horizontal Constraints

One limitation of the system that the team observed relates to the placement of the external sensors. Although the exact placement of the sensors varies by bus make and model (as will be discussed in Section 8.3.1), by design, the rear-most sensor on the bus is typically located 8 to 10 ft. from the front of the bus.[28] This means that any vehicles adjacent to the rear half of the bus would not be detected at highway speeds since the detection distance is 8 ft. at highway speeds and the sensors would therefore only detect objects adjacent to the front 16-18 ft. of a 40-foot bus (Figure 2-12). It is important to note that prior versions of the system tested with operators at the Port Authority had additional sensors, and the feedback from those operators

[28] Measurements of actual sensor locations were provided by the participating agencies.

was that the number of sensors should be reduced.[29] This is discussed further in Section 5.3.1, *Perception of System Detection Capabilities and Reliability*.

Another limitation that has to do with lack of coverage of the rear of the bus is blind spot issues that arise during tight turns. Many of the most problematic blind spot issues that arise when making tight turns actually occur at the rear of the bus where there are no sensors so it is possible that the system will not help reduce many of these collisions.

Height Constraints

The height of the sensors also impacts the effectiveness of the system. One example of this is mirrors. Mirrors are the collision point of contact on the bus in a good deal of side collisions (at one of the agencies reviewed as part of this study, the mirror was the contact point in 41 percent of all side collisions). Unfortunately the system will not be effective in many of the "mirror" collisions since the sensors are typically positioned more than 4 ft. below the mirrors and the sensor range is only 4 ft. when the bus is traveling below 15 mph. As a result of this, objects that are at the height of the mirror (such as a sign) would not be detected (Figure 2-13).

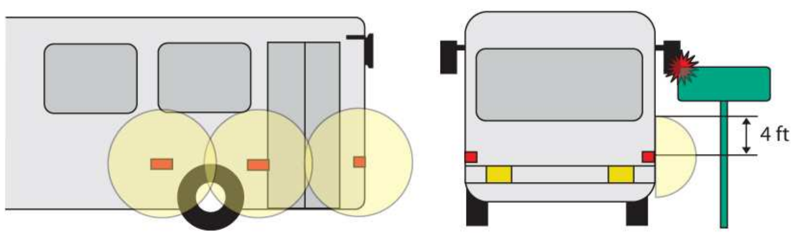

Figure 2-13. Vertical Sensor Coverage.

Lack of Data Archiving

Unlike some on-board technologies such as video systems, SODS does not archive incidents or system activity. In other words, it does not record or report system "uptime", and it does not maintain information on the number of alarms that sound in a particular run or on a particular day.

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[29] Tate, W. H., Orben, J. E., Clark, H. M., & Luglio, T. J. (2003). Evaluation Report: Driver Experience with the Enhanced Object Detection System for Transit Buses. USDOT Final Report.

3 PARTICIPATING AGENCIES

3.1 OVERVIEW / SELECTION

In order to carry out an evaluation of this technology, the FTA and the evaluation team identified agencies across the country with SODS units that were interested in participating in this effort. The goal was to identify agencies that (1) were far enough along in their deployments to suit the timeline of the evaluation, (2) had a significant number of SODS units in their fleet, and (3) were interested and supportive of the evaluation.

In considering agencies with which to partner, the team found that many agencies did already have SODS devices in their fleet, but that many of these agencies had a very small number of units, such as 5 to 10. The FTA and the evaluation team elected to partner with three agencies, each of which had a significant number of units in hand or planned for deployment in the near future.[30] The three agencies included in the study were:

- The Washington Metropolitan Area Transit Authority (WMATA) in Washington, DC.
- The Greater Cleveland Regional Transit Authority (GCRTA) in Cleveland, Ohio.
- The Utah Transit Authority (UTA) in Salt Lake City, Utah.

Each of these agencies has different operating conditions, as well as different operating characteristics and management policies (e.g., how often their bus operators change routes, how detailed their collision records are, etc.). Additionally, each of these agencies deployed their SODS units in a somewhat different way; for example, some deployed SODS-equipped buses only on select routes while others deployed them on a mix of routes. Because of these differences, a “one size fits all” approach was not feasible for the evaluation.

Successfully achieving the goals of this evaluation required the evaluation team to capitalize on these differences and select methods of evaluation that would take advantage of each agency’s operating characteristics and policies. In order to do this, the evaluation team had to have an in-depth understanding of the details of each agency’s deployment (e.g., how many units they were deploying and when) and other details, such as how bus operator assignments are made, how bus assignments are made, and how collision records and claims records are handled. Knowing these details was critical to developing a realistic plan for determining the benefits of SODS.

Confidentiality of agency documents and data was a critical concern in the evaluation process. The remainder of this chapter provides specific information about each of the participating agencies to provide the reader with the context necessary for understanding the details of the evaluation. However, to protect the privacy of these agencies and their staff, no agency names will be used beyond this section.

[30] Note that the evaluation team initially also planned to partner with a fourth agency, the Port Authority of Allegheny County, the agency that had been involved in the testing of previous generations of the system. However, the Port Authority was unable to continue participation in the evaluation.

3.2 AGENCY 1

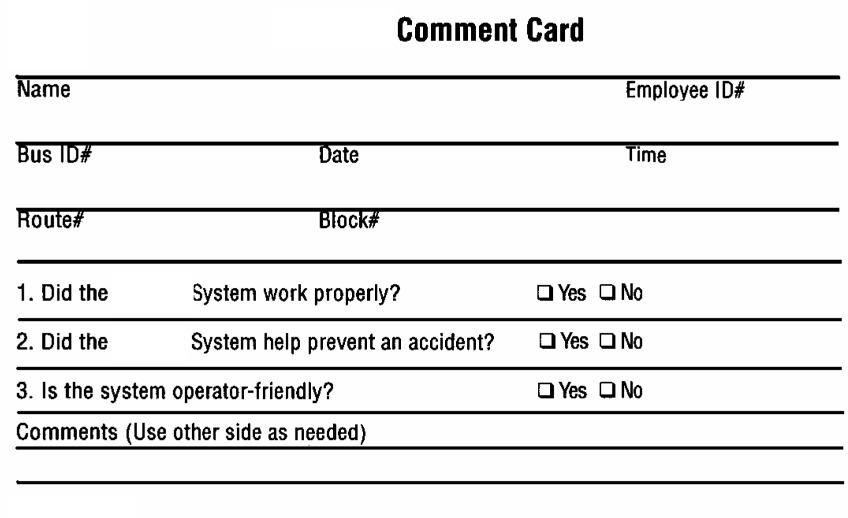
Agency 1 has a total of 93 SODS buses, 48 of which have been in operation since January 2006 and 45 of which have been in operation since December 2006 (all 40-ft. buses). The buses are distributed between the agency's three transit districts as follows:

- 45 operate out of one garage and are dedicated to one route (a branded route with uniquely painted buses).
- 24 each operate out of two other garages with buses assigned at random to all of the routes operating out of these garages.

The agency has between 300 and 400 operators assigned to each of the agency's three garages for a total of approximately 1,030 operators. Operators typically change routes four times each year, but these changes did not impact the evaluation since operators are exposed to SODS on a random basis with the exception of those operators assigned to the dedicated route. All operators received training on SODS when the first SODS buses arrived in early 2006 while new operators receive training on SODS as part of their new operator training.

3.3 AGENCY 2

Agency 2 began internally experimenting with SODS in the summer of 2005 when they obtained five buses equipped with the device. They assigned these five buses to high-collision routes operating out of one of their garages, and they conducted two 90-day tests with the devices in the interest of gauging operator response to determine whether purchasing additional units made sense for the agency. Although cost elements were not included in the study (the agency recognized that larger scale testing would be required in order to accurately assess the cost savings due to SODS), they were able to obtain valuable operator feedback. Operator feedback was gathered throughout the use of comment cards (Figure 3-1) that the agency developed specifically for this purpose based on successful use of comment cards for other on-board systems. They also organized a focus group at the end of the 90-day period with 10 operators who had been exposed to the system frequently during the study period. They found there to be quite a range of opinions expressed by the operators, but overall there was agreement among operators that the system improved their awareness of objects in their blind spots and played a role in helping them to avoid accidents.[31,32]



Comment Card

Name Employee ID#

Bus ID# Date Time

Route# Block#

1. Did the System work properly? ❑ Yes ❑ No

2. Did the System help prevent an accident? ❑ Yes ❑ No

3. Is the system operator-friendly? ❑ Yes ❑ No

Comments (Use other side as needed)

Figure 3-1. Operator Comment Card used by one Agency.

[31] Side Object Detection System Evaluation Results, February 28, 2006.

[32] Discussions with Jack Sturtevant, Project Manager for SODS Study, and Reliability Engineer, Office of Bus Maintenance, 2007.

Following this initial study, the agency ordered 50 additional SODS buses (40-foot buses) and assigned them to one of their garages. Forty-six of the buses are distributed among three routes there. This distribution accommodates the peak demand on these three routes, meaning that only SODS buses operate on these routes. For simplification purposes, the additional four SODS buses were not included in the study since these buses were not assigned to a dedicated route but were instead rotated among many routes.

Approximately 90 of the operators who work at the garage are assigned to these three routes at any given time. However, like most transit agencies, operator assignments change a few times each year, so the 90 operators assigned to the "SODS routes" varied during the course of the study. Some operators changed routes (and garages) in June while others changed routes in September.

This agency was unique in that its participation in the evaluation preceded deployment of SODS. Thus, the evaluation team was able to evaluate SODS in the context of training and initial use. The agency trained their operators in January 2007 and activated the SODS units in early February after all operators had been trained. Their instructors first participated in a train-the-trainer session with a representative of the product supplier, and these individuals subsequently trained those operators who were likely to operate a bus equipped with SODS. New operators receive training on SODS as part of their new operator training.

3.4 AGENCY 3

Agency 3 has a total of 164 buses equipped with SODS. Of these, 53 have been in operation since January 2006, 41 have been in operation since early 2007, 60 have been in operation since early 2008, and 10 have been in operation since mid-2008. None of the buses are on assigned routes (meaning that all are randomly distributed among routes).

The agency has a total of approximately 600 bus operators and nearly every operator was exposed to SODS at some point in time during the study. Like the other agencies, the agency has three times each year when operators may change routes, but these changes did not impact the evaluation since there are no SODS-dedicated routes and operators would be exposed to SODS on a random basis regardless of the routes to which they are assigned. As with Agency 1, all operators received training on SODS when the first SODS buses arrived (early 2006). New operators receive training on SODS as part of their new operator training.

3.5 EVALUATION OPPORTUNITIES / CHALLENGES

Each of the three agencies had a different role in the evaluation. This was the result of the many differences in the timing of and strategy for deploying SODS. While this makes a precisely controlled analysis impossible, there are many advantages to there being so many differences among the agencies. Primarily, many of the unique qualities and approaches among agencies are based on practical and realistic agency policies and business practices. Thus, the evaluation plan was designed to leverage these differences and to take advantage of intra-agency and inter-agency similarities and distinctions. While subsequent chapters provide detailed descriptions of the evaluation approaches, the following sections provide an overview of each agency's involvement in the evaluation. Table 3-1 provides a summary of the agency and garage characteristics.

Table 3-1. Summary of Agency and Garage Characteristics.

Agency	Garage	Route(s)	Route Characteristics	Number of Buses equipped with SODS		
				2006	2007	2008
Agency 1	Garage 1	Some buses on dedicated route / others distributed among routes	Highway, city, suburban, mixed retail and residential. Narrow lanes with telephone poles and signs located close to curb edge.	20	45	45
	Garage 2	Buses distributed among all routes	Highway, city, suburban, mixed retail and residential.	14	24	24
	Garage 3		Highway, city, suburban, mixed retail and residential.	14	24	24
Agency 2	Garage 1	Route 1	Highway, suburban, mixed retail and residential. Sections of the route have no curbs and very narrow lanes.	-	29	29
		Route 2	Highway, suburban, mixed retail and residential.	-	12	12
		Route 3	City and industrial. Not many potential obstacles.	-	5	5
Agency 3	Garage 1	Buses distributed among all routes	Highway, city, suburban, mixed retail and residential. Wide lanes. High-speed merge onto highways.	20	20	59
	Garage 2			20	30	57
	Garage 3			13	44	44
	Garage 4			-	-	4

3.5.1 Agency 1

This agency's units had been in operation for nearly a year at the start of the evaluation, so working with this agency offered the evaluation team an opportunity to obtain feedback both from operators who had been using the device for nearly a year as well as from those who had been using it for only a short time. This was useful in determining whether the length of exposure to the system has an effect on operators' perceptions of the system. The length of time that the agency had been using the system also put them in a position to be able to share information about system maintenance and reliability – issues that take time to understand.

Additionally, since some of the agency's SODS buses are dedicated to specific routes and other buses are randomly assigned to routes, operators had quite a range of experience using the system. Some operators had used SODS on a daily basis over the prior year (i.e., those who had been assigned to the dedicated route for a quarter or more), while others had used SODS only on a periodic basis. This afforded the evaluation team the opportunity to gain insight into whether the frequency of exposure to the system has an effect on operators' perceptions of the system.

3.5.2 Agency 2

The timing and strategy of this agency's deployment offered several opportunities to the evaluation team. For one, the deployment coincided with the start of the evaluation. This timing was opportune because it allowed the evaluation team to gather perceptions from operators after they had been exposed to the system for only a short time. It also allowed the evaluation team to determine how operator perceptions change over time based on their experience level with SODS. Additionally, because of the assignment of SODS buses to dedicated routes, operators had consistent (as opposed to periodic) experience with the system.

An additional benefit of the dedicated SODS routes was that the evaluation team was able to work with a more limited data set for collision and claims data (i.e., only the data for the three select SODS routes) when determining the impact of SODS. With this agency's data, the team compared collisions occurring on these specific routes before SODS to those occurring after SODS. The smaller data set allowed the team to explore the data in more detail and to look at collisions on a route-specific basis. One challenge that the evaluation team faced with regard to data, however, was a lack of historic accident data for two of the three routes. These routes had not been in operation very long before SODS was added, so "before" data was limited.

3.5.3 Agency 3

Like Agency 1, this agency's units had been in operation for nearly a year at the start of the study, so working with this agency offered the evaluation team an opportunity to determine whether the length of exposure to the system has an effect on operators' perceptions of the system.

Since all of the SODS buses are randomly assigned to routes at this agency, there was an opportunity to look at collisions occurring fleetwide rather than focusing on specific routes. This provided an interesting contrast to the analysis that the team performed using collision data from Agency 2, where the buses were on dedicated routes.

4 EVALUATION METHODOLOGY

4.1 EVALUATION GOALS

The three goals of this evaluation were: (1) to assess operator acceptance of the current technology by considering system usability and operator performance, (2) to assess the impact of SODS on collision avoidance and determine the cost savings and return on investment associated with this reduction in collisions, and (3) to use this information to identify institutional issues associated with deploying SODS to provide "lessons learned" for other agencies that may be considering purchasing a similar system for their fleets.

4.1.1 Determining Operator Acceptance

The first evaluation goal was to understand whether operators accepted the addition of SODS to their buses. The evaluation team considered four factors related to acceptance:

1. Operator perceptions of usability of SODS.
2. Effects of SODS on operator performance and alarm handling.
3. Barriers and challenges to operators' acceptance of SODS.
4. Operator reported acceptance of SODS.

The evaluation team worked with the three agencies to obtain data for each of these issues through surveys, focus groups, interviews, and site visits and observations.

4.1.2 Determining the Return on Investment (ROI)

In order to have the necessary information to calculate the return on investment that an agency might expect to see from SODS, the evaluation team obtained a wide range of data, including collision records, costs associated with side object collisions, and costs associated with SODS installation and maintenance. The evaluation team worked with the three agencies to obtain data regarding each of these variables and to determine the overall cost-savings associated with SODS. This portion of the evaluation was primarily based on data provided by the agencies, but interviews were used to supplement this information where needed.

4.1.3 Documenting Institutional Issues and Lessons Learned

Several institutional issues could potentially affect successful SODS deployment. These issues were derived from the data collection activities mentioned already but, most importantly, though direct dialogue with each agency regarding institutional issues.

Above, the issue of operators' acceptance of SODS was introduced. While lack of operator acceptance is one type of institutional issue that can affect the deployment of the system, several others exist, including the type of support that the technology supplier provides to the original equipment manufacturers and the transit agency, the type of training that an agency elects to provide, and agency maintenance practices. These are the types of issues that were considered in this portion of the evaluation.

4.2 OVERVIEW OF DATA COLLECTION APPROACH

Because of the realistic conditions in which SODS was evaluated, the data collection methods needed to be flexible and complement the advantages and limitations of each situation. Data could not be collected in a sterile or controlled experimental environment. Consequently, the evaluation team developed a data collection plan that dealt with the wide variations in the agencies' deployment of SODS including:

- *Timing:* Each agency involved deployed SODS at different times. When the evaluation began, two agencies had been using SODS for over a year, while one was just beginning deployment.
- *Scope:* Each agency differed in fleet size and the degree to which SODS was present in the fleet (e.g., how many buses were equipped with SODS, how many operators interfaced with SODS).
- *Dispersement:* Each agency differed in its approach to distributing SODS buses among the fleet. In one case (Agency 2), all of the SODS-equipped buses were located at one garage. In the other two cases (Agencies 1 and 3), the buses were distributed across several garages. This affected the evaluation since training among operators and maintenance staff differed between the garages.
- *Saturation:* In some cases, entire routes were equipped with SODS buses. In other cases, SODS-equipped buses were distributed across routes, meaning that only some buses on each route were equipped with SODS. This influenced the consistency or the frequency with which an operator might drive a SODS bus.
- *Collision frequency:* Side object collisions are relatively rare events. Some agencies will inevitably experience a much higher number of side collisions due to the nature of the routes that their buses frequent (e.g., buses on a route in an urban environment with narrow streets and parked cars may experience a relatively higher number of side collisions; similarly, buses on a commuter route that involves a high-speed merge onto a freeway may experience a high number of side collisions as compared to buses on other routes).
- *Record-keeping:* Agencies differed in the format and level of detail available in their collision and cost records. These differences created challenges in collecting usable data for the return on investment analysis.

In sum, the agencies participating in the evaluation varied greatly in their characteristics and in their experience with the system. In selecting an approach that could capitalize on similarities and differences across and within agencies, the evaluation team leveraged complementary data collection methods and data sources as presented in Table 4-1.

Table 4-1. Complementary Data Collection Methods Capitalizing on the Agency Deployments.

Data Collection Method	Advantages	Limitations
Surveys	• Effective means to get a representative sample. • Generates quantitative ratings and rankings. • Consistent way to measure trends over time. • Covers a broad range of topics in a relatively short amount of time.	• Difficult to gather detailed data. • Potentially low survey return rate. • Risk of incomplete responses. • Self-reports can be inaccurate or biased.
Focus Group Meetings	• Rich descriptive information (about using the system, near-misses, reporting of maintenance issues). • Ability to follow-up and explore new issues and ask open-ended questions. • Ability to sample specific types of participants (i.e., particular demographic, situational, or experience characteristics).	• Time limits the amount of discussion that is possible. • Limited sample may not be representative. • Self-reports can be inaccurate or biased. • Peer pressure may limit the range or honesty of responses (due to influence of co-workers and/or management). • "Experimental bias" in which participants try to please the facilitator.
Operator Interviews	• Very high level of detail (about using the system, near-misses, reporting of maintenance issues). • Ability to follow-up and explore new issues and ask open-ended questions. • Ability to sample specific types of interviewees (i.e., particular demographic, situational, or experience characteristics). • Easy to build rapport and obtain candor from interviewee.	• Limited sample may not be representative. • Self-reports can be inaccurate and/or biased. • "Experimental bias" in which participants try to please the facilitator.
Agency Visits and Observations	• Observation enables judgment of accuracy of people's self-reports. • Fosters understanding of situation (SODS configuration and performance) across different sites.	• Difficult to follow up during observation activities (ask questions). • Only a "snapshot" and may not be representative.

Taken together, these methods can be used to understand the role of SODS at different transit agencies in terms of acceptance by operators, return on investment, and institutional issues. Each data collection method is described in greater detail as it relates to an evaluation goal in the following chapters.

- *Chapter 5, Operator Acceptance - Data Collection Approach and Findings.*
- *Chapter 6, Framework for Determining Return on Investment.*

- *Chapter 8, Institutional Issues - Approach and Findings.*

Table 4-2 shows a timeline of data collection activities. While the evaluation team led the data collection, this effort would have been far less successful without the cooperation and support of agency management and staff who:

- Administered the paper survey provided by the evaluation team.
- Recruited operators for focus groups and interviews and assisted in scheduling interviews with agency staff, including operations, maintenance, and claims staff.
- Provided buses, operators, and other staff for demonstration and observation purposes.
- Responded to requests for collision records, maintenance reports, and cost data.

Table 4-2. Timeline of Data Collection Activities.

Evaluation Method	Agency	Month (2007)											
		January	February	March	April	May	June	July	August	September	October	November	December
Survey	Agency 1				■							■	
	Agency 2				■							■	
	Agency 3				■							■	
Focus Group Meetings and Operator Interviews	Agency 1								■				
	Agency 2		■			■						■	
	Agency 3											■	
Agency Visits and Observations*	Agency 1	■							■				
	Agency 2	■	■					■			■		
	Agency 3											■	
Agency Interviews	Agency 1								■				
	Agency 2										■		
	Agency 3											■	

** Agency visits and observations were supplemented by phone calls and e-mail exchanges regarding the status of SODS deployment, feedback on system performance and agency perceptions, and evaluation activities updates.*

5 OPERATOR ACCEPTANCE - DATA COLLECTION APPROACH AND FINDINGS

5.1 INTRODUCTION

This chapter presents the details of the data collection activities that the evaluation team conducted to assess operator acceptance. It also presents the detailed findings of this portion of the evaluation.

5.2 DATA COLLECTION APPROACH

Surveys, focus group meetings, and interviews formed the basis for the collection of data about operator acceptance of SODS. Surveys provided the broadest range of information in the highest level of detail. Focus group meetings expanded on a subset of these issues in more detail while interviews provided the most detail on a few specific topics. Using these three approaches with different groups of people enabled the evaluation team to focus on several different objectives, gradually gathering more detail where needed. This multi-faceted approach is shown in Figure 5-1.

The data gathered though this process was supplemented through frequent contact with the agencies, including site visits and observations.

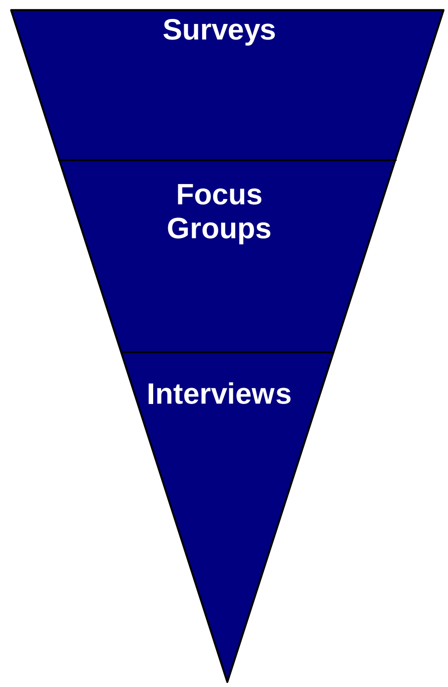


Figure 5-1. Multi-Faceted Approach to Gathering Feedback from Operators.

5.2.1 Operator Surveys

The evaluation team conducted surveys to obtain information from a larger sample of operators than was possible through focus group meetings and interviews alone. Additionally, surveys provided an opportunity to use a consistent rating scale to investigate a set of evaluation issues across agencies and over time. The same survey instrument was used at all three transit agencies participating in the SODS evaluation and the survey was issued to each agency twice throughout the duration of the evaluation (first in April and then 7 months later in November) to determine if operator perceptions and acceptance of SODS changed over time.

The survey was designed to be easily completed in just a few minutes by an operator. The survey was comprised primarily of statements requiring a simple rating on a scale of 1 to 7 (Strongly Disagree to Strongly Agree) although a small number of questions required the operator to provide a short response. To ensure that operators would understand the language used on the survey, care was taken to ensure that layman's terms were used. In addition, the survey was reviewed by all three participating agencies as well as by members of the evaluation team, including a former transit agency safety manager and a former transit bus operator. The evaluation team also delayed finalizing the survey instrument until after the first focus group meeting (held with operators at Agency 2 in February 2007). The first focus group allowed the team to gain a basic understanding of the operators' interactions with SODS up to that point so that the survey designed would be clear, meaningful, and in the operators' own language.

A copy of the survey is shown in Appendix A and details on the survey responses are presented in Appendix B. The survey consisted of 34 questions, the vast majority of which were designed to be answered on a 7-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (7). These rating scale questions covered topics including use of the system (i.e., usability), the impact of the system on driving behaviors, and operator acceptance of the system. Where appropriate, these questions were asked with respect to the two primary system modes, 0-15 mph (lights only) and over 15 mph (lights and sound). Several open-ended items queried operators about situations in which SODS might be most useful, collision avoidance, and suggestions for improving SODS. Operator information was also collected including age, sex, and length of experience driving with and without SODS.

The evaluation team worked with the agencies to distribute the survey to the entire population of bus operators at each location rather than to a sample of operators. The "population" of operators at each location was defined by each agency based on its method of SODS deployment (i.e., at Agency 2 this was a smaller subset of operators since SODS was deployed only on a limited number of routes and all operators were not exposed to it). Surveys were distributed to:

- All operators assigned to the three SODS routes at Agency 2 (approximately 90).
- All operators at Agency 1 (approximately 1,030).
- All operators at Agency 3 (approximately 600).

The evaluation team provided printed copies of the survey instrument to supervisors at the three participating agencies who then distributed the survey to operators, requiring that they return them by the end of the shift on the day they received the survey. The agencies then returned the completed surveys to the evaluation team for analysis. The evaluation team obtained a total of 306 surveys in round 1 and 299 surveys in round 2, for overall response rates of 18 percent and 17 percent respectively.

5.2.2 Focus Group Meetings and Interviews with Operators

Focus groups and interviews provided an opportunity to gather more detailed data directly from operators about how SODS functions, how well it met their expectations, and how useful they find the system to be. Operators were able to relate their first-hand experiences in detail in a relaxed and non-threatening environment. The evaluation team used this information to better understand and qualify what was learned from other sources (e.g., the survey). What follows is a description of the focus group meetings and interviews timeline, participants, and protocols.

5.2.2.1 Timeline

Operator meetings were conducted throughout 2007 on the dates listed in Table 5-1 below. Focus group meetings with Agencies 1 and 2 were formal in structure, including a scripted protocol and a trained focus group facilitator leading the discussions. The meetings with operators at Agency 3 were intended to be one-on-one interviews, but the evaluation team was provided the opportunity to speak with operators in a group setting. As a result, these interviews were less formal as compared to the focus groups and were instead structured like group interviews.

Table 5-1. Focus Group Timeline.

Agency	Focus Group Dates (2007)
Agency 1	August 21 / 22
Agency 2	February 22, June 14, November 15
Agency 3	October 9 / 10

The meetings with Agency 2 differed from the other two agencies in that the evaluation team had the opportunity to collect data early in the deployment process and to see if opinions changed as operators gained exposure to the system. Since the agency had just begun to use SODS in late January 2007 (their operators were trained on the system in early January 2007 and the system was activated in early February), the evaluation team conducted the first focus group in mid-February, just a few weeks after the operators were first exposed to the system.

A critical goal of the evaluation was to gain an understanding of how variations in operator use of the system and day-to-day experience with the system affect perceptions and behavior over time, so the team took a longitudinal approach to the focus groups with operators at this agency. In other words, focus groups were conducted at various stages of system implementation: first in February, immediately after first exposure to the system; next in June, approximately 5 months after first exposure to SODS; and finally in November, approximately 10 months after first exposure to SODS. This provided a unique opportunity to assess how perceptions of operators changed between first contact with the system and during subsequent use over the first year. The evaluation team was able to capture operators' early and later experiences with the system as drivers were trained in and became experienced with SODS.

5.2.2.2 Participants

Agency 2's SODS buses are distributed in such a way that operators who were assigned to SODS buses used them every day during their particular assignment. Therefore, most of the operators in the focus groups drove a SODS-equipped bus on a regular basis, with the exception of some "extra-board" operators who were exposed to SODS on a random basis (those operators who are "on standby" for work assignments and who are therefore exposed to a wide range of routes). In contrast, all operators at Agencies 1 and 3 were exposed to SODS on a random basis, making their experience with SODS quite varied.

Agency 2 operators were trained on SODS prior to assignment to a SODS route in January 2007. The evaluation team worked with the agency to recruit approximately 10 operators to participate in each of three 90-120 minute focus groups. The participants selected for the focus groups represented a mix of operators from each of the three SODS-dedicated routes. The recruiters strove to obtain a mix of operators in terms of age, gender, and years of experience. The details of the three focus groups are shown in Table 5-2.

The evaluation team conducted a formal focus group with a selection of operators at Agency 1 as well as an informal group interview with select operators at Agency 3. These meetings provided a contrast to the focus groups with operators at Agency 2 since these operators are assigned to routes where they might or might not drive a SODS-equipped bus on any given day (the one exception to this is the Agency 1 operators who are assigned to the dedicated route, and some of these operators were intentionally included in the focus group discussion). The discussions with operators at Agencies 1 and 3 allowed the evaluation team to assess longerterm performance and perceptions of SODS, since both agencies had been using SODS for approximately a year and a half at the time of their meetings in August and October.

Table 5-2. Details of Focus Group Meetings and Interviews

Agency	Focus group	Date (2007)	Months since SODS deployment*	Number of participating operators	Average years driving experience (total)	Average years driving experience (current agency)	Average months since first exposed to SODS
Agency 1	A	August 21	Approximately 20 months	7	18	14	12
	B	August 22		6	19	17	13
Agency 2	1st	February 22	1 month	7	20	5	1
	2nd	June 14	5 months	13	26	5	5
	3rd	November 15	10 months	12	7	6	7
Agency 3	A	October 9	Approximately 20 months	8	unknown	14	unknown
	B	October 10		6	unknown	13	unknown

**Operators were not necessarily driving a SODS-equipped bus continuously during this time due to variations in the use of SODS on a particular route and because of changes in route assignments.*

5.2.2.3 Protocols

To address the varied goals of the operator acceptance study, the evaluation team developed three unique focus group protocols focused on three specific topics as depicted in Table 5-3.

Table 5-3. Overview of Focus Group Topics over Time (2007).

Protocol #	Topic	Agency 1	Agency 2	Agency 3
1	Training and initial impressions	-	February	-
2	Early experience	-	June	-
3	Later experience and changes in perceptions from early experience	October	November	August

Only Agency 2 participated in all three protocols because of the unique timing of their deployment in relation to the start of the evaluation. The first focus group was used to assess operators' understanding of side-impact incidents and their understanding of SODS based on their training and very early experience and adaptation to driving with the system in place. The later focus groups touched on these issues, but focused mainly on operator experience with the system on a day-to-day basis. Operators who had varied experience with the system (Agency 1 and 3 operators as well as the extraboard operators at Agency 2) were also asked to compare their operating experience with and without SODS.

Because of these differences in timing, the meeting goals and specific questions asked varied between agencies and over time. In general, focus group meetings focused on a few key issues:

- Incidents – how do side object collisions occur?
- System comprehension – how does SODS work?
- Training experience – how was SODS introduced?
- Impact on behavior – how does SODS affect driving?
- Incident avoidance – has SODS assisted in avoiding collisions?
- Opinions – what is liked and disliked about SODS?
- Preferences – if given a choice, would you prefer to drive a SODS-equipped bus?
- Suggestions – what improvements could be made to SODS or SODS training?

For several reasons, operators may not have had continuous exposure to SODS (e.g., assignment as an extraboard operator, assignment change off or to a SODS-equipped route, and assignment to a route where only a portion of buses were SODS-equipped). These operators with mixed experiences were queried on a number of different topics, such as:

- Changes in behavior associated with switching back and forth between SODS-equipped and non-SODS equipped buses.
- Memory for system performance or functionalities after driving a non-equipped bus.
- Preferences for a SODS-equipped bus or a non-equipped bus.

5.2.3 Agency Visits and Observations

During the course of the evaluation, the evaluation team visited each site at least once. The team also held an in-person workshop with limited representatives of all three agencies in McLean, Virginia in August 2006. The purpose of the workshop was to discuss the desired evaluation activities and to discuss possibilities and limitations for the evaluation. The team visited Agency 1 over a 2-day period in August 2007, Agency 3 over a 2-day period in October 2007, and Agency 1 multiple times during the study. The team augmented these limited opportunities to meet in person with conference calls conducted at various points of time from late 2006 to late 2007.

The in-person visits were invaluable to understanding the unique perspectives, needs, and conditions in which the deployment took place. During these visits, the team met formally and informally with a wide range of agency staff – management, operator supervisors, field supervisors, maintenance staff, training staff, and operators – to capture the full picture about the technology. Early meetings involved determining the history and planning of SODS deployments and developing a mutual understanding of the evaluation process at each agency. In the case of Agency 1, because of their more recent deployment, the team was able to make observations of training. Later meetings provided the team with opportunities to view SODS in use on different buses and to ride along typical routes on which SODS-equipped buses operate. These activities are described in further detail below.

5.2.3.1 On-Board Observations

It would be impossible to truly understand and contextualize operator perceptions and opinions without having a detailed perspective of the driving environment and the role of SODS in that environment. On-board observations provided the team a “real-world” sense of how SODS behaved and is perceived. In order to obtain a more objective understanding of how SODS impacts the operator and the driving task, the evaluation team made observations of SODS-equipped bus operations. The purpose of this was three-fold: (1) to understand the routes and system configuration; (2) to guide the development of the survey, focus groups, and interviews; and (3) to complement and validate the subjective data obtained from other sources.

The evaluation team performed some “ride-alongs”, first privately with an operator and agency staff (i.e., while the bus was *not* in revenue service), and then with an operator driving a regularly scheduled public route. These observations gave the team a sense for:

- The frequency of alarms.
- Causes/sources of alarms.
- Characteristics of different routes.
- Roadway conditions under which alarms occur (pulling into a bus stop, changing lanes, turning, etc.).
- Environmental conditions under which alarms occur (rush hour, rain, etc.).
- The types of driving tasks which are interrupted (scanning for pedestrians and vehicles at an intersection, looking over shoulder during a merge, etc.).
- Operator reactions to alarms and corrective actions/behavior.
- Whether the system appeared to be working as intended.
- Reliability of the system to detect and alarm.
- Frequency of false alarms.
- Operator workload.
- Any passenger response to alarms that occur.

5.2.3.2 Training Observations

The evaluation team made observations of training at Agency 1 in January, February, and July of 2007. First, a team member attended a SODS “Train-the-Trainer” event, in which a representative from the product supplier trained supervisory staff both in the use of SODS and in how to educate operators about SODS. Subsequently, team members observed four operator training sessions.

5.2.3.3 Agency Interviews

During the site visits, the evaluation team conducted interviews with a wide range of transit agency staff including operators’ supervisors and field supervisors, trainers, safety staff, maintenance personnel, and claims staff. Interviews were generally conducted one-on-one and focused on perceptions and challenges observed during all phases of SODS deployment, including:

- *Pre-deployment:* What is the agency's policy for selecting, obtaining, and deploying a new technology? Who provides input into this decision? What considerations go into selecting a system?
- *Deployment:* How was system training developed? Were there problems or delays associated with implementation? Would they advise other agencies to do training differently in retrospect?
- *Post-deployment:* What feedback has been provided formally or informally about the system – by staff or by the public? What could be done to improve the deployment process – by the agency, the product supplier, or the end-users (trainers, operators, maintenance staff, etc.)?

The evaluation team's approach to the interviews was to ask open-ended questions and to encourage respondents to openly express their thoughts about SODS. This resulted in data reflecting both actual experiences and recommendations of ways to improve the process of deployment. Thus, these findings are reported in the current chapter and are also discussed in *Chapter 8, Institutional Issues – Data Collection Approach and Findings.*

5.3 FINDINGS

The following sections describe the findings associated with evaluating operators' acceptance of SODS. The major elements of acceptance are perceptions of usability, operator performance and alarm handling, barriers and challenges to acceptance, and reported acceptance. These findings are derived from the survey, focus group meetings, interviews, and observations described previously.

5.3.1 Operator Perceptions of Usability of SODS

Usability refers to the quality of the operators' experience when using SODS to achieve their goals—to safely and efficiently operate a bus by maintaining a schedule, providing effective customer service, and avoiding collisions. In addition to assessing perceptions of the user-friendliness of SODS, the evaluation team also focused on issues of the operators' comprehension of system functionality and reliability, perceptions of the impact of SODS on their driving behavior, and their opinions regarding system design elements and general SODS ease of use. The evaluation team was interested in whether the operators understood how the system functioned and how they believed they were supposed to react to alarms.

General Understanding

The evaluation team found that operators understood how SODS worked at a general level, although they often conveyed an incomplete or confused understanding about the details of the system. In discussions with operators, they tended to focus on the audible part of the system as a way to detect cars in blind spots when changing lanes on the highway. Operators rarely volunteered information about the light display warning. Observations of training by the evaluation team found that the trainers also tended to emphasize the audible part of the system (and seemed predisposed to believe this would help the operators most). In contrast, operators at Agency 1 seemed to believe that the lights and audible elements were always on together; in actuality, the audible alarms are only present at highway speeds and with turn signal use.

Comprehension of the Visual Alerts

When probed, some operators did not seem to understand or pay attention to the dynamic elements of the visual displays (i.e., the differences between a solid light, slow flash, and fast flash). Even those who could describe the different light patterns claimed to not pay much attention to the lights for two reasons. First, the lights changed too rapidly to be meaningful. One comment about the lights was, "If I see them, I'm standing still." Another operator said, "There's a lot to be remembering about people and cars…lights blink slow, fast, solid; it's too much." Second, by the time operators noticed the lights providing an alert, it was often too late to react. This latter opinion led some operators to suggest that more sensors were needed on the rear of the bus to provide earlier warnings for approaching vehicles and when making turns.

Operators responding to the survey generally agreed that the lights were placed in such a manner as to catch their attention, and they reported not adjusting the lights prior to driving. Operators also tended to agree that the lights drew their attention away from the road. This is counter to the intent of the system design to be intuitive and augment an operator's normal routine (i.e., without looking directly at the lights). Some operators felt the lights were most helpful at night, although others thought they were too bright and distracting at night. In all cases, agencies experienced operators disconnecting the lights or turning them away from their view (a filter was later provided to diminish the brightness of the light).

Comprehension of the Audible Alerts

The majority of the operators clearly understood that the auditory part of the system was activated at higher speeds by their turn signals. Some of their comments included: "At certain speeds, the closer you get to an object, you get different lights, audible alert"; "System works the same in slower mode, just lights"; and "Only makes noise when you use your signal." They conveyed an understanding that the system gives a warning based on speed and distance (i.e., proximity to an object). However, most did not precisely elaborate the details of system performance, including the speed at which different system modes are in effect or the proximities which trigger different warnings.

Many operators seemed to feel that the audible warnings had significant *potential* to assist with identifying hazards in blind spots while changing lanes. However, they clearly disliked the *actual* audible part of the system. Some of their comments included: "Passengers don't like it"; "When driving an urban route, you get a headache from the noise constantly going off as you go up and down the streets"; "Needs a better sound"; " [sounds like] a flock of geese"; and "[I] always use signals, and signal noise is annoying, but you start tuning it out." One operator suggested that the alarm could actually interfere with normal driving (e.g., missing a "request stop" bell). While many of the comments were negative, some of the positive comments included: "Helps with blind spots"; and "Noise wakes up tired operators… can be good for long hours." This mix of comments was pretty consistent over time at Agency 2 and across the three agencies.

Perceptions of System Detection Capabilities and Reliability

In addition to commenting on the operator alerts, many operators commented on the actual placement of sensors on the bus. There was overwhelmingly consistent feedback that the sensors should protect further back on the bus, near the rear wheels. This finding was consistent in focus groups across agencies, and the feeling seemed to strengthen over time at Agency 2. Further, operators desired sensors which could reliably detect pedestrians.

In general, operators reported that they did not feel that the system functioned consistently or alerted them to real objects in the environment. Operators felt that the system was not always reliable, that alerts were not necessarily valid, or that the system did not provide enough reaction time. One operator commented, "[The system] has not been working consistently. [I have] driven a few buses where the system has not worked properly." At Agency 3, operators also reported that the system was too sensitive and often was triggered by rain or snow.

Immediately after deployment (i.e., at the first focus group), Agency 2 operators seemed to indicate that the system was operating in an inconsistent manner. Comments that were made included, "Half the time it doesn't work," or "Yesterday it went off constantly." Only at the third and final focus group meeting did operators mention this less often. They still seemed dissatisfied with the noise and the consistency of the audible alarm. Further investigation revealed that the system had been active for some time on some buses prior to formal deployment. Thus, some operators were not trained to understand the alarm and this influenced their perception of how well it was working when it was deployed.

Additionally, there are certain design limitations that may be difficult to explain to operators, but that are critical in ensuring that they completely understand the system's operations and trust the system. A design limitation of the system is its inability to detect passing vehicles if the speed differential between that vehicle and the bus is greater than 15mph. This is by design, but this can confuse operators who believe that the system is not operating properly when they observe vehicles passing the bus without a system warning. At a speed differential of 15 mph, the passing vehicle travels 22 ft/sec faster than the bus. Since lane changes typically occur at a relative speed of 2.5 to 3 mph, fast moving objects will pass the bus before any action by the bus operator can be taken. Consequently, if the system were to attempt to warn the operator, that warning would come too late for the operator to take evasive action. Many operators perceived this as the system failing to detect a vehicle in their blind spot.

However, not all complaints about reliability were based on misunderstandings of the system's capabilities. The evaluation team heard numerous reports from maintenance staff, particularly at Agency 1, that SODS had repeated maintenance issues. The maintenance issues stemmed from a variety of causes including improper installation by the OEM in some cases, lack of reporting of system failures by operators, and lack of understanding of how to repair the system by maintenance staff.

Impact on Driving Performance

In response to the survey, operators at Agencies 1 and 3 felt that SODS did not interfere with their driving task. In contrast, operators at Agency 2 felt more strongly that SODS did interfere with driving. Of particular note, these operators agreed more strongly than the operators at the other two agencies that SODS decreases the use of turn signals, presumably to reduce the frequency of the audible alarm. However, operators at all agencies generally disagreed that SODS decreased their use of mirrors, indicating they did not overly rely on SODS and still used their mirrors.

In focus group reports, operators at all agencies claimed that the system had not affected their driving behavior. Most of the operators did not think SODS was needed as their general driving training was sufficient if not excellent. Some of these comments included: "Wouldn't say I feel safer, but it may help"; "You get trained to look in mirrors… you need common sense"; "Might help people who aren't doing the right thing"; and "[It doesn't affect me because] I don't take my eyes off the road to look at the lights." A few operators said it assists them, but they do not depend on it. In general, operators reported that they feel that they had been trained well to make good "observations," and that while the system might help, it was not necessary or to be relied on. Some operators felt that it could actually be quite detrimental to new operators, who would come to rely on it and not learn to make good judgments independent of the system. They felt that new operators already have so much to learn that they may become dependent on the technology and not fully develop their own skills. Many operators felt that the system was unnecessary and could be detrimental to good driving behaviors if operators came to rely on it.

However, a small number of comments implied that operators might really have changed their standard driving practice in order to alleviate the noise factor (consistent with the survey findings):

- "Gets on my nerves. The beeping noise is a distraction - [I] stopped using my signal so it won't go off"
- "I slow down to use my signals so that I don't have the noise"
- "[I am] cautious not to use signals because I do not want to hear it."
- At one agency, operators were reported to have "pulled the plug" (until instructed not to do so) and covered the audible alert speaker with tape to diminish the noise.

While a lot of operators did not feel that their behavior had changed with the introduction of SODS, many did allude to changes in how they felt while driving. Comments included: "makes you more stressed" and "the noise is nerve-racking." Survey results clearly show that SODS certainly did not *reduce* the stress of driving a bus (especially for Agency 2).

Overall Findings

The survey showed agency differences among operators on the question of whether SODS is easy to use. Operators at Agency 1 agreed most that SODS was easy to use, while operators at Agency 3 were more neutral, and operators at Agency 2 disagreed strongly. Interestingly, operators at Agency 2 showed a significant decrease in agreement between the first and second survey (in other words, they found it to be less easy to use over time).

However, the focus group meeting and interview findings highlight that even operators who admit that SODS is easy to use do not necessarily trust the warnings it provides. Perhaps operators feel that they understand the system; they just do not like how they have to interact with it. In general, findings related to SODS usability include:

- Operator inattention or disregard of the visual displays; the rapidly changing visual information is difficult to process or is distracting.
- Operator distaste for the audible alert; most operators found it annoying. Some operators reported tuning it out while others actually tried to disable it.
- Operator perception that the system is unreliable in terms of providing false alarms and not providing a warning when it should.
- Operator perception that coverage does not extend far enough back on the rear sides of the bus.

Based on the observations and operator reports, some operators might have an incomplete, imprecise, or unbalanced understanding of SODS, especially in the first few months of use. It is certainly possible that the apparent lack of understanding is due to the simple fact that it is difficult to express in words how the system works. However, based on the overall tone of the focus group discussions, it seems that the audible portions of SODS are much more salient and well understood by operators, especially early in deployment.

These usability findings are consistent with the findings of the 2003 FOT – mainly that the audible alert was easier to understand and that the flash rates of the lights made them difficult to interpret. FOT operators had suggested redesigning the chime to distinguish between the left and right sides of the bus. This was not a need perceived by the operators in this evaluation as the chime was tied directly to the activation of the turn signal. However, operators in the current evaluation suggested that a heads-up display indicating the location of a potential collision would be quite helpful.

Reliability also was a major issue among the operators. This was particularly evident at Agency 2 in the timeframe immediately following deployment of SODS. Follow-up interviews with Agency 2 indicate that operators came to believe that the system improved over time—"it's gotten better"—but that this did not entirely improve their trust in the consistency of the system. This lack of trust was consistent across agencies. At Agency 1, where SODS had been in place for approximately 2 years, operators still reported that the system works inconsistently, that it "does whatever it wants to, whenever it wants to do it." For instance, one operator reported that the system is overly sensitive to parked cars. However, this did not appear to be true to all operators. Another operator complained that the system has "just stopped working in the middle of a run." Similarly, Agency 3 operators, who had also used the system for about 2 years, also reported that they did not trust the system and that it did not always go off when it should. Thus, operators reported that both *false alarms* and *misses* were problems. This is the same finding that was uncovered in the FOT in which operators felt that the alarms were not always reliable or simply were too frequent to be useful.

Even with these negative findings, operators remained open-minded to the potential of a side-impact warning device of some kind. In particular, operators felt there was a great potential for SODS or a similar system to assist them with blind spot checks (e.g., when changing lanes). However, they felt that operators' perspectives had not been considered enough in the system development and that SODS' lack of reliability (consistency) interfered with its performance.

5.3.2 Effects of SODS on Operator Performance and Alarm Handling

How do operators respond to alarms? The survey was used to query operators about alarm events—do they know what object causes an alarm, does SODS detect unseen objects, and does SODS tell them when a correction is needed? Operators responded neutrally, with the exception of Agency 2 operators, who responded negatively to these items. The survey also detected an implication in the operator responses, especially at Agency 2, that there are too many alarms to make sense of them all. These findings are consistent with what was reported in the operator focus group meetings and interviews.

The survey also asked operators under which conditions SODS is useful. Each operator could select multiple situations resulting in 1,700 responses by operators over both rounds of the survey. Table 5-4 shows the percentage of operators selecting a particular situation (some operators selected more than one response). Most situations were selected with roughly the same frequency between 20 percent and 30 percent with no clear winner. The two most frequently selected situations (over 30 percent) were "changing lanes" and "operating in dark or poorly lighted conditions". "Operating in slow traffic" was selected less frequently (approximately 15 percent of respondents). Approximately thirty percent of operators reported that SODS was useful in "none" of the situations listed. Therefore, two-thirds of the operators feel that SODS does have the potential to be helpful in multiple situations. This division in opinions of operators is consistent with what was observed in the focus groups and interviews.

Table 5-4. Operators' Survey Responses about Situations in which SODS is Useful.

SODS is most useful when…	Round 1 (n=306)		Round 2 (n=299)		Combined (n=605)	
	n	%	n	%	n	%
Making right turns	76	25%	91	30%	167	28%
Making left turns	65	21%	74	25%	139	23%
Changing lanes	108	35%	118	40%	226	37%
Operating my bus in dark or poorly lighted areas	92	30%	108	36%	200	33%
Operating my bus on narrower streets	88	29%	106	36%	194	32%
Operating my bus in a construction zone	77	25%	89	30%	166	27%
Operating my bus in heavy traffic	76	25%	101	34%	177	29%
Operating my bus in slow traffic	39	13%	53	18%	92	15%
Operating my bus in fast traffic	77	25%	88	29%	165	27%
None of the above	92	30%	78	26%	170	28%
Other	0	0%	4	1%	4	<1%

Collision Avoidance

The previous sections have indicated that operators do believe that a side object detection system can be useful, but they neither find aspects of SODS useful nor trust SODS. Survey results further indicated that operators do not believe that SODS makes them safer operators or that it reduces accidents (especially at Agency 2).

However, the evaluation team did find evidence that SODS might actually have been used to prevent collisions. During the first Agency 2 focus group meeting, one operator related a personal story in which she felt SODS had prevented a collision. The incident occurred at night when she was driving at highway speed and attempted to change lanes as she was passing under an overpass. She did not see a passing vehicle that was traveling with its lights turned off. She was convinced that SODS had prevented a collision in this situation. While this was convincing to the other operators, none knew of similar experiences, and none reported a similar experience at later meetings. One other operator at a later meeting reported having the system alert him to the presence of a vehicle in his blind spot, although it was not an incident-incipient event. The evaluation team heard several similar stories in which operators were warned of a vehicle in their blind spot (most citing the audible warning only). However, in these cases, the operators claimed to be aware of the vehicle prior to the SODS alert.

Survey results support these narratives. All three agencies reported the use of SODS to avoid collisions. In total, operators reported 937 situations of SODS helping to avoid a collision (over two rounds of surveys).[33] Table 5-5 shows that approximately 37 percent of operators reported that SODS helped them to avoid at least one collision.

Table 5-5. Operator Reports of Collision Avoidance.

Has SODS ever helped you to avoid a collision?	Round 1 (n=306)		Round 2 (n=299)		Combined (n=605)	
	n	%	n	%	n	%
No	197	64%	183	61%	380	63%
Yes	109	36%	116	39%	225	37%

Table 5-6 indicates that "changing lanes" and "pulling in or out of a stop" accounted for approximately 50 percent of avoided collision reports.

Table 5-6. Percentage of All "Yes" Responses for Each Collision Avoidance Situations.

	Round 1		Round 2		Combined	
Yes (total)	248		309		557	
Yes to avoid a vehicle while *changing lanes*	73	29%	93	30%	166	30%
Yes to avoid hitting a fixed object (such as a parked car or pole) while *pulling in or out of a stop*	63	25%	69	22%	132	24%
Yes to avoid hitting a fixed object (such as a parked car or pole) when *making a turn*	49	20%	68	22%	117	21%
Yes to avoid hitting a fixed object (such as a parked car or pole) while *driving straight*	45	18%	63	20%	108	19%
Yes, other	18	7%	16	5%	34	6%
**Note that many operators reported more than one "yes" response.*						

The fact that one out of every three operators reported that SODS helped them avoid a collision seems quite high in contrast to the subjective reports from focus groups and interviews and the collision data. While it seems that SODS has definitely helped in certain situations, it is unlikely that it has had this dramatic an effect as the survey indicates. The evaluation team believes that this question was probably misinterpreted by operators. It is more probable that many of these reports actually reflect situations in which operators found the alarms to be accurate but not necessarily the key factor in avoiding the collision. Consistent with this, several operators suggested that by the time they heard alarms or saw rapidly flashing lights, they were already aware of the object of concern.

These findings indicate that SODS does indeed have the potential to prevent collisions, and may actually be doing so. However, these findings must be considered in light of a far greater quantity of reports suggesting that SODS is simply not being used. Claims of lack of use are because: (a) operators don't find it reliable, (b) operators don't perceive the information as useful, or (c) operators don't think it addresses actual situations. Whether these are accurate claims or not, most operators clearly *believe* that SODS is not a valuable tool.

[33] Ninety-four operators reported taking the survey twice, so some of these 937 reports may be duplications. However, the proportion of collisions types avoided remained roughly consistent across both rounds.

Overall Findings

The findings of this evaluation are consistent with the FOT findings in which several operators reported that SODS had assisted them in avoiding a collision. Yet, the majority of those operators too placed little value on SODS because of its rate of false alarms. In the present evaluation, there is evidence that operators credit SODS with avoiding or having the potential to avoid a collision, particularly blind spot collisions with vehicles when changing lanes or pulling in or out of a stop. However, operators don't express confidence that SODS effectively conveys the nature of an alarm or suggests to them a proper response to an alarm.

5.3.3 Barriers and Challenges to Operator Acceptance of SODS

The evaluation team set out to determine if there were any barriers to operator acceptance and to identify potential solutions. Further description of the lessons associated with these findings also can be found in Section 8.3 of the *Instructional Issues* chapter.

Under-informed with respect to deployment and training

The survey results indicate that operators at Agency 1 felt well prepared by their training to use SODS. Operators at Agency 2 responded neutrally, while operators at Agency 3 strongly disagreed that their training prepared them well. Focus group meetings and interviews revealed different perspectives. At Agency 3, only half of operators claimed that they received any training at all, while at Agency 2, operators reported receiving training and believed their training was sufficient.

Agency 2 operators' perceptions of deployment preparation were burdened by the fact that on some buses, SODS was accidentally turned on for a brief period prior to official system deployment.[34] Some operators reported hearing and being surprised by the audible alarm weeks before any official introduction to the system. Some operators saw (or heard) the system and asked the maintenance staff what it was. One operator reported thinking it was "more cameras." Some operators expressed the perception that the system was not calibrated properly at this point and "went off all the time." After training, operators felt that the system "worked better," and in a manner consistent with how they were trained. Unfortunately, this early experience may have predisposed operators to be skeptical of the system's capabilities and performance.

Undesirable/Unreliable System Performance

In general, operators claimed to be open-minded with regard to a side object collision avoidance system. However, as discussed in other sections, operators felt that the system was not designed or selected with the operators' input or perspectives considered. Operators felt that SODS neither conveyed useful information nor performed consistently.

The survey findings revealed several specific ways to improve acceptance among operators (Table 5-7). Note that the responses reflected in this table do not total to 100 since operators were asked to select all responses that apply.
The three most frequent suggestions were:

- Alter the warning alarm by changing the sound, disabling the sound, or lowering volume.

[34] As discussed earlier, the SODS devices had accidentally been turned "on" for a short period of time immediately upon delivery of the buses. Once managers realized that this had occurred, the devices were turned off until all operator training had been completed.

- Decrease false alarms by altering sensor sensitivity/accuracy
- Modify the lights or have lights only (no warning alarm).[35]

These suggestions are fairly consistent with the results reported thus far. They all are related to a desire to improve the quality of the alarms.

Table 5-7. Suggestions by Operators of How to Improve Operator Acceptance of SODS.

Suggestions to Improve Operator Acceptance	Agency 3		Agency 1		Agency 2	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
Change sound / disable sound / lower volume	52%	21%	33%	30%	24%	30%
Modify training / demo / information	16%	33%	50%	22%	35%	7%
Calibrate / false alarms / sensitivity / accuracy	37%	30%	44%	7%	33%	46%
Change / modify lights / lights only	11%	13%	-	30%	7%	17%
Switch to turn off/on	5%	3%	-	-	7%	6%
Improve mirrors	2%	-	-	-	-	-
Remove it	12%	8%	11%	15%	7%	24%
Better understanding of SODS	-	5%	-	-	-	-
Make SODS mandatory	-	6%	-	11%	-	-
Add camera	-	2%	-	-	-	2%
Improve detection on rear of the bus	-	2%	-	-	-	2%
Other	12%	14%	17%	-	26%	13%
Don't Know/ Nothing	8%	10%	11%	11%	13%	4%

Recurring Maintenance Issues

The first issue of maintenance is lack of consistent system performance. Several operators at different agencies reported that SODS seemed to perform differently from day to day and from bus to bus. Maintenance staff reported that there were indeed cases of SODS malfunctioning. The second issue of maintenance is the feeling by operators that their concerns are not being addressed. At one agency, for example, operators reported that they had "written up" a system that seemed to be malfunctioning, but that doing so never seemed to lead to any improvements.

Awareness of Passengers' Reactions to SODS Alarms

Several operators reported that passengers notice the audible alarm and that it might confuse them or they might find the sound annoying. At Agency 3 in particular, operators expressed concern that passengers might have a negative opinion of "my driving with all the beeping." The

[35] Most operators indicated a preference for the audible alarm. However, the desire to remove the audible alarm may be related to a desire to eliminate the noise which so many operators found annoying and instead focus on improving the information provided by the lights.

survey results indicated that on a whole, operators were not too concerned with this issue, although Agency 2 operators indicated an increased concern with passenger perceptions over time.

Overall Findings

Operator acceptance of SODS could be improved by

- Informing, educating, or consulting operators about SODS prior to deployment
- Making training more meaningful to operators
- Improving the quality of the alarms
- Improving system reliability
- Responding promptly to maintenance issues
- Considering passengers’ perceptions in alarm design

Operators were open-minded to the potential of a side-impact warning device. One operator said that operators might be more accepting of the system if “the bugs were worked out.” Operators felt that their perspectives had not been considered enough in the system development and deployment and that SODS reliability interfered with its performance.

5.3.4 Operator Reported Acceptance of SODS

It was hypothesized that operators would perceive the system as useful, accurate, and valuable both initially and over time. As discussed in previous sections, many operators question the functionality, usability, and reliability of SODS. These feelings impacted day-to-day use of the system. At one agency the evaluation team observed that a SODS visual display had been turned away from the operator and tape had been placed over the audible speaker to diminish the sound. Maintenance staff at another agency reported that operators were unplugging the visual displays until they were told to stop.

These examples reflect operators’ level of acceptance of SODS. It was hypothesized that operators would perceive the system as useful, accurate, and valuable both initially and over time. As discussed in previous sections, operators question the functionality, usability, and reliability of SODS. During the Agency 2 and Agency 1 focus groups operators were asked if they would rather drive a bus with or without SODS if given the choice. Table 5-8 shows the findings at two agencies. At Agency 2’s second focus group, most operators wouldn’t admit to actually using the system, but had a “can’t hurt” sort of attitude. With time, these feelings diminished and during the final Agency 2 focus group, most operators preferred to get rid of SODS altogether. This is consistent with Agency 1 where all operators said they would prefer to not have SODS on their buses with its current design and operational characteristics.

Table 5-8. Operator Opinions Regarding SODS: Prefer to Drive a Bus with or without SODS?

Agency	Focus Group	With SODS	Without SODS	No Opinion
Agency 1	**A / B**	**0**	**13**	**0**
Agency 2	**1st**	**9**	**4**	**0**
	2nd	**4**	**7**	**1**

These findings generally agree with the results of the survey query, "I would rather operate my bus without SODS." Operators showed moderate to strong agreement that they would rather operate a bus without SODS, especially at Agency 2. There was also moderate disagreement among operators with the statement, "I would like SODS to be kept on my bus in the future," with the exception of operators at Agency 2 who *strongly* disagreed. However, for the statement, "I think every bus in the fleet should be equipped with SODS," there was neutral to moderate agreement, except for Agency 2 who strongly disagreed.

The Effect of Operator Experience

Why did operators generally reject SODS-equipped bused? Many of the operators felt that they rely on experience and training. There is an overwhelming perception that if an operator is following training and doing a proper job, that a warning system is irrelevant. In general, operators did not think they could or should rely on the system, as evidenced by the comments, "You can't depend on it, it's just a machine" and "I rely on my eyes." Survey results also showed moderate to strong agreement among operators that SODS is not necessary for more experienced operators, especially among operators at Agency 2.

In the focus groups, some operators felt that novice operators might benefit most from SODS. However, others felt that it might become a crutch that results in poorer driving. The survey results indicated moderate agreement among operators that SODS is helpful to new, less experienced operators. An exception to this is that operators at Agency 2 strongly disagreed.

Understanding of Side-Impact Incidents

To put these perceptions of usefulness and desirability in context, operators were asked about their perceptions of side-impact incidents, specifically when or why they occur, and their importance to the operators. First, operators felt that side-impact incidents were relatively unimportant compared to other types of incidents (e.g., pedestrian collisions). However, they did report that side-impact collisions are a concern to their respective agencies but that they may be more of a problem for new operators.

In general, Agency 2 operators reported that they worry most about inattentive or unpredictable actions by other vehicles,[36] including cars in blind spots (when changing lanes or leaving a stop), cars jumping in front of the bus (to make a right turn), and cars flinging doors open into the travel lane. Operators at all agencies reported that parked cars and other fixed objects tend to be a big issue (on tight right turns and when pulling into a stop),

Even though they worry less about these types of incidents, Agency 2 operators reported that *all* accidents are stressful—even those involving "just a scratch" because an operator is held

[36] Operators also reported concerns about collisions with pedestrians. However, these are not relevant to the SODS evaluation and will not be discussed here.

strictly accountable by the agency (including a lengthy and tedious incident reporting process). However, relatively speaking, they felt that side-impact incidents are only a small concern because they do not occur frequently. Some reasons for this included "because you can see most of the sides of the bus" especially with the "new convex mirrors" and because of good instruction, including the requirement to look "three to five" (meaning that they should look at their mirrors every 3 to 5 seconds).

Overall Findings

One Agency 1 operator summarized the feelings of many operators exposed to SODS: "…on paper it [SODS] sounds like a good thing, but on the streets it's not effective." The findings indicate that operators are concerned with side-impact collisions if for no other reason than the potential for disciplinary action should such incidents occur. However, operators clearly feel that SODS, as it currently exists, does not do what it should to assist operators to prevent incidents.

5.3.5 Overall Findings of Operator Acceptance Evaluation

Throughout this evaluation, the evaluation team had to consider a variety of contradictory information. Naturally, operators and other agency staff disagreed at points about the usability and effectiveness of SODS. Additionally, some operators would indicate contradictory views from one moment to the next. Generally in focus groups and interviews, some operators would express strong and detailed opinions about the quality of the system – claiming to ignore the light warnings, to dislike the audible alarm, and to generally worry about the reliability of the system. However, they might also claim that that the system should be installed on more buses and that they believe it could help prevent collisions (as the survey results suggest) or that it could be helpful to new drivers. The evaluation team believes that these conflicting findings stem from a conflict between an awareness that collisions happen, and a pride and confidence (maybe over-confidence) in their own driving abilities. That is, operators seem to feel that the system may be good for others, but few were willing to admit they *needed* help. Further, the evaluation team believes that the findings indicate a desire among operators for support to avoid collisions but frustration with the system as it is currently deployed.

Thus, operators were relatively open-minded to the use of a side-impact collision warning device like SODS, although these types of collisions are not a critical concern to them relative to other types of collisions. Many operators did believe SODS helped them to avoid a collision, particularly blind spot collisions with vehicles when changing lanes or pulling in or out of a stop. However, operators did not find the system usable in its current design, particularly with regard to the quality and frequency of visual and audible alerts. Operators also complained about the consistency with which the system functioned, partly because of true maintenance issues and partly because of uncertainties in understanding the systems' capabilities.

The main findings related to SODS usability included:

- Operator inattention or disregard of the visual displays; the rapidly changing visual information is difficult to process or distracting.
- Operator distaste for the audible alert; most operators found it annoying. Some operators reported tuning it out while others actually tried to disable it.
- Operator perception that the system is unreliable in terms of not providing a warning when it should and in terms of providing false alarms

- Operator perception that coverage did not extend far enough back on the rear sides of the bus.

Among the suggestions to improve the design of the system included changing the quality of the alerts. The three most frequent suggestions were:

- Alter the warning alarm by changing the sound, disabling the sound, or lowering volume.
- Decrease false alarms by altering sensor sensitivity/accuracy.
- Modify the lights or have lights only (no warning alarm).[37]

Operators were very forthcoming in discussing the challenges to operator acceptance. From these discussions, the evaluation team determined several ways to improve operator acceptance of SODS.

- Informing, educating, or consulting operators about SODS prior to deployment.
- Making training more meaningful to operators.
- Improving the quality of the alarms.
- Improving system reliability.
- Promptly responding to maintenance issues.
- Considering passengers' perceptions in alarm design.

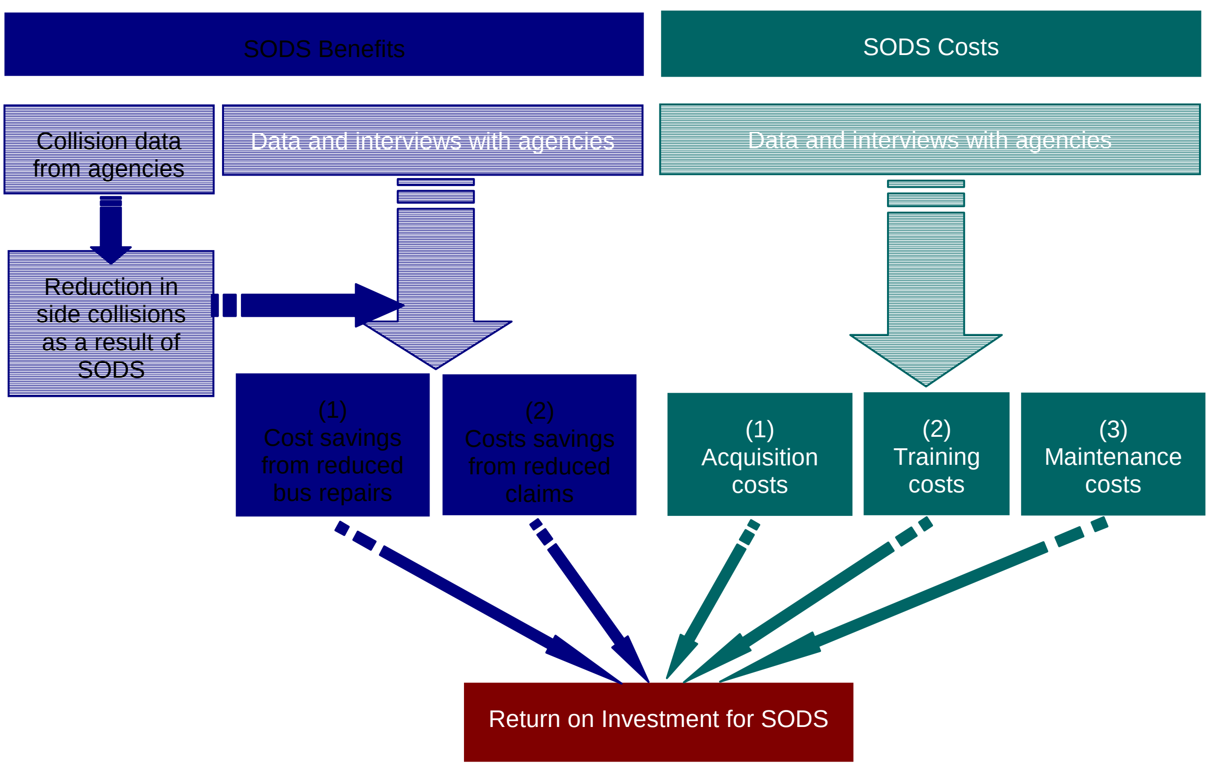
[37] Most operators indicated a preference for the audible alarm. However, the desire to remove the audible alarm may be related to a desire to eliminate the noise that so many operators found annoying.

6 FRAMEWORK FOR DETERMINING THE RETURN ON INVESTMENT

6.1 INTRODUCTION

In order to calculate the return on investment that an agency might expect to see from SODS, it is necessary to obtain information on both the costs and benefits of SODS. The framework for determining the return on investment of SODS is shown in Figure 6-1. As shown in the left side of the figure, the benefits of SODS are actually the cost savings resulting from a reduction in side collisions. As such, determining the benefits of SODS requires collision data as well as data on bus repair costs and claims costs. These cost savings are the two components of the "benefits" side of the equation. As shown in the right side of the figure, determining the costs associated with SODS requires information about three cost components that make up the "costs" side of the equation: the cost of acquisition, training, and maintenance.

Figure 6-1. Framework for Determining ROI for SODS.



The remainder of this chapter discusses how the team collected data for each of the cost elements and presents a summary of the data that was obtained (Section 6.2). Information about how these values were compiled into the overall return on investment analysis, and what the overall findings were with regard to the return on investment for the technology are presented in Chapter 7, *Return on Investment Calculation and Findings*.

6.2 DATA COLLECTION APPROACH

This section presents information about how the team collected data for each of the cost/benefit elements shown in the previous figure and presents a summary of the data that was obtained from the agencies. Sections 6.2.1 and 6.2.2 respectively present the benefits and costs.

6.2.1 SODS Benefits

The benefits of SODS are actually the cost savings associated with a reduction in side collisions resulting from SODS. In basic terms there are two components to this cost savings (see Figure 6-2):

(1) The cost savings associated with reduced bus repairs, and

(2) The cost savings associated with reduced claims.

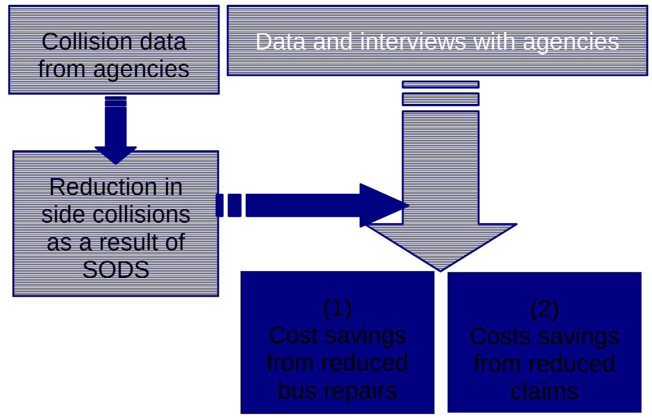


Figure 6-2. Determining SODS Benefits.

The cost savings could be expanded to include a third category of savings to represent a variety of other indirect costs that are incurred due to a collision. These costs may include:

- Any resulting fines and penalties.
- The cost of having a bus out of service while repairs are made.
- The cost of replacing an operator unavailable for normal duties as a result of a side collision.
- The cost of short-term operational disruptions.
- The cost of schedule delays.
- The cost of accident investigation and administrative and legal costs (time for the operator involved in the collision to report it, time for the supervisor to review the collision information, time for the claims administrators to deal with any associated claims).
- Rising insurance costs (for agencies that are not self-insured) or a rising insurance reserve fund (for larger agencies that are self-insured).

These factors are typically difficult to quantify, so for purposes of simplification, and to reduce burden on the participating agencies, these additional factors have been excluded from the analysis.

Reduction in Side Collisions as a Result of SODS

As shown in the figure, the *reduction in side collisions as a result of SODS* must also be known as this is used as a multiplier in determining the total cost savings or benefit. To determine the impact of SODS on collision rates, one would ideally compare collision data for SODS and non-

SODS buses traversing the same routes, since the route itself can have an impact on the number of, and nature of, collisions experienced.[38] For Agency 2 this analysis was possible since their SODS buses were operating on three dedicated routes throughout the duration of the study. Therefore Agency 2 provided collision data for only the three routes that were equipped with SODS so that a "before / after" analysis could be conducted (i.e., a comparison could be made between the number and type of collisions occurring on these three routes before SODS was installed, to those occurring on these same routes after installation).

Due to the nature of the way in which SODS buses were distributed throughout the entire fleets for the other two agencies, however, this type of analysis was not possible. Instead the evaluation team conducted a "with / without" analysis of the collision data from these agencies. That is, the team asked that both agencies provide collision data for all collisions occurring fleetwide during the timeframe of the study (for both SODS buses and non-SODS buses) so that a comparison could be made between collisions experienced by SODS buses during the timeframe of the study to those experienced by non-SODS buses during this same time period.

For all three agencies, the team asked for the following information for each collision:

- Date of the collision.
- Route the bus was traveling on at the time of the collision.
- Bus ID number.
- Intersection / location of the collision (e.g., in the garage, at a bus stop, etc.).
- Vehicle type (e.g., make and model which defines the size of the bus).
- Event classification (e.g., sideswipe, etc).
- Detailed collision description - for example:
  - Where on the bus the damage or point of impact occurred.
  - What the bus was doing when the impact occurred (e.g., moving straight, turning right, pulling into a bus stop, etc.).
  - What object the bus struck or by which it was struck.
  - If the other object hit was a moving vehicle, what the other vehicle was doing at the time of the impact.

For the collision analysis the evaluation team also obtained where possible:

- *Mileage information for all buses within the fleet.* In the interest of establishing collision rates in terms of vehicle miles traveled (VMT) between collisions (rather than in terms of collisions per year per vehicle), the evaluation team asked the agencies to provide mileage information for all buses in their fleet over the time period of the collision data. It is important to look at the collision rate in terms of VMT as considering collisions on strictly a per-bus basis would assume that every vehicle in the fleet had the same exposure, and this is not a correct assumption as newer buses are typically in service more than older buses. This means that newer buses have greater exposure to potential risks and therefore have a greater chance of being involved in a collision. This

[38] Motor Fleet Safety Manual, 3rd Edition, National Safety Council.

is a particularly important factor in this analysis as the SODS buses were all new buses and therefore in service more often than the non-SODS buses on average.[39]

- *Bus inventory information.* It was necessary for the team to obtain information from the agencies regarding the dates that buses were placed into service. It was important to obtain this information as a bus will only appear in the collision database when it has been involved in a collision, so those buses that did not experience any collisions during the timeframe of the study in fact did not appear in the collision database at all.

A summary of the collision data obtained is presented in Table 6-1 below. The findings of the analysis are presented in Chapter 7, *Return on Investment Calculation and Findings*.

Table 6-1. Collision Data Included in Study.

Agency	Data Obtained
Agency 1	**2 years of data for all collisions occurring fleetwide (January 9, 2006 - January 8, 2008)**
Agency 2	**10 years of data for all collisions occurring at garage with SODS (February 3, 1998 - December 31, 2007)**
Agency 3	**2.5 years of data for all avoidable collisions occurring fleetwide (January 1, 2006 – June 30, 2008)**

(1) Cost Savings from Reduced Side Collisions – Bus Repair Costs

To determine the benefit in terms of the cost savings associated with reduced bus repairs resulting from a reduction in side collisions, the team obtained maintenance records that included the labor and parts costs associated with side collision repairs. In gathering maintenance data to determine the cost of repairs due to side collisions, the team found that some of the agencies' maintenance records do not specify the reason for the repair so it was difficult to isolate those records that were associated with collision repairs. For this reason, in addition to reviewing maintenance records, the team also conducted interviews with maintenance personnel in order to obtain estimates of the cost of repairs associated with the types of accidents that SODS is likely to reduce.

(2) Cost Savings from Reduced Side Collisions – Claims Costs

All three agencies that participated in this study are self-insured and therefore experience claims costs.[40] Therefore, to determine the cost savings associated with reduced claims resulting from a reduction in side collisions, the team obtained claims costs. Claims costs associated with side collisions include: costs associated with bodily injury to agency employees, costs associated with other party damages, and costs associated with bodily injury to other parties.

A summary of the data obtained regarding claims costs is presented in Table 6-2. In considering claims costs is it important to note that claims are often not closed out and reported in the system until some time after the incident occurs (the participating agencies reported that

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[39] In fact, when comparing mileage information for SODS buses and non-SODS buses for one agency, it was found that SODS buses were "on the road" 60 percent more often than non-SODS buses during the course of the study.

[40] Agencies that are not self-insured will not experience claims costs, but will instead pay associated deductables. Most large agencies are self-insured. Since this evaluation focuses primarily on larger agencies, claims costs are used in the ROI calculations.

property-damage only incidents are typically closed out within 1 month of the incident but others typically take longer), so some of the more costly claims may be underrepresented in this dataset. Detailed findings are presented in Chapter 7, *Return on Investment Calculation and Findings*.

Table 6-2. Data Obtained Regarding Claims Costs Associated with Side Collisions.

Agency	Data
Agency 1	**2 years of data for claims associated with all collisions occurring fleetwide (January 9, 2006 through January 8, 2008)**
Agency 2	**Nearly 8 years of data for all side collision claims occurring fleetwide* (July 1, 2000 - April 30, 2008)**
Agency 3	**2.5 years of data for claims associated with all collisions occurring fleetwide (January 1, 2006 – June 30, 2008)**

Agency 2 provided the team with data for all garages rather than just for the garage with SODS to increase the sample size of the data set.

6.2.2 SODS Costs

In order to calculate the return on investment that an agency might expect to see from SODS, it is necessary to obtain information about the various costs associated with purchasing and maintaining SODS. As Figure 6-3 shows, these costs include:

(1) The initial expense of acquiring and installing the system.

(2) The cost of training personnel in the use of the technology, including trainers, operators, maintenance staff, and others as needed.

(3) The ongoing costs associated with maintaining the system including periodic testing as well as repairs required as a result of component failure or damage.

These three cost components are described in more detail below.

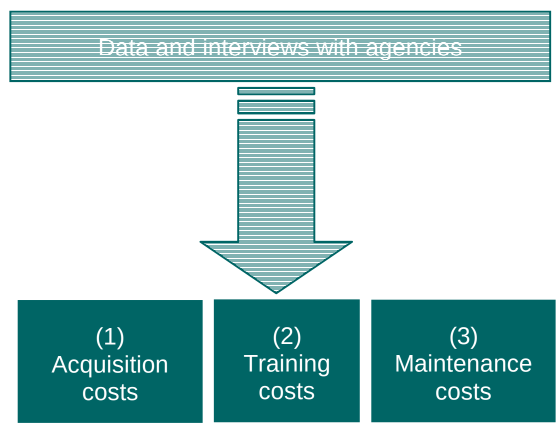

Figure 6-3. Determining SODS Costs.

(1) Acquisition Costs

The initial cost of acquisition was defined through interviews with the agencies and the product supplier. All three agencies elected to purchase their units as part of a new bus procurement and this per unit purchase cost was used in the ROI calculation. Since all agencies purchased the technology as part of a new bus procurement, as opposed to a retrofit, they paid for both acquisition and installation of the system at the same time and therefore installation was not a separate cost and is not included in this ROI calculation. It should be recognized that all agencies may not acquire SODS or similar technologies in this manner and this cost may be understated for retrofits.

(2) Training Costs

Training costs were estimated based on interviews with training managers. Training costs include both the initial cost of training (conducting train-the-trainer sessions and then training all operators and maintenance staff), as well as on-going training costs such as refresher training for operators and mechanics. The evaluation team asked each agency to consider all of these cost elements when providing an estimate of training costs. It was assumed that the cost of training new operators and mechanics will be negligible since it will be part of their overall training when they are hired.

(3) Maintenance Costs

The ongoing maintenance costs related to component failures and replacement of parts were derived through interviews with fleet maintenance personnel as well as through a review of maintenance records. The team obtained records on maintenance costs directly from two agencies. No costs were obtained from the third agency however, as that agency's SODS repair costs are covered through their existing maintenance support contract with the product supplier. Consequently, they incurred no additional maintenance expenses for having maintenance performed on the SODS equipment.

Although the three agencies that participated in this study did not perform any system testing (beyond basic testing as part of routine bus inspections which typically only occur only once a year), it is important not to overlook this cost as routine testing of the system would reduce system down-time and improve system performance which can have a significant impact on operator acceptance of the technology. The evaluation team generated estimates of this cost based on industry averages for mechanic hourly rates and based on certain assumptions regarding how much time this routine testing would require each year.

A summary of the data obtained regarding the cost of maintaining SODS is presented in Table 6-3. It is important to note that the maintenance costs obtained are limited to early maintenance costs since all agencies had had their units for 3 years or less at the time that the data collection for this study was completed in December 2007. Detailed findings about all of these costs are presented in Chapter 7, *Return on Investment Calculation and Findings*.

Table 6-3. Data Obtained Regarding the Cost of Maintaining SODS.

Agency	Data
Agency 1	**2 years of maintenance records agency-wide (March 1, 2006 – February 29, 2008)**
Agency 2	**N/A - maintenance of SODS is not provided in-house**
Agency 3	**1.5 years of maintenance records agency-wide (January 3, 2006 – June 28, 2007)**

7 RETURN ON INVESTMENT CALCULATION AND FINDINGS

7.1 INPUTS INTO CALCULATING THE RETURN ON INVESTMENT

This Chapter discusses how the evaluation team arrived at the inputs for the costs and benefits required for the return on investment calculation and presents the findings of the ROI analysis.

7.1.1 SODS Benefits

Figure 7-1 shows the benefits associated with SODS. The following sections detail how the evaluation team arrived at the inputs for the benefits-side of the ROI calculation.

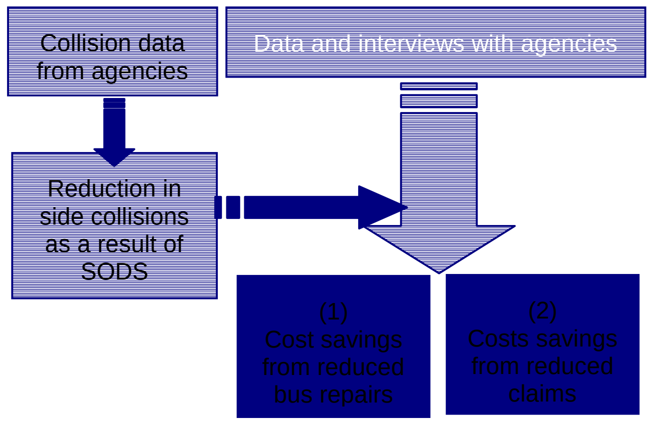

Figure 7-1. SODS Benefits.

It should be noted that the benefits of SODS as described here would most likely be realized by large transit agencies, as the exposure to SODS-relevant collisions is greater for large transit agencies than it is for medium and small agencies. Large transit agencies differ in several respects from medium and small transit agencies. Large transit agencies serve metropolitan areas with high density populations. High density populations are typically characterized by significant traffic congestion, low vehicle operating speeds, and the requirement for tight maneuvers due to narrow streets and parked cars; thus, increasing the probability of a SODS-relevant collision. The increase in exposure for larger agencies is also due to the number of transit buses actively in operation on any given day. However, medium to small agencies may benefit if they have a higher than expected number of fixed-object or sideswipe collision types. Transit agencies should carefully evaluate the costs of, and the benefits that may be derived from, SODS as part of a decision to procure SODS for their fleet.

(1) Cost Savings from Reduced Side Collisions – Bus Repair Costs

Agency 1 provided the team with data on the bus repair costs associated with each side collision for which they provided collision data. The other two agencies were unable to provide this information as their maintenance database does not track bus repairs against collisions. Consequently it was not possible to determine from the maintenance records which repairs resulted from a side collision for these two agencies. Therefore, for these two agencies the team conducted interviews with maintenance personnel to generate estimates of the cost of repairs associated with the types of accidents that SODS is likely to reduce.

A summary of the reported bus repair costs associated with side collisions is shown in Table 7-1 as well as the value that was selected for the ROI calculation (the average of the three agency values). Again note that the numbers presented for Agencies 2 and 3 are based on estimates obtained through interviews with maintenance staff at these agencies. Following the table are further details about how the cost for Agency 1 was determined.

Table 7-1. Summary of Cost Savings from Reduced Side Collisions – Bus Repair Costs.

Agency	Average Bus Repair Cost Associated with Side Collisions (per collision)
Agency 1 (n=342)	**$295**
Agency 2 (estimated through interviews)	**$1,000**
Agency 3 (estimated through interviews)	**$1,000**
ROI Calculation Value	**$765**

Agency 1 provided the team with bus repair costs for 900 collisions occurring during the years 2006 and 2007. Based on the evaluation team's assessment of SODS-relevance, 342 of the collisions, or 38 percent, were SODS-relevant.[41] Table 7-2 shows the average bus repair cost for each type of collision (in terms of the point of contact on the bus). The average bus repair cost associated with a SODS-relevant collision was $295. It is interesting to note that side collisions are just as costly as other collisions when it comes to bus repair costs. The cost of SODS-relevant collisions is quite similar to the average bus repair costs associated with collisions ($295 compared to $243), and that the percent of collisions resulting in no bus repair costs is also similar for the two (55 percent compared to 58 percent).

Table 7-2. Costs Associated with Repairing Buses after SODS-Relevant Collisions (Agency 1).

Point of Contact in Collision	Average Cost	
	Left	Right
Front (n=6)	**$922**	
Side Front (n=46)	**$497**	**$411**
Side Middle (n=104)	**$377**	**$300**
Side Mirror (n=82)	**$87**	**$100**
Side Rear (n=88)	**$272**	**$351**
Rear	**N/A (no rear collisions considered to be SODS-relevant)**	
Other (n=16)	**$250**	
Total (n=342)	**$295**	

(2) Cost Savings from Reduced Side Collisions – Claims Costs

All three agencies provided data on third party claims costs associated with SODS-relevant collisions. Table 7-3 presents a summary of the reported claims costs associated with side collisions as well as the value that was selected for the ROI calculation (the average of the three agency values). Following the table are further details about how these values were determined.

[41] SODS-relevance was determined based on the process previously discussed of assigning a "SODS-Relevance" value between 0 and 1 to each collision. More detail about this process is provided in Appendix D.

Table 7-3. Summary of Cost Savings from Reduced Side Collisions – Claims Costs.

Agency	Average Claims Cost (per collision)
Agency 1 (n=347)	**$168**
Agency 2 (n=8,329)	**$421**
Agency 3 (n=163)	**$643**
ROI Calculation Value	**$411**

Agency 1 provided third-party claims costs associated with 1,053 collisions occurring during the 2-year period January 9, 2006 through January 8, 2008. Based on the evaluation team's assessment of SODS-relevance, it appears that 446 of the claims, or 42 percent, are SODS-relevant. The average cost of a claim associated with a SODS-relevant collision during this timeframe was $156. The average cost of a claim associated with a collision in general was much higher at $329. Interestingly, 79 percent of SODS-relevant collisions and 89 percent of the collisions in general had no associated claims costs (or at least had none reported in the claims database). It is likely that the reason for this is that the claims have not yet been settled for many of the more recent collisions (i.e., those that occurred within the 6-month period prior to the data reporting). Therefore, to account for this likely discrepancy, the evaluation team narrowed the analysis to only include those collisions occurring prior to July 8, 2007. Based on an analysis of these data (347 collisions), the average cost of a claim associated with a SODS-relevant collision was higher, at $168.

Agency 2 provided claims costs for all "SODS-relevant" collisions occurring fleetwide (note that this expands beyond the three routes of interest and even beyond the garage with SODS to provide a larger data set) for the time period July 1, 2000 through April 24, 2008. Based on the evaluation team's assessment of SODS-relevance, it appears that 8,528 of the 13,020 claims, or 65 percent, are SODS-relevant. The average cost of the claims associated with SODS-relevant collisions was $416 while the average cost of a claim associated with a collision in general was much higher at $3,213. Similar to Agency 1, 80 percent of SODS-relevant collisions and 79 percent of collisions in general had no associated claims costs (or at least had none reported in the claims database). Again, to account for this likely discrepancy, the evaluation team narrowed the analysis to those collisions occurring prior to 2008. Based on an analysis of this smaller dataset (of 8,329 collisions), the average cost of a claim associated with a SODS-relevant collision was slightly higher, at $421.

Agency 3 provided third-party claims costs associated with 527 collisions occurring between 2005 and 2008. Based on the evaluation team's assessment of SODS-relevance, it appears that 177 of the claims, or 34 percent, are SODS-relevant. The average cost of a claim associated with a SODS-relevant collision was $601 while the average cost of a claim associated with a collision in general was nearly 3 times higher at $1,748. Similar to both Agencies 1 and 2, there were a number of collisions with no associated claims costs, but not nearly as many (38 percent of SODS-relevant collisions and 28 percent of the collisions in general). Again, to account for the discrepancy of recent claims costs not yet being reported, the evaluation team narrowed the analysis to only include those collisions occurring prior to 2008. Based on an analysis of these data (163 collisions), the average cost of a claim associated with a SODS-relevant collision was $643. Table 7-4 below provides additional detail on the costs by collision type. This level of analysis was not possible with the other two agencies. The most common collision was the bus hitting an object (nearly half of all SODS-relevant collisions), but these collisions are also the least expensive in terms of claims costs.

Table 7-4. Claims Costs Associated with SODS-Relevant Collisions (Agency 3).

Collision Type	Average Claims Cost per SODS-Relevant Collision
Side impact (n=23)	**$1,739**
Bus turning left (n=9)	**$1,925**
Bus turning right (n=3)	**$610**
Bus hit parked vehicle (n=44)	**$770**
Bus hit object (n=81)	**$154**
Collision between agency vehicles (n=3)	**$0**
Total (n=163)	**$643**

7.1.2 SODS Costs

Figure 7-2 shows the costs associated with SODS. The following sections detail how the evaluation team arrived at the inputs for the costs-side of the ROI calculation.

(1) Acquisition Costs

The initial cost of acquisition was defined through interviews with the agencies and the product supplier. All three agencies elected to purchase their units as part of a new bus procurement at a per unit price of $2,000. This cost was used in the ROI calculation. Since all agencies purchased the technology as part of a new bus procurement (as opposed to a retrofit), they paid for both acquisition and installation of the system at the same time and therefore installation was not a separate cost and is not included in this ROI calculation. All agencies may not acquire SODS or similar technologies in this manner and this cost may be understated for retrofits.

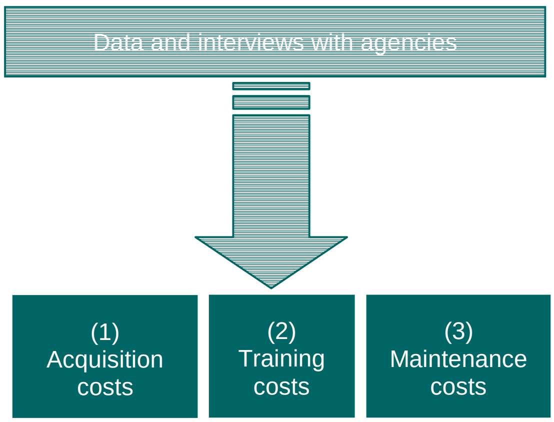

Figure 7-2. SODS Costs.

(2) Training Costs

The evaluation team requested that the training staff at each agency provide the evaluation team with estimates of the cost of training operators on how to use SODS. The training costs included both the cost of initial training as well as the cost of refresher training.

Table 7-5 presents a summary of the reported SODS training costs including both the cost of initial training and the cost of refresher training. It also presents the values that were selected for the ROI calculation. Since the hourly wages vary by agency and these agencies differ from the national average, the evaluation team elected to use the national average for the hourly rate in the ROI calculation. Following the table are further details about how these values were determined.

Table 7-5. Summary of SODS Training Costs.

Agency	Cost of Initial Training (per operator in first year)	Refresher Training (per operator per year after first year)
Agency 1	**0.51 hrs**	**N/A**
Agency 2	**0.56 hrs**	
Agency 3	**0.52 hrs**	
ROI Calculation Values*	**$14.13 (0.5 hrs)**	**$14.13 (0.5 hrs)**

Note that the ROI Calculation uses an estimated 2008 national average of $28.25 per hour, taken from the Bureau of Labor Statistics (see footnote).

Agency 1 reported that their initial training costs included a 30-minute train-the-trainer session for 13 instructors (6.5 man-hours) followed by course development (3 man-hours). Their instructors then provided training for each of 1,000 operators (approximately 500 man-hours).

$$\left(6.5hrs + 3hrs + \left(\frac{0.5hrs}{operator} \times 1000operators\right)\right) = 509.5hrs$$

$$\frac{509.5hrs}{1000operators} = 0.51hrs / operator$$

Agency 2 reported that their training included 30 minutes of training for each of their 10 line platform instructors (5 man-hours) followed by 30-minute operator training that was conducted in small groups (generally 5 to 10 operators at a time).

$$\left(5hrs + \left(\frac{0.5hrs}{operator} \times 90operators\right)\right) = 50hrs$$

$$\frac{50hrs}{90operators} = 0.56hrs / operator$$

Agency 3 reported that their training included 30 minutes of training for each of the approximately 30 operations instructors (15 man-hours). This was followed by 30-minute operator training that was conducted in small groups.

$$\left(15hrs + \left(\frac{0.5hrs}{operator} \times 660operators\right)\right) = 345hrs$$

$$\frac{345hrs}{660operators} = 0.52hrs / operator$$

All three agencies believed that the initial training would require 30 minutes per operator and that the refresher training would require 30 minutes per operator per year. Based on an estimated national hourly rate of $28.25,[42] this equates to a total cost of $14.13 per operator for initial training and $14.13 per operator per year for refresher training.

$$\frac{0.5hrs}{operator} \times \frac{\$28.25}{hr} = \$14.13 / operator$$

The agencies believed that their maintenance staff required 30 minutes of training on the system in the first year. Based on an estimated national hourly rate of $30.07,[43] this equates to a total cost of $15.04 per mechanic for initial training.

$$\frac{0.5hrs}{mechanic} \times \frac{\$30.07}{hr} = \$15.04 / mechanic$$

(3) Maintenance Costs

Table 7-6 presents a summary of the reported SODS maintenance costs including both annual maintenance costs as well as the cost of routine testing. The table also provides information about the values that were selected for the ROI calculation. For the sensor replacement rate and the labor hours for sensor replacement the evaluation team elected to use a lower value (half of the value reported by the agencies). The reason for this is that maintenance staff and the product supplier believe that sensors were replaced more often than necessary as maintenance staff performed troubleshooting. Similarly, it is believed that much of the labor hours reported were associated with troubleshooting rather than directly replacing a sensor.

Table 7-6. Summary of SODS Maintenance Costs.

Agency	Sensor Replacement Rate (per bus per year)	Labor Hours for Sensor Replacement (per sensor)	Cost of Parts for Sensor Replacement (per sensor)	Annual Maintenance Cost (per bus per year)	Cost of Routine Testing (per bus per year)
Agency 1	**0.570**	**Unknown**	**$325.00**	**$225.00**	**N/A**
Agency 3	**0.170**	**3.5**	**unknown**	**$73.14**	
ROI Calculation Values*	**0.185**	**1.75**	**$325.00**	**$69.86**	**$7.52**

Note that the ROI Calculation uses an estimated 2008 national average of $30.07 per hour, taken from the Bureau of Labor Statistics (see footnote).

Agency 1 provided the evaluation team with information about SODS repair costs for the period March 1, 2006 – February 29, 2008. During this 2-year period, 65 sensors were replaced on 57 buses. This indicates that over half of the SODS fleet required a sensor replacement during the first 2 years and the average sensor replacement rate is 0.570 sensors per bus per year. The cost per sensor was $325 and the total cost of labor for these 65 repairs was $4,533.02. This results in an average labor cost per sensor of $69.74. Replacing 0.570 sensors per bus per

42 Taken from the Bureau of Labor Statistics May 2006 median hourly earnings for urban transit system bus operators of $19.94, applying 31 percent fringe benefits, and applying a 4 percent annual inflation rate. http://www.bls.gov/oco/ocos242.htm Accessed 8/4/2008.

43 Taken from the Bureau of Labor Statistics 2006 median hourly earnings for bus and truck mechanics of $21.22, applying 31 percent fringe benefits, and applying a 4 percent annual inflation rate. http://www.bls.gov/oco/ocos182.htm Accessed 8/4/2008.

year at an average materials cost of $325 per sensor and an average labor cost of $69.74 per sensor results in an average annual maintenance cost of $225.00 per bus as shown below.

$$\frac{0.570 sensors/bus}{year} \times \frac{(\$325.00 + \$69.74)}{sensor} = \$225.00/bus/year$$

At the time that Agency 2 received their units, they had an on-call support contract already in place with the product supplier for other in-vehicle systems, and they now continue to use this support contract for SODS maintenance at no extra cost. Since the agency does not perform maintenance activities in-house, the agency did not have maintenance costs to report.

Agency 3 provided the team with data covering the time period January 3, 2006 through June 28, 2007. This 18-month represents their early experiences with SODS (i.e., the first year and half with their first fleet of 53 buses and the first 6 months with their second fleet of 41 buses). During this time the agency recorded 12 SODS repairs involving the replacement of 17 sensors and 2 system controllers. They reported an average of 3.5 labor hours for replacing a sensor. They did not report equipment costs, but using the cost per sensor provided by Agency 1 ($325.00) and using an estimated national average for hourly pay of $30.07,[44] the total cost of replacing a sensor equates to $430.25. Replacing an average of 0.170 sensors per bus per year results in an average annual maintenance cost of $73.14 per bus as shown below.

$$\$325.00/sensor + \left(3.5 hrs/sensor \times \frac{\$30.07}{hr}\right) = \$430.25/sensor$$

$$\frac{0.170 sensors/bus}{year} \times \frac{\$430.25}{sensor} = \$73.14/bus/year$$

To determine the value to be used in the ROI calculation, the evaluation team used the national average for hourly rate and half of the average sensor replacement rate from the two agencies.

$$\$325.00/sensor + \left(1.75 hrs/sensor \times \frac{\$30.07}{hr}\right) = \$377.62/sensor$$

$$\left(\left(\frac{0.170 sensors/bus}{year} + \frac{0.570 sensors/bus}{year}\right)/2\right)/2 = \frac{0.185 sensors/bus}{year}$$

$$\frac{0.185 sensors/bus}{year} \times \frac{\$377.62}{sensor} = \$69.86/bus/year$$

Beyond repairs to SODS, routine testing of the system is critical to ensure that the system is working properly and to maintain trust in the system among operators. If it is assumed that each system is inspected once each year and that an inspection requires 15 minutes of a mechanic's time, using the estimated national hourly rate, this equates to an on-going annual expense of $7.52 per bus as shown below.

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[44] Using as estimated 2008 national average of $30.07 per hour, taken from the Bureau of Labor Statistics 2006 median hourly earnings for bus and truck mechanics of $21.22, applying 31 percent fringe benefits, and applying a 4 percent annual inflation rate. http://www.bls.gov/oco/ocos182.htm Accessed 8/4/2008.

$$\frac{0.25 hrs / bus}{year} \times \frac{\$30.07}{hour} = \$7.52 / bus / year$$

7.1.3 Summary of Cost and Benefit Inputs into ROI Calculation

A summary of the cost and benefit inputs that were used in the ROI calculation are shown in Table 7-7 (benefits) and Table 7-8 (costs).

Table 7-7. Detail of Benefits (Cost Savings) Used in ROI Calculation.

Benefit Component	Value Used in ROI Calculation	Notes / Observations
(1) Labor and parts costs associated with repairing the bus following a SODS-relevant collision.	**$765 per side collision.**	**Derived from maintenance records as well as through interviews with maintenance staff.** **May underestimate costs for smaller agencies (e.g., some agencies may not have their own body shop).**
(2) Claims costs associated with a SODS-relevant collision.	**$411 per side collision.**	**Derived through claims data from three agencies.**
Total costs associated with each SODS-relevant collision.	**$1,176 per side collision**	**Sum of benefit components (1) and (2).**

Table 7-8. Detail of Costs Used in ROI Calculation.

Cost Component	Value Used in ROI Calculation	Notes / Observations
(1) The initial expense of acquiring the system.	**$2,000 per bus.**	**Defined through interviews with agencies and product supplier.** **Acquisition cost may be understated for agencies that purchase device as a retrofit, although retrofit purchases are unlikely.**
(2) The cost of initial training and refresher training for various personnel including trainers, operators, maintenance staff, and others as needed.	**$14.13 (0.5 hours) per operator in first year for initial operator training.** **$15.04 (0.5 hours) per mechanic in first year for initial maintenance training.** **$14.13 (0.5 hours) per operator per year for annual refresher training.**	**Estimated based on interviews with training managers.** **Assumes that the cost of training new operators is negligible since it is part of overall new operator training.** **Uses 2006 hourly rate from the Bureau of Labor Statistics; applies 4% per year for inflation to bring to 2008 values; applies 31% fringe to account for benefits.** **Cost could be higher for some agencies due to operator replacement costs and/or union contractual requirements.**
(3) The ongoing costs associated with maintaining the system including periodic testing as well as repairs required as a result of component failure or damage.	**$69.86 per bus per year for SODS repairs.** **$7.52 per bus per year (0.25 hours) for annual SODS testing.**	**Derived through interviews with fleet maintenance personnel and review of maintenance records.** **Limited to maintenance costs from early years.** **Based on maintenance costs for current state of SODS applications in the U.S. May over-state repair costs for future procurements since some of repair costs experienced may be attributed to improper installation, which may not be a problem with future procurements.**

7.1.4 Reduction in Side Collisions as a Result of SODS

All costs are on a per-bus basis or on a per-operator basis. The benefits, however, are on a per-collision basis. Therefore before calculating the return on investment, it is necessary to determine what value will be used for the number of collisions reduced as a result of SODS. As shown in Figure 7-3, the reduction in collisions is a multiplier that is used to determine the total cost savings associated with SODS.

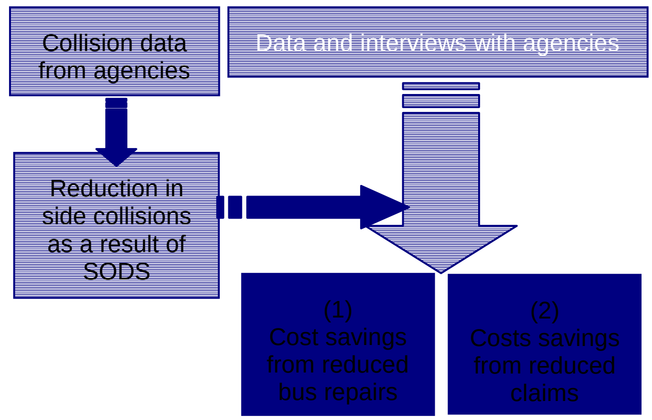

Figure 7-3. SODS Benefits.

Analysis of Agency 2 Collision Data

Agency 2 provided the evaluation team with nearly 9 years of "before" collision data covering the time period February 3, 1998 through December 6, 2006. The agency also provided the team with nearly 1 full year of "after" data covering the time period February 5, 2007 through December 31, 2007. This data set represented all collisions occurring at the garage with SODS over this time period. However, the evaluation team was unable to obtain vehicle miles traveled information about all buses during the timeframe of the study so the collision rate could not be determined on a per bus or per vehicle mile traveled basis.

Analysis of Agency 3 Collision Data

Agency 3 provided collision data for non-SODS buses for the 1.5-year period from June 1, 2005 through January 16, 2007, and collision data for SODS buses for the nearly 3-year period from July 26, 2005 through June 16, 2008. The agency's data is limited to fields containing short descriptions of the collision. The short descriptions do not provide enough detail to clearly determine the nature of the collision or whether the collision is SODS-relevant. For example, a record might say, "bus made contact with another bus," but it will not indicate whether the vehicles were moving in the same direction or in opposite directions or where the point of contact was made on the bus.

The data included information on 446 collisions occurring across their fleet of 644 buses (164 of which were equipped with SODS). The data does not include enough detail to make a definitive determination as to how many collisions are SODS-relevant, but a crude assessment based on the brief incident descriptions available[45] indicates that 25 percent (113 of the 446 collisions) may be SODS-relevant as shown in Table 7-9 below.

As shown in the table, the data show a difference between the average collision rate for SODS buses and non-SODS buses. This is true both when considering SODS-relevant collisions and when comparing collisions in general. The average overall collision rate for SODS buses was 0.420 collisions per 100,000 vehicle miles traveled (VMT) as compared to 1.309 for non-SODS buses. The average collision rate for SODS-relevant collisions was also lower for SODS buses, at 0.096 collisions per 100,000 vehicle miles traveled versus 0.337 for non-SODS buses.

[45] SODS-relevance was determined based on the process previously discussed of assigning a "SODS-Relevance" value between 0 and 1 to each collision. More detail about this process is provided in Appendix D.

Assuming that only the reduction in SODS-relevant collisions can be attributed to SODS, this indicates a reduction of 0.241 collisions per bus per 100,000 VMT.

Table 7-9. Actual Collision Rates for SODS Buses vs. Non-SODS Buses (Agency 3).

Bus Type	Number of Collisions	Number of SODS-Relevant Collisions	Percent SODS-Relevant Collisions	Overall Collision Rate per 100,000 VMT	SODS-Relevant Collision Rate per 100,000 VMT
SODS Buses (n=164)	**66**	**15**	**23%**	**0.420**	**0.096**
Non-SODS Buses (n = 480)	**380**	**98**	**26%**	**1.309**	**0.337**
Total (n=644)	**446**	**113**	**25%**		

Analysis of Agency 1 Collision Data

Agency 1 provided the evaluation team with 2 years of collision data (covering the time period January 9, 2006 through January 8, 2008) representing 900 collisions occurring fleetwide among the agency's event classification codes that were initially deemed as possibly SODS-relevant.[46]

As shown in Table 7-10, the data show a small difference between the average collision rate for SODS buses and non-SODS buses. This is true both when considering SODS-relevant collisions and when comparing collisions in general. As shown in Table 7-10, the average overall collision rate for SODS buses was 1.673 collisions per 100,000 vehicle miles traveled (VMT) as compared to 1.917 for non-SODS buses. The average collision rate for SODS-relevant collisions was also lower for SODS buses, at 0.599 collisions per 100,000 vehicle miles traveled versus 0.730 for non-SODS buses. Assuming that only the reduction in SODS-relevant collisions can be attributed to SODS, this indicates a reduction of 0.131 collisions per bus per 100,000 VMT.

Table 7-10. Actual Collision Rates for SODS Buses vs. Non-SODS Buses (Agency 1).

Bus Type	Number of Collisions	Number of SODS-Relevant Collisions	Percent SODS-Relevant Collisions	Overall Collision Rate per 100,000 VMT	SODS-Relevant Collision Rate per 100,000 VMT
SODS Buses (n=93)	**127**	**46**	**35.8%**	**1.673**	**0.599**
Non-SODS Buses (n = 632)	**773**	**295**	**38.1%**	**1.917**	**0.730**
Total	**872**	**324**	**37.2%**		

Summary of Measured Reduction in Side Collisions

Table 7-11 shows a summary of the reduction in side collisions seen in the data (the measured reduction in the number of collisions per bus per year). These values were derived directly from data – that is, from a direct comparison of the actual number of collisions that occurred on

[46] Of Agency 1's event classification codes, 28 were deemed as potentially SODS-relevant by the evaluation team and representatives from the agency's Risk Management Department through an initial asssesment of event classification code descriptions. For the 2-year dataset obtained, these event classification codes identified represented 89 percent of the total revenue collisions that the agency experienced over this time period.

SODS buses to the actual number of collisions occurring on non-SODS buses. The table also provides information about the value that was selected for the ROI calculation (the average of the two agency values).

Table 7-11. Measured Reduction in Side Collisions due to SODS.

Agency	Before / Without SODS-Relevant Collision Rate (per 100,000 VMT)	After / With SODS-Relevant Collision Rate (per 100,000 VMT)	Reduction in Side Collisions due to SODS (per 100,000 VMT)
Agency 1	0.730	0.599	0.131
Agency 3	0.337	0.096	0.241
ROI Calculation Value	N/A		0.186

The values presented in this table indicate that the agencies that participated in this study are not experiencing a large reduction in side object collisions due to SODS. This is not surprising considering that the early adopters had to overcome challenges that caused SODS to be less useful than its full potential. As discussed in the chapter on operator acceptance (Chapter 5), and as will be discussed in further detail in the institutional issue chapter (Chapter 8), device failures that occurred periodically were not always reported in a timely manner or repaired in a timely manner. Additionally, agencies experienced problems with operators disabling units. Further, discussions with operators revealed that many operators distrust the system and therefore ignore it, making it difficult to know if operators are taking notice of the system and reacting to it properly.

Because of these challenges, these findings may not paint a realistic picture of what other agencies might find if they were to invest in the technology. A more mature version of the system, coupled with training and maintenance practices that take advantage of the lessons learned by the early adopters, can be expected to perform better. Without doing further research, the best way to get an indication of how much better performance could be expected, is to identify the factors that influence the rate of collision avoidance with SODS and to then perform a sensitivity analysis on these factors.

Expected Reduction in Collisions Determined through Other Means

To determine the expected reduction in collisions from SODS, it is important to first consider what impacts system effectiveness. As shown in Figure 7-4, the reduction in side object collisions that an agency can expect as a result of SODS is primarily a function of three factors:

- *The SODS-relevant collision rate* – the average number of SODS-relevant collisions that the agency experiences per bus per year. This can vary quite significantly depending on the agency's routes (e.g., the number of tight turns that buses must make, the number of high-speed lane changes that are required) and the agency's bus stop geometry (e.g., whether there are many stops where the operator must negotiate parked cars that have encroached on the bus stop area; or whether there are poles, newspaper boxes, or shelters close to the curb at bus stops).
- *The system uptime* – the percent of time that the system is properly functioning. This is dependent on the agency's maintenance staff and can be affected by the level of training provided as well as by the extent to which the staff are decentralized.

- *The SODS utilization factor* – the percent of time when the operator properly reacts to the system to avoid a collision. The operator plays a significant role in the success of the device. Unlike anti-lock brakes or an airbag, the operator has to receive proper training to ensure that they understand the information being relayed by the system and that they react in a manner in which to prevent a collision whenever possible. As with the system uptime, this is highly dependent on the training provided.

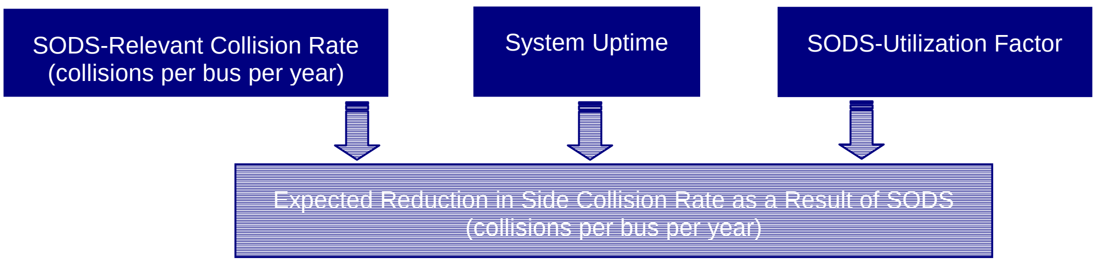

Figure 7-4. Factors Influencing the Expected Reduction in Side Collisions as a Result of SODS.

The SODS-relevant collision rate can be determined by reviewing the agency's collision data and assessing which collisions appear to be SODS-relevant based on what is known about the nature of each collision and about the system itself (i.e., which collisions the system is likely to help reduce and which is it not). The system uptime and SODS utilization factor can be estimated based on what is known about an agency's maintenance and training practices. If it is assumed that the assessment of SODS-relevancy is accurate, then the *system efficacy* can be defined to be simply a combined factor of the system uptime and the SODS-utilization factor as shown below (otherwise the efficacy would include another factor to account for the expected inaccuracy in assessing SODS-relevance). Although it is not certain how accurate the assessment of SODS-relevance is, for purposes of simplification, the system efficacy is characterized as simply a combination of these two factors for the purposes of this study.[47]

$$\textit{SODS-Relevant Collision Rate} \times \overbrace{\textit{System Uptime} \times \textit{SODS-Utilization Factor}}^{\textit{System Efficacy}} = \textit{Expected Reduction in Side Collisions Rate as a Result of SODS}$$

Determining the expected reduction in side collisions as a result of SODS (the bottom box in Figure 7-4) in this manner, rather than using the value measured directly from the data as presented in Table 7-11, is a better approach in the case of this evaluation due to the challenges faced by the early-adopters and the resulting inaccuracies in the analysis. Although this method relies on subjective measures to estimate which collisions are expected to be avoided with SODS, it eliminates the underestimated benefit surely present in the actual data.[48] For this reason, <u>the remainder of the return on investment calculations primarily focus on results derived through this method of determining the reduction in side collisions due to SODS.</u> The

[47] Determination of SODS-relevancy is an inaccurate process. Even with an in-depth understanding of the system it is difficult to know in which cases the system would have alarmed in a useful way.

[48] System failures, maintenance challenges, and operator distrust in the system, are all issues that the early-adopters faced, and these issues make it difficult to see an improvement when comparing collisions occuring on SODS buses to those occuring on non-SODS buses.

one exception to this is what is being termed the *basic* ROI calculation, which is presented first in the *ROI Findings* (Section 7.3), and which uses the actual measured reduction in collisions.

To determine the SODS-relevant collision rate, the team reviewed the three agencies' collision records for non-SODS buses, making determinations as to which collisions could be considered "SODS-relevant" based on the team's knowledge of the system. More details about the process used for determining SODS-relevance can be found in Appendix D, but in short, the team worked with each of the participating agencies to gain an understanding of their incident reporting process which helped the evaluation team understand the limitations of each of the agency's collision databases. The team then carefully reviewed each of the datasets, making determinations as to which collisions could be deemed SODS-relevant based on the collision characteristics available for each dataset. The level of detail in the data varied significantly from agency to agency. In some cases there was no detail beyond the brief event classification while in other cases there was a good deal of detail describing the circumstances of the collision.

Through this method it is estimated that Agency 1 could avoid 0.730 collisions per bus per 100,000 VMT.[49] Similarly, it is estimated that Agency 3 could avoid 0.337 collisions per bus per 100,000 VMT. Again this value was unable to be calculated from Agency 2 data due to the fact that VMT data was not available for all buses in the fleet. As shown in Table 7-12, the evaluation team derived the value used in the ROI calculation by averaging the values determined for Agencies 1 and 3.

Table 7-12. SODS-Relevant Collision Rate.

Agency	SODS-relevant collision rate (per 100,000 VMT)
Agency 1	0.730
Agency 3	0.337
ROI Calculation Value	0.534

The other factors that affect the reduction in side collisions due to SODS are the *system uptime* and the *SODS-utilization factor* (recall Figure 7-7). These factors must be assumed, rather than derived from data, and they are presented in the next section, Section 7.2. <u>For purposes of the basic return on investment calculation based on measured reductions in collisions (presented in Section 7.3.1), these factors do not come into play since the reduction in side collisions as a result of SODS was directly measured and any reduction in effectiveness of the system due to operator reaction or due to the system being down is already taken into account in the data.</u>

ROI calculations and findings based on both the measured reduction in collisions and the expected reduction in collisions are presented below.

[49] Determined through a review of the data as described in Appendix D.

7.2 ROI CALCULATION

This section determines the cost effectiveness of SODS by comparing the discounted costs of SODS with the discounted benefits of SODS. There a number of ways to look at the cost effectiveness including:

- *The return on investment.* This is the level of benefit relative to cost over the life of the technology. It is expressed in terms of the percent of investment recouped at the end of the useful life of the technology.
- *The benefit-cost ratio.* This is the ratio of the benefits to the costs. A benefit-cost ratio greater than one implies that the investment benefits exceed the costs over the useful life of the technology.
- *The payback time period.* This is the year when accrued net benefits (ongoing benefits less ongoing costs) equal or exceed the initial investment in the technology. Shorter payback periods reflect less funding risk. If the payback period is longer than the project lifecycle, the project is not considered economically worthwhile.

To derive the ROI and payback time periods for the SODS technology, the evaluation team compared annual per bus benefits to annual per bus technology costs. Given that the benefits are expected to begin accruing immediately following deployment and are expected to last over the life of the SODS unit, while many of the SODS costs will be incurred upon deployment, with some lesser operations and maintenance costs over the life of the unit, the time-value of money must be considered and certain assumptions must be made. Assumptions that were used in the analysis include:

- *A system useful life, or forecast period, of 12 years.* This corresponds with FTA-accepted 12-year life of a bus and assumes that the system will have a useful life that equals or exceeds the life of the bus.[50] This assumes that all agencies purchase units as part of new bus procurements and not through retrofits (retrofits would have a shorter useful life).
- *Discount rates of 3 and 7 percent.* The time-value of money is an economic concept that states that a dollar sometime in the future will be worth less than a dollar today. To address this concept to equate future cash flows with current cash flows, future cash flows need to be discounted by some factor. Discounting benefits and costs transforms gains and losses occurring in different time periods to a common unit of measurement. Discount rates of 3 and 7 percent are consistent with the Office of Management and Budget (OMB) recommendations for benefit-cost analyses.[51]

With these assumptions, the benefits and costs can be discounted over the life of the system and compared in the form of a benefit-cost ratio to assess the cost effectiveness of the system. The benefit-cost ratio is computed as follows:

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[50] The technology is comprised of off-the-shelf technology that has already been proven in the bus environment. Although it is possible that the technology itself may become obsolete in less than 12 years due to competing technologies or due to other advancements in the transit industry, the impact of these possibilities is unknown. Further, the FTA has acknowledged that the useful life of new electronics technologies will not be known until these technologies have been in service for many years ("Useful Life of Transit Buses and Vans", FTA, Report No. FTA VA-26-7229-07.1, April 2007).

[51] Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. Office of Management and Budget, Circular No. A-94 Revised.

$$Benefit - CostRatio = \frac{\sum_{t=1}^{n} \frac{Benefits_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Costs_t}{(1+i)^t}}$$, where

n is the forecast period in years (12 years in this case)

i is the discount rate (3 and 7 percent in this case)

$Benefits_t$ is the investment benefits in year *t*

$Costs_t$ is investments costs in year *t*

It is important to note that the benefit-cost ratio presented in this report is in terms of the *present value* of the benefits and cost rather than simple totals. Also note that the analysis ignores the effects of inflation and presents all dollar figures in 2008 inflation-adjusted dollars, and that the discount rate is a real rather than nominal rate.

7.3 ROI FINDINGS

Based on what has been presented thus far, there are two ways to calculate the ROI as the evaluation team determined two values for one of the inputs into the equation, the reduction in side collisions resulting from SODS:

- One set of calculations is based on the actual crash-reduction experiences measured at the three transit agencies, as imperfect and potentially unrepresentative as this value may be (due to the challenges experienced by the early adopters that caused many of the systems to be inoperable during much of the study period). This calculation is termed the *measured ROI*.
- The other set of calculations is based on the expected crash reductions estimated for a typical transit agency. This value was derived using an assumed collision reduction rate determined through a review of data for buses not equipped with SODS estimating how many collisions could be deemed SODS-relevant. This calculation is termed the *expected ROI*.

7.3.1 Measured ROI

Based on the *measured* reduction in side collisions of 0.186 collisions per 100,000 VMT (as was presented in Table 7-11), it does not appear likely that the agencies who were early-adopters of the system will see a return on their investment within the life of the bus. The data show that they will likely only recoup 27 percent of their initial investment and ongoing maintenance and operational costs over the 12-year life of the unit with a benefit-cost ratio of 0.27.[52] More details on this basic ROI analysis can be found in Appendix E.

[52] These calculations were performed using a discount rate of 3 percent. Using a discount rate of 7 percent, an agency could expect to recoup only 24 percent of their investment over the 12-year study horizon and could expect to acheive a benefit-cost ratio of 0.24.

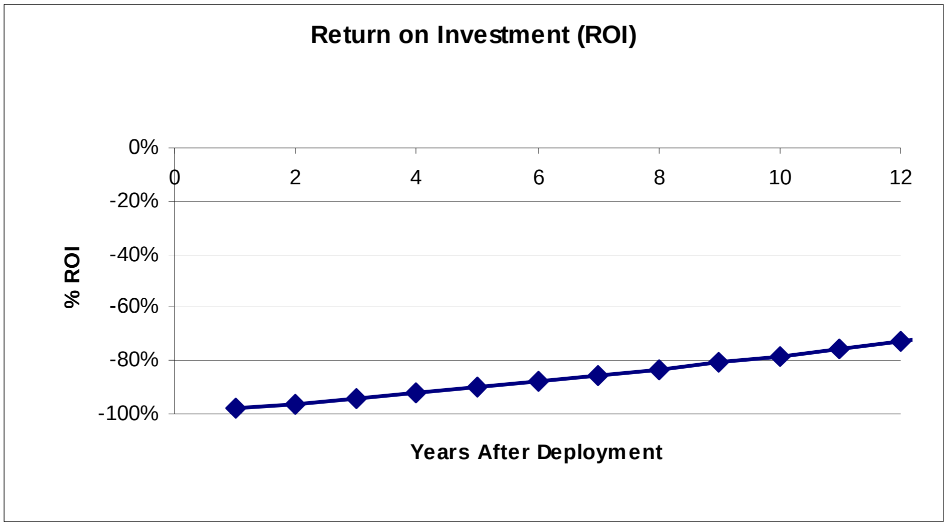


Figure 7-5. Return on Investment based on Measured Reduction in Side Collisions.

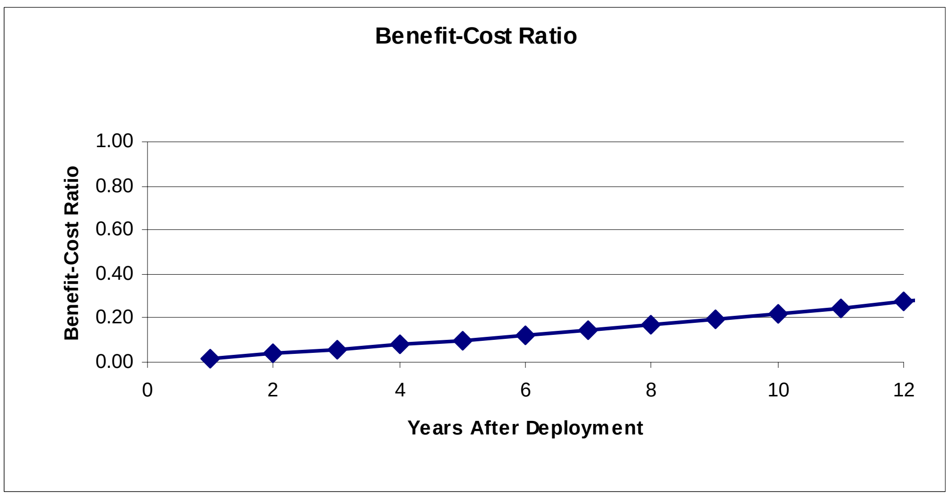


Figure 7-6. Benefit-Cost Ratio based on Measured Reduction in Side Collisions.

7.3.2 Expected ROI

Unfortunately, using the *expected* reduction in side collisions (determined through other means and presented in Table 7-12) also does not show a positive return on investment. The following sections present this analysis (again the details can be found in Appendix E). Note that all of the scenarios from here on out use the *derived* SODS-relevant collision rate of 0.534 collisions per 100,000 VMT.

Best-Case Scenario

Although SODS would ideally prevent 100 percent of the accidents that it is designed to prevent in a best-case scenario, this is not realistic. With thorough operator training practices, it seems reasonable that operators could react in an appropriate manner 95 percent of the time. Similarly, based on discussions with maintenance staff it seems reasonable that the system could function as expected 95 percent of the time. This assumes that the system is inspected on an annual basis and that any maintenance issues are reported and in a timely manner.[53] Therefore, the "best-case" scenario that an agency could most likely hope to achieve is a 90 percent efficacy (0.95 x 0.95). Even with this best-case scenario an agency would only recoup 88 percent of their initial investment and ongoing maintenance and operational costs over the 12-year life of the unit (Figure 7-7) with a benefit-cost ratio of 0.88 (Figure 7-8).[54] This scenario shows that an agency could expect to see a positive return on investment within 14 years.

As the IVBSS Business Case Analysis recently conducted by FTA showed a positive benefit-cost ratio for SODS (of 1.43),[55] it is important to point out the differences between that analysis and the analysis presented here. One reason for this discrepancy is that the business case analysis defined SODS in a generic sense while this study looked at a very specific technology already on the market. The IVBSS study defined SODS as a system that monitors the entire length of the bus (all the way to the rear bumper), while the system under study in this evaluation only covers the front half of the bus. Also the business case analysis primarily relied on national databases (i.e., the National Transit Database [NTD], and the Buses Involved in Fatal Accidents [BIFA] database) for estimating the number of side collisions, while this analysis includes a review of detailed collision data from three agencies.

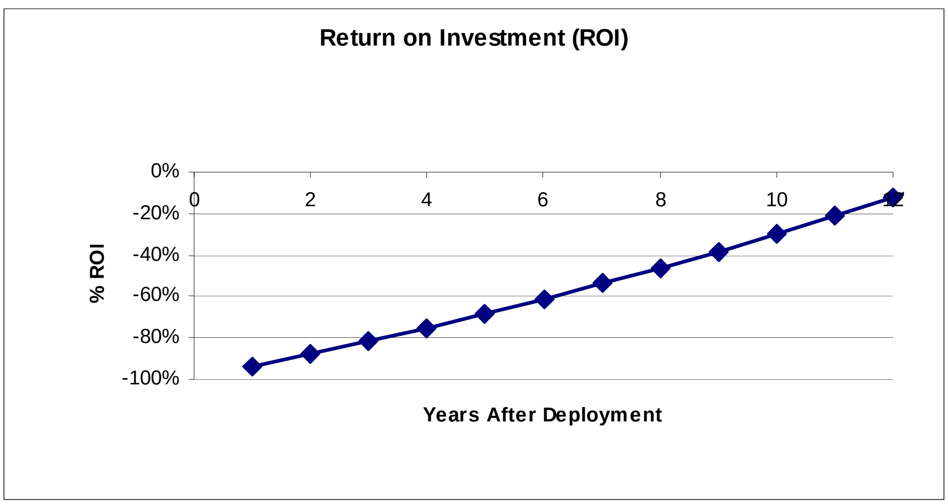


Figure 7-7. Return on Investment for Best-Case Scenario based on Expected Reduction in Side Collisions.

[53] Note that recommendations regarding SODS training are presented in Section 8.3.

[54] These calculations were performed using a discount rate of 3 percent. Using a discount rate of 7 percent, an agency could expect to recoup only 77 percent of their investment over the 12-year study horizon and could expect to acheive a benefit-cost ratio of 0.77.

[55] Travis Dunn, Richard Laver, Douglas Skorupski, Deborah Zyrowski (2007). Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses; Federal Transit Administration.

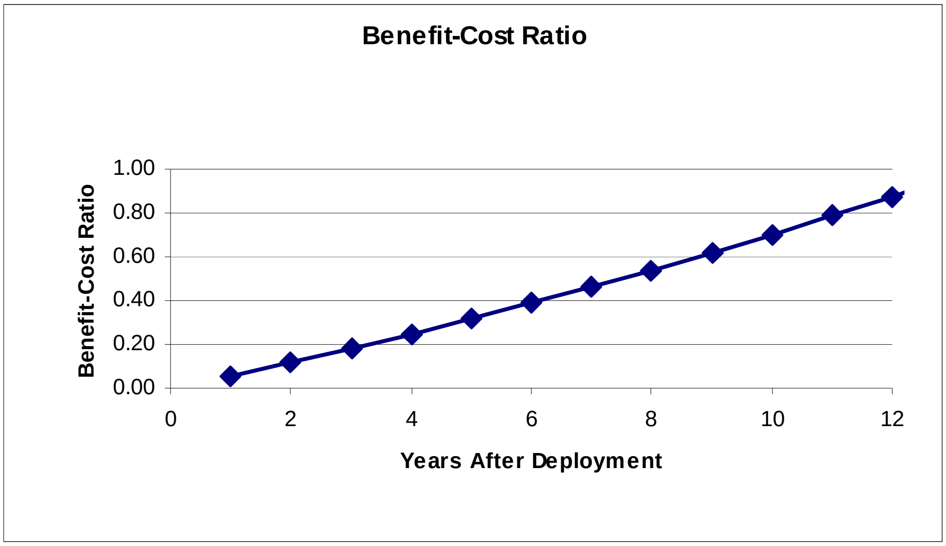


Figure 7-8. Benefit-cost Ratio for Best-Case Scenario based on Expected Reduction in Side Collisions.

Agency's Influence on SODS Effectiveness

It is important for an agency to be aware of how much influence "executive leadership buy-in", meaning acceptance of the system among operations managers, maintenance managers, and even the executive director of the agency, can have over the effectiveness of the system. As Figure 7-9 illustrates, the buy-in among executive leadership about the system impacts the reduction in side collisions that an agency can expect to experience due to SODS. The buy-in among executive leadership can impact the quality of the operator and maintenance training, which can then directly impact the system uptime and the operator acceptance of the system. In addition to this, operator acceptance of the system can be impacted by the system uptime, and conversely the system uptime can be impacted by negative operator perception due to tampering.

Figure 7-10 shows how much of an impact operator acceptance (i.e., the SODS-utilization factor) can in fact have on the system.[56] If operators accept the system and respond to it properly 95 percent of the time, an agency can expect to recoup 88 percent of their investment within the life of the bus. However, if operators only accept the system and respond to it properly 75 or 55 percent of the time, the results are much less favorable. With 75 percent, only 69 percent of the investment is recouped within the life of the bus; with 55 percent only 51 percent of the investment is recouped within the life of the bus.

[56] This assumes that the system is functioning properly 95 percent of the time (i.e., a system uptime of 95 percent) and assumes a 3 percent discount rate. Using a discount rate of 7 percent, an agency could expect to recoup 77, 61, and 45 percent of their investment, respectively.

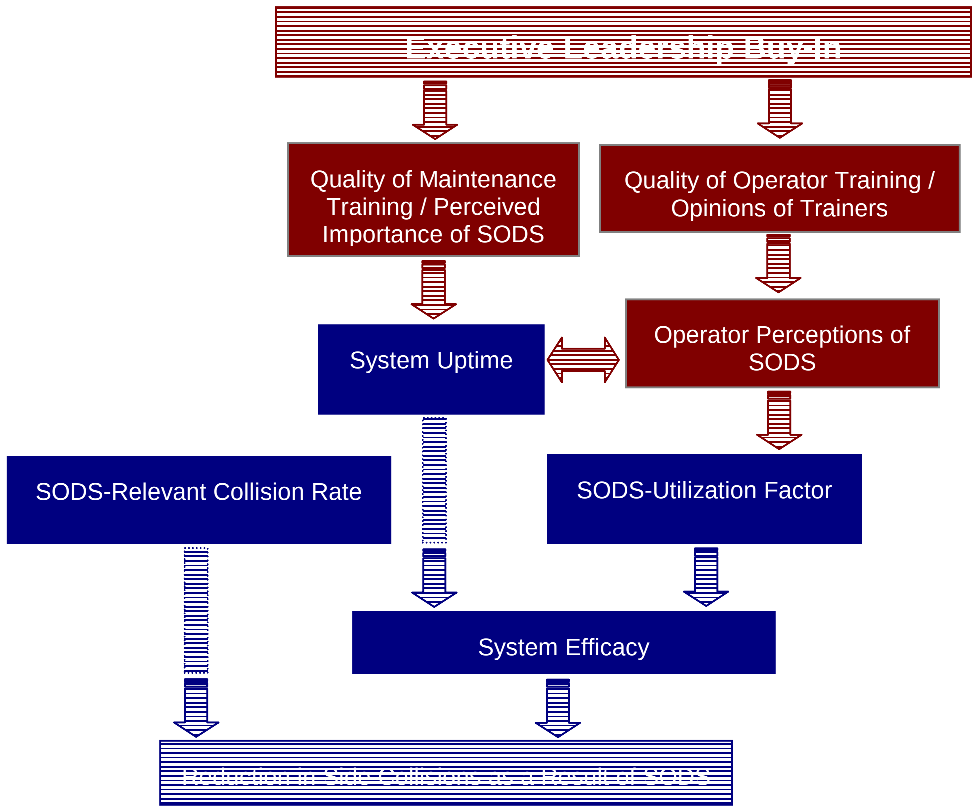


Figure 7-9. Influence Diagram of Executive Leadership Buy-In and SODS Benefit.

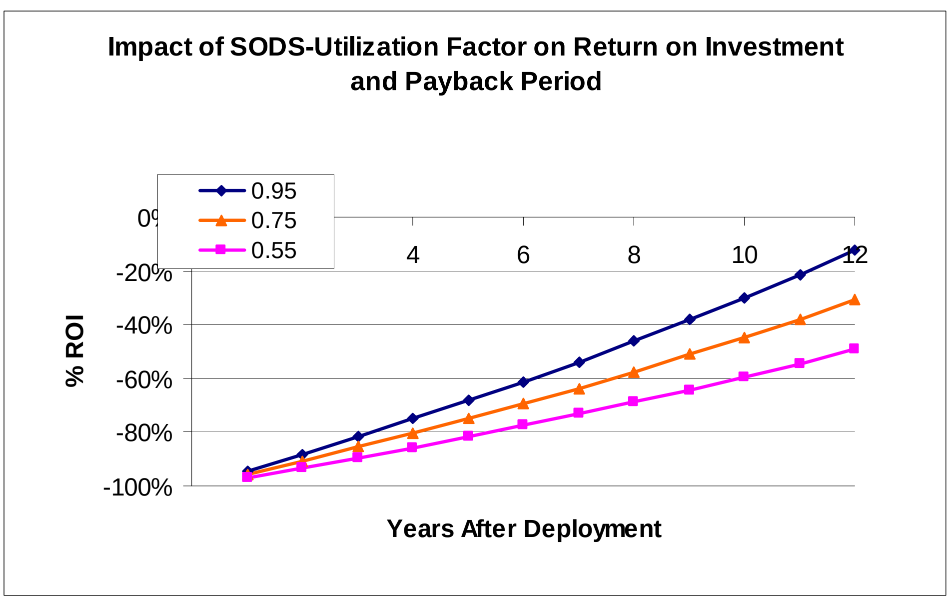


Figure 7-10. Impact of SODS-Utilization Factor on Return on Investment and Payback Period (System Uptime of 95 Percent and Discount Rate of 3 Percent).

7.3.3 Summary of Findings

The results of the ROI analysis indicate that, based on the current state of SODS deployment in the United States, the early-adopters of this technology will not likely experience a return on investment within 12 years, the typical life of a bus. Agencies investing in this type of technology in the future may not face the same challenges as the early-adopters, and thus would likely see a better return on their investment. However, given the current cost of the device and the current expected benefit of the device (based on collision data and cost data from the three agencies participating in this study), it does not appear that an agency would see a positive return on investment within the life of the unit even if those institutional issues faced by the early-adopters were overcome.

There are scenarios, however, under which an agency could expect to see a positive return on investment. For example, an agency could expect to see a positive return on investment if the cost of the device were less expensive ($1,650 instead of $2,000). Another scenario for which the return on investment could be positive is if the agency's SODS-relevant collision rate is higher than the average rate for the three agencies presented here. If the agency's collision rate is about 15 percent higher (at 0.614 collisions per 100,000 VMT) then the agency would see a positive ROI.[57] Alternatively the agency could strategically deploy SODS only on routes that have a high incidence of side collisions. A final scenario for which the return on investment would be positive is if the sensor reliability is actually higher than what it was assumed to be in this study. If a typical bus only needs to have one sensor replacement over the life of the bus this would also result in a positive ROI for the agency.

Before making the decision to invest in an in-vehicle safety technology, it is important for agencies to consider their operating environment as well as the nature of the collisions that the agency most commonly experiences. The benefits of SODS are quite dependent on the number of, and nature of, side collisions that an agency experiences. Therefore, agencies should carefully consider their collisions as part of a decision to procure SODS for their fleet.

[57] These scenarios are based on a system efficacy of 0.9 (SODS-utilization factor of 0.95 and system uptime of 95%) and a discount rate of 3%.

8 INSTITUTIONAL ISSUES - APPROACH AND FINDINGS

8.1 INTRODUCTION

This chapter details the evaluation team's approach to gathering and documenting the instructional issues and lessons learned. It also presents the detailed findings of the institutional issues evaluation.

8.2 EVALUATION APPROACH

The goal of this portion of the evaluation was to identify any institutional issues that might play a role in the successful deployment and adoption of SODS or of similar technologies for transit buses. Some of what was learned was through the driver usability and acceptance portion of the evaluation, in which detailed information was gathered through the surveys, focus groups, and interviews. However, to obtain a broad understanding of both the success factors and the impediments to wide-scale adoption of SODS, the evaluation team also conducted interviews with a range of transit agency staff at all three agencies, including those who handle maintenance, accident claims, operator training, operations, and safety for these agencies. The interviews solicited information on any difficulties experienced in deploying the system, institutional issues that had to be overcome, and operational challenges. The interviews also served as a means for understanding how each of the agencies trained their operators and maintenance staff, how their incident reporting procedures worked, and how information is shared within the agency, among other topics. The following sections present the key issues that were uncovered through these interviews.

8.3 FINDINGS

Agencies interested in investing in SODS or a similar technology should be fully aware of the challenges that they may face in introducing such a technology into their fleet. Several institutional issues could potentially affect successful SODS deployment. Above, the issue of operators' acceptance of SODS was introduced. While barriers and challenges to acceptance are one set of institutional issues that can affect the deployment of the system, several others also exist. These are discussed in the following sections.

8.3.1 Installation of the Technology

For this technology, as with most on-board technologies, the agencies acquired the units as part of a new bus procurement. Installation of the system is performed by the OEM (rather than by the product supplier as would be the case in after-market installations). Although the supplier provides an installation manual, the team found that sensor placement varies among bus manufacturers. In some cases this is due to the front end configuration of the bus design, which may limit placement of the sensors and interior system displays. Differences in placement are also found between bus models from the same manufacturer. In some cases, however, the variation appears to be due to the manufacturers' interpretation of the installation guide. This can be a significant issue since it is not uncommon for an agency to deal with multiple OEMs, or even different models of buses with a single OEM. Among the three participating agencies in this study, there were four OEMs and a half dozen bus types.

This is important as sensor location impacts the object detection zone; in other words what the sensors are able to "see". For example, at one agency the evaluation team noted that the front corner sensors were positioned quite differently depending on the front-end design of the bus. According to the installation manual, the front corner sensor should always point towards the corner of the bumper. The evaluation team, however, did not always find this to be the case. In some cases the sensors were placed on the side of the front corner, while in others, they were located on the front panel itself. Another consideration is sensor height placement. In order for the system to detect optimally, sensors must be placed between 14 and 42 in. (25 and 106 cm) from the ground. This provides the bus manufacturer options in sensor height placement. The system controller must then be programmed to the installed sensor heights.

Sensor location variation from bus to bus results in differing system detection characteristics. This can, and understandably did, lead operators to perceive the system to be unreliable and ultimately this led to distrust of the system among operators. Since operator acceptance is paramount to achieving the greatest benefit from this system, uniformity in sensor detection zone characteristics for all buses within an agency's fleet is an important consideration. Each vehicle manufacturer's model needs to be pre-engineered before a system can be properly installed or deployed. This heightens the importance of manufacturers' understanding the functional operating characteristics of the system and the need for adhering to the installation guidelines.

In addition to sensor placement and height considerations, the operating environment must be considered. Sensor sensitivity may be adjusted to account for specific characteristics of agency's routes such as utility poles placed close to the roadway. Sensitivity, when properly adjusted, will permit the system to "see" that a bus is not encroaching on the object more closely than might be reasonably expected. Appropriate sensitivity adjustments are critical to the operation of the system and increase operator confidence in the system.

Another significant consideration to system installation is the placement of the interior visual display and audible alert. As with the sensors the evaluation team found that placement of both the display and audible alert speaker varied from bus model to bus model. The variation was due to the interior design of the buses. Unfortunately, this variation also contributed to the lack of operator acceptance of the system. Many operators complained of the display placement, saying that the lights were too bright and were often directly in the operator's field of vision. The operators complained that these two factors resulted in operator discomfort. Similarly, operators complained that the audible alert was too loud and irritating. With one bus model, the speaker for the audible alert was placed directly over the operator's head, further compounding the annoyance. As a consequence of these complaints, some operators altered the audible alert and light display, and in some cases, rendered the system itself inoperable. Follow-on operators, unaware that the system had been tampered with, believed the system to be unreliable (as the lights would illuminate but there was no audible alert or vice versa) and contributed further to the operators' dismissal of the system. Given the frequency with which the audible alert and visual display annunciate, and reliance on the system to convey information, operator acceptance of the visual and audible alerts must be addressed from the outset, during bus design discussions.

The evaluation team identified a number of recommendations regarding the appropriate role of the agency, the OEM, and the supplier in installation, and these are presented in Table 8-1.

Table 8-1. Recommendations Regarding the Role of the Agency, the OEM, and the Supplier in Installation.

Participant in SODS Deployment	*Recommended Role in Installation*
Transit Agencies	• Use personnel qualified in the technology to verify that the system was installed properly at the factory. • Consider contracting with the supplier of the technology to oversee system installation and factory testing. • Ensure a system functional test is performed at the factory. • For each bus model, confirm proper sensor placement before factory testing. • Confirm proper placement through factory testing. • Obtain clear guidance from the supplier on system acceptance testing. • Consider including the product supplier in the acceptance testing. • Obtain explicit testing and maintenance instructions from the supplier. • Solicit operators' input on the placement of the visual display and audible alert. • Confirm placement of the visual and audible alerts with the bus manufacturer. • Solicit supplier input on the appropriate sensitivity setting for the sensors.
Original Equipment Manufacturer (OEM)	• Recognize that Installation of the technology may be unique to each bus model. • Seek detailed information and guidance from the supplier on the proper installation and testing of the system for each bus model. • Confirm proper placement of the visual display and audible alert with the transit agency. • Perform a functionality system test on each equipped bus. • Consider contracting with the supplier to oversee installation and factory testing of the system.
Suppliers	• Provide detailed information on the technology, including operating characteristics. • Provide explicit written installation instructions, detailing sensor placement. • Provide explicit system testing instructions. • Provide information on the parameters for sensor sensitivity adjustment. • Consider the use of alternate media (video, DVD, etc.) to demonstrate proper system placement and testing.

8.3.2 Understanding the Technology

A system such as SODS requires human interaction. It will not operate on its own like an airbag that automatically engages and protects the user. Proper training is as critical to the successful deployment of the system as selecting the best location for the audible alert and visual display.

If operators do not have the proper understanding of the system, they are not likely to accept or trust the technology, and they are then not likely to react in a way that makes the most of the system. Due to the lack of operator understanding, some of the participating agencies reported problems with operators' initial system acceptance. As many agencies have experienced when first introducing other in-vehicle technologies such as Automatic Vehicle Locating systems (AVL) or CCTV cameras, agencies experienced problems with tampering. Operators used a variety of means to disable the system including unplugging or taping over the speaker (simply placing tape over the speaker is sufficient to silence the speaker when combined with the background noise of the bus), unplugging the visual displays, turning the visual displays away from the operator so that the lights are out of their field of view, and cutting wires to the sensors. After maintenance staff reported these problems to supervisory staff, there was a reduction in tampering with the devices.

It is critical that operators be fully trained in how the system works, as well as why it was designed as it was, to ensure that operators gain a complete understanding of the system's operations and form the basis for trust in the system. A design limitation of the system, as discussed earlier, is its inability to detect passing vehicles if the speed differential between that vehicle and the bus is greater than 15mph. This is by design, but this can confuse operators, who may believe that the system is not operating properly when they observe vehicles passing the bus without a system warning. At a speed differential of 15mph, the passing vehicle travels 22 ft/sec faster than the bus. Since lane changes typically occur at a relative speed of 2.5 to 3mph, fast moving objects will pass the bus before any action by the bus operator can be taken. Consequently, if the system were to attempt to warn the operator, that warning would come too late for the operator to take evasive action.

Introduction to the Technology

Many operators are by nature distrustful of their agency's intentions with an on-board technology and this can lead to skepticism when introducing a new technology. Many agencies experienced initial problems when introducing cameras into their fleet for safety reasons or when introducing AVL systems to monitor bus locations. Despite the fact that SODS has no monitoring components like these other systems, operators may suspect that it does and this will only make the deployment more difficult. "Advertising" plans for the new technology as soon as the procurement decision has been made—and before the systems arrive—can help to quell any fears that may exist and any rumors that may arise.

Training

All three agencies provided in-person training to the bus operators. The extent of the training activity, however, was inconsistent among operators from transit agency to agency. The team also found variation within the agencies themselves (e.g., from garage to garage), and even among operator instruction personnel.

At one agency, initial training consisted of hands-on instruction, which required operators to demonstrate their knowledge and use of SODS along a route. This initial training involved only a small number of operators since SODS was not deployed agency-wide. When the system was about to be fully deployed, the training needs increased significantly, affecting a larger numbers of operators. Because of the strain on training resources, many operators received hands-on instruction, but without the on-the-road portion of the instruction. At one agency, training consisted of a very brief introduction of the system with an instructor demonstrating hard and soft target detection. The primary focus of this instruction was on how the device assists with detection of objects in the bus blind spot. Little instruction was provided on how the system is to be used at speeds below 15 mph. In other cases, operators only received informational cards that endeavored to convey the purpose of the technology and how it was to be used. At times, the information describing the system and its function was found to be incomplete and did not fully explain the limitations of the system. This left operators to experiment with the system and to draw conclusions on their own. Skepticism of the technology extended to some training staff, as well, as they were not fully convinced of the technology's utility and reliability. Some operators reported that this skepticism among the training staff was passed on to new operators during training.

The nature of the deployment must be also be carefully evaluated prior to system activation, as it affects operator training and knowledge retention. Each of the participating transit agencies deployed SODS in a different way. One agency elected to deploy the technology only on selected routes. This significantly eased the training needs for operators and greatly contributed to operator knowledge retention.

Other agencies deployed the SODS buses agency-wide, with some SODS buses assigned to each of the agency's garages. Although this enabled the buses to be evaluated over a wider range of operating environments, the deployment required all operators within the agency to be trained prior to system activation. Unfortunately, activation inadvertently occurred prior to all operators being trained, resulting in a large number of untrained operators being assigned to buses in which the system was activated. Operators did not understand the functionality of the system and second-guessed its purpose and operation. Also, as there were very few SODS buses available at each garage, a small minority of operators had regular exposure to SODS. This presented a significant challenge for operators, who may have experienced a large time gap between uses of a SODS bus. This made it difficult for operators to remember the system's functionality and operating characteristics.

As previously discussed, sensor placement and sensitivity significantly impact the detection zone characteristics of the system. Operator safe driving performance is predicated on their understanding of the technology and, in particular, the sensing characteristics. For operators to fully understand the system's capabilities, they must be completely familiar with sensor placement, sensor sensitivity, and the limitations of the sensors. As discussed in Chapter 5, without this knowledge, operator perceptions will be erroneous and will erode user confidence in the system.

In terms of what agencies should consider with regard to training, below follow some recommendations for consideration.

- *Provide clear and thorough training for all operators who will be exposed to the technology prior to activating the system*. The training should include both in-class and hands-on instruction. It is important to ensure that operators understand what SODS is intended to do and what it is not intended to do; e.g., it is not intended to detect pedestrians. Another example is that the system was intentionally designed not to detect vehicles approaching the bus if those vehicles are traveling 15-20 mph faster than the bus. If operators do not understand this and see a vehicle passing them without the system engaging, they may lose trust in the system.

  In the three deployments studied as part of this project, the focus groups demonstrated that operators had a very mixed understanding and that many operators had a poor understanding of SODS. During one focus group, some operators expressed the belief that the system was to ensure that they take turns at the proper speed.

  The product supplier recommends both in class and on-bus training, with trainers demonstrating how SODS reacts to both soft and hard targets, and that a reminder card (shown in Figure 7-1) be kept on each SODS-equipped bus for operator reference. The reminder card is one element of training that did seem to carry through. Many of the operators (in particular those who had been trained on the system in the few months preceding their use of it) did report that they keep their reminder card handy (most had it in their breast pocket).

- *Provide training on the technology for all new operators.* It is important that all operators, including new operators, have a clear understanding of the technology. This is particularly important at agencies that have high operator turnover rates.
- *Provide refresher training for all operators who are exposed to the system.* Some of the operators involved in this test were trained on SODS 18 months prior to the focus group or operated a SODS equipped bus on an irregular basis. Others had been trained on the device only 1 month before the focus group. The evaluation team noted a large difference in reactions among operators based on how much time had passed since they had been trained on the system. It is important to ensure that operators do not forget how it works.
- *Use a variety of techniques for getting the information to operators.* This could include reminder cards (as shown in Figure 8-1), bulletins, and booklets on the technology.
- *Be aware that operators many not feel that they need the system.* Many operators reported that they felt that the system was unnecessary for experienced operators. Convincing operators that the system is worth their time and attention may be difficult. If they do not believe that it is necessary then they may ignore it, and the investment will not be worthwhile. Make sure that agency trainers fully understand the system and can convey this to operators.

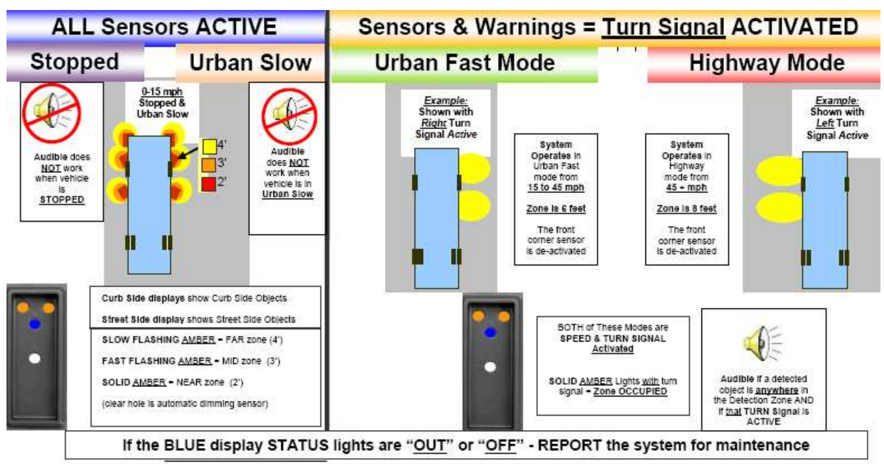


Figure 8-1. Tri-Fold Reference Card Provided to Operators.

- *Ensure uniform understanding of the technology among training staff.* Some operators reported that the trainers did not fully understand the system, and in one case, that the trainer even disparaged the system. If the training staff do not have a good understanding of the system (or respect for it), this lack of understanding and skepticism will be passed on to operators.
- *Consider introducing the technology in a stepwise fashion (at one garage or on one route at a time).* This would allow initial training to be focused on those operators assigned to the "SODS routes" or the "SODS garage". This permits a gradual transition to the technology within the transit agency's fleet, allows training to be provided at a

more even pace, and allows for lessons learned in the early stages to be applied in later stages.

8.3.3 Maintenance Practices

It is critical that maintenance staff have a thorough understanding of the system. The evaluation team met with maintenance personnel responsible for maintaining SODS from each of the participating agencies to gain a better understanding of the maintenance issues associated with the system. The team found a range of understandings both between the participating agencies and within the agencies themselves (i.e., from garage to garage within an agency). In some cases there was a clear lack of understanding of the functionality of the system, the factors that influence detection, the testing methodology, and the frequency of preventive maintenance. In other cases, access to maintenance manuals and test procedures were not always available.

As with operator training, maintenance personnel responsible for maintaining the technology should have a thorough understanding of the technology, functionality of the system, and its capabilities. Most maintenance staff interviewed felt that seeing the system in action during training is critical.

Upon delivery of the system, the supplier offered in-person instruction on the product to demonstrate how the product works. The supplier also provided maintenance manuals. The ”Maintenance Handbook” includes a maintenance troubleshooting checklist, a test procedure, and a system maintenance and troubleshooting reminder card. The troubleshooting reminder card advises maintenance staff that the system continually monitors its ability to function during runtime, that 40 KHz ambient noise (such as compressed blowing air) can cause the system to lock in a near zone alert, and that there is an optional interface which allows the user to run the self check routine as well as test the range of the sensors and LEDs to make sure they are communicating with the controller. Many of those interviewed, however, believed that the training should be more comprehensive and leave the maintenance staff with a complete understanding of the system, including anything that interferes with the system’s operation or effectiveness. They also believed that the instruction should include a hands-on component that permits maintenance personnel to see the system in operation and provides simulated conditions that require diagnosis.

The need for hands-on, dynamic instruction is evident for SODS technology. Unlike other technologies, such as a CCTV camera system, the uniqueness of the technology makes it difficult to know whether it is working properly and what may be causing malfunctions. Because of the lack of thorough instruction and an unclear understanding of the technology, some agencies chose to replace sensors rather than troubleshoot an issue. The results of the decision to replace rather than troubleshoot added significantly to the cost of the system, as many of the sensors were later found not to be defective. Other agencies, however, did report that they were able to check each sensor thoroughly through what they termed a “cardboard test” -- a test using a large cardboard sheet to determine if a sensor was operating properly. It is interesting to note that some of the lessons learned were not shared with other garages within the same transit agency. Another garage reported that it was experiencing a number of system malfunctions. Maintenance personnel surmised the malfunctions were attributable to water intrusion from the bus wash or that the bus wash brushes themselves were scratching the lenses of the sensors. Either way, the maintenance staff at this particular garage had realized that some aspect of the bus wash was causing the system to register erroneous detections.

An important factor in gaining operator acceptance is system reliability. The system units must be demonstrated to be reliable from the moment of initial activation through continuing use. If improperly maintained, operators will become distrustful of the system and fail to report system problems as they occur; therefore, the benefits of the technology cannot be realized with improperly operating systems. Lastly, the maintenance practice for the technology needs to be uniform among all maintenance garages.

In terms of what agencies should consider with regard to maintenance practices, below follow some recommendations for consideration.

- *Consider getting on-call support from the product supplier* (at least for new technologies). However, be aware that having this support will not be enough unless operators and maintenance staff report failures in a timely manner.
- *Consider developing a technology trouble card for use by bus operators.* Bus operators need to be educated on what to look for and when to report problems.
- *Educate maintenance staff on those issues that need to be reported to the supplier.*
- *As part of new bus procurements, include a provision for in-person, hands-on technical support throughout the warranty period.*

8.3.4 "Buy-in" at All Levels within the Agency

Deployment of a new technology frequently involves a number of transit agency stakeholders, including operations, maintenance, training, safety, and claims department representatives. These departments should collectively determine the need for the technology and how its deployment will achieve the desired result. In the case of SODS, the desired result was potentially improved safety and cost savings. Informed decisions regarding sensor placement, system activation, training needs, maintenance practices, and interior system configuration of the display and audible alert require buy-in on the technology at all levels, including the ultimate end users: operators and technology maintainers (i.e., maintenance staff). All of these stakeholders must clearly understand the intended purpose of the technology, its operating characteristics, and, equally important, it limitations. Buy-in from each of these departments is required, as each plays a role in the successful deployment of the technology.

9 SUMMARY AND CONCLUSIONS

9.1 INTRODUCTION

This report has presented the findings of an FTA-sponsored independent evaluation of the only currently commercially-available side object collision warning system for transit buses. The FTA and evaluation team worked with three transit agencies across the country to assess this technology. The study aimed to provide information that would help the USDOT determine whether to further support development and deployment of side object detection systems, and to provide information that will help transit agencies make important decisions about purchasing this and similar on-board technologies for their fleets. With this in mind, the evaluation aimed to address three key goals: (1) to assess operator usability and acceptance of SODS, (2) to assess the return on investment of SODS, and (3) to identify lessons learned and other information that would be useful to agencies considering deployment of SODS or similar technologies in the future (e.g., if there are barriers and challenges to operator acceptance, and if so, how these can be overcome).

What follows is a summary of the findings of the study according to the key evaluation goals, followed by conclusions and recommendations regarding the future of this technology and other similar bus technologies.

9.2 SUMMARY OF FINDINGS

A summary of the findings of each of the evaluation goals are presented below.

9.2.1 Summary of Operator Acceptance Findings

Operators were optimistic about the potential of a side-impact collision warning device, even though these types of collisions are not a critical concern to them relative to other collision types. They reported that SODS was useful in certain situations and had prevented collisions, particularly those that involved detecting an object in the operator's blind spot.

However, operators did not find the system usable in its current design, particularly with regard to the quality and frequency of visual and audible alerts. Among the suggestions to improve the design of the system were changing the sound to be less annoying. Operators also complained about the consistency with which the system functioned, partly because of true maintenance issues and partly because of uncertainties in understanding the system's capabilities. Finally many operators suggested that the visual alerts be moved to a different position such as on the dashboard or on the front windshield. It appears that more research is needed in determining the optimal display placement and the range of adjustments needed to accommodate the variations present in the anthropomorphic bus operator workforce.

9.2.2 Summary of Return on Investment Findings

The results of this study indicate that, based on the current state of SODS deployment in the United States, the early-adopters of this technology are not likely to experience a return on investment within 12 years, the typical life of a bus.

Agencies investing in this type of technology in the future may not face the same challenges as the early-adopters, and thus would likely see a better return on their investment. However, given the current cost of the device and the current expected benefit of the device (based on collision data and cost data from the three agencies participating in this study), it does not appear that an agency would see a positive return on investment within the life of the unit even if the institutional issues faced by the early-adopters were overcome.

There are scenarios, however, under which an agency could expect to see a positive return on investment. For example, an agency could expect to see a positive return on investment if the cost of the device were less expensive ($1,650 instead of $2,000). Another scenario for which the return on investment could be positive is if the agency's SODS-relevant collision rate is higher than the average rate for the three agencies presented here. If the agency's collision rate is about 15 percent higher (at 0.614 collisions per 100,000 VMT) then the agency would see a positive ROI.[58] Alternatively the agency could strategically deploy SODS only on routes that have a high incidence of side collisions. A final scenario for which the return on investment would be positive is if the sensor reliability is actually higher than what it was assumed to be in this study. If a typical bus only needs to have one sensor replacement over the life of the bus this would also result in a positive ROI for the agency.

9.2.3 Summary of Institutional Issues Findings

The institutional issues can be significant if not properly accounted for prior to system deployment. All transit agency stakeholders—operations, maintenance, training, safety, and claims—must have a clear understanding of the technology capabilities and its limitations. Inconsistency in system installation resulted in varying operational characteristics among the different bus models. This influenced the operators' perceptions of system reliability. Accordingly, proper factory installation and testing is critical to the successful deployment of a technology. This creates the basis for correct system operation and, ultimately, operator acceptance.

Effective training programs promote operator understanding and teach drivers how the technology can improve their driving safety. However, incomplete training and system activation prior to all affected operators being trained led many operators to incorrectly understand the technology, system operation, and system limitations. Similarly, incomplete maintenance staff training led to improper troubleshooting and testing of the technology. These matters further exacerbated operator perception of system unreliability.

9.3 CONCLUSIONS AND RECOMMENDATIONS

An important question to ask at the conclusion of this study is whether or not there is a future for this technology or other similar bus technologies. Through discussion with transit agencies, it appears that there remains significant interest in this type of system. Furthermore, nearly every individual that the evaluation team spoke with throughout the course of the study (including operators) felt that the system had potential despite any complaints they may have had. Most, however, felt that the system -- as it currently exists and within the conditions and environment in which it is currently being used -- is not addressing their needs.

Agencies investing in this type of technology in the future may not face the same challenges as the early-adopters, and thus would likely see a better return on their investment. Certainly a

[58] These scenarios are based on a system efficacy of 0.9 (SODS-utilization factor of 0.95 and system uptime of 95%) and a discount rate of 3%.

better ROI could be achieved if system modifications were put into place and if the institutional issues faced by the early-adopters were overcome.

Although the results of this study indicate that there is not an acceptable return on investment with the current system, they do indicate that a positive ROI could be achieved under different circumstances such as a lower device purchase price or a higher side collision rate. In addition to this, the return on investment analysis as presented here only takes into account the direct costs of collisions to transit agencies in the form of bus repair costs and claims costs. Beyond these direct costs, there other costs associated with collisions such as personal injury and incident-related traffic congestion, costs, which if quantified, could significantly increase the "cost" of a collision. In other words, there is the possibility that SODS contributes to policy goals of reducing transportation injuries and congestion, even if it does not "pay for itself" in strictly financial terms.

9.3.1 Recommendations for Agencies Considering Deployment of Similar Technologies

Agencies interested in investing in a technology such as SODS should first be fully aware of the challenges that they may face in introducing such a technology into their fleet. It is critical that agencies:

- Work with the original equipment manufacturer (OEM) to ensure that the technology is properly installed. This includes considering involvement of the product supplier in the factory and acceptance testing processes.
- Properly educate all within the agency about the technology (from maintenance staff and their managers, to operators and their managers, to training staff). It is important to provide information on why the agency made the decision to invest in the technology, how the system works, what the system can and cannot do for a bus operator, and how to know if the system is working properly (so that operators can report system failures to maintenance staff in a prompt manner).
- Properly maintain the system and encourage information sharing between garages as they learn through experience how to troubleshoot and maintain the system. Proper maintenance should include routine system testing to identify component failures promptly to avoid creating distrust among operators about the system.
- Encourage and ensure "buy in" for the technology at all levels within the agency.

Furthermore, before making the decision to invest in an in-vehicle safety technology, it is important for agencies to consider their operating environment as well as the nature of the collisions that the agency most commonly experiences. The benefits of SODS as described here would most likely be realized by large transit agencies, as the exposure to SODS-relevant collisions is greater for large transit agencies than it is for medium and small agencies. Large transit agencies differ in several respects from medium and small transit agencies. Large transit agencies serve metropolitan areas with high density populations. High density populations are typically characterized by significant traffic congestion, low vehicle operating speeds, and the requirement for tight maneuvers due to narrow streets and parked cars; thus, increasing the probability of a SODS-relevant collision. The increase in exposure for larger agencies is also due to the number of transit buses actively in operation on any given day. However, medium to small agencies may benefit if they have a higher than expected number of fixed-object or sideswipe collision types. Transit agencies should carefully evaluate the costs of, and the benefits that may be derived from, SODS as part of a decision to procure SODS for their fleet.

9.3.2 Recommendations for Future Research in this Area

Future studies in the area of collision warning systems for transit buses should give consideration to issues that arose out of this study, including further exploration into questions such as: *What is the most appropriate sensing technology for this application? What is the optimal placement of sensors? What is the optimal placement of the visual displays and what is the best combination of audible and visual alerts for the operator?* More details about each of these questions are described below.

Sensing Technology

The sensing technology itself is important as it drives the accuracy of the system and the number of missed readings and false positives that operators will experience. It also drives what the system is able to detect. Many operators that the evaluation team spoke with were disappointed that the system did not detect pedestrians. This is a major consideration when selecting the most appropriate sensing technologies for future systems. In terms of accuracy with the existing system, one agency believes that it may be experiencing a problem with false alarms due to interference in the sensors, which the agency suspects results from hard water build-up in the sensors caused by the bus wash. Also, it is known that compressed air from the air brakes can cause false readings. False readings can be just as damaging as missed readings since they can result in distrust among operators, which can lead to inattention to the alerts or disabling of the device. Although it is not clear whether a better technological approach exists, it is clear that this current system has challenges. The solution could be an improved sensor housing, modifications to the sensor placement, or it could simply be that there are better technologies to serve this purpose.

Placement of the Sensors

There are a number of issues with the sensor locations that should be further explored. Sensor placement on buses is not always consistent (within or between agencies). This is important because the placement of the sensors affects the “field of view” of the sensors and the zone of object detection. In some cases the varying sensor placement is due to limitations presented by the bus design itself (e.g., one model of bus may not accommodate identical sensor placement to another model), but in many cases it is simply the result of inconsistent installation by the OEM, who may have limited knowledge of the system and the importance of proper placement. As many agencies work with multiple OEMs, and many have multiple bus models in their fleet, varying sensor placement is highly likely if a decision is made to invest in SODS fleetwide.

Based on responses from the surveyed operators and on-board observations, the current sensor configuration does not appear to have coverage far enough back on the bus to provide timely warning to operators in lane-change situations or to provide coverage of all blind spots when making tight turns.

It would be desirable if the supplier of this technology or of any future technologies were more actively involved in working with the OEM to ensure that sensors are installed in a consistent fashion. It may also be advisable to involve the product supplier in the acceptance testing. Finally, additional research is needed to confirm the most appropriate sensor placement.

Placement of the Visual Displays

Additional consideration should be given to the placement of the visual displays. Many operators reported that they were not pleased with the current placement. Some felt that modifications as simple as making the height adjustable would accommodate the challenge of varying operator heights while others thought the placement was poor altogether. As with the placement of the sensors, the placement of the displays varied within and between agencies. The intent of the system design was to display a visual warning that would be visible to operators through their peripheral vision while practicing safe driving habits (e.g., the curbside display was intended to be in their peripheral vision when looking toward the curb when making a tight right turn). It is possible that this is true if the displays are properly positioned when installed, in which case inconsistencies in display placement upon installation would need to be addressed. However, it could also be that more research is needed in determining the optimal display placement.

Design of the Audible and Visual Alerts

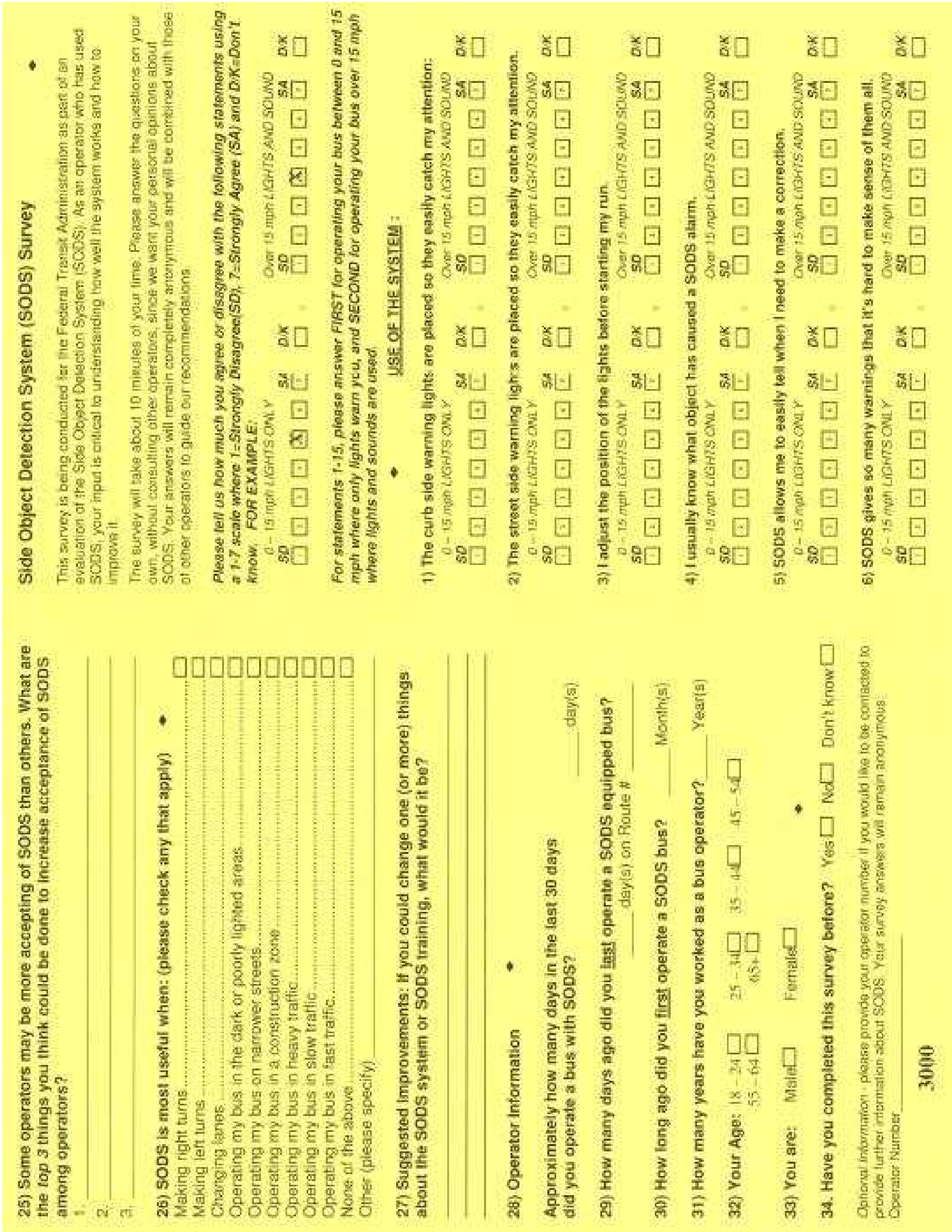
Additional consideration should be given to the design of the audible and visual alerts. As with prior studies, there was a perception by some operators that the two flash rates (i.e., slow and fast) were difficult to distinguish, distracting, and perhaps unnecessary. In terms of the audible alert, some operators found the chime to be too loud (passengers could hear it, which bothered many operators). Some commented that they would like the frequency or pitch of the chime to be changed. Others suggested that the sound level of the audible alert be adjustable. Although there were many divergent opinions on this topic, a number of operators felt strongly that the system would be more effective for them if it provided an audible warning even at speeds below 15 mph. The operators felt that the lights alone were not enough, especially with many side collisions occurring at slower speeds (e.g., while making a tight right turn, or while merging back into traffic after a service stop). Interestingly enough, in Agency 2’s initial test of the device, they did have the audible alert at low speeds and operators asked that this be changed due to the frequency of alarms and the interference with being able to hear the stop-request. This area should be further studied.

9.3.3 Conclusions

Future research is needed to determine how to deploy side object detection systems in a cost-effective manner for the transit industry. In addition to addressing a multitude of institutional issues, the current system design needs to be reconsidered. Further modification to the current system is one option. Another option is to adapt one or more technologies that already exist for personal automobiles and heavy vehicles to the unique conditions of transit operations. However, a key challenge to improving the design of the system is the size of the transit market. In comparison to the passenger car and heavy truck markets, the transit industry represents a significantly smaller market with unique needs, thus limiting interest among potential suppliers.

APPENDIX A: SURVEY INSTRUMENT

Note: The format of the following survey has been modified to fit this document. The content remains the same.


25) Some operators may be more accepting of SODS than others. What are the *top 3* things you think could be done to increase acceptance of SODS among operators?
1. ______
2. ______
3. ______

26) SODS is most useful when: (please check any that apply)
- Making right turns ☐
- Making left turns ☐
- Changing lanes ☐
- Operating my bus in the dark or poorly lighted areas ☐
- Operating my bus on narrower streets ☐
- Operating my bus in a construction zone ☐
- Operating my bus in heavy traffic ☐
- Operating my bus in slow traffic ☐
- Operating my bus in fast traffic ☐
- None of the above ☐
- Other (please specify) ______

27) Suggested Improvements: If you could change one (or more) things about the SODS system or SODS training, what would it be?

______

28) Operator Information

Approximately how many days in the last 30 days did you operate a bus with SODS? ______ day(s)

29) How many days ago did you last operate a SODS equipped bus? ______ day(s) on Route # ______

30) How long ago did you first operate a SODS bus? ______ Month(s)

31) How many years have you worked as a bus operator? ______ Year(s)

32) Your Age: 18 – 24 ☐ 25 – 34 ☐ 35 – 44 ☐ 45 – 54 ☐ 55 – 64 ☐ 65+ ☐

33) You are: Male ☐ Female ☐

34. Have you completed this survey before? Yes ☐ No ☐ Don't know ☐

Optional Information - please provide your operator number if you would like to be contacted to provide further information about SODS. Your survey answers will remain anonymous.
Operator Number ______

3000

Side Object Detection System (SODS) Survey

This survey is being conducted for the Federal Transit Administration as part of an evaluation of the Side Object Detection System (SODS). As an operator who has used SODS, your input is critical to understanding how well the system works and how to improve it.

The survey will take about 10 minutes of your time. Please answer the questions on your own, without consulting other operators, since we want your personal opinions about SODS. Your answers will remain completely anonymous and will be combined with those of other operators to guide our recommendations.

Please tell us how much you agree or disagree with the following statements using a 1-7 scale where 1=Strongly Disagree(SD), 7=Strongly Agree (SA) and D/K=Don't know. FOR EXAMPLE:

0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☒ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☒ ☐ ☐ ☐ SA D/K ☐

For statements 1-15, please answer FIRST for operating your bus between 0 and 15 mph where only lights warn you, and SECOND for operating your bus over 15 mph where lights and sounds are used.

USE OF THE SYSTEM :

1) The curb side warning lights are placed so they easily catch my attention:
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

2) The street side warning lights are placed so they easily catch my attention.
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

3) I adjust the position of the lights before starting my run.
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

4) I usually know what object has caused a SODS alarm.
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

5) SODS allows me to easily tell when I need to make a correction.
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

6) SODS gives so many warnings that it's hard to make sense of them all.
0 – 15 mph LIGHTS ONLY SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐ — *Over 15 mph LIGHTS AND SOUND* SD ☐ ☐ ☐ ☐ ☐ ☐ ☐ SA D/K ☐

IMPACT OF THE SYSTEM:

7) SODS interferes with my driving tasks.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

8) SODS decreases my use of my turn signals.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

9) SODS increases my use of my turn signals.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

10) SODS decreases my use of my sideview mirrors.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

11) SODS increases my use of my sideview mirrors.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

12) SODS reduces the stress of operating my bus.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

13) SODS reduces the number of accidents and near-accidents.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

14) SODS helps me detect objects I otherwise would not have seen.

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

15) It makes me anxious when passengers notice a SODS warning

0 – 15 mph LIGHTS ONLY								Over 15 mph LIGHTS AND SOUND							
SD						SA	D/K	SD						SA	D/K
1	2	3	4	5	6	7	☐	1	2	3	4	5	6	7	☐

ACCEPTANCE OF THE SYSTEM:

16) The information, introduction, and/or training I received prepared me very well for using SODS.

SD						SA	D/K
1	2	3	4	5	6	7	☐

17) It is easy to use SODS.

SD						SA	D/K
1	2	3	4	5	6	7	☐

18) I would rather operate my bus *without* SODS.

SD						SA	D/K
1	2	3	4	5	6	7	☐

19) SODS is *not* necessary for experienced bus operators.

SD						SA	D/K
1	2	3	4	5	6	7	☐

20) SODS makes me a safer bus operator.

SD						SA	D/K
1	2	3	4	5	6	7	☐

21) I think every bus in our fleet should be equipped with SODS.

SD						SA	D/K
1	2	3	4	5	6	7	☐

22) SODS is helpful to newer, less experienced drivers.

SD						SA	D/K
1	2	3	4	5	6	7	☐

23) I would like SODS to be kept on my bus in the future.

SD						SA	D/K
1	2	3	4	5	6	7	☐

24) Has SODS ever helped you to avoid a collision? (please check any that apply)

- NO, SODS has not helped me avoid a collision ☐
- YES, to avoid a vehicle while changing lanes ☐
- YES, to avoid hitting a fixed object (such as a parked car, pole) while pulling in or out of a stop ☐
- YES, to avoid hitting a fixed object (such as a parked car, pole) when making a turn ☐
- YES, to avoid hitting a fixed object (such as a parked car, pole) while driving straight ☐
- YES, other (please describe)____________________ ☐

APPENDIX B: DETAILED SURVEY FINDINGS

Data analysis involved:

- *Cross-tabulations* (with appropriate tests of statistical significance[59]) to assess relationships between attitudinal variables and demographic variables (such as gender, age, and years of experience as a bus operator).
- *T-tests* to assess the significance of any changes from Wave 1 to Wave 2 in attitudinal variables.
- *Analysis of Variance* to test for differences across the six agencies in regard to attitudinal variables.

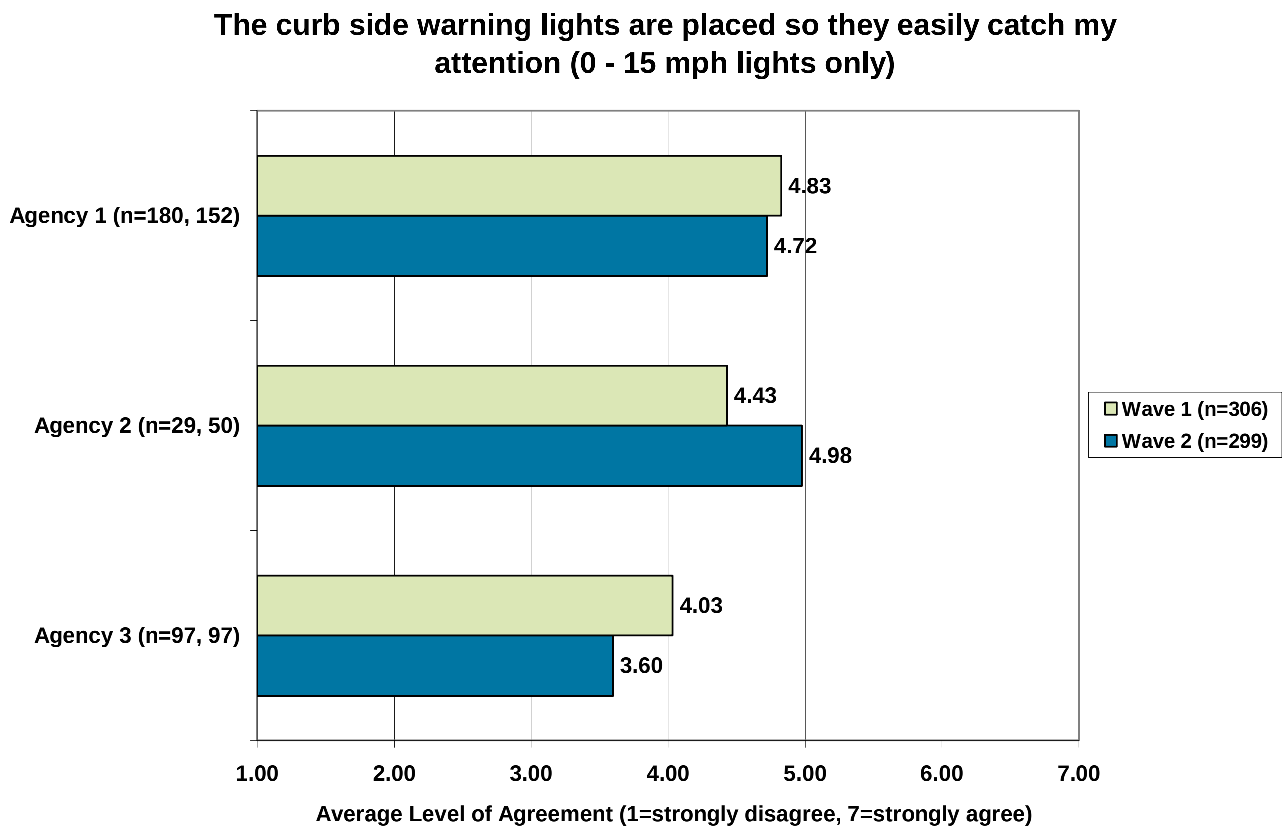
The results of the analysis are summarized at the beginning of each sub-section of this chapter, with more detailed results presented in the accompanying charts. Results are used to describe differences among agencies in terms of SODS usability, operator acceptance, barriers and challenges to acceptance, and effects on operator performance and alarm handling.

[59] *Cramer's V* is a measure of the relationship between two variables and is appropriate to use when one or both of the variables are at the nominal level of measurement. *Cramer's V* ranges from 0 to +1 and indicates the strength of a relationship. The closer to +1, the stronger the relationship between the two variables. The *Kendall's tau c* statistic is a measure of the relationship between two variables and is appropriate to use with ordinal level variables. *Tau c* ranges from –1 to +1 and indicates the strength and direction (inverse or direct) of a relationship. The closer to either +1 or –1, the stronger the relationship between the two variables. The accompanying "p" scores presented in this report for Cramer's V, Kendall's tau c, indicate the level of statistical significance.

Determine the *usability* of SODS in terms of operator perceptions of system design, features, and interface

Key Findings:

- Medium agreement among operators that curbside and street side warning lights are place correctly, with operators at Agency 3 less likely to agree (especially during Wave 2).
- High disagreement among operators that they adjust the warning lights when needed (at both speed modes), with operators at Agency 3 less likely to adjust the warning lights. Additionally female operators at Agency 2 were more likely than males to adjust the warning lights when traveling at speeds below 15 mph (Wave 1).
- Moderate disagreement among operators at Agencies 1 and 2 that SODS interferes with driving tasks (at both speed modes). Operators at Agency 3 were more likely to agree that SODS interferes with driving tasks. Younger drivers at Agency 2 were more likely to agree that SODS interferes with driving tasks at both speed modes (Waves 1& 2).
- Responses indicate that SODS does not increase or decrease the use of turn signals. Experienced operators at Agency 3 were more likely to agree SODS decreases the use of turn signals (Waves 1).
- Responses indicate that SODS does not increase or decrease the use side-view mirrors. Female operators at Agency 1 were more likely than males to agree that SODS increases use of side-view mirrors at speeds over 15 mph (Wave 2). Younger operators at Agency 1 were more likely to agree that SODS decreases the use of side-view mirrors at speeds below 15 mph (Wave 1). Older operators at Agency 2 were more likely to agree that SODS decreases the use of side-view mirrors at speeds below 15 mph (Wave 1).
- High disagreement among operators that SODS reduces the stress of operating a bus. This was especially the case among operators at Agency 3. Older and more experienced operators at Agency 2 were more likely to agree that SODS reduces stress when traveling at speeds over 15 mph (Wave 2).
- Medium agreement among operators that SODS is easy to use, but less so for operators at Agency 3 (especially during Wave 2) and more so for operators at Agency 2. Older and more experienced operators at Agency 2 were more likely to agree that SODS is easy to use (Wave 2). Interestingly, operators at Agency 3 showed a significant decrease in agreement from Wave 1 to 2 (in other words, they found it to be less easy to use over time).



Significant differences by agency:

- Agency 1 was more likely to agree than Agency 3 (Wave 1)
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)

Significant differences over time:

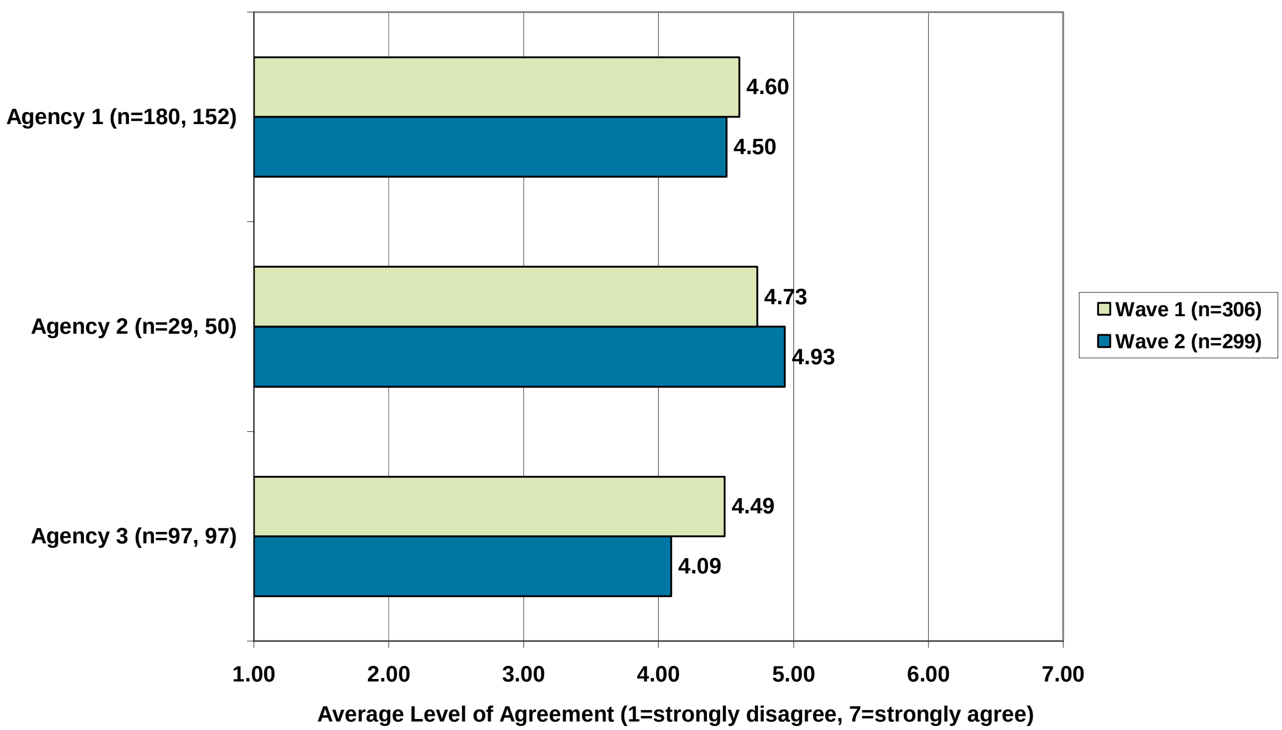
- None

Significant differences by demographics:

- Females are more likely to agree (Wave 1, Agency 2)[60]
- Younger operators are more likely to agree (Wave 1, Agencies 1 & 2)[61]

[60] Cramer's V = .736, p = .035
[61] Agency 2 – Kendal's tau-c = -.392, p = .001; Agency 3 – Kendall's tau-c = -.180, p = .036

The curb side warning lights are placed so they easily catch my attention (Over 15 mph Lights and Sound)



Significant differences by agency:

- None

Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 1, Agency 1)[62]
- Younger operators are more likely to agree (Wave 1, Agency 2)[63]
- Older operators are more likely to agree (Wave 2, Agency 1)[64]

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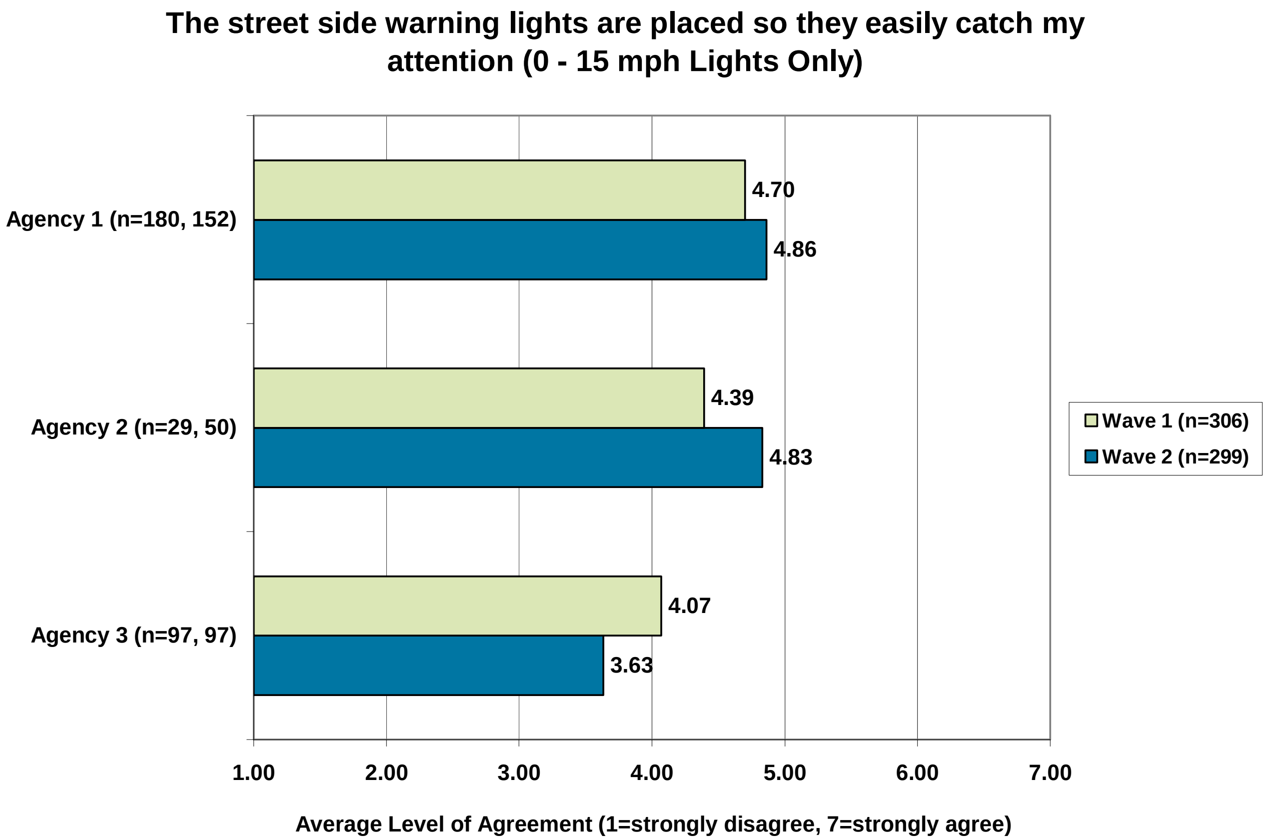
[62] Kendall's tau-c = .117, p = .047
[63] Kendall's tau-c = -.308, p = .015
[64] Kendall's tau-c = .128, p = .048



Significant differences by agency:

- Agency 1 was more likely to agree than Agency 3 (Wave 1)
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)

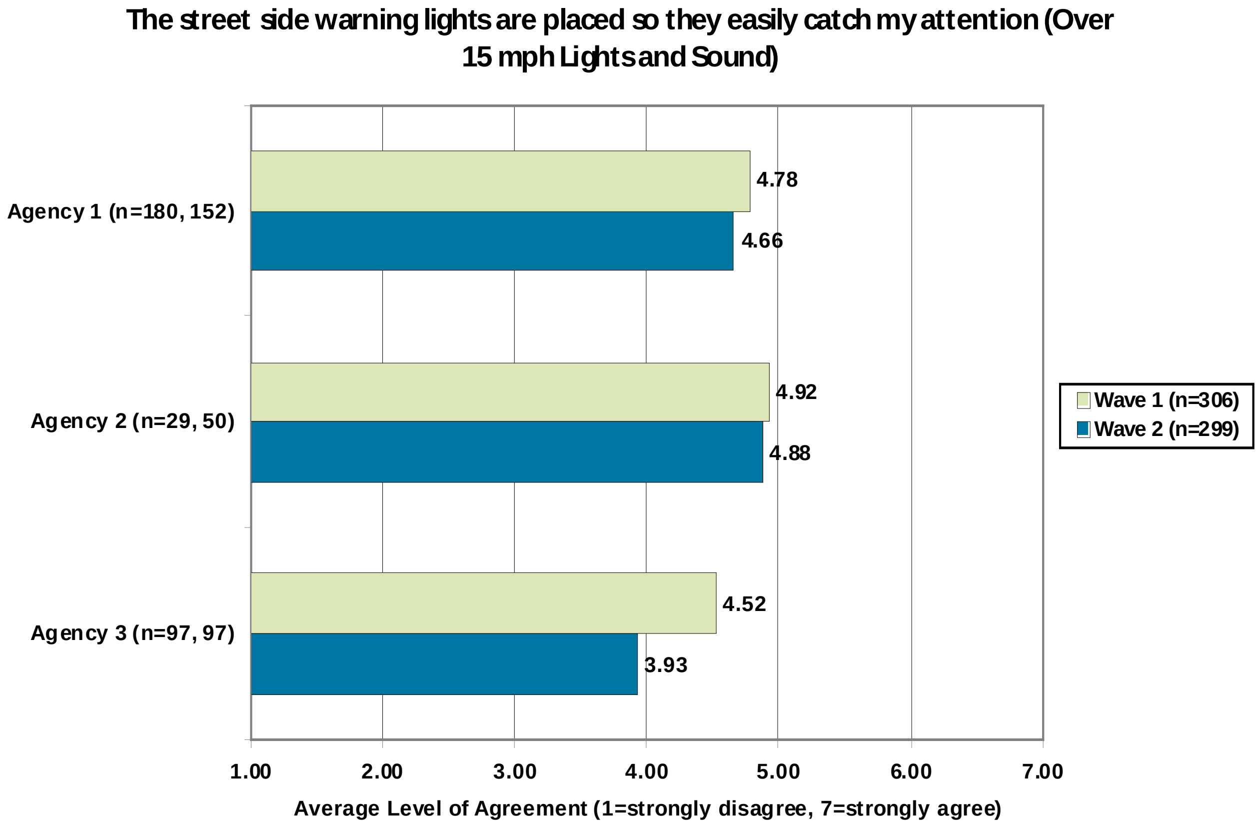
Significant differences over time:

- None

Significant differences by demographics:

- Younger operators are more likely to agree (Wave 1, Agencies 2 & 3)[65]
- Males are more likely to agree (Wave 2, Agency 1)[66]

[65] Agency 2 – Kendall's tau-c = -.355, p = .015; Agency 3 – Kendall's tau-c = -.181, p = .042
[66] Cramer's V = .377, p = .009



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)

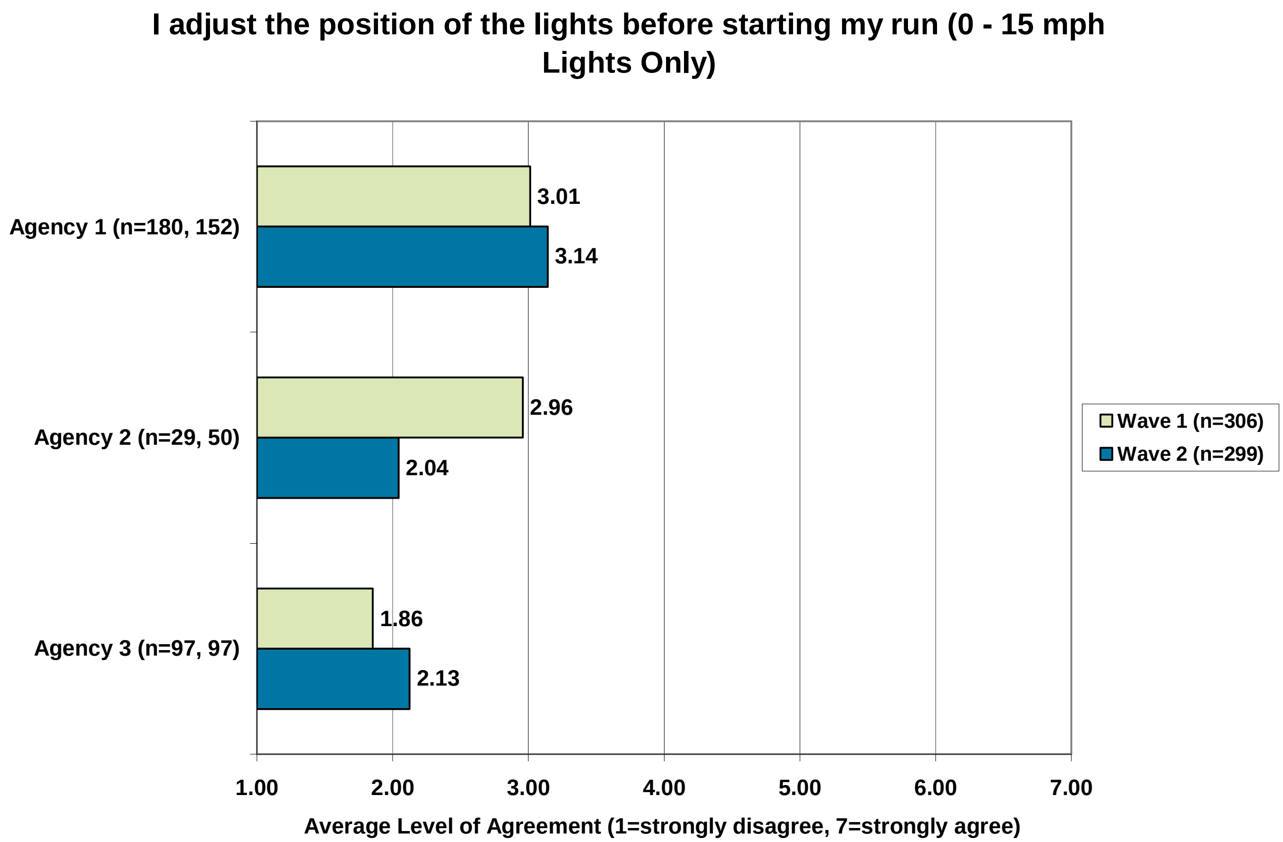
Significant differences over time:

- None

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 1, Agency 2)[67]
- Older operators are more likely to agree (Wave 2, Agency 2)[68]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 2)[69]

[67] Kendall's tau-c = .333, p = .011
[68] Kendall's tau-c = .202, p = .046
[69] Kendall's tau-c = .236, p = .024



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1)
- Agency 1 was more likely to agree than Agency 2 and Agency 3 (Wave 2)

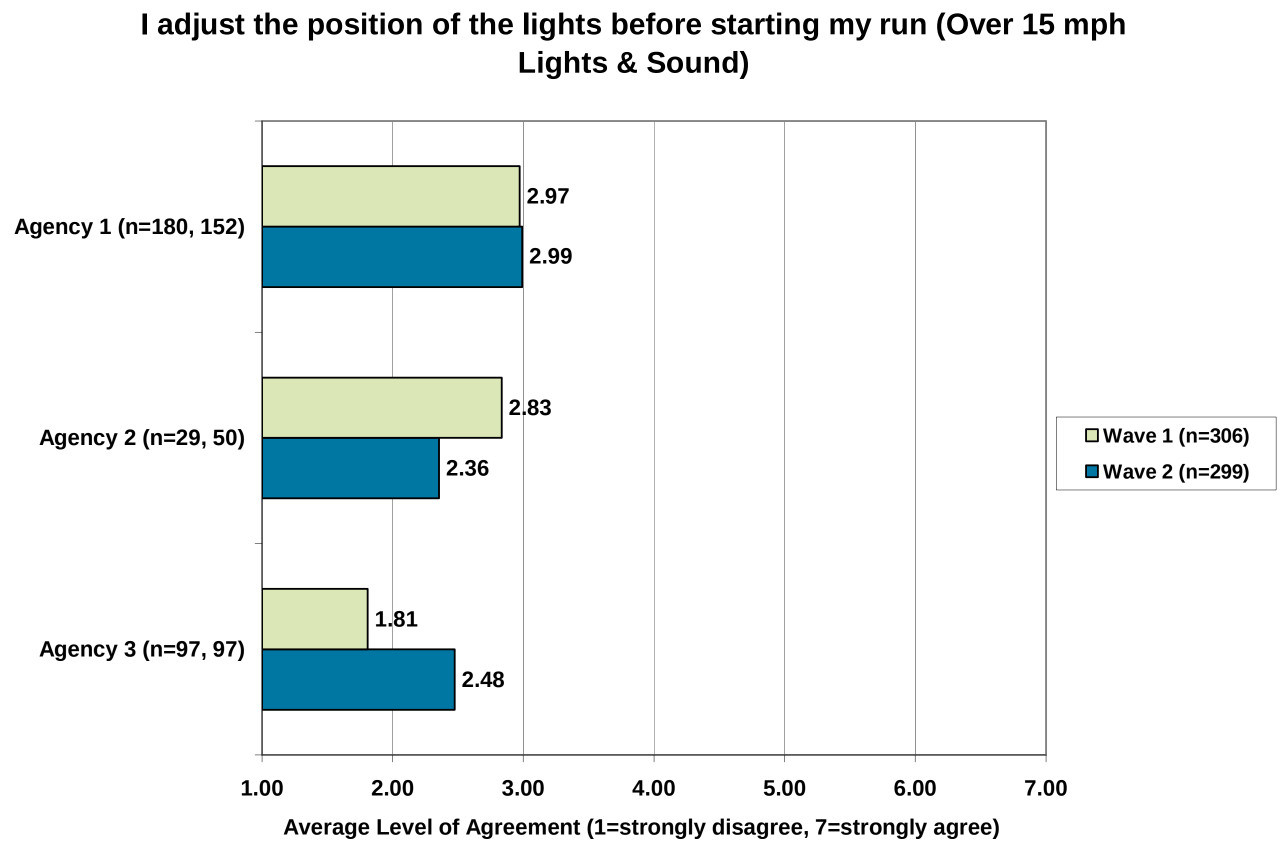
Significant differences over time:

- Agency 2 showed a significant decrease in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Females are more likely to agree (Wave 1, Agency 1)[70]

[70] Cramer's V = .316, p = .05



Significant differences by agency:

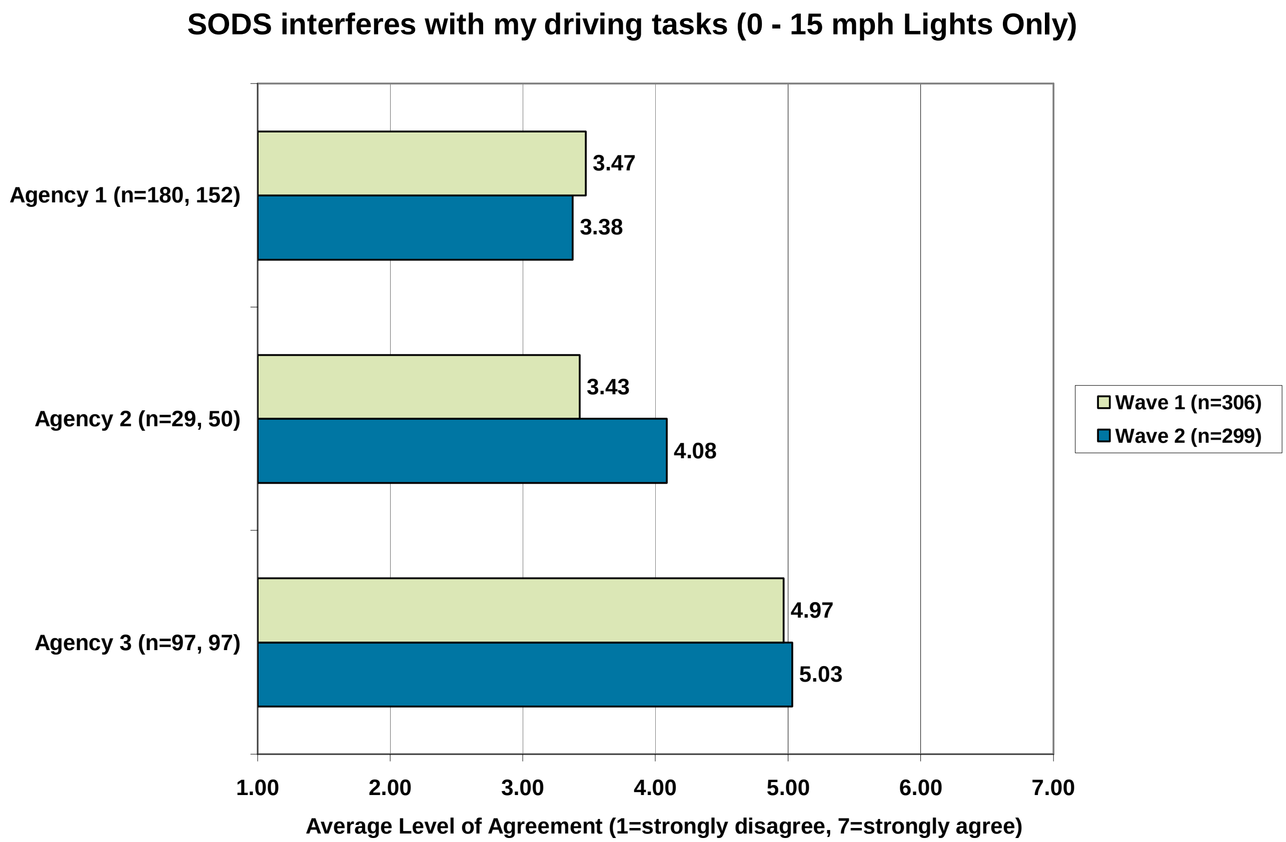
- Agency 1 was more likely to agree than Agency 3 (Wave 1)

Significant differences over time:

- Agency 3 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- None



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1)
- Agency 1 was less likely to agree than Agency 3 (Wave 2)

Significant differences over time:

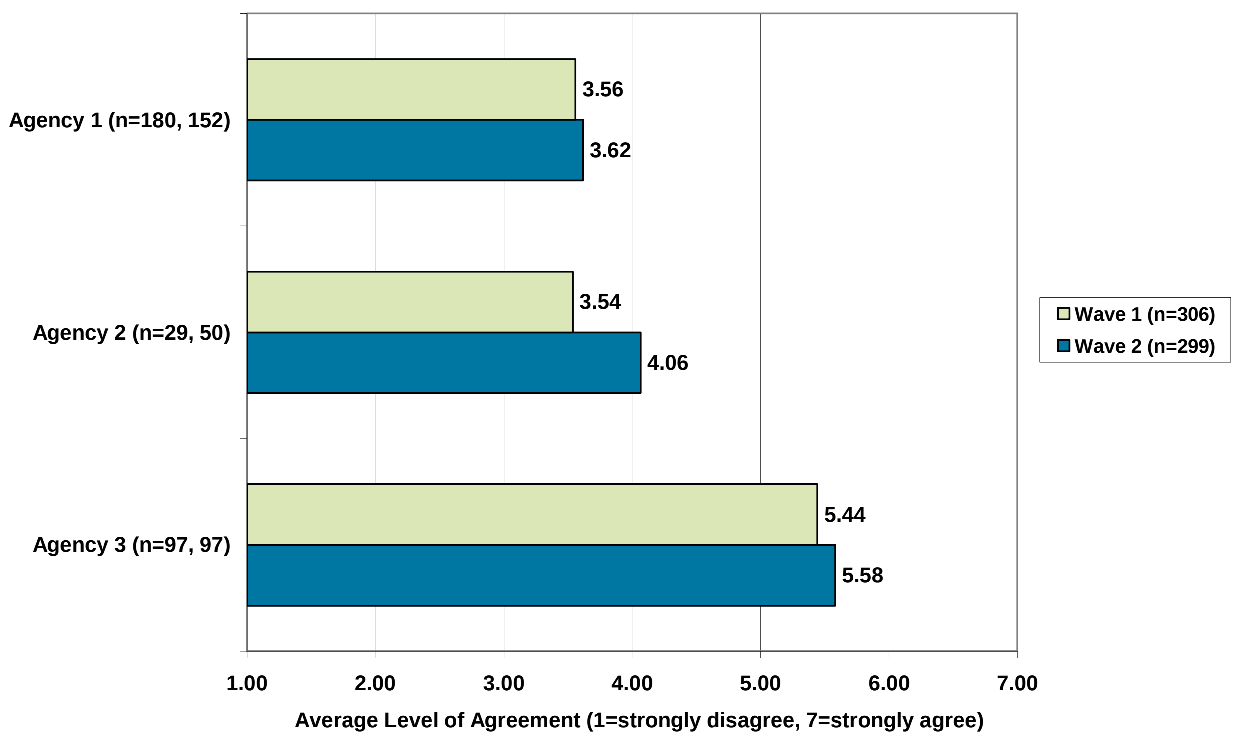
- None

Significant differences by demographics:

- Younger operators are more likely to agree (Wave 2, Agency 2)[71]

[71] Kendall's tau-c = -.323, p = .003

SODS interferes with my driving tasks (Over 15 mph Lights & Sound)



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

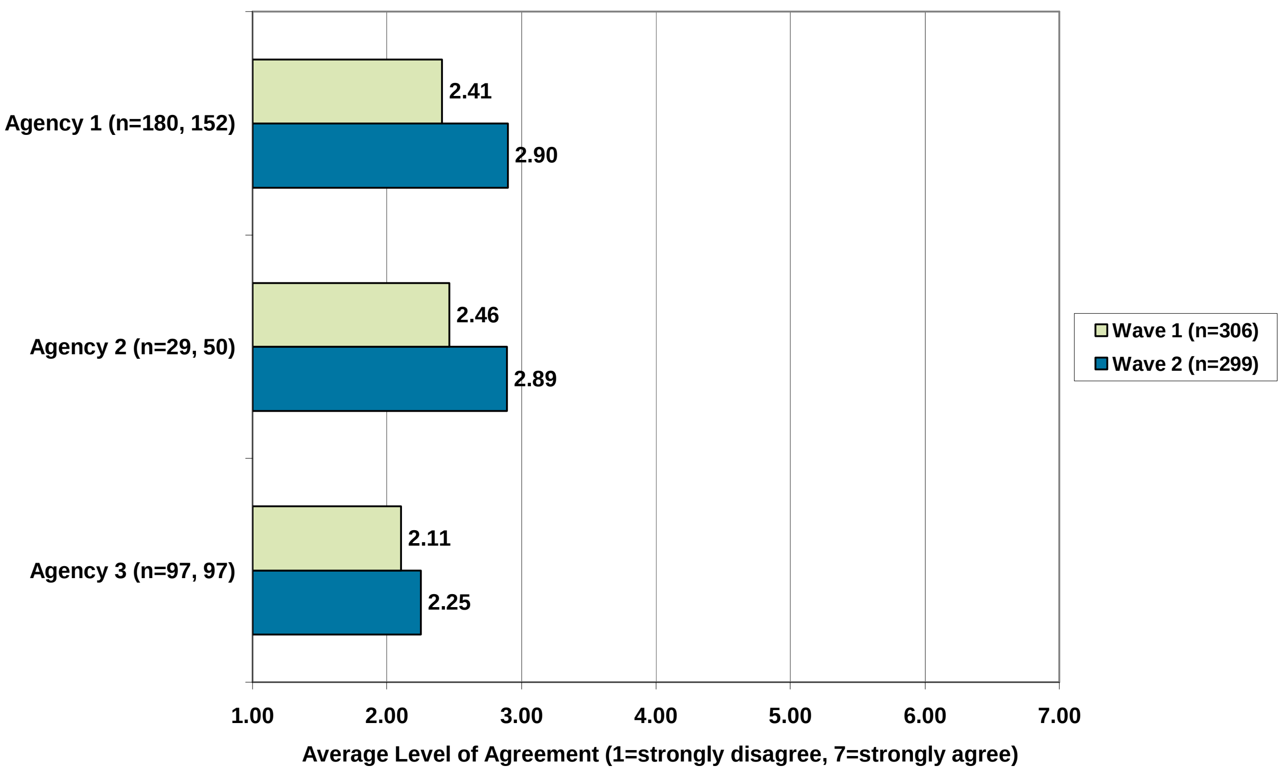
- None

Significant differences by demographics:

- Younger operators are more likely to agree (Wave 2, Agency 2)[72]

[72] Kendall's tau-c = -.315, p = .003

SODS decreases my use of my turn signals (0 - 15 mph Lights Only)



Significant differences by agency:

- None

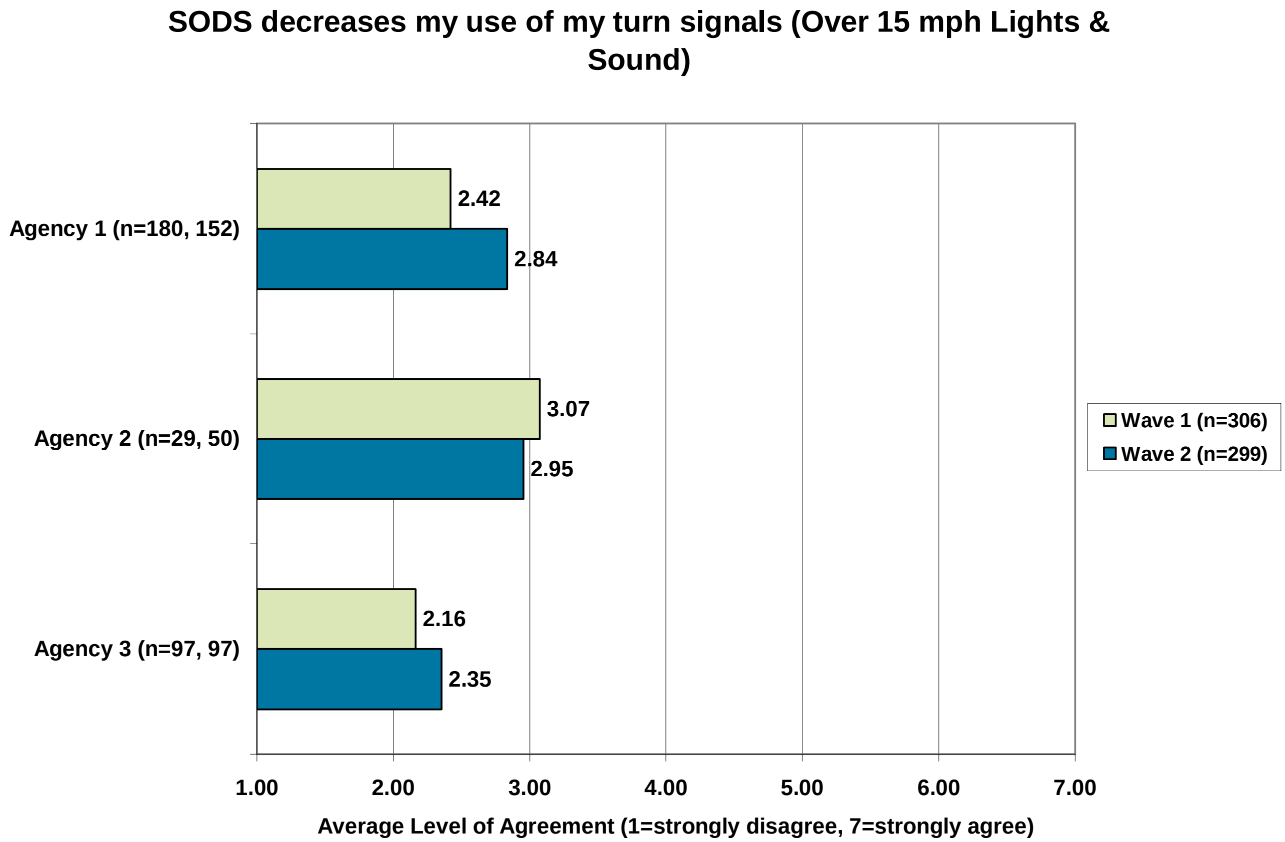
Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 1, Agency 3)[73]

[73] Kendall's tau-c = .175, p = .020



Significant differences by agency:

- None

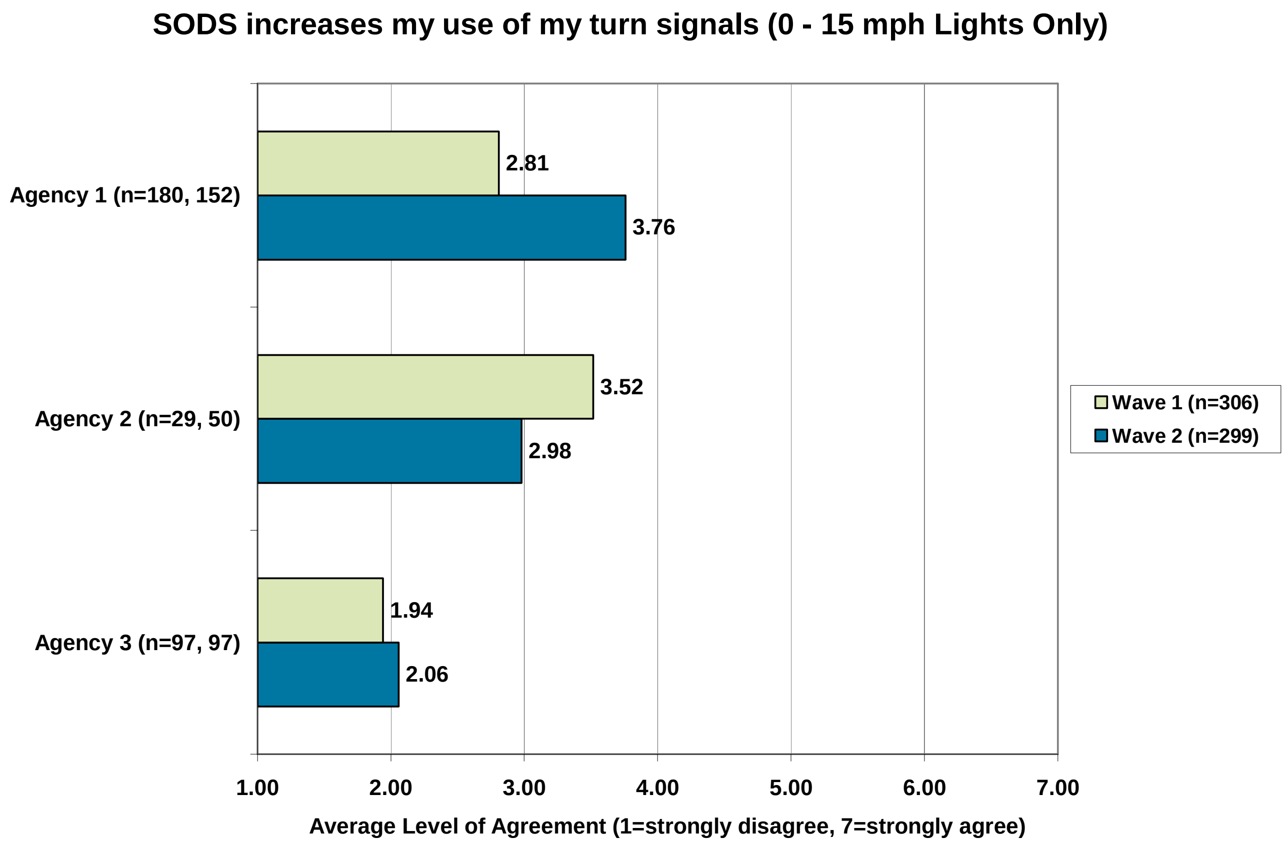
Significant differences over time:

- None

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 1, Agency 3)[74]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 1)[75]

[74] Kendall's tau-c = .165, p = .035
[75] Kendall's tau-c = .165, p =.015



Significant differences by agency:

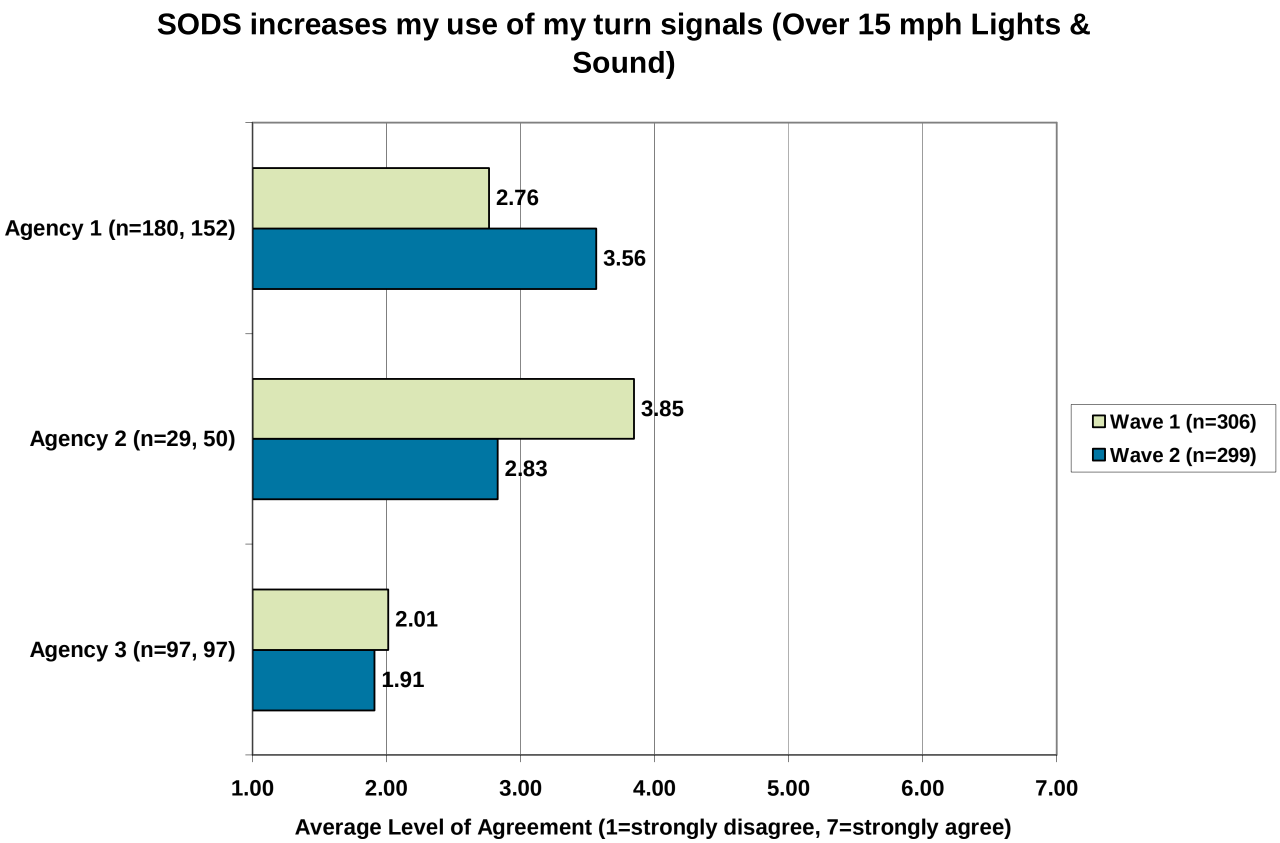
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1)
- Agency 1 was more likely to agree than Agency 3 (Wave 2)

Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- None



Significant differences by agency:

- Agency 3 was less likely to agree than Agency 1 and Agency2 (Wave 1)
- Agency 1 was less likely to agree than Agency 2 (Wave 1)
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)

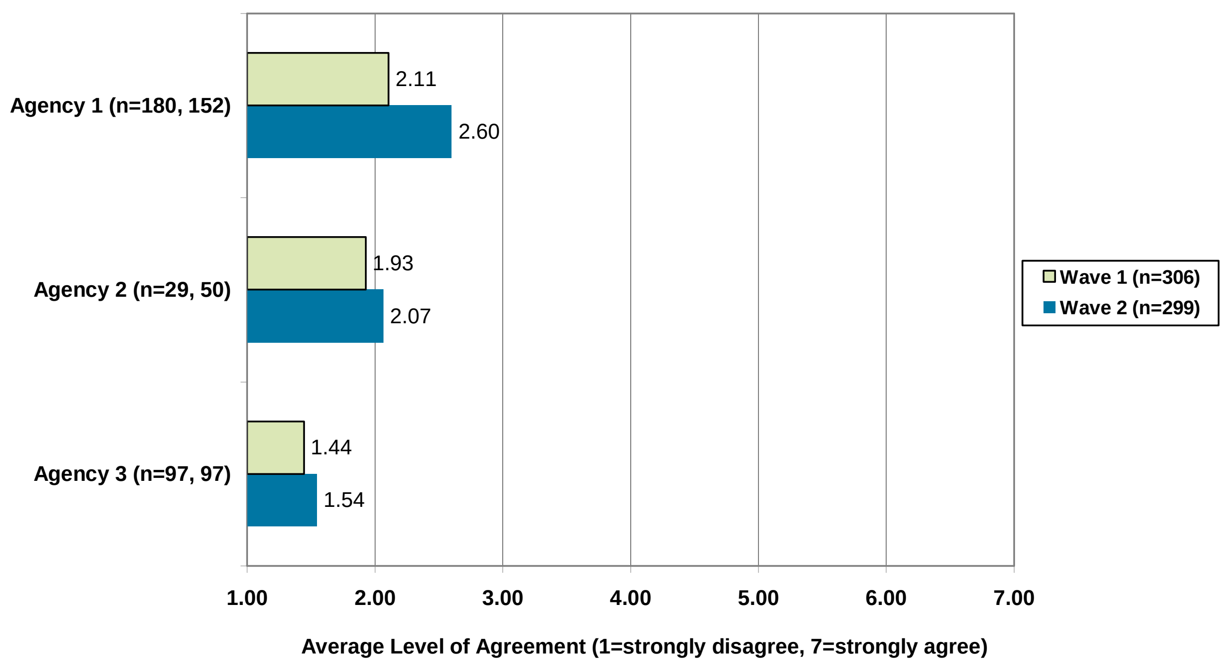
Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- None

SODS decreases my use of my sideview mirrors (0-15 mph Lights Only)



Significant differences by agency:

- Agency 1 was more likely to agree than Agency 3 (Wave 1, Wave 2)

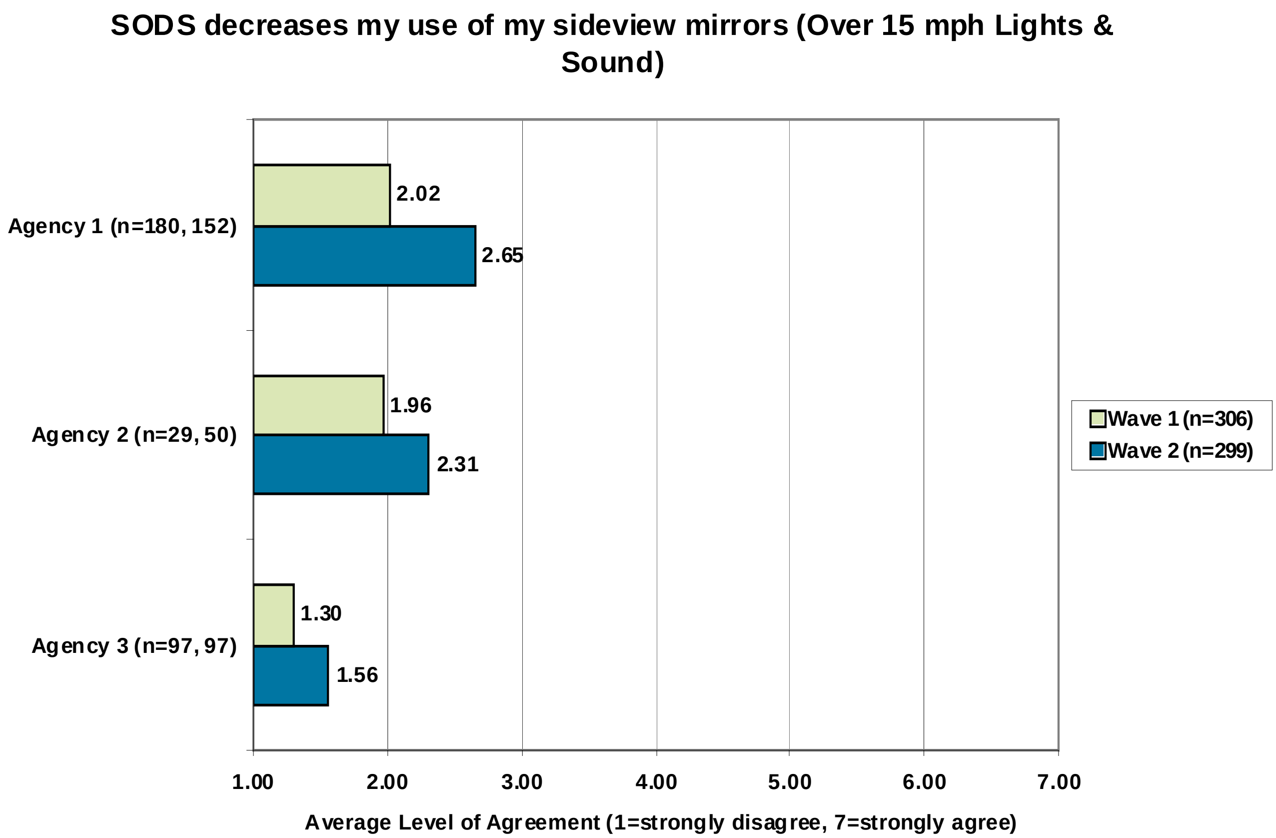
Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Younger operators are more likely to agree (Wave 1, Agency 1)[76]
- Older operators are more likely to agree (Wave 1, Agency 2)[77]

[76] Kendall's tau-c = -.108, p = .051
[77] Kendall's tau-c = .303, p = .002



Significant differences by agency:

- Agency 1 was more likely to agree than Agency 3 (Wave 1, Wave 2)

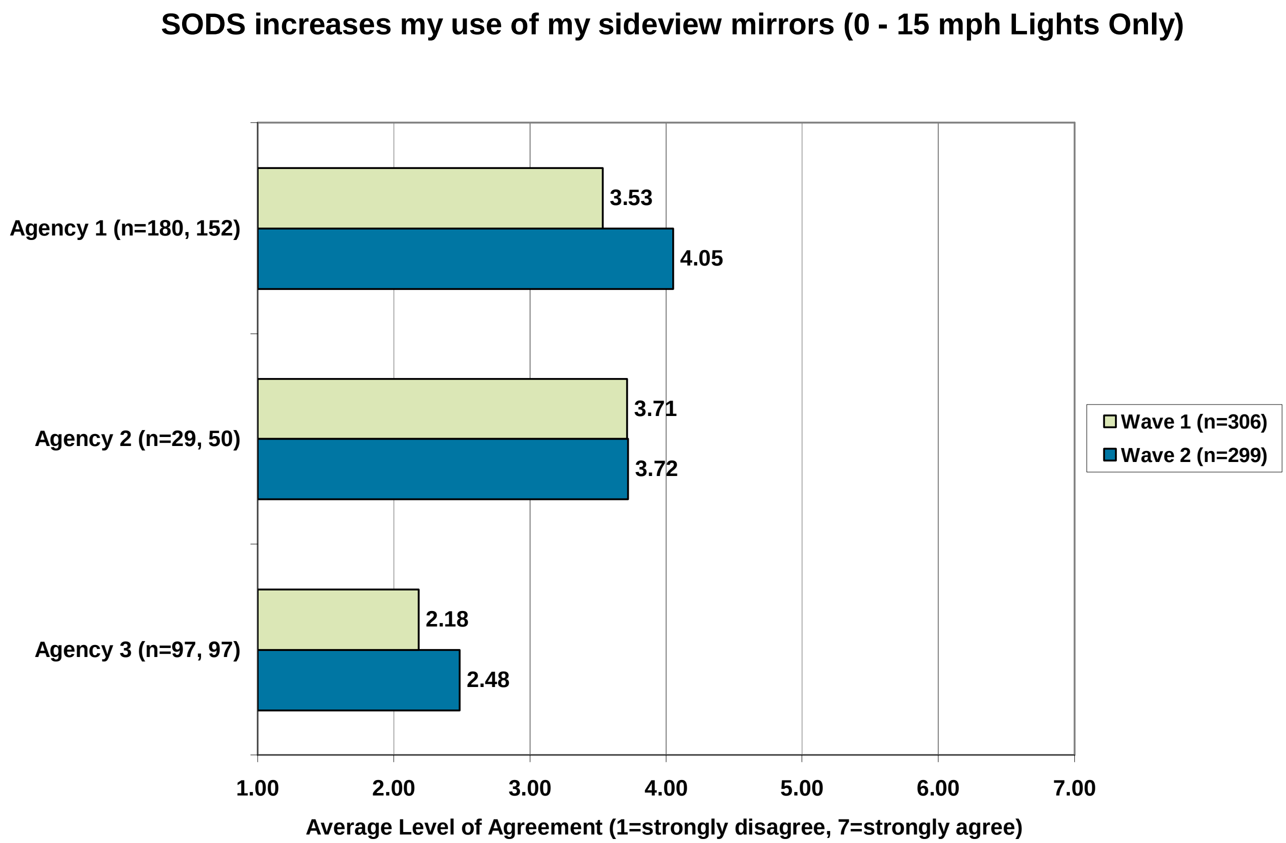
Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Females are more likely to agree (Wave 2, Agency 1)[78]

[78] Cramer's V = .355, p = .023



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

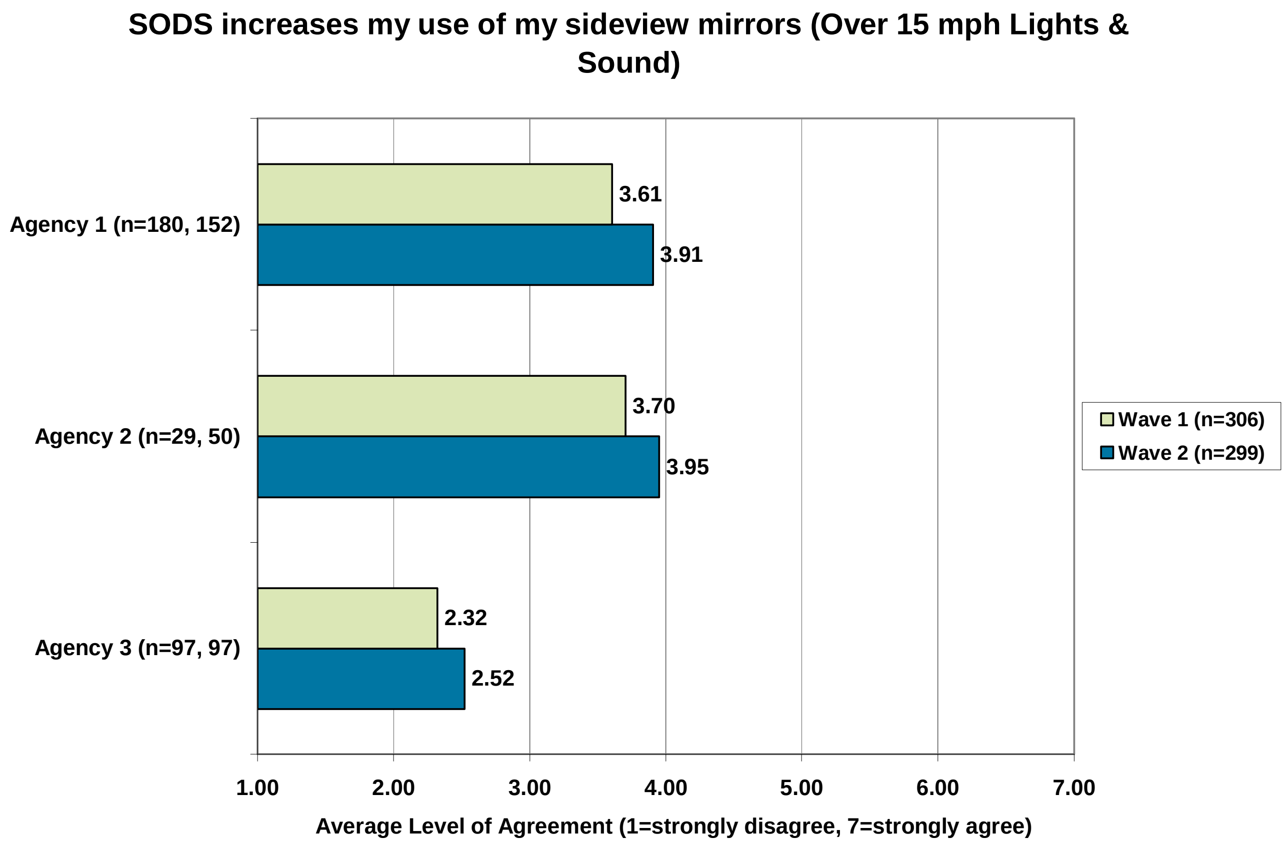
Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Males are more likely to agree (Wave 2, Agency 3)[79]
- Younger operators are more likely to agree (Wave 2, Agency 3)[80]

[79] Cramer's V = .397, p = .05
[80] Kendall's tau-c = -.162, p = .035



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

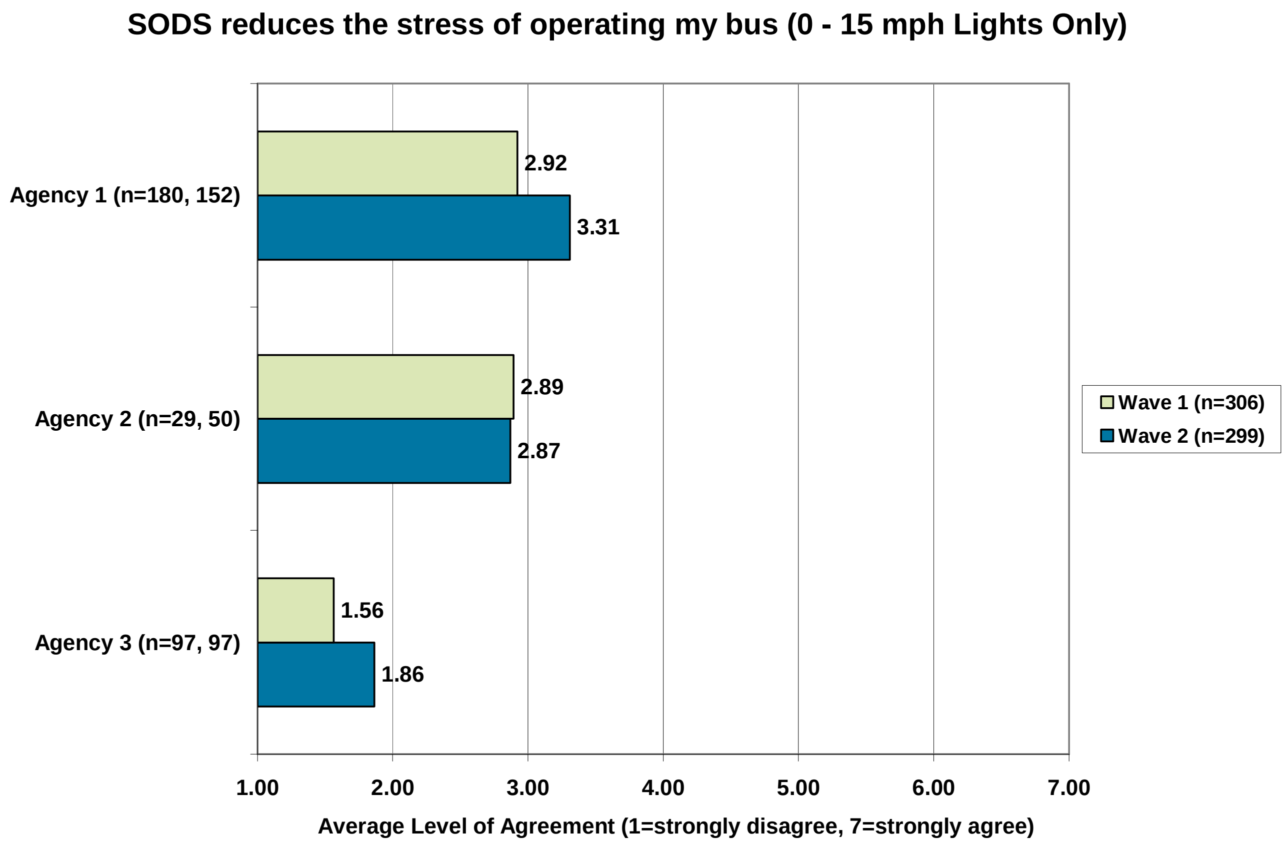
Significant differences over time:

- None

Significant differences by demographics:

- Operators with fewer years of experience are more likely to agree (Wave 1, Agency 1)[81]

[81] Kendall's tau-c = -.157, p = .021



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

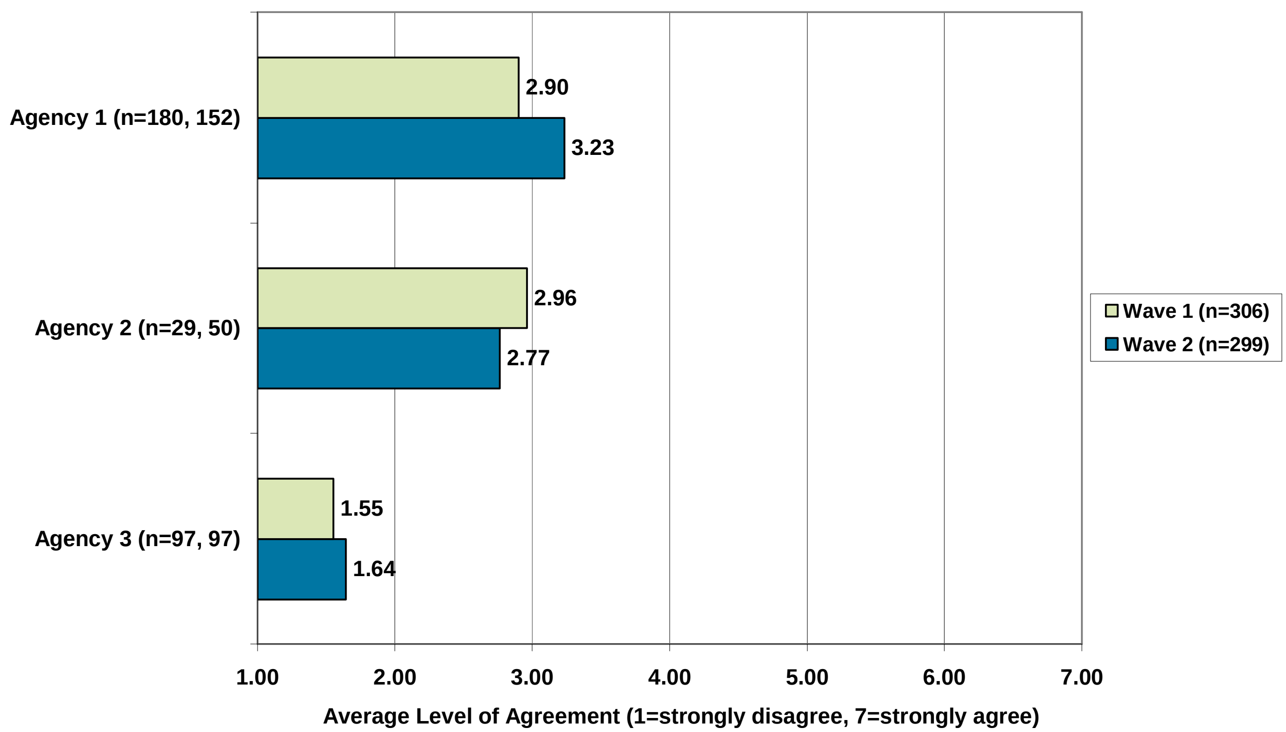
- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[82]

[82] Kendall's tau-c = .334, p = .001

SODS reduces the stress of operating my bus (Over 15 mph Lights & Sound)



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

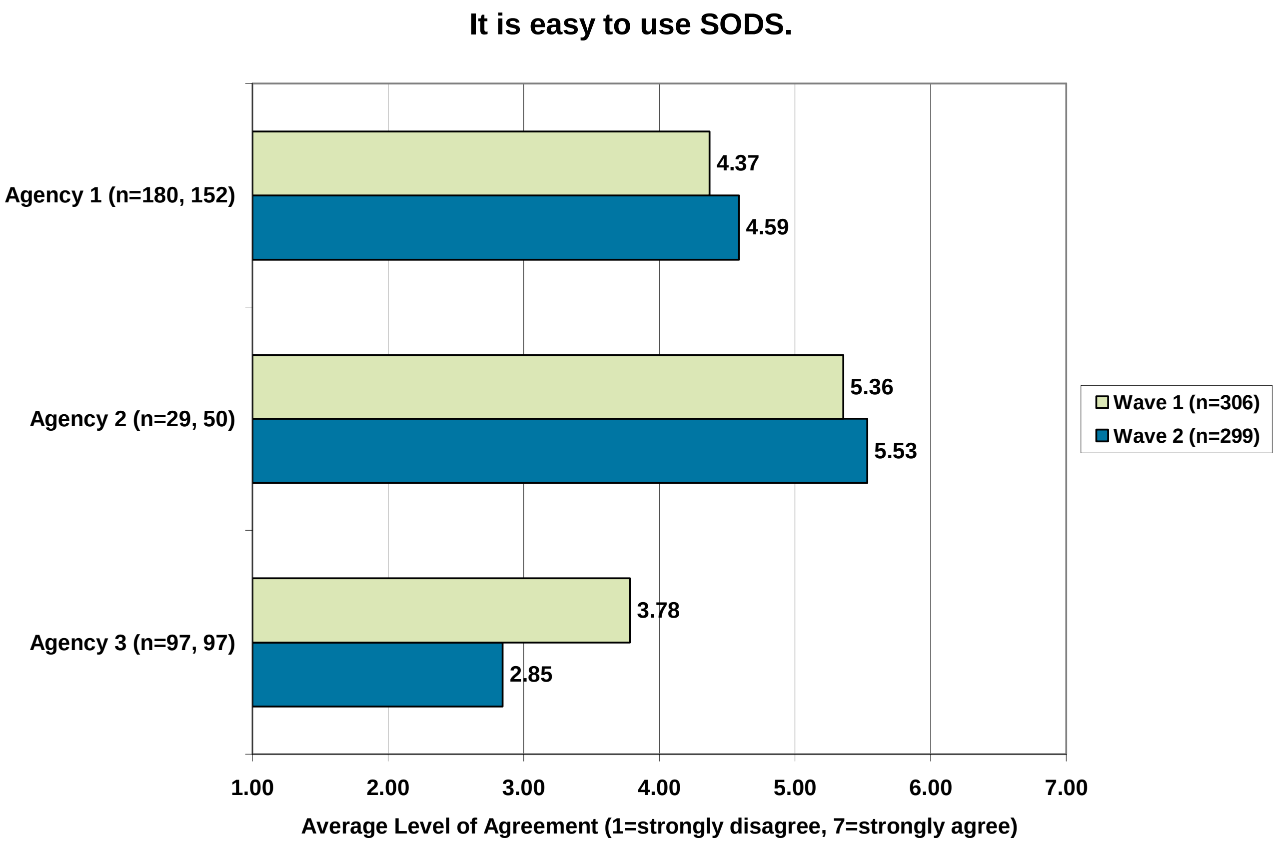
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[83]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 2)[84]

[83] Kendall's tau-c = .287, p = .008
[84] Kendall's tau-c = .234, p = .036



Significant differences by agency:

- Agency 2 was more likely to agree than Agency 3 (Wave 1)
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)
- Agency 2 was more likely to agree than Agency 1 (Wave 2)

Significant differences over time:

- Agency 3 showed a significant decrease in agreement from Wave 1 to Wave 2

Significant differences by demographics:

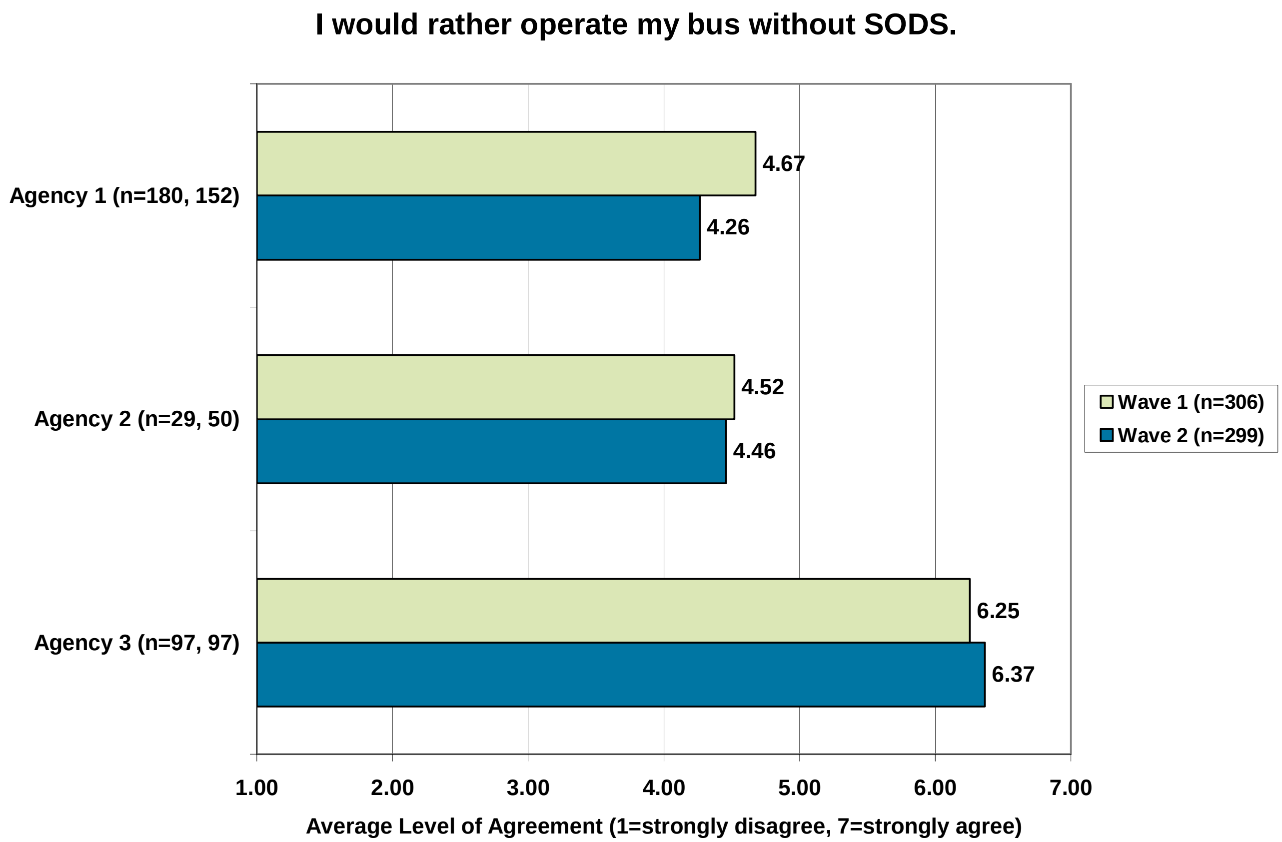
- Older operators are more likely to agree (Wave 2, Agency 2)[85]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 2)[86]

[85] Kendall's tau-c = .187, p = .046
[86] Kendall's tau-c = .263, p = .018

How Do Operators Perceive SODS Accuracy, Usefulness and Value?

Key Findings:

- Medium to strong agreement among operators that they would rather operate bus without SODS, especially among the more experienced operators at Agency 3 (Wave 2). Younger operators at Agency 2 were more likely to agree (Waves 1 & 2).
- Medium to strong agreement among operators that SODS is not necessary for more experienced operators, especially among operators at Agency 3. Experienced operators at Agencies 1 and 3 were in general more likely to agree SODS is not necessary for more experienced operators (Wave 1 for both agencies and Wave 2 for Agency 1). Younger operators at Agency 2 were more likely to agree (Wave 2).
- Medium agreement among operators (with the exception of those at Agency 3) that the entire fleet should be SODS equipped. Operators at Agency 3 strongly disagreed that the fleet should be equipped while older operators at Agency 2 were more likely to agree that it should (Wave 2).
- Medium agreement among operators that SODS is helpful to new, less experienced drivers. An exception to this is that operators at Agency 3 strongly disagreed. Also older operators at Agency 2 were more likely to agree (Wave 2).
- Medium disagreement among operators that they would like SODS to stay on the buses, with the exception of operators at Agency 3 who strongly disagreed. Older operators at Agency 2 were more likely to agree (Wave 1 & 2). Interestingly, Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2, indicating that they were happier with SODS over time.



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

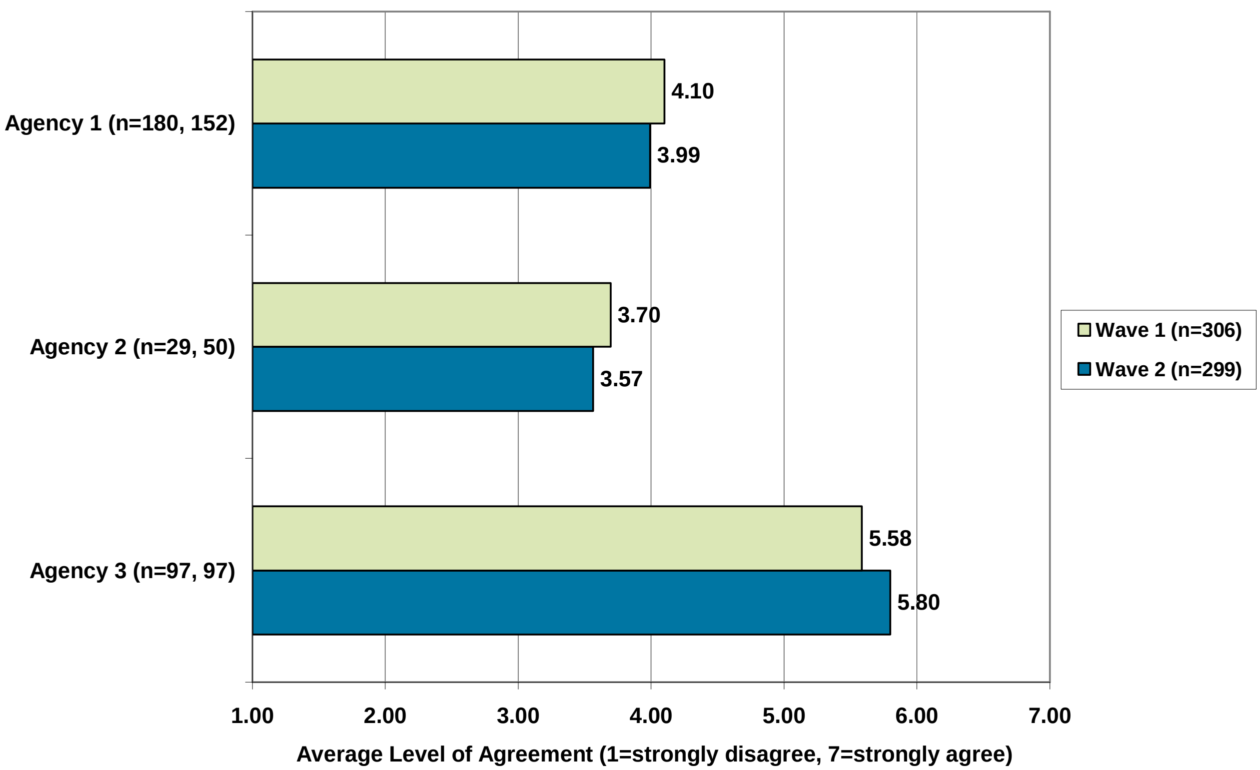
- None

Significant differences by demographics:

- Younger operators are more likely to agree (Wave 1, Agency 2)[87]
- Younger operators are more likely to agree (Wave 2, Agency 2)[88]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 3)[89]

[87] Kendall's tau-c = -.298, p = .040
[88] Kendall's tau-c = -.311, p = .001
[89] Kendall's tau-c = .115, p = .037

SODS is not necessary for experienced bus operators.



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

- None

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 1, Agencies 1 & 3)[90]
- Younger operators are more likely to agree (Wave 2, Agency 2)[91]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 1)[92]

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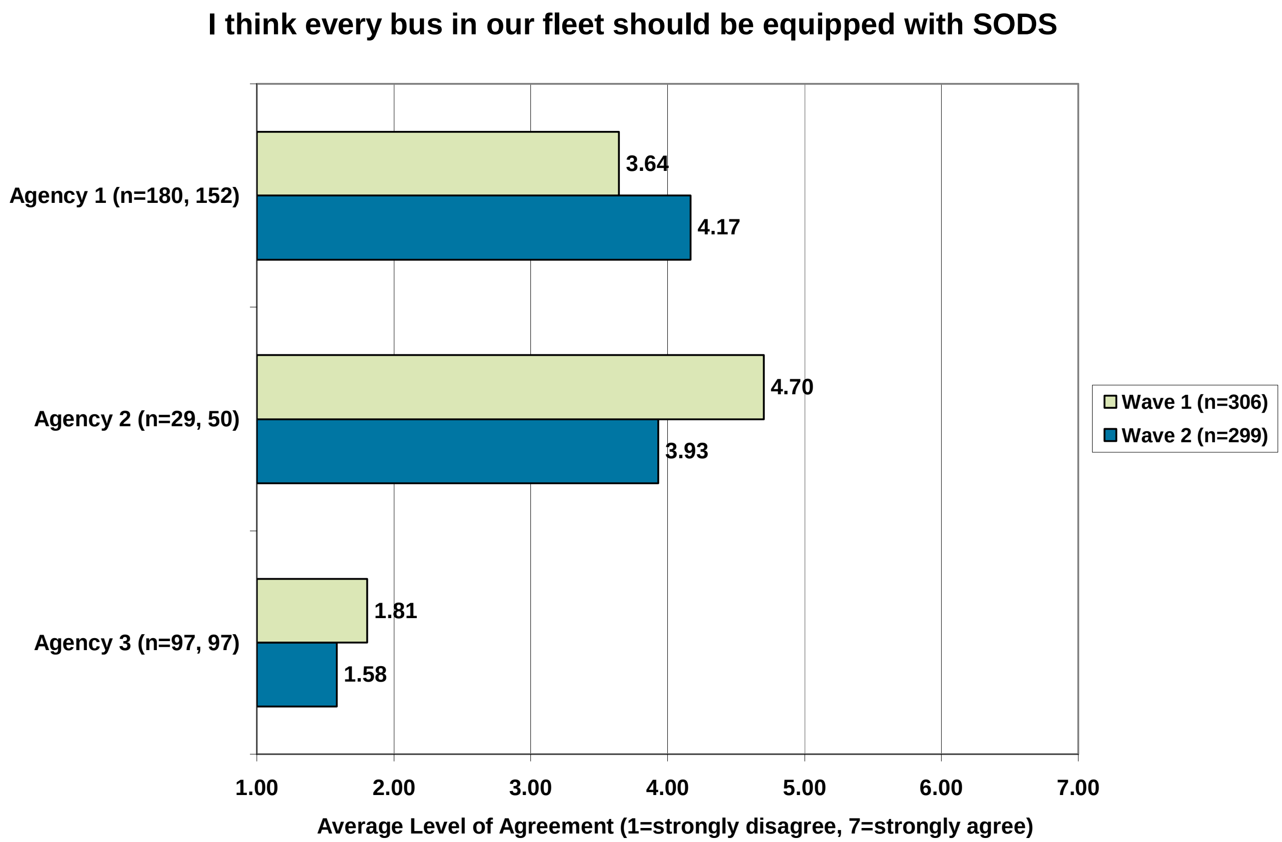
[90] Agency 1 – Kendall's tau-c = -.148, p = .019; Agency 3 – Kendall's tau-c = -.186, p = .009
[91] Kendall's tau-c = -.318, p = .001
[92] Kendall's tau-c = .145, p = .05



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

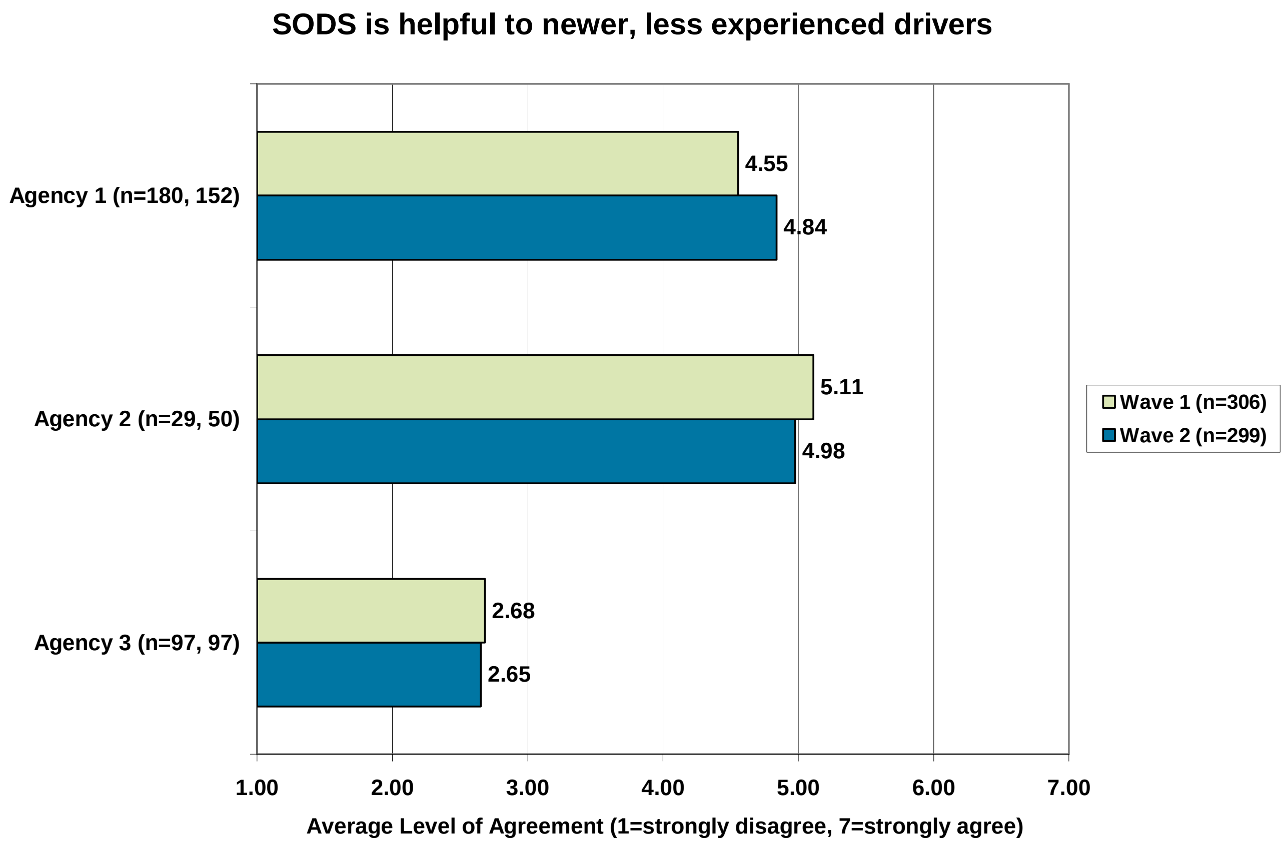
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[93]

[93] Kendall's tau-c = .268, p = .01



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

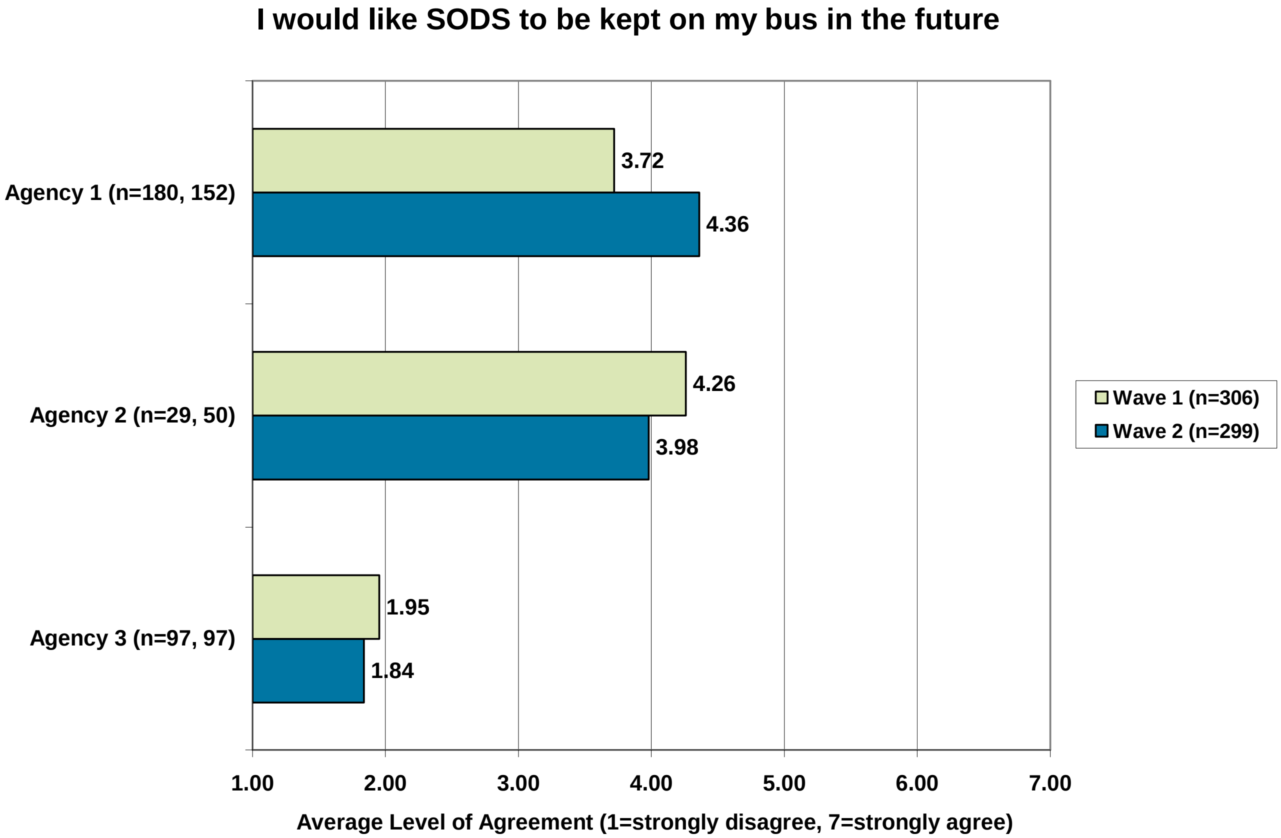
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[94]

[94] Kendall's tau-c = .230, p = .022



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

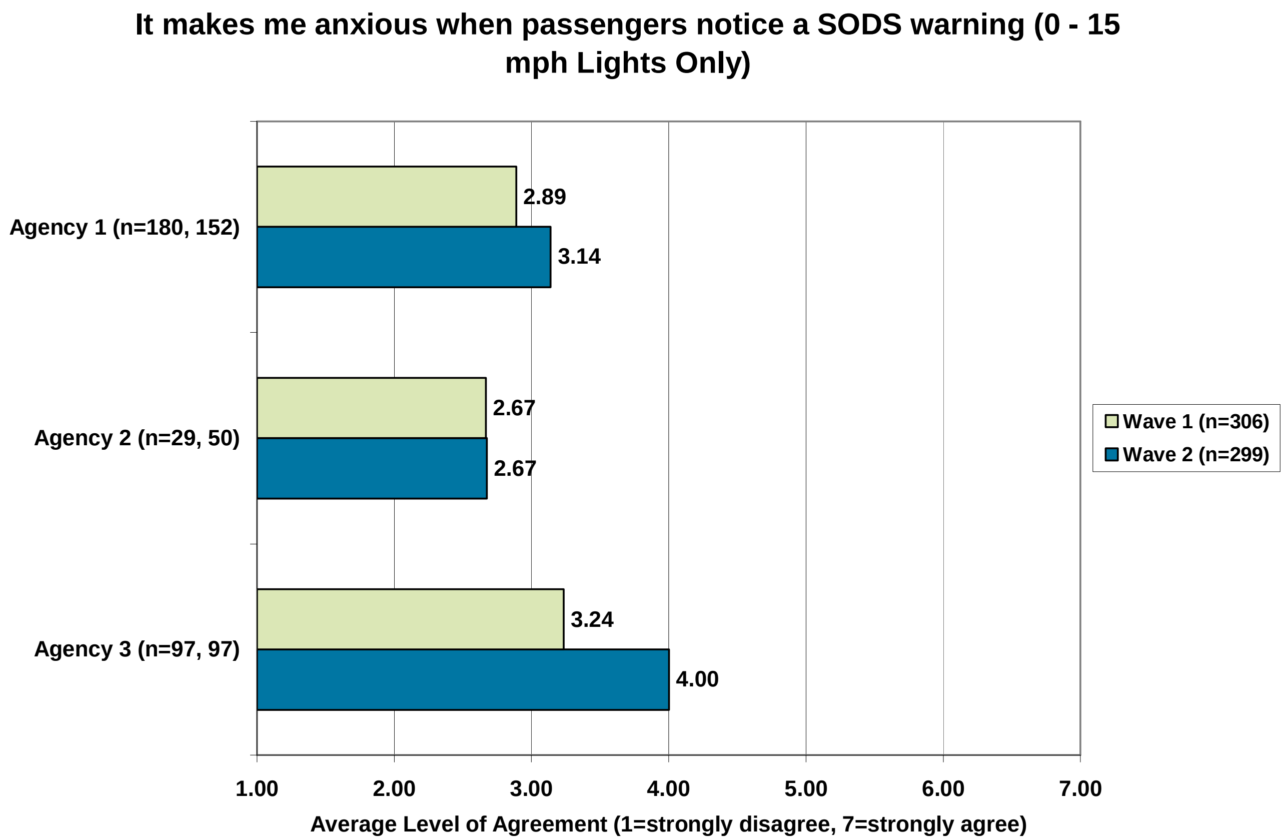
- Older operators are more likely to agree (Wave 1 & 2, Agency 2)[95]

[95] Wave 1 – Kendall's tau-c = .348, p = .008; Wave 2 – Kendall's tau-c = .297, p = .003

Determine if *barriers and challenges* to operator acceptance exist and, if so, how they can be overcome

Key Findings:

- Medium disagreement among operators that SODS makes operators anxious when passengers notice warnings, with operators at Agency 3 more likely to agree it makes them anxious. Operators at Agency 3 showed increased agreement that SODS makes them anxious by Wave 2. Experienced operators at all 3 agencies were more likely to agree that SODS makes them anxious (Wave 1 for Agencies 1, 2, and 3, and Wave 2 for Agencies 1 and 2).
- Medium agreement among operators that training prepared them very well for using SODS. The exception to this was operators at Agency 3 who disagreed that the training prepared them well for SODS. Operators at Agency 1 increased agreement from Wave 1 to Wave 2.
- Top 3 reported ways to improve acceptance among operators:
  - Alter the warning alarm by changing the sound, disabling the sound, or lowering volume.
  - Decrease false alarms by altering sensor sensitivity/accuracy
  - Modify the lights or have lights only (no warning alarm).
- Agency 3 showed a large increase in the percent of operators who recommended removing SODS, from Wave 1 (6.5 percent) to Wave 2 (24.1 percent). Males (14 percent) were more likely than females (9 percent) to suggest removing SODS.



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 2)

Significant differences over time:

- Agency 3 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 1, Agency 3)[96]
- Operators with more years of experience are more likely to agree (Wave 2, Agencies 1 & 2)[97]

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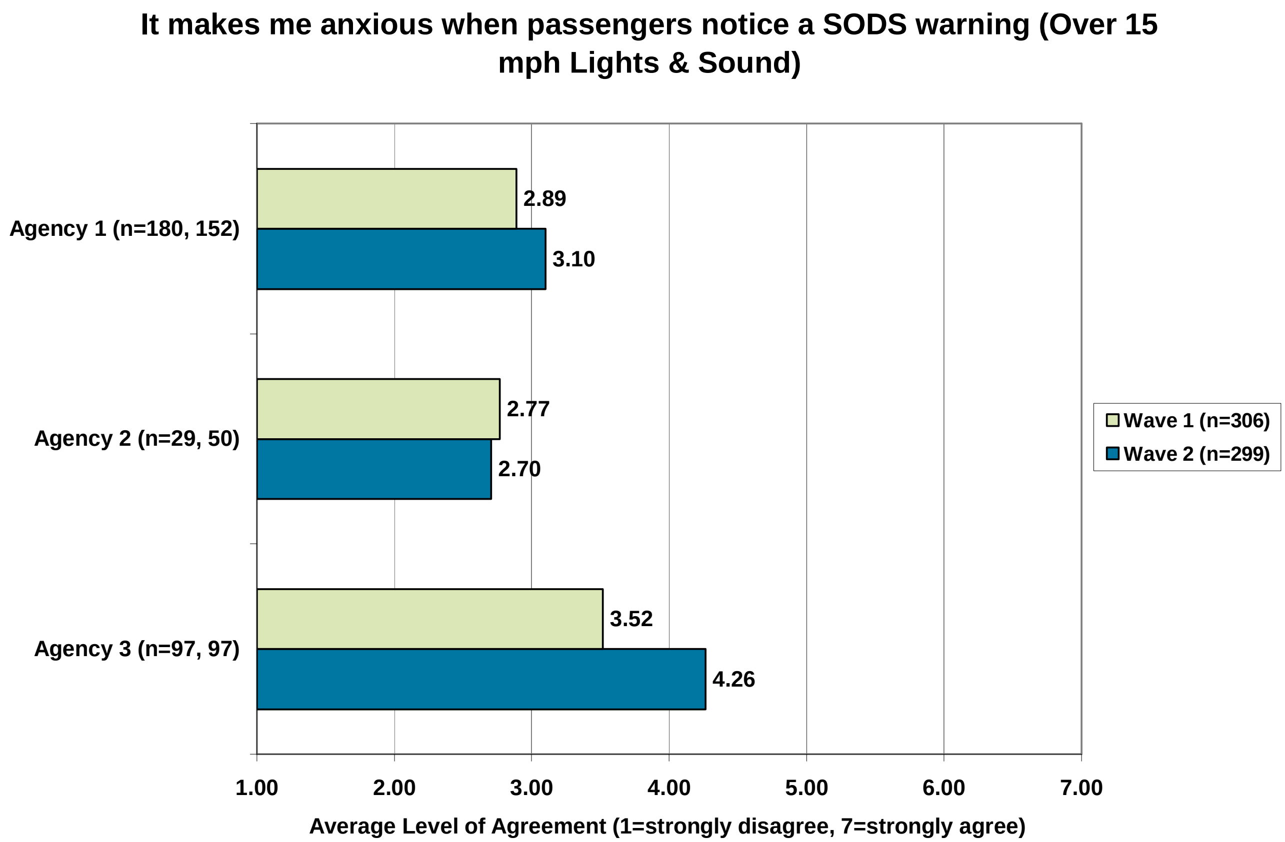
[96] Kendall's tau-c = .162, p = .039
[97] Agency 1 – Kendall's tau-c = .210, p = .003; Agency 2 – Kendall's tau-c = .234, p = .022



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 2)

Significant differences over time:

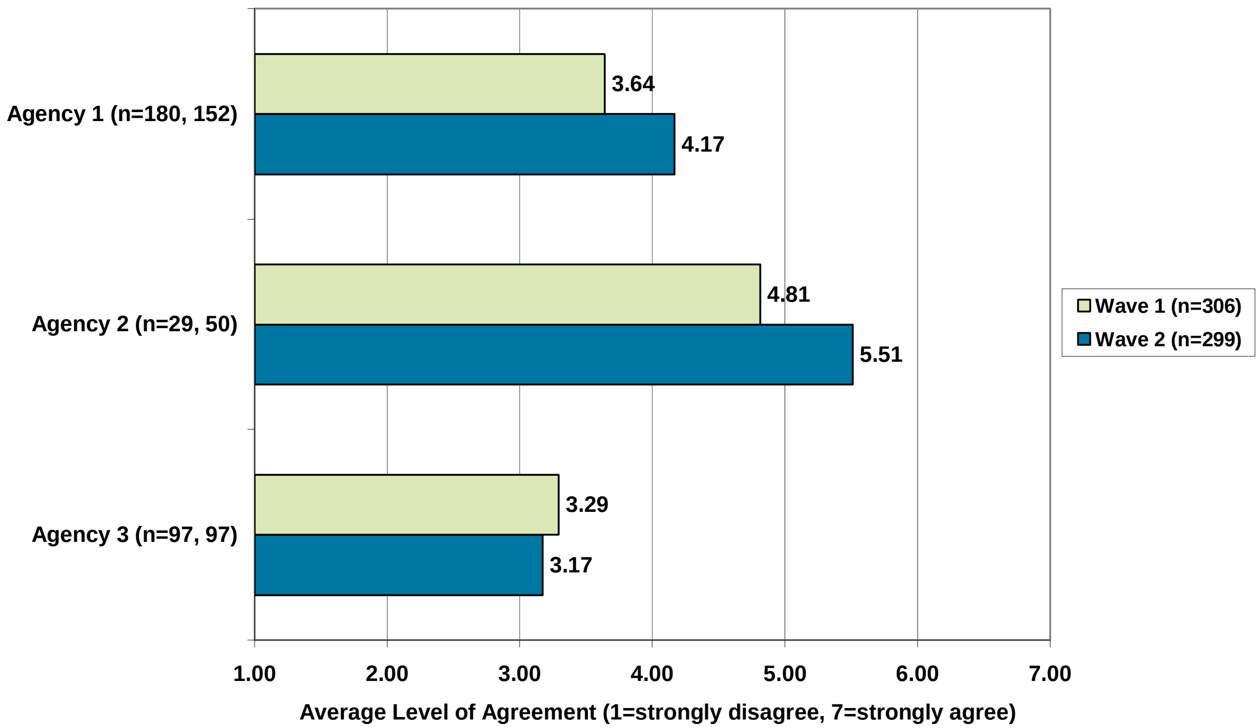
- Agency 3 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 2, Agencies 1 & 2)[98]

[98] Agency 1 – Kendall's tau-c = .224, p = .003; Agency 2 – Kendall's tau-c = .259, p = .015

The information, introduction and/or training I received prepared me very well for using SODS



Significant differences by agency:

- Agency 2 was more likely to agree than Agency 1 and Agency 3 (Wave 1)
- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 2)
- Agency 2 was more likely to agree than Agency 1 (Wave 2)

Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- None

Operator Suggestions of Things That Could be Done to Increase Acceptance of SODS Among Operators

	Agency 1		Agency 2		Agency 3	
	Wave 1	Wave 2	Wave 1	Wave 2	Wave 1	Wave 2
Change sound /disable sound/ lower volume	51.7	20.6	33.3	29.6	23.9	29.6
Modify training /demo/information	15.7	33.3	50.0	22.2	34.8	7.4
Calibrate/false alarms /sensitivity/accuracy	37.1	30.2	44.4	7.4	32.6	46.3
Change/modify lights / lights only	11.2	12.7		29.6	6.5	16.7
Switch to turn off/on	4.5	3.2			6.5	5.6
Improve mirrors	2.2					
Remove it	12.4	7.9	11.1	14.8	6.5	24.1
Better understanding of SODS		4.8				
Make mandatory		6.3		11.1		
Add camera		1.6				1.9
Backing up		1.6				1.9
Other	12.4	14.3	16.7		26.1	13.0
DNK / nothing / N/A	7.9	9.5	11.1	11.1	13.0	3.7

Top 3 ways to improve acceptance:

1. Alter the warning alarm by changing the sound, disabling the sound, or lowering volume.
2. Decrease false alarms by altering sensor sensitivity/accuracy.
3. Modify the lights or have lights only (no warning alarm).

Differences over time:

- Agency 3 showed a large increase from Wave 1 to Wave 2 in the percent of operators recommending that SODS be removed (7 percent to 24 percent).

Differences by demographics:

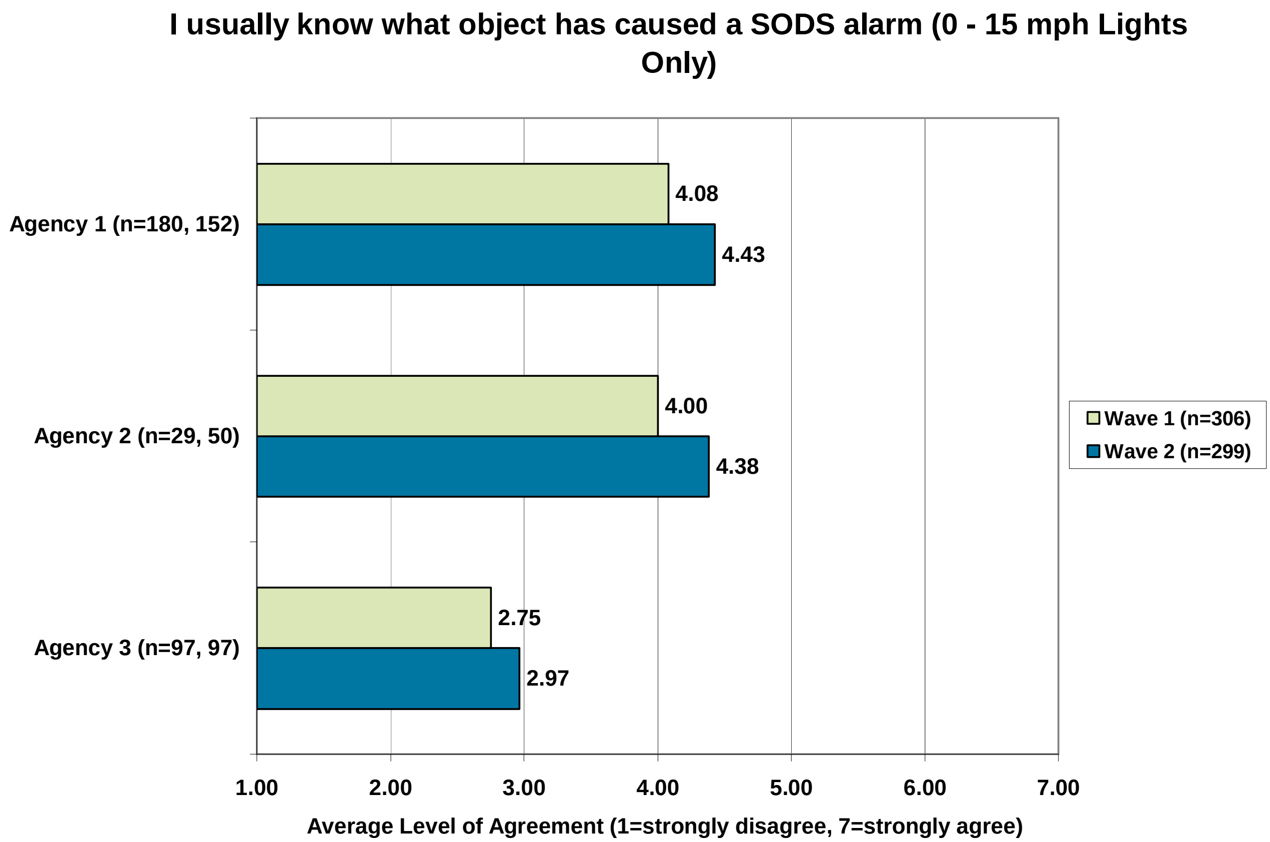
- Males (14 percent) were more likely than females (9 percent) to suggest removing SODS.
- Females (44 percent) were more likely than males (30 percent) to want to change the sound, disable the sound, or lower the volume.

- Females (20 percent) were more likely than males (11 percent) to want to change or modify the lights or to have lights only.

Determine effect of system on operator performance and *alarm handling*

Medium disagreement (for both speed categories) with knowing what object has caused the alarm, except for Agency 3 which disagreed more. Agency 1 operators with less experience were more likely to agree (Wave 2).

- Medium disagreement (for both speed categories) that they know when to make a correction, except for Agency 3 which strongly disagreed. Agency 2 operators with more years of experience were more likely to agree (Wave 2).
- Medium agreement (for both speed categories) that there are too many warnings to make sense of them all. Strong agreement that there are too many warnings among Agency 3 operators. Agency 1 & 3 older operators were more likely to agree than younger operators (Wave 1).
- Medium disagreement (for both speed categories) that SODS reduces accidents, except for Agency 3 which strongly disagreed. Older Agency 2 operators or those with more experience are more likely to agree (Wave 2).
- Medium disagreement (for both speed categories) that SODS helps detect objects otherwise not seen, except for Agency 3 which strongly disagreed. For the 0-15 mph speed category, Agency 1 males were less likely to agree than females (Wave 1). Agency 2 older operators were more likely to agree than younger operators (Waves 1 & 2). For the 0-15 mph speed category, Agency 1 increased agreement from Wave 1 to Wave 2.
- Medium disagreement that SODS makes them safer operators, except for Agency 3 which strongly disagreed. Agency 3 operators with less years of experience were more likely to agree SODS makes them a safer operator (Waves 1 & 2). Agency 1 increased agreement from Wave 1 to Wave 2.



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

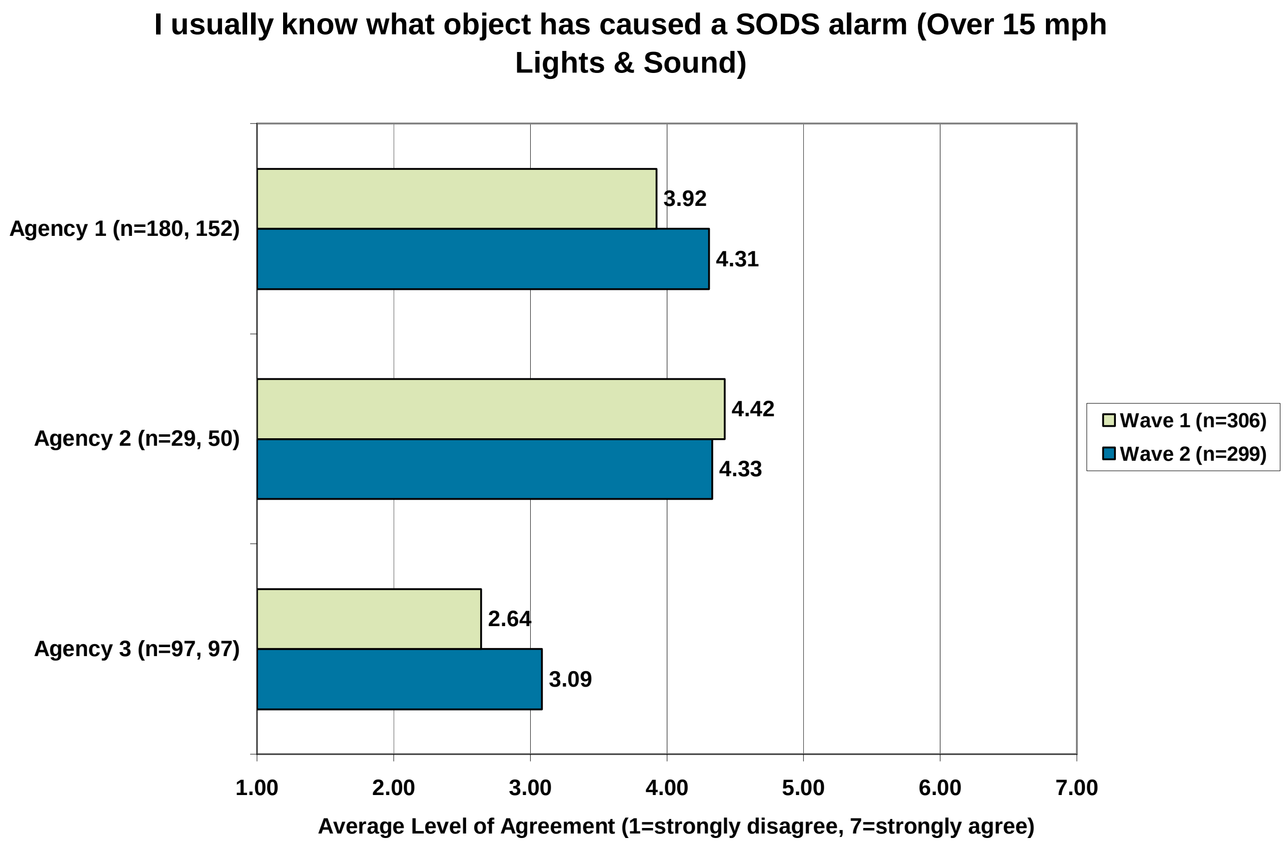
Significant differences over time:

- None

Significant differences by demographics

- Operators with less years of experience are more likely to agree (Wave 2, Agency 1)[99]

[99] Kendall's tau-c = -.129, p = .049



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 1, Agency 1)[100]
- Operators with less years of experience are more likely to agree (Wave 2, Agency 1)[101]

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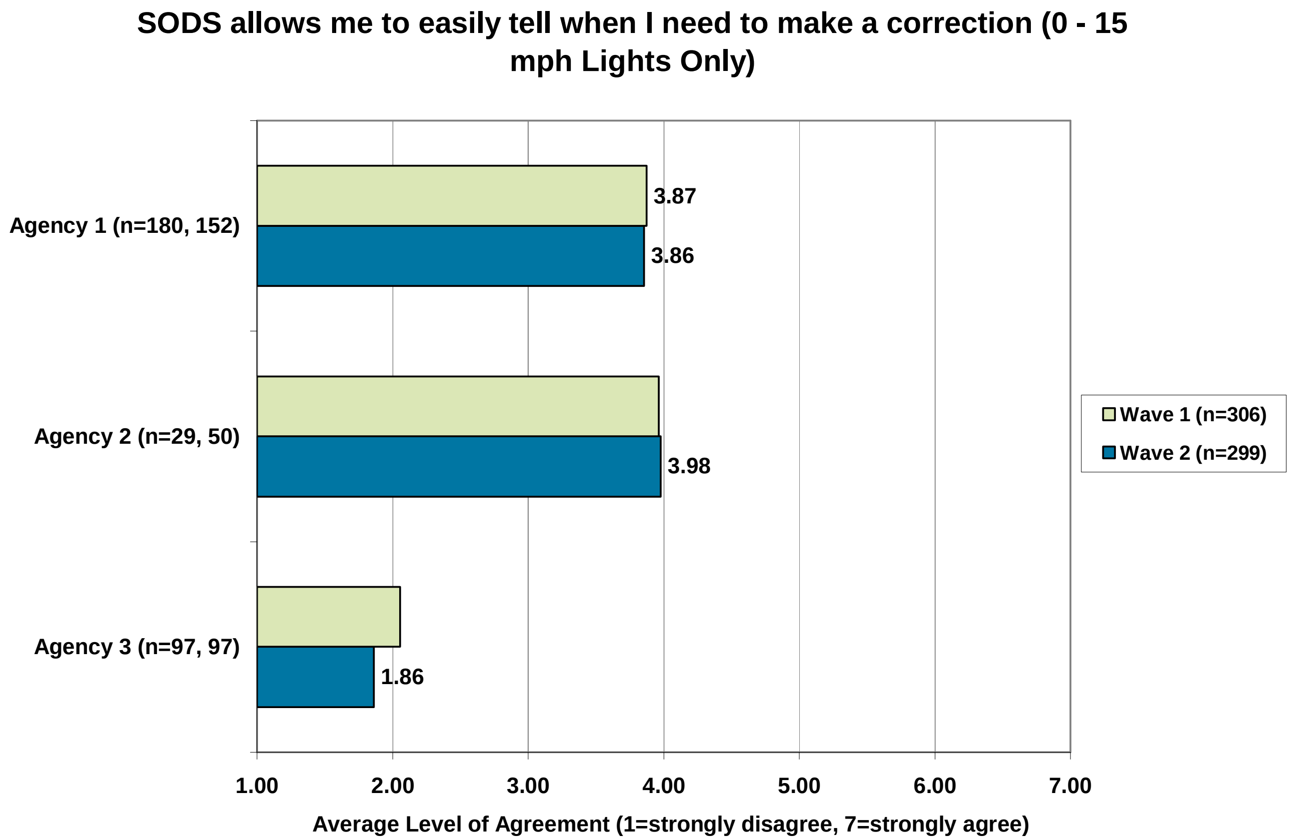
[100] Kendall's tau-c = .123, p = .023
[101] Kendall's tau-c = -.148, p = .024



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

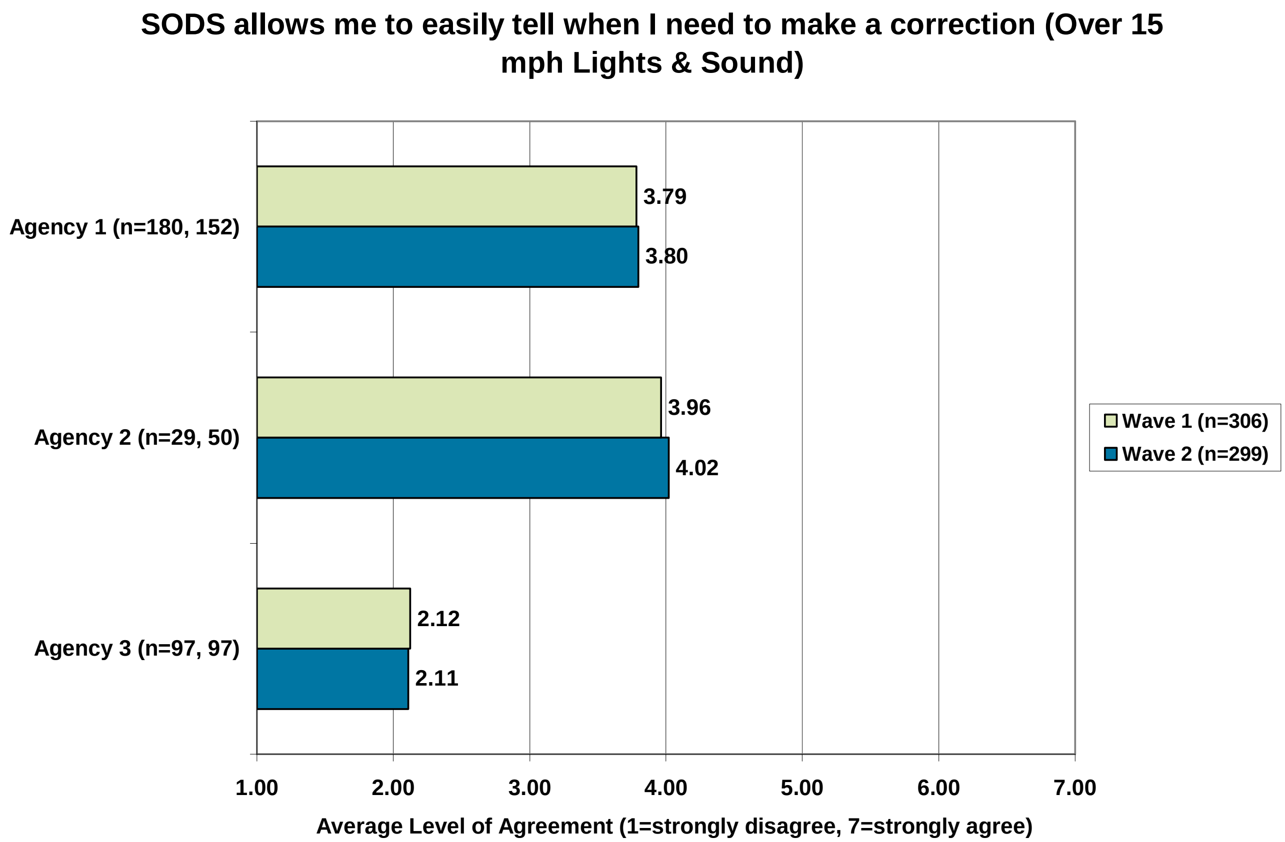
Significant differences over time:

- None

Significant differences by demographics:

- Operators with more years of experience are more likely to agree (Wave 2, Agency 2)[102]

[102] Kendall's tau-c = .681, p = .045



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

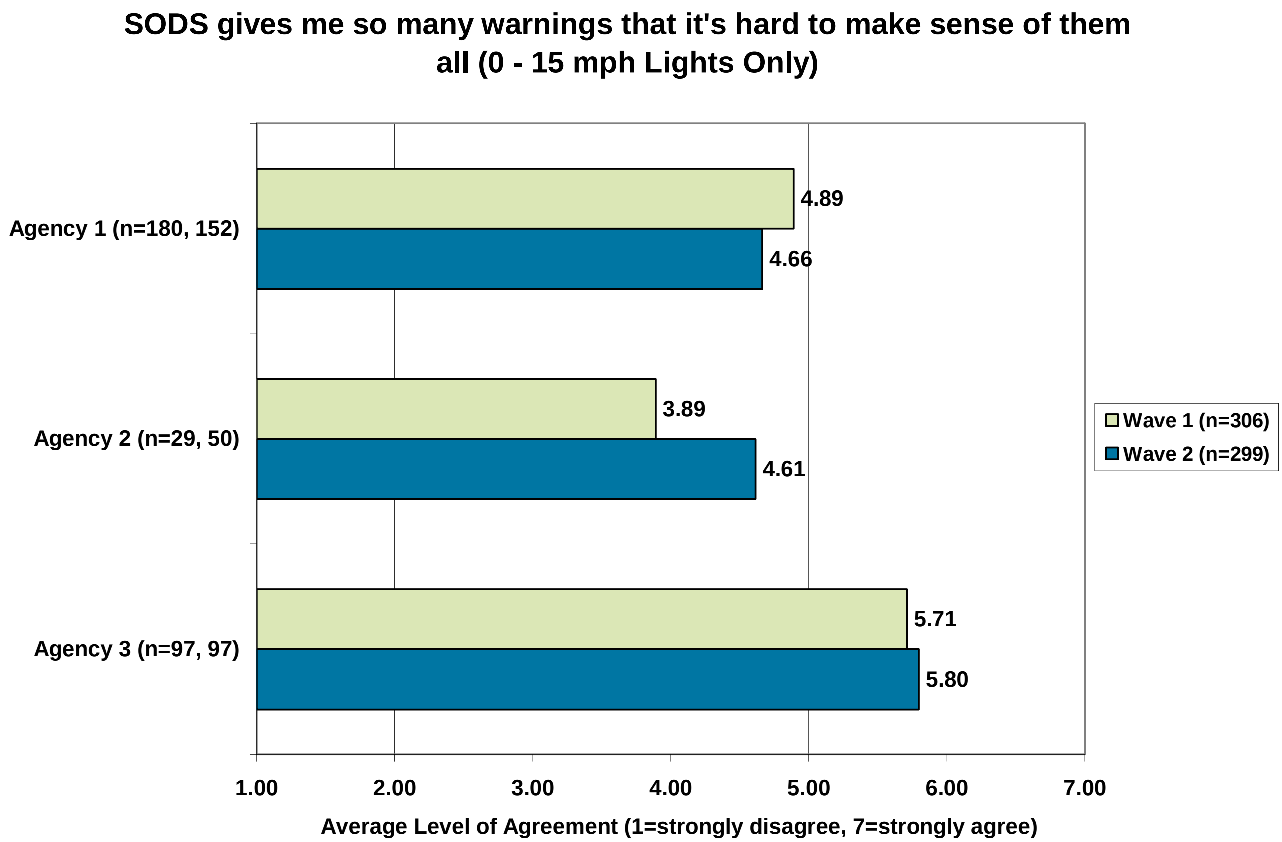
Significant differences over time:

- None

Significant differences by demographics:

- Females are more likely to agree (Wave 1, Agency 1)[103]

[103] Cramer's V = .336, p = .022



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1, Wave 2)

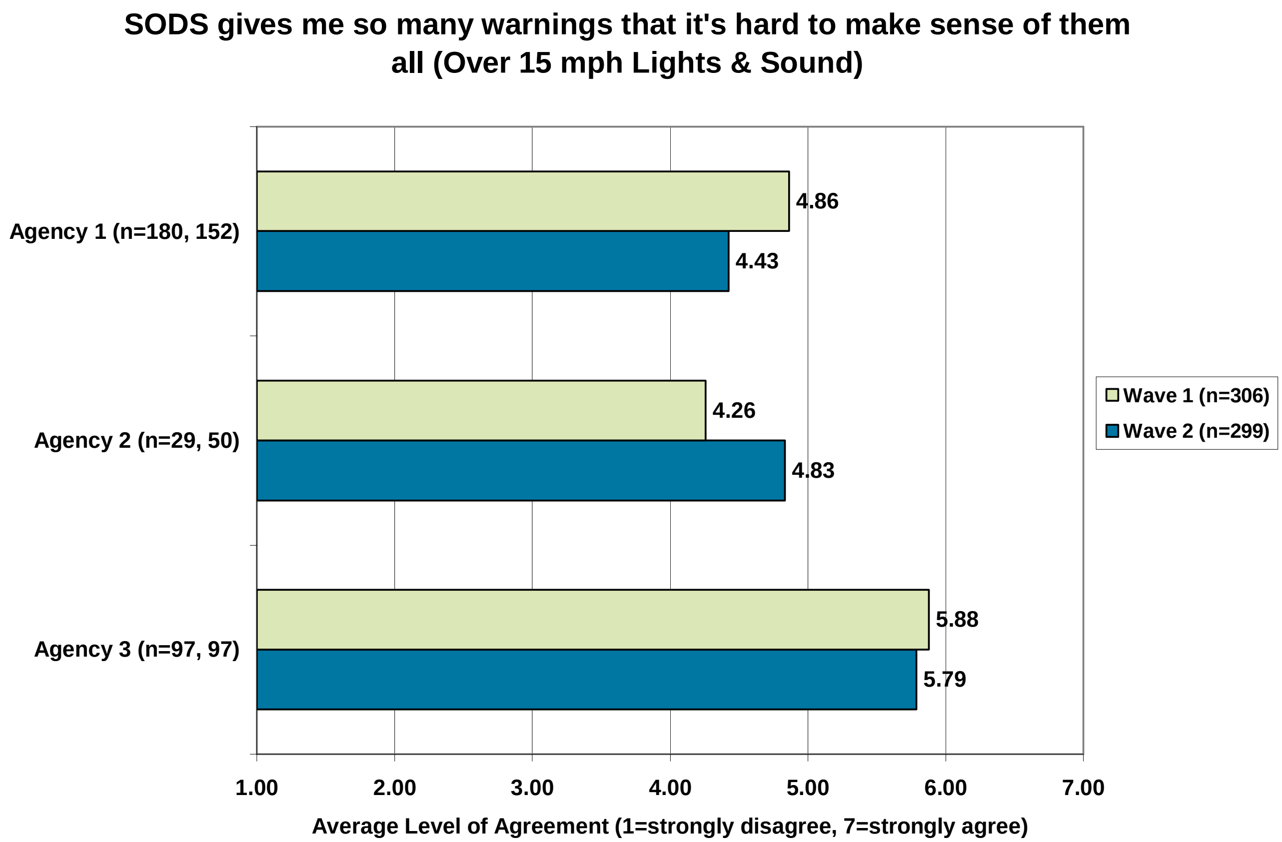
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 1, Agencies 1 & 3)[104]

[104] Agency 1 – Kendall's tau-c = .132, p = .024; Agency 3 – Kendall's tau-c = .154, p = .040



Significant differences by agency:

- Agency 1 and Agency 2 were less likely to agree than Agency 3 (Wave 1, Wave 2)

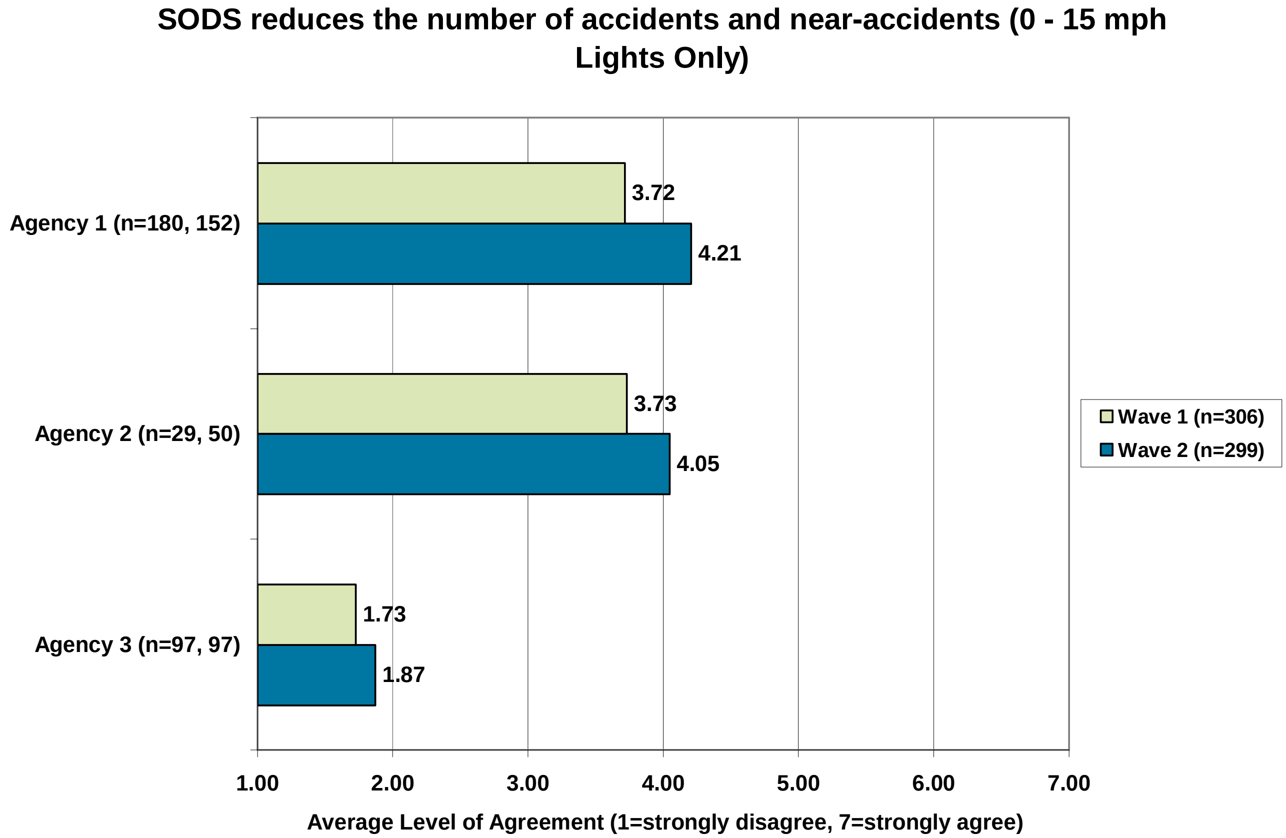
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 1, Agency 3)[105]

[105] Kendall's tau-c = .147, p = .046



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[106]
- Operators with more years of experience are more likely to agree (Wave 2, Agency 2)[107]

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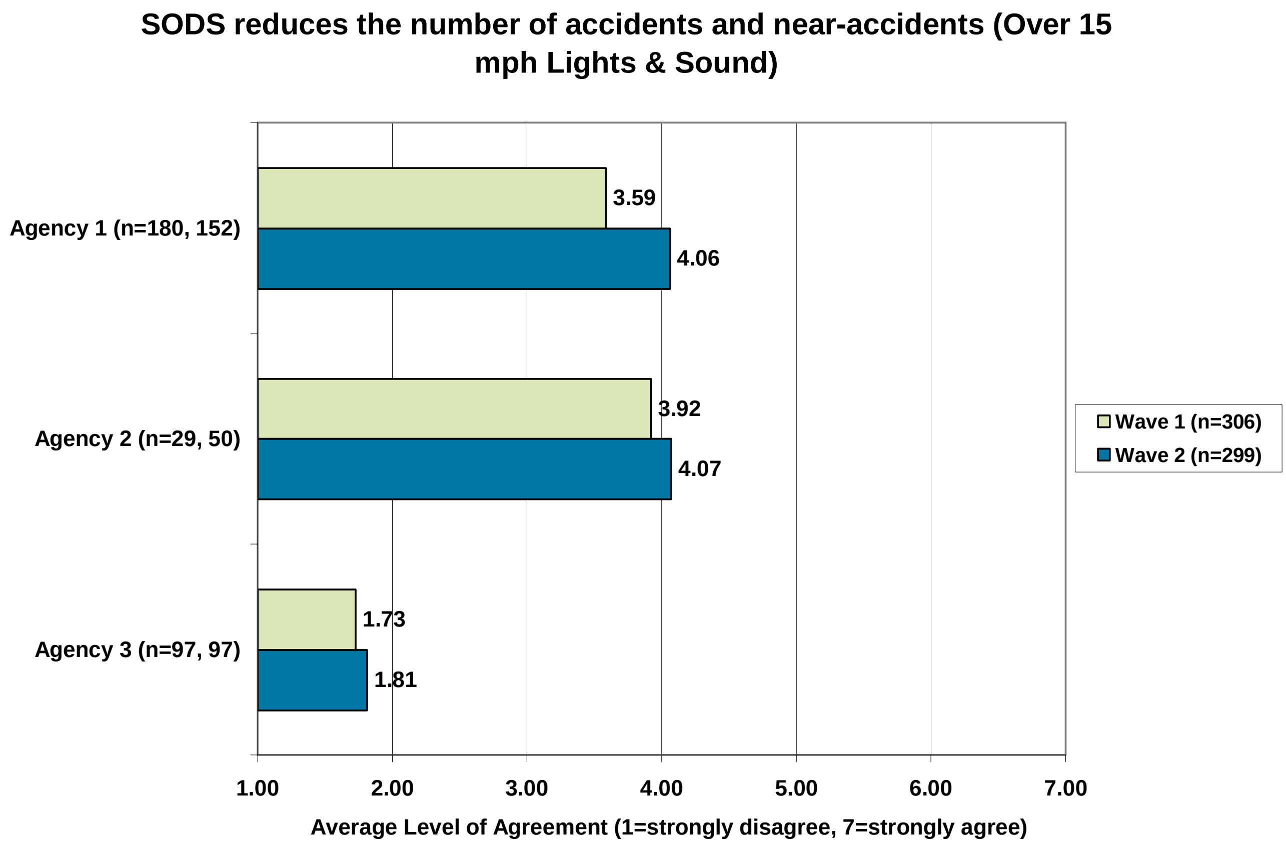
[106] Kendall's tau-c = .263, p = .002
[107] Kendall's tau-c = .228, p = .044



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

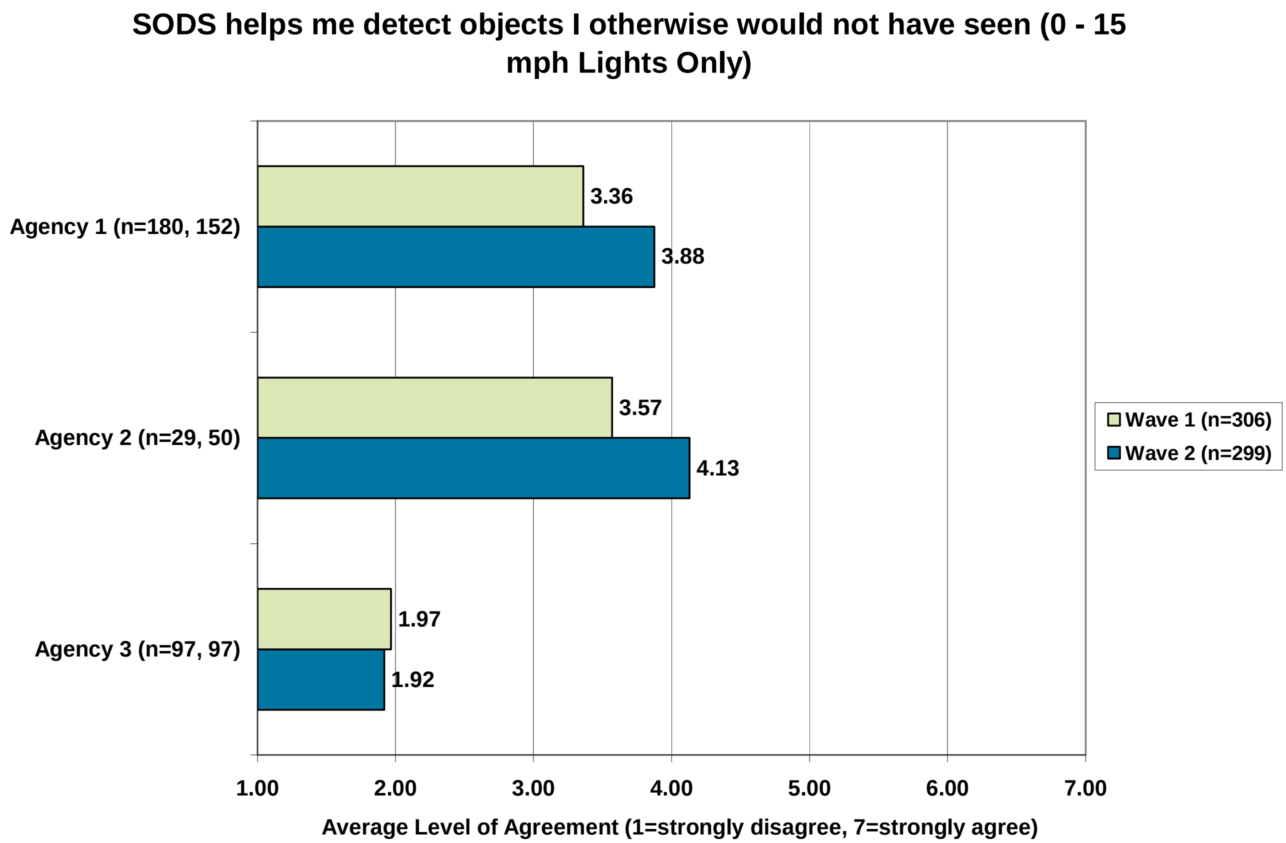
Significant differences over time:

- None

Significant differences by demographics:

- Older operators are more likely to agree (Wave 2, Agency 2)[108]

[108] Kendall's tau-c = .207, p = .026



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

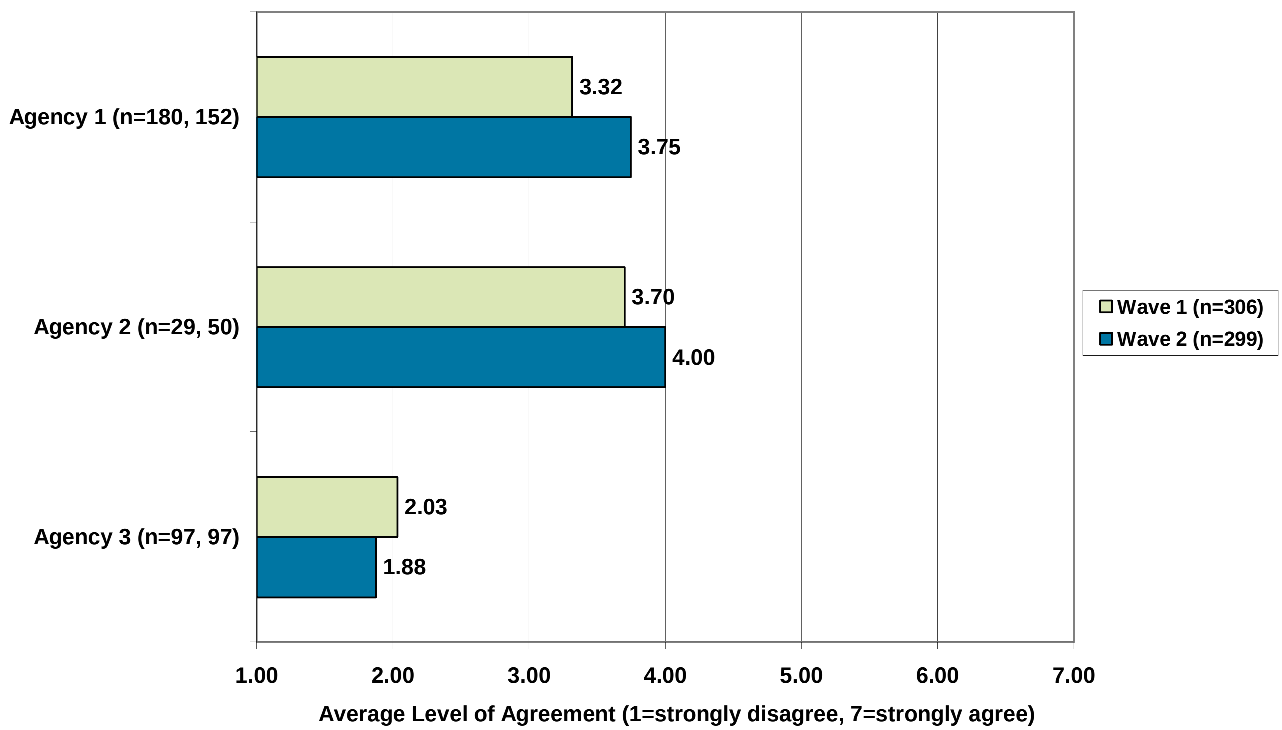
- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Older operators are more likely to agree (Waves 1 & 2, Agency 2)[109]

[109] Wave 1 – Kendall's tau-c = .270, p = .051; Wave 2 – Kendall's tau-c = .316, p = .003

SODS helps me detect objects I otherwise would not have seen (Over 15 mph Lights & Sound)



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

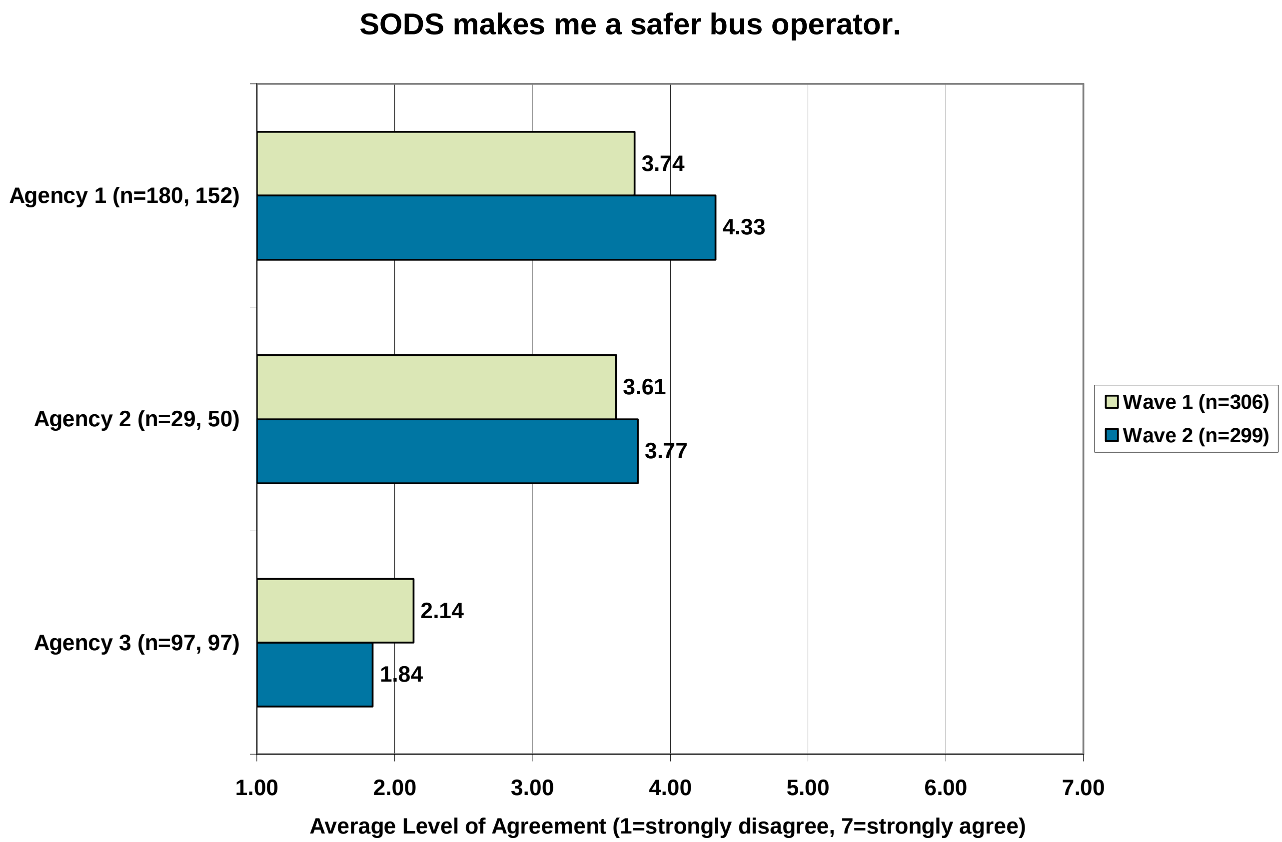
Significant differences over time:

- None

Significant differences by demographics:

- Males are more likely to agree (Wave 1, Agency 1)[110]
- Older operators are more likely to agree (Wave 2, Agency 2)[111]

110 Cramer's V = .308, p = .046
111 Kendall's tau-c = .328, p = .002



Significant differences by agency:

- Agency 1 and Agency 2 were more likely to agree than Agency 3 (Wave 1, Wave 2)

Significant differences over time:

- Agency 1 showed a significant increase in agreement from Wave 1 to Wave 2

Significant differences by demographics:

- Operators with less years of experience are more likely to agree (Wave 1, Agencies 1 & 3)[112]
- Younger operators are more likely to agree (Wave 2, Agency 3)[113]

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[112] Agency 1 – Kendall's tau-c = .-148, p = .019; Agency 3 – Kendall's tau-c = -.186, p = .009
[113] Kendall's tau-c = -.158, p = .043

Has Sods Ever Helped to Avoid a Collision?

Each of the following three agency-specific charts reports on the ways in which SODS has or has not helped operators avoid a collision. Because this was a survey question in which more than one answer was acceptable, the percentages do not necessarily add up to 100.

Significant differences over time:

- Agency 1 showed a decrease in reporting that SODS has never helped them avoid a collision from 61percent to 48percent, indicating that SODS helped to avoid collisions during the time that lapsed between the first and second wave of the survey.[114]
- Specifically Agency 1 showed an increase in reporting that SODS helped:
  - Avoid hitting a vehicle while changing lanes (27 to 43 percent).[115]
  - Avoid hitting a fixed object when making a turn (18 to 35 percent).[116]
  - Avoid hitting a fixed object when driving straight (18 to 32 percent).[117]
- Agency 3 showed a decrease in reporting that SODS helped to avoid hitting a fixed object while pulling in or out of a stop (10 to 3 percent).[118]

Significant differences by agency:

- Agency 3 had the lowest percentage of operators (approximately 20) reporting that SODS has helped them to avoid a collision, while Agencies 1 and 2 had higher percentages of operators (approximately 53 percent for Agency 1, and approximately 39 percent for Agency 2) reporting that SODS has helped them avoid a collision.[119,120]
- Operators at Agency 3 reported that SODS has helped to avoid:
  - Hitting a vehicle while changing lanes (Wave 1 [11 percent][121] & Wave 2 [8 percent][122]).
  - Hitting a fixed object while pulling in or out of a stop (Wave1 [10 percent][123] & Wave 2 [3 percent][124]).
  - Hitting a fixed object while making a turn (Wave 1 [8 percent][125] & Wave 2 [3 percent][126]).

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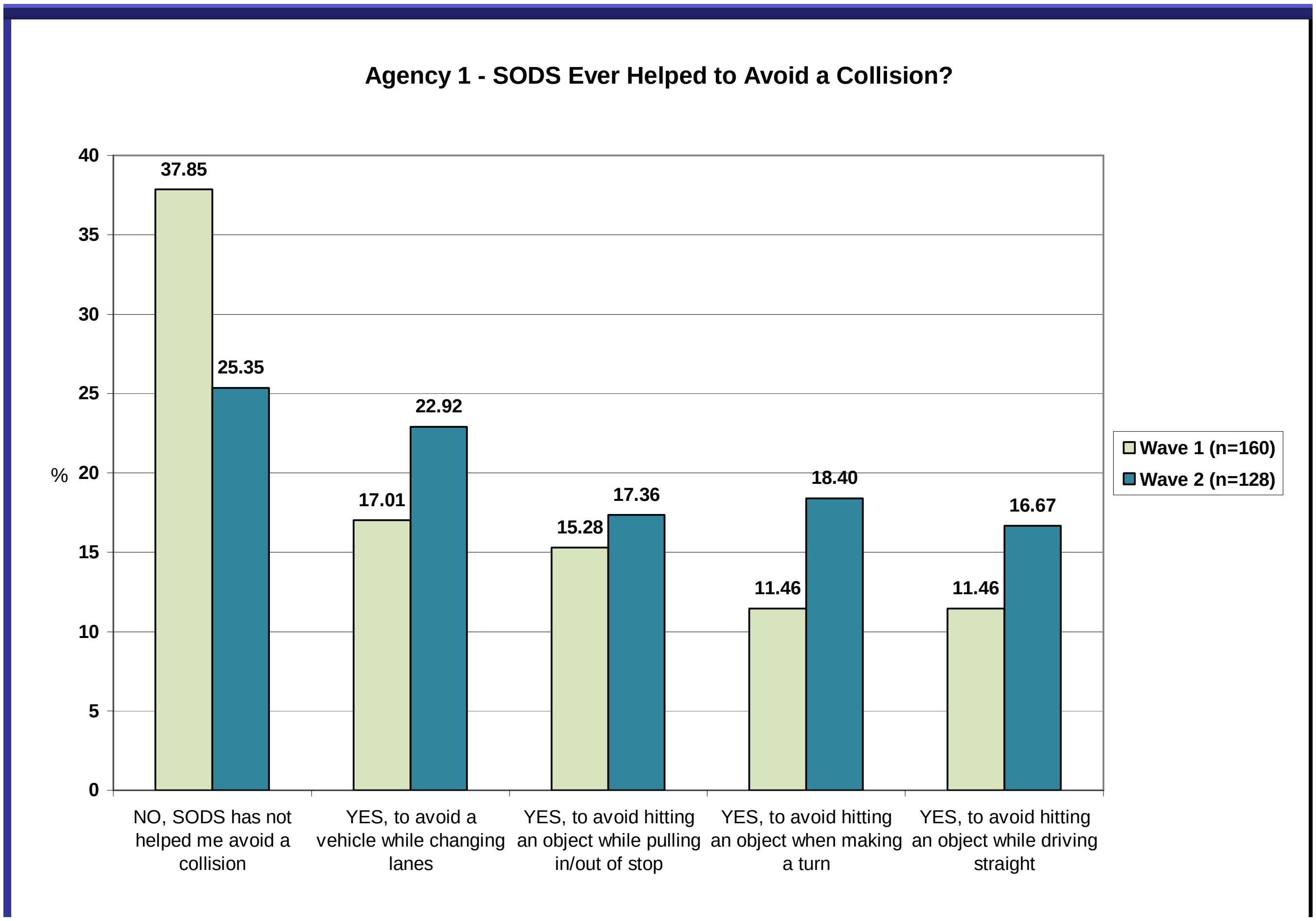
114 Cramer's V = .125, p = .022
115 Cramer's V = .170, p = .002
116 Cramer's V = .188, p = .001
117 Cramer's V = .154, p = .005
118 Cramer's V = .144, p = .044
119 Cramer's V = .207, p = .001
120 Cramer's V = .305, p = .000
121 Cramer's V = .232, p = .000
122 Cramer's V = .345, p = .000
123 Cramer's V = .179, p = .007
124 Cramer's V =.329, p = .000
125 Cramer's V = .161, p = .019
126 Cramer's V = .338, p = .000

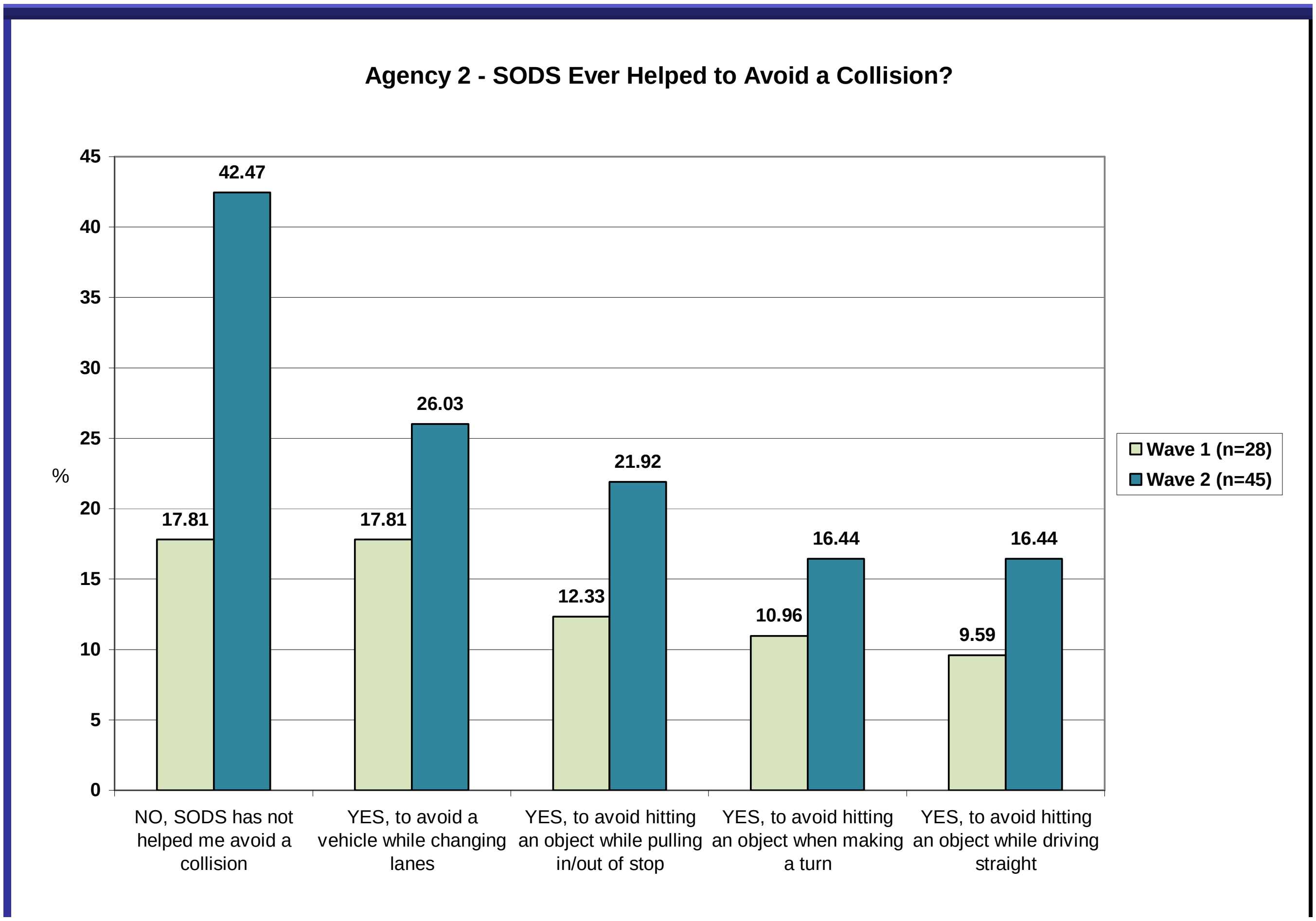
- Hitting a fixed object while driving straight (Wave 1 [5 percent][127] & Wave 2 [3 percent][128]).

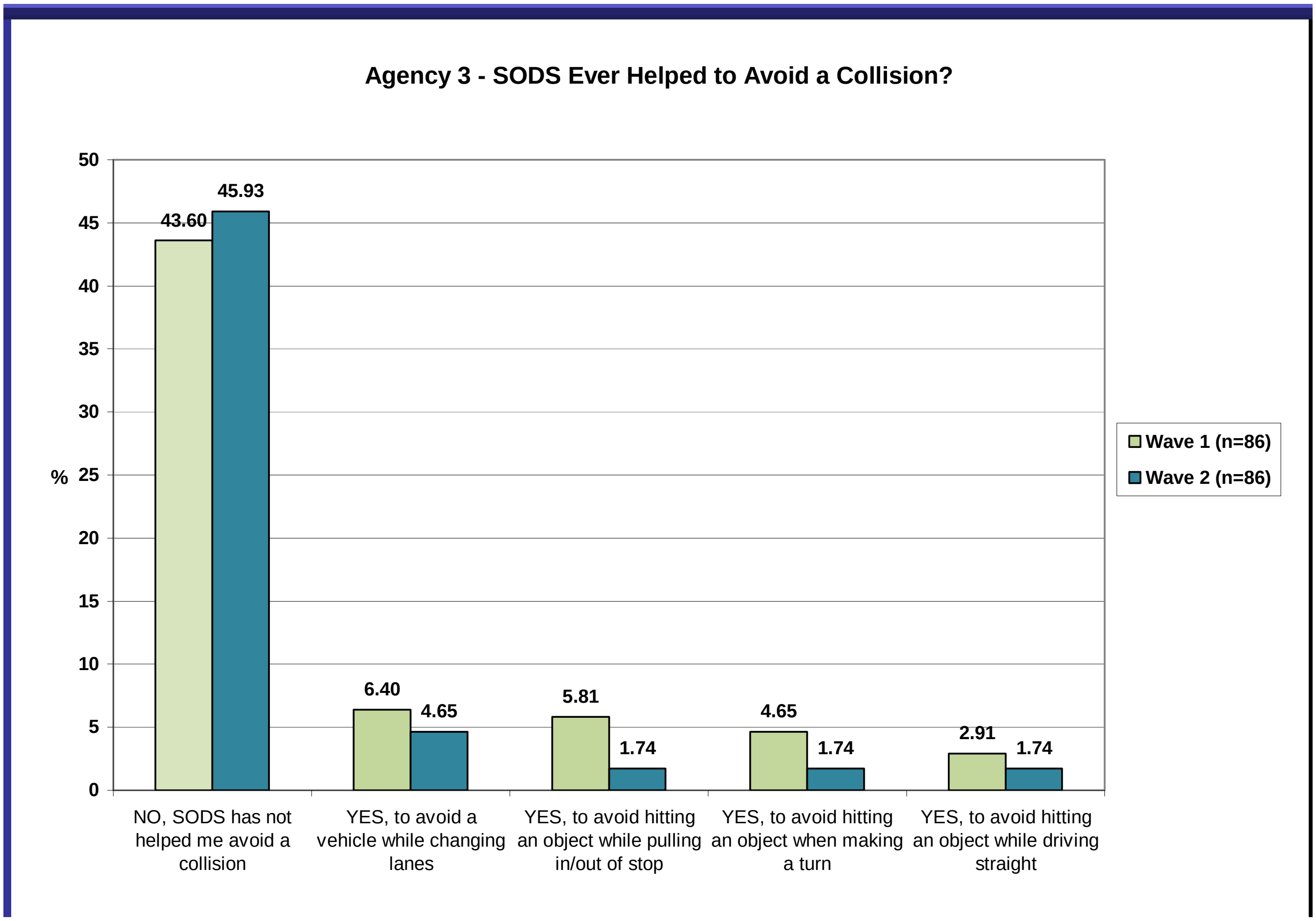
Significant differences by demographics:

- Female operators were more likely than males (67 percent versus 29 percent) to think SODS has helped to avoid a vehicle when changing lanes (Wave 1, Agency 2)[129]
- Female operators were more likely than males (42 percent versus 7 percent) to report that SODS has helped them avoid hitting a fixed object when driving straight (Wave 1, Agency 2)[130]

[127] Cramer's V = .190, p = .004
[128] Cramer's V = .313, p = .000
[129] Cramer's V = .381, p = .052
[130] Cramer's V = .408, p = .037


Agency 1 - SODS Ever Helped to Avoid a Collision?
%
40
35
30
25
20
15
10
5
0
37.85
25.35
17.01
22.92
15.28
17.36
11.46
18.40
11.46
16.67
NO, SODS has not helped me avoid a collision
YES, to avoid a vehicle while changing lanes
YES, to avoid hitting an object while pulling in/out of stop
YES, to avoid hitting an object when making a turn
YES, to avoid hitting an object while driving straight
Wave 1 (n=160)
Wave 2 (n=128)


Agency 2 - SODS Ever Helped to Avoid a Collision?
45
40
35
30
25
20
15
10
5
0
%
42.47
26.03
21.92
17.81
17.81
16.44
16.44
12.33
10.96
9.59
NO, SODS has not helped me avoid a collision
YES, to avoid a vehicle while changing lanes
YES, to avoid hitting an object while pulling in/out of stop
YES, to avoid hitting an object when making a turn
YES, to avoid hitting an object while driving straight
Wave 1 (n=28)
Wave 2 (n=45)


Agency 3 - SODS Ever Helped to Avoid a Collision?
%
50
45
40
35
30
25
20
15
10
5
0
43.60
45.93
6.40
4.65
5.81
1.74
4.65
1.74
2.91
1.74
NO, SODS has not helped me avoid a collision
YES, to avoid a vehicle while changing lanes
YES, to avoid hitting an object while pulling in/out of stop
YES, to avoid hitting an object when making a turn
YES, to avoid hitting an object while driving straight
Wave 1 (n=86)
Wave 2 (n=86)

When is SODS Most Useful?

Each of the following three agency-specific charts reports on when SODS is most useful to operators. Because this was a survey question in which more than one answer was acceptable, the percentages do not necessarily add up to 100.

Significant differences over time:

- Agency 3 showed a decrease in reporting that SODS is most helpful when:
  - Making right turns (10 percent to 3 percent)[131]
  - In a construction zone (13 percent to 3 percent)[132]
  - In heavy traffic (12 percent to 4 percent)[133]
- Agency 1 showed an increase in reporting that SODS is most useful when:
  - Operating on narrower streets (36 percent to 49 percent)[134]
  - Operating in construction zones (32 percent to 45 percent)[135]
  - Operating in heavy traffic (28 percent to 50 percent)[136]

Significant differences by agency:

- Agency 3 (10 percent) was least likely to report that SODS is most useful when making right turns, while Agency 1 (32 percent) and Agency 2 (28 percent) were more likely to report that it is most useful when making right turns (Wave 1).[137]
- Agency 3 (5 percent) was least likely to report that SODS is most useful when making right turns, while Agency 1 (41 percent) and Agency 2 (48 percent) were more likely to report that it is most useful when making right turns (Wave 2).[138]
- Agency 3 (10 percent) was least likely to report that SODS is most useful when making left turns; while Agency 1 (26 percent) and Agency 2 (31 percent) were more likely to report that it is most useful when making left turns (Wave 1).[139]
- Agency 3 (3 percent) was least likely to report that SODS is most useful when making left turns; while Agency 1 (34 percent) and Agency 2 (40 percent) were more likely to report that it is most useful when making left turns (Wave 2).[140]
- Agency 3 (20 percent) was least likely to report that SODS is most useful when changing lanes; while Agency 1 (41 percent) and Agency 2 (52 percent) were more likely to report that it is most useful when chaining lanes (Wave 1).[141]

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[131] Cramer's V = .144, p = .044
[132] Cramer's V = .187, p = .009
[133] Cramer's V = .150, p = .037
[134] Cramer's V = .139, p = .011
[135] Cramer's V = .134, p = .014
[136] Cramer's V = .222, p = .000
[137] Cramer's V = .215, p = .001
[138] Cramer's V = .385, p = .000
[139] Cramer's V = .186, p = .005
[140] Cramer's V = .352, p = .000

- Agency 3 (11 percent) was least likely to report that SODS is most useful when changing lanes; while Agency 1 (50 percent) and Agency 2 (62 percent) were more likely to report that it is most useful when changing lanes (Wave 2).[142]
- Agency 3 (13percent) is least likely to report that SODS is most useful when operating in dark or poorly lit areas; while Agency 1 (39 percent) and Agency 2 (31 percent) are more likely to report that it is most useful when operating in dark or poorly lit areas (Wave 1).[143]
- Agency 3 (7 percent) is least likely to report that SODS is most useful when operating in dark or poorly lit areas; while Agency 1 (49 percent) and Agency 2 (52 percent) are more likely to report that it is most useful when operating in dark or poorly lit areas (Wave 2).[144]
- Agency 3 (13 percent) is least likely to report that SODS is most useful when operating in construction zones; while Agency 1 (32 percent) and Agency 2 (24 percent) are more likely to report that it is most useful when operating in construction zones (Wave 1).[145]
- Agency 3 (3 percent) is least likely to report that SODS is most useful when operating in construction zones; while Agency 1 (45 percent) and Agency 2 (36 percent) are more likely to report that it is most useful when operating in construction zones (Wave 2).[146]
- Agency 3 (12 percent) is least likely to report that SODS is most useful when operating in heavy traffic; while Agency 1 (28 percent) and Agency 2 (49 percent) are more likely to report that it is most useful when operating in heavy traffic (Wave 1).[147]
- Agency 3 (4 percent) is least likely to report that SODS is most useful when operating in heavy traffic; while Agency 1 (50 percent) and Agency 2 (42 percent) are more likely to report that it is most useful when operating in heavy traffic (Wave 2).[148]

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[141] Cramer's V = .233, p = .000

[142] Cramer's V = .408, p = .000

[143] Cramer's V = .252, p = .000

[144] Cramer's V = .417, p = .000

[145] Cramer's V = .191, p = .004

[146] Cramer's V = .410, p = .000

[147] Cramer's V = .225, p = .000

[148] Cramer's V = .439, p = .000

- Agency 3 (5 percent) is least likely to report that SODS is most useful when operating in slow traffic; while Agency 1 (17 percent) and Agency 2 (10 percent) are more likely to report that it is most useful when operating in slow traffic (Wave 1).[149]
- Agency 3 (3 percent) is least likely to report that SODS is most useful when operating in slow traffic; while Agency 1 (24 percent) and Agency 2 (26 percent) are more likely to report that it is most useful when operating in slow traffic (Wave 2).[150]
- Agency 3 (18 percent) is least likely to report that SODS is most useful when operating in fast traffic; while Agency 1 (36 percent) and Agency 2 (34 percent) are more likely to report that it is most useful when operating in fast traffic (Wave 2).[151]

Significant differences by demographics:

- Females are more likely to think SODS most useful when:
  - Making left turns (Wave 1, Agency 2, Females 50 percent, Males14 percent)[152]
  - Changing lanes (Wave 1, Agency 2, Females 75 percent, Males 36 percent)[153]
  - Operating on narrower streets (Wave 1, Agency 2, Females 83 percent, Males 14 percent)[154]
  - Operating in construction zones (Wave 1, Agency 1, Females 45 percent, Males 28 percent[155] & Agency 2, Females 42 percent, Males 7 percent[156])
  - Operating in heavy traffic (Wave 1, Agency 2, Females 67 percent, Males 29 percent)[157]
  - Operating in slow traffic (Wave 1, Agency 2, Females 25 percent, Males 0 percent)[158]
  - Operating in fast traffic (Wave 1, Agency 2, Females 50 percent, Males 14 percent)[159]
- Males (43 percent) are more likely than females (22 percent) to think SODS most useful when operating in fast traffic (Wave 2, Agency 1)[160]

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[149] Cramer's V = .168, p = .015

[150] Cramer's V = .266, p = .000

[151] Cramer's V = .181, p = .007

[152] Cramer's V = .386, p = .049

[153] Cramer's V = .393, p = .045

[154] Cramer's V = .690, p = .000

[155] Cramer's V = .167, p = .038

[156] Cramer's V = .408, p = .037

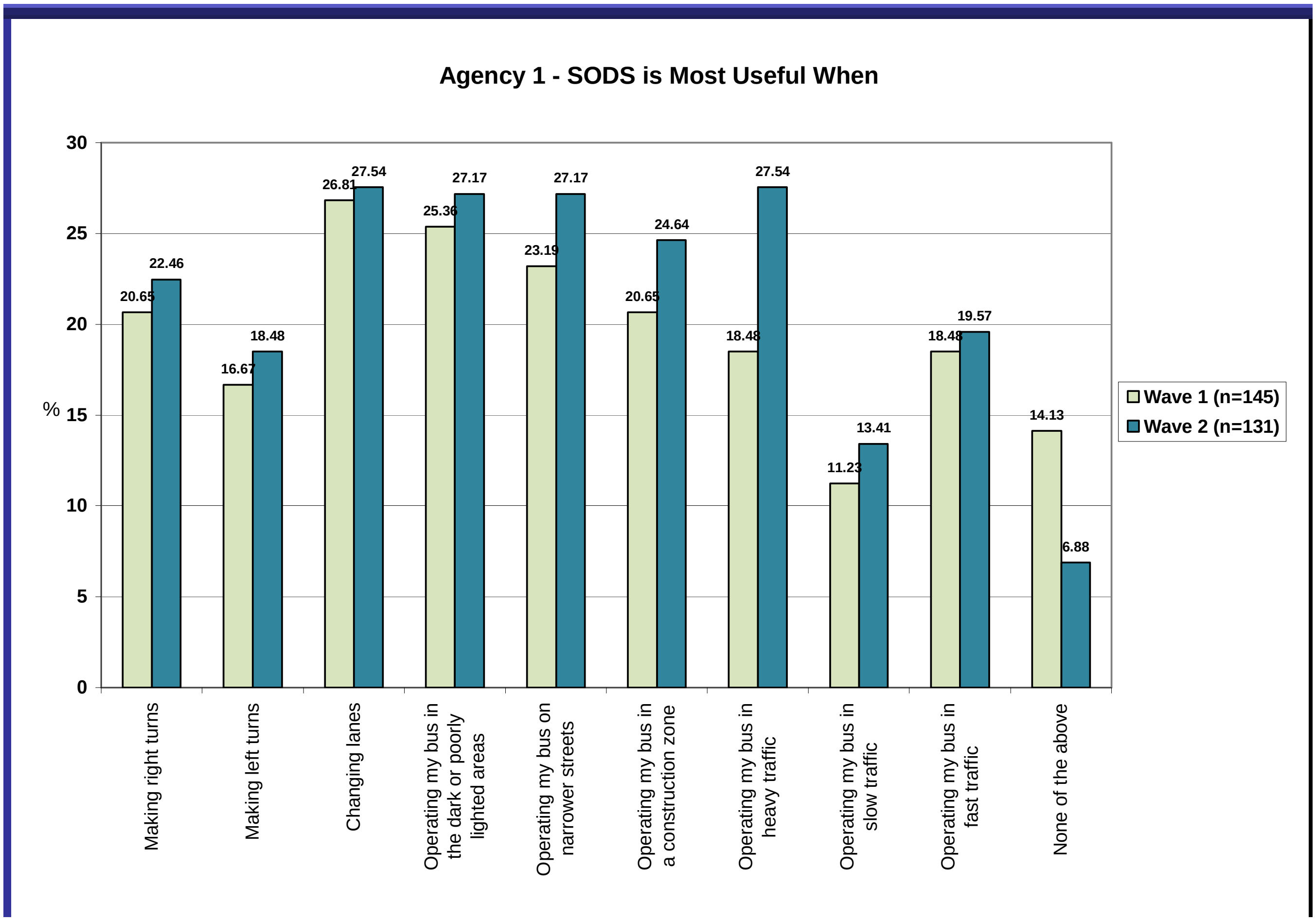
[157] Cramer's V = .381, p = .052

[158] Cramer's V = .390, p = .047

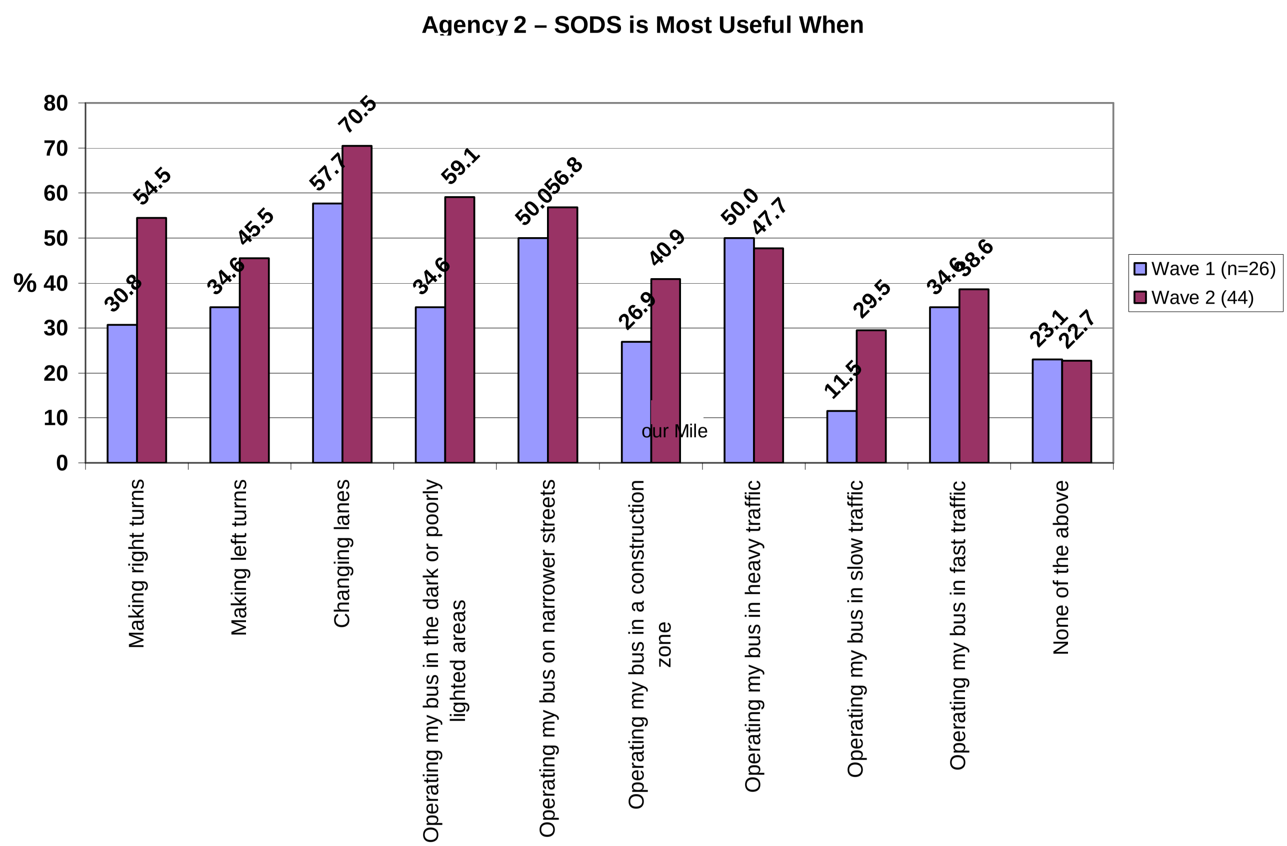
[159] Cramer's V = .386, p = .049

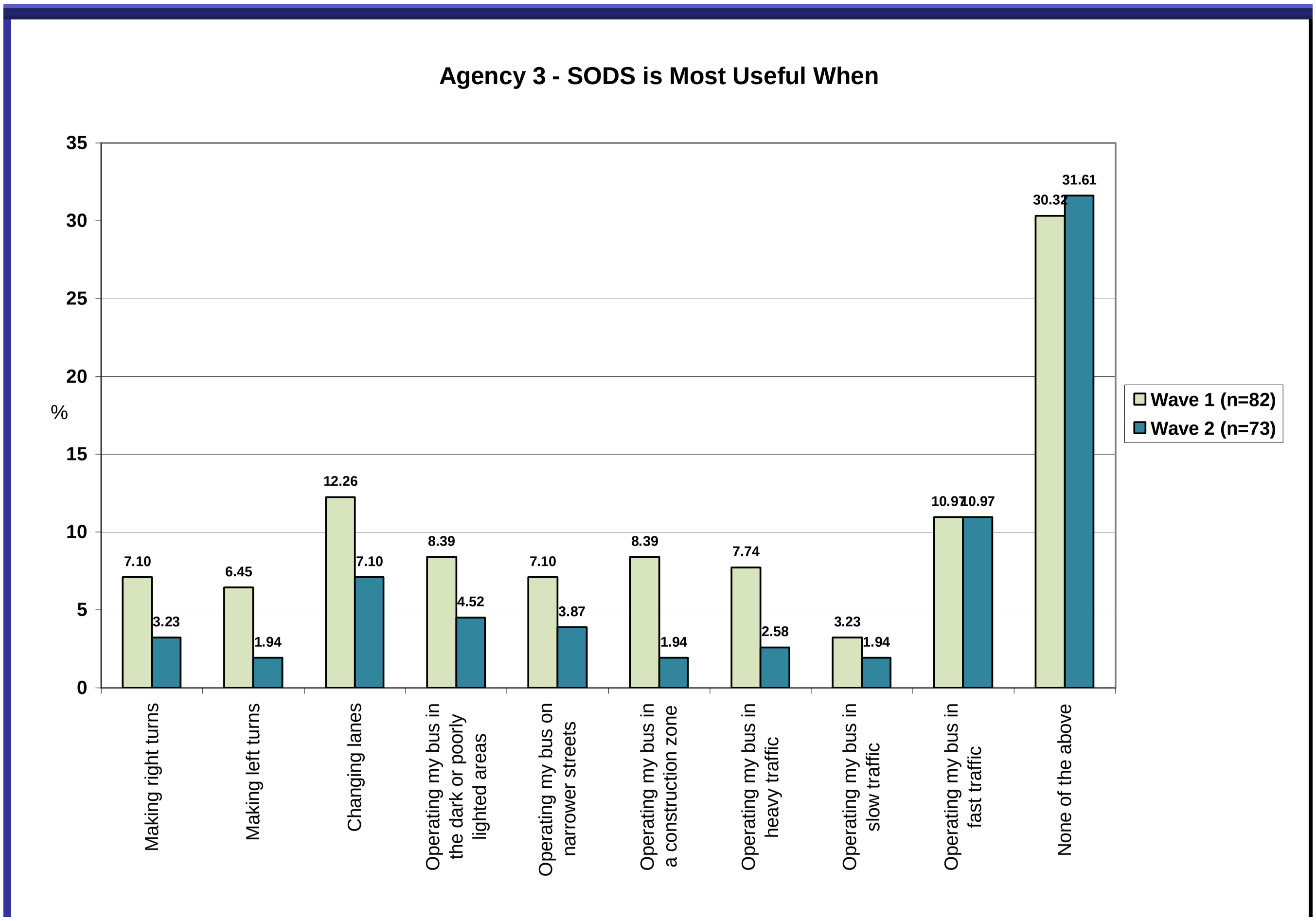
[160] Cramer's V = .212, p = .015

- Younger operators are more likely to think SODS is most useful when operating on narrower streets (Wave 1, Agency 2)[161]
- Operators with less years of experience are more likely to think SODS is most useful when operating in a construction zone (Wave 1, Agency 3)[162]



161 Kendall's tau-c = -.384, p = .043
162 Kendall's tau=c = -.159, p =.039


Agency 2 – SODS is Most Useful When
%
0
10
20
30
40
50
60
70
80
30.8
54.5
34.6
45.5
57.7
70.5
34.6
59.1
50.0
56.8
26.9
40.9
50.0
47.7
11.5
29.5
34.6
38.6
23.1
22.7
our Mile
Making right turns
Making left turns
Changing lanes
Operating my bus in the dark or poorly lighted areas
Operating my bus on narrower streets
Operating my bus in a construction zone
Operating my bus in heavy traffic
Operating my bus in slow traffic
Operating my bus in fast traffic
None of the above
Wave 1 (n=26)
Wave 2 (44)


Agency 3 - SODS is Most Useful When
35
30
25
20
%
15
10
5
0
7.10
3.23
6.45
1.94
12.26
7.10
8.39
4.52
7.10
3.87
8.39
1.94
7.74
2.58
3.23
1.94
10.97
10.97
30.32
31.61
Making right turns
Making left turns
Changing lanes
Operating my bus in the dark or poorly lighted areas
Operating my bus on narrower streets
Operating my bus in a construction zone
Operating my bus in heavy traffic
Operating my bus in slow traffic
Operating my bus in fast traffic
None of the above
Wave 1 (n=82)
Wave 2 (n=73)

APPENDIX C: DETAILS OF REGRESSION ANALYSIS CONDUCTED IN DETERMINING SODS-RELEVANT COLLISIONS

This appendix describes the approach used to analyze the bus collision data to support the SODS benefit-cost analysis.

If the usage of every bus considered in this study were identical, then the number of collisions observed during a period of time should follow a Poisson Model:

$$p(k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

where $p(k)$ is the probability of observing k collisions during the specified period of time and λ is the expected number of collisions for each bus during that period of time. Because bus usage is the same for all buses, λ is a constant. Figure C-1 below depicts the Poisson distribution for λ equal to 2.

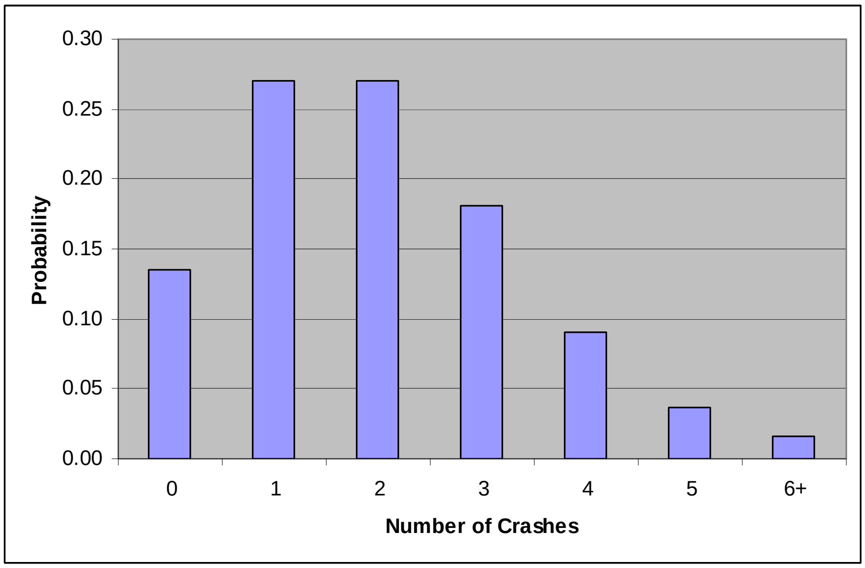


Figure C-1. The Poisson Distribution for λ Equals 2.

One of the difficulties with analyzing collision data is the broad distribution for the number of observed collisions for the Poisson distribution. In the above distribution, the expected number of collisions is 2. However, one is likely to observe as few as zero collisions or 4 or more collisions.

The situation is further complicated by the fact that the expected number of collisions actually differs from bus to bus. One bus may be driven more often or in more collision-prone areas, in which case the expected number of collisions for that bus is higher. Another bus may be driven less often or may only be available for part of the period under study, in which case the expected number of collisions for that bus is lower. One way to account for this in the model is to include in the model the possibility that the expected number of collisions will vary from bus to bus – one can assume that λ follows a defined distribution. The Gamma distribution is often used for this because this distribution fits the basic constraint that λ must be positive. The Gamma distribution is given by the formula:

$$p(\lambda) = \frac{\lambda^{r-1} e^{-\lambda/\theta}}{\Gamma(r)\theta^r}$$

where the two terms θ and r are parameters that define the shape of the Gamma distribution. Two facts of interest are that the mean of the Gamma distribution is given by $\theta\, r$ and the variance by $\theta^2\, r$. Note that, if the variance is a small fraction of the mean, then expected number of collisions varies little from bus to bus and the Poisson model above will be accurate. Otherwise, this more complex model is needed.

These two models can be combined to give the Poisson-Gamma model. If the expected number of collisions for the buses in the sample is distributed according to the Gamma model, then the observed number of collisions follows the Poisson-Gamma model:

$$p(k) = \frac{\Gamma(k+r)}{\Gamma(k+1)\Gamma(r)}\left(\frac{1}{\theta+1}\right)^{r}\left(\frac{\theta}{\theta+1}\right)^{k}$$

One can apply this model to the observed number of collisions for SODS and non-SODS buses by computing the maximum likelihood estimator for the parameters, as shown in Table C-1.

Table C-1. Poisson-Gamma Model Parameters for the Expected Number of Collisions.

Bus Type	r	θ	Mean	Variance
SODS	2.43	0.28	0.68	0.23
Non-SODS	1.67	0.37	0.61	0.19

This model indicates that the average number of collisions per year for SODS buses is about 0.68 collisions per year, but that there is a lot of variation in this value from bus to bus, as shown in Figure C-2. Note that, while the average for the expected number of collisions for SODS buses is slightly larger than for non-SODS buses, the model indicates that there is a lot of variation in this value from bus to bus.

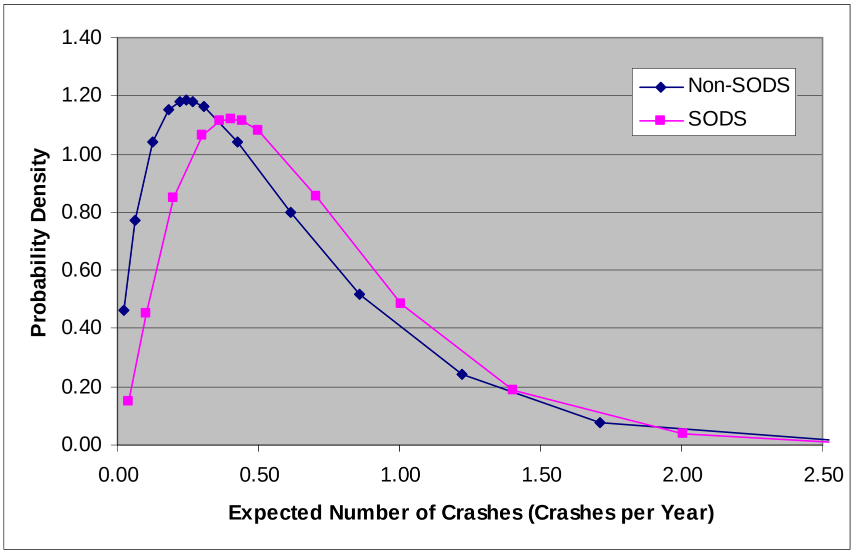


Figure C-2. Probability Density for the Expected Number of Collisions per Year.

One potential source for this variation is the amount of usage for each bus. Some buses are used frequently, so are exposed to higher collision risks. Other buses are used less frequently, so have less exposure. Charts of the vehicle miles traveled each year for SODS and non-SODS buses (see Figures C-3 and C-4) show the variation in collision exposure for these buses.

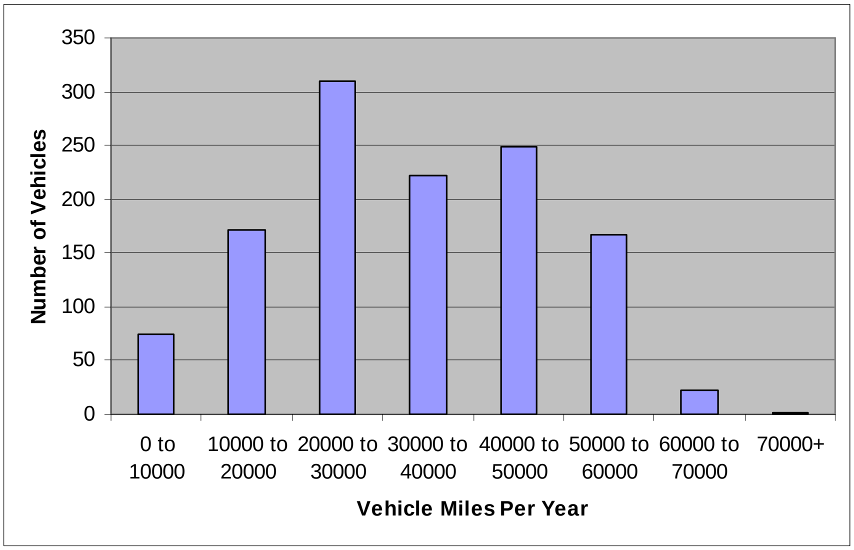


Figure C-3. Distribution of Vehicle Miles Traveled Per Year for Non-SODS Buses.

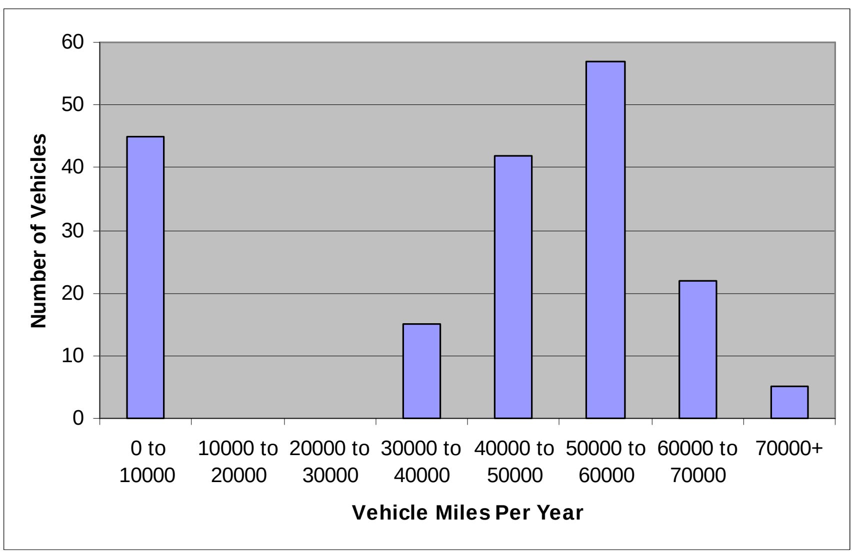


Figure C-4. Distribution of Vehicle Miles Traveled Per Year for SODS Buses.

In fact, the average vehicle miles traveled per year for SODS buses was 40,807, while it was only 33,152 for non-SODS buses. Because the SODS buses were driven further on average than the non-SODS buses, one would expect more collisions for these buses.

One can correct for this difference by assuming that each bus has a constant chance of a collision for every mile traveled and allowing this number to vary from bus to bus. Let *m* be the expected number of collisions per vehicle mile for a bus and assume that *m* follows a Gamma distribution. The maximum likelihood estimation for the Gamma distribution parameters for *m* are shown in Table C-2.

Table C-2. Poisson-Gamma Model Parameters for the Expected Number of Collisions per Vehicle Mile.

Bus Type	*r*	*Θ*	Mean	Variance
SODS	9.10	1.84e-6	1.67e-5	3.08e-11
Non-SODS	4.36	4.20e-6	1.83e-5	7.70e-11

The resulting distributions for the expected number of collisions per vehicle mile are shown in Figure C-5. Note that this model indicates that SODS buses were less prone to collisions than non-SODS buses – it was apparently the fact that SODS buses were driven more frequently that led to the higher average number of collisions per bus for SODS buses.

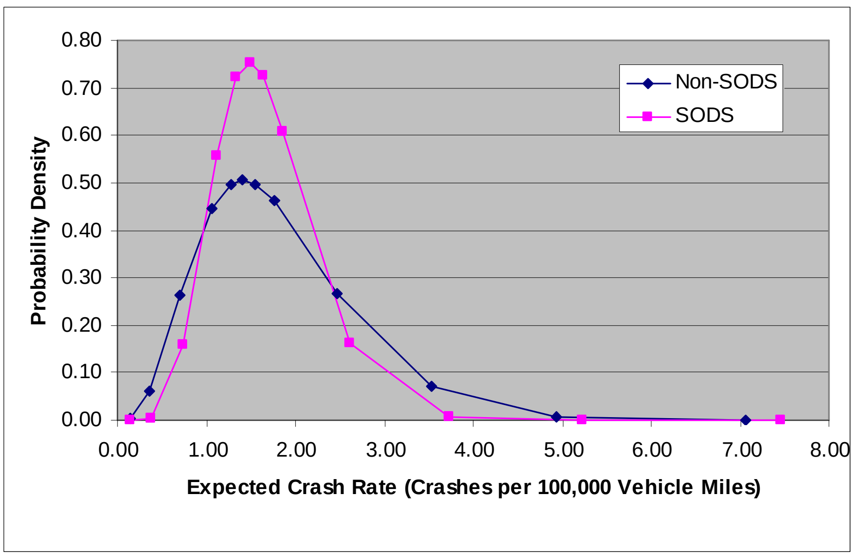


Figure C-5. Probability Density for the Expected Number of Collisions per 100,000 Vehicle Miles.

It also appears that this model explains more of the variation in the observed collisions than assuming a constant value for the expected number of collisions for each bus. One can interpret the width of these distributions as the variation that is not explained by the model used. If the model were perfect, all of the variation in observations would be explained by the model parameters (i.e., the *m* value) and the distributions would be very narrow. The ratio of the square root of the variation to the mean is an indicator of how much variation there is in the model parameters. In the case of the first model from Table D-3, these ratios are 0.64 and 0.78 for SODS and non-SODS buses, respectively. For the second model, these ratios are 0.33 and 0.48, respectively. There is less variation from bus-to-bus in the estimate for the expected number of collisions per vehicle mile than there is in the estimate for the expected number of collisions per bus-year, indicating that the second model explains more of the observed variation than the first model.

It is worth noting that there is still much variation in the observations that are not explained by the model. A number of factors may contribute to these differences. Different buses may be used on different types of routes, with the risk of a collision being different for each route. The buses may be of different sizes or equipped differently, or some drivers may be safer and prefer to drive certain buses. It is interesting to note that unexplained variation for the SODS buses was less than that for the non-SODS buses, which would be consistent with the fact that the SODS buses were otherwise similar to each other.

Figures C-6 and C-7 show the observed number of collisions for each bus for each year, plotted against the vehicles miles traveled during that year, for Non-SODS and SODS buses, respectively. The line on each chart shows the model estimate for the expected number of collisions based on the vehicle miles traveled.

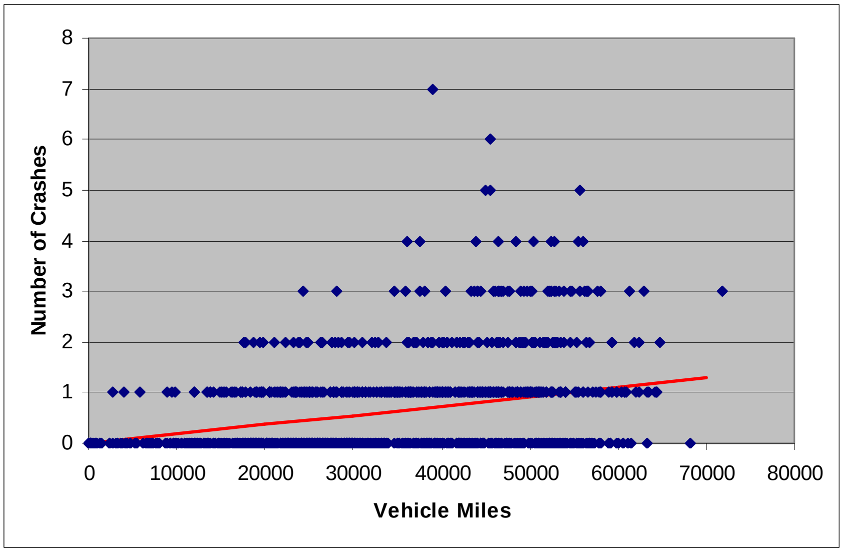


Figure C-6. Observed Collisions for Non-SODS Buses and Model Estimate for Expected Number of Collisions.

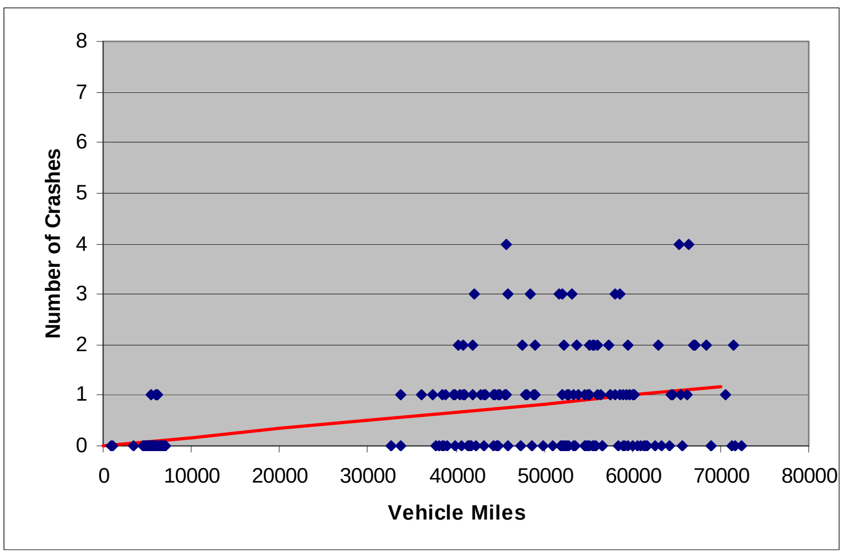


Figure C-7. Observed Collisions for SODS Buses and Model Estimate for Expected Number of Collisions.

This second model indicates that the expected number of collisions per vehicle mile was about 10 percent lower for SODS buses than non-SODS buses. However, it is not clear whether this drop was due to SODS or to some other factor, such as the newer SODS buses being easier to drive or being used on safer routes. One way to test whether the drop was due to SODS would be to examine the drop in the expected number of collisions for those collisions that are SODS-relevant – for those types of collisions for which SODS is most likely to alarm in a useful manner.

If the presence of SODS was responsible for the lower number of collisions per vehicle mile, then one should expect to see a greater percentage reduction in the number collisions for SODS-relevant collisions than for other collisions. To check this, the above model was repeated with the collisions restricted to those that were SODS-relevant. Specifically, the model was repeated restricting to those collisions whose SODS-relevance was estimated at 0.25 or above, 0.50 or above, 0.75 or above, and 1.00. The results are shown in Table C-3.

Table C-3. SODS-relevant Collisions per 100,000 Vehicle Miles for Indicated Value of SODS Relevance.

Bus Type	Expected Number of Collisions with SODS-relevance as Indicated				
	≥ 0.00	≥ 0.25	≥ 0.50	≥ 0.75	= 1.00
SODS	1.67	0.98	0.78	0.37	0.28
Non-SODS	1.83	1.21	0.82	0.42	0.28
Ratio	0.91	0.81	0.95	0.88	1.00

This table indicates that the lower collisions per vehicle mile on SODS buses was distributed across all collisions, not concentrated on those collisions that were most likely to be impacted by SODS. This indicates that it was not the presence of SODS that contributed to the lower number of collisions per vehicle mile observed on those buses equipped with SODS. It is still possible that SODS did help prevent collisions. For example, if the SODS buses were more often used on routes that were more prone to the types of side-impact collisions preventable by SODS, then the higher likelihood of SODS-relevant collisions on those routes may have masked the impact of equipping the buses with SODS. The evaluation team is not aware of any such bias in how SODS buses were used at Agency 1, so that the simplest explanation for the observations is that SODS had little or no effect on the likelihood of collisions at Agency 1.

APPENDIX D: ASSIGNMENT OF SODS-RELEVANT FACTOR

This appendix describes the approach utilized in determining the expected reduction in the side collision rate as a result of SODS for the ROI calculations. As was discussed in Section 7.3, the ROI was first calculated using the measured reduction in side collisions when comparing SODS buses to non-SODS buses. However, due to challenges faced by the early-adopters, it was thought that this data did not paint an accurate picture of the benefits of the system. Therefore the team then separately estimated the SODS-relevant collision rate based on the agencies' collision records and used this to determine the expected reduction in the side collision rate resulting from SODS (recall Figure 7-4).

To determine the SODS-relevant collision rate the evaluation team first worked closely with each of the participating agencies to gain an understanding of their incident reporting process which helped the evaluation team understand the limitations of each of the agency's collision data. The team then carefully reviewed each of the datasets, making determinations as to which collisions could be deemed SODS-relevant based on the collision characteristics available for each dataset. The level of detail in the data varied significantly from agency to agency. In some cases there was no detail beyond the brief event classification while in other cases there was a good deal of detail describing the circumstances of the collision.

As an example of the level of detail that was provided, the team made the assessment of SODS-relevance based on five collision characteristics with one of the datasets:

- *Event Category.* This characteristic describes the general nature of the collision, such as a collision with a fixed object or a collision that occurred when another vehicle was overtaking or passing the bus.
- *Bus Operator Action.* This characteristic describes what the operator was doing immediately prior to the collision (e.g., stopped, turning left).
- *Bus Point of Contact.* This characteristic describes the initial point of impact on the bus (e.g., left mirror, left-front).
- *Other Vehicle Driver Action.* This characteristic describes what the driver of the other vehicle was doing immediately prior to the collision (e.g., stopped, turning left).
- *Other Vehicle Point of Contact.* This characteristic describes the initial point of impact on the other vehicle (e.g., left mirror, left-front).

In the datasets that had enough detail to do so, collisions were assigned a "SODS-relevant value" ranging from 0 to 1. Those collisions that were clearly not within the side object collision definition (such as those where the other driver was at fault, in which case the bus operator could not have avoided the collision) were assigned a rating of 0 and were eliminated, and those collisions that would clearly have been SODS-relevant were assigned a rating of 1.[163] All remaining collisions were assigned a rating between 0 and 1 based on the likelihood of SODS alarming. Assumptions were made in this determination including:

- *It is not likely that collisions involving the "rear" and "side rear" of the bus are SODS-relevant.* As described in Section 2.3.2, the system does not sense objects adjacent to the rear half of the bus.

[163] Note that a rating of "1" does not necessarily indicate that SODS would have prevented the collision – only that SODS was likely to alarm in manner that might have helped prevent the collision. This is the reason for the separate "SODS-utilization Factor" and "System Uptime" factors discussed in Section 7.1.4.

- *It is not likely that the low-speed collisions involving mirrors are SODS-relevant*. As was discussed in

- Section 2.3.2, the sensors are typically positioned more than 4 feet below the mirrors, and the sensor range is only 4 feet when the bus is traveling below 15 mph. As a result of this, any objects that are close to the bus only at the height of the mirror (such as a tall sign) would not be detected. The data did not always provide the level of detail required to make this type of assessment, but where it did, the evaluation team made use of this information.

- *It is not likely that collisions occurring when the bus was stopped are SODS-relevant.* The reason for this is that if the bus was not moving at the time of the collision, the collision was caused by another vehicle's improper maneuver, and the operator could not have taken action to prevent the incident even if SODS alarmed. Any collisions occurring when the bus was stationary were assigned a SODS-relevant factor of zero.

Typical collisions that were categorized as SODS-relevant included collisions where:

- *The bus struck a fixed object while making a right or left turn.* Note that due to the limitations just discussed, if the point of contact on the bus was the rear side of the bus or the mirror (in cases where the data revealed this level of detail), the collision was eliminated from the analysis (i.e., assigned a SODS-relevant factor of zero).

- *The bus sideswiped a parked car or other fixed object.* These collisions would typically occur while the bus is pulling into or away from a bus stop. Again, due to the limitations just discussed, if the point of contact on the bus was the rear side of the bus, the collision was typically eliminated from the analysis (i.e., assigned a SODS-relevant factor of zero).

- *The bus sideswiped another vehicle traveling in the same direction as the bus.* High-speed lane changes would be included in this category. It is important to note that some sideswipe collisions were not due to lane changes (i.e., the collision was caused because the other vehicle changed lanes and hit the bus), but it was not always possible to decipher from the data available whether the bus was making a lane change.

It should be noted that in arriving at the "number" of collisions that are SODS-relevant, many collisions (in fact most) were assigned non-integer values such as 0.3 or 0.5. Each of these non-integer values were summed to arrive at the total number of estimated collisions that are SODS-relevant. As an example, value of 0.5 is counted as half a collision. As a result, the resulting SODS-relevant collision rate, expressed in terms of collisions per bus per year, is not actually a count of all collisions thought to be SODS-relevant.

The reason that non-integer values were used for many of the assignments is simply due to the lack of detail in the data making it difficult to accurately assess SODS-relevance.

APPENDIX E: DETAILS OF BENEFIT-COST ANALYSIS

This appendix presents additional details on the benefit-cost analysis.

Table E-1 presents additional factors required for the analysis that have not been discussed thus far in the report. Following the table is a presentation of the equations required for the ROI calculation, followed by tables showing the detailed analysis for each of the scenarios that were discussed in Chapter 7.

Table E-1. Explanation of Assumptions for Other Factors Required for Analysis.

Factor required for analysis	Description of factor	Value used in analysis	Information about source / reference
Number of SODS Units	This represents the number of units that the agency plans to introduce into the vehicle fleet each year.	48	Based on the number of new buses that the 100 largest transit agencies (in terms of bus fleetsize) procures each year (assuming that agencies replace 1/12 of their fleet on average each year and assuming a fleetsize 20 percent higher than the average "active fleet" for top 100 agencies) -- *From 2007 National Transit Database.*
Number of Operators	This represents the total number of operators who will be exposed to SODS regardless of the expected frequency of exposure. All operators who will be exposed to SODS need to be trained on the system at the start. An exception to this is if the agency deploys the units to one garage at a time.	212	Based on average number of vehicle operations employees (an executive, professional, secretarial, or supervisory transit system person engaged in vehicle maintenance, a person performing inspection and maintenance, vehicle maintenance of vehicles, performing servicing functions for revenue and service vehicles, and repairing damage to vehicles resulting from vandalism or accidents) at U.S. transit agencies (assumes that 23 percent of employees are administrative and operations support staff) -- *From 2006 National Transit Database.*
Number of Mechanics	This represents the total number of mechanics within the organization.	56	Based on average number of vehicle maintenance employees (an executive, professional, secretarial, or supervisory transit system person engaged in vehicle maintenance, a person performing inspection and maintenance, vehicle maintenance of vehicles, performing servicing functions for revenue and service vehicles, and repairing damage to vehicles resulting from vandalism or accidents) at U.S. transit agencies (assumes that 23 percent of employees are administrative and maintenance support staff) -- *From 2006 National Transit Database.*
Average Miles	Average number of miles that a bus travels per year.	41,667 miles	Based on expected life per Federal Transit Administration of 500,000 over 12 years.

Initial Costs (only in first year):

Training costs:

$$\left[212 operators \times \frac{0.5 hrs}{operator/unit} \times \frac{\$28.25}{hr}\right] + \left[56 mechanics \times \frac{0.5 hrs}{mechanic/unit} \times \frac{\$30.07}{hr}\right] = \$3{,}836.67 / unit$$

Annual Costs:

Cost per unit per year for annual testing:

$$\left(\frac{0.25 hrs / year}{unit} \times \frac{\$30.07}{hr}\right) = \$7.52 / unit / year$$

Cost per unit per year for annual maintenance (excludes first year where unit is under warranty):

$$\left[\frac{0.185 sensors / unit}{year} \times \left(\left(\frac{1.75 hrs}{sensor} \times \frac{\$30.07}{hr}\right) + \frac{\$325.00}{sensor}\right)\right] * \left(\frac{11 years}{12 years}\right) = \$64.04 / unit / year$$

Cost per unit per year for annual operator refresher training:

$$\left[212 operators \times \frac{0.5 hrs}{operator / unit} \times \frac{\$28.25}{hr}\right] / 576 units = \$5.20 / unit / year$$

Annual Benefits:

Annual benefit per unit:

$$\left(\left(\frac{0.534 collisions}{100{,}000 miles} \times \frac{41{,}667 miles / bus}{year}\right) \times (0.95) \times (0.95) \times (\$1{,}176 / collision)\right) = \$236.15 / unit / year$$

"Basic" ROI Calculation (Based on Measured Reduction in Side Collisions per Table 7-11)

Discount Factor	***1.000***	***1.030***	***1.061***	***1.093***	***1.126***	***1.159***	***1.194***	***1.230***	***1.267***	***1.305***	***1.344***	***1.384***	***1.426***
Year	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Non-Discounted													
Cost	$99,837	$91,684	$87,368	$83,052	$78,737	$74,421	$70,105	$65,789	$61,473	$57,157	$52,842	$48,526	$44,210
Benefit	$0	$3,544	$7,087	$10,631	$14,174	$17,718	$21,261	$24,805	$28,348	$31,892	$35,435	$38,979	$42,522
Benefit-Cost	-$99,837	-$88,141	-$80,281	-$72,422	-$64,563	-$56,703	-$48,844	-$40,984	-$33,125	-$25,266	-$17,406	-$9,547	-$1,688
Cumulative													
Cost	$99,837	$191,521	$278,889	$361,942	$440,678	$515,099	$585,204	$650,993	$712,467	$769,624	$822,466	$870,991	$915,201
Benefit	$0	$3,544	$10,631	$21,261	$35,435	$53,153	$74,414	$99,219	$127,567	$159,459	$194,894	$233,873	$276,395
Benefit-Cost	-$99,837	-$187,977	-$268,259	-$340,681	-$405,243	-$461,946	-$510,790	-$551,775	-$584,900	-$610,165	-$627,572	-$637,119	-$638,807
Discounted													
Cost	$99,837	$89,014	$82,353	$76,005	$69,956	$64,196	$58,712	$53,493	$48,528	$43,806	$39,319	$35,056	$31,008
Benefit	$0	$3,440	$6,680	$9,728	$12,593	$15,283	$17,806	$20,168	$22,378	$24,442	$26,367	$28,159	$29,824
Benefit-Cost	-$99,837	-$85,573	-$75,673	-$66,276	-$57,363	-$48,913	-$40,906	-$33,324	-$26,149	-$19,364	-$12,952	-$6,897	-$1,184
Cumulative													
Cost	$99,837	$188,850	$271,203	$347,208	$417,165	$481,361	$540,073	$593,565	$642,093	$685,899	$725,218	$760,274	$791,282
Benefit	$0	$3,440	$10,121	$19,849	$32,443	$47,726	$65,532	$85,700	$108,079	$132,521	$158,888	$187,047	$216,871
Benefit-Cost	-$99,837	-$185,410	-$261,083	-$327,359	-$384,722	-$433,635	-$474,541	-$507,865	-$534,014	-$553,378	-$566,330	-$573,227	-$574,411
Benefit-Cost Ratio		0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.17	0.19	0.22	0.25	0.27
Return on Investment		-98%	-96%	-94%	-92%	-90%	-88%	-86%	-83%	-81%	-78%	-75%	-73%

"Best-Case" Scenario (System Uptime of 0.95 / SODS-Utilization Factor of 0.95 for Overall System Efficacy of 0.90; Discount Rate of 0.03)

Discount Factor	***1.000***	***1.030***	***1.061***	***1.093***	***1.126***	***1.159***	***1.194***	***1.230***	***1.267***	***1.305***	***1.344***	***1.384***	***1.426***
Year	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Non-Discounted													
Cost	$99,837	$91,684	$87,368	$83,052	$78,737	$74,421	$70,105	$65,789	$61,473	$57,157	$52,842	$48,526	$44,210
Benefit	$0	$11,335	$22,670	$34,005	$45,340	$56,676	$68,011	$79,346	$90,681	$102,016	$113,351	$124,686	$136,021
Benefit-Cost	-$99,837	-$80,349	-$64,698	-$49,047	-$33,396	-$17,745	-$2,094	$13,557	$29,208	$44,859	$60,509	$76,160	$91,811
Cumulative													
Cost	$99,837	$191,521	$278,889	$361,942	$440,678	$515,099	$585,204	$650,993	$712,467	$769,624	$822,466	$870,991	$915,201
Benefit	$0	$11,335	$34,005	$68,011	$113,351	$170,027	$238,037	$317,383	$408,064	$510,080	$623,431	$748,117	$884,139
Benefit-Cost	-$99,837	-$180,186	-$244,884	-$293,931	-$327,327	-$345,072	-$347,167	-$333,610	-$304,403	-$259,544	-$199,035	-$122,874	-$31,063
Discounted													
Cost	$99,837	$89,014	$82,353	$76,005	$69,956	$64,196	$58,712	$53,493	$48,528	$43,806	$39,319	$35,056	$31,008
Benefit	$0	$11,005	$21,369	$31,120	$40,284	$48,889	$56,958	$64,515	$71,584	$78,187	$84,344	$90,076	$95,403
Benefit-Cost	-$99,837	-$78,009	-$60,984	-$44,885	-$29,672	-$15,307	-$1,754	$11,023	$23,057	$34,380	$45,025	$55,020	$64,395
Cumulative													
Cost	$99,837	$188,850	$271,203	$347,208	$417,165	$481,361	$540,073	$593,565	$642,093	$685,899	$725,218	$760,274	$791,282
Benefit	$0	$11,005	$32,374	$63,494	$103,778	$152,667	$209,625	$274,140	$345,724	$423,911	$508,255	$598,331	$693,734
Benefit-Cost	-$99,837	-$177,845	-$238,830	-$283,715	-$313,387	-$328,694	-$330,448	-$319,425	-$296,368	-$261,988	-$216,963	-$161,944	-$97,549
Benefit-Cost Ratio		0.06	0.12	0.18	0.25	0.32	0.39	0.46	0.54	0.62	0.70	0.79	0.88
Return on Investment		-94%	-88%	-82%	-75%	-68%	-61%	-54%	-46%	-38%	-30%	-21%	-12%

Sensitivity Based on SODS-Utilization Factor (System Uptime of 0.95 / SODS-Utilization Factor of 0.95 for Overall System Efficacy of 0.9; Discount Rate of 0.07)

Discount Factor	***1.000***	***1.030***	***1.061***	***1.093***	***1.126***	***1.159***	***1.194***	***1.230***	***1.267***	***1.305***	***1.344***	***1.384***	***1.426***
Year	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Non-Discounted													
Cost	$99,837	$91,684	$87,368	$83,052	$78,737	$74,421	$70,105	$65,789	$61,473	$57,157	$52,842	$48,526	$44,210
Benefit	$0	$11,335	$22,670	$34,005	$45,340	$56,676	$68,011	$79,346	$90,681	$102,016	$113,351	$124,686	$136,021
Benefit-Cost	-$99,837	-$80,349	-$64,698	-$49,047	-$33,396	-$17,745	-$2,094	$13,557	$29,208	$44,859	$60,509	$76,160	$91,811
Cumulative													
Cost	$99,837	$191,521	$278,889	$361,942	$440,678	$515,099	$585,204	$650,993	$712,467	$769,624	$822,466	$870,991	$915,201
Benefit	$0	$11,335	$34,005	$68,011	$113,351	$170,027	$238,037	$317,383	$408,064	$510,080	$623,431	$748,117	$884,139
Benefit-Cost	-$99,837	-$180,186	-$244,884	-$293,931	-$327,327	-$345,072	-$347,167	-$333,610	-$304,403	-$259,544	-$199,035	-$122,874	-$31,063
Discounted													
Cost	$99,837	$89,014	$82,353	$76,005	$69,956	$64,196	$58,712	$53,493	$48,528	$43,806	$39,319	$35,056	$31,008
Benefit	$0	$11,005	$21,369	$31,120	$40,284	$48,889	$56,958	$64,515	$71,584	$78,187	$84,344	$90,076	$95,403
Benefit-Cost	-$99,837	-$78,009	-$60,984	-$44,885	-$29,672	-$15,307	-$1,754	$11,023	$23,057	$34,380	$45,025	$55,020	$64,395
Cumulative													
Cost	$99,837	$188,850	$271,203	$347,208	$417,165	$481,361	$540,073	$593,565	$642,093	$685,899	$725,218	$760,274	$791,282
Benefit	$0	$11,005	$32,374	$63,494	$103,778	$152,667	$209,625	$274,140	$345,724	$423,911	$508,255	$598,331	$693,734
Benefit-Cost	-$99,837	-$177,845	-$238,830	-$283,715	-$313,387	-$328,694	-$330,448	-$319,425	-$296,368	-$261,988	-$216,963	-$161,944	-$97,549
Benefit-Cost Ratio		0.06	0.12	0.18	0.25	0.32	0.39	0.46	0.54	0.62	0.70	0.79	0.88
Return on Investment		-94%	-88%	-82%	-75%	-68%	-61%	-54%	-46%	-38%	-30%	-21%	-12%

Sensitivity Based on SODS-Utilization Factor (System Uptime of 0.95 / SODS-Utilization Factor of 0.75 for Overall System Efficacy of 0.71; Discount Rate of 0.07)

Discount Factor	***1.000***	***1.030***	***1.061***	***1.093***	***1.126***	***1.159***	***1.194***	***1.230***	***1.267***	***1.305***	***1.344***	***1.384***	***1.426***
Year	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Non-Discounted													
Cost	$99,837	$91,684	$87,368	$83,052	$78,737	$74,421	$70,105	$65,789	$61,473	$57,157	$52,842	$48,526	$44,210
Benefit	$0	$8,949	$17,898	$26,846	$35,795	$44,744	$53,693	$62,641	$71,590	$80,539	$89,488	$98,436	$107,385
Benefit-Cost	-$99,837	-$82,735	-$69,471	-$56,206	-$42,942	-$29,677	-$16,412	-$3,148	$10,117	$23,381	$36,646	$49,911	$63,175
Cumulative													
Cost	$99,837	$191,521	$278,889	$361,942	$440,678	$515,099	$585,204	$650,993	$712,467	$769,624	$822,466	$870,991	$915,201
Benefit	$0	$8,949	$26,846	$53,693	$89,488	$134,232	$187,924	$250,566	$322,156	$402,695	$492,182	$590,619	$698,004
Benefit-Cost	-$99,837	-$182,572	-$252,043	-$308,249	-$351,191	-$380,868	-$397,280	-$400,428	-$390,311	-$366,929	-$330,283	-$280,373	-$217,197
Discounted													
Cost	$99,837	$89,014	$82,353	$76,005	$69,956	$64,196	$58,712	$53,493	$48,528	$43,806	$39,319	$35,056	$31,008
Benefit	$0	$8,688	$16,870	$24,568	$31,803	$38,596	$44,967	$50,933	$56,514	$61,726	$66,587	$71,113	$75,318
Benefit-Cost	-$99,837	-$80,326	-$65,483	-$51,437	-$38,153	-$25,600	-$13,745	-$2,559	$7,986	$17,920	$27,268	$36,057	$44,310
Cumulative													
Cost	$99,837	$188,850	$271,203	$347,208	$417,165	$481,361	$540,073	$593,565	$642,093	$685,899	$725,218	$760,274	$791,282
Benefit	$0	$8,688	$25,558	$50,126	$81,930	$120,526	$165,493	$216,426	$272,940	$334,667	$401,254	$472,367	$547,684
Benefit-Cost	-$99,837	-$180,162	-$245,645	-$297,082	-$335,235	-$360,834	-$374,579	-$377,139	-$369,153	-$351,233	-$323,964	-$287,908	-$243,598
Benefit-Cost Ratio		0.05	0.09	0.14	0.20	0.25	0.31	0.36	0.43	0.49	0.55	0.62	0.69
Return on Investment		-95%	-91%	-86%	-80%	-75%	-69%	-64%	-57%	-51%	-45%	-38%	-31%

Sensitivity Based on SODS-Utilization Factor (System Uptime of 0.95 / SODS-Utilization Factor of 0.55 for Overall System Efficacy of 0.52; Discount Rate of 0.07)

Discount Factor	***1.000***	***1.030***	***1.061***	***1.093***	***1.126***	***1.159***	***1.194***	***1.230***	***1.267***	***1.305***	***1.344***	***1.384***	***1.426***
Year	***0***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Non-Discounted													
Cost	$99,837	$91,684	$87,368	$83,052	$78,737	$74,421	$70,105	$65,789	$61,473	$57,157	$52,842	$48,526	$44,210
Benefit	$0	$6,562	$13,125	$19,687	$26,250	$32,812	$39,375	$45,937	$52,499	$59,062	$65,624	$72,187	$78,749
Benefit-Cost	-$99,837	-$85,122	-$74,243	-$63,365	-$52,487	-$41,609	-$30,730	-$19,852	-$8,974	$1,904	$12,783	$23,661	$34,539
Cumulative													
Cost	$99,837	$191,521	$278,889	$361,942	$440,678	$515,099	$585,204	$650,993	$712,467	$769,624	$822,466	$870,991	$915,201
Benefit	$0	$6,562	$19,687	$39,375	$65,624	$98,436	$137,811	$183,748	$236,248	$295,309	$360,934	$433,121	$511,870
Benefit-Cost	-$99,837	-$184,958	-$259,202	-$322,567	-$375,054	-$416,663	-$447,393	-$467,245	-$476,219	-$474,315	-$461,532	-$437,871	-$403,332
Discounted													
Cost	$99,837	$89,014	$82,353	$76,005	$69,956	$64,196	$58,712	$53,493	$48,528	$43,806	$39,319	$35,056	$31,008
Benefit	$0	$6,371	$12,371	$18,017	$23,323	$28,304	$32,976	$37,351	$41,444	$45,266	$48,831	$52,149	$55,233
Benefit-Cost	-$99,837	-$82,642	-$69,982	-$57,988	-$46,634	-$35,892	-$25,736	-$16,142	-$7,084	$1,460	$9,512	$17,093	$24,225
Cumulative													
Cost	$99,837	$188,850	$271,203	$347,208	$417,165	$481,361	$540,073	$593,565	$642,093	$685,899	$725,218	$760,274	$791,282
Benefit	$0	$6,371	$18,743	$36,759	$60,082	$88,386	$121,362	$158,713	$200,156	$245,422	$294,253	$346,402	$401,635
Benefit-Cost	-$99,837	-$182,479	-$252,461	-$310,449	-$357,083	-$392,975	-$418,711	-$434,853	-$441,937	-$440,477	-$430,966	-$413,872	-$389,647
Benefit-Cost Ratio		0.03	0.07	0.11	0.14	0.18	0.22	0.27	0.31	0.36	0.41	0.46	0.51
Return on Investment		-97%	-93%	-89%	-86%	-82%	-78%	-73%	-69%	-64%	-59%	-54%	-49%