Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses

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13. ABSTRACT (Maximum 200 words)

This document presents an analysis of Integrated Vehicle Based Safety Systems (IVBSS) for transit buses. The study took a three-pronged approach. The first was an analysis of the available IVBSS products, possible future products and the technologies. The second was a benefit-cost analysis of transit IVBSS. The third assessed the receptiveness among transit operators to use IVBSS products and the willingness of manufacturers to develop them.

This study used the National Transit Database and crash data from 6 U.S. transit operators. The data show that there is an average of 1.5 collisions per transit bus and related annual costs of over $4,000. Of the technologies evaluated, only side object detection systems showed the potential to be cost effective. In general, transit agencies are receptive to in-vehicle safety devices when there is evidence of their effectiveness. Several vendors currently offer products while others are awaiting commitments from the U.S. DOT or coordinated transit industry interest before developing their products. It is recommended that the U.S. DOT pursue operational tests of the side object detection system and other stronger-performing systems in order to validate the findings of this study.

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Integrated Vehicle Based Safety Systems, Integrated Collision Warning System, Forward Collision Warning System, Side Collision Warning System, Side Object Detection System, Pedestrian Detection, Lane Departure Warning, Rear Object Detection System, Rear Collision Warning System, Transit Bus, Transit Safety

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Assessing the Business Case for Integrated Collision Avoidance Systems on Transit Buses

Final Report

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PREFACE

The work presented in this report was conducted by Booz Allen Hamilton. This study was sponsored by the Federal Transit Administration (FTA) and the ITS Joint Program Office at the U.S. Department of Transportation (U.S. DOT) as part of the Integrated Vehicle-Based Safety Systems (IVBSS) program. Results generated from this study will be an important reference for the transit IVBSS project teams with their ongoing work of studying and developing transit IVBSS technologies.

The authors would like to acknowledge Mr. Sébastien Renaud of FTA and Eric Traube, Kathryn Wochinger, and David Yang of Noblis for their contributions to this report.

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List of Acronyms

AATA	Ann Arbor Transportation Authority
AC Transit	Alameda County Transit Authority
APC	Automatic Passenger Counter
APTA	American Public Transportation Association
AVL	Automatic Vehicle Location
AWS	Advance Warning System
BIFA	Buses Involved in Fatal Accidents
CAD	Computer-Aided Dispatch
Caltrans	California Department of Transportation
CAS	Collision Avoidance Systems
CTA	Chicago Transit Authority
CWS	Collision Warning Systems
CWS+	A system containing a FCWS, a LDWS and a PDS
DOT	U.S. Department of Transportation
DVI	Driver Visual Interface or Driver-Vehicle Interface
FARS	Fatality Analysis Reporting System
FCSD	Forward Collision/Side Detection (a combination of FCWS and SODS)
FCWS	Forward Collision Warning System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FODS	Forward Object Detection System
FTA	Federal Transit Administration
GCRTA	Greater Cleveland Regional Transit Authority
GES	General Estimates System
GIS	Geographical Information Systems
GM	General Motors
GPS	Global Positioning Systems
HMW	Headway Monitoring and Warning
ICWS	Integrated Collision Warning System
IT	Information Technology
ITS	Intelligent Transportation Systems
IVBSS	Integrated Vehicle-Based Safety Systems
IVI	Intelligent Vehicle Initiative
JPO	Joint Program Office
LDWS	Lane Departure Warning System
LED	Light Emitting Diode

LLS	Laser Line Striper
Metro	Los Angeles County Metropolitan Transportation Authority
MPH	Miles per Hour
MTA	Maryland Transit Administration
Muni	San Francisco Municipal Railway
NCTD	North County Transit District
NHTSA	National Highway Transportation Safety Administration
NTD	National Transit Database
O&M	Operations and Maintenance
ODS	Object Detection Systems
OEM	Original Equipment Manufacturer
PAAC	Port Authority of Allegheny County
Pace	Pace Suburban Bus
PDO	Property-Damage-Only
PDS	Pedestrian Detection System
PED	Pedestrian
PMT	Passenger-Miles Traveled
RCWS	Rear Collision Warning System
RICWS	Rear Impact Collision Warning System
RODS	Rear Object Detection System
RTD	Regional Transportation District (Denver)
SamTrans	San Mateo County Transit District
SCWS	Side Collision Warning System
SODS	Side Object Detection System
TTC	Time to Contact
UMTRI	University of Michigan Transportation Research Institute
US	United States
UTA	Utah Transit Authority
VTA	Santa Clara Valley Transportation Administration
WMATA	Washington Metropolitan Area Transit Authority

1.0 EXECUTIVE SUMMARY

1.1 Background

Transit buses are involved in approximately 100,000 collisions each year, leading to nearly 100 fatalities and 7,500 injuries. Transit bus operators must address all of the financial costs typically associated with these collisions, including damage repairs, claims payments, legal fees, workers' compensation, and lost productivity. Moreover, public perceptions of safety can be tarnished by a single incident, eroding the trust and confidence of the public and generating unfavorable media attention. Collisions can also disrupt bus service and cause delays for all roadway users, inhibiting the operator's ability to fulfill its mission to the public.

Transit operators continuously seek methods and products that reduce their exposure to safety hazards. However, investment specifically in advanced in-vehicle safety systems has been slow because of operator uncertainty about the effectiveness of such systems in preventing or mitigating collisions. Likewise, some suppliers of safety systems are reluctant to invest resources in developing transit-specific products while the operators' potential demand remains uncertain.

In recognition of the potential to improve the performance and deployment rates of in-vehicle safety systems across all roadway travel modes, the U.S. Department of Transportation (DOT) initiated the Integrated Vehicle-Based Safety Systems (IVBSS) program. The specific goals of the IVBSS program are to integrate, simplify, and reduce the costs of safety technologies; increase safety benefits (e.g., by reducing collision incident rates); improve overall safety system performance; improve acceptance of in-vehicle technologies; and enhance the marketability of safety devices. To date, the IVBSS program has included widespread demonstration and evaluation of safety systems designed specifically for passenger vehicles and heavy trucks, but not for transit vehicles.

1.2 Study Objectives and Approach

The purpose of this study is to evaluate the business case for (or against) the development of integrated safety systems for transit buses. Specifically, this study addresses the question of whether the expected benefits from investing in these systems (e.g., expected sales by vendors or reductions in accident costs to transit agencies) outweigh the costs. Based on the results of this study and other related studies, the U.S. DOT will determine whether bus transit safety systems warrant additional investment in operational tests, demonstrations, and evaluations. This report represents an input to that "go/no go" decision.

The business case evaluation presented here focuses on the following seven existing and potential safety systems, referred to collectively as "collision avoidance systems:"

- Forward Collision Warning System (FCWS)
- Rear Collision Warning System (RCWS)
- Side Object Detection System (SODS)
- Forward Object Detection System (FODS)
- Rear Object Detection System (RODS)
- Lane Departure Warning System (LDWS)
- Pedestrian Detection System (PDS)

This study evaluated the technical, financial, and qualitative investment merits of these seven systems, both as standalone systems and as integrated (i.e., IVBSS) investments, by following a three-pronged approach:

1. **Technology Evaluation:** Identified and evaluated the functional and technical characteristics of in-vehicle safety systems applicable to transit buses.
2. **Benefit-Cost Analysis:** Conducted a benefit-cost analysis of the safety systems (both individually and in integrated "IVBSS" packages) from the perspective of an investing transit agency (to determine whether agency investment benefits exceed direct agency costs) and from the perspective of system vendors.
3. **Industry Outreach:** Conducted outreach sessions with transit operators to document their perceptions of these systems as well as the qualitative risks, rewards, and concerns likely to determine their interest in investing in these and similar systems.

1.3 Key Findings

Technology evaluation

The following are key findings regarding technology evaluation:

- Collision avoidance systems are divided into two categories: 1) object detection systems (ODS) and 2) collision warning systems (CWS). ODS monitor the area in close proximity to the vehicle and are designed to detect objects that are not within the view of the driver. Systems available at this time include forward, side, and rear object detection. Most manufacturers of non-video-based object detection systems do not guarantee that their systems will detect pedestrians because their sensing techniques may not return a strong reflection from people. Video-based recognition can be used to detect pedestrians. CWS, on the other hand, warn drivers of potential collisions by monitoring the time to contact with an object (not including pedestrians). Forward CWS warn the driver of an impending collision with another vehicle or hard object. Rear CWS are fixed to the rear of the bus and warn other drivers if they are approaching too fast of an impending collision with the bus (the bus operator would not be warned by rear collision warning). Finally, lane departure warning systems (LDWS), although not technically designed to detect impending collisions, use image recognition to warn drivers of impending un-signaled lane departures that can lead to collisions or road departures.
- While a variety of vendors currently supply in-vehicle safety systems to the auto and heavy-truck industries, only two vendors have shown interest in pursuing the transit market. Of these two, only one has deployed its products to a limited number of U.S. transit operators. The effectiveness of each of these manufacturers' products in reducing transit bus collisions remains undetermined.
- The study found that potential suppliers are hesitant to make any significant investments in developing transit-oriented products given the small transit market size and uncertainty in the demand among potential customers. At least one supplier is waiting for the U.S. DOT to make a funding decision before committing its own resources to further development. Similarly, some suppliers are awaiting an expression of widespread, organized interest among transit agencies.

Benefit-Cost Analysis

From a purely financial standpoint, only one of the standalone devices, SODS, was found to be cost effective (i.e., the benefit-cost ratio exceeded one) under most, but not all, circumstances. While pedestrian detection systems were also found to be cost effective for operators with above-average collision rates or high collision costs, none of the seven standalone technologies evaluated here were found to be cost-effective under all circumstances. When bundled together as "IVBSS" investments, systems containing a SODS performed best, generally passing the benefit-cost test under most conditions. However, as with the standalone systems, none of the bundled systems was able to pass the benefit-cost test under a full range of sensitivity assumptions.

The relative cost-effectiveness of SODS is driven by the fact that a high proportion of sideswipe collisions with other vehicles and collisions with fixed objects are avoidable by transit operators. This collision type is also relatively common, even though its costs are relatively low. On the other hand, the frequency and avoidability of forward, rear, and angle collisions is low, which hurts the potential for savings from technologies that address those types of collisions. Even with sensitivity analysis, few of these technologies demonstrated benefit-cost ratios above one.

Table 1-1 and Table 1-2 summarize the benefit-cost ratios for each device and six combinations of devices. The tables also include a range of ratios using 90-percent confidence intervals for the input variables. Even when considering the range, only SODS (highlighted in the table in yellow) and combinations containing SODS have a high-end estimate above one. While advanced safety systems are appropriate and financially justifiable for high-speed applications such as over-the-road trucks and passenger cars, they do not appear to be as beneficial in the transit operating environment, where low-speed, low-impact collisions are often unavoidable.

Table 1-1: Range of Benefit-Cost Ratios for Standalone Safety Systems[1]

In-Vehicle Safety System Description	Baseline	Range	Estimated purchase price
Forward Collision Warning (FCWS)	0.45	0.22 - 0.81	$1,500
Rear Collision Warning (RCWS)	0.59	0.10 - 1.44	$1,449
Side Object Detection (SODS)	1.43	0.37 - 3.55	$2,550
Forward Object Detection (FODS)	0.26	0.13 - 0.45	$2,350
Rear Object Detection (RODS)	0.14	0.05 - 0.28	$2,550
Lane Departure Warning (LDWS)	0.10	0.04 - 0.20	$900
Pedestrian Detection (PDS)	0.81	0.11 - 1.62	$1,800

Table 1-2: Range of Benefit-Cost Ratios for Integrated (IVBSS) Systems[2]

Package of systems	Baseline	Range	Estimated purchase price
SODS & FODS	1.60	0.47 - 3.79	$2,750
SODS, FODS, & RODS	1.59	0.48 - 3.72	$3,150
SODS & FCWS	1.25	0.37 - 2.93	$4,250
FCWS & LDWS	0.49	0.22 – 0.88	$1,800
FCWS, LDWS, & PDS	0.83	0.21 - 1.61	$3,600
FCWS, LDWS, PDS, & RODS	0.69	0.19 - 1.33	$5,450
All 7 Systems	1.38	0.37 - 3.08	$7,999

When all seven systems are taken together, it is estimated that they can prevent approximately 22 percent of all transit collisions. If all 72,000 transit buses in the United States were equipped, this level of collision reduction would save approximately 15-20 lives, prevent approximately 1,500 injuries, and reduce collision-related costs by nearly $100 million each year. SODS alone would prevent an estimated 11 percent of all collisions, thereby saving about 2-3 lives, preventing 400 injuries, and reducing costs by over $40 million on an annual basis.

[1] Results of benefit-cost analysis in 4.0.
[2] Results of benefit-cost analysis in 4.0.

The benefit-cost analysis rests on several assumptions, including the following two key assumptions:

- First, the analysis assumes that in-vehicle safety technologies will be most effective in addressing incidents that the participating transit agencies considered "avoidable" on the part of the bus operator. Table 1-3 shows that avoidable collisions represent less than one-third of all collisions. This fact has major implications for in-vehicle technologies, which are assumed to be relatively ineffective against the two-thirds of collisions considered "unavoidable." In practice, one or more technologies may prove effective in preventing or mitigating some collisions currently considered "unavoidable."

Table 1-3: Percent of Collisions Judged "Avoidable" by Type of Collision[3]

With vehicle					With pedestrian	With object	All collisions
Front	Rear	Angle	Sideswipe	Other			
28%	16%	14%	18%	32%	35%	90%	29%

- Second, the actual effectiveness of each of these technologies in preventing or mitigating bus collisions has not yet been determined. Given the absence of extensive service histories for these technologies, the study relied on lengthy reviews of over 60 well-documented collision scenarios to assess how each technology is *expected* to perform under each of these scenarios. Once again, the service histories of each of these technologies will need to be extensive, covering thousands of service miles before prevention effectiveness is known with any accuracy. Until such time that the actual effectiveness is measured empirically, the cost-effectiveness of these systems can only be estimated using techniques such as that applied here.

Industry Outreach

There was significant interest in the prospect of reducing collisions, which transit agencies view as costly nuisances that can strain relationships between the agency and its customers, the public and lawmakers. However, many expressed skepticism about IVBSS for several reasons. First, few believed that any in-vehicle system could address collisions without providing a large number of false alarms, given the dense operating environment of transit buses. In addition, many transit buses are already equipped with a variety of technical enhancements, which discourages managers from endorsing the deployment of further add-on systems. Furthermore, transit operators expressed doubt or concern that there will be advances made in the small and fragmented transit market. To elicit a reasonably priced, effective product offering from suppliers, agencies must organize and exert a coordinated demand.

That said, agency staff universally recognize the importance of safety as part of their ability to deliver services to customers, and all were willing to consider adoption of systems that can provide for meaningful collision reduction.

1.4 Recommendations

In-vehicle safety systems have the potential to deliver significant non-financial benefits to operators—most notably, an improved public image. Based on the results of the financial analysis, only SODS (or packages containing side object detection) were found to be cost-effective under common operating conditions. Furthermore, at current avoidable collision rates and system prices, none of the other safety systems were found to be cost effective unless assumptions about collision occurrence and prevention rates were modified. However, pedestrian detection devices were determined to be cost effective for operators with an above-average number of pedestrian collisions and/or high pedestrian collision costs.

[3] Based on data collected from 2 transit agencies for the benefit-cost analysis in 4.0.

Moreover, many of the combinations of devices were cost effective, which suggests that an economy of scales exists, at least for those devices using common underlying technology elements.

Based on these findings and the feedback received from transit operators, the following recommendations are proposed.

Pursue Operational Tests on Those Systems with Higher Cost Effectiveness

Based on the results of this study, it is recommended that the U.S. DOT pursue further operational tests of the systems that appear cost effective. Namely, systems that address object collisions, sideswipes, and pedestrian collisions have the greatest potential to achieve substantial benefits. Among the existing systems, future evaluations should focus on SODS and pedestrian detection systems as likely the most (and potentially the only) cost-effective standalone investments. Due to the low marginal cost associated with expanding the detection capabilities of a SODS to include forward and rear detection, the benefits of such an expansion may be compelling.

Determine True Effectiveness of Systems through Operational Tests

At present, there are no accurate empirical measurements of the effectiveness of bus collision avoidance systems in preventing or mitigating bus collisions. In the absence of such information, the benefit-cost analysis in this study rests on estimated system effectiveness rates based a detailed classification of accident scenarios. It is recommended that the U.S. DOT conduct sufficient operational tests to determine the effectiveness of these systems. Given the results of this study, these tests should again focus primarily on SODS and secondly on pedestrian detection systems as likely the most cost-effective systems. Once the collision prevention effectiveness of these systems has been assessed with sufficient accuracy, the benefit-cost analysis presented here should be updated. The U.S. DOT may also wish to conduct more limited testing of the remaining collision avoidance systems (although the lower frequency collision reduction rates and lower cost savings expected with these systems may make it difficult to obtain a definitive assessment of these systems' overall effectiveness).

Develop a Comprehensive Operational Test and Deployment "Roadmap"

Develop a comprehensive operational test and deployment "roadmap" similar to that outlined in 6.0. This roadmap and its related standards for designing and implementing operational tests will help ensure that test cases are well considered (e.g., using proper control group comparisons), results are properly measured, and the findings are robust.

Focus on Human Interface Components

Further development of any in-vehicle systems for transit should consider additional improvements to system human interface components to minimize operator interaction requirements, maintenance needs, and false alarms.

Integrate Existing Bus Systems

Focus transit technology resources on integrating existing bus systems to make the acquisition of systems more efficient, simplify the level of technical sophistication required by agency operations and maintenance staff, and reduce the number of operator distractions, allowing them to focus their attention on their core competency—operating a motor vehicle.

Deliver a Consistent Message to the Transit Industry

During on-site interviews and a roundtable session, managers at many agencies expressed concern that the U.S. DOT's progress in helping to develop, test, deploy, and encourage safety systems in the transit market appeared slow, which has caused some agency decision-makers to question whether this is a sign that there is little value in studying and deploying safety devices. Should the U.S. DOT decide to invest additional resources in the development of IVBSS for transit, it is imperative to deliver a consistent message to agencies on the level of federal commitment to the program, and to communicate progress regularly to the industry so that agencies do not draw inaccurate conclusions about the efficacy of safety systems.

2.0 INTRODUCTION

2.1 Background

Roadway collisions take a significant toll on society. In 2005, there were over 42,000 fatalities and 2.5 million injuries in over 6.2 million police-reported crashes. This problem extends to transit buses, which annually are involved in over 15,000 federally reported collisions, leading to approximately 100 fatalities and 7,500 injuries. Moreover, collision records from six transit agencies participating in this study suggest that approximately 85,000 additional minor, property-damage-only (PDO) collisions go unreported each year.

Proportional to the number of passenger-miles traveled, the likelihood of injury or death in transit bus-involved crashes is far smaller than for any other mode of roadway travel. However, the rate of collision incidents is nearly four times higher for transit buses than for all modes, as shown in Table 2-1. Moreover, the mix of collision types for transit buses is different from the collision mix experienced by other roadway modes, as shown in Table 2-2. Notably, the proportion of transit bus collisions that involves sideswipes is far greater than that of all roadway travel modes.

Table 2-1: Safety Summary for Transit Buses vs. All Roadway Modes (PMT= Passenger-Miles Traveled)

	Transit buses[4]		All roadway modes[5]	
	Number	Rate per million PMT	Number	Rate per million PMT
PMT (millions)	22,000	n/a	4,700,000	n/a
Crashes	100,000	4.55	6,200,000	1.32
Fatalities	80	0.004	43,000	0.009
Injuries	7,500	0.34	2,700,000	0.57

Table 2-2: Mix of Collisions by Type for Transit Buses vs. Other Modes[6]

Mode	Collisions with vehicles			Other/non-collision[7]	Pedestrian collision	Object collision
	Front/rear	Angle	Sideswipe			
Transit Bus	30%	11%	33%	13%	2%	10%
All Roadway Modes	30%	29%	8%	4%	2%	27%

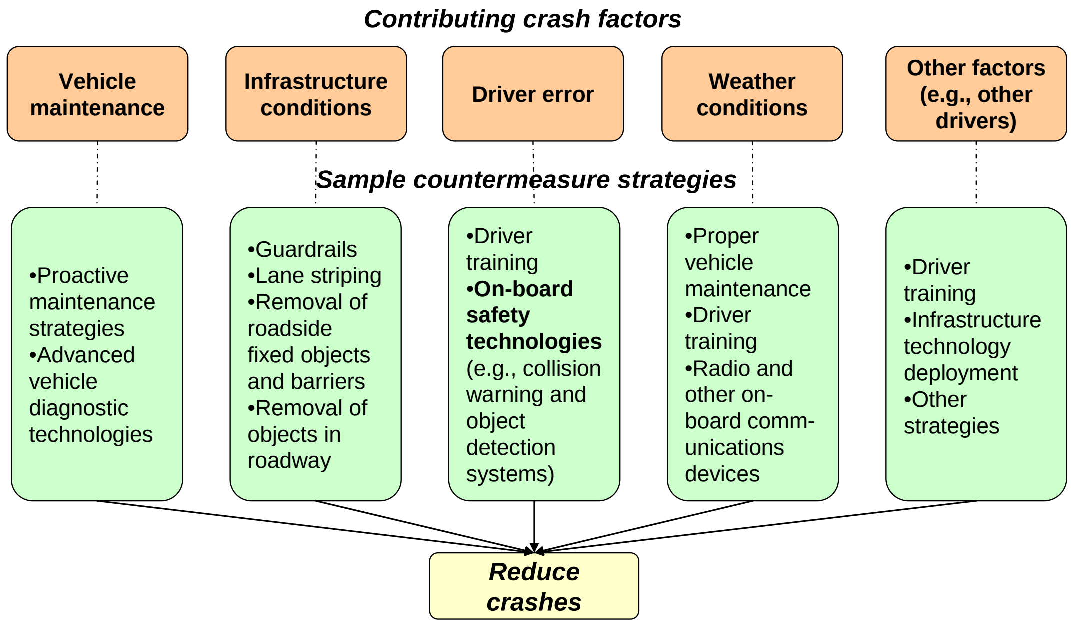
For transit agencies, however, the safety problem goes deeper than collision, fatality, and injury rates. Agencies must also address the financial costs directly associated with collisions, including accident repairs, claims payments, legal fees, workers' compensation, and lost productivity. Collisions can also disrupt bus service and cause delays for all roadway users, inhibiting the operator's ability to fulfill its mission to the public. Furthermore, public perceptions of safety can be tarnished by a single incident, thus eroding the trust and confidence of riders, lawmakers, and funding agencies and generating unfavorable media attention.

A systematic strategy for improving bus safety at transit agencies must begin by building an understanding of the causal factors that contribute to vehicle collisions. Such factors include bus operator errors, errors by other drivers, weather, infrastructure conditions, and vehicle conditions. Strategies

[4] Source: Estimated based on 2005 National Transit Database (NTD) and collision data collected from a sample of six agencies for this report.
[5] Source: Federal Highway Administration (FHWA) *2005 Highway Statistics* (Table VM-1) and National Highway Transportation Safety Administration (NHTSA) *Traffic Safety Facts* (2005 Data Overview).
[6] The figures in this table corresponding to the "transit bus" mode are based on analysis of data from NTD and collision records provided by six transit agencies participating in this study. The values shown for "all roadway modes" are based on General Estimates System (GES) data.
[7] Includes, for example, road departure crashes, rollovers, and other accidents not otherwise classified.

targeted at reducing collisions must recognize the causal factor that they can influence. Examples of countermeasure strategies for these factors include driver training, deployment of on-board safety devices to assist operators with detection and warning of collision threats, and proactive vehicle maintenance. Figure 2-1 illustrates these causal factors and countermeasure strategies.

Figure 2-1: Collision Countermeasure Strategies



Although each collision can have many causal factors, agency-supplied data indicate that between 10 and 30 percent of all transit bus-involved collisions are primarily the fault of the bus operator, while most of the remaining collisions are primarily the fault of other roadway users. Weather, infrastructure, and vehicle conditions also contribute to bus collisions, but rarely are the sole cause. Given these figures, operator error stands out as the largest single cause of bus collisions that the transit industry can address directly. Most transit agencies recognize this problem and have rigorous training processes for operators. These processes are designed to prevent accidents from occurring through operator training, while enforcing strict disciplinary and retraining procedures for operators who are involved in reported collisions.

At the same time, vendors of advanced technologies and university researchers have begun to develop, test, and market safety systems designed to assist transit bus operators in avoiding collisions with other vehicles, pedestrians, and fixed objects. These systems are in many cases also capable of helping to avoid collisions whose primary cause is not operator error. The purpose of this report is to present findings related to these systems, including their expected performance capabilities, cost effectiveness, and investment risks.

2.1.1 Federal Safety Technology Initiatives

In recognition of the need for improved roadway safety, including transit bus safety, the U.S. Department of Transportation's (U.S. DOT's) Intelligent Vehicle Initiative (IVI) began in the 1990s. The goal of the program was to improve vehicle safety for all modes of roadway travel through development and deployment of advanced in-vehicle safety systems. Since then, a variety of systems has been studied for application to passenger cars, heavy trucks, and transit buses. Specific systems evaluated under the IVI program include the following:

- Forward collision warning
- Side object detection
- Rear impact collision warning
- Vehicle lane-assist
- Driver-vehicle interfaces (DVI) for all safety devices

More recently, as the number and variety of on-board safety systems have expanded, vehicle manufacturers and operators have expressed interest in integrating them, in hopes of reducing investment costs while increasing the benefits of deployment. Recognizing the potential to improve the performance and accelerate the adoption of safety systems, the U.S. DOT initiated the IVBSS program. The U.S. DOT's IVBSS program has the following goals:

- Integrate/simplify technologies
- Increase safety benefits
- Improve overall system performance
- Reduce system cost (e.g., due to economies of scale in system design or production)
- Improve acceptance of in-vehicle technologies among bus operators and transit management
- Enhance marketability of safety devices for transit.

Among passenger vehicles and heavy trucks, IVBSS has progressed to widespread demonstration and evaluation. Despite the progress in the auto and heavy-truck markets, adoption of in-vehicle safety systems by transit bus operators has been slow.

2.1.2 IVBSS for Transit

Two primary reasons likely account for the slow adoption of in-vehicle safety systems in transit. First, the size of the transit bus market is relatively small compared to the passenger car and heavy truck markets. There are approximately 72,000 transit buses in the United States, with average replacement cycles of 12 years or longer. By contrast, approximately 15 to 20 million new passenger cars are purchased each year, and the total fleet size now exceeds 230 million in the United States alone. The population of heavy trucks is well over 1 million, with average replacement cycles of 3 to 5 years. Given transit's significantly smaller market size, many safety system manufacturers and vendors are understandably less interested in developing systems that meet the specific safety needs of transit operators.

Second, the operating environment of a transit bus is different from the driving environments generally experienced by other vehicle types. Specifically, transit buses tend to operate in densely trafficked urban settings, make frequent stops, interact often with passengers and pedestrians (e.g., at bus stops and crosswalks), and operate at relatively low speeds (i.e., average bus operating speeds are 12 mph). In contrast, autos and heavy trucks tend to travel at significantly higher average speeds, over many highway miles of travel, in lower traffic densities, and with less pedestrian interaction. Given that the vehicle safety systems evaluated under IVI were developed primarily with the larger auto and truck markets in mind, many are not well suited to addressing the types of threats typically encountered in the transit operating environment. For example, lane-departure warning, adaptive cruise control, and rollover stability control systems focus on preventing or mitigating crashes that occur most frequently in high-speed, long-haul environments.

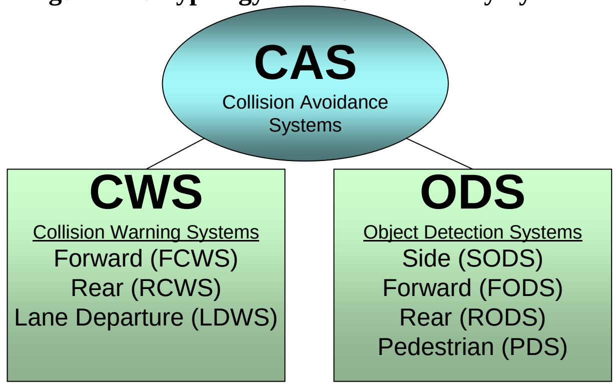
Despite these challenges, a small number of suppliers has developed and is currently marketing safety systems whose functionalities address the unique requirements of the transit operating environment. University researchers have also developed prototype systems for testing. Many of these commercially available products and research prototypes either have been tested or are currently being tested on transit agency vehicles. These commercially available products and research prototypes include the following safety system types, collectively referred to as Collision Avoidance Systems (CAS):

- Forward Collision Warning System (FCWS)
- Rear Collision Warning System (RCWS)
- Side Object Detection System (SODS)
- Forward Object Detection System (FODS)
- Rear Object Detection System (RODS)
- Lane Departure Warning System (LDWS)
- Pedestrian Detection System (PDS)

For purposes of this study, bus in-vehicle CAS have been separated into object detection systems (ODS) and collision warning systems (CWS). Figure 2-2 illustrates this typology. As a rule, ODS monitor the area in close proximity to the vehicle and detect objects that are not within the view of the driver. Systems available at this time include front, side, and rear object detection. Most manufacturers of non-video-based ODS do not guarantee that their systems will detect pedestrians. Their sensing techniques cannot ensure return of a strong reflection from identified pedestrians. However, video-based recognition can be used to detect pedestrians. Therefore, for this study, pedestrian detection systems are considered a distinct category of ODS.

CWS, on the other hand, warn a driver of a potential collision by monitoring the time to contact with an object (not including pedestrians). Forward CWS warn the driver of the equipped vehicle of an impending collision with another vehicle or hard object. Rear CWS are fixed to the rear of the bus and warn other drivers approaching too fast of an impending collision with the bus (the bus operator would not be warned by rear collision warning). Finally, lane departure warning systems (LDWS), although not technically designed to detect impending collisions, use image recognition to warn drivers of impending lane departures. When any two or more of these collision avoidance systems, whether CWS or ODS, are bundled together and "integrated," only then can they truly be considered an IVBSS investment.

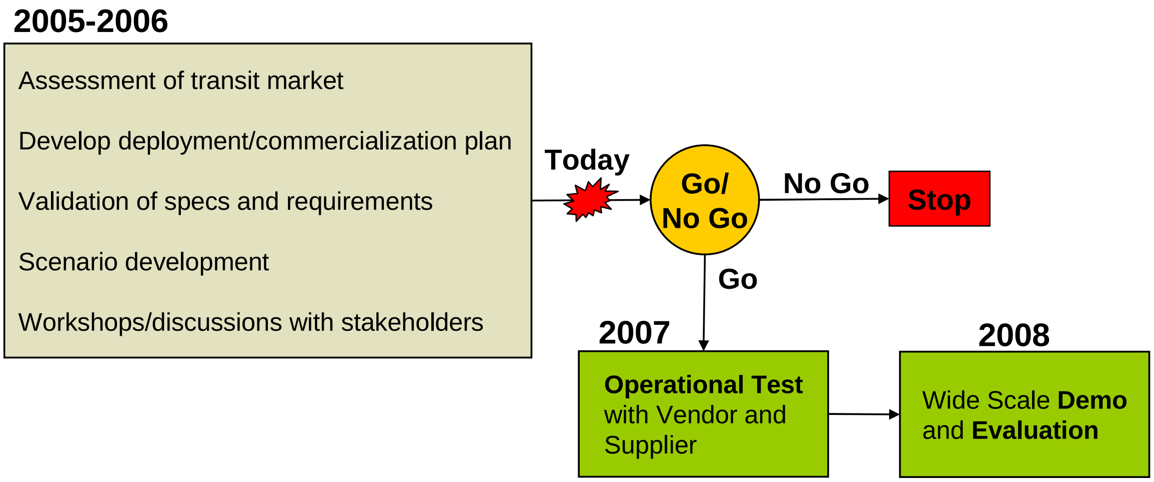
Figure 2-2: Typology of In-Vehicle Safety Systems



2.2 Study Objectives

The primary purpose of this study is to evaluate the business case for (or against) the development of safety systems by equipment vendors and the adoption of those systems by U.S. transit bus operators. Specifically, the study addresses the question of whether the expected benefits from investing in these systems (e.g., expected vendor sales or agency reductions in accident costs) outweigh the costs. Based on this study and other related analyses, the U.S. DOT will make a determination of whether further investment in transit-based versions of these systems warrant investment in additional operational tests, demonstrations, and evaluations. This report represents an input to that "go/no go" decision. Figure 2-3 presents a schematic of the U.S. DOT's decision-making process for further investment in transit IVBSS.

Figure 2-3: U.S. DOT Decision-Making Process for Transit IVBSS



In addition to evaluating the financial benefits and costs of investment in safety systems, the study also addresses several questions of interest to potential IVBSS investors. These questions include:

1. What is the current state of the art? What types of safety systems are available, how do they work, and how effective are they likely to be in reducing collision frequency and collision severity?
2. Under what circumstances will transit operators deploy these systems? What characteristics do transit operators want these systems to have in terms of cost, maintainability, and human factors? How effective do the systems need to be before agencies will invest?
3. Are there any "show stoppers"? Do transit operators harbor any key concerns or investment risks (e.g., potential liability issues) that will effectively dampen or prevent widespread deployment of IVBSS and related systems?

2.3 Study Approach

This study adopted a three-pronged approach to evaluating safety systems as they apply to transit buses:

1. **Technology Evaluation:** Identified and evaluated the functional and technical characteristics of commercially available collision avoidance systems applicable to transit buses.
2. **Benefit-Cost Analysis:** Conducted a benefit-cost analysis of various safety systems (both individually and in integrated "IVBSS" packages) from the perspective of an investing transit agency to determine whether investment benefits exceed direct agency costs.
3. **Industry Outreach:** Conducted outreach sessions with transit operators to document their perceptions of these systems as well as the qualitative risks, rewards, and concerns that determine their interest in investing in these and similar systems.

2.3.1 Technology Evaluation

This study's technology evaluation provides a comprehensive review and assessment of all commercially available CAS and a brief assessment of potential future product offerings. The evaluation was completed using data from a wide range of sources including reports from prior technology evaluations and field tests, product supplier technology specifications, interviews with supplier representatives, interviews with users, and other research relating to in-vehicle safety systems. In addition to yielding a solid understanding of the differing objectives and operating principles behind each of these systems, this review provided an understanding of the expected effectiveness of these systems, which was essential to development of the study's benefit-cost analysis.

2.3.2 Benefit-Cost Analysis

Each of the seven CAS is designed to reduce the frequency or mitigate the severity of one or several specific types of collision. For example, SODS are designed to reduce the incidence of sideswipe vehicle collisions and collisions with fixed objects. The cost-effectiveness of any given bus CAS is largely determined by the following four factors:

1. **System Cost:** What does it cost to purchase, operate, and maintain the system?
2. **Collision Frequency:** What types of collisions is the system intended to address and what is the frequency of those collision types? Also, what is the range (and frequency) of severities for collision types addressed by the system?
3. **Collision Cost:** What is the typical cost of collision types addressed by the system (for each level of severity)?
4. **System Effectiveness:** How effective is the system in reducing the frequency and/or the cost of these collision types?

Obtaining answers to these questions is critical to the process of evaluating the business case for all seven bus CAS, both as standalone systems and as integrated investments. Systems will tend to perform best if they are both low cost and effective in preventing or mitigating accidents of high frequency and/or high cost. For example, while the cost of collisions in which no one is injured is generally low (relative to other collision types), the frequency of these collisions is very high. Consequently, any system that is reasonably effective in preventing or mitigating collisions of these types should also perform well from a financial perspective. In contrast, while fatal collisions are financially very costly, they are also extremely rare in the transit industry (with fewer than 100 people killed in transit bus-related collisions each year, approximately one-quarter of whom are pedestrians). Because of the relative rarity of pedestrian injuries and fatalities, systems designed to reduce pedestrian collisions need to be very effective in preventing or mitigating such incidents in order to be financially effective.

It is also important to recognize that the interplay of the four factors identified above can vary significantly from one transit agency to the next. Each transit agency's safety performance is unique and, by extension, the frequencies and costs of each collision type vary between agencies. Given this interplay, systems that are not cost-effective for some transit operators may prove highly effective for others. Similarly, system effectiveness could vary within a given agency if the operating environment varies sufficiently across that operator's service area (e.g., a system may be effective in dense urban traffic but not on suburban routes). The sensitivity analysis presented in below addressed these issues.

While recognizing the above issues, the objective of the study's benefit cost-analysis was to determine which bus CAS—either individually or in integrated systems of two or more systems—appear cost-effective from the viewpoint of a transit agency (i.e., the investment benefits exceed the investment costs). The benefit-cost analysis first assessed the frequency and cost of actual transit bus collisions by type and by severity. To do so, collisions were segmented into a matrix of seven collision types and five collision severities (yielding 35 unique collision type/severity combinations). Table 2-3 presents a summary of collision rates.

Table 2-3: Annual Frequency of Collisions by Type and Severity per 1000 Transit Buses[8]

Severity	Collisions with vehicles					Collisions with pedestrians	Collisions with objects	Total	% of Total
	Front	Rear	Angle	Side-swipe	Other				
Major fatal	0.2	0.2	0.1	0.0	0.0	0.4	0.0	0.9	0%
Major non-fatal	6	5	4	2	1	0	1	18	1%
Non-major with injury	15	12	8	3	2	4	10	48	3%
Non-major PDO	36	28	20	8	5	4	10	111	7%
Not FTA-reported	161	198	138	494	193	21	143	1348	88%
Total	218	244	170	507	202	27	158	1526	100%
% of Total	14%	16%	11%	33%	13%	2%	10%	100%	

This segmentation permits a more precise categorization and understanding of the costs associated with collisions of each type and severity than has been considered in prior benefit-cost analyses of these systems. Specifically, using this segmentation, each safety technology could be assessed based on its ability to prevent or mitigate the costs associated with those specific types of collisions that technology was intended to address (e.g., side-object detection systems were assessed in terms of their ability to prevent or mitigate sideswipe collisions and collisions with fixed objects impacting the side of the bus). Data to support these estimates were obtained from Federal Transit Administration's (FTA's) National Transit Database (NTD) and from six transit agencies. The agencies were: 1) San Francisco Municipal Railway (Muni), 2) Alameda County Transit Authority (AC Transit), 3) Los Angeles County Metropolitan Transportation Authority (Metro), 4) North County Transit District (NCTD), 5) Chicago Transit Authority (CTA), and 6) Greater Cleveland Regional Transit Authority (GCRTA). The complete analysis assesses how the cost of investing in each safety system (either individually or in integrated systems with more than one system) compares with the benefits.

2.3.3 Industry Outreach

Finally, the study included outreach sessions designed to obtain input from U.S. transit agencies on their perceptions, interest in, and concerns with safety systems. These sessions included both a multi-agency roundtable session conducted during the October 2006 American Public Transportation Association (APTA) Annual Meeting in San Jose, CA, and extensive on-site meetings with management and staff of six different transit agencies from across the country. These interactions generated a wealth of

[8] The number of collisions "Not FTA-reported" was estimated based on data provided by agencies participating in this study. All other data were obtained directly from NTD.

information about agency perspectives on anticipated system deployment issues, including those relating to investment risks, driver acceptance, anticipated system effectiveness, experiences with new system investments in general, and their interest in IVBSS in particular.

2.4 Report Format

The remainder of this report provides detailed results of the research and analyses. Chapter 3 "Technology Assessment" summarizes safety systems for transit buses, including those currently available and those under development. Chapter 4 summarizes the benefit-cost analysis and results. Chapter 5 discusses the "soft business case" based on qualitative feedback from a sample of transit agencies that participated in this study. Chapter 6 suggests steps for future study and deployment. Finally, Chapter 7 summarizes the findings and recommendations for transit IVBSS.

3.0 TECHNOLOGY ASSESSMENT

The objective of this chapter is to provide a comprehensive assessment of the types of collision avoidance systems (CAS) that are either commercially available or for which prototype systems exist. Table 3-1 provides an overview of the reviewed technology. The table depicts the categories of systems used for analysis in this study, the sensor technologies used in each system, the companies currently manufacturing each system, and a description of the commercial availability of each system.

The sections in this chapter correspond with the column headings in Table 3-1. The first section begins with a description of each CAS. The next section reviews the general types of sensor technologies underlying the various existing CAS. Section 3.3 then provides detailed descriptions of the two commercially available CAS suitable for use in transit bus operations. Section 3.4 describes the three prototype CAS used in transit operational tests and provides an overview of safety systems available in the heavy-truck market. Finally, Section 3.5 discusses collision avoidance systems in the truck market (not represented in Table 3-1).

Table 3-1: Overview of Collision Avoidance Systems

Collision Avoidance Systems	Sensor Technology	System Manufacturer	System Availability
FCWS	Video	Mobileye	Commercialized
	Lidar/Radar	PATH	Prototype
RCWS	Lidar	AATA / UMTRI	Prototype
SODS	Ultrasonic	Clever Devices	Commercialized
	Video	Mobileye	Under development
FODS	Ultrasonic	Clever Devices	Commercialized
RODS	Ultrasonic	Clever Devices	Under Development
	Video	Mobileye	Under development
LDWS	Video	Mobileye	Commercialized
	Video	Iteris	Commercialized - trucks only
	Video	Assistware	Commercialized - trucks only
PDS	Video	Mobileye	Application only

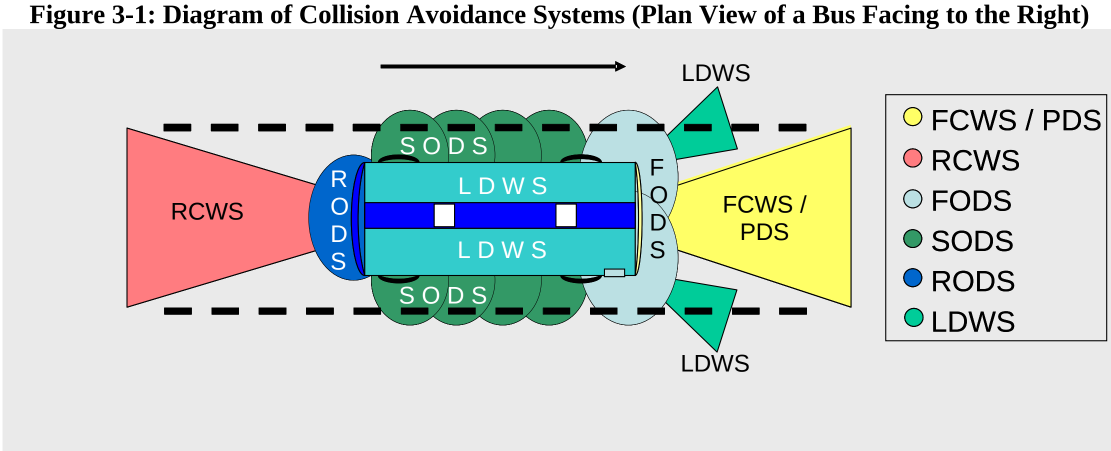
The key findings of this chapter include the following:

- Only two CAS are currently commercially available in the transit industry.
- Only the RCWS is envisioned as a standalone product; the remaining CAS either exist as part of or are planned to be part of a bundled package of two or more integrated systems.
- The dominant technologies used for CAS are video and ultrasonic detection. Video detection uses cameras together with object recognition algorithms and software to identify potential threats to vehicle safety, while ultrasonic detection uses radar waves to identify the location and proximity of objects.

3.1 Collision Avoidance Systems

In 1990, a little-known research and development company, Radar Control Systems, debuted one of the first forward collision warning applications in anticipation of a new and emerging market for intelligent vehicles. The system used a radar transmitter/receiver to scan traffic in front of the vehicle. By processing collision warning algorithms, the application was capable of predicting an impending crash and aiding the vehicle in reacting prior to the collision. Since 1990, CAS expanded to include a broad array of additional applications, including FCW, LDW and automatic cruise control, all designed to assist drivers and improve safety. CAS provides the drivers with knowledge of the environment surrounding the vehicle with the intention of reducing the probability of accidents. Figure 3-1 depicts the "zone" of applicability of the various CAS. CAS can be divided into two basic categories: 1) object detection systems and 2) collision warning systems. Each system is described in detail below.

Figure 3-1: Diagram of Collision Avoidance Systems (Plan View of a Bus Facing to the Right)



3.1.1 Object Detection Systems

Object detection systems (ODS) are intended to monitor the area within close proximity of the vehicle (e.g., up to 10 feet) and provide a visual or audible warning when an object is detected near the vehicle. Given this small proximity, ODS are sometimes considered an "enhancement" to the driver's mirror. These systems can detect the *presence* of an object but not its distance or relative speed. In Figure 3-1, ODS are represented by the circular shaped areas. They are defined as follows:

- **FODS** – As shown by the gray/light blue-shaded area, FODS monitors the area in front of a vertical plane intersecting the front bus wheels (the area within the forward view of the driver).
- **SODS** – As shown by the dark green area, SODS monitors the area behind the vertical plane intersecting the front bus wheels. It does not include the area behind the vehicle, only the area from the front wheels, down the side of the bus, to the rear bumper.
- **RODS** – As shown by the dark blue area, RODS monitors the area directly behind the vehicle.

3.1.2 Collision Warning Systems

Collision warning systems (CWS) monitor distances further away from the vehicle (up to 500 feet) and warn the driver of impending collisions. Algorithms use distance and relative speed information supplied by the detection sensors to calculate the time to contact a detected object, and then provide the driver with visual or audible warnings that increase in intensity as the time to contact approaches zero. The systems will provide warnings to the driver as vehicles/objects enter the field of view or as the vehicle approaches a fixed object.

Figure 3-1 illustrates the different type of CWS with triangular shapes. They include the following:

- **Forward Collision Warning System (FCWS)** – Shown in yellow, FCWS uses forward-looking sensors and warns the driver of the "Time to Contact" with a vehicle in the driver's lane. Forward sensors are situated in the front of a vehicle with a widening view as they scan farther ahead.
- **Rear Collision Warning System (RCWS)** – Shown in red, RCWS warn the driver of an approaching vehicle of a rear-end collision. The warning is an external indicator on the back of the equipped bus that alerts the driver in the approaching vehicle. (The driver of the equipped vehicle is not alerted of the impending collision.)
- **Lane Departure Warning Systems (LDWS)** – As shown by the green area, LDWS are camera-based systems that monitor lane markings. Together with object recognition software and algorithms that compute closing distance, LDWS provide warnings when a lane or road edge departure is imminent via visual, audible, or tactile warning signals.

3.1.3 Pedestrian Detection System

Pedestrian detection systems (PDS) notify the vehicle operator of an impending collision with a pedestrian. The systems can be designed to provide cocoon or direction of travel coverage. Due to constraints with radar and Lidar sensors, video-based recognition accounts for the majority of technologies used to implement pedestrian detection. The systems use pattern recognition and optical flow techniques to differentiate between a pedestrian and an inanimate object. PDS detect pedestrians through a search of objects containing specific characteristics. The systems then separate a potential pedestrian from the background images. The software compares body ratios, specific size constraints, etc. to differentiate a non-human object from a pedestrian. A PDS has a normal range of 10 to 40 meters.

3.2 Sensor Technologies

Each collision avoidance system relies on at least one of the following four underlying detection technologies:

- Lidar, which are radar-like systems that function at near-infrared wavelengths
- Traditional radar-based systems
- Ultrasonic-based sensors
- Video-based systems

The role of these technologies is to provide information on the presence of objects near a vehicle, the proximity of those objects and, for some technologies, the differences in the relative speeds of the bus and the detected object. The selection of which specific detection technology to use in developing any given collision avoidance system depends directly on the system's intended application, the desired performance characteristics, and the supplier's design philosophy. The following are brief descriptions of each of these detection methods.

3.2.1 Lidar-Based Systems

Lidar-based systems transmit a light beam to the area surrounding the vehicle and then detect the presence of nearby objects through the reflected signal. In addition to direction, Lidar systems can determine an object's distance and relative speed. The ideal operation range for Lidar is 2 to 30 meters over which this technology provides excellent angle resolution. Lidar systems are susceptible to the weather conditions (e.g., to being able to "see" through fog or heavy precipitation). In general, if an object is not "detectable" by the naked eye, it is unlikely that a Lidar-based system will provide an adequate warning of an impending collision. Therefore, during times of fog, heavy rain, or heavy snow, the system will become inoperable. Given these characteristics, Lidar-based systems are preferred by those that believe a collision avoidance system should not extend beyond the driver's view. This position is based in part on the concern that systems that extend the driver's view beyond what is visible with the naked eye may encourage reckless driving, particularly in poor weather conditions. Lidar sensors have a high cost of implementation and the output power level must be limited to meet eye safety constraints due to the light beam operating in the near-infrared range.

3.2.2 Radar-Based Systems

In contrast to Lidar, the performance of radar-based systems is not adversely affected by poor weather conditions. Hence, this technology is favored by those who believe collision avoidance systems offer their greatest benefits during adverse weather. Radar-based systems are capable of detecting objects out to 150 meters but suffer from low angular resolution, poor detection at medium range (i.e., 30 to 60 meters), and generally inferior resolution to Lidar. As with Lidar, radar sensors have a high cost of implementation.

3.2.3 Ultrasonic-Based Sensors

Ultrasonic-based sensors are reliable and inexpensive. They operate at a high frequency (20 kHz to 200 kHz) and are similar to the back-up sensors installed on sports utility vehicles. The sensors emit an ultrasonic signal that is capable of traveling 10 to 12 feet. The system detects the object when a recognizable echo is reflected from it and can measure the detected object's distance and relative speed. Sensors provide a clear signal for detection algorithms and are less influenced by interference than are radar and Lidar. Their disadvantage is the limited detection range; they cannot detect objects beyond a small area around the vehicle. In addition, they are only capable of providing a recognizable echo from solid objects. Therefore, they should not be used for "soft object" detection (e.g., pedestrians).

3.2.4 Video-Based Sensors

Video-based sensors use a forward-looking camera for detection of objects. A pixel-based recognition algorithm identifies objects that may be of concern to the driver. The use of pixel-based recognition can distinguish pedestrians from other objects, a form of detection that is not possible with Lidar, radar, or ultrasonic-based systems. With the low-cost of the camera, video-based sensors have a low cost of implementation. Video-based sensors rely on ideal lighting conditions for detection. Therefore, in situations where the driver's field of vision is impaired, the system will not function well (including adverse weather conditions, direct sunlight, evening). In the video systems reviewed below, the video-based suppliers supplemented their systems using infrared sensors to ensure object detection under a greater range of conditions than that permitted by a video-based system alone.

3.3 System Manufacturers

Market research conducted for this study only identified two companies interested in supplying collision avoidance systems to the transit bus market. Beyond these two suppliers, commercial and passenger vehicle suppliers have shown little interest in expanding their line of business to include transit buses given the small size and specialized needs of the transit market. A number of commercial companies were contacted to determine the reasons for lack of interest. This information is in the section entitled, “Prototype Systems.”

3.3.1 Clever Devices

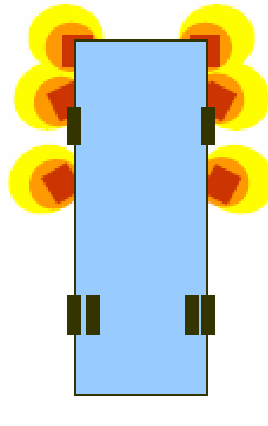
Clever Devices has focused solely on providing technology solutions to the transit industry since 1987. The company’s products provide improved communications and safety systems for the transit agency applications, including passenger information systems and intelligent vehicle systems. Clever Devices entered the ODS market in a partnership with the FTA, Carnegie Mellon University, and the Port Authority of Alleghany County. They developed a prototype as part of the FTA’s Intelligent Vehicle Initiative. The original product, the Enhanced Object Detection System, was refined during the IVI field tests and commercialized as the Seymor System.

Clever Devices’ Seymor System is marketed specifically for object detection within a transit bus application. The system was designed to be an extension of the driver’s mirrors, providing blind-spot coverage. Ultrasonic sensors detect non-stationary objects within a defined perimeter (Figure 3-2). The sensors are installed at six locations on the vehicle—one sensor on each front corner and one sensor each fore and aft of the left/right front wheels (Figure 3-3). Sensors may also be installed at the rear of the vehicle for backing functions. The sensors transmit a signal and detect objects based on a recognizable echo reflected from an object.

Figure 3-2: Clever Device’s Ultrasonic Sensor[9]

[9] Source: Clever Devices – *Installation, Operation, and Maintenance Instructions for Seymor Object Detection System. Revision 1.1,* November 2004.

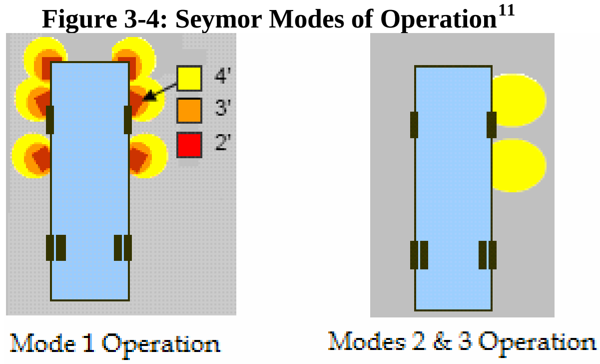
Figure 3-3: Seymor System Sensor Locations[10]



The system employs three distinct modes of operation (Figure 3-4) based on the vehicle speed:

1. **Mode 1** – When the system is operating in an urban/slow environment (0 to 15 mph), the system will detect objects within a 4-foot perimeter of each sensor. All sensors within the system will be active. If the system detects an object, a visual aid will flash with a frequency based on object distance. (In Figure 3-4, the yellow area equates to 4 feet.) As the object moves closer to the vehicle, the frequency of the blinking light increases. Finally, an audible tone will sound when the object is within 2 feet of the vehicle.
2. **Mode 2** – When the system is operating in an urban/fast environment (15 to 45 mph), the system will detect objects only when a turn signal is activated. With an activated turn signal, the detection zone is a 6-foot perimeter of the side sensors in the direction indicated by the turn signal. The front sensors are inactive at speeds over 15mph. If the system detects an object, it issues a solid visual indicator in conjunction with an audible alarm. (Note: Figure 3-4 shown with right turn signal activated.)
3. **Mode 3** – When the system is operating in a highway environment (45+ mph), the system will operate similar to the Mode 2 with the exception of a detection zone of 8 feet for the activated side of the vehicle. (Note: Figure 3-4 is shown with right turn signal activated.)

Figure 3-4: Seymor Modes of Operation[11]



The Seymor System communicates object detection through visual and audible warnings to the driver (Figure 3-5). Three identical visual driver displays are mounted within the peripheral line of sight of the side mirrors (one at the left mirror, and a high/low mounting at the right mirror; see Figure 3-6). As the

[10] Ibid.
[11] Ibid.

operator uses the mirrors for turning maneuvers or lane changes, he/she can reference the displays to determine whether unseen objects are present. A flashing display (frequency determines distance of object to vehicle) will notify the operator of a potential object in the path of the vehicle. A speaker is mounted behind the driver's seat to provide audible warnings as the threat of the object increases.

Figure 3-5: Seymor Driver Visual Interface (DVI)[12]

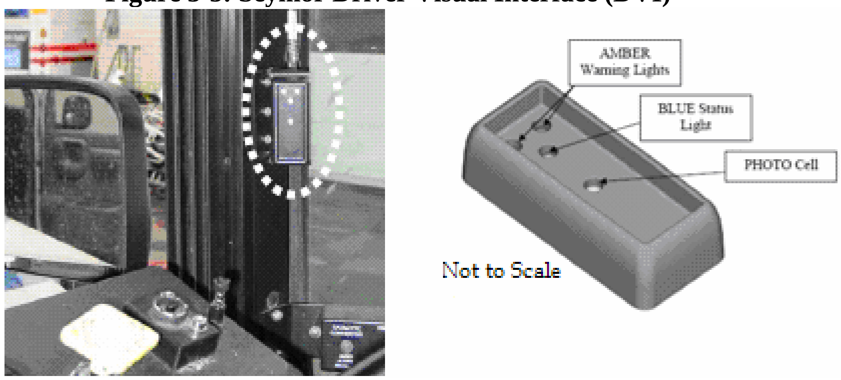
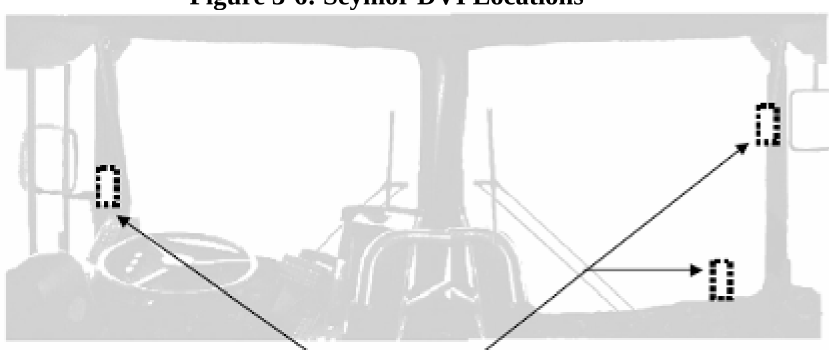


Figure 3-6: Seymor DVI Locations[13]



The Seymor System has the following properties and characteristics:

- **Detection Options:** The Seymor System is designed for front and side object detection as the standard model. Clever Devices is in the development stages for a RODS. Combined with the standard system, the RODS would provide a cocoon surrounding the vehicle for detecting objects. A standard system (front only) costs $2,600 to $2,900 (excluding engineering design customizations). The system includes a standard 1-year warranty and maintenance option. The projected lifespan of the technology is 10 to 15 years. The RODS is not available for commercial sale at this time.
- **Applicable Properties:** The first generation Seymor System has been installed at the Washington Metropolitan Area Transit Authority (WMATA), the Utah Transit Authority (UTA), the Greater Cleveland Regional Transit Authority (GCRTA), and the Port Authority of Allegheny County (PAAC). Delivery time for the system is approximately 8 to 10 weeks. Installation requires 4 hours per bus. Clever Devices has established a training course for the Transit Authorities for operators and maintenance personnel. The classes take from 0.5 to 1 day. As the system is very intuitive, the training required is minimal.
- **Business Plan:** Clever Devices markets the Seymor System with its corporate capabilities. By attending trade shows and distributing brochures on the technology, Clever Devices has been

[12] Ibid.
[13] Ibid.

marketing the advantages of the Seymor System for the transit agency. As of January 2007, WMATA has installed the system on 50 buses for a year-long trial. Other transit authorities have worked with Clever Devices to develop a system specification to require the installation of the Seymor System in their next vehicle purchase. Clever Devices has not been contacted by bus manufacturers to date, leading the company to believe the specification of their product was not part of the final purchase agreement by those other authorities.

- **Future Technologies:** Clever Devices is currently in the final stages of developing an RODS application. The system has entered the final testing phases and may be released to the market shortly. The application is an upgrade to the existing Seymor Forward Object Detection System. Four sensors would be installed at the rear of the bus to support back-up object detection notification. Cost data for the application has not been released at this time.

3.3.2 Mobileye

Founded in 1999, Mobileye's mission has been to develop vision systems for accident reduction and driver assistance. They have established themselves as a leader in vision systems for intelligent transportation systems. Through the years, the company has developed algorithms and hardware for lane departure warning, headway monitoring, and collision mitigation applications. The technology has been installed as an aftermarket product under the AWS (Advance Warning System) brand name. AWS integrates a series of advanced safety systems for installation as a single collision warning system. Mobileye's products are used in the auto, truck, and transit markets.

Mobileye uses monocular vision analysis techniques to detect vehicles and to measure the distance and relative speed between vehicles and between vehicles and objects. The technique also measures the vehicle position relative to the lane boundaries as well as road geometry and lane curvature to identify the "closest in path" vehicle. Mobileye uses a single video camera mounted on the front windshield and Mobileye's EyeQ CMOS chip to detect objects.

Mobileye's EyeQ product provides a low-cost solution while combining high performance and consolidating multiple applications on a single platform. Installed on a single board half the size of a standard business card (Figure 3-7), it processes visual images along three main areas—pattern recognition (vehicles, pedestrians), image processing (lane following), and visual motion understanding (analysis of collision and cut-in maneuvers). The classification of these visual images allows the system to assist in preventing unintentional lane departure, detecting forward collision scenarios and maintaining a safe headway.

Figure 3-7: EyeQ Chip and SeeQ Board[14]

Mobileye's AWS is an aftermarket driver assistance system for accident prevention and mitigation. It combines the benefits of forward collision warning, lane departure warning, and headway assistance in a

[14] Reprinted with permission from Mobileye Vision Technologies, Ltd.

single package. A single camera is mounted on the front windshield along with the EyeQ processing board (Figure 3-8). The package detects and measures distances to lanes and vehicles to provide timely alerts of impending safety-critical situations.

Figure 3-8: Mobileye's Monocular System - Single Camera with Internal EyeQ Board[15]

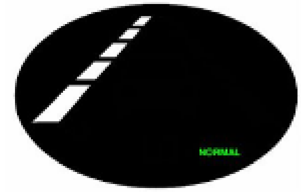
The *Forward Collision Warning (FCW)* application detects situations where the vehicle has the potential to collide with another vehicle if no change is made to the speed or direction of travel. Using EyeQ's vision-based algorithms, the system determines an object's boundaries and classifies the target as vehicles or non-vehicles. If the object is determined a threat, the system tracks the time to contact (TTC) (Figure 3-9). As the TTC falls below 2.7 seconds, the system begins to issue a series of warnings to the driver. The system will continue to monitor the TTC, continuing the alert if the driver does not react to the initial warnings. The application operates at speeds above 3 mph.

Figure 3-9: Mobileye's DVI Demonstrating FCW[16]

The Lane Departure Warning (LDW) application uses a lane detection algorithm to detect lane markings and provide various measurements related to them. The system is capable of detecting a variety of lane markings (e.g., solid markings, dashed markings, and double lane markings) under various weather and road conditions (e.g., asphalt, concrete). The color of the markings and the time of day do not affect the technology. The algorithms measure the distance from the vehicle's wheel to the marking. The vehicle speed with respect to the lane marking is calculated from the vehicle's lateral position, lateral speed, road curvature, and speed. The system will warn the driver of an impending lane departure only if the appropriate turn signal has not been activated. The warning associated with LDW is both an audible (direction rumble sound relative to direction of deviation) and visual (Figure 3-10). The figure demonstrates a left-side lane departure. The system setting is adjustable so that the system will issue a warning when the vehicle crosses the lane marker or when it approaches the lane marker. The application is only active at speeds over 34 mph.

[15] Ibid.
[16] Ibid.

Figure 3-10: Mobileye's DVI Demonstrating LDW[17]

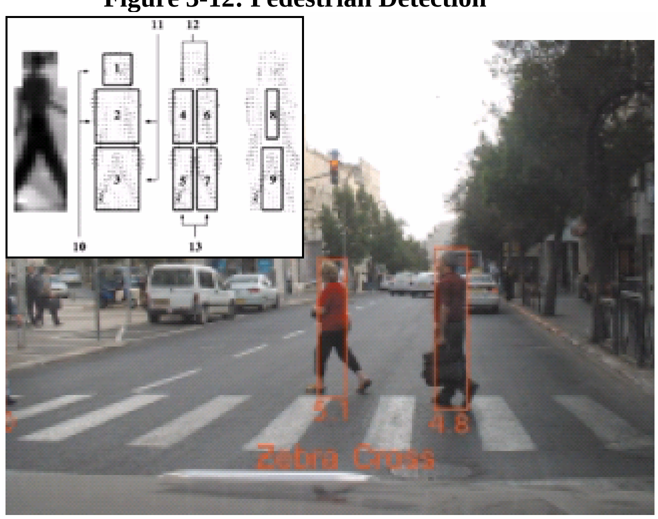


The Headway Monitoring and Warning (HMW) application provides the driver with a digital distance gauge to assist in keeping a safe separation from the vehicle in front. The headway algorithms identify the rear profile of a car in lit situations and the rear taillights in the evenings/unlit conditions. The information detects the closest vehicle in the path of the driver. The vehicle display will provide a headway distance to the detected vehicle, in seconds, after the separation has fallen below 2.5 seconds. As the vehicle closes in on the detected vehicle, the seconds on the display will decrease and the icon will change from green to amber to red (Figure 3-11). Once the headway has reached a dangerous separation, an audible warning will alert the driver. The timing of the audible warning is adjustable based on the level of security the driver desires (early versus late warning). The HMW application is only active at speeds over 25 mph.

Figure 3-11: Mobileye's DVI Demonstrating HMW[18]

Mobileye offers a separate *Pedestrian Detection* technology/algorithm. Mobileye currently provides pedestrian detection as a technology only. The customer is responsible for implementing all applications, including driver interface and detection hardware. The technology uses the monocular vision camera and infrared sensors for night applications (Figure 3-12).

Figure 3-12: Pedestrian Detection[19]



[17] Ibid.
[18] Ibid.
[19] Ibid.

The pedestrian detection application is one of several advanced development programs for production by automotive original equipment manufacturers (OEMs). Using the basic monocular camera (as used within the AWS-4000 system), the algorithm can detect pedestrians based on the visual spectrum. To achieve daylight performance levels regardless of lighting conditions, a near infrared sensor is required. The system can effectively detect passengers/pedestrians within a 30-meter range. In a future aftermarket application, the system will be paired with a visual/audible alert for the driver. The visual alert is implemented through an LED or other icon on the driver's display. An audible warning is annunciated through the existing speaker system. The mid-range detection option can be expanded to include 360-degree coverage. The all-around option is implemented with six individual cameras installed around the vehicle. The range of the detection is shortened to 15 meters, and is intended for scenarios with slow-moving vehicles. The driver is notified of a pedestrian as done with the mid-range detection.

The AWS-4000 is a complete package for front collision warning, lane departure, and headway monitoring. The system is bundled and designed specifically for after-market installations. It includes the driver display, the camera/processor combination, and speakers. The unit retails for $1,800 installed. The system has a 1-year warranty and maintenance option, with a lifespan of at least 5 years.

The pedestrian detection application is a sensing application only with the software running on the EyeQ chip or the SeeQ board. The integrators are responsible for providing the appropriate displays to warn the driver of a detected pedestrian. The estimated cost for implementation is $1,800. The system may be bundled with the AWS-4000 for an additional cost.

In addition, Mobileye offers several individual applications to enhance AWS. These applications include:

- **Night Vision (Near/Far Infrared)** – The night vision is required for pedestrian detection. It also enhances the video analysis during the evening or during times of adverse weather.
- **Side Object Warning** – Using the forward collision warning components and software, cameras installed around the vehicle detect slow-moving vehicles. The detection distance is just 45 feet, but the field of view is 90 to 100 degrees. The system is under development at this time with an expected release date at the beginning of 2008.
- **Blind Spot/Lane Change Aid** – Using cameras mounted in the side mirrors, the system analyzes the opportunity to change lanes. It will estimate speed of approaching vehicles and warn if the speed is excessive. The cameras are capable of detecting vehicles in the adjoining lane within 60 meters. The technology has an expected release date of the end of the third quarter in 2008.

The technologies offered by Mobileye could be combined to provide a complete object detection system for the area surrounding the vehicle.

The Mobileye system has been installed on 150 transit buses in Israel. At this time, Mobileye is establishing a distributor network. Installation time should not exceed four hours per vehicle. The system does not require driver interaction after installation, but allows driver customization (e.g., volume, display brightness, and warning level). With a quick-start guide, it is estimated that the operator can begin using the AWS-4000 within 10 minutes.

Mobileye is scheduled to provide its technology to six passenger car production platforms in 2007 (start of production) with a major U.S. and two leading European car manufacturers, including the BMW 5-series. Additional OEMs and Tier 1 suppliers (i.e., those supplying GM, Chrysler, and the other major auto manufacturers) have Mobileye evaluation systems installed in vehicles for advanced development and research programs with an additional number of production intent agreements in place.

Within the next year, Mobileye plans the release of two new data logging technologies. By the end of the second quarter of 2007, a data logging feature will be available for the AWS-4000. Owners will be able to track the driving practices of their operators, including typical headways, number of lane changes, number of illegal lane changes, etc. By the end of the third quarter of 2007, a video accident recorder will be available for the AWS-4000. The video recorder is activated at the time of a collision. The video will record 20 seconds prior to the crash, and continue to record for 5 seconds following the crash. The video can be used for accident reconstruction.

Over the next two years, Mobileye plans to finalize two collision warning/detection technologies. The Side Object Warning technology has an expected release date of the beginning of 2008. The Blind Spot Detection/Lane Change Aid has an expected release date of September 2008.

3.4 Prototype Systems

Several prototype collision avoidance systems for transit buses have been developed and field tested in recent years. These include:

- Rear Impact Collision Warning System (Ann Arbor Transportation Authority)
- Forward Collision Warning System (California DOT)
- Side Collision Warning System (Pennsylvania DOT)
- Integrated Collision Warning System (California and Pennsylvania DOT)
- Pedestrian Warning Devices (PDS)

The following sub-sections describe each of these systems and the known test results.

3.4.1 Rear Impact Collision Warning System

The Rear Impact Collision Warning System (RICWS)[20] was developed by the Ann Arbor Transportation Authority (AATA) in partnership with General Dynamics. The RICWS was a research project to assist the FTA in the mitigation of rear-end transit bus collisions. The system provides warnings to vehicles following a bus as the headway between the bus and the vehicle was reduced (see Figure 3-13).

Figure 3-13: RICWS Installed at AATA[21]

The system used a rear-scanning Lidar sensor, a processing unit, and an 8-segement LED display. The Lidar sensor detects the presence and range of an approaching vehicle. The sensor was capable of detecting a vehicle up to 125 meters, with the vehicle detected before it is within 72 meters. A processing

[20] Ann Arbor Transportation Authority and Kirk Lucksheiter. *Develop Performance Specifications for a Rear Impact Collision Warning System for Transit Systems*. November 2003.
[21] Source: Final Report, *Develop Performance Specifications for a Rear Impact Collision Warning System for Transit Systems*. November 2003.

unit uses the information in conjunction with the bus's speed to determine whether the warning criteria are met. If the processing algorithm determines evasive action may be necessary, the 8cm by 150cm LED is illuminated with increasing warnings. The system is capable of determining the approaching vehicle's time to contact and provide sufficient warning to allow the approaching driver to brake/swerve to avoid a collision. The RICWS is autonomous, and does not impose or distract the driver of the bus. The driver is not warned of the impending crash.

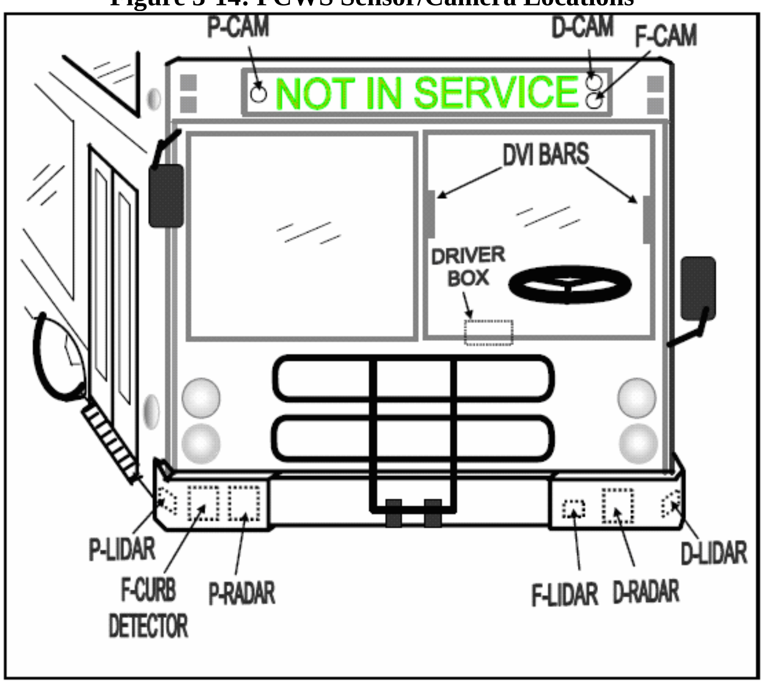
The system has not been commercialized at this time. The field operational test was completed in Ann Arbor on two transit buses in 2003. A specification has been developed for the system, but no further action has been taken.

3.4.2 Forward Collision Warning System

The University of California at Berkley's PATH program developed the Forward (Front) Collision Warning System (FCWS)[22] under the direction of the FTA. PATH worked with the California Department of Transportation and SamTrans to design a system that could detect imminent crashes, provide warnings for smooth maneuvering, and provide warnings for reduced headways. The system, as outlined in the final report, contained five sensors, four cameras, and a single processing unit.

The FCWS contains radar and Lidar sensors to enhance the detection capabilities of the system. Two forward-looking radar sensors are on the right and left front corners of the bus (see Figure 3-14). A single forward-looking Lidar sensor is at the center of the bus. Two forward-looking Lidar sensors are installed in tandem with the radar sensors. The sensors measure the distance and angle to the detected object. The system is capable of detecting objects within the same lane from 3 to 100 meters. The recommended Lidar sensors are deactivated below 3 m/s to ensure the safety of the surrounding pedestrians.

Figure 3-14: FCWS Sensor/Camera Locations[23]

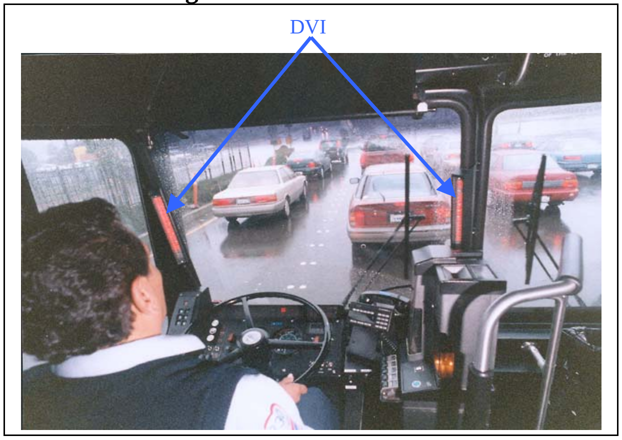


[22] X. Wang, et. al. *Transit Bus Frontal Collision Warning System.* March 2002. X. Wang, et. al. *Development of Requirement Specifications for Transit Frontal Collision Warning System.* August 2003.
[23] Source: Final Report, *Development of Requirement Specifications for Transit Frontal Collision Warning System.* August 2003.

The cameras mounted as part of the FCWS were for recording capabilities only. The video feeds were not used for processing algorithms. Cameras were installed as follows: 1) one forward-looking camera, 2) one backward-looking driver and passenger-side camera, and 3) one internal (passenger cabin) camera. The cameras in conjunction with the sensors identified detected objects during the field tests. The cameras may also be used as an accessory for reviewing injury claims.

The FCWS DVI is a set of vertical columns on the left and center pillars of the bus (Figure 3-15). The columns illuminate from top to bottom to indicate increasing severity. Each column independently operates to notify the operator of the physical location of the object. If the object is in front of the vehicle, both columns will illuminate simultaneously.

Figure 3-15: FCWS DVI[24]



The system has not been commercialized at this time. A specification has been developed for the system, but no further action has been taken at this time. The design was provided to Mark IV for commercialization possibilities. At this time, they have not initiated plans to commercialize the system.

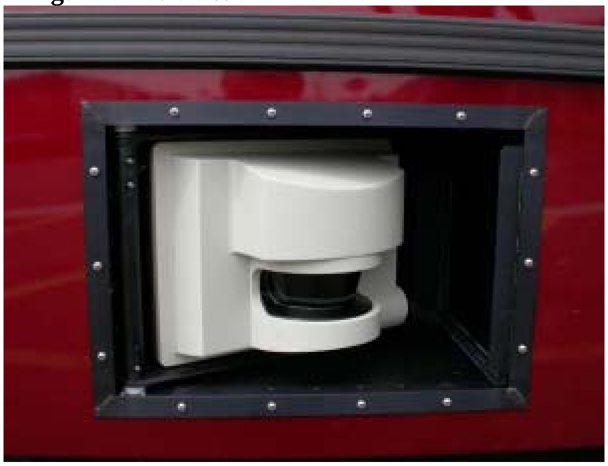
3.4.3 Side Collision Warning System

Carnegie Mellon University's Robotics Institute developed the *Side Collision Warning System (SCWS)*[25] under the direction of the FTA. The Robotics Institute worked with the Pennsylvania Department of Transportation and the PAAC to develop a system that tracked objects surrounding the bus (within a 3-meter perimeter). The system is capable of detecting objects up to 50 meters away. It contains laser scanners for object detection and equipment for curb detection/prediction. In addition to the sensors, the processor monitors the vehicle communications network to establish the bus states (turn signals, speed, warning lights, door status, etc).

The scanners are installed on each side of the bus behind the front wheel and below floor level. They extend four inches from the side of the bus, but are installed within a retractable box. The scanner is capable of detecting an imminent collision, retracting prior to colliding with an object (Figure 3-16).

[24] Ibid.
[25] D. Duggins, et. al. *Developing and Testing of Performance Specifications for a Next Generation Side Collision Warning System*. April 2002.

Figure 3-16: SCWS Retractable Laser Scanner[26]



The intention was for the scanners to predict and warn the driver of a pedestrian under the bus. When the bus was at a speed below 5 mph, the scanner tracks objects/pedestrians as they approach the vehicle. If the pedestrian disappeared after entering a particular range surrounding the bus, the scanner would hypothesize that the pedestrian fell under the bus. To account for pedestrians boarding the bus, the algorithm used the door state of the bus to cancel any warnings that arose in the area of the door during embarking/disembarking. During testing, the pedestrian detection algorithm was not successful. The laser scanner did not clearly differentiate pedestrians from inanimate objects. The original tests showed a number of false positives, suggesting that design enhancements are required prior to implementation.

The curb detector is part of the SCWS for curb prediction and detection. If the system detects a pedestrian on the curb, it is considered safer than if it detected in the roadway. It contains a laser line striper (LLS) and a camera installed inside the front bumper on the non-driver's side. The LLS projects a pattern of light that is imaged by the camera. The results are used to compute distance to detected objects. The system returns the cross-section profile of the environment beside the bus, providing the final distance from the bus to the curb.

The SCWS DVI illuminates a set of arrows to warn of a detected side object. The illuminated arrows represent the location of the object. For example, the top arrow illuminates when an object is detected at the front of the bus, and the bottom arrow illuminates when an object is detected at the back of the bus.

The current plans do not include the commercialization of the SCWS. Not only is cost for the system hardware is cost prohibitive, there are problems with the detection algorithms.

3.4.4 Integrated Collision Warning System (Forward/Side Collision Warning)

The Integrated Collision Warning System (ICWS)[27] combined the research from PATH and the Robotics Institute to integrate the two separate collision warning systems into a single product. The teams continued their work with the California Department of Transportation (Caltrans) and the Pennsylvania Department of Transportation. A complete system was installed on vehicles at SamTrans and the PAAC (Figure 3-17) for a final field operational test.

[26] Source: Final Report, *Integrated Collision Warning System Final Technical Report*. December 2004.
[27] University of California PATH and Carnegie Mellon University Robotics Institute. *Integrated Collision Warning System Final Technical Report*. December 2004.

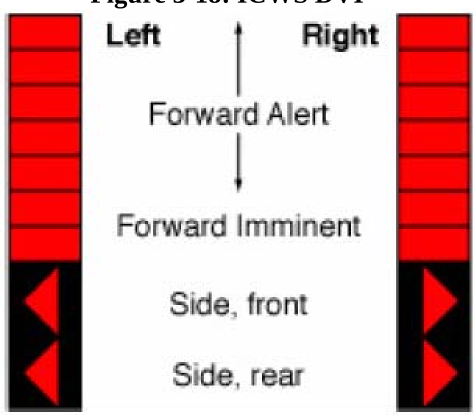
Figure 3-17: SamTrans and PAAC ICWS Buses[28]

Using knowledge from the original development projects, FCWS and SCWS were combined into a single system to provide an ICWS. The systems are linked through a mutual computer, allowing each to operate independently. The mutual computer allows the passing of critical data between the two systems, such as objects that move from the side to the front, via a serial link.

The systems are differentiated via a "plane" that passes vertically through the front wheels of the bus. FCWS processes all objects in "front" of the plane and SCWS processes all objects "behind" the plane. The system does not include collision warning or object detection for the rear of the bus.

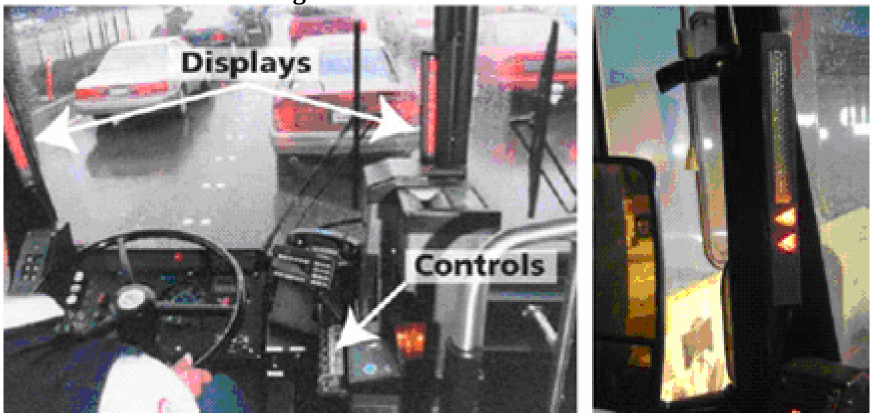
An integrated DVI was installed on the vehicles using the detection techniques for the FCWS and the SCWS. A single display (Figure 3-18 and Figure 3-19) informs the operator of impending crashes at the front or at the side of the vehicle.

Figure 3-18: ICWS DVI[29]



[28] Source: Final Report, *Integrated Collision Warning System Final Technical Report*. December 2004.
[29] Ibid

Figure 3-19: Installed ICWS DVI[30]



a) DVI Illumination for Front Detection b) Illumination for Side Detection

The field operational test was completed at SamTrans and PAAC in 2003, and there is a specification for the system. However, the system is not commercially available and there are no further plans to test it.

3.4.5 Pedestrian Warning Devices

In January 2007, WMATA began a pilot program of PWD on its transit bus fleet. WMATA installed a special warning strobe atop its test fleet of Metrobuses. The yellow warning strobe light (see Figure 3-20) warns pedestrians and motorists of an approaching Metrobus. The strobe lights resemble the warning lights on school buses to increase vehicle visibility. As stated in WMATA's press release, "Metro is the first transit agency in the United States to test warning strobe lights atop buses. We believe this is another helpful safety tool designed to improve pedestrian safety throughout the region."

Figure 3-20: WMATA Safety Warning Strobe Light[31]

3.4.6 Truck Collision Avoidance Suppliers

The market for collision avoidance systems on commercial vehicles far exceeds the available transit-based systems. A prior IVBSS report identified 18 suppliers that currently supply collision avoidance and related technologies to the commercial vehicle market. Of those 18 suppliers, only two companies (Clever Devices and Mobileye) are currently marketing their systems to the transit industry.

[30] Ibid
[31] Source: Washington Metropolitan Area Transit Authority Press Release, www.wmata.com

Three major suppliers of truck collision avoidance systems were contacted to discuss their interest in the transit collision avoidance market. Each supplier voiced similar concerns for not venturing into the transit bus market. These concerns included:

1. Market size is too small.
2. Urban setting presents challenges their technologies are not designed to address.
3. Transit operating speeds are lower than commercial vehicle speeds.
4. Driver fatigue is less of a concern in transit.

The interviewed companies stated that the market size and the perceived low demand did not warrant marketing their systems to the transit industry. The transit industry has limited funding for general purchases, with very little or nothing to spare for the research and development of collision avoidance systems. Therefore, few transit authorities are interested in using their limited funds to install a system that is not yet validated. In addition, transit buses account for just 70,000 of registered vehicles, compared to the 1.7 million commercial trucks registered in the United States[32]. The sheer number of commercial trucks allows a company to make a sound business case to develop a commercial system. A transit authority will only provide limited orders for a particular system. The suppliers would not reap the benefits of mass production, as each transit authority is likely to special order a system.

The systems for commercial vehicles are used in a highway environment, which is characterized by high speeds and minimal contact with non-vehicular objects. In this operating environment, it is logical for the commercial systems to label most detected objects as a potential threat. In contrast, transit buses operate in an urban environment with many inanimate objects and at a slower traveling speed. These conditions render the assignment of a threat very difficult, with an increased likelihood of false alarms. Systems with high false alarm rates will be ineffective if the operators begin to ignore all warnings. One supplier installed its collision warning system on Greyhound buses. Due to the high false alarm rate, Greyhound removed the systems after a single year in operation. The supplier has since completed numerous hardware and software revisions to address the false alarm rate; however, Greyhound has not ventured back into the collision avoidance system market.

One supplier stated that commercial truck drivers experience different driving conditions than transit bus operators. Long-haul drivers frequently experience fatigue. Driver fatigue/inattention may lead to lane drift and smaller following distances. Each of the suppliers interviewed used CAS to assist fatigued drivers. With the shorter driving times, bus operators may not experience the same fatigue as commercial truck drivers. (It should be noted that bus drivers might experience fatigue or boredom because of driving the same or similar routes frequently.)

One benefit of interviewing the suppliers was the in-field experience they had gathered from the operators. One supplier distributed surveys to approximately 300 drivers to solicit feedback on their experience with the collision avoidance system. Of the drivers surveyed, 75 percent felt the system provided adequate feedback to facilitate safer operation of their vehicle. Additionally, 65 percent of drivers felt that the LDWS reduced their fatigue. The drivers were more likely to pull over after receiving an alert for lane drift. The result was presumably reduced fatigue by avoiding additional driving.

An interviewee stated that driver understanding and willingness to accept the product was directly related to the management's implementation of the system. As management provides a proactive approach to the system implementation, the drivers appear to be more receptive to integrating the system into their

[32] Source: Bureau of Transportation Statistics, 2003

routine. This information demonstrates that the successful incorporation of any collision avoidance system will require the support of not only the upper management but also the support of the local union.

4.0 BENEFIT-COST ANALYSIS

The objective of this chapter is to conduct a benefit–cost analysis of collision avoidance systems. The analysis is preliminary, as the effectiveness of these systems in mitigating or preventing collisions (i.e., the benefits) has yet to be fully determined through operational tests. In addition, because of limited development and deployment, the total cost to purchase and maintain these systems remains uncertain. To address these uncertainties, the study's benefit-cost analysis has relied on a detailed assessment of current bus collision frequencies and costs; an assessment of the likely effectiveness of various existing and potential future safety systems in addressing a broad range of well-documented crash types; and current expectations of the costs of safety systems once commercially available. The results of this chapter include identification of those conditions under which the benefits of various bus collision avoidance systems— either individually or collectively—are expected to exceed the costs. In addition, this chapter discusses several sensitivity analyses performed on the results and the implications of the results for transit agencies.

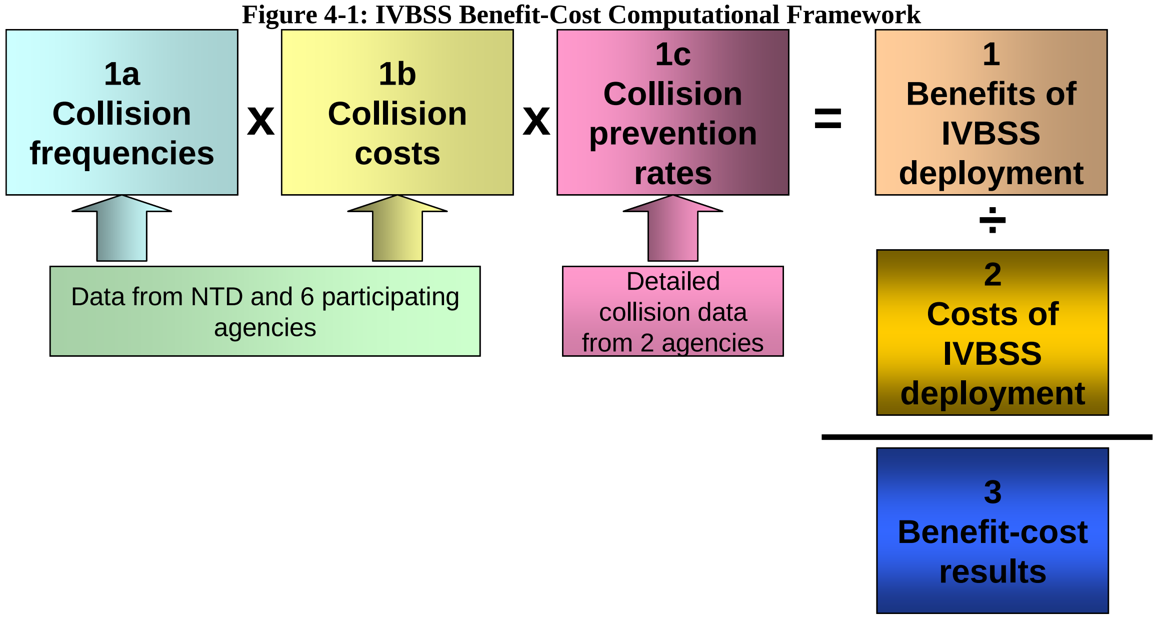
Key findings of the benefit-cost and sensitivity analyses include the following:

- Collisions are a substantial source of costs to transit operators. Fatalities, injuries, and property damage constitute, on average, between 5 and 10 percent of bus operating costs. On average, U.S. agencies spend over $4,000 per bus in collision-related costs each year.
- Agencies face numerous non-financial collision effects, including strains on administrative human resources, negative public perceptions of bus safety, and even contention with lawmakers and funding authorities.
- Only SODS and combinations of systems containing SODS "passed" the benefit-cost test with a ratio above one consistently (under a range of assumptions about collision rates and technology costs).
- One other strong performer was pedestrian detection systems; however, this had a benefit-cost ratio above one only under a minority of the scenarios considered as part of the sensitivity analysis.
- While many of the data used to populate the benefit-cost analysis are reliable, some are subject to significant uncertainty along several dimensions. Thus, the results of the benefit-cost analysis should be interpreted with caution due to the subjective nature of some of the analysis inputs, and the sources of raw data used in developing estimates of the benefit-cost ratios should be considered. Data sources are indicated throughout this chapter, along with qualitative explanations of their shortcomings and, in some cases, attempts to quantify the level of uncertainty.
- Sensitivity analyses were performed to account for some of the uncertainty in the results. These sensitivity analyses provide additional insights into the overall performance of various technologies and, in general, confirm the baseline findings that only SODS and combinations containing SODS consistently achieve benefit-cost ratios above one.

Figure 4-1 presents an overview of the computational framework for the benefit-cost analysis, which corresponds with the structure of this chapter. Section 4.1 describes the first step of the analysis framework (including steps 1a through 1c), culminating with an estimation of IVBSS benefits, while Section 4.2 discusses the total costs of IVBSS (step 2). Section 4.3 presents the results of the benefit-cost analysis (step 3).

In addition, Section 4.4 describes the parameters and results of a sensitivity analysis. Finally, Section 4.5 describes the implications of the benefit-cost results, particularly as they relate to agencies with insurance coverage for accidents and liability claims.

Figure 4-1: IVBSS Benefit-Cost Computational Framework



4.1 Benefits of IVBSS Deployment (step 1)

IVBSS for transit buses offer a wide range of potential benefits to agencies and to society in general. These benefits include the following:

- Direct cost savings to agencies investing in IVBSS attained through avoidance or mitigation of collisions
- Improved public image
- Reduction in damage and injury claims related to non-collision events (e.g., passenger falls on board) due to improvements in operator training and safety practices enabled by IVBSS
- Reduction in external costs indirectly related to collisions, such as congestion
- Improved ridership and customer satisfaction
- Improved training capabilities

This analysis considers only the first of the above benefit categories—**direct cost savings to investing agencies attained through avoidance or mitigation of collisions**. As a result, the analysis excludes qualitative agency benefits and all social benefits.

Estimating the financial benefits stemming from collision avoidance requires the following steps:

- In step 1a, the **frequencies** of collisions are quantified according to a matrix of collision types and severities.
- In step 1b, the **costs** of collisions are quantified according to the matrix of collision types and severities.
- In step 1c, available data are analyzed in order to estimate **collision prevention rates.**

- Finally, these three pieces are assembled to produce summary estimates of IVBSS collision avoidance benefits.

Data Sources

There are two primary sources of national transit bus collision data: 1) the National Transit Database (NTD) and 2) the Buses Involved in Fatal Accidents (BIFA) database.[33] NTD is an FTA-maintained database covering operational characteristics, service characteristics, capital assets, revenues, and financial performance of the more than 600 transit agencies receiving Section 5307 federal formula funds. NTD's Safety and Security module contains data on major and non-major collisions, defined by the FTA as follows:

- Major collisions are those that involve at least one fatality, at least two injuries, and/or property damage exceeding $25,000 (including damage sustained both by the transit agency and by third parties).
- Non-major collisions are those in which at least one person was injured and/or total property damage exceeded $7,500. (Agencies must also report non-major collisions.)

NTD data corresponding to these reporting thresholds are available for calendar years 2002 through 2005. Prior to 2002, NTD used a lower reporting threshold, reporting all accidents with property damage in excess of $2,000.

BIFA is a census of all fatal bus-involved collisions, derived from the Fatality Analysis Reporting System (FARS) and maintained by the University of Michigan Transportation Research Institute (UMTRI). UMTRI also performs detailed follow-up investigations with operators, witnesses, and transit agencies for each bus collision. Fewer than 100 fatal transit bus collisions are recorded each year; furthermore, detailed BIFA records are unavailable to the public. As a result, this data source was not used in the estimation of collision avoidance benefits.

Prior to this study, relatively few data had been collected on the cost and frequency of "minor" collisions (non-injury collisions with property damage below $7,500). To develop a more complete picture of *all* bus collision types (of minor collisions in particular), FTA requested and received internal collision records from six transit agencies ("participating agencies"). The participating agencies have a combined active fleet of 7,000 buses, or approximately 10 percent of the national transit bus fleet. Collision records covered an average of almost 3 years of data per participating agency and yielded 17 "agency-years" of data in total. Although no standardized methods of collecting collision data exist across transit agencies, the collision records provided sufficient information to support the segmentation of collision types and severities developed for this study. Agency data also provided cost and frequency data on minor collisions not reported to NTD.

Step 1a: Collision Frequencies

The effectiveness of bus collision avoidance systems will vary depending on collision type and collision severity. For example, safety systems are unlikely to prevent or mitigate the severity of high-speed, right-angle ("T-bone") collisions, but might be effective in reducing the frequency and severity of sideswipe collisions. Given these expected differences in system effectiveness based on each collision's characteristics, the benefit-cost analysis reflects the anticipated differences in investment benefits for each collision type and level of severity (note that prior benefit-cost analyses of safety systems have not utilized a detailed segmentation of collision types and severities). This subsection presents the

[33] The General Estimates System (GES) is a commonly used source for national crash data. However, since GES includes only sample crash data, it does not accurately reflect transit bus-involved collisions. As a result, GES data are not used in this benefit-cost analysis.

segmentation of collision types and severities used by the benefit-cost analysis and the estimates used to populate that segmentation.

Collisions can be categorized in many ways. However, the categorization scheme selected for this analysis was based on the organization of collision data from NTD and the participating agencies in order to enable usage of a broadly representative data set. Bus collisions were segmented into a matrix of five collision severities and seven collision types, yielding 35 unique severity-type combinations. The five collision severity categories include the following:

- **Major Fatal:** Collisions reported to NTD as major collisions with at least one fatality
- **Major Non-Fatal:** Collisions reported to NTD as major collisions with no fatalities (i.e., at least two injuries and/or property damage in excess of $25,000)
- **Non-Major with Injury:** Collisions reported to NTD as non-major collisions with at least one injury
- **Non-Major PDO:** Collisions reported to NTD as non-major collisions with no injuries (i.e., property damage between $7,500 and $25,000)
- **Not FTA-Reported:** All other collisions not reported to NTD (i.e., no injuries, property damage below $7,500, and recorded internally by the transit agency as a collision)[34]

The seven collision type categories include:

- **Frontal:** Frontal collision with another vehicle (e.g., bus rear-ends a vehicle)
- **Rear:** Rear collision with another vehicle (e.g., another vehicle rear-ends bus or bus rolls backward into another vehicle)
- **Sideswipe:** Sideswipe with another vehicle (e.g., bus scrapes the side of another vehicle during a right turn maneuver or while changing lanes)
- **Angle:** Angle collision with another vehicle (e.g., another vehicle broadsides or "t-bones" a bus while the bus is traveling straight through an intersection)
- **Other:** Any other collision type with another vehicle (e.g., insufficient details to categorize confidently, but enough detail to know that collision involved another motor vehicle)
- **Pedestrian:** Collision with a pedestrian (PED) or bicyclist (e.g., bus collides with pedestrian while making a turn or pedestrian chases and falls beneath bus)
- **Fixed Object:** All other collisions, including predominantly collisions with fixed objects (e.g., bus mirror strikes mailbox or street sign while approaching a stop)

Figure 4-2 presents the complete matrix of collision types and severities. Any recorded transit bus collision can be placed into one of the 35 categories in the collision scenario matrix. Specifically, NTD data support estimates of collision frequencies and costs in the 28 green-shaded cells, while data from the participating agencies are used to estimate collision frequencies and costs for the seven red-shaded cells. Note that this classification scheme explains only the "type" and "severity" of each collision, and not fault (e.g., "sideswipe" includes all sideswipe collisions, regardless of whether it was the fault of the transit bus or another vehicle).

[34] In addition, there are collisions that go unreported even within transit agencies. However, by definition, there is no record of such collisions, so they were ignored for purposes of this benefit-cost analysis.

Figure 4-2: Collision Scenario Matrix

Severity	Collisions with vehicles					Collisions with PEDs/Bikes	Collisions with objects
	Front	Rear	Angle	Side-swipe	Other		
Major fatal							
Major non-fatal							
Non-major with injury							
Non-major PDO							
Not FTA-reported							
Total							
% of Total							

The collision scenario matrix serves as an organizing framework for the estimation of IVBSS benefits. The analysis populated the collision scenario matrix with collision frequency estimates, based on data collected from NTD (for green-shaded cells) and from the six participating agencies (for red-shaded cells). First, the raw collision counts from both sources were segmented into the collision types and severities outlined in Figure 4-2. Next, these raw counts were annualized to account for the number of years of data collected and then normalized to account for variations in bus fleet sizes. Agencies reporting data to NTD have a combined fleet size of 62,400 buses,[35] while the six participating agencies have a combined fleet size of 7,000 buses. The result is a per-vehicle, annual accident rate for each collision and severity type.

For example, there were 58 major, fatal, frontal collisions with other vehicles reported to NTD between 2002 and 2005. To annualize and normalize, the following computation was followed:

$$\frac{58 collisions}{4 years} = 14.5 \Rightarrow \frac{14.5 collisionsperyear}{62{,}400 buses} \times 1{,}000 = 0.2 \text{ collisions per year per } 1{,}000 \text{ buses}$$

The summary of the annualized, normalized collision frequencies for all collision type-severity combinations is in the collision scenario matrix in Table 4-1. According to the results, the transit industry experiences, on average, about 1,526 collisions per 1,000 buses per year, or about 1.5 collisions per bus nationwide. The majority (88 percent) of these collisions go unreported to FTA because they lack injuries and involve property damage of less than $7,500. Less than 1 percent of the collisions involve a fatality. In fact, according to NTD, the number of annual nationwide fatalities in transit bus-involved collisions is fewer than 100. Approximately one-third of all collisions are sideswipes with other vehicles, while 14 percent involve a bus rear-ending another vehicle, 16 percent involve another vehicle rear-ending a bus, 11 percent are angle collisions, 2 percent involve a collision with a pedestrian or bicyclist, and 10 percent involve a collision with a fixed object.

[35] Both “motor bus” (MB) and “trolley bus” (TB) modes were considered when counting collisions and computing fleet sizes in NTD.

Table 4-1: Average Annual Number of Collisions per 1,000 Buses by Type and Severity[36]

Severity	Collisions with vehicles					Collisions with PEDs/Bikes	Collisions with objects	Total	% of Total
	Front	Rear	Angle	Side-swipe	Other				
Major fatal	0.2	0.2	0.1	0.0	0.0	0.4	0.0	0.9	0%
Major non-fatal	6	5	4	2	1	0	1	18	1%
Non-major with injury	15	12	8	3	2	4	10	48	3%
Non-major PDO	36	28	20	8	5	4	10	111	7%
Not FTA-reported	161	198	138	494	193	21	143	1,348	88%
Total	218	244	170	507	202	27	158	1,526	100%
% of Total	14%	16%	11%	33%	13%	2%	10%	100%	

Normalizing collisions by the number of buses assumes a uniform exposure for all buses, regardless of their miles traveled, hours in service, or other metric. The disadvantage of this approach is that collision rates per bus may not be combinable across agencies. For example, the number of collisions per bus in agencies with relatively few miles of travel may be smaller than in an agency with more miles of bus travel. However, analysis of available collision data among the participating agencies revealed similar rates of collision on both a per-mile-traveled basis and on a per-bus basis. The advantage of a per-bus normalization is that the cost of in-vehicle safety technologies must be expressed on a per-bus basis (i.e., collision warning devices are sold for buses, and not for vehicle-miles of bus travel). Consequently, to estimate the benefits and costs on comparable terms, collision rates were expressed on a per-bus basis. These findings should alleviate any potential concerns about combining and normalizing collision data across agencies on a per-bus basis. Furthermore, the sensitivity analysis in Section 4.4 accounts for variability in collision rates.

Several other sources of uncertainty affected the findings in Table 4-1, including temporal variability, geographic variability, and “collision mix” variability. With regard to the first source of uncertainty, temporal variability, there was no evidence of any trend toward higher or lower crash rates based on the year-to-year changes in collision rates in either NTD or in the agency-specific collision records. In other words, there have been no appreciable changes in the annual rate of collisions per bus in either NTD or among the six participating agencies over the past several years. This finding supports the decision to use recent data (2000 through 2006) to estimate current annual average collision rates. For example, NTD data used in this analysis spanned 4 years (2002 to 2005). Collision records obtained from the six participating agencies effectively covered a combined 17 “agency-years” of service, all from the period 2000 to 2006.

A variety of environmental factors can also influence collision rates. For example, *a priori* factors that influence collision rates from agency to agency may include traffic density, average operating speed, land

[36] The number of collisions “Not FTA-reported” was estimated based on data provided by agencies participating in this study. All other data were obtained directly from NTD.

use characteristics, ridership, agency size, average bus age, terrain, climate, and others. Table 4-2 summarizes several characteristics of the six participating transit agencies—size, operating environment, and regional terrain. Despite a wide variety of agency sizes, climates, operating environments, and terrains, this study found that collision rates among the six participating agencies ranged between 1.40 and 1.75 collisions per bus per year, or approximately 8 percent above and 14 percent below the weighted average rate. This finding suggests that geographic and environmental factors do not appear to have a significant quantitative impact on per-bus collision rates. When normalized by vehicle revenue-miles, rates range from 3.5 to 6.8 collisions per 100,000 revenue-miles, with a weighted average of 4.8. However, as discussed above, the per-bus normalization is a more appropriate normalization metric for the benefit-cost analysis.

Table 4-2: Characterization of Six Participating Transit Agencies

Agency	Fleet Size	Operating Environment	Terrain
San Francisco Municipal Railway (Muni)	861	Urban	Hilly
Alameda County Transit Authority (AC Transit)	674	Urban and suburban	Hilly
Los Angeles Metro	2,570	Suburban	Hilly
North County Transit District (NCTD)	174	Suburban	Hilly
Chicago Transit Authority (CTA)	2,049	Urban and suburban	Flat
Greater Cleveland Regional Transit Authority (GCRTA)	544	Urban and suburban	Flat

The third source of uncertainty relates to the “mix of collisions.” The frequency of each specific type of collision (e.g., vehicle sideswipes versus pedestrian collisions) varies from agency to agency based on environmental factors and differences in data reporting methods. Table 4-3 illustrates the variability for each collision type. For example, on average, 88 percent of all collisions are collisions with other vehicles. However, among the six participating agencies, the proportion of crashes recorded as vehicle collisions ranged from 74 to 91 percent, with a standard deviation of 6.6 percent from the average.

Table 4-3: Variability in Mix of Collision Types Among Six Transit Agencies

Collision type	% of total collisions		
	Range	Weighted average	Std dev
Collisions with vehicles	74-91%	88%	6.6%
Frontal	5-20%	14%	5.5%
Rear	13-17%	16%	1.9%
Angle	4-15%	11%	3.7%
Sideswipe	20-54%	33%	12.1%
Other	3-16%	13%	4.6%
Collisions with pedestrians	1-3%	2%	0.9%
Collisions with objects	7-24%	10%	6.4%

Despite the variability in the mix of collisions among the participating agencies, the weighted average value for each collision type category (shown in Table 4-1) was used for the benefit-cost analysis. The sensitivity analysis presented in Section 4.4 considers the differing benefit-cost characteristics of alternative collision rate assumptions.

Step 1b: Collision Costs

As with collision frequencies, the estimate of the costs of transit bus collisions was based on the collision scenario matrix in Figure 4-2. Consultations with staff involved with safety, maintenance, and claims at the six participating agencies in regards to the costs typically encountered by agencies; we quantified each cost category by analyzing the data provided by the agencies. The items summarized in Table 4-4 show the types of costs encountered by agencies as reflected by their responses during the interview process. All of the costs listed in the table result directly from collisions. Indirect costs to society (e.g., traffic congestion) and agency fixed costs (e.g., cost of maintenance labor hours related to bus repairs) are not included in these estimates.

Table 4-4: Major Categories of Costs Related to Transit Bus Collisions

Cost category	Magnitude of potential costs
Costs paid to claimants on behalf of fatally injured parties	High
Costs paid to claimants for medical care and other injury-related expenses (includes pedestrians, bus occupants, and other vehicle occupants)	High
Costs of administering third-party claims (e.g., legal fees, administrative costs, and investigation costs)	Low
Workers’ compensation costs paid to cover transit employees’ collision-related injuries (i.e., bus operator injuries)	Medium
Costs to replace workers during time off for collision-related injuries	Medium
Costs to repair to the transit bus (material costs only; that is, excluding labor costs)	Low
Cost of third-party property damage, including damage to other motor vehicles, private real estate, public infrastructure, or other personal property	Medium
Costs related to workers’ compensation claims	Low
Costs to perform drug and alcohol testing of drivers following a collision	Low

The participating agencies provided the majority of the cost data used for this analysis, with some additional data obtained from NTD (e.g., injury and fatality counts). Data were analyzed from all sources in order to link costs to specific collision types and severities. Given the sensitive nature of the cost data used for this analysis, this report does not provide details of the cost buildup for each collision type, nor does to provide costs according to the more detailed collision scenario matrix. Nonetheless, collision cost results are presented by collision type in Table 4-5. The estimated total annual cost per bus of collisions was $4,374. Vehicle collisions account for nearly 80 percent of these costs. Collisions with pedestrians account for 7 percent of all collision costs (despite making up only 2 percent of collisions, according to Table 4-1). Collisions with fixed objects account for 15 percent of all collision costs.

The costs shown in Table 4-5 represent the “baseline” collision costs, or the best estimate of current collision-related expenditures encountered by transit agencies. According to a separate reporting module in NTD, transit agencies spend approximately $5,000 per bus for “casualty and liability” costs each year, reflecting the average cost per bus of insurance premiums and accident-related claims paid. The collision cost estimates summarized in Table 4-5 are similar. The NTD-based estimate and the component cost buildup-based estimate produced comparable results.

Table 4-5: Annual Collision Cost Per Bus by Collision Type

Type		Cost	% of Total
With vehicle	Front	$672	15%
	Rear	$623	14%
	Angle	$531	12%
	Sideswipe	$1,036	24%
	Other	$544	12%
With pedestrian		$306	7%
With object		$662	15%
Total		$4,374	100%

Step 1c: Collision Prevention Rates

According to findings summarized in the previous two sections, the average transit bus encounters 1.5 collisions and over $4,000 in collision-related expenses each year. The analysis presented in this section considers the proportion of those collisions and costs that transit agencies can expect to prevent by deploying collision avoidance systems.

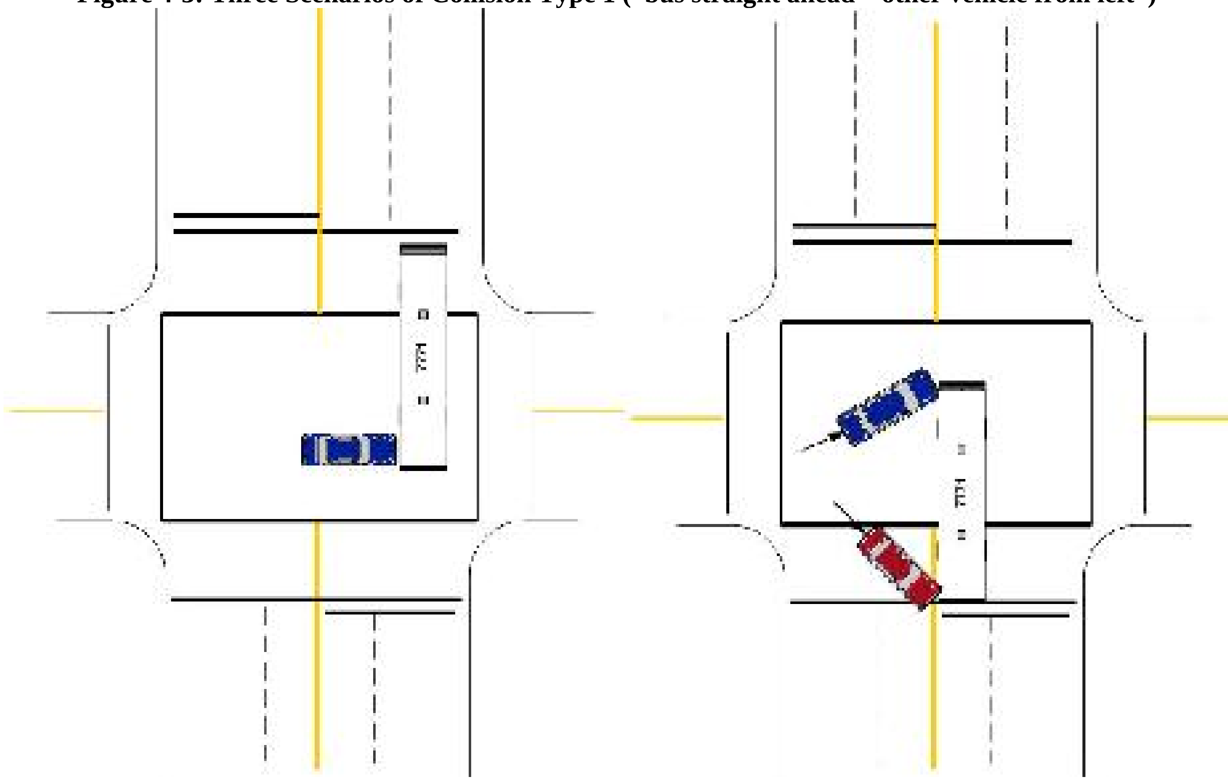
Given the limited amount of field evaluations conducted on CAS on transit buses, the effectiveness of these systems against specific collision types is not yet determined (i.e., there are no statistically robust, empirical collision prevention effectiveness data). Consequently, this study relied on a new methodology for estimating the ability of a technology to address a particular type of collision. This new methodology builds on a significant amount of data collected and provided by several transit agencies. However, it also relies on "expert choice," which is a subjective method for developing quantitative measures in the absence of objective data. Readers should be familiar with this method, described below, so they can understand its strengths and uncertainties.

As a starting point for estimating collision prevention rates, two of the six transit agencies participating in this study (with combined fleet size of over 3,000) provided collision records spanning one year. These records, which were more detailed than the data for steps 1a and 1b, used a common classification system under which each collision is categorized as one of 58 detailed, pre-defined crash scenarios. The 58 crash scenarios are identical for each agency. For example, collision types 1 through 12 describe various types of collisions that occur at intersections. Collision type 1 is called "bus straight ahead – other vehicle from left." The illustrations in Figure 4-3 depict several scenarios, each of which would be categorized as type 1. Accompanying these illustrations are narrative descriptions of the crash type. For example, crash type 1 is described as follows:

> [Collision type 1] means that the bus was proceeding straight ahead in the intersection and the other vehicle came from the left side of the bus. This includes areas where the bus is proceeding straight and the other vehicle came on to the roadway from a street or driveway on the left side.

Each of the 58 types of crashes has one or several scenario illustrations, such as those in Figure 4-3 for crash type 1, and a text description of the crash.

Figure 4-3: Three Scenarios of Collision Type 1 ("bus straight ahead – other vehicle from left")[37]



In addition to classifying each collision according to exactly one of 58 detailed scenarios, transit agency records also indicate whether each collision was "avoidable" or "unavoidable." An "unavoidable" collision is generally one in which no action taken by the bus operator could have prevented the collision, suggesting that the causes and events of the collision were beyond the operator's control. Expert, trained bus instructor supervisors are responsible for determining whether a collision is "avoidable." The supervisors base their judgment on objective data as well as their extensive training and experience in crash reconstruction and investigation. This training typically includes training from the FTA-sponsored Transit Safety Institute. As part of their investigations of each collision, supervisors review reports submitted by each of the following individuals:

- The bus operations control manager for the division in which the accident occurred
- An on-scene division supervisor who inspected the crash site
- The bus operator involved in the collision
- The responding police officer (if available)
- Any witnesses to the collision (if available)

If, after reviewing these reports, the supervisor is unable to make a determination, he or she may also interview the operator, other involved parties, bus occupants, and/or other witnesses to the collision. Although determination of "avoidability" is subject to errors in human judgment, agencies make every effort to employ trained experts to make correct determinations, as avoidability ratings are important tools used by the agencies to study safety performance patterns, develop training programs, and train their operators and other staff to improve safety practices.

[37] Image provided courtesy of Mr. Clarence Massar of LA Metro.

According to staff at the participating agencies, it is rare for a supervisor's avoidability judgment to be overturned. However, there is a process, governed by labor contracts, that allows operators to challenge avoidability decisions. If the supervisor judges a collision avoidable, the case proceeds automatically to a review board consisting of two peer bus operators, two supervisors, and a division manager, who then confirms that the accident was avoidable or reverses the decision. If the avoidable decision is upheld, the operator has an opportunity to request a second hearing with a new review board consisting of two peer bus operators, two supervisors, and a labor relations officer. Finally, if the collision is still upheld as avoidable, the operator may request to send the case to an outside, independent accident reconstruction group. Fewer than 10 percent, perhaps as few as 2 to 3 percent, of avoidable judgments are reversed.

Because determining avoidability is a subjective process, it was important to analyze the data to ensure their usage would not adversely influence the findings related to effectiveness. First, among the collision records obtained from the two agencies, 29 percent were judged "avoidable." According to one crash reconstructionist and transit safety expert, this finding is consistent with the national averages provided by transit operators and emergency responders, where avoidable collisions account for "anywhere from 28 to 32 percent of all collisions." In addition, although 29 percent of all collisions are "avoidable," there is substantial variability among specific collision types, as shown in Table 4-6. For example, fixed-object collisions were judged avoidable 90 percent of the time, an intuitive result given that operators should usually be able to avoid colliding with immovable objects. Likewise, collisions that occur "in the zone" (at a curbside, codified as collision type 28) should usually be unavoidable since the bus is not moving and engaged in passenger loading or unloading. Indeed, less than 1 percent of these collisions were judged "avoidable." This cursory inspection of the data helped to confirm the suitability of using avoidability data.

Table 4-6: Percent of Collisions Judged "Avoidable" by Type of Collision[38]

With vehicle					With pedestrian	With object	All collisions
Front	Rear	Angle	Sideswipe	Other			
28%	16%	14%	18%	32%	35%	90%	29%

Based on the criteria and processes used by agencies to make avoidability judgments, it follows logically that a passive collision avoidance system (i.e., one that advises/warns the operator but does not take control of the vehicle) would only be effective in preventing or mitigating some percentage of avoidable collisions, but would not be effective against unavoidable collisions. Therefore, collision avoidance systems, with the exception of RCWS, were assumed in this analysis to address only avoidable collisions. RCWS were assumed to address *only* unavoidable collisions, since they specifically target unavoidable collisions caused by other drivers. Although these assumptions are not verifiable, they do provide a quantitative starting point for analysis and in the absence of objective data, this approach provides a strong foundation, based on real collision data, to estimate the effectiveness of CAS.

Next, a panel of four reviewed the 58 collision types to assess how appropriate each collision avoidance system would be in preventing or mitigating each crash type. The panel consisted of two crash data experts and two technology experts familiar with the collision avoidance systems. In completing this evaluation, the study considered seven distinct collision avoidance systems:

- Forward Collision Warning System (FCWS)
- Rear Collision Warning System (RCWS)
- Side Object Detection System (SODS)
- Forward Object Detection System (FODS)

[38] Based on data collected from two agencies.

- Rear Object Detection System (RODS)
- Lane Departure Warning System (LDWS)
- Pedestrian Detection System (PDS)

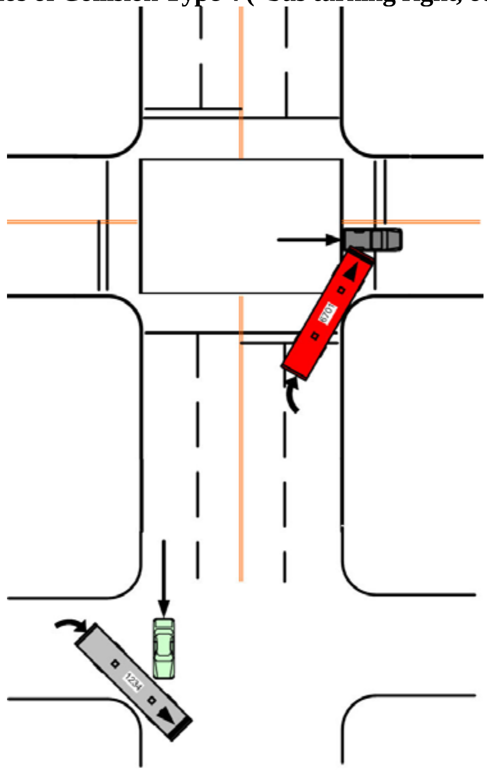
The panel rated each system's effectiveness in preventing each type of collision according to the scale below (which was developed independently of the avoidability data):

Table 4-7 Scale Used to Rate Each System's Effectiveness in Preventing Different Types of Collisions

Verbal Rating		Rating Score
Not at all effective	(0 percent)	Rating= 0
Minimally effective	(25 percent)	Rating= 1
Moderately effective	(50 percent)	Rating= 2
Effective	(75 percent)	Rating= 3
Very effective	(100 percent)	Rating= 4

The panel's judgment was reached by consensus in most cases. In instances for which no consensus existed, all viewpoints were argued during a period of discussion. Ultimately, if no consensus could be reached through discussion, a middle ground was recorded. The panels' decisions are in a matrix, a portion of which is shown in Table 4-8 (the complete matrix can be found in Appendix C). For example, collision type 4 is a frontal collision with another vehicle, which occurs when the left side of a bus making a right turn collides with another vehicle. According to agency data, 21 percent of these collisions were "avoidable." Figure 4-4 is an illustration of two scenarios that are classified as collision type 4. Based on this diagram and the seven collision avoidance systems, the panel determined by consensus that only FODS would be applicable to this crash type and, furthermore, that it would be only "minimally effective" (25 percent) in preventing such crashes. The justification for this rating is that the other vehicle approaches from the left side of the bus, which is typically outside the range of detection of a forward-mounted sensor. Furthermore, sensors only detect objects within a range of 4 to 6 foot, and many collisions of this scenario are likely to occur with a vehicle traveling too fast to be detected by the sensor with enough time for the operator to avoid the collision.

Figure 4-4: Two Scenarios of Collision Type 4 ("bus turning right, other vehicle from left")[39]



To provide a quantitative measure of IVBSS effectiveness, the percentage of avoidable collisions was multiplied by the percentage effectiveness for each crash type. In the example above, FODS would be 25 percent effective against avoidable type 4 collisions. Since 21 percent of type 4 collisions are avoidable, FODS is 5.25 percent (25% x 21%) effective against type 4 collisions. To illustrate another example, 60 percent of type 6 collisions were avoidable and 40 percent were unavoidable. Analysis of this collision scenario type suggested that an RCWS would be "moderately effective" (50 percent) in preventing such collisions. Recall that RCWS are designed to address unavoidable collisions. Hence, it is estimated that RCWS would prevent 20 percent (40% x 50%) of type 6 collisions.

Table 4-8: Sample Portion of the IVBSS Effectiveness Evaluation Framework (from Appendix C)

Code	Crash type	% Avoidable	System effectiveness						
			FCWS	RCWS	SODS	FODS	RODS	LDWS	PDS
1	Frontal	12%	0	0	0	0	0	0	0
2	Angle	10%	0	0	0	0	0	0	0
3	Angle	100%	0	0	0	0	0	0	0
4	Frontal	21%	0	0	0	1	0	0	0
5	Frontal	11%	1	0	0	0	0	0	0
6	Rear	60%	0	2	0	0	0	0	0
7	Angle	25%	0	0	0	0	0	0	0
39	Pedestrian	50%	0	0	0	0	0	0	4

Figure 4-5 provides a conceptual illustration of the computational steps taken to estimate the effectiveness of IVBSS against frontal collisions. Half of all frontal vehicle collisions were judged as "unavoidable" by transit agency safety staff. Of the remaining 50 percent, FODS and FCWS were judged to be potentially

[39] Image provided courtesy of Mr. Clarence Massar of LA Metro.

able to prevent 20 percent of the collisions (each would prevent 10 percent, non-overlapping, of all frontal collisions with vehicles).

Figure 4-5: IVBSS Effectiveness in Preventing Frontal Collisions with Vehicles

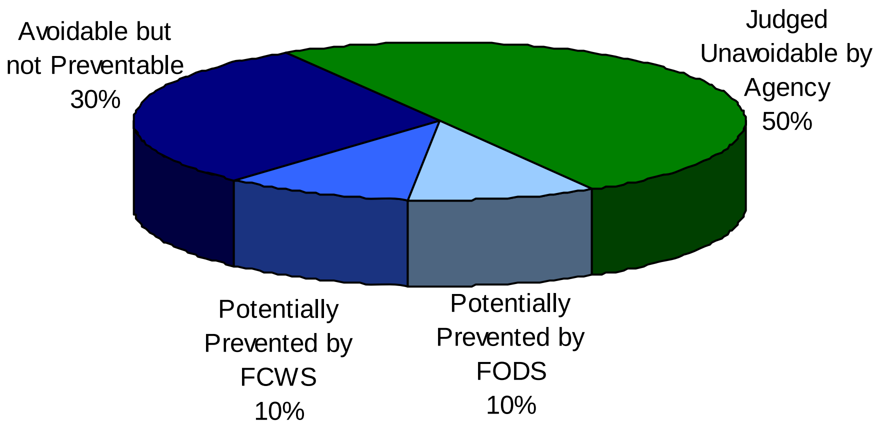


Table 4-9 provides the complete results of the collision evaluation process for each of the seven safety systems considered here. For example, FCWS was estimated to prevent 10 percent of frontal collisions and 2 percent of sideswipe collisions with other vehicles, which together represent 2 percent reduction in *all* bus collisions.

Table 4-9: Collision Prevention Rates by System and Collision Type[40]

System	Collisions with vehicles					Collisions with pedestrians	Collisions with objects	All Collisions
	Front	Rear	Angle	Side-swipe	Other			
FCWS	10%	-	-	2%	-	-	-	2%
RCWS	-	32%	-	-	-	-	-	6%
SODS	-	1%	-	12%	21%	-	45%	11%
FODS	10%	-	-	-	-	-	-	2%
RODS	-	5%	-	-	-	-	-	1%
LDWS	-	-	-	2%	-	-	-	-
PDS	-	-	-	-	1%	29%	-	1%
All	20%	39%	-	16%	22%	29%	45%	22%

The collisions prevented by each system are assumed to be "mutually exclusive" events. This assumption is based on the distinct operating conditions of each technology. For example, the three object detection systems cover non-overlapping zones around the bus (SODS, FODS, and RODS). FCWS and FODS, which do cover an overlapping zone, function at non-overlapping speeds—FODS functions continuously below 15 mph, while FCWS functions only when above 25 mph. RODS and RCWS, which also cover an overlapping zone, do not provide warnings to the same vehicles—RODS is designed to prevent only those collisions involving a transit bus rolling backward into another vehicle or object, while RCWS is designed to prevent collisions involving another vehicle rear-ending a bus. Therefore, mutual exclusivity

[40] These prevention rates are based on an understanding of avoidability rates among collision types together with expert choice methodology, rather than field test data. They are subject to revision.

not only simplifies the analysis, but also is a realistic assumption driven by the distinct functionality and purpose of each collision avoidance system.

The mathematical consequence of assuming mutual exclusivity is that collision prevention rates become additive. For example, FCWS and FODS were estimated to prevent 10 percent of frontal collisions, for an additive 20 percent (i.e., it was assumed that among those 20 percent of frontal collisions, none could have been prevented by *both* FCWS *and* FODS). By extension, the results shown in Table 4-9 suggest that a bus equipped with all seven safety systems could expect to prevent roughly 20 percent of frontal collisions, 39 percent of rear-end collisions, 16 percent of sideswipes, 22 percent of other vehicle collisions, 29 percent of pedestrian collisions, and 45 percent of fixed-object collisions. Based on these estimates, safety systems have the combined potential to prevent 22 percent of all collisions. Note that half of this total (11 out of 22 percent) is sideswipes. The remaining 11 percent of all collisions are prevented by the other six collision avoidance systems.

Step 1 Summary: Benefits of IVBSS Deployment

To compute the savings an agency can expect from avoiding collisions, three items (collision frequency, collision cost, and collision prevention rate) are multiplied together within each cell of the collision scenario matrix. For each system or package of systems under evaluation, this computation is repeated 35 times, once for each cell in the matrix. Then, the products are aggregated. A mathematical representation of this computation follows:

$$Benefits_t = \sum_j \sum_i \left(Frequency \times Cost\right)_{ij} \left(Prevention\right)_{it} \text{ , where}$$

$Benefits_t$ is the collision-related cost savings per bus expected in year 1 attributable to system t
t is the type of system or combination of systems being evaluated
i is the type of collision
j is the severity of collision
$Frequency_{ij}$ is the number of collisions per bus per year of type i and severity j
$Cost_{ij}$ is the cost of a single collision of type i and severity j
$Prevention_{it}$ is the percentage reduction in collisions of type i attributable to system t

Table 4-10 summarizes the results of the analysis, showing the expected savings accrued during the first year of deployment attributable to the system's ability to prevent collisions on a per-vehicle basis. For example, FCWS was estimated to save $131 in collision costs per bus, while SODS was estimated to save $586 per bus. A bus equipped with all seven systems could save a maximum of $1,335 in annual collision costs, or approximately 30 percent of the estimated $4,374 in average annual collision costs per bus.

Table 4-10: Year 1 Benefits by System (per equipped vehicle)

System	Benefits in first year of deployment
FCWS	$131
RCWS	$178
SODS	$586
FODS	$100
RODS	$58
LDWS	$23
PDS	$258
All systems	$1,335

This step developed estimates of the benefits of investing in bus collision avoidance systems. This next section summarizes the costs associated with those systems.

4.2 Costs of IVBSS Deployment (step 2)

Deployment of a new safety system involves more than simply purchasing and installing a product. Transit agencies incur costs over the entire life cycle of the product, starting even before purchase and installation. Each of the following life-cycle costs was estimated for all seven collision avoidance systems:

- **Planning and Design:** New systems require planning and evaluation by agency staff, which may lead to an investment decision. Staff evaluation may involve meetings with system vendors, small-scale field tests on a sample of the bus fleet, outreach to stakeholders (including operators, mechanics, union representatives, trainers, safety managers, financial managers, and others), computation of expected costs and benefits of deployment, and presentation of findings and recommendations to agency management and/or governing boards. Costs are computed for this category by considering labor costs attributable to agency manager and staff time to research the product and develop recommendations.
- **Acquisition:** Once the decision to purchase a product has been made and approved, the agency must physically acquire the products. Acquisition costs typically constitute the greatest share of costs related to most new systems.
- **Installation:** Some vendors include product installation as part of the purchase cost (i.e., once purchased, no additional installation costs are incurred). If not, the agency must arrange for its own staff or hire outside contractors to perform the installations.
- **Training:** As with installation, some vendors will include training within the purchase price. However, the agency can expect to incur additional costs for paying operators during the training and for paying its own training staff where necessary.
- **Annual operations and maintenance (O&M):** Some contracts mandate the vendor to provide maintenance for a period of time after the agency purchases a device. In addition, maintenance of advanced technology products such as IVBSS will inevitably require the attention of agency staff with specialized training.

Table 4-11 summarizes each of these costs for the seven “unbundled” safety systems—FCWS, RCWS, SODS, FODS, RODS, LDWS, and PDS. The cost of each system was developed using estimates from a variety of data sources. However, since none of these systems has been widely deployed in the transit market and system development is ongoing, the estimates reflect significant uncertainty, as described in the following paragraphs.

Planning and Decision

This category reflects the one-time costs to an agency of making the initial decision to purchase in-vehicle safety devices. Particularly for larger agencies, this cost on a per-vehicle basis is insignificant, as the cost can be diluted across a large number of vehicles. This cost reflects the time spent by management and staff to handle all tasks related to decision making, which include time spent by management and technology staff with equipment supplier representatives; meetings among management and safety staff; meetings among management, bus operators, and labor union representatives; and time for technical analysis staff to provide decision-support cost estimates. However, it was determined that the staff whose time is required for planning and decision making are not uniquely required for deployment of safety systems. In other words, the cost of staff time for decision-making is fixed and is incurred regardless of the decision to invest in a safety system. Consequently, although there is a real opportunity cost associated with planning and decision-making, such costs were not considered relevant for the benefit-cost analysis.

Acquisition

Acquisition costs are the most significant, driving costs of collision avoidance systems. These costs were estimated based on information from existing system vendors. FCWS is available commercially for approximately $1,500. SODS and FODS are also available commercially, but are only offered by the supplier as a bundled package of six sensors, two for the side and two for the front of the bus. The total cost of the bundled package is $2,750. The majority of this cost is for product engineering, as opposed to the actual hardware. Consequently, assuming a cost of $100 per sensor, the cost of SODS alone was assumed to equal $2,550 (two fewer sensors than the bundled package), while FODS (four fewer sensors than the total package) was assumed to cost $2,350. RODS, which has the same number of sensors as SODS, was assumed to have the same cost of $2,550. LDWS is available commercially for the heavy truck market as either a factory-installed or an aftermarket device at a cost of approximately $900 per unit. The cost of PDS was assumed to be $1,800, since it uses the same equipment as FCWS but requires additional product engineering and software. Finally, RCWS was estimated based on a cost buildup using capital cost figures from the U.S. DOT's ITS Benefits website for sensor and processing ($650), in-vehicle display ($100), communication equipment ($400), and a 26 percent additional cost for engineering, or a total of $1,449 per unit.

Installation

According to equipment suppliers, the prices of FCWS, LDWS, and PDS include installation, so no additional cost was assumed for those three systems. For the other systems, installation costs were based on a fully loaded labor rate of $23.50 per hour for a mechanic.[41] The number of hours for installation of each item was assumed as follows:

- 8 hours for RCWS ($188)
- 4 hours each for SODS, FODS, and RODS ($94)

Training

Nominal training costs were also included in the estimates of system costs; however, training costs are expected to be negligible for most agencies. According to suppliers, only 15 minutes of training are required for FCWS, LDWS, and PDS, while several hours are required for SODS, FODS, and RODS.

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[41] Hourly labor rates based on values provided by the Bureau of Labor Statistics.

RCWS was assumed to require no training. An hour of training was assumed to cost the agency $20.[42] Training costs were doubled (e.g., 30 minutes, or $10, for FCWS) to account for the fact that the ratio of drivers to vehicles in a typical fleet is greater than one.

Annual O&M

Based on an hourly labor rate of $23.50, and 30 minutes of service each month for a year, annual operations and maintenance costs for each device were computed as $23.5 x 0.5 x 12 = $141.

Table 4-11: Costs of Various Unbundled Safety Systems per Unit Assuming Fleet Size of 100

Configuration	FCWS	RCWS	SODS	FODS	RODS	LDWS	PDS
Planning & Decision	$0	$0	$0	$0	$0	$0	$0
Acquisition	$1,500	$1,449	$2,550	$2,350	$2,550	$900	$1,800
Installation	-	$188	$94	$94	$94	-	-
Training	$10	-	$120	$120	$120	$10	$10
Annual O&M	$141	$141	$141	$141	$141	$141	$141
Total Cost	$1,646	$1,778	$2,865	$2,665	$2,865	$1,046	$1,946

Although the unbundled system cost estimates provided in Table 4-11 are necessary to support the benefit-cost analysis, none of the systems is currently offered as a standalone product. Moreover, a key objective of the IVBSS initiative is to consider the advantages of bundling these systems together. Consequently, seven combinations of the unbundled systems were constructed for the analysis. Two of the combinations reflect currently available products, while the other five combinations are hypothetical (but logical) future potential product offerings. The seven combinations include the following:

- **Combination 1 (“ODS”):** This package is currently available commercially. It includes a FODS and a SODS.
- **Combination 2 (“ODS Cocoon”):** This package would contain RODS in addition to a FODS and a SODS, nicknamed here as “Cocoon” Object Detection.
- **Combination 3 (“FCSD”):** This package would contain an FCWS and a SODS, hence the acronym FCSD (forward collision/side detection).
- **Combination 4 (“CWS”):** This commercially available package includes an FCWS and an LDWS.
- **Combination 5 (“CWS+”):** This system would contain an FCWS, an LDWS, and a PDS.
- **Combination 6 (“CWS Cocoon+”):** This package has an FCWS, an LDWS, a PDS, and a RODS.
- **Combination 7 (“All”):** A hypothetical package of all seven systems.

Table 4-12 summarizes the cost estimates for each of the six combinations of safety systems. Note that the cost of bundled systems is less than the sum of the individual component purchase costs; that is, they enjoy some economies of scale, particularly the object detection packages (ODS and ODS Cocoon). Note that the acquisition costs of “ODS” and “CWS” are based on actual commercially available products. The other combinations are scaled from there based on an understanding of the cost of component technologies. For example, ODS Cocoon costs $400 dollars more than ODS because of the assumed addition of four rear sensors (at $100 per sensor), but with no additional costs for product engineering. FCSD, meanwhile, combines forward collision warning technology with side object detection technology.

[42] Ibid.

Because these two systems rely on distinct detection methods, the cost of FCSD is equal to the sum of the cost of ODS and FCWS.

Table 4-12: Costs of Various Integrated (IVBSS) Safety Systems

Configuration	ODS	ODS Cocoon	FCSD	CWS	CWS+	CWS Cocoon+	All
Planning & Decision	$0	$0	$0	$0	$0	$0	$0
Acquisition	$2,750	$3,150	$4,250	$1,800	$3,600	$5,450	$7,999
Installation	$94	$94	$94	$0	$0	$0	$94
Training	$120	$120	$130	$10	$10	$130	$130
Annual O&M	$141	$141	$141	$141	$141	$141	$141
Total Cost	$3,065	$3,265	$4,570	$1,946	$3,746	$5,676	$8,319

4.3 Benefit-Cost Results (step 3)

This section combines the cost savings from reduced collision frequencies and severities (i.e., the investment benefits; see Table 4-10) with the investment costs (see Table 4-11 and Table 4-12) to determine the cost effectiveness of the safety systems, both individually and as bundled systems. To perform the benefit-cost analysis, several additional assumptions are required, including the following:

- System useful life of 12 years. It is assumed that safety systems will have a useful life that corresponds to that of the vehicle it is installed on—in this case, a heavy-duty transit bus. FTA's minimum service life for heavy-duty buses is 12 years (although agencies operate their vehicles for an average of 15 years). This assumption implies, for analytical purposes only, that systems are installed on new vehicles and not retrofitted to older ones.
- Inflation rate of 2.5 percent, which is consistent with recent rates.
- Discount rate of 7 percent, which is consistent with OMB recommendations for benefit-cost analyses.

These assumptions are required to develop a flow of annual investment benefits (reduced collision costs) and costs (acquisition, operation, and maintenance) over the life of each system. The flow of investment benefits and costs can then be discounted and compared—in the form of a benefit-cost ratio—to assess the financial cost effectiveness of these systems, both individually and in groups. A benefit-cost ratio greater than one implies that the investment benefits exceed the costs. The formal mathematical representation of the computation of the benefit-cost ratio follows:

$$BCRatio = \frac{\sum_{t=1}^{n} \frac{Benefits_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Costs_t}{(1+i)^t}}, \text{ where}$$

n is the forecast period in years
i is the discount rate
$Benefits_t$ is the investment benefits in year *t*
$Costs_t$ is investments costs in year *t*

Table 4-13 summarizes the benefit-cost ratios for each of the seven individual safety systems considered above. Of the seven systems, SODS is the only system to pass the benefit-cost test, with a benefit-cost ratio of 1.43. Of the remaining systems, PDS, with a ratio of 0.81, is the strongest performer.

Table 4-13: Benefit-Cost Ratio under Baseline Assumptions for Various Standalone Safety Systems

System	Baseline
FCWS	0.45
RCWS	0.59
SODS	1.43
FODS	0.26
RODS	0.14
LDWS	0.10
PDS	0.81

When the standalone safety systems are combined into "packages," the benefit-cost ratios generally improve, as shown in Table 4-14. All, ODS, ODS Cocoon, and FCSD have ratios above one. It is important to note that each of these four packages (ODS, ODS Cocoon, FCSD, and All) include side object detection, which is driving the higher performance of those packages.

Table 4-14: Benefit-Cost Ratio under Baseline Assumptions for Various Safety System Combinations

Combination	Baseline
ODS	1.60
ODS Cocoon	1.59
FCSD	1.25
CWS	0.49
CWS+	0.83
CWS Cocoon+	0.69
All	1.38

Another useful measure for decision makers considering an investment in safety systems is the payback period. This measure answers the question regarding the number of years it will take until the investment benefits equal or exceed the investment costs. Table 4-15 summarizes the payback periods for standalone systems, while Table 4-16 summarizes the measure for integrated systems.

Table 4-15: Payback Period under Baseline Assumptions for Various Standalone Safety Systems

System	Payback period (years)
FCWS	>12
RCWS	>12
SODS	5.9
FODS	>12
RODS	>12
LDWS	>12
PDS	>12

Table 4-16: Payback Period under Baseline Assumptions for Various Safety System Combinations

Combination	Payback period (years)
ODS	5.0
ODS Cocoon	5.1
FCSD	8.1
CWS	>12
CWS+	>12
CWS Cocoon+	>12
All	7.1

The results of this benefit-cost analysis suggest that, among standalone systems, only SODS have a reasonable chance of delivering sufficient financial benefits to justify investment by transit agencies. However, some integrated packages of safety systems present a more compelling financial case, particularly those that include side object detection.

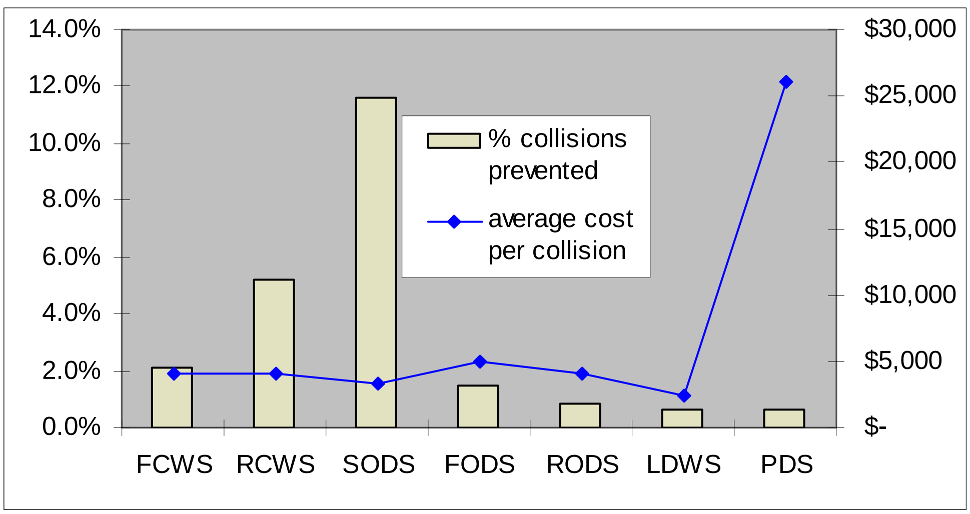
The relative success of SODS is driven by the following key factors. First, the systems are designed to prevent or mitigate collision types that are of both high frequency (sideswipes with vehicles are 33 percent and fixed-object collisions are 10 percent of all collisions) and relatively high avoidability (18 percent of sideswipes are avoidable, and 90 percent of fixed-object collisions are avoidable). Second, SODS were determined to be effective, preventing 66 percent of avoidable sideswipes and 50 percent of avoidable fixed-object collisions. In contrast, the lower frequency and avoidability of the collision types addressed by the other systems and the difficulties of preventing or mitigating these incident types using advanced technologies (which often involve higher relative rates of speed between the bus and the object struck) yield lower investment benefits for these other system options.

From the values in Table 4-17, it is possible to summarize preventable collisions by system. In Figure 4-6, the bars illustrate the percentage of all collisions that each system can prevent (with scale on the left axis), while the line represents the average cost of the prevented collisions (with cost scale shown on the right axis). The two systems that stand out are SODS, due to the high proportion of collisions it prevents (11 percent of all collisions), and PDS, due to the high average cost of the collisions it prevents ($26,000).

Table 4-17: Details about System Performance against Collision Types

Collision type		Percent of all collisions (A)	Avoidability (B)	System	Avoidable collisions prevented by system (C)	Percent potentially prevented among all collisions A x B x C
With Vehicle	Frontal	14%	28%	FCWS	36%	1.4%
				FODS	37%	1.5%
	Rear	16%	16%	RCWS	38%[43]	5.1%
				SODS	7%	0.2%
				RODS	33%	0.8%
	Angle	11%	14%	n/a	0%	0.0%
	Side-swipe	33%	18%	FCWS	11%	0.7%
				SODS	66%	4.0%
				LDWS	11%	0.7%
	Other	13%	32%	SODS	67%	2.8%
				PDS	3%	0.1%
Pedestrian		2%	35%	PDS	83%	0.5%
Object		10%	90%	SODS	50%	4.6%
Total						22.4%

Figure 4-6: Collisions Prevented and Collision Costs by System



As discussed above, there is currently no empirical data describing the actual effectiveness of the seven safety systems in preventing or mitigating bus collisions. Consequently, this benefit-cost analysis was developed based on an assessment of the *expected* effectiveness of each system in addressing 60 different collision scenarios (considered to be a reasonably complete description of all collision scenarios). Nevertheless, the actual performance of the safety systems remains unknown and may be better (or worse) than that assumed above.

To address the uncertainty in actual system effectiveness, an alternative analysis was performed that does not rely on the assumed prevention rates from step 1c. Instead, by using the frequencies of collisions (step

[43] The value for "C" is the percentage of unavoidable collisions prevented by RCWS (38%), and the value for AxBxC is the product of A, the percent of all collisions (16%); B, unavoidability (84%); and C (38%), or 5.1%.

1a), costs of collisions (step 1b), and system costs (step 2), it is possible to estimate the prevention rate that is *required* by a given collision avoidance system in order for that system to pass the benefit-cost test. In other words, we fix the benefit-cost ratio at one and determine the minimum values in step 1c to attain that ratio. Table 4-18 summarizes the results of this analysis. For example, although in Table 4-13, FCWS were estimated to have a benefit-cost ratio of only 0.45, Table 4-18 suggests that if forward collision warning were able to prevent 43 percent of the costs associated with frontal vehicle collisions, it could be cost-effective.

Table 4-18 also shows each system's "percent of collisions that is avoidable" in the center-right column. The values in this column reflect the percentage of crashes of each type that were judged to be avoidable by transit agencies, thereby providing a measure of the pool of collisions that IVBSS can begin to address. For example, although FCW systems must prevent 27 percent of frontal vehicle collisions to be cost-effective, 28 percent of frontal collisions are considered "avoidable," and only 10 percent were assumed to be preventable by deployment of an FCWS. This result suggests that only a maximally effective FCWS purchased as a standalone product would be cost effective (i.e., 27 percent out of the available 28 percent must be prevented).To be financially justifiable, systems must have a "percent avoidable" that is equal to or greater than the percentage effectiveness required. FCWS, RCWS, and SODS are the only standalone systems meeting this requirement. For the remaining four systems (FODS, RODS, LDWS, and PDS), it is clear that the required break-even effectiveness is *greater* than the percent of incidents deemed by transit agencies to be avoidable. In other words, even if 100-percent effective in eliminating avoidable collisions, each of these systems would not be cost effective.

Table 4-18: Effectiveness Required to Break Even under Baseline Assumptions for Standalone Systems

System	To break even, system must be effective in the following percentage of collisions:	Percent of collisions that is avoidable	Percent of collisions currently assumed prevented
FCWS	27% of Frontal	28%	10%
RCWS	58% of Rear	84%[44]	32%
SODS	12% of Sideswipe, Rear, Other, and Object	30%	16%
FODS	33% of Frontal	28%	10%
RODS	66% of Rear	16%	5%
LDWS	27% of Sideswipe	18%	2%
PDS	47% of Pedestrian	35%	29%

Table 4-19 summarizes the results of this alternative analysis for various safety system combinations. All of the combination systems have "avoidable" values greater than the required effectiveness.

[44] For RCWS, the percentage of unavoidable collisions is provided.

Table 4-19: Effectiveness Required to Break Even Under Baseline Assumptions for System Packages

Combination	To break even, system must be effective in preventing the following percentage of collisions:	Percent of collisions that is avoidable	Percent of all collisions currently assumed prevented
ODS	9% of Front, Sideswipe, & Object	33%	15%
ODS Cocoon	10% of Front, Sideswipe, Object, & Rear	30%	16%
FCSD	13% of Front, Sideswipe, & Object	33%	16%
CWS	14% of Front & Sideswipe	21%	6%
CWS+	16% of Front, Sideswipe, & Pedestrian	22%	7%
CWS Cocoon+	17% of Front, Sideswipe, Pedestrian, & Rear	20%	6%
All	15% of All Costs	29%	22%

4.4 Sensitivity Analysis

Each of the inputs to the benefit-cost analysis presented above is subject to varying levels of uncertainty. For example, the alternative analysis method presented at the end of Section 4.3 served to eliminate estimates of IVBSS effectiveness—and thus uncertainty in those estimates—as inputs to the analysis. This section presents the results of a sensitivity analysis whose goal is to assess the impact of uncertainty of all the input variables on the analysis results. Sensitivity analyses are helpful in determining whether some systems currently failing the benefit-cost test may pass that test under circumstances different from those assumed in the baseline scenario in Section 4.3.

The fundamental assumptions driving the benefit-cost results include the following:

- Cost of collisions
- Frequency of collisions
- Collision prevention rates
- Safety system useful life
- Discount and inflation rates
- Cost of safety systems

Section 4.3 presented the results of an alternative analysis that addresses uncertainty in collision prevention rate estimates, and hence will not be considered again here. In addition, uncertainty in system useful life, inflation rates, and discount rates was not found to affect the results of the benefit-cost analysis materially (see Appendix D). Consequently, only the cost and frequency of collisions, and the cost of safety systems are addressed in this sensitivity analysis.

4.4.1 Collision Cost and Frequency Sensitivity

Data from NTD and participating agencies were used to estimate collision costs and frequencies. For the sensitivity analysis, the variability of these data was assessed and the full range of collision costs and frequencies tested to determine their impacts on the benefit-cost analysis. For example, the data used to perform the cost buildup included agency estimates of the cost of fatality claims, injury claims, third-party damage claims, and agency-reported bus repairs. Assuming a normal distribution among these data across all agencies, a 95-percent confidence interval for the cost of collisions was constructed. This interval is summarized according to crash type in Table 4-20.

Table 4-20: Range of Collision Costs by Crash Type, Using 95% Confidence Interval on Cost Buildup

Crash type		Baseline cost	Range
With vehicle	Front	$672	$305 - $1,260
	Rear	$623	$138 - $1,451
	Angle	$531	$216 - $1,129
	Sideswipe	$1,036	$334 - $2,123
	Other	$544	$231 - $987
With Pedestrian		$306	$39 - $614
With Object		$662	$85 - $2,010
Total		$4,374	$1,348 - $9,574

Similarly, 95-percent confidence intervals were constructed for the frequency of unreported collisions per 1,000 buses across NTD and the six participating agencies, as summarized in Table 4-21.

Table 4-21: Range of Unreported Collision Frequencies Per 1000 Vehicles, Using 95% Confidence Intervals

Crash type		Baseline rate	Range
With vehicle	Front	161	83 - 243
	Rear	199	171 - 224
	Angle	139	86 - 188
	Sideswipe	494	265 - 727
	Other	193	126 - 261
With Pedestrian		21	5 - 33
With Object		143	24 - 266
Total		1350	759 - 1944
Unreported as a % of total		88%	81% - %92

Using the upper and lower extreme values shown in Table 4-20 and Table 4-21, the benefit-cost analysis was repeated. The resulting range of benefit-cost ratios is summarized in Table 4-22 for each standalone safety system and in Table 4-23 for the various integrated systems.

Table 4-22: Range of Benefit-Cost Ratios for Standalone Systems Based on 95% Confidence in Collision Costs and Frequencies

System	Baseline	Range
FCWS	0.45	0.22 - 0.81
RCWS	0.59	0.10 - 1.44
SODS	1.43	0.37 - 3.55
FODS	0.26	0.13 - 0.45
RODS	0.14	0.05 - 0.28
LDWS	0.10	0.04 - 0.20
PDS	0.81	0.11 - 1.62

Table 4-23: Range of Benefit-Cost Ratios for System Combinations Based on 95% Confidence in Collision Costs and Frequencies

Combination	Baseline	Range
ODS	1.60	0.47 - 3.79
ODS Cocoon	1.59	0.48 - 3.72
FCSD	1.25	0.37 - 2.93
CWS	0.49	0.22 – 0.88
CWS+	0.83	0.21 - 1.61
CWS Cocoon+	0.69	0.19 - 1.33
All	1.38	0.37 - 3.08

The magnitude of the benefit-cost ratios computed for the sensitivity analysis is consistent with the baseline findings. In other words, the best-performing systems under the baseline are likewise best performing when comparing the range of results. Among standalone systems, for example, SODS has a benefit-cost range between 0.37 and 3.55, the highest of any other standalone system. Likewise, among system combinations, ODS has the highest benefit-cost ratio range, 0.47 to 3.79. Although none of the systems exceeded a benefit-cost ratio of one (even at the low end of the 95% confidence interval), the performance of SODS and the investments that had SODS performed strongly.

Although the ranges of benefit-cost ratios are wide, they reflect 95-percent confidence in both the costs and the frequencies of collisions.

4.4.2 Agency Collision Frequency Sensitivity

A second sensitivity test was performed by varying the collision rates for all collisions based on estimates of the range of collision rates experienced by agencies. It is expected that agencies with the least amount of collisions stand to benefit the least by deploying collision avoidance systems. Conversely, agencies with high collision rates have the most to gain by deploying systems to reduce collisions. Figure 4-7 and Figure 4-8 illustrate the relationship between benefit-cost ratio and collision frequency for each system. For agencies with an average collision frequency, only SODS among standalone systems had ratios above one. Among combination systems, several have ratios above one, including ODS, ODS Cocoon, FCSD, and All. However, among agencies with high collision rates (those whose collision frequencies are approximately twice the rate of the average), the standalone SODS and PDS and all of the integrated packages (except for the CWS package) have benefit-cost ratios above one. For agencies with low collision rates (those whose collision rates are approximately one-third the rate of the average), all of the systems and packages of systems have benefit-cost ratios below 0.5.

Figure 4-7: Benefit-Cost Ratio Variation with Collision Frequency for Standalone Systems

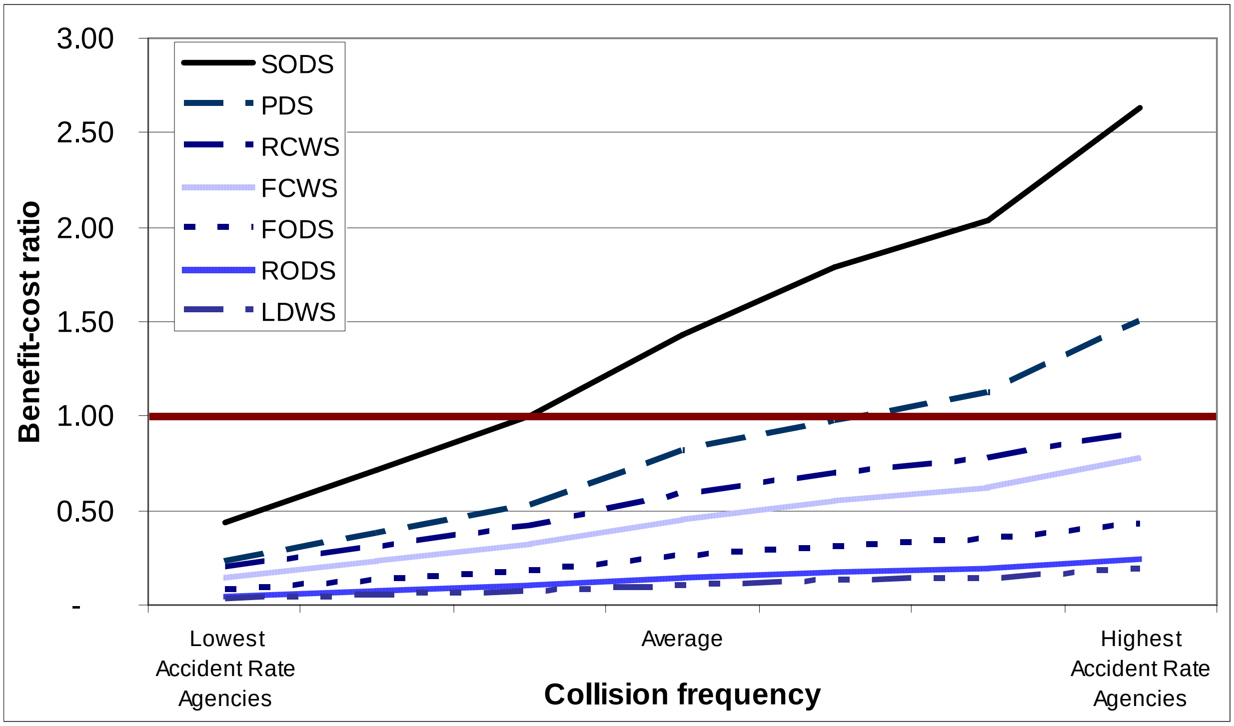
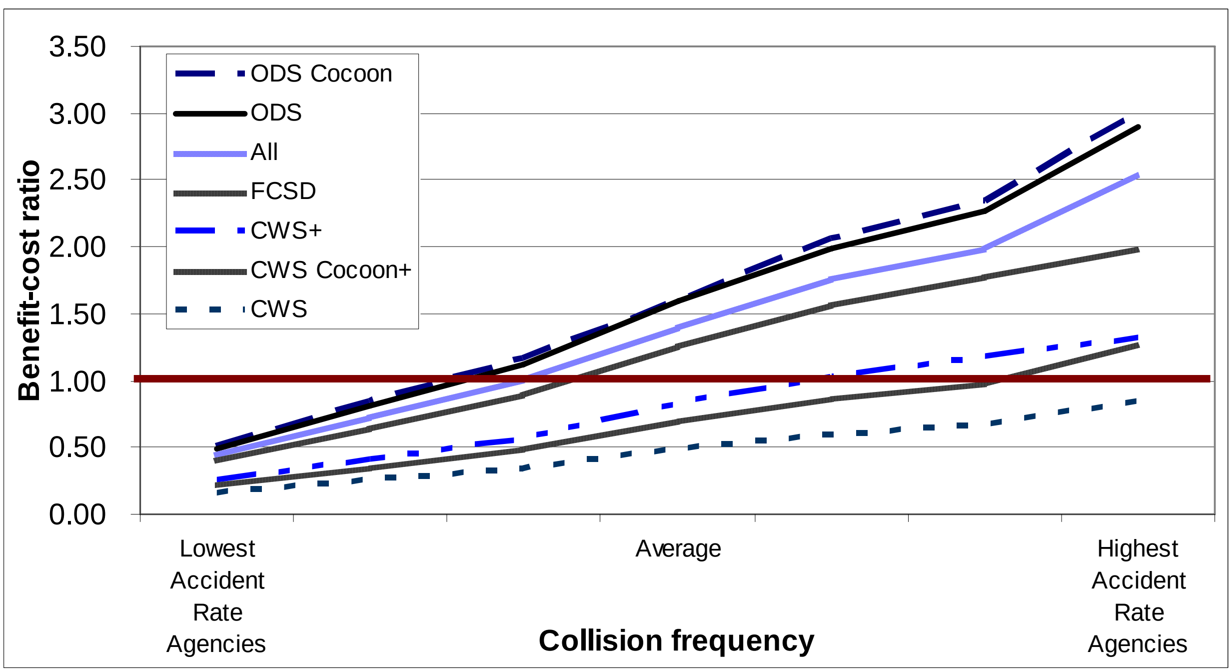


Figure 4-8: Benefit-Cost Ratio Variation with Collision Frequency for Combination Systems



4.4.3 System Cost Sensitivity

One of the least certain inputs to the benefit-cost analysis is the cost of the safety systems, few of which are commercially available. As the systems are developed and refined, it is reasonable to expect that the cost per unit will decline. As prices decline, the attractiveness of the systems will change, so it becomes critical to understand how changes in price affect the benefit-cost analysis. Based on the benefit-cost analysis structure, the relationship between system cost and the benefit cost ratio is nearly linear, meaning that a decline in system cost will result in a proportional increase in the benefit-cost ratio. To illustrate, the full cost of each system, including annual O&M costs, was reduced by 50 percent to examine the effects of such an impact on the benefit-cost results. As expected, the benefit-cost ratio roughly doubled from their baseline values, as shown in the center column of Table 4-24. For example, the benefit-cost ratio for FCWS increased from 0.45 to 0.91.

An additional test on system cost was performed that answered the question—Under baseline assumptions about collision costs, collision frequencies and collision avoidance system effectiveness, what percentage reduction in system price must be attained before a system can deliver a benefit-cost ratio above one? For example, RCWS have a benefit-cost ratio of 0.59 under all baseline assumptions, including the assumption that the system acquisition cost is $1,449 per bus, with annual operating and maintenance costs of $141. To achieve a benefit-cost ratio of one, the assumed total cost of system ownership must be reduced by 41 percent, as shown in Table 4-24 (this reduction would result in a new acquisition price of $855 and an annual maintenance cost of about $85).

Table 4-24: Sensitivity Analysis Results For System Cost

System or Package	Benefit-cost ratio		% Price reduction needed to break even
	Baseline	Half-off system price	
FCWS	0.45	0.91	55%
RCWS	0.59	1.18	41%
SODS	1.43	2.87	-
FODS	0.26	0.51	74%
RODS	0.14	0.28	86%
LDWS	0.10	0.20	90%
PDS	0.81	1.62	19%
ODS	1.60	3.20	-
ODS Cocoon	1.59	3.18	-
FCSD	1.25	2.49	-
CWS	0.49	0.97	51%
CWS+	0.83	1.67	16%
CWS Cocoon+	0.69	1.37	31%
All	1.38	2.77	-

4.5 Other Implications of This Analysis

The results of the benefit-cost analysis and related sensitivity analysis suggest that many safety systems may not be cost effective when evaluated strictly in terms of direct financial costs and benefits. Integrated systems appear to offer better prospects for cost effectiveness (given the ability to spread some fixed investment costs over each of the systems bundled together); no single system or combination of systems passed the benefit-cost test under all conditions in the sensitivity test. This section discusses the implications of the results for transit agencies, insurers, and system vendors.

4.5.1 Implications for Transit Agencies

While many of the systems were not found to be cost effective on financial grounds alone, this analysis has yielded several insights that agencies may wish to incorporate into their decision-making processes. These include the following:

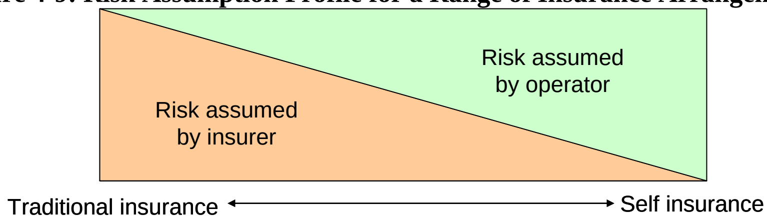
- Agencies should collect collision data in a manner that allows for analysis of safety issues and trends. Specifically, agencies should record details of each collision related to the manner of collision, speed, location, number of injuries, number of fatalities, costs, claims, operator actions (i.e., whether the collision was avoidable), and other information. By collecting detailed information, agencies can better identify the types of collision events that are most frequent and/or costly. Such information can support changes in safety practices, procedures, and investments. The analysis presented in this chapter represents the average American transit bus, but each agency should also be able to recreate the analysis with its own set of data so that investment decisions for particular systems can be better informed by agency-specific data.
- Agencies can target “avoidable” collisions through operator-focused strategies, including training and driver-assist technologies. Avoidable crashes are those that the bus operator could have acted to prevent.
- “Unavoidable” crashes (i.e., those for which another party is likely at fault) constitute a large majority of transit bus collisions nationally, as many as 90 percent according to data collected from some participating agencies. If a significant portion of an agency’s collision-related costs can be traced to unavoidable collisions, then safety strategies focused outside of the vehicle may also be worth investigating. For example, devices that more prominently indicate the presence of a bus, including more exterior reflective surfaces, beacons, audible signals, and warning signs, might address more collisions than in-vehicle devices for the simple reason that exposure to collisions caused by other drivers is much more frequent.
- The distinction between avoidable and unavoidable collisions underscores the need for agencies to understand exactly what types of collisions can be prevented by various systems.

4.5.2 Implications for Transit Agencies with Insurance

Until now, this analysis has assumed that all collision avoidance benefits will accrue to the transit agency. However, many agencies carry insurance to reduce their exposure to collision costs. Only when the benefit-cost analysis results are explained within the context of various insurance arrangements can agencies fully understand the implications of IVBSS. This section describes the principal insurance arrangements used in the transit industry and how the IVBSS benefit-cost results should be interpreted by agencies under each arrangement.

Transit agencies have many options for insuring themselves against collision-related property damage and liability, ranging from “traditional insurance” to “self-insurance.” Under traditional insurance, a transit agency pays another party (a private insurance company) in exchange for assumption of the agency’s risk; specifically, the agency pays a periodic premium, while the insurer assumes responsibility for all collision-related costs and for performing all claims administration. Under self-insurance, at the opposite end of the spectrum, a transit agency assumes full responsibility for its own collision costs, including responsibility for repairing its own property and for handling and paying claims to third parties. Figure 4-9 illustrates the risk assumed by insurance agencies and transit agencies along the spectrum between these two “limiting cases” of insurance strategy.

Figure 4-9: Risk Assumption Profile for a Range of Insurance Arrangements



In reality, insurers and transit agencies rarely assume *all* risk for collisions; instead, the risk is shared according to one of a variety of arrangements, away from the edges of the spectrum illustrated in Figure 4-9. For example, most agencies with an arrangement close to "traditional insurance" actually retain a modest amount of risk in the form of a per-incident deductible. The amount of the deductible determines how much risk the agency assumes (i.e., higher deductibles cause the agency to move toward the right in Figure 4-9). Typical deductible amounts in the transit industry range from several hundred to several thousand or even tens of thousands of dollars per incident. By assuming greater risk through higher deductibles, an agency can reduce its premiums. Agencies that retain large amounts of risk, up to several million dollars per incident, are characterized as "self insured" because they are close to the right edge of the spectrum. However, these agencies often contract with "excess" insurers to transfer the responsibility for extremely expensive collisions that exceed a specified dollar amount (e.g., several million dollars or more), which are low-risk events due to their extremely low probability of occurrence.

Consider the following two insurance arrangements:

- If a fully or largely self-insured agency could reduce its collisions and associated costs through IVBSS deployment, it would realize all the savings associated with the reduced collisions. The benefit-cost analysis results as presented in this chapter are directly applicable to such agencies.
- On the other hand, it is not immediately clear how the benefits of collision avoidance would be allocated to an agency with traditional insurance. The insurer who pays the costs of collisions (e.g., property damage and third-party claims) will benefit from IVBSS because there will be fewer collision claims. The agency will continue to pay premiums to its insurer and, as a result, will not realize many financial benefits of collision reduction, at least initially. Over time, however, the insurer will pass on the benefits of collision reduction to the agency by reducing premiums, if the reduction in collision-related costs can be demonstrated consistently over a period of several years.

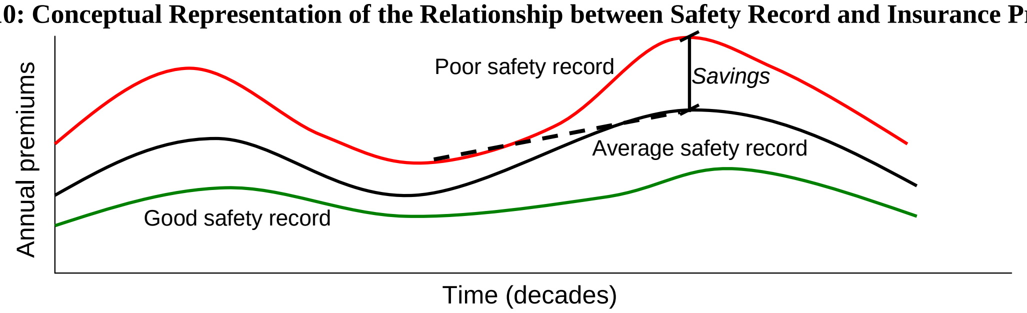
The benefits of IVBSS for self-insured and traditionally insured agencies have only one notable difference—traditionally insured agencies accrue benefits from IVBSS in the form of reduced premiums only after a period of years, while self-insured agencies accrue benefits immediately by reducing their collision-related expenditures.

One final element of the insurance business will affect traditionally insured agencies deploying IVBSS. Agencies can reduce their insurance premiums by deploying IVBSS and demonstrating a sustained reduction in collision costs; however, premium rate reductions may be obscured by other factors influencing rates that are beyond the control of transit agencies. These other factors may give agencies the erroneous impression that collision performance is unrelated to premium rates. However, it is important that agencies understand these other factors so that their safety investment decisions are made with full awareness of the insurance cost mechanisms.

Insurers typically bundle their cash flows (premiums received from customers) and invest them in open markets. When the economy performs poorly, the insurers must then raise premiums to account for the poor performance of their investments elsewhere; transit agencies have no control over this phenomenon. As a result, changes in premium rates for a single agency may not correlate with that agency's safety performance. For example, an agency could improve its safety performance over a period of years and still experience an increase in premiums. Despite this phenomenon, past and future expected loss rates are major factors in the determination of insurance rates, so an agency can minimize its premiums by maintaining a strong safety record.

Figure 4-10 illustrates conceptually the phenomenon of insurance premiums increasing and decreasing over time as a function of external factors. Note that a "good" safety record is rewarded with premiums that are both less in magnitude and in variability than "average" and "poor" safety records. This connection between safety and premiums may not be visible, however, to a single agency whose record has improved. For example, consider the agency represented in the figure by the dotted line. Due to underlying structural changes in insurance premiums, this agency's premiums have increased in real terms, despite the fact that the agency has improved its safety record from "poor" to "average." Because of the increase in premiums, the agency may discredit the impact of improved safety on insurance costs. However, it is important for the agency to recognize that it has actually accrued significant savings relative to the premiums it would be experiencing if it still had a poor safety record.

Figure 4-10: Conceptual Representation of the Relationship between Safety Record and Insurance Premiums



In light of these insurance practices, it is appropriate to interpret the benefit-cost analysis results from the perspective of transit agencies, regardless of their insurance arrangements. However, agencies should remain aware of the following:

- Insurers typically require a sustained reduction in collision-related losses over a period of several years before renegotiating premium rates. Consequently, installation of a proven IVBSS system, for example, would not be grounds for immediate reduction in premiums. Sustained reduction in risk as measured by collision rates and losses over a period of years, however, would.
- Sustained reduction in collision and loss rates does not lead necessarily to a real reduction in premium rates due to the possibility of changes in factors influencing premiums that are beyond the control of transit agencies. However, agencies that improve their safety records will see a reduction in premium rates relative to their expected rates without such improvements, as illustrated in Figure 4-10.

5.0 RISK ASSESSMENT AND MARKET VIABILITY

Prior chapters of this report have considered the business case for safety systems from the viewpoints of both technological preparedness and potential return-on-investment. This chapter considers the qualitative factors likely to influence the investment decisions of local transit agencies interested in purchasing collision avoidance systems and of equipment vendors interested in supplying systems to the transit market. Qualitative factors include both the potential non-financial benefits of investment in collision avoidance systems (e.g., rider perceptions of improved safety) and the potential risks of investment (e.g., opposition from labor unions, early technological obsolescence).

In addition, this chapter also combines the results of these quantitative and qualitative analyses to determine the total potential market size for collision avoidance systems for transit buses. The larger the potential market, the greater the incentive for vendors to reduce costs and improve product quality, leading in turn to still wider adoption and an increased likelihood that the systems will be successful.

5.1 Agency View

Agencies considering investing in collision avoidance systems will not base their decisions on return-on-investment considerations alone. Rather, any investment in a new transit technology will typically reflect a mix of both quantitative (including financial) and qualitative considerations. This section considers those qualitative factors likely to influence local agency investment decisions both for and against collision avoidance systems. In addition, this section identifies awareness of these systems among transit agencies, perspectives on system design and performance requirements (ranging from human factors to technology capabilities considerations), and overall agency investment priorities and constraints.

5.1.1 Approach

Agency perspectives on the qualitative benefits, costs, risks, and overall desirability of collision avoidance systems were obtained through the two outreach activities:

- An industry roundtable session
- Site visits to six transit properties

Industry Roundtable Session

The study team conducted an industry outreach session on October 10, 2006, at the APTA Annual Meeting in San Jose, California. Session panel members included 16 representatives from 12 U.S. transit operators as well as 2 representatives from Clever Devices, a technology vendor. Appendix A provides the complete list of attendees.

This roundtable session provided attendees with some background materials on the IVBSS program, the related technologies, and the annual costs to the industry from bus collisions, including estimates of property damage, injuries, and fatalities. The panel members were then asked their views on a series of issues related to collision avoidance systems for buses including:

- Technology awareness
- Factors most likely to drive the decision to invest in IVBSS
- Investment risks (e.g., liability risks)
- Expected/desired system design and performance characteristics
- Experience with other advanced technologies (e.g., AVL, on-board cameras)

- Institutional barriers to investment
- Agency investment priorities
- Deployment strategy

Agency Site Visits

In addition to the industry outreach session, the study team also conducted extensive on-site interviews with staff members from six different U.S. transit operators. These agencies included the following:

- Alameda County Transit Authority (AC Transit), Oakland, CA
- Chicago Transit Authority (CTA), Chicago, IL
- Los Angeles County Metropolitan Transportation Authority (Metro), Los Angeles, CA
- San Francisco Municipal Transportation Authority (Muni), San Francisco, CA
- North County Transit District (NCTD), Oceanside, CA
- Pace Suburban Bus (Pace), Arlington Heights, IL

Staff members from each of these agencies were selected to provide their views, concerns, and perspectives on the adoption and use of collision avoidance systems. To ensure a diversity of opinion, the agencies were asked to invite staff to participate who represented each of the following agency functions/responsibilities:

- Director Bus Operations (i.e., head of all bus operations)
- Director of Bus Technology/Engineering for information about past, present, and future bus technology
- Director of Bus Safety for information about collisions and collision data
- Accident Claims Manager for information about costs of crashes borne by agencies
- Federal Reporting Staff for information about bus collision data reported to FTA
- Senior Manager for Bus Maintenance for information about *major* incidents/collisions and their repair costs
- Bus Garage/Depot Maintenance Manager for information about *minor* collisions repair costs
- Bus Depot Operations Manager for input on vehicle operator concerns
- Human Resources Manager for information about accident liability and claims

Agency staff were interviewed using a prepared interview guide with sets of questions designed to reflect the various responsibilities and concerns of the staff positions identified above. Appendix B presents a copy of the interview guide. The interview guide questions cover largely the same topics as those addressed in the agency outreach session.

Each interview session commenced with a brief description of the goals and objectives of the project followed by a brief overview of the commercially available collision avoidance systems. Next, the participating staff responded to those questions from the interview guide that pertained most closely to their areas of responsibility. Finally, it should be noted that these local agency site visits were also used to obtain bus collision cost and frequency data to support the benefit-cost analysis described above.

5.1.2 Findings

The remainder of this sub-section summarizes the findings of the industry outreach session and the on-site agency interviews. Given that the materials covered by these two sources are largely the same, participant responses for these two sources have been grouped together here. The list of issue areas addressed here are the same as those identified above under the description of the industry outreach session.

Technology Awareness

Participants of the industry outreach session and on-site agency interviews were asked to describe their prior awareness of and interest in collision avoidance systems for transit. The vast majority of outreach session participants were generally aware of the technologies' existence, but many were not aware of the *specific* systems available (e.g., object detection versus collision warning) or of their differing capabilities. The relatively high rate of general awareness with the session participants is not surprising given their participation in the session. Virtually all session participants 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.

Technology awareness was significantly lower among the agency staff participating in the on-site interviews, with less than half of the participating staff having any prior knowledge of a collision avoidance system. Note, however, that technology awareness was generally high for staff with responsibilities relating either to bus vehicle engineering or fleet safety. Outside of these key agency functions, technology awareness was generally low.

Factors Most Likely to Drive the Decision to Invest

Participants of the industry outreach session and on-site agency interviews were asked to identify those factors mostly likely to induce them to either consider or actually invest in a collision avoidance system. Respondents identified the following key factors:

- Reduction in pedestrian injuries and fatalities
- Reduction in minor incidents
- Reliability
- Proven effectiveness
- Integration

Reduction in Pedestrian Injuries and Fatalities: Although few in number relative to other collision types, collisions involving pedestrians have very high costs (i.e., injury claims). Moreover, these incidents frequently attract widespread media attention and have the potential to reduce public perceptions of service safety. Given these concerns, study respondents were understandably interested in the ability of these systems to reduce pedestrian collisions or at least mitigate their severity. Reduction in pedestrian collisions was typically the highest investment decision factor identified by senior agency staff (e.g., agency GMs or directors of bus operations) and by agency claims staff. As will become clear, the primary investment decision factors vary by agency staff, reflecting differences in their roles, responsibilities, and differing understandings of collision-related issues.

Reduction in Minor Incidents: Although typically of low cost, minor incidents account for by far the greatest proportion of all internally reported agency collisions. Here, a “minor” incident might be considered any collision (whether reported internally or not) resulting in roughly $7,500 or less in damage. Many interviewees believe that this incident type ultimately accounts for the greatest share of agency collision costs due to its large number. In fact, the benefit-cost analysis confirms this suspicion. It is important to note here that none of the agency staff interviewed possessed a clear understanding or supportive data identifying which form of collision was ultimately most costly to their agency—the infrequent but costly collisions with pedestrians or the frequent but inexpensive minor incidents. Many respondents also expressed the belief that minor collisions were likely the type of incident that collision avoidance systems will be most effective in mitigating. The reduction of minor incidents was usually cited as a high investment decision factor by agency staff responsible for bus accident repairs and day-to-day bus maintenance. Respondents were, of course, also interested in reducing the frequency and severity of ***all*** incidents types. However, emphasis was more frequently placed on minor incidents as likely being the more preventable by these systems.

Reliability: After the reduction in pedestrian collisions and the mitigation of incident severity, respondents cited system reliability as a key investment decision factor. Many respondents noted that, if available, all buses equipped with the system would likely be required to have the system functioning before a vehicle would be approved for pull-out into revenue service. Under these circumstances, the system would need to be highly reliable (e.g., greater than 99 percent reliable) to ensure sufficient buses were available to support scheduled revenue service. Lower reliability rates would either: 1) represent a significant barrier to system adoption or 2) require an increase in the size of the agency's spare fleet as required to ensure revenue service needs. System reliability was considered a key investment decision factor by 1) bus division directors, 2) bus engineering/technology staff, and 3) staff responsible for bus operations.

Proven Effectiveness: While virtually all participants expressed interest in the potential of collision avoidance systems, most appear to have adopted a "wait and see" attitude to investment. Specifically, agencies want to see hard evidence of a decline in accident frequencies (or costs). One operator reported having deployed collision avoidance equipment on a portion of its bus fleet (based on the test results of a peer operator), but had not yet been able to demonstrate a conclusive reduction in collisions from this investment. This operator is holding out on further deployment until decisive benefits have been demonstrated through reduced collision-related costs or collision occurrence rates. System effectiveness was considered a key investment decision factor by bus division directors and engineering and technology staff.

Integration: Many respondents expressed concerns with the growing number of independent systems coexisting (e.g., AVL, fare collection, on-board cameras) on fleet vehicles. Currently, vehicle operators are required to "boot-up" and logon to each of these systems independently. Moreover, each add-on will have its own maintenance needs. Consequently, the agencies have concerns regarding the addition of yet another device or set of devices to their vehicle fleets. Rather than looking for integration of more than one collision avoidance system, agencies appear to be more interested in the integration of all existing bus technologies and would be more supportive of collision avoidance if these systems were integrated with other bus technologies. System integration was considered an investment decision factor by virtually all types of agency staff.

Agency Investment Risks

Participants of the industry outreach session and on-site agency interviews were asked to identify the primary risks of implementing collision avoidance systems. Examples of risks include:

- **Liability:** How will the presence (or absence) of a collision avoidance system impact a transit agency's liability in the event of an accident?
- **Technological Obsolescence:** Will an agency's concerns of significant technology change limit willingness to deployment?
- **Operator Acceptance:** Will vehicle operators accept or reject the new technology?

Liability: Liability related risks represented the most significant investment concern identified by participants in the outreach session and on-site interviews. Here, two diametrically opposed positions were commonly identified: 1) liability risk from investing in collision avoidance systems and 2) liability risk from not investing in these systems.

- *Liability Risk with Investment:* Several interviewees suggested that agencies with collision avoidance equipped fleets might be subject to additional liability risk. The argument is that, if an equipped vehicle was involved in a serious accident, the agency may be subject to penalties for not having prevented the incident (e.g., due to operator negligence or improper maintenance). Among those with liability concerns, this was the minority position.
- *Liability Risk Without Investment:* The opposing view suggested that agencies may face increased penalties in the event of an accident if their fleet vehicles are *not* equipped with collision avoidance systems and these systems are considered widely available (or widely adopted by peer operators) and sufficiently effective to have prevented the incident. Indeed, participants with this view suggested that, should industry adoption of these systems become sufficiently widespread and technology effectiveness be perceived as effective, all transit operators will be expected to, or even required to, adopt these systems (e.g., by the public, by legislators, or by insurers). Here, the example of "cow catchers" designed to prevent pedestrians from falling under transit buses was cited as an example of a required safety improvement. Most staff with liability concerns adopted this position.

Liability risk concerns were most frequently cited by agency staff with safety, claims processing, or legal counsel related responsibilities.

Technological Obsolescence: A small number of participants stated that their agencies might not invest in collision avoidance until the technology was more mature and established within the industry. This strategy avoids the risk of investing in an early form of a technology, only to replace it a few years later once a new and better technology becomes available. Relatively few participants expressed this concern. More participants took the position that deployment within their agency would be driven more by demonstrations of technology effectiveness, reliability, and maintainability at peer operators, and less by concerns of rapid initial technological change.

Operator Acceptance: A small number of participants also pointed to the risk that vehicle operators might reject the new technology. For example, if not well designed, the visual or audio mechanisms used to warn drivers of potential collisions may generate too many "false positives" or otherwise prove too distracting or taxing (e.g., produce "sensory overload"). Alternatively, operators may have concerns that the technology may somehow increase the likelihood of the driver being assigned responsibility for an incident. Many more participants rejected the latter view, noting that related technologies (e.g., on-board cameras) have had the opposite impact of more clearly demonstrating when the operators were not at fault. More importantly, most participants noted that, while operator acceptance was of significant concern to each agency, operators are not in a position to "reject" the technology.

Desired Performance Characteristics

Participants in the industry outreach session and on-site agency interviews were also asked to identify their preferred design and performance characteristics for collision avoidance systems. Participants identified the following desirable characteristics:

- Prevention/mitigation of injuries and fatalities
- Maximized coverage/minimized blind spots
- Optimized human factors design
- Vital system operation
- Autonomous vehicle control

- Incident recording capability
- Collision warning for auto drivers and pedestrians

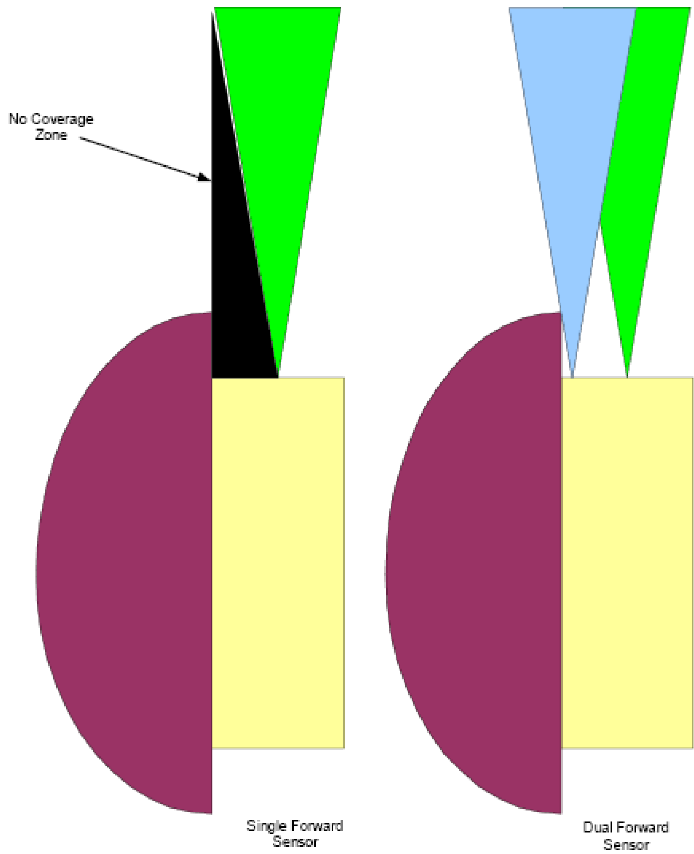
Each of these characteristics is considered in turn.

Prevention/Mitigation of Injuries and Fatalities: While participants were, of course, interested in the ability of technologies to reduce accident frequency and severity in general, many reiterated their desire that the technology reduce injuries and fatalities in particular. In doing so, these participants highlighted their desire that the technology be able to distinguish pedestrians from other objects. Participants also reflected on the more frequent characteristics of collisions involving pedestrians and the related requirements for any pedestrian detection system to be most effective in mitigating these types of incidents. Specific examples included:

- *Pedestrian Collisions on Left- and Right-Hand Turns:* A transit bus is executing a 90-degree left or right turn onto a different street and collides with a pedestrian crossing the intersection. In many instances, the collision is the result of the pedestrian being "located" in the blind spot created by pillars located at the front-right and front-left of the bus (the operator literally did not see the pedestrian was there).
- *Collision with Pedestrians Located Adjacent to the Side of the Bus:* A second example cited was the case of pedestrians located adjacent to the side of the bus but still in the roadway. This would include riders preparing to board the bus or having just disembarked as well as cyclists riding between the side of the bus and the street curb.

Participants suggested that collision avoidance with a pedestrian detection component would be most effective (and more investment worthy) if these blind spots are well covered, thus allowing the operator to "see" pedestrians in these critical locations.

Figure 5-1: Coverage Zone of Two Alternative Sensor Arrangements[45]



Maximized Coverage/Minimized Blind Spots: The preceding discussion emphasized the desire for pedestrian detection in vehicle blind spots. More generally, some study interviewees expressed interest in any object detection capabilities in vehicle blind spots (i.e., not just pedestrian detection). Moreover, most participants agreed on the general desirability of systems that provide near complete coverage of the *entire* vehicle (with the possible exception of the rear of the bus, where the desire for coverage varied). At the same time, there was equal concern that, with a full coverage vehicle, it may not be possible to design a reasonable driver interface that can quickly inform the driver of the approximate location of an impending collision.

A related concern was the desire to equip the right side of each vehicle towards the rear of the bus. Many operators noted that a significant proportion of collisions with objects (other than other vehicles and pedestrians) occur at the side and towards the rear of the vehicle, and most frequently on the right-hand-side. To avoid these types of collisions, object detection must be located toward the rear of the vehicle. It is important to note that SODS have been more typically deployed toward the front of the vehicle, with little or no coverage toward the rear.

Finally, further discussion of the value of relatively complete vehicle coverage should be tempered by the: 1) benefit-cost analyses, 2) operational tests demonstrating the effectiveness of coverage at different locations around the bus, and 3) the feasibility of designing diver interfaces that can successfully inform operators of the location on the vehicle about to be struck.

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[45] Image provided by authors.

Optimized Human Factors Design: Discussion of human factors issues generated intense interest in the outreach session and in all of the on-site agency interviews. Specifically, virtually all interviewees expressed concern as to the best means to communicate collision avoidance information to the vehicle operator such that the operator can quickly determine the location and nature of an impending collision and safely execute an evasive maneuver.

Curiously, there was *no* agreement on the best means to inform bus operators of an impending incident. Many respondents suggested that audio warnings were the best (or only) means of communicating information to drivers in a driving environment already heavily laden with visually based cues (e.g., dash gauges, traffic signals, mirrors, lights, and passengers boarding and alighting the bus). Other respondents felt equally strongly that audio warnings could not quickly communicate the location of an impending threat as effectively as a visual display. Moreover, continuous audio "false positives" in heavy traffic might prove irritating to vehicle operators and passengers alike.

Ultimately, virtually all participants did agree on the following key points regarding human factors:

- *Human factors design is critical to the success of the collision avoidance systems*: The interface must provide information in a manner that the operator can both determine the location and nature of the impending threat, and then be able to take an evasive action without jeopardizing the passengers.
- *False positives must be minimized:* Transit buses are primarily operated in dense urban areas and in dense traffic. Hence, bus collision avoidance systems must successfully address the issue of false positives—either by severely limiting the number of false positives or by providing collision avoidance information to the driver in such a way that false positives do not lead to sensory overload or operator and passenger annoyance.
- *Prevent Operator Overload*: Transit bus operators must remain alert to auto traffic, traffic signals, passengers boarding and alighting the vehicle, fare payment, schedule requirements, radio communications, and passenger safety. The addition of collision avoidance systems represents another source of information for the operator. To be successful, the system must successfully integrate into the operators' other responsibilities without contributing materially to driver fatigue.

Vital System Operation: Modern transit buses include a variety of systems that need to be operational before most agencies will permit the vehicle to enter revenue service. Examples include fare collection systems, on-board cameras, radio system, AVL, and others. The question posed to outreach session members and on-site agency interviewees was whether an installed collision avoidance system would be required to be operationally ready before an equipped vehicle would be permitted to enter service. Respondents offered two perspectives here. First, agency staff expressed concern that their agency might be liable to pay additional damages in cases where a vehicle equipped with a malfunctioning collision avoidance system was permitted to enter service and then involved in an accident. Second, given that the system would likely be required to be operating, respondents reiterated their concerns that the technology be highly reliable. If a fully functional system was required to enter revenue service and if all fleet vehicles were so equipped, then a low system reliability would result in either: 1) insufficient vehicles being available for pull-out on a regular basis and/or 2) agencies would need to expand their spare fleets.

Another concern was the possibility that bus operators may choose to disable the system prior to a service run. Given the liability issues already noted here, many respondents felt that operators should not have the means to "turn off" a collision avoidance system.

Autonomous Vehicle Control: A few respondents suggested that a fully integrated collision avoidance system (i.e., integrated with all other bus functions including the power train, steering, brakes, etc.) should be able to “take control” of the vehicle in the event of a significant collision warning. Key issues include the precise circumstances when the vehicle should take autonomous control and the types of evasive actions the autonomous vehicle should be capable of. One respondent provided a dissenting view, suggesting that there are a number of potential situations (e.g., railway crossings) where such autonomous vehicle control may prove considerably less effective than human judgment.

Incident Recording Capability: Several respondents expressed interest in the ability of collision avoidance systems to record the circumstances of collision and near collision events. Depending on the type of collision avoidance system in place and the detection technology, this might include relative vehicle speeds, separation distances (for near collisions), and pictures from camera-based systems. This information would then be used both for driver training purposes (to identify and correct unsafe driving habits) as well as for accident reconstruction (to help identify which party was responsible). After pursuing this line of reasoning with several transit agencies, it become clear to the study team that this type of capability would be redundant when grouped with other existing technologies such as on-board vehicle cameras and “black box” technologies that already record vehicle speed and other characteristics around accidents. While not a key capability given the availability of these other incident-recording technologies, data incident recorded by collision avoidance systems would represent valuable corroborating information.

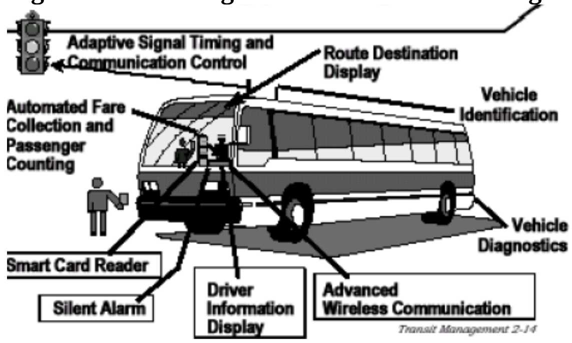
Collision Warning for Auto Drivers and Pedestrians: Many participating agency staff members identified a need to provide collision warnings both to other vehicles and pedestrians (as opposed to just the bus operators). For example, it was suggested that buses making right or left turns provide an audible warning such that pedestrians entering a cross walk could be warned of the bus’s presence (similar to warnings provided by larger vehicles when backing up). Staff also identified rear collision warning systems to warn auto drivers when they are approaching the rear of an equipped bus too quickly (i.e., similar to the system tested by Ann Arbor, MI). For rear collision warning, agencies are interested in avoiding collisions where a bus is either pulling into or out of a dedicated bus stop and a following vehicle attempts to overtake the bus too quickly, resulting in a rear-left collision.

Experience with Other Advanced Technologies

Study participants were also asked to share their agencies’ experiences with other advanced technologies such as Computer-Aided Dispatch (CAD, Automatic Vehicle Location (AVL), Automatic Passenger Counters (APC), voice annunciation, and signal prioritization (see Figure 5-2 for examples of existing technologies). The purpose of this questioning was to understand if such experiences may have influenced their desire to invest in collision avoidance. Specific questions included the following:

- What advanced technologies has your agency adopted?
- Were there any unexpected costs/benefits to implementation?
- Did operator or mechanic staff require any special training?
- Was maintenance outsourced?
- Have your prior experiences influenced your plans or desire to implement other advanced technologies (positively or negatively)?

Figure 5-2: Existing Transit Vehicle Technologies



All of the participating agencies reported having one or more "advanced" technologies on at least some portion of their fleet. Where these devices involve the collection or processing of significant amounts of data (e.g., smart card transactions, vehicle tracking, passenger counts), many operators reported experiencing greater than expected costs from investing in these technologies (including the need for more IT staff to store, maintain, and process data). Many participants also reported the need for additional operator and mechanic staff training to ensure these technologies are used effectively and properly maintained. Two large operators reported that maintenance of some of these electronic-based systems was beyond the abilities of their vehicle mechanic staff. In response, these agencies have entered into long-term maintenance agreements with their technology suppliers. Other participants noted the lack of available maintenance resources (e.g., appropriately trained mechanics) as barriers to new technology investment.

Without actual experience maintaining a collision avoidance system, the participants were reluctant to express an opinion as to whether these systems would also require a specialized maintenance contract. However, many did express concern that training, operation, and maintenance of these systems may be beyond the abilities of many smaller operators, thus potentially limiting the realizable market size for these systems.

Finally, virtually all participants agreed that the benefits of having invested in advanced technologies were generally worth it (more so with proven technologies). Based on these prior experiences, these participants concluded that prior investment experiences would not constrain their interest in investing in collision avoidance systems if the benefits of these technologies can be effectively demonstrated.

Institutional Barriers to Investment

Study participants were also asked to identify any potential agency barriers to collision avoidance deployment. Examples of barriers include staff resistance to the technologies, funding constraints, or labor union conflicts. Nearly all staff agreed that funding availability represents the greatest existing barrier to the deployment of any new technology. Even if return-on-investment analysis suggests very strong positive returns, agencies still face stringent funding barriers to new investment and long lists of deferred capital replacement needs. Wherever agencies move forward with new technology investments (such as collision avoidance), it will be at the expense of other investment needs. It is important, nevertheless, to note that the participants did not identify any "show stoppers" likely to prevent investment in collision avoidance systems. Moreover, staff felt reasonably sure that agency board members and senior staff would be supportive of investment in these systems provided their benefits could be demonstrated.

Finally, the participants did identify the small size of the transit market as a potential barrier, not to agency deployment, but to vendor interest in delivering and continuing to support deployment of collision avoidance systems. Agency staff were concerned that if their vendors leave the market, they would lose support for maintenance of their products.

Agency Investment Priorities

Given that collision avoidance systems are likely to compete with other investment priorities, the outreach session participants were asked to rank the relative importance of various investment needs as high, medium, or low. The result of this informal poll is presented below in Table 5-1. Note that no investment need was ranked as having a "low" priority.

Table 5-1: Investment Priorities of Outreach Session Participants

Investment Category	Investment Priority
Fleet replacement / expansion	High
Facilities re-investment	Medium
Other Technologies	Medium
Collision Avoidance – Reduces Minor Collisions	Medium
Collision Avoidance – Mitigates Collisions by >25%	High

More importantly, the outreach session participants generally rated the investment priority for a collision avoidance system that reduces minor collisions as "medium." However, if the technology was capable of mitigating the severity of all accidents by more than 25 percent, the respondents increased the investment priority to "high." Participants reiterated the claim that many would invest in the technology today if it had a proven track record (thereby displacing other investment plans).

Deployment Strategy

Finally, the study participants were asked how they would most likely deploy collision avoidance systems on their fleets. Specifically, the participants were asked:

1. "If the technology were available and proven would you…"
   a. Invest today or wait for future generations of the technology?
   b. Wait until a peer agency has proven the technology?
2. Would you deploy on your existing fleet or only on new vehicles?
3. Would you include collision avoidance in your new bus specs?

In response to these questions, agency staff reiterated their positions that they will not invest in the technology until proven. However, assuming that the technology was demonstrated to be reasonably effective in reducing collision frequencies and/or severities, virtually all participants stated that their agency would very likely invest. Moreover, the technology would be included in all new bus specifications and, assuming it could be accomplished at reasonable cost, their existing fleets would be retrofitted with this technology. Hence, once again the issue of acceptance lies on proof of technology effectiveness.

5.2 Vendor View

Equipment vendors have their own assessment of investment determinants, risks, and rewards. In general, vendors of bus collision avoidance systems face two key areas of investment risk:

- Technical risks
- Economic and commercial risks

5.2.1 Technical Risks

For equipment vendors, the technical risks of investing in an IVBSS product relate to the performance (i.e., effectiveness) of the product sold. Specifically, it has yet to be determined (at least to the satisfaction of the transit agencies interviewed for this report) whether the existing systems are sufficiently effective in reducing collisions or mitigating collision severity to warrant investment by financially constrained agencies. As discussed above, it is not certain whether these systems will be able to distinguish potential accidents from non-threatening events. Also, it is not certain whether they will have a sufficiently effective user interface for drivers to avoid an impending collision. The primary technical risk to a potential technology vendor is that these problems are not "solvable" in a cost-effective manner.

It has also been suggested that an inability to integrate collision avoidance systems with other vehicle systems may also pose an "agency acceptance risk." In other words, some agencies may not wish to purchase a new system that has not been integrated with one or more existing systems. Based on the agency responses, this risk is minimal, as most agencies appear very willing to invest in collision avoidance if it can be shown to be effective in reducing collision frequency and/or severity.

5.2.2 Economic and Commercial Risks

The ultimate commercial viability of any product depends on whether the product can be sold at a combination of price and volume such that the vendor enjoys a positive net return. The fact that more than one vendor has entered the market for collision avoidance systems suggests that these vendors have some confidence in the long-term commercial viability of these products. From the vender perspective, the greater risk then lies in backing a specific technology only to become eclipsed by a competing system at some point in the future. Entrance of a competing technology can generate price competition that reduces profits or lead to product obsolescence. The fact that more than one vendor has entered the market suggests that these risks are not sufficient to deter initial market entry. Based on these considerations, it would appear that vendors have discounted the economic and commercial risks of developing and selling collision avoidance systems. At this point, the more significant vendor risk lies in convincing transit operators that their technology is effective in reducing collision frequency and severity.

5.3 Market Viability

This section considers the potential size and viability of the market for transit-based collision avoidance systems. Market size has important implications for product pricing (prices generally decrease as market size increases), long-term viability and maintainability of the technology, and most importantly the total impact on collisions. Ultimately, the market size and viability for a given technology will reflect the "target" market (i.e., just transit bus or other user groups as well) and perceptions of effectiveness. Each of these concerns is addressed below.

5.3.1 Target Market

Vendors of collision avoidance systems applicable to transit bus operations may choose to target a variety of market segments. In addition to the transit market itself, potential markets include local delivery vehicles (e.g., FedEx vehicles), large trucks, or even personal automobiles. The technology assessment included in this document has identified at least three different models that might be considered with respect to a vendor's "target market."

The first model is that of an equipment vendor that currently supplies the transit bus market with specialized equipment other than collision avoidance systems (e.g., APC) and which has an interest in expanding its product offerings to include collision avoidance systems. In this model, the vendor has a clear interest in focusing on the transit market with the objective of securing a position of as a premier supplier of advanced equipment to the transit bus market. As such, this model of supplier also offers clear advantages in the long-term goal of physically integrating its various product offerings (as noted above, transit operators expressed considerable interest in being able to better integrate their different vehicle systems). Under this model, the vendor may have only limited interest in supplying its collision avoidance system to non-transit customers (as these lie outside of the core customer base). Moreover, as described in detail in the technology assessment, the characteristics of collision avoidance systems for transit bus (i.e., designed for low speed, high density traffic environments) will only have limited applications outside of transit. Given these concerns, the perceived total market potential for a vendor with this model is the combined fleet size of the nation's bus operators.

A second observed model is that of vendors developing collision avoidance and other safety systems for the long-haul truck market. As noted in the technology assessment, many such truck-based systems are either commercially available or are in development; however, these products are not designed to address low speed, high-density traffic environments in which transit buses operate. At the same time, the vendors of these technologies view the much larger truck market as their core customer base and have indicated that the transit market is not of sufficient size to warrant development of transit-appropriate solutions.

Finally, the third observed model is that of a vendor developing collision avoidance systems for the full automotive market. In the absence of any specific interest by transit operators or vendor expectations of a high rate of deployment within the transit market, it is unlikely that this model of vendor will focus on the interests of a small transit market relative to the much larger automotive market. The risk to transit under this model is that technologies that may be effective in reducing transit bus collisions are not deployed by transit (at least in the short- to medium-term) and that the design of these technologies is not optimized to meet transit needs. As a result, while this model can promote lower technology costs (given the broader size of the market relative to a transit-only solution), it may not yield a transit-appropriate solution.

Given these considerations, it would appear that the appropriate market segment of analysis for collision avoidance systems effective for transit applications is, in fact, the transit bus market itself. While this market can benefit from technologies developed for broader market applications (e.g., for the general automotive market), the transit operating environment and transit bus vehicle characteristics require that vendors target this market with transit-specific solutions.

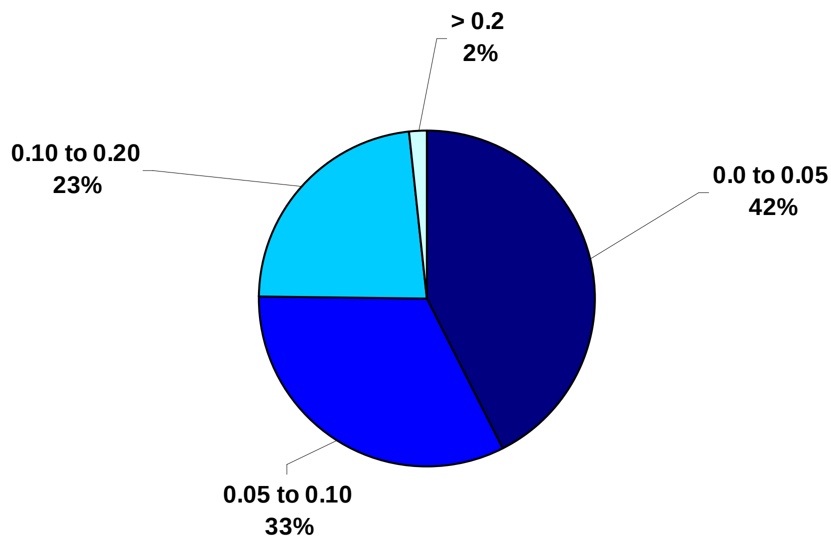
5.3.2 Market Potential

Current purchase costs for collision avoidance systems for bus (including training, application engineering, and OEM support) are roughly $2,700 per vehicle (based on Seymour System estimates for WMATA). Note, however, that current costs reflect deployment in a small market with relatively few early adopters. As the technology matures, unit costs should be expected to drop. This price behavior is consistent with the product life-cycles of most automotive and electronics technologies (e.g., antilock brake systems). For collision avoidance systems, the final level of market penetration (and hence lowest price) will ultimately be determined by the number and types of users (e.g., transit agencies, private delivery truck, and private auto users) who perceive its benefits as exceeding its costs. Initially, there may only be a few industry segments that perceive a net benefit (e.g., those with higher frequency collisions and/or higher collision costs). The greater the number of these early adopters, the greater the opportunity for increased market penetration and reduced costs.

Within the transit bus market, the ultimate level of technology deployment will depend on the transit industry's perceptions of the technology's effectiveness. The more effective the technology is considered to be in reducing collision frequency or cost, the greater the number of agencies that will be willing to invest in the technology. Related to this is the consideration that, for a given level of technology effectiveness, an individual agency's interest in investing in the technology will depend on that agency's collision rates and average collision severity. For example, agencies with high collision rates and/or high collision costs will be more interested in investing in a "low effectiveness" technology than will agencies with lower accident rates.

Based on a review of collision rates for U.S. transit agencies and the total fleet holdings for each agency, it is clear that the level of technology effectiveness will likely have an impact on the total level of industry deployment (assuming agencies deploy the technology based on a combination of technology effectiveness and each agency's own accident rates). Figure 5-3 presents the number of U.S. transit vehicles exposed to varying rates of major and non-major collisions, as documented in NTD. The chart shows that 38 percent of U.S. transit buses are in fleets that average between 0.0 and 0.05 major or non-major collisions per vehicle per year. An additional 39 percent are exposed to collision rates between 0.05 and 0.10 accidents per year. In contrast, only 2 percent of vehicles are exposed to rates of more than 0.20 major and non-major collisions per bus per year. If collision avoidance systems are, in some sense, only "minimally" effective, the ultimate market size may be limited to this small proportion of the market (e.g., 2 percent) that may perceive a net benefit from investment in the system. In contrast, the systems may need to meet a greater threshold of effectiveness to be sufficiently cost-effective to induce agencies with lower annual collision rates to invest in the technology.

Figure 5-3: Percent of U.S. Transit Buses Exposed to Various Major and Non-Major Accident Rates per Bus per Year



Based on this analysis of bus populations by collision involvement rate, it is possible to determine the number of buses for which the various collision avoidance systems are financially worthwhile. This analysis is summarized visually in Figure 5-4 for standalone systems and in Figure 5-5 for combinations of systems. The benefit-cost ratios determined in 4.0 are plotted as lines that vary by collision involvement rate. For example, agencies with low collision involvement rates toward the left side of the figures, expect a lower benefit-cost ratio. Meanwhile, the population of buses within each collision involvement bin are plotted as bars and overlaid on the line chart. The result is a visual depiction of benefit-cost ratios for each system along with the number of buses to which that benefit-cost ratio applies.

The number of buses corresponding to each benefit-cost ratio can also be quantified, as shown in Table 5-2. This table contains seven categories of collision involvement rates—lowest, low, middle-low, average, middle-high, high, and highest, along with the number of buses corresponding to those categories. The table summarizes whether each system passes or fails for each collision involvement rate category. For example, SODS "pass" (benefit-cost ratio above one) only for buses whose collision involvement rates are average and above. This corresponds to almost 31,000 buses, but fails for buses with collision involvement rates below the average. The object detection system (which contains both forward and side object detection) and ODS+ (which combines forward, side, and rear object detection) pass for over 40,000 buses. Pedestrian detection and several of the combinations of technologies also pass, but only for approximately 5,000 buses or fewer.

Figure 5-4: Benefit-Cost Ratios for Seven Standalone Systems and Bus Population, by Collision Involvement Rate

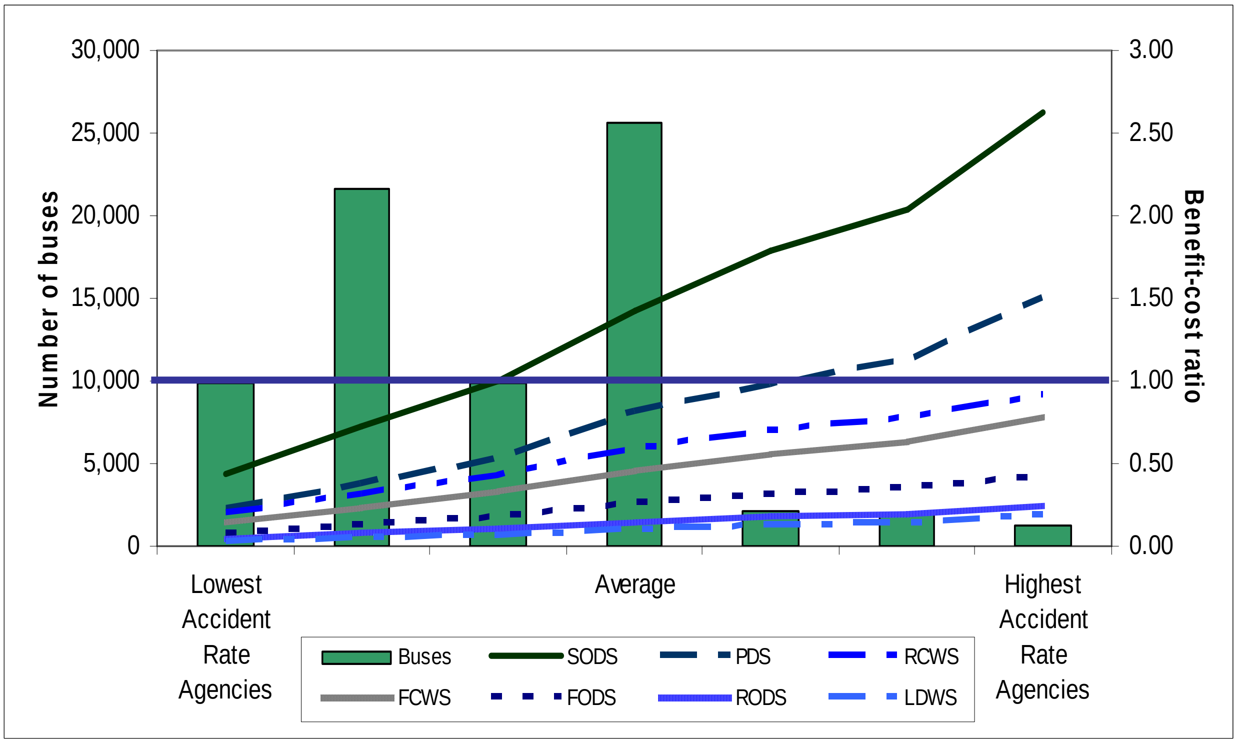


Figure 5-5: Benefit-Cost Ratios for Technology Packages and Bus Population, by Collision Involvement Rate

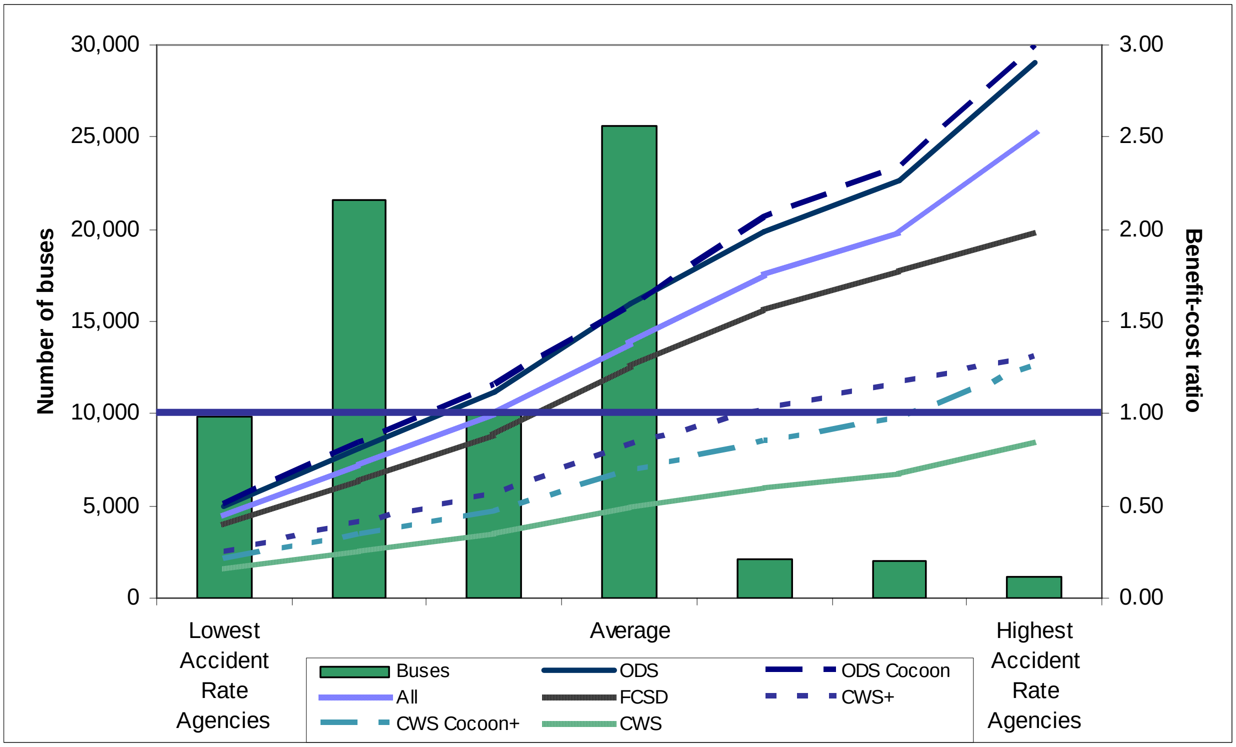


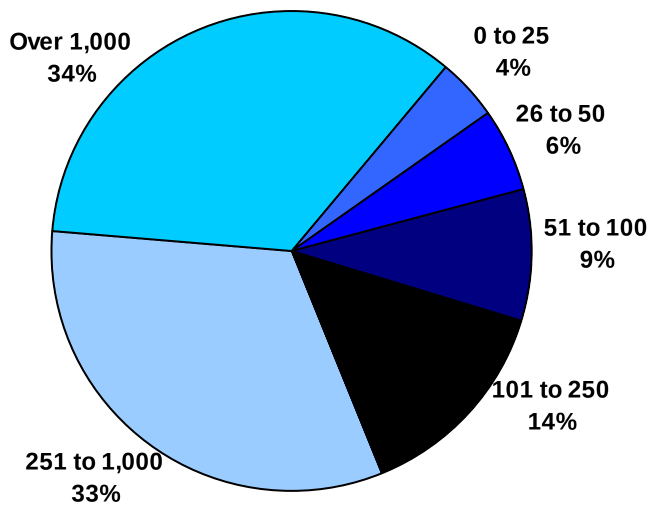
Table 5-2: Number of Buses for Which Investment Is Financially Justifiable, by System

Collision involvement rate:		Lowest	Low	Middle-Low	Average	Middle-High	High	Highest	# Buses Passing
Bus Population		9,836	21,571	9,910	25,630	2,135	1,970	1,193	72,245
System	FCWS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	RCWS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	SODS	Fail	Fail	Fail	Pass	Pass	Pass	Pass	30,928
	FODS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	RODS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	LDWS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	PDS	Fail	Fail	Fail	Fail	Fail	Pass	Pass	3,164
Package	ODS	Fail	Fail	Pass	Pass	Pass	Pass	Pass	40,838
	ODS+	Fail	Fail	Pass	Pass	Pass	Pass	Pass	40,838
	FCSD	Fail	Fail	Fail	Pass	Pass	Pass	Pass	30,928
	CWS	Fail	Fail	Fail	Fail	Fail	Fail	Fail	-
	CWS+	Fail	Fail	Fail	Fail	Pass	Pass	Pass	5,298
	CWS Cocoon+	Fail	Fail	Fail	Fail	Fail	Fail	Pass	1,193
	All	Fail	Fail	Fail	Pass	Pass	Pass	Pass	30,928

A second determinant of a system's ultimate market potential is the ability of individual agencies to maintain the technology. As noted above, in-house maintenance of new technologies such as on-board camera systems, AVL, and (potentially) collision avoidance systems requires specialized training for maintenance staff and potentially additional IT staff as well. Training and long-term employment of these specialized staff is generally more cost effective for operators with large fleets, but may not prove realistic for smaller operators with more limited resources. Hence, in addition to an agency's annual collision rates, an agency's ability to maintain a collision avoidance system may also determine its interest in acquiring the technology (with smaller operators being less likely to invest than larger operators).

Figure 5-6 presents the number of U.S. transit buses within transit fleets of various sizes (based on 2005 NTD vehicle count data). For example, based on these data, 34 percent of the nation's transit buses reside in agency fleets with more than 1,000 buses (note: there are roughly 25 U.S. agencies with fleet sizes of greater than 1,000). If the staffing requirements for collision avoidance systems are sufficiently specialized such that a fleet of 1,000 vehicles or more is required for system investment to be cost effective, the total market size for collision avoidance systems will be roughly 34 percent of the nation's total fleet (or roughly 25,000 vehicles). In contrast, if operators with more than 250 vehicles have the ability to maintain the system, the total market size is roughly two-thirds of all U.S. transit buses (about 50,000 vehicles). While the actual requirements for maintaining these systems remain undetermined, ongoing and future operational tests should help address this question.

Figure 5-6: Number of U.S. Transit Buses within Fleets of Various Sizes



When this analysis of bus population by fleet size is combined with the analysis summarized in Table 5-2 of bus population by collision involvement rate, the potential market size for collision avoidance systems can be further refined. For example, according to Table 5-2, the market size for SODS, based on bus collision involvement rate and its implication for return-on-investment, is roughly 30,000 buses. However, if only two-thirds of buses belong to fleets of sufficient size (>250 vehicles) to maintain collision avoidance systems, then the true market size is actually 20,000 buses. Likewise for the object detection system combination, for which 40,000 buses passed the benefit-cost test, true market size based on fleet sizes is 40,000 x 2/3 = 27,000 buses.

5.3.3 Vendor's Sales Potential

The analyses in the preceding sections and chapters suggest that investment in at least some of the bus collision avoidance technologies "makes sense" from the viewpoint of transit operators (i.e., the benefits exceed the costs). However, we must consider the viewpoint of equipment vendors. Does the market for bus collisions avoidance systems look sufficiently promising to warrant investment in system development, refinement, production, marketing, distribution and product support?

Based on the review of the existing product suppliers, the answer to this question is a qualified "yes." At present, one vendor is already selling SODS to U.S. transit agencies while a second vendor clearly expressed interest in supplying forward collision warning and pedestrian detection system products to that same market. It is clear, then that these vendors already consider this market sufficiently promising, based on their own internal evaluations, to actively market their existing collision avoidance products.

Another approach to assessing the attractiveness of the IVBSS market to vendors is to estimate the value of the market based on the preceding analyses. The analyses provide estimates of the sales potential of retrofitting vehicles in fleets where each technology was found to pass the benefit-cost test. Specifically, Table 5-3 considers two different scenarios. The first is to assume that agencies retrofit *all* vehicles for which technology investment is expected to pass the benefit-cost test (i.e., the 100-percent penetration scenario). The second scenario assumes a 35-percent penetration rate (roughly the amount to equip only those agencies with more than 1,000 vehicles for which the investment passes the benefit-cost test)[46]. Review of Table 5-3 suggests that SODS and the various packages containing SODS offer reasonable sales potential, even if market penetration is relatively low.

Table 5-3: Retrofit Market Sales Potential

Technology	Number of buses in fleets where technology passes B/C test	Sales cost per unit (b)	Sales potential – 100% penetration ($ millions): Retrofit	Sales potential – 35% penetration ($ millions): Retrofit
	(a)	(b)	(c)	(d)
Individual systems				
SODS	30,928	$2,550	$78.9	$27.6
PDS	3,164	$1,800	$5.7	$2.0
Packages				
ODS	40,838	$2,750	$112.3	$39.3
ODS+	40,838	$3,150	$128.6	$54.0
FCSD	30,928	$4,250	$131.4	$46.0
CWS+	5,298	$3,600	$19.1	$6.7
CWS Cocoon+	1,193	$5,450	$6.5	$2.3
All	30,928	$7,999	$247.4	$86.6

It is important to note that both scenarios presented in Table 5-3 only consider the ***"one-time"*** sales resulting from retrofitting all (or some of) the existing bus fleets for which investment makes sense. In contrast, the sales potential to equip new vehicles is considered in Table 5-4. This table repeats the analysis presented in Table 5-3, but focusing on only that level of sales required to equip new buses (purchased for replacement or expansion purposes), but with no provision to retrofit existing vehicles. Unlike the "one-time" retrofit sales presented in Table 5-3, the sales in Table 5-4 represent ongoing, annual sales levels. The expected annual sales revenues from equipping new buses are much lower than the one-time cost to retrofit. Here again, SODS and the various packages integrating SODS and other technologies appear to offer reasonable market potential for high penetration rates, but none of these technologies appears to have significant long-term sales volumes under lower market penetration rates.

[46] Here, the number of vehicles in fleets where a technology passed the benefit-cost test is taken directly from Table 5-2, and the estimated costs of those technologies are taken from Tables 4-9 and 4-10.

Table 5-4: Market Sales Potential to Equip New Buses

Technology	Annual bus sales to fleets where technology passes b/c test	Sales cost per unit (b)	Sales potential – 100% penetration ($ millions)	Sales potential – 35% penetration ($ millions)
	(a)	(b)	(c)	(d)
Individual systems				
SODS	2,076	$2,550	$5.3	$1.8
PDS	212	$1,800	$0.4	$0.1
Packages				
ODS	2,741	$2,750	$7.5	$2.6
ODS+	2,741	$3,150	$8.6	$3.0
FCSD	2,076	$4,250	$8.8	$3.1
CWS+	356	$3,600	$1.3	$0.5
CWS Cocoon+	80	$5,450	$0.4	$0.2
All	2,076	$7,999	$16.6	$5.8

It is important to note here that agencies participating in the outreach efforts clearly indicated that they would retrofit older vehicles with IVBSS technologies if they were shown to be cost effective. Hence, if agencies do begin to deploy these technologies, it should be expected that sales volumes would be much higher in the short-term as compared to the long-term (i.e., as agencies retrofit their vehicles initially and then only purchase new units as required to equip new replacement and expansion buses). In other words, vendors can expect the higher sales amounts presented in Table 5-3 during initial deployment, tapering off to the lower annual sales amounts presented in Table 5-4 as the market matures. Of course, sales would increase further both with ongoing expansion of the nation's bus fleets and replacement with newer technologies as they arise.

Based on this assessment, the market for SODS and the various packages containing SODS do appear to be promising from the vendor's perspective, especially if these systems are sold in conjunction with other products in the vendor's portfolio (e.g., AVL, APC).

5.3.4 Vendor Profitability

For vendors, it is not sufficient merely to sell a large number of units. Rather sales of these units must be profitable to provide the incentive to enter the market. Without a detailed understanding of vendor costs, it is impossible to determine what level of sales is required to obtain a reasonable rate of return on each of the technologies considered in this report (many of which are not commercially produced). However, based on the preceding analyses in this report, there are good reasons for believing that some of these products represent profitable opportunities for vendors.

First, as already noted, there are two vendors currently ready to serve the market. One of these already sells electronics technologies to transit bus operators and the sale of bus collision avoidance systems represents the addition of one more product to an existing portfolio of transit specific products. Hence, under this business model, the small size of the transit market is not a significant issue as this type of vendor is already operating in that market and has demonstrated an interest in development of new products for that market. The second vendor has designed its product for use in the broader auto and truck market, with minimal to no modification required to install this system on transit vehicles. Here again, under this second business model, the small size of the transit market is not an issue as product profitability rests on sales across all markets, not just transit.

Aside from these two vendor's obvious willingness to enter the market with collision avoidance system products, there are other factors indicating that the production of some technologies should be profitable to the vendor. For example, product profitability is largely dependent on unit sales. As the number of unit sales increases, the fixed cost of production (including design and re-tooling costs) can be spread over an increasing number of units, thus reducing production cost per unit. Taking SODS as an example, based on the analysis above, the potential exists to sell between 10,000 and 30,000 of these units for retrofitting and an additional 700 to over 2,000 units annually thereafter to equip new vehicles. These unit sales provide a large base over which fixed production costs may be distributed, leading to improved opportunity for profitability. These unit sales are also comparable to those relating to the initial and long-term sales for many existing transit bus products including AVL, APCs, destination signs, and on-board cameras. It should be noted here that the existing SODS technologies are of a similar level of complexity to these existing systems (which are currently staples of the transit technology market) and hence should not be assumed to be any less profitable. The same applies to the other technologies with higher expected unit sales identified above (including the various IVBSS packages that contain SODS).

6.0 NEXT STEPS: OPERATIONAL TESTS AND DEPLOYMENT STRATEGIES

The benefit-cost analysis in this study rests on estimated technology effectiveness rates established based on reviews of a detailed classification of accident scenarios. The analysis found SODS to be cost effective (i.e., the benefit-cost ratio exceeded one) under most circumstances and pedestrian detection systems to be cost effective for operators with above-average collision rates or high collision costs. To more accurately determine the benefit and costs of collision avoidance systems, operational test data on the effectiveness of these systems is needed. It is recommended that DOT conduct field operational tests of side object detection and pedestrian detection systems. The DOT may wish to conduct more limited testing of the remaining collision avoidance systems. The planning of a field operational test should start with the development of a technology "roadmap." The roadmap should clearly present all steps relating to the further development, testing deployment, and commercialization of IVBSS technologies for transit as shown in Figure 6-1 below.

Figure 6-1: Road Map Steps

Operational Tests and Deployment Schedule		
Year 1	**Years 2-4**	**Years 3-5**
Research & Testing Activities	**Award Contract**	**Communication & Outreach**
A) Technology Review (update to this study)	A) Release request for applications	A) Disseminate the results of these reports through industry conferences
B) Identify and review recent and on-going research activities	B) Evaluate applications	B) Document and communicate early success stories
C) Gain understanding of industry development and test activities	C) Award conductor team	C) Document best practices related to implementing technology
Define objectives of the field test	**Conduct FOT**	D) Address institutional issues
A) Review past FOT objectives	A) Equip buses with safety systems	**Program for the supplier community**
B) Define preliminary test objectives	B) Collect data	A) Develop consensus around core performance and functionality
C) Test objective brainstorming session with government stakeholders	C) Analyze data	B) Assist industry develop specifications and standards
D) Develop consensus on test objectives	D) Report on results	C) Review commercially-available systems and specifications
Develop field test guidelines		D) Review specifications developed for commercial motor vehicles
A) Interview transit authorities		E) Reduce development risk to suppliers
B) Determine number of buses, miles, operating environment, costs		F) Develop deployment strategies
C) Perform statistical and financial assessment of test guidelines		**Technology monitoring**
D) Develop safety benefits approach		A) Develop technology monitoring plan
Monitor and evaluate on-going research activities		B) Track number of units sold, vendors, advertising
Develop field test plan		C) Interview transit authorities
Organize and conduct technical workshop with government and industry		D) Identify best practices used to market and sell systems
A) Review and discuss field test plan		

Beyond merely laying out these steps, the roadmap needs to address the federal interest and role in further assessing these technologies as well as the interests and roles of all key stakeholder groups including:

- Transit agency staff (e.g., bus operators, maintenance managers, bus engineering personnel, and finance staff)

- The supplier industry (e.g., suppliers of core “building block” technologies, IVBSS integrators, and bus OEMs)
- Additional automotive safety researchers, as well as stakeholders involved in the current large-truck and light-duty vehicle IVBSS initiative, to solicit input on lessons learned thus far that may have relevance for the transit IVBSS work
- FTA, NHTSA and Joint Program Office (JPO) staff involved in IVBSS planning for transit

Throughout this testing, deployment, and commercialization process, it is important that U.S. DOT continue to support the collection and dissemination of recent qualitative and anecdotal data regarding technology effectiveness, user acceptance, privacy concerns, and other related issues that could impact deployment planning and market adoption. Dissemination of such data is important to building both industry wide awareness and consensus for any new technology. Activities that U.S. DOT can sponsor to help build the market for new safety technologies generally fall into the following categories:

- Research and testing activities
- Communication and outreach efforts
- Programs for the supplier community
- Technology monitoring

This chapter considers each of these four groups of activities in detail.

6.1 Research and Testing Activities

An important component of the roadmap will focus on FTA’s role in supporting innovation and continued research. The integrated collision warning system project completed by PATH/Carnegie Mellon and the Clever Device Seymor System currently under evaluation by WMATA, GCRTA and UTA will provide a strong start for exploring the operational effectiveness and customer acceptance of IVBSS for transit. Future research programs will likely need to focus on the following questions:

- What are the actual safety benefits of IVBSS for transit in quantitative terms (e.g., reductions in injuries, property damage, litigation costs, etc.)?
- What are the long-term impacts on driver behavior? Do bus operators overly rely on the system and alter their driving behavior?
- How can the technology be better implemented to reduce “nuisance” alarms so that operators view the systems as a help rather than a detriment to their daily mission?
- How should IVBSS for transit technology be combined with other commercial vehicle safety technologies such as wireless communication between vehicles and crash prevention technologies? What are the safety benefits and customer acceptance implications?
- What other, new fundamental technologies exist for identifying obstacles or roadside “furniture” (such as highly accurate GIS maps combined with highly accurate AVLS systems)? What is the current stage of development and what research should be done in these areas?

FTA has an important role to play in helping industry move forward on these and other research issues. It is recommended that FTA tailor a specific research plan for IVBSS for transit, ensuring that it complements other research efforts. It is also recommended that FTA determine the potential for alternative public-private partnerships and demonstrations to address the research questions listed above. It will be important to coordinate research and development efforts sponsored by FTA with ongoing research by private sector commercial companies as well as international research and product development efforts.

Furthermore, it is recommended that FTA develop operational test guidelines to be used in the development of an overall experimental design that will facilitate a clear and objective comparison of bus safety performance for vehicles with and without transit IVBSS technologies. It is likely that guidelines will need to be tailored depending on the host site but they should define the standards for evaluation and success.

6.1.1 Develop Field Test Objectives

It is recommended that FTA define the central objectives of a field test. These objectives will be used to guide the structure and scope of the field test program. Probable field test objectives will include:

- Determine the safety benefits of transit IVBSS within an acceptable level of certainty
- Determine IVBSS performance and functional requirements
- Determine IVBSS reliability and maintainability
- Evaluate failure modes to ensure a “fail safe” mode
- Evaluate customer acceptance

Defining the precise list of objectives for the field test may be accomplished through interviews with the stakeholders listed earlier. It is also recommended that FTA gain consensus on and articulate the key questions that the field test should answer. Key stakeholders could be brought together for a half-day “brainstorming” session to help with this effort and to generate ideas about the “experimental design” for an efficient field operational test. This would include a discussion of issues such as:

- The number of buses to be included in the program
- The number of test sites (transit agencies) to be involved (including whether the field operational test needs to be at multiple sites)
- Use of un-equipped, “control” fleets to improve judgment of the benefits of IVBSS for equipped vehicles
- The types of systems and vendors that should be tested
- Required duration of a test program
- Data collection and analyses requirements

Table 6-1 summarizes the annual number of expected collisions, by type of collision, that will occur in a fleet with 1,000 buses, based on a sample of historical, nationally-collected data (see Section 4.0 for details). For example, there are approximately 507 sideswipe collisions each year, or roughly 1 sideswipe collision for every 2 buses. Pedestrian collisions, on the other hand, are relatively rare, with roughly one pedestrian collision annually for every 35-40 buses.

Table 6-1: Annual Collisions Per 1,000 Buses by Collision Type (National Average)

Collisions with vehicles					Collisions with pedestrians	Collisions with objects	Total
Front	Rear	Angle	Side-swipe	Other			
218	**244**	**170**	**507**	**202**	**27**	**158**	**1,526**

Summary crash data such as those presented above should be used to determine field test parameters such as the fleet size and length of experiment that are required in order to produce statistically valid results about the performance of safety devices. For example, a field test of pedestrian detection systems should not realistically expect to gather enough data to draw statistically valid conclusions about system performance unless the test involves a very large sample (>1,000 buses) over a period of at least 1 year. On the other hand, because of the very high baseline frequency of sideswipe collisions, an experiment of SODS could likely yield useful results about the performance of that device. In short, field tests may or may not be an appropriate and feasible means of determining the effectiveness of some technologies to reduce collisions, depending on the baseline frequency of occurrence of the collision types they purport to address.

6.1.2 Develop Field Test Guidelines

Field test guidelines should address varying costs, durations, and approaches. The guidelines should include specifics on the number of buses, type of buses, miles, and operating environment required to meet program objectives. It is recommended that FTA investigate how the field test could be executed and who might participate. This would consist of informal discussions with specific transit authorities and safety system manufacturers.

Many factors need to be considered in developing guidelines for an experimental test plan. Key questions include:

- **Do operators drive the same bus each day, or are they randomly assigned to different buses?** Most large transit agencies do not assign operators to a particular bus unit due to scheduling and dispatching difficulties, although smaller agencies occasionally can afford this luxury. If the transit agency normally does not explicitly assign operators to a unique bus, can they consistently assign drivers to a sub-set of buses? It is recommended that operators not move from test to non-test buses randomly since a significant factor in how well the IVBSS works will involve the “learning curve” with the system. FTA should work closely with the host site agencies to determine whether the experimental design can ensure that operators assigned to the “test buses” (those equipped with IVBSS) will in fact be scheduled to operate the buses exclusively (or at least a very high percentage of the time) so as to ensure they acquire a fully mature “mental model” of the system, and therefore, realize the full benefits of the system. In fact, the flexibility and control that the transit agency has in assigning operators to buses should be one of the criteria used to select a host site.
- **Can the safety performance of the drivers be properly “baselined”?** It is rare that a transit agency is able to provide reliable and detailed records that link particular operators to minor side impact events (i.e., those below the agency’s internal accident reporting thresholds). A driver could “side-swipe” a fixed object, incur minor damage, and then not report the incident (the driver may not even know it happened depending on impact severity, number of people on the bus, noise levels inside the bus, etc.). Since many transit agencies do not conduct a detailed assessment of the exterior condition of the bus at the beginning and end of each shift, the information linking a particular operator to a particular incident can often be lost. In developing the overall experimental design, it will be important to work with the host agencies to implement an inspection and data collection process that can capture such information. However, the vehicle inspection and data collection system should ideally be located to be “invisible” to the operator. If operators of the “baseline” or “control” test fleet are aware that the buses they operate will be inspected at the beginning and end of each shift, that may influence their driving behavior and skew the results.
- **Are there skill differences among operators involved in the test?** This is an important consideration in conducting field operational tests, particularly when a comparatively small number of vehicles and operators will be involved. For example, if one of the host site agencies installs IVBSS on 10 buses and designates 10 other buses (operating on the same route) as the “control” fleet,

there is no guarantee that the driving skills (safety performance) of the operators assigned to the test fleet are the same as or similar to the operators assigned to the control fleet. If, for example, there are one or two operators assigned to the test fleet that exhibit poor driving skills relative to side impacts, then these operators could reduce the measured/observed success of the IVBSS system. While every effort should be made to work with the transit agencies involved to identify such operators (through examination of driving records, as well as through interviews with operator supervisors), the baseline performance of the operator may not be well known due to the "non reporting" issue cited above. The "ideal" way to address this issue would be to baseline the driving performance of the operators to be assigned to the test fleet (the fleet with IVBSS units) by monitoring their performance relative to side impacts in non-test buses for some period of time before the actual IVBSS test begins. This step would provide solid safety-related metrics (i.e., number and severity of impact events) on the operators to be assigned to the test fleet both before and after installation of IVBSS. extend the schedule for the field operational test by requiring this "pre-test" baselining of operator performance.

- **Selection of host site agencies and specific routes.** As previewed above, the characteristics of the host site agencies would also be an important factor in the overall experimental design. It would be advantageous to select agencies with comparatively poor safety metrics (e.g., based on collision data reported to NTD), since improvements would be more visible. Such safety-related data are available at the "macro" level for transit agencies.
- **Testing standalone vs. integrated systems**. Transit IVBSS includes a variety of possible combinations of standalone collision avoidance systems. There are several advantages to testing systems in combination, particularly those that are based on similar technologies (e.g., SODS, FODS, and RODS). These advantages include: 1) greater feedback on the ability of operators to manage several systems, 2) test results that are more indicative of the integrated systems, and 3) cost savings in testing several systems at once. However, these potential advantages must be balanced against the potential complications. Designing, managing, and analyzing field tests is a complex task and layering several safety systems could overwhelm the data collection and analysis required. Moreover, because many of the systems being considered for integration are "non-overlapping" (i.e., they address distinct types of collisions), the benefits of collision avoidance are additive. Consequently, testing systems in isolation may yield results for collision avoidance that are equally as informative as the results of a test of systems in combination.

6.1.3 Safety Benefits Approach

Determining the safety benefits of advanced safety systems using data from field operational tests has proven problematic. As part of the Intelligent Vehicle Initiative, the U.S. DOT evaluated several commercially available safety technologies on commercial motor vehicles. In 1999, the U.S. DOT entered into cooperative agreements with four partnerships to conduct Generation Zero field operational tests of advanced safety systems. For each of the field operational tests, a team consisting of a truck manufacturer, safety system supplier, fleet operator, and data analysis contractor deployed a relatively small number of trucks equipped with safety systems. Sophisticated data acquisition systems were fitted to the trucks to record large amounts data from vehicle and safety system sensors. Recognizing that truck crashes occur infrequently, teams employed a "safety benefits" equation developed by the Volpe Transportation Center under contract with the U.S. DOT.

To determine the safety benefits of IVBSS for transit, it is recommended that U.S. DOT use multiple test sites, fielding larger groups of vehicles over a long period. Such a field operational test could be costly; however, rather than implementing very costly and difficult to maintain on-board data recorders that would record virtually all drivers and vehicle parameters, it is suggested that using a limited on-board data recording system can save project resources. Safety benefits would be determined through actual incidents that occurred during the test period, as well as through interviews with operators and other transit staff. This is a low-risk approach that is achievable based on incident statistics for buses.

6.2 Communication and Outreach Efforts

A first step in building market demand for a new technology is to develop a comprehensive outreach and education program. Key content of the outreach activities should focus on the costs and benefits of the technology, early success stories, and information on best practices for implementing the new technology.

Costs of Poor Safety Performance. The full cost of poor safety performance is not well quantified or understood. While some transit authorities intuitively understand many of the indirect costs, purchase decisions for new equipment often must be justified on readily identifiable direct costs only. Alternatively, purchase decisions for safety-related equipment are often made on “gut feelings” and insufficient return-on-investment information. The availability and dissemination of reliable data regarding collision costs and the effectiveness of collision avoidance and other technologies in reducing those costs (such as that provided in earlier chapters of this report) are critical to agency adoption of these technologies. Indeed, outreach session participants clearly stated that their agencies would not invest in IVBSS related technologies until the investment benefits (i.e., reductions in collisions) were clearly demonstrated.

Document Early Success Stories. An important deployment strategy will be to document and communicate early success stories with IVBSS for transit. Transit authorities tend to be less skeptical of information from fellow bus operators. Agencies want to see concrete evidence of a reduction in accident frequency, severity, or other benefits before investing in these technologies.

Best Practices for Selection, Implementation, and Operation of IVBSS for Transit. In addition to documenting and validating the success that transit authorities have had with IVBSS, it will also be important as part of the outreach message to document best practices related to implementing the technology at the fleet level. For example, this type of analysis should answer questions such as:

- Are some technologies more effective than others?
- Under what circumstances are these technologies most effective (e.g., routes operated in dense versus light traffic)?
- What are the critical issues related to system operation or maintenance that affect technology effectiveness or reliability?

Addressing Institutional Issues. Deployment strategies must address institutional issues and risks related to privacy concerns, such as the use of IVBSS data for issuing driver violations or for tort litigation. Dissemination of data and findings that can address and potentially alleviate such concerns will also help facilitate technology adoption.

6.3 Programs for the Supplier Community

Supporting the supplier community will also be important for encouraging development and deployment. Here, it is recommended that FTA provide support in areas such as developing and identifying core performance and functional specifications and standards, and reducing various risks that suppliers of new technology must address.

6.3.1 Developing Consensus Around Core Performance and Functionality

For vehicle systems that involve a driver interface, excessive diversity in design, functionality, or operation can hinder customer acceptance. These problems can be exacerbated with safety-related systems where a multiplicity of designs and standards might lead to more rather than less accidents. Finally, too much diversity in core performance and functionality during early stages of a product's life-cycle may cause agencies to delay their buying decision "until the bugs get worked out." Hence, FTA clearly has an important role to play in helping the industry move forward on specification and standards development.

It is recommended that FTA develop a minimum set of performance specifications that will facilitate the development and integration of a safety system suitable for use on transit buses. In developing the specifications, the following should be reviewed:

- Results of past safety system projects for transit
- Commercially-available safety system specifications
- Transit authorities' bid specifications
- Safety system specifications developed for the commercial truck industry
- Detailed specifications from existing transit suppliers, which are available for Clever Devices' and Mobileye's systems

Finally, Federal Motor Carrier Safety Administration (FMCSA) recently released a document on the concept of operations and operational requirements for forward collision warning systems. This document contains requirements on the features and the ability of systems to withstand the electrical and environmental extremes commonly found on commercial vehicles. The type of requirements for collision warning systems includes:

- Functional requirements
- Data requirements
- Hardware and software requirements
- Maintenance and support requirements

These are voluntary requirements, and manufactures may include additional functions to augment system capability and features that may be useful beyond minimum system functionality. The information contained in this document may apply to transit and assist in developing performance specifications.

6.3.2 Reducing Development Risks for Suppliers

Suppliers must address a variety of risks when introducing new safety technologies including technical obsolescence, customer acceptance, costs associated with early education of the customer, warranty and liability issues, and business model issues (such as a supplier linking exclusively with a single OEM or licensing the technology to competitors). It is recommended that FTA develop deployment strategies and recommendations on what specific actions suppliers can take to help reduce such risks.

6.4 Technology Monitoring

A critical component of the deployment roadmap is a plan to monitor the penetration of the system into the market place. A monitoring plan should include tactics for tracking units sold per year and units sold to date, and for estimating units in operation. Initially, the plan should call for direct contact with manufacturers through phone interviews, and then verification with the transit authorities that they identify as having purchased the systems. If direct data from transit IVBSS suppliers is not forthcoming, it may be possible to track deployment by contacting suppliers of subcomponents (such as specialized sensors) that are unique to the collision warning system. The monitoring plan should also call for leveraging industry associations such as APTA, ITS America, and others.

At present there are roughly twenty different suppliers of safety systems serving the U.S. commercial motor vehicle industry. In contrast, only one manufacturer, Clever Devices, has a product specifically tailored for the transit industry. Given that the number of suppliers can be an indication of the market success of a technology, the monitoring plan should continually track the number of suppliers of IVBSS for transit (e.g., by conducting Internet research and interviews with bus manufacturers and suppliers).

It is not uncommon for products to succeed or fail in the marketplace due to their technology, product enhancements, or training support. Hence, the monitoring plan should also identify best practices being used to market and sell IVBSS. Vendor upgrades, enhancements, or integrations with other technologies should be tracked.

7.0 FINDINGS AND RECOMMENDATIONS

7.1 Key Findings

The findings of this study can be grouped into three categories: assessment of IVBSS technologies, benefit-cost analysis results, and outreach results. Each is presented in the following sections.

7.1.1 Technical Assessment of IVBSS

The business case evaluation presented here focused on seven existing and potential technologies which are referred to as “bus collision avoidance systems” when considered on an individual basis. Specifically, these seven collision avoidance systems include the following:

- Forward Collision Warning System (FCWS)
- Rear Collision Warning System (RCWS)
- Side Object Detection System (SODS)
- Forward Object Detection System (FODS)
- Rear Object Detection System (RODS)
- Lane Departure Warning System (LDWS)
- Pedestrian Detection System (PDS)

At present, only two commercial equipment vendors offer transit versions of some of these technologies (FCWS, SODS, FODS, and PDS), while university researchers and transit agencies have developed and tested prototypes of these and other technologies (FCWS, RCWS, SODS, and FODS).

The technical performance of many of these IVBSS systems has already been subject to limited testing and evaluation. Approximately six transit operators have tested various safety devices, including SamTrans (California), PAAC (Pennsylvania), AATA (Michigan), WMATA (Washington, DC), GCRTA (Ohio), and UTA (Utah). Devices tested at the agencies include FCWS, RCWS, SODS, and FODS. The results of these tests have not produced conclusive evidence of significant reductions in collision frequency or severity. However, these evaluations have gathered extensive feedback on the operational features of the devices, including the quality of operator interfaces, functionality, and false alarm rates.

Finally, the study found that although some transit agencies are researching in-vehicle safety devices, many commercial suppliers, including firms supplying safety products to the heavy-truck market, are hesitant to make any significant investments in development. Many of these suppliers are awaiting an expression of widespread, organized interest among the nation’s larger transit agencies before developing and/or marketing products for the transit market.

7.1.2 Benefit-Cost Analysis

The study also included a benefit-cost analysis of seven standalone systems, both individually and as bundled “IVBSS” systems. This analysis determined, based on the expected effectiveness of these technologies in addressing approximately sixty distinct collision types, whether each system’s investment benefits (reductions in collision costs) exceed the investment costs (acquisition, operation and maintenance). This analysis was limited to direct costs and benefits as experienced by the investing transit agency and did not consider either qualitative benefits enjoyed by investing agencies (e.g., rider perceptions of increased safety) or benefits to society as a whole (e.g., congestion relief due to a reduction in collisions).

From this purely financial standpoint, only SODS was found to be cost effective (i.e., the benefit-cost ratio exceeded one) under most, but not all, circumstances. PDW were also found to be cost effective for operators with above-average collision rates or high collision costs, none of the seven technologies was found to be cost-effective under all circumstances. When bundled together as "IVBSS" investments, systems containing a SODS performed best. The relative cost-effectiveness of SODS is driven by the fact that a high proportion of sideswipe collisions with other vehicles and collisions with fixed objects are avoidable by transit operators and this collision type is also relatively common, even if their cost is relatively low. In contrast, the frequency and avoidability of frontal, rear, and angle collisions is low, which hurts the potential for savings. Even with sensitivity analysis, few technologies were able to demonstrate benefit-cost ratios above one.

All of the bundled IVBSS systems that contain SODS performed very strongly (i.e., baseline benefit-cost ratio above 1), while those packages that do not contain SODS performed poorly (benefit-cost ratio below 1). Clearly, SODS drives the strong performance of IVBSS system combinations. However, for the ODS combination (SODS and FODS), the additional marginal benefit of adding FODS appears to exceed the marginal costs associated with adding FODS. In other words, the addition of forward-mounted sensors to an object detection system adds little to the acquisition and maintenance costs of the device, such that the benefits of avoiding forward collisions exceed those marginal costs.

Table 7-1 and Table 7-2 summarize the benefit-cost ratios for each standalone device and the six combinations of devices considered. The tables also include a range of ratios, based on using 90% confidence intervals for the input variables. Again, even when considering the range, only SODS and combinations containing SODS have a high-end estimate above one.

Table 7-1: Range of Benefit-Cost Ratios for Standalone Safety Systems Using 95% Confidence Interval for Collision Cost and Frequency Inputs

Technology	Baseline	Range
Forward Collision Warning (FCWS)	0.45	0.22 - 0.81
Rear Collision Warning (RCWS)	0.59	0.10 - 1.44
Side Object Detection (SODS)	1.43	0.37 - 3.55
Forward Object Detection (FODS)	0.26	0.13 - 0.45
Rear Object Detection (RODS)	0.14	0.05 - 0.28
Lane Departure Warning (LDWS)	0.10	0.04 - 0.20
Pedestrian Detection (PDS)	0.81	0.11 - 1.62

Table 7-2: Range of Benefit-Cost Ratios for System Combinations Using 95% Confidence Interval for Collision Cost and Frequency Inputs

Combination	Baseline	Range
ODS (SODS & FODS)	1.60	0.47 - 3.79
ODS Cocoon (SODS, FODS, & RODS)	1.59	0.48 - 3.72
FCSD (FCWS & SODS)	1.25	0.37 - 2.93
CWS (FCWS & LDWS)	0.49	0.22 – 0.88
CWS+ (FCWS, LDWS, & PDS)	0.83	0.21 - 1.61
CWS Cocoon+ (FCWS, LDWS, PDS & RODS)	0.69	0.19 - 1.33
All	1.38	0.37 - 3.08

Table 7-3 and Table 7-4 summarize the proportion of collisions of each type that must be prevented in order to break even on the investment, the proportion of collisions determined to be avoidable, and the proportion of collisions estimated to be preventable by each technology. These tables suggest that some technologies, even if maximally effective (i.e., prevent 100% of avoidable collisions), would not provide sufficient benefits to achieve a benefit-cost ratio above one. Although the prospects are better for integrated packages, they were also determined not to perform well due to the limited number of avoidable collisions which can be addressed by safety technology (unless they contained SODS).

Table 7-3: Effectiveness Required to Break Even under Baseline Assumptions for Standalone Safety Systems

System	To break even, system must be effective in the following percentage of collisions:	Percent of collisions that is avoidable	Percent of collisions currently assumed prevented
FCWS	27% of Frontal	28%	10%
RCWS	58% of Rear	84%[47]	32%
SODS	12% of Sideswipe, Rear, Other, and Object	30%	16%
FODS	33% of Frontal	28%	10%
RODS	66% of Rear	16%	5%
LDWS	27% of Sideswipe	18%	2%
PDS	47% of Pedestrian	35%	29%

Table 7-4: Effectiveness Required to Break Even Under Baseline Assumptions for System Packages

Combination	To break even, system must be effective in preventing the following percentage of collisions:	Percent of collisions that is avoidable	Percent of all collisions currently assumed prevented
ODS	9% of Front, Sideswipe, & Object	33%	15%
ODS Cocoon	10% of Front, Sideswipe, Object, & Rear	30%	16%
FCSD	13% of Front, Sideswipe, & Object	33%	16%
CWS	14% of Front & Sideswipe	21%	6%
CWS+	16% of Front, Sideswipe, & Pedestrian	22%	7%
CWS Cocoon+	17% of Front, Sideswipe, Pedestrian, & Rear	20%	6%
All	15% of All Costs	29%	22%

A major factor that could affect future performance of technologies in the business case analysis is technology cost. This analysis considered the full life-cycle costs of each technology based on current best estimates of costs from suppliers and agencies. Many of the technologies are available at an acquisition cost in excess of $2,000 per bus. However, because of the low frequency of some collision types and the limited number of those collisions that are considered avoidable, improvements in the benefit-cost performance for technologies that address these types of collisions can only be attained through a reduction in the cost of those technologies.

The benefit-cost analysis was founded in two key assumptions that should be researched further in future operational tests and evaluations. The following are two caveats to the benefit-cost analysis:

- First, the analysis rests on the assumption that these technologies will be most effective in addressing those incidents that the participating transit agencies considered “avoidable” on the part of the bus operator. In practice, one or more of these technologies may prove effective in preventing or mitigating some collisions not currently considered “avoidable.”
- Second, and more generally, the actual effectiveness of each of these technologies in preventing or mitigating bus collisions has not yet been determined. Given the absence of extensive service histories for these technologies, the study relied on lengthy reviews of over sixty well-documented

[47] For RCWS, the percentage of unavoidable collisions is provided.

collision scenarios to assess how each technology is *expected* to perform under each of these scenarios. Once again, the service histories of each of these technologies will need to be quite extensive, covering many thousands of service miles before prevention effectiveness will be known with any accuracy. Until such time that the actual effectiveness is measured with some accuracy, the actual cost-effectiveness of these systems can only be estimated using techniques such as that applied here.

7.1.3 Outreach Results

Finally, the study included several outreach sessions, a round table discussion with participants from several US transit operators conducted during the 2006 APTA Annual Meeting in San Jose, California, and on-site interviews conducted at six different transit properties. The objective of these sessions was to assess the qualitative factors associated with investment in IVBSS systems, including investment risks, potential implementation barriers, and technology performance concerns.

Overall, the participating agency staff expressed significant interest in any technology that can significantly reduce the frequency and cost of bus collisions. While some participants highlighted their desire that the technology target reductions in pedestrian injuries and fatalities as a first priority, many participants recognized that these technologies may be most cost effective in reducing lower cost but higher frequency collisions, such as sideswipes (a viewpoint supported by the benefit-cost analysis). Regardless of the type of collision addressed by the technology, virtually all representatives expressed the opinion that their agency was unlikely to invest in any collision avoidance system (or integrated systems) until these systems have been shown to be cost effective by a peer operator. However, if collision avoidance systems are shown to be effective in reducing collision frequency and cost, virtually all participants indicated that their agency would very likely provide room in their capital budgets for these systems.

When asked to consider these investments in the context of other vehicle technologies, most participants noted that modern transit vehicles already possess several, un-integrated technologies, including AVL, APCs, on-board cameras, and fare collection systems. Most transit operators require that most or all of these systems be fully functioning before a vehicle equipped with these technologies be approved for pullout into revenue service. The concern with respect to IVBSS for these agencies is that the addition of another system, with an unproven reliability record, could lead to an increasing number of vehicles not being available for revenue service. These agencies also complained of having experienced unexpected recent increases in operating and maintenance costs following the introduction of new technologies and hence have some reluctance in investing in new systems until the cost consequences of those investments are better understood. Finally, “straw polls” conducted during the outreach session and at agency on-site meetings revealed a clear preference for investment in the integration of the multiplicity of existing technologies over the deployment of new technologies (including those for safety).

Many participants also expressed concerns over the ability of IVBSS technologies to inform operators of potential collisions in such a way that the operator could process and respond to the information in a timely fashion. Similarly, few participants had confidence that any device could address collisions without providing a large number of false alarms, given the high-density traffic in which most transit buses operate, leading to the additional concern of operator “information overload.” Some of these concerns can be overcome through development of algorithms that reduce false alarms and alternative human interface options that address concerns about the technology providing more interference to bus operations than assistance.

At the outset, several agency representatives expressed confusion about the IVBSS program, citing the similarities between today’s technologies and those promoted by FTA and suppliers over a decade ago.

There is a general perception that little progress is being made in the development of technologies. In a similar vein, several participants expressed concern that any advances could be made within a small market like transit buses, particularly when the operators are fragmented. In order to elicit a reasonably priced, effective product offering from suppliers, agencies must organize and exert a coordinated demand.

7.2 Key Recommendations

IVBSS technologies have the potential to deliver significant non-financial benefits to operators, most notably an improved public image. However, based on the results of the financial analysis, only SODS (or packages containing side object detection) was found to be cost-effective under common operating conditions. Furthermore, at current avoidable collision rates and technology prices, none of the other safety systems was found to be financially justifiable, even if the devices could successfully prevent all avoidable collisions. However, pedestrian detection devices were determined to be cost effective for operators with an above average number of pedestrian collisions and/or high pedestrian collision costs.

Based on these findings and the feedback received from transit operators, the following recommendations are proposed:

Pursue Operational Tests on Those Systems with Higher Cost Effectiveness

Based on the results of this study, it is recommended that the U.S. DOT pursue further operational tests and evaluations of those systems for which appear cost effective under a reasonable range of operating conditions. Namely, systems that address object collisions, sideswipes, and pedestrian collisions have the greatest potential to achieve substantial benefits. Among the existing systems, future evaluations should focus on SODS and pedestrian detection systems as likely the most (and potentially the only) cost-effective standalone investments. Due to the low marginal cost associated with expanding the detection capabilities of SODS to include forward and rear detection, the benefits of such an expansion may be compelling.

Determine True Effectiveness of Systems through Operational Tests

At present, there are no accurate empirical measurements of the effectiveness of bus collision avoidance systems in preventing or mitigating bus collisions. In the absence of such information, the benefit-cost analysis in this study rests on estimated system effectiveness rates established based on reviews of a detailed classification of accident scenarios. It is recommended that the U.S. DOT conduct sufficient operational tests to determine the effectiveness of these systems. Given the results of this study, these tests should again focus primarily on SODS and secondly on pedestrian detection systems as likely the most cost-effective systems. Once the collision prevention effectiveness of these systems has been assessed with sufficient accuracy, the benefit-cost analysis presented here should be revisited and updated. The U.S. DOT may also wish to conduct more limited testing of the remaining collision avoidance systems (although the lower frequency collision reduction rates and lower cost savings expected with these systems may make it difficult to obtain a definitive assessment of these systems' overall effectiveness).

Develop a Comprehensive Operational Test and Deployment "Roadmap"

Develop a comprehensive operational test and deployment "roadmap" similar to that outlined in 6.0. This roadmap and its related standards for designing and implementing operational tests will help ensure that test cases are well considered (e.g., using proper control group comparisons), results are properly measured, and the findings are robust.

Focus on Human Interface Components

Further development of any in-vehicle systems for transit should consider additional improvements to system human interface components to minimize operator interaction requirements, maintenance needs, and false alarms.

Integrate Existing Bus Systems

Focus transit technology resources on integrating existing bus systems to make the acquisition of systems more efficient, simplify the level of technical sophistication required by agency operations and maintenance staff, and reduce the number of operator distractions, allowing them to focus their attention on their core competency—operating a motor vehicle.

Deliver a Consistent Message to the Transit Industry

During on-site interviews and a roundtable session, managers at many agencies expressed concern that the U.S. DOT's progress in helping to develop, test, deploy, and encourage safety systems in the transit market appeared slow, which has caused some agency decision-makers to question whether this is a sign that there is little value in studying and deploying safety devices. Should the U.S. DOT decide to invest additional resources in the development of IVBSS for transit, it is imperative to deliver a consistent message to agencies on the level of federal commitment to the program, and to communicate progress regularly to the industry so that agencies do not draw inaccurate conclusions about the efficacy of safety systems.

Appendix A: IVBSS Outreach Session Attendees

IVBSS Industry Outreach Session
October 10, 2006
List of Attendees

Number	Name	Property
1	William Mooney	Chicago Transit Authority
2	Don Gee	San Francisco Muni
3	Greg Yates	RTD-Denver
4	Richard Katzmar	VTA
5	Kyle Lomax	Clever Devices
6	Edward Brandis	Clever Devices
7	George Fokos	City of San José
8	Eric Muntan	Miami-Dade Transit
9	Greg Cooper	Pace Suburban Bus
10	James Pearson	Vapor Bus International
11	Ronald Keele	Maryland MTA
12	Betty Donaldson	Maryland MTA
13	Heidi Samuels	VTA
14	Mike Hursh	VTA
15	John Inglish	Utah Transit
16	Chester Patton	SamTrans
17	Mark Johnson	Lane Transit District
18	Dan Smith	VTA

Appendix B: Agency Interview Guide

PRE-INTERVIEW PRIMER

Background

Over the past several years, the U.S. Department of Transportation (U.S. DOT) has been testing and evaluating prototype technologies designed to prevent or mitigate the severity of motor-vehicle collisions. The ultimate objective of these programs is to foster development and commercial release of collision-avoidance systems for three vehicle markets (passenger cars, commercial trucks, and transit buses). These efforts are now part of U.S. DOT's Integrated Vehicle-Based Safety Systems (IVBSS) program.

In support of the IVBSS program, the Federal Transit Administration (FTA) recently retained the consulting firm Booz Allen Hamilton to conduct a business case analysis of integrated front- and side-collision avoidance systems for transit buses. The business case will determine, in part, whether FTA pursues funding for continued testing and development of collision-avoidance technologies applicable to transit. This business case is relying on feedback and real data from transit agencies that reflect industry realities.

FTA has requested that staff from your agency knowledgeable in the areas of bus vehicle safety, technology, operations, and crash claims/costs meet with Booz Allen staff at your premises. Booz Allen staff also request access to internal cost data related to bus collisions; all data and information you can provide will remain strictly confidential and anonymous.

The on-site meetings and data collection will help identify the expected costs, benefits, risks, and challenges the transit industry will likely face with implementation of collision-avoidance systems. The meetings will also provide a forum for agency staff to present your views and concerns relating to deployment of collision-avoidance systems and related innovative technologies for transit.

Available transit safety data

FTA maintains financial, operating, safety, and other data about transit agencies in its National Transit Database (NTD). Of note, NTD contains the *Safety and Security* data module, which documents "major" and "non-major" incidents as reported by agencies throughout the year. Major incidents must be reported within 30 days; they include crashes with at least one fatality and/or two injuries and/or property damage exceeding $25,000. Non-major incidents, meanwhile, include crashes with one injury and/or property damage exceeding $7,500. Data are reported for non-major crashes on a monthly or quarterly basis and include only aggregated information (e.g., total cost of non-major incidents per agency per month). Minor incident data are not required to be reported to FTA for inclusion in NTD. Minor incidents include crashes with no injuries and property damage below $7,500.

Another source of crash data is the University of Michigan Transportation Research Institute's *Buses Involved in Fatal Accidents* (BIFA) database. BIFA contains detailed records of every fatal bus-involved crash in the country on an annual basis, including information about driving conditions, fatalities, injuries, collision events, and harmful events. BIFA does not, however, include information about the cost of property damage.

Key staff to be interviewed

- **Director Bus Operations** (i.e., head of all bus operations)
- **Director of Bus Technology/Engineering** or General Technology/Engineering Staff for information about past, present, and future bus technology
- **Director of Bus Safety** or General Safety/Security Staff for information about crashes, crash data, crash costs, and crash prevention
- **Accident Claims Manager** for information about costs of crashes borne by agencies
- **Data/Federal Reporting Staff** for information about bus collision data reported to FTA
- **Senior Manager for Bus Maintenance** for information about *major* incidents/collisions and their repair costs; especially for those accidents repaired at your agency's heavy maintenance shops
- **Bus Garage/Depot Maintenance Manager** for information about *minor* garage incidents/collisions (including incidents not reported to NTD)
- **Bus Depot Operations Manager** (division level) for input on vehicle operator issues / concerns
- **Human Resources Manager** or Employee Relations Staff for information about accident liability and claims

Information sought

Our interviews seek three broad categories of information: crash and crash cost data, technology feedback, and management feedback.

Crash data: NTD and BIFA, while helpful, do not provide a full picture of the occurrences and costs of crashes involving transit buses because neither data source documents the frequency of occurrence and costs of "minor" crashes, nor do they provide estimates of the relative frequency or cost of "non-major" crashes on a per-crash basis. As a result, we are seeking additional data from your agency to complete our understanding of the types of crashes that transit buses are likely to experience, the frequency with which those crashes occur, and the costs that agencies expect to incur as a result of crashes. Staff in the following areas are expected to be able to provide feedback about crash data: safety, accident claims/financial/accounting, human resources, garage/maintenance, and data/federal reporting.

Technology feedback: In addition to understanding your agency's crash and crash cost history, we seek to understand your agency's view of IVBSS technologies, including your estimation of their ability to prevent crashes, your estimation of their relevance to your particular agency, and human factors based on your unique operating conditions. Staff in the following areas are expected to be able to provide technology feedback: technology/engineering, safety, garage/maintenance, and vehicle operators.

Management feedback: Aside from an agency's crash costs and the relevance of IVBSS technology, a variety of additional factors will ultimately determine whether IVBSS is purchased and deployed. These other factors may include the ease with which IVBSS can be bundled as part of new vehicle purchases, the availability of federal resources to support the purchase, and impacts on customer service (e.g., perceived safety benefits, actual ride comfort, and any countervailing effects). Staff in the following areas are expected to be able to provide management feedback: bus operations manager and safety.

Sample Questions

Booz Allen staff will meet with various representatives of your agency over the course of one day. Within the three areas described above, Questions for your staff will cover the following general topic areas:

Crash data

- NTD requires reporting of crashes with at least $2,000 in property damage. Is "property damage" measured systematically, and if so, how? What is the frequency/cost of crashes that are not reported to NTD?
- Does your agency track crashes beyond the information reported as part of NTD?
  - Do you maintain records of crashes/collisions/incidents? If so, what type of data do you collect?
  - Do you track costs of crashes, by crash? Do you maintain records of crash costs and, if so, to what level of detail are those records maintained?

Technology

- What technologies, specifically safety technologies, does your agency currently use?
- What technologies, if any, is your agency currently evaluating for potential use?
- Describe the decision-making process related to deployment of new technologies.
  - What information is required as inputs to the decision process?
  - What staff are involved in collecting, preparing, and analyzing information?
  - Who ultimately makes the decisions, and on what bases?
- Is your agency aware of IVBSS (in transit, integrated front- and side-collision warning systems)? If so, what is your initial reaction to the technology as a safety asset?
- What barriers to implementation of new technology does your agency typically encounter?

Management

- Describe the decision-making process related to deployment of new technologies.
  - What information is required as inputs to the process?
  - What staff are involved in collecting, preparing, and analyzing information?
  - Who ultimately makes the decisions, and on what bases?

- What do you perceive to be your most important bus safety issues? Similarly, what do you perceive to be your most important bus safety ***cost*** issues?
- What are your safety-related risks, how do you rank them, and how does your agency approach managing them?
- What barriers to implementation and/or competing priorities do you envision for a safety technology such as collision warning?
- What conditions (e.g., technologically, financially, politically/institutionally) would make IVBSS an attractive product for your agency?

Thank you for agreeing to participate in this study. We look forward to the opportunity to learn from your agency's past experiences and outlook; likewise, we will share as much information with you as is available about the IVBSS program and the current outlook for transit safety technologies.

Preliminary Schedule

Session 1: Meet individually with **Bus Operations Manager** to obtain overall understanding of bus operations and safety:

- Profile of bus service: demographics and geography of region served; number, type, and age of buses; types of bus operations; and ridership.
- Crashes, crash data collection and analysis, and NTD data reporting
- Technology acquisition process, with particular emphasis on safety
- Safety program: driver training, technology utilization, incident monitoring and management

Sessions 2+: Meet individually or in small groups with **Secondary Contacts** in other areas. Discuss each person's roles, access to crash-related data, and information about use of advanced technology in transit buses:

- Crash data collection and analysis
- Involvement in safety program
- Involvement in technology analyses

INTERVIEW GUIDE

Preliminary Schedule

Session 1: Meet individually with **Bus Operations Manager** to obtain overall understanding of bus operations and safety:

- Profile of bus service: demographics and geography of region served; number, type, and age of buses; types of bus operations; and ridership.
- Crashes, crash data collection and analysis, and NTD data reporting
- Technology acquisition process, with particular emphasis on safety
- Safety program: driver training, technology utilization, incident monitoring and management

Sessions 2+: Meet individually or in small groups with **Secondary Contacts** in other areas. Discuss each person's roles, access to crash-related data, and information about use of advanced technology in transit buses:

- Crash data collection and analysis
- Involvement in technology analyses
- Involvement in safety program

Interview Guide Organization

This guide is organized in modules. The first module is a "general module," which contains questions and topics for all interviewees. A series of secondary modules follows the general module; each secondary modules contains questions designed for specific staff with whom we intend to meet individually or in small groups at each transit agency. Such staff include the following:

- **Director Bus Operations** (i.e., head of all bus operations)
- **Director of Bus Technology/Engineering** or General Technology/Engineering Staff for information about past, present, and future bus technology
- **Director of Bus Safety** or General Safety/Security Staff for information about crashes, crash data, crash costs, and crash prevention
- **Accident Claims Manager** for information about costs of crashes borne by agencies
- **Data/Federal Reporting Staff** for information about bus collision data reported to FTA
- **Senior Manager for Bus Maintenance** for information about *major* incidents/collisions and their repair costs; especially for those accidents repaired at your agency's heavy maintenance shops
- **Bus Garage/Depot Maintenance Manager** for information about *minor* garage incidents/collisions (including incidents not reported to NTD)
- **Bus Depot Operations Manager** (division level) for input on vehicle operator issues / concerns
- **Human Resources Manager** or Employee Relations Staff for information about accident liability and claims

Director of Bus Operations (i.e., head of all bus services including maintenance, operations and new investments; direct report to GM)

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. What are your top priorities in terms of investments in or improvements to your bus operations (please prioritize)?:
    a. Service efficiency and effectiveness (e.g., cost per hour, ridership productivity, recovery ratio)?
    b. Service quality / reliability?
    c. Safety?
    d. Security?
    e. Other?

2. What do you perceive to be your most important bus safety issues (please rank the following)?
    a. Accidents
    b. Vehicle / mechanical issues
    c. Vandalism / assault / terrorism
    d. Rider safety perceptions
    e. Other

    Where do collisions fit within this list?

3. What do you perceive to be your most important bus collision ***cost*** issues (please rank)?
    a. Collisions with persons – in-service or out-of-service?
    b. Collision with other vehicles – in-service or out-of-service?
    c. Collision with objects – in-service or out-of-service?

4. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
    a. Peak period traffic
    b. Night driving conditions
    c. Front, side or rear collisions

d. Wet weather / snow (or other environmental)
e. Substance abuse
f. Other

5. Discuss crash costs.
    a. What types of costs does the agency bear in a crash (e.g., bus damage, property damage, insurance claims, litigation, medical care, incident documentation, vehicle operator replacement, public perception)?
    b. What are your typical crash costs for various types/severities of crashes? If unknown, what are the major crash cost elements (e.g., bus damage, damage to other vehicles, damage to infrastructure, accident response/recovery, vehicle operator replacement, litigation, medical care, etc.)?
    c. Do you have and can you describe your agency's process for responding to a crash, from the immediate response to the longer-term addressing of repairs and crash-related payments?

6. Within your agency, who holds responsibility for documenting and reporting the circumstances and costs of bus vehicle collisions?
    a. Depot managers?
    b. Heavy maintenance facility manager?
    c. Accident claims?
    d. Legal?
    e. NTD reporting staff?
    f. Other?
    g. Is there a centralized point where data from all these groups is coordinated to document the overall costs and circumstances of a major or minor accident?
    h. Is there an established process for documenting the costs and circumstances of major and/or minor bus accidents?
    i. How/when are accident frequency, cost and circumstances reported to you?

7. <u>Is there a specific staff member you can assign to help us document bus collision accident costs over the coarse of this study?</u>

<u>Technology Concerns:</u> Implementation of a bus collision avoidance systems would introduce a new technology to your bus fleet. The following questions address your experiences with other advanced technologies as well as your interest and concerns associated with the introduction of bus collision avoidance systems in particular.

8. Discuss any advanced technologies used either currently or in the past (e.g., AVL, APCs, computer automated dispatch).
    a. Describe any advance technologies purchased and operated either currently or in the past.

b. Were there any unforeseen disadvantages/problems (e.g., unexpected maintenance costs, requirements for mechanic training, reliability issues, vehicle operator issues)?
c. Describe your rationale, strategy, or criteria for acquiring and deploying new technologies.
d. Where does the push for new technologies typically originate? From the "ground up" (i.e., bus engineering staff) or from the "top down" (e.g., the board of directors).
e. How has your prior experiences with these advanced technologies influenced you or your agency's plans or desire to implement other advanced technologies (e.g., from no impact to great reluctance to implementing new technologies)?

9. Are you currently evaluating any new technologies?
   a. What are your main motivations for evaluating this technology?
   b. What considerations or criteria are you specifically interested in through the evaluation?
   c. What considerations or criteria, if any, does upper management have that differ from yours?

10. What is your familiarity with collision avoidance systems?
   a. Are you aware of this technology?
   b. If so, what specific technologies are you familiar with?
   c. What perceptions do you have of these technologies (i.e., positive, negative, unsure, cautious)
   d. Do you have any current plans to test or deploy such technologies?
   e. What would be your primary motivation for implementing such technologies (e.g., reduce fatalities/injuries or reduce costs)?
   f. What minimum performance requirements would you desire in such technologies?
      i. Can detect pedestrians?
      ii. Minimum "false positives"?
      iii. Desired useful life minimum?
      iv. Reliability?
      v. Compatible with other vehicle systems?
      vi. Vehicle operator acceptance?

11. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
   a. What was your experience with the system tested?
      i. From a technology effectiveness perspective
      ii. From a operators perspective
      iii. From a maintenance perspective
   b. How much did the system cost to purchase, install, operate and maintain?
   c. Will you continue to use and maintain this system into the future (if no, why not)?

d. If not, under what circumstances would you consider adopting another collision avoidance technology?
e. Do you think smaller operators would be able to maintain such systems in reliable working order?
f. Having used a system, how effective do you believe it to be in preventing or mitigating a:

Frontal Collisions:

i. High speed collision (over 30 mph): highly, moderately or not effective
ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
iii. Low speed collision (under 10 mph): highly, moderately or not effective

Side Collisions:

i. High speed collision (over 30 mph): highly, moderately or not effective
ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
iii. Low speed collision (under 10 mph): highly, moderately or not effective

12. What would it take to get your agency to invest in this technology?
a. A clear business case? (i.e., benefits > costs)?
b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
c. Inexpensive and reliable technology?
d. Most interested in preventing fatalities and significant injuries
e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
f. How interested would your agency be if the technology did ***not*** prevent any major incidents / fatalities but did significantly reduce minor collisions (which may constitute a significant cost savings)?

13. Discuss prospects for future technology.
a. What information would you require in order to convince upper management for authorization/financial support of a new technology deployment?
b. What information would you require in order to convince yourself of the value of a new technology deployment?
c. What factors would help make any technology (consider IVBSS in particular) more attractive"

i. Safety benefits?
ii. Cost benefits?
iii. Public perception benefits?
iv. Vehicle operator demand?
v. Others?

Director of Bus Technology/Engineering: or General Technology/Engineering Staff for information about past, present, and future bus technology. Consider the following questions specifically with regard to IVBSS.

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems.

Technology Concerns: Implementation of a bus collision avoidance systems would introduce a new technology to your bus fleet. The following questions address your experiences with other advanced technologies as well as your interest and concerns associated with the introduction of bus collision avoidance systems in particular.

1. What is your role in dealing with / helping prevent bus crashes/collisions:
    a. What responsibilities do you have for immediate incident response?
    b. What responsibilities do you have for investigating the incident?
    c. What types of crashes require your involvement (e.g., major vs. non-major vs. minor)?
    d. Do you have any other responsibilities related to crashes/collisions?

2. Discuss any advanced technologies used either currently or in the past (e.g., AVL, APCs, computer automated dispatch).
    a. Describe any advance technologies purchased and operated either currently or in the past.
    b. Were there any unforeseen disadvantages/problems (e.g., unexpected maintenance costs, requirements for mechanic training, reliability issues, vehicle operator issues)?
    c. Describe your rationale, strategy, or criteria for acquiring and deploying new technologies.
    d. Where does the push for new technologies typically originate? From the "ground up" (i.e., bus engineering staff) or from the "top down" (e.g., the board of directors).
    e. How has your prior experiences with these advanced technologies influenced you or your agency's plans or desire to implement other advanced technologies (e.g., from no impact to great reluctance to implementing new technologies)?

3. Are you currently evaluating any technologies?
    a. What are your main motivations for evaluating this technology?
    b. What considerations or criteria are you specifically interested in through the evaluation?
    c. What considerations or criteria, if any, does upper management have that differ from yours?

4. What is your familiarity with collision avoidance systems?
    a. Are you aware of this technology?
    b. If so, what specific technologies are you familiar with (if any)?
    c. What perceptions do you have of these technologies (i.e., positive, negative, unsure, cautious)
    d. Do you have any current plans to test or deploy such technologies?
    e. What would be your primary motivation for implementing such technologies (e.g., reduce fatalities/injuries or reduce costs)?
    f. What minimum performance requirements would you desire in such technologies?
        i. Can detect pedestrians?
        ii. Minimum "false positives"?
        iii. Desired useful life minimum?
        iv. Reliability?
        v. Compatible with other vehicle systems?
        vi. Vehicle operator acceptance?

5. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
    a. What was your experience with the system tested?
        i. From a technology effectiveness perspective
        ii. From a operators perspective
        iii. From a maintenance perspective
    b. How much did the system cost to purchase, install, operate and maintain?
    c. Will you continue to use and maintain this system into the future (if no, why not)?
    d. If not, under what circumstances would you consider adopting another collision avoidance technology?
    e. Do you think smaller operators would be able to maintain such systems in reliable working order?
    f. Having used a system, how effective do you believe it to be in preventing or mitigating a:

        <u>Frontal Collisions:</u>
        iv. <u>High</u> speed collision (over 30 mph): highly, moderately or not effective
        v. <u>Moderate</u> speed collision (15 to 20 mph): highly, moderately or not effective
        vi. <u>Low</u> speed collision (under 10 mph): highly, moderately or not effective

        <u>Side Collisions:</u>
        i. <u>High</u> speed collision (over 30 mph): highly, moderately or not effective
        ii. <u>Moderate</u> speed collision (15 to 20 mph): highly, moderately or not effective

iii. Low speed collision (under 10 mph): highly, moderately or not effective

6. What would it take to get your agency to invest in this technology?
   a. A clear business case? (i.e., benefits > costs)?
   b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
   c. Inexpensive and reliable technology?
   d. Most interested in preventing fatalities and significant injuries
   e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
   f. How interested would your agency be if the technology did ***not*** prevent any major incidents / fatalities but did significantly reduce minor collisions (which may constitute a significant cost savings)?

7. Discuss prospects for future technology.
   a. What information would you require in order to convince upper management for authorization/financial support of a new technology deployment?
   b. What information would you require in order to convince yourself of the value of a new technology deployment?
   c. What factors would help make any technology (consider IVBSS in particular) more attractive"
      i. Safety benefits?
      ii. Cost benefits?
      iii. Public perception benefits?
      iv. Vehicle operator demand?

Director of Bus Safety or General Safety / Security Staff for information about crashes, crash data, crash costs, and crash prevention

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. What do you perceive to be your most important bus safety issues (please rank the following)?
    a. Accidents
    b. Vehicle / mechanical issues
    c. Vandalism / assault / terrorism
    d. Rider safety perceptions
    e. Other

    Where do collisions fit within this list?

2. What is your role in dealing with bus crashes/collisions:
    a. What responsibilities do you have for immediate incident response?
    b. What responsibilities do you have for investigating the incident?
    c. What types of crashes require your involvement (e.g., major vs. non-major vs. minor)?
    d. Do you have any other responsibilities related to crashes/collisions?

3. What do you perceive to be your most important bus collision ***cost*** issues (please rank)?
    a. Collisions with persons
        i. in service
        ii. out of service
    b. Collisions with other vehicles
        i. in service
        ii. out of service
    c. Collisions with objects
        i. in service
        ii. out of service

4. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
    g. Peak period traffic

h. Night driving conditions
i. Front, side or rear collisions
j. Wet weather / snow (or other environmental)
k. Substance abuse
l. Other

5. Within your agency, who holds responsibility for documenting and reporting the circumstances and costs of bus vehicle collisions?
   a. Depot managers?
   b. Heavy maintenance facility manager?
   c. Accident claims?
   d. Legal?
   e. NTD reporting staff?
   f. Is there a centralized point where data from all these groups is coordinated to document the overall costs and circumstances of a major or minor accident?
   g. Is there an established process for documenting the costs and circumstances of major and/or minor bus accidents?
   h. How/when are accident frequency, cost and circumstances reported to you?

6. Please discuss the following specific types of crash costs:
   a. Property damage costs.
      i. Transit bus damage repair/replacement
      ii. Road/infrastructure damage
      iii. Repair/replacement of other vehicles involved
      iv. Other (specify)
   b. Medical costs.
      i. Cost to treat transit employees
      ii. Worker compensation (e.g., lost wages and benefits)
      iii. Cost to treat other persons involved – Pedestrians
      iv. Cost to treat other persons involved – Passengers
      v. Other (specify)
   c. Emergency Response Costs:
      i. Cost of incident response personnel/transit police
      ii. Other (specify)
   d. Work Force Adjustment Cost:
      i. Transit bus operator drug & alcohol test/loss of work time
      ii. Cost and frequency of job retraining and/or vehicle operator replacement
      iii. Effort to process crash-related documents and activities (e.g., filing claims, finding alternative vehicle operators)
      iv. Cost of out-of-service time for the bus
      v. Other (specify)
   e. Insurance Administration & Legal/Court Costs:
      i. Cost to process insurance claims

- ii. Traffic violation fines
- iii. Legal fees associated with litigation
- iv. Crash investigation costs (on behalf of insurance and/or legal representatives)
- v. Payment/settlement fee for varying levels of injury and property damage (e.g., fatality vs. severe injury vs. minor injury; total property damage vs. minor property damage).
- vi. Other (specify)

f. If any of the above are missing, are they significant to the overall cost of a crash?
- vii. If yes, how would you suggest obtaining/estimating such values?
- viii. If no, why not?

7. What is your familiarity with collision avoidance systems?
   a. Are you aware of this technology?
   b. If so, what specific technologies are you familiar with (if any)?
   c. What perceptions do you have of these technologies (i.e., positive, negative, unsure, cautious)
   d. Do you have any current plans to test or deploy such technologies?
   e. What would be your primary motivation for implementing such technologies (e.g., reduce fatalities/injuries or reduce costs)?
   f. What minimum performance requirements would you desire in such technologies?
      - i. Can detect pedestrians?
      - ii. Minimum “false positives”?
      - iii. Desired useful life minimum?
      - iv. Reliability?
      - v. Compatible with other vehicle systems?
      - vi. Vehicle operator acceptance?

8. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
   a. What was your experience with the system tested?
      - i. From a technology effectiveness perspective
      - ii. From a operators perspective
      - iii. From a maintenance perspective
   b. How much did the system cost to purchase, install, operate and maintain?
   c. Will you continue to use and maintain this system into the future (if no, why not)?
   d. If not, under what circumstances would you consider adopting another collision avoidance technology?
   e. Do you think smaller operators would be able to maintain such systems in reliable working order?
   f. Having used a system, how effective do you believe it to be in preventing or mitigating a:

<u>Frontal Collisions:</u>

i. <u>High</u> speed collision (over 30 mph): highly, moderately or not effective
ii. <u>Moderate</u> speed collision (15 to 20 mph): highly, moderately or not effective
iii. <u>Low</u> speed collision (under 10 mph): highly, moderately or not effective

<u>Side Collisions:</u>

i. <u>High</u> speed collision (over 30 mph): highly, moderately or not effective
ii. <u>Moderate</u> speed collision (15 to 20 mph): highly, moderately or not effective
iv. <u>Low speed collision (under 10 mph): highly, moderately or not effective</u>
v.

14. What would it take to get your agency to invest in this technology?
    a. A clear business case? (i.e., benefits > costs)?
    b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
    c. Inexpensive and reliable technology?
    d. Most interested in preventing fatalities and significant injuries
    e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
    f. How interested would your agency be if the technology did ***<u>not</u>*** prevent any major incidents / fatalities but <u>did</u> significantly reduce minor collisions (which may constitute a significant cost savings)?

Accident Claims Manager for information about all crash related costs borne by your agency.

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

2. What is your role in dealing with crashes/collisions:
   a. What responsibilities do you have for immediate incident response?
   b. What responsibilities do you have for investigating the incident?
   c. What types of crashes require your involvement (e.g., major vs. non-major vs. minor)?
   d. Do you have any other responsibilities related to crashes/collisions?

3. What do you perceive to be your agency's most important bus collision ***cost*** issues (please rank)?
   a. Collisions with persons
      i. in service
      ii. out of service
   b. Collisions with other vehicles
      i. in service
      ii. out of service
   c. Collisions with objects
      i. in service
      ii. out of service

4. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
   a. Peak period traffic
   b. Night driving conditions
   c. Front, side or rear collisions
   d. Wet weather / snow (or other environmental)
   e. Substance abuse
   f. Other

5. Within your agency, who holds responsibility for documenting and reporting the circumstances and costs of bus vehicle collisions?

   a. Depot managers?
   b. Heavy maintenance facility manager?
   c. Accident claims?
   d. Legal?
   e. NTD reporting staff?
   f. Is there a centralized point where data from all these groups is coordinated to document the overall costs and circumstances of a major or minor accident?
   g. Is there an established process for documenting the costs and circumstances of major and/or minor bus accidents?
   h. How/when are accident frequency, cost and circumstances reported to you?

6. Please discuss the following specific types of crash costs / Which of the following crash cost data do you receive following an incident?
   a. Property damage costs.
      i. Transit bus damage repair/replacement
      ii. Road/infrastructure damage
      iii. Repair/replacement of other vehicles involved
      iv. Other (specify)
   b. Medical costs.
      i. Cost to treat transit employees
      ii. Worker compensation (e.g., lost wages and benefits)
      iii. Cost to treat other persons involved
      iv. Other (specify)
   c. Emergency Response Costs:
      i. Cost of incident response personnel/transit police
      ii. Other (specify)
   d. Work Force Adjustment Cost:
      i. Transit bus operator drug & alcohol test/loss of work time
      ii. Cost and frequency of job retraining and/or vehicle operator replacement
      iii. Effort to process crash-related documents and activities (e.g., filing claims, finding alternative vehicle operators)
      iv. Cost of out-of-service time for the bus
      v. Other (specify)
   e. Insurance Administration & Legal/Court Costs:
      i. Cost to process insurance claims
      ii. Traffic violation fines
      iii. Legal fees associated with litigation
      iv. Crash investigation costs (on behalf of insurance and/or legal representatives)
      v. Payment/settlement fee for varying levels of injury and property damage (e.g., fatality vs. severe injury vs. minor injury; total property damage vs. minor property damage).
      vi. Other (specify)

f. If any of the above are missing, are they significant to the overall cost of a crash?
    i. If yes, how would you suggest obtaining/estimating such values?
    ii. If no, why not?

7. Are there any other crash cost data do you obtain (i.e., not identified on the list above)?

8. What other crash characteristic data do you obtain?
    a. Time and location?
    b. Object struck?
    c. Number of injuries / fatalities?
    d. Weather / environmental conditions?
    e. Police reports?
    f. Other

9. Who provides you with cost and accident characteristics data?

10. What types of crashes are not reported to you (e.g., small accidents in bus lots)? Or conversely, are there specific classes or types of accidents that are reported to you (e.g., over a specific damage of injury reporting threshold)?

11. Successful completion of this FTA study requires access to a sample of your agency's bus accident records including accident frequencies, damage costs, injury counts and costs, fatality counts and costs, collision circumstances and related information. FTA's specific interest lies in establishing the good quality estimates of the total cost of front and side collisions of transit buses with persons, other vehicles and other objects. The objective is to support a benefit-cost analysis of front and side collision avoidance systems. **All analysis will be kept in strict confidence and anonymity will be maintained for all agencies providing data**.
    a. How can the consultant team gain access to these detailed bus accident records?
    b. Is there a specific staff member you can assign to help us document these costs over the coarse of this study?

Human Resources Manager or Employee Relations Staff for information about internal accident liability and claims

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. What is your role in dealing with bus vehicle crashes/collisions:
    a. What responsibilities do you have for immediate incident response?
    b. What responsibilities do you have for investigating the incident?
    c. What types of crashes require your involvement (e.g., major vs. non-major vs. minor)?
    d. Do you have any other responsibilities in this area?

2. Which of the following crash cost data do you receive / evaluate / document following a bus crash incident?
    a. Property damage costs.
        i. Transit bus damage repair/replacement
        ii. Road/infrastructure damage
        iii. Repair/replacement of other vehicles involved
        iv. Other (specify)
    b. Medical costs.
        i. Cost to treat transit employees
        ii. Worker compensation (e.g., lost wages and benefits)
        iii. Cost to treat other persons involved
        iv. Other (specify)
    c. Emergency Response Costs:
        i. Cost of incident response personnel/transit police
        ii. Other (specify)
    d. Work Force Adjustment Cost:
        i. Transit bus operator drug & alcohol test/loss of work time
        ii. Cost and frequency of job retraining and/or vehicle operator replacement
        iii. Effort to process crash-related documents and activities (e.g., filing claims, finding alternative vehicle operators)
        iv. Cost of out-of-service time for the bus
        v. Other (specify)

e. Insurance Administration & Legal/Court Costs:
    i. Cost to process insurance claims
    ii. Traffic violation fines
    iii. Legal fees associated with litigation
    iv. Crash investigation costs (on behalf of insurance and/or legal representatives)
    v. Payment/settlement fee for varying levels of injury and property damage (e.g., fatality vs. severe injury vs. minor injury; total property damage vs. minor property damage).
    vi. Other (specify)

f. If any of the above are missing, are they significant to the overall cost of a crash?
    i. If yes, how would you suggest obtaining/estimating such values?
    ii. If no, why not?

g. Are there any other crash cost data do you obtain (i.e., not identified on the list above)?

1. **Is there a specific staff member you can assign to help us document these costs over the coarse of this study?**

Manager of Bus Heavy Maintenance Facility for information about *major* incidents/collisions and their repair costs; especially for those accidents repaired at your agency's heavy maintenance shops

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. Major Accidents: It is assumed that buses are sent to your heavy maintenance repair facility following collisions requiring significant vehicle repairs.
    a. Are there any guidelines or policies which determine which accidents are repaired at your heavy duty maintenance facility versus other division shops?
    b. If not, under what circumstances are vehicles typically brought to you facility following an accident (e.g., vehicles with structural damage)?
    c. Who is responsible for the repair of these vehicles at your heavy maintenance facility?
    d. Do you have an annual budget amount for bus collision repairs? If so, how is the cost of such major accident repairs budgeted?
    e. How is the final repair cost of each (or all) accident(s) documented? Are these costs documented specifically as accident related. If so, how can these costs be extracted from your reporting systems?
    f. Who, if anyone, is the final repair cost of each (or all) accident(s) reported to?
    g. How can we gain access to the repair cost data (or repair hours) for accidents treated in these facilities?

2. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
    a. Peak period traffic
    b. Night driving conditions
    c. Front, side or rear collisions
    d. Wet weather / snow (or other environmental)
    e. Substance abuse
    f. Other

3. <u>Is there a specific staff member you can assign to help us document these costs over the coarse of this study?</u>

<u>Technology Concerns:</u> Implementation of a bus collision avoidance systems would introduce a new technology to your bus fleet. The following questions address your experiences with other advanced technologies as well as your interest and concerns associated with the introduction of bus collision avoidance systems in particular.

4. Discuss any advanced technologies used either currently or in the past (e.g., AVL, APCs, computer automated dispatch).
    a. Describe any advance technologies purchased and operated either currently or in the past.
    b. Were there any unforeseen disadvantages/problems (e.g., unexpected maintenance costs, requirements for mechanic training, reliability issues, vehicle operator issues)?
    c. Describe your rationale, strategy, or criteria for acquiring and deploying new technologies.
    d. Where does the push for new technologies typically originate? From the "ground up" (i.e., bus engineering staff) or from the "top down" (e.g., the board of directors).
    e. How has your prior experiences with these advanced technologies influenced you or your agency's plans or desire to implement other advanced technologies (e.g., from no impact to great reluctance to implementing new technologies)?

5. Are you currently evaluating any new technologies?
    a. What are your main motivations for evaluating this technology?
    b. What considerations or criteria are you specifically interested in through the evaluation?
    c. What considerations or criteria, if any, does upper management have that differ from yours?

6. What is your familiarity with collision avoidance systems?
    a. Are you aware of this technology?
    b. If so, what specific technologies are you familiar with?
    c. What perceptions do you have of these technologies (i.e., positive, negative, unsure, cautious)
    d. Do you have any current plans to test or deploy such technologies?
    e. What would be your primary motivation for implementing such technologies (e.g., reduce fatalities/injuries or reduce costs)?
    f. What minimum performance requirements would you desire in such technologies?
        i. Can detect pedestrians?
        ii. Minimum "false positives"?
        iii. Desired useful life minimum?
        iv. Reliability?

v. Compatible with other vehicle systems?
vi. Vehicle operator acceptance?

9. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
   a. What was your experience with the system tested?
      i. From a technology effectiveness perspective
      ii. From a operators perspective
      iii. From a maintenance perspective
   b. How much did the system cost to purchase, install, operate and maintain?
   c. Will you continue to use and maintain this system into the future (if no, why not)?
   d. If not, under what circumstances would you consider adopting another collision avoidance technology?
   e. Do you think smaller operators would be able to maintain such systems in reliable working order?
   f. Having used a system, how effective do you believe it to be in preventing or mitigating a:
      Frontal Collisions:
      i. High speed collision (over 30 mph): highly, moderately or not effective
      ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
      iii. Low speed collision (under 10 mph): highly, moderately or not effective
      Side Collisions:
      i. High speed collision (over 30 mph): highly, moderately or not effective
      ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
      iv. Low speed collision (under 10 mph): highly, moderately or not effective

15. What would it take to get your agency to invest in this technology?
   a. A clear business case? (i.e., benefits > costs)?
   b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
   c. Inexpensive and reliable technology?
   d. Most interested in preventing fatalities and significant injuries
   e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
   f. How interested would your agency be if the technology did ***not*** prevent any major incidents / fatalities but did significantly reduce minor collisions (which may constitute a significant cost savings)?

Bus Depot/ Garage Maintenance Manager for information about minor garage incidents/collisions

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Cost and Characteristics: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. Your agency is required to report bus vehicle collisions for all incidents over $7,500 in cost (or with one more injuries or fatalities).
    a. Under what circumstances are you or your staff required to report a bus vehicle collision / accident / damage?
        i. Who do you report these data to?
        ii. What cost data do you report? Please provide a sample of accident reports submitted for this type of incident.
        iii. What cost data do you not report (for incidents for which you do report some cost)
        iv. What accident characteristics do you report?
    b. Under what circumstances do you not report bus collisions /accidents / damage (e.g., collisions within maintenance facilities or vehicle parking lots)?
        i. How frequent are these accidents?
        ii. Under what circumstances do these non-reported accidents typically occur (e.g., vehicle collisions with facility structures or other vehicles in the lot)?
        iii. Are there any other defining characteristics for these accidents (e.g., do they typically occur at low speeds and/or on agency property?)
        iv. What are the typical costs of such accidents individually? Are these costs significant in aggregate (e.g., relative to other maintenance costs)?
        v. How/where can we obtain data on the cost and/or frequency of these accidents? Conversely, where would these cost ultimately be recorded / documented? (e.g., within the agency's maintenance management system records?) Would agency maintenance records record all/any or some of these incidents as "accidents". If so, please provide a sample of maintenance /

<u>vehicle repair cost data for bus vehicles involved in non-reported collisions.</u>

vi. Under what circumstances would a bus' collision with another object (person, vehicle or fixed object) <u>not</u> be recorded in any way what so ever? Examples include minor dents and scrapes that would not be treated immediately. What is the frequency of such occurrences and what would the ultimate cost be (if any)?

2. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
    a. Peak period traffic
    b. Night driving conditions
    c. Front, side or rear collisions
    d. Wet weather / snow (or other environmental)
    e. Substance abuse
    f. Other

3. Major Accidents: It is assumed that buses are sent to your heavy maintenance repair facility following collisions requiring significant vehicle repairs.
    a. Are there any guidelines or policies which determine which accidents are repaired at your heavy duty maintenance facility versus other division shops?
    b. Who is responsible for the repair of these vehicles at your heavy maintenance facility?
    c. How can be gain access to the repair cost data (or repair hours) for accidents treated in these facilities?
    d. How is the cost of such major accident repairs budgeted?
    e. Who, if anyone, is the final repair cost of each (or all) accident(s) reported to?

<u>Technology Concerns:</u> Implementation of a bus collision avoidance systems would introduce a new technology to your bus fleet. The following questions address your experiences with other advanced technologies as well as your interest and concerns associated with the introduction of bus collision avoidance systems in particular.

4. Discuss any advanced technologies used either currently or in the past (e.g., AVL, APCs, computer automated dispatch).
    a. Describe any advance technologies purchased and operated either currently or in the past.
    b. Were there any unforeseen disadvantages/problems (e.g., unexpected maintenance costs, requirements for mechanic training, reliability issues, vehicle operator issues)?
    c. Describe your rationale, strategy, or criteria for acquiring and deploying new technologies.
    d. Where does the push for new technologies typically originate? From the "ground up" (i.e., bus engineering staff) or from the "top down" (e.g., the board of directors).

e. How has your prior experiences with these advanced technologies influenced you or your agency's plans or desire to implement other advanced technologies (e.g., from no impact to great reluctance to implementing new technologies)?

5. Are you currently evaluating any new technologies?
   a. What are your main motivations for evaluating this technology?
   b. What considerations or criteria are you specifically interested in through the evaluation?
   c. What considerations or criteria, if any, does upper management have that differ from yours?

6. What is your familiarity with collision avoidance systems?
   a. Are you aware of this technology?
   b. If so, what specific technologies are you familiar with?
   c. What perceptions do you have of these technologies (i.e., positive, negative, unsure, cautious)
   d. Do you have any current plans to test or deploy such technologies?
   e. What would be your primary motivation for implementing such technologies (e.g., reduce fatalities/injuries or reduce costs)?
   f. What minimum performance requirements would you desire in such technologies?
      i. Can detect pedestrians?
      ii. Minimum "false positives"?
      iii. Desired useful life minimum?
      iv. Reliability?
      v. Compatible with other vehicle systems?
      vi. Vehicle operator acceptance?

10. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
   a. What was your experience with the system tested?
      i. From a technology effectiveness perspective
      ii. From a operators perspective
      iii. From a maintenance perspective
   b. How much did the system cost to purchase, install, operate and maintain?
   c. Will you continue to use and maintain this system into the future (if no, why not)?
   d. If not, under what circumstances would you consider adopting another collision avoidance technology?
   e. Do you think smaller operators would be able to maintain such systems in reliable working order?
   f. Having used a system, how effective do you believe it to be in preventing or mitigating a:
      <u>Frontal Collisions:</u>

i. High speed collision (over 30 mph): highly, moderately or not effective
ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
iii. Low speed collision (under 10 mph): highly, moderately or not effective

Side Collisions:

i. High speed collision (over 30 mph): highly, moderately or not effective
ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
iv. Low speed collision (under 10 mph): highly, moderately or not effective

16. What would it take to get your agency to invest in this technology?
   a. A clear business case? (i.e., benefits > costs)?
   b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
   c. Inexpensive and reliable technology?
   d. Most interested in preventing fatalities and significant injuries
   e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
   f. How interested would your agency be if the technology did ***not*** prevent any major incidents / fatalities but did significantly reduce minor collisions (which may constitute a significant cost savings)?

Bus Deport Operations Manager for input about the technology from the vehicle operator's perspective (e.g., human factors)

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Technology Concerns: Implementation of a bus collision avoidance systems would introduce a new technology to your bus fleet. The following questions address your experiences with other advanced technologies as well as your interest and concerns associated with the introduction of bus collision avoidance systems in particular.

1. Discuss any advanced technologies used either currently or in the past (e.g., AVL, APCs, computer automated dispatch).
    a. Identify any advance technologies purchased and operated either currently or in the past.
    b. What were the vehicle operators response to these technologies?
    c. What were the benefits to the operator?
    d. What concerns or problems did the operators experience / comment on?

2. Are you currently evaluating any new technologies?
    a. What are your main motivations for evaluating this technology?
    b. What considerations or criteria are you specifically interested in through the evaluation?
    c. What considerations or criteria, if any, does upper management have that differ from yours?

3. What is your familiarity with collision avoidance systems?
    a. Are you aware of this technology?
    b. If so, what specific technologies are you familiar with?
    c. What perceptions do you have of these technologies from a vehicle operations perspective and why (i.e., positive, negative, unsure, cautious)
    d. Does your agency have any current plans to test or deploy such technologies?
    e. From an operations perspective, what would be your primary motivation for supporting or opposing such technologies?
    f. What minimum performance requirements would you desire in such technologies?
        i. Can detect pedestrians?
        ii. Minimum "false positives"?
        iii. Desired useful life minimum?

iv. Reliability?
v. Compatible with other vehicle systems?
vi. Vehicle operator acceptance?

4. Are you currently using or testing a collision avoidance system or have you done so in the past? If yes:
   a. What was your experience with the system tested?
      i. From a technology effectiveness perspective
      ii. From a operators perspective
      iii. From a maintenance perspective
   b. How much did the system cost to purchase, install, operate and maintain?
   c. Will you continue to use and maintain this system into the future (if no, why not)?
   d. If not, under what circumstances would you consider adopting another collision avoidance technology?
   e. Do you think smaller operators would be able to maintain such systems in reliable working order?
   f. Having used a system, how effective do you believe it to be in preventing or mitigating a:
      Frontal Collisions:
      i. High speed collision (over 30 mph): highly, moderately or not effective
      ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
      iii. Low speed collision (under 10 mph): highly, moderately or not effective
      Side Collisions:
      i. High speed collision (over 30 mph): highly, moderately or not effective
      ii. Moderate speed collision (15 to 20 mph): highly, moderately or not effective
      iv. Low speed collision (under 10 mph): highly, moderately or not effective

17. What would it take to get your agency to invest in this technology?
   a. A clear business case? (i.e., benefits > costs)?
   b. Specific performance requirements (e.g., known to prevent/mitigate *x*% of all collisions, injuries or fatalities)?
   c. Inexpensive and reliable technology?
   d. Most interested in preventing fatalities and significant injuries
   e. Most interested in preventing minor collisions (i.e., collisions that account for most collision costs and which are also the most preventable)?
   f. How interested would your agency be if the technology did ***not*** prevent any major incidents / fatalities but did significantly reduce minor collisions (which may constitute a significant cost savings)?

Data/Federal NTD Reporting Staff for information about safety data reported to FTA

Background: This study is intended to evaluate the business case for the adoption of front and side collision avoidance systems for transit buses (including the technology's cost effectiveness, reliability, risks, concerns, etc.). The primary objectives of these interviews are to 1) thoroughly document the frequency and costs of bus accidents (front and side collision) including those occurring both in- and out-of-service, and 2) evaluate potential technical and institutional concerns with collision avoidance systems. Data collection relating to bus collision frequency, circumstances and cost may require future follow-up questions and data collection requests.

Bus Accident Costs, Characteristics and Responsibilities: The following questions address issues relating to the cost and characteristics of bus collisions as well as your roles, responsibilities and experiences with respect to these accidents.

1. What is your role in dealing with crashes/collisions:
    a. What responsibilities do you have for immediate incident response?
    b. What responsibilities do you have for investigating the incident?
    c. What types of crashes require your involvement (e.g., major vs. non-major vs. minor)?
    d. What is your relation to other staff collecting and evaluating accident costs or circumstances?

2. Describe your NTD reporting process:
    a. NTD requires reporting of crashes exceeding $7,500 in property damage. How do you measure "property damage" for the NTD reports? Furthermore, what are your data sources for estimating property damage costs?
    b. What are your data sources for inputting the type of collision and other facts such as the number of injuries and fatalities (who provides this data)?
    c. Can we access a sample report to NTD?
    d. Does your agency have a unique accident/incident tracking code or identifier that can be used to cross reference the cost and other characteristics of specific incidents across different departments within the agency? Conversely, is there some way the consultant staff can correlate the collision data reported to FTA with other internal agency sources documenting collision characteristics and costs.
    e. How much detail underlies your reports but is not reflected?

3. Do you receive data for crashes not reported to NTD?
    a. If yes, what are the characteristics of crashes not reported to NTD?
    b. What is the frequency/cost of crashes not reported to NTD?
    c. Can you provide access to crash frequency and cost data for crashes not reported to NTD? If not, who maintains such data?

4. Within your agency, who holds responsibility for documenting and reporting the circumstances and costs of bus vehicle collisions?
    a. Depot managers?

b. Heavy maintenance facility manager?
c. Accident claims?
d. Legal?
e. NTD reporting staff?
f. Is there a centralized point where data from all these groups is coordinated to document the overall costs and circumstances of a major or minor accident?
g. Is there an established process for documenting the costs and circumstances of major and/or minor bus accidents?
h. How/when are accident frequency, cost and circumstances reported to you?

5. Which of the following crash costs do you utilize or have access to?
   a. Property damage costs.
      i. Transit bus damage repair/replacement
      ii. Road/infrastructure damage
      iii. Repair/replacement of other vehicles involved
      iv. Other (specify)
   b. Medical costs.
      i. Cost to treat transit employees
      ii. Worker compensation (e.g., lost wages and benefits)
      iii. Cost to treat other persons involved
      iv. Other (specify)
   c. Emergency Response Costs:
      i. Cost of incident response personnel/transit police
      ii. Other (specify)
   d. Work Force Adjustment Cost:
      i. Transit bus operator drug & alcohol test/loss of work time
      ii. Cost and frequency of job retraining and/or vehicle operator replacement
      iii. Effort to process crash-related documents and activities (e.g., filing claims, finding alternative vehicle operators)
      iv. Cost of out-of-service time for the bus
      v. Other (specify)
   e. Insurance Administration & Legal/Court Costs:
      i. Cost to process insurance claims
      ii. Traffic violation fines
      iii. Legal fees associated with litigation
      iv. Crash investigation costs (on behalf of insurance and/or legal representatives)
      v. Payment/settlement fee for varying levels of injury and property damage (e.g., fatality vs. severe injury vs. minor injury; total property damage vs. minor property damage).
      vi. Other (specify)
      vii.
   f. If any of the above are missing, are they significant to the overall cost of a crash?
      i. If yes, how would you suggest obtaining/estimating such values?
      ii. If no, why not?

7. What factors tend to contribute most to your bus collisions / what tend to be the more frequent characteristics of your bus accidents:
   a. Peak period traffic
   b. Night driving conditions
   c. Front, side or rear collisions
   d. Wet weather / snow (or other environmental)
   e. Substance abuse
   f. Other

<u>Is there a specific staff member you can assign to help us document bus accident costs over the coarse of this study?</u>

Appendix C: Technology Effectiveness Assessment

Technology Effectiveness Assessment

In the absence of actual, empirical data on the effectiveness of collision avoidance systems in preventing or mitigating the impact of bus collisions, the study relied instead on analysts assessments of each technology can be expected to perform under 60 different collision scenarios recognized by two of the local transit agencies participating in this study. In completing this evaluation, the study considered how effective each of the following seven different collision avoidance systems would be in preventing/mitigating each of these collision scenario:

- FCWS: Forward Collision Warning System
- RCWS: Rear Collision Warning System
- SODS: Side Object Detection System
- FODS: Forward Object Detection System
- RODS: Rear Object Detection System
- LDWS: Lane Departure Warning System
- PDS: Pedestrian Detection System

Each system's effectiveness in preventing was rating according to the following scale:

- Not at all effective (0%) [0]
- Minimally effective (25%) [1]
- Moderately effective (50%) [2]
- Effective (75%) [3]
- Very effective (100%) [4]

The results of this analysis are presented in Table C-1.

Table C-1
Assessed Technology Collision Prevention Effectiveness

Crash Code	Crash Type	% of Total	% Avoidable	Technology Effectiveness						
				FCWS	RCWS	SODS	FODS	RODS	LDWS	PDS
1	Angle	3.6%	14%	0	0	0	0	0	0	0
2	Angle	4.1%	9%	0	0	0	0	0	0	0
3	Angle	0.1%	100%	0	0	0	0	0	0	0
4	Frontal	1.2%	35%	0	0	0	1	0	0	0
5.1	Frontal	1.3%	11%	1	0	0	0	0	0	0
5.2	Frontal	2.0%	87%	1	0	0	0	0	0	0
6	Rear	1.1%	57%	0	2	0	0	0	0	0
7	Angle	0.3%	25%	0	0	0	0	0	0	0
8	Angle	2.0%	30%	0	0	0	0	0	0	0
9	Angle	1.0%	29%	0	0	0	0	0	0	0
10	Rear	0.6%	31%	0	3	0	0	0	0	0
11	Frontal	3.6%	7%	0	0	0	0	0	0	0

Crash Code	Crash Type	% of Total	% Avoidable	Technology Effectiveness						
				FCWS	RCWS	SODS	FODS	RODS	LDWS	PDS
12	Other	2.5%	21%	0	0	2	0	0	0	0
13	Frontal	0.2%	9%	1	0	0	0	0	0	0
14	Sideswipe	3.9%	54%	1	0	4	0	0	1	0
15	Sideswipe	0.7%	9%	2	0	0	0	0	2	0
16	Sideswipe	11.1%	7%	0	0	2	0	0	0	0
17	Frontal	3.1%	10%	0	0	0	1	0	0	0
18	Frontal	1.0%	20%	2	0	0	2	0	0	0
19	Other	4.7%	44%	0	0	4	0	0	0	0
20	Sideswipe	1.2%	64%	0	0	4	0	0	0	0
22	Other	3.0%	15%	0	0	0	0	0	0	0
23F	Frontal	3.4%	76%	4	0	0	4	0	0	0
23R	Rear	1.1%	76%	0	0	0	0	4	0	0
24F	Rear	4.1%	2%	0	2	0	0	0	0	0
24R	Frontal	1.0%	2%	0	0	0	0	0	0	0
25	Other	0.8%	61%	0	0	4	0	0	0	0
26	Other	0.6%	80%	0	0	4	0	0	0	0
27	Rear	1.0%	34%	0	1	2	0	0	0	0
28.1	Rear	2.3%	2%	0	2	0	0	0	0	0
28.2	Rear	2.2%	2%	0	2	0	0	0	0	0
28.3	Frontal	1.1%	0%	0	0	0	0	0	0	0
28.4	Sideswipe	3.4%	1%	0	0	0	0	0	0	0
28.5	Angle	1.1%	0%	0	0	0	0	0	0	0
28.6	Angle	1.1%	0%	0	0	0	0	0	0	0
28.7	Rear	2.2%	3%	0	0	0	0	0	0	0
29	Sideswipe	0.8%	32%	0	0	4	0	0	0	0
30	Other	1.4%	41%	0	0	1	0	0	0	1
31	Sideswipe	0.7%	38%	0	0	4	0	0	0	0
32	Sideswipe	0.6%	36%	1	0	4	0	0	1	0
33	Sideswipe	0.0%	0%	2	0	0	0	0	2	0
34R	Rear	1.0%	60%	0	2	0	0	0	0	0
34F	Frontal	1.0%	60%	2	0	0	0	0	0	0
35.1R	Rear	0.0%	0%	0	2	0	0	0	0	0

Crash Code	Crash Type	% of Total	% Avoidable	Technology Effectiveness						
				FCWS	RCWS	SODS	FODS	RODS	LDWS	PDS
35.1F	Frontal	0.0%	0%	2	0	0	0	0	0	0
35.2R	Rear	1.2%	43%	0	2	0	0	0	0	0
35.2F	Frontal	1.2%	43%	2	0	0	0	0	0	0
36F	Frontal	0.3%	70%	0	0	0	0	2	0	0
36S	Sideswipe	0.3%	78%	0	0	2	0	0	0	0
37	Other	0.8%	9%	0	0	0	0	0	0	0
39	Pedestrian	0.5%	52%	0	0	0	0	0	0	4
40	Pedestrian	0.2%	63%	0	0	0	0	0	0	4
41	Pedestrian	0.1%	100%	0	0	0	0	0	0	0
42	Pedestrian	0.2%	22%	0	0	0	0	0	0	4
43	Pedestrian	0.5%	15%	0	0	0	0	0	0	1
45	Object	9.2%	92%	0	0	2	0	0	0	0
48	Other	2.1%	25%	0	0	0	0	0	0	0
100	Object	0.3%	17%	0	0	2	0	0	0	0

Appendix D: Sensitivity Analysis on Alternative Input Variables

The sensitivity analysis results described in Section 4.4 focused on developing confidence intervals for the primary input variables (i.e., collision rates, collision costs, and technology costs). However, the benefit-cost results were also tested for sensitivity to other, ancillary input variables, including technology useful life, inflation rate, and discount rate. All other baseline assumptions remained unchanged. The range considered for this portion of the sensitivity analysis is summarized as follows:

- Inflation rate varied from 1% to 4.% (baseline rate of 2.5%)
- Discount rate varied from 5% to 9% (baseline rate of 7%)
- Forecast period ranged from 6 years to 18 years (baseline period of 12 years)

The range of benefit-cost ratios resulting from these variable assumptions are summarized for each technology and combination of technologies in the two tables below. Benefit-cost ratios at the low end of the estimated range assumed the following:

- Inflation rate of 1%
- Discount rate of 9%
- Forecast period of 6 years

Meanwhile, ratios at the high end of the estimate range were based on the following assumptions:

- Inflation rate of 4%
- Discount rate of 5%
- Forecast period of 18 years

Technology	Benefit-cost ratio	
	Baseline	Range
Forward Collision Warning (FCWS)	0.45	0.32 – 0.58
Rear Collision Warning (RCWS)	0.59	0.41 – 0.76
Side Object Detection (SODS)	1.43	0.93 – 1.96
Forward Object Detection (FODS)	0.26	0.17 – 0.35
Rear Object Detection (RODS)	0.14	0.09 – 0.19
Lane Departure Warning (LDWS)	0.10	0.08 – 0.12
Pedestrian Detection (PDS)	0.81	0.56 – 1.05

Combination	Benefit-cost ratio	
	Baseline	Range
ODS (FODS & SODS)	1.60	1.03 – 2.21
ODS+ (FODS, SODS, & RODS)	1.59	1.01 – 2.23
FCSD (FCWS & SODS)	1.25	0.77 – 1.81
CWS (FCWS & LDWS)	0.49	0.33 – 0.63
CWS+ (FCWS, LDWS, & PDS)	0.83	0.53 – 1.19
CWS Cocoon+ (FCWS, LDWS, PDS & RODS)	0.69	0.42 – 1.02
All	1.38	0.82 – 2.14

Appendix E: References

Ann Arbor Transportation Authority and Kirk Lucksheiter. *Develop Performance Specifications for a Rear Impact Collision Warning System for Transit Systems*. November 2003.

Clever Devices. *Installation, Operation, and Maintenance Instructions for Seymor Object Detection System.* Revision 1.1, November 2004.

Duggins, D., et. al. *Developing and Testing of Performance Specifications for a Next Generation Side Collision Warning System*. April 2002.

Federal Highway Administration (FHWA) *2005 Highway Statistics* (Table VM-1).

Federal Transit Administration (FTA). *Understanding Transit Accidents Using the National Transit Database and the Role of Transit Intelligent Vehicle Initiative Technology in Reducing Accidents*. June 2004.

National Highway Transportation Safety Administration (NHTSA) *Traffic Safety Facts* (2005 Data Overview).

National Transit Database (NTD) collision data (2005).

University of California PATH and Carnegie Mellon University Robotics Institute. *Integrated Collision Warning System Final Technical Report.* December 2004.

Wang, X., et al. *Transit Bus Frontal Collision Warning System.* March 2002.

Wang, X., et al. *Development of Requirement Specifications for Transit Frontal Collision Warning System.* August 2003.