A Research Roadmap for Substantially Improving Safety for Transit Buses through Autonomous Braking Assistance for Operators

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ABSTRACT
This paper documents significant negative trends and impacts on the transit industry due to bus collisions, and the resulting injuries, fatalities and casualty and liability expenses. We outline a research roadmap to counter the trends by applying autonomous collision avoidance technology and autonomous emergency braking to transit buses.

Bus transit is one of the safest ways to travel in the United States. Bus passengers are more than three times safer than automobile passengers when comparing the rate of fatalities per 100 million passenger miles. However, buses can be made even safer.

We propose a research assessment to determine: why casualty and liability claims are increasing, the potential for automated collision avoidance systems to reduce fatalities, injuries and claims in transit buses, and to initiate the development of functional requirements and standards to allow installation of collision avoidance and driver assist technology on new transit buses and retrofit of existing buses.

Dollars spent on casualty and liability expenses are wasted dollars, arguably spent to mitigate the effects of collisions that should not have happened. The best way to reduce those wasted dollars is to prevent collisions from happening, and that is what will be discussed in subsequent sections of this paper.

INTRODUCTION
The purpose of this paper is to lay the groundwork for development of autonomous collision avoidance and autonomous emergency braking for transit buses. Although significant progress is being made in bringing autonomous collision avoidance and autonomous emergency braking to automobiles and trucks, the transit industry is being left behind. Bus transit has taken second place behind rail transit in the public perception of safety needs. Consequently it has not attracted attention from those who set research priorities and make funding decisions, in spite of data that show that bus exceeds rail in injuries and casualty and liability expenses.

We lay out a draft research roadmap for the adaptation to buses of proven technology that has been shown to reduce collisions and claims for automobiles. Our objectives are first to educate the industry on the magnitude of the problem, second, to provide a draft program that would lead to the desired outcomes, and third, to seek stakeholder involvement to refine the program and support to seek funding for it.

DIMENSIONING THE PROBLEM USING NATIONAL BUS SAFETY DATA
Bus transit is one of the safest ways to travel in the United States. Bus passengers are more than three times safer than automobile passengers when comparing the rate of fatalities per 100 million passenger miles.[1] However, we believe buses can be made even safer.

As shown in Table 1, which uses data from the Federal Transit Administration (FTA) National Transit Database (NTD) for the reporting periods shown, buses and vanpools have been involved in 85,391 collisions, experienced 1,340 fatalities, 201,382 injuries, and created expenditures for casualty and liability expenses of $5.7 billion. Included in these data are 56 fatalities and 16,312 injuries involving bus transit workers.

Recent events have focused attention on rail safety in the press. Consequently, it may be appropriate to examine whether there is an equitable balance in the application of resources to both bus and rail safety. Although we do not draw conclusions about the allocation of resources, we have included in Table 1 data comparing fatalities, injuries and costs of casualty

Table 1 Collisions, Fatalities, Injuries, Casualty and Liability Expenses by Transit Mode 2002-2014
Source: Federal Transit Administration (FTA) National Transit Database (NTD)
http://www.ntdprogram.gov/ntdprogram/data.htm accessed July 17, 2015

Mode	Reporting Period 2002-2014 Except as Noted					Reporting Period 2002-2013 Except as Noted		
	Collisions	Fatalities		Injuries		Total Casualty and Liability Expenses by Mode	Average Annual Vehicle Fleet	Average Annual Cost of Casualty and Liability Expenses per Vehicle
		Employees[a]	Total	Employees[a]	Total			
Commuter Bus (CB)[b]	94	0	3	33	390	$34,599,730[b]	2357	$4,894
Demand Responsive (DR)	14,513	6	120	3,055	19,833	$668,245,896	28,449	$1,957
Demand Responsive Taxi (DT)[c]	144	0	3	33	262	$2,123,284[c]	3,960	$134
Motor Bus (MB)	69,722	49	1,185	13,079	177,931	$4,908,851,572	62,307	$6,565
Bus Rapid Transit (RB)[b]	55	0	0	18	358	$2,752,895[b]	137	$6,714
Trolley Bus (TB)	486	0	10	59	2,096	$57,539,948	581	$8,257
Van Pool (VP)	377	1	19	35	512	$79,677,613	9,581	$693
Total Bus, Demand Responsive and Van Pool	85,391	56	1,340	16,312	201,382	$5,753,790,938	N/A	N/A
Total Rail[d,e]	6,118	36	1,303	1,462	89,806	$3,174,067,800	N/A	N/A

[a] Includes transit operators, transit employees, and other workers
[h] Data reporting started in 2012, included in Motor Bus (MB) for prior years
[c] Data reporting started in 2011, included in Demand Responsive (DR) for prior years
[d] Rail includes Automated Guideway (AG), Cable Car (CC), Commuter Rail (CR) , Heavy Rail (HR), Light Rail (LR), Monorail/Guideway (MG), Monorail (MO), Streetcar Rail (SR), Hybrid Rail (YR);
[e] Collisions, fatalities, and injuries are not reported for Commuter Rail (CR).; casualty and liability expenses are included for Commuter Rail (CR).;

and liability expenses for bus modes and the total for rail transit modes. A few highlights from a comparison between bus and rail show that injuries to transit workers are eleven times greater for bus than rail, and passenger injuries for bus are more than twice the number of rail injuries. Even more compelling is the fact that casualty and liability expenses for bus at $5.7 billion are more than 80 per cent higher than for rail.

Casualty and Liability Expenses

Casualty and liability expenses are reported on an annual basis to the FTA NTD as part of the Operating Expense report.[2] According to the manual, casualty and liability expenses "are the expenses a transit agency incurs for loss protection. If a transit agency is liable for someone's loss, then the agency must report all applicable compensation under this object class. Casualty and liability costs include: physical damage insurance premiums, recovery of physical damage losses for public liability and property damage insurance premiums, insured and uninsured public liability and property damage settlement pay outs and recoveries, and other corporate insurance premiums (e.g., fidelity bonds, business records insurance)"[3] Expenses are broken out by mode code for each agency and categorized as either: general administration, vehicle maintenance, or non-vehicle maintenance. Not all expenses attributable to vehicle collisions are reported as casualty and liability expenses. Such costs may include the following:

- Accident investigation
- Drug and alcohol testing
- Emergency services response
- Hearings and discipline
- In-house legal services
- In-house vehicle repair
- Lost fare revenue
- Overtime wages
- Passenger and service delays
- Sick time
- Spare vehicles and replacements
- Vehicle recovery
- Workers compensation

Transit agencies are required to submit reports on individual incidents and collisions for the Safety and Security Module of the NTD. Although property damage expenses exceeding certain thresholds are reported for each incident, the costs of individual casualty and liability claims for injuries and fatalities are not reported by incident. Consequently, it is difficult to assemble the total cost to an agency of an individual collision.

Safety reporting typically uses the numbers and rates of injuries and fatalities as metrics. Although as humans we are emotionally moved when people are injured or killed in an accident, if they are unknown to us and unseen by us, the numbers are abstract and the significance of changes is difficult to comprehend. However, the total casualty and liability expense of claims can be considered as an index of the misery caused by collisions, and is easily tracked over time.

Many transit agencies are self-insured for claims up to a specified monetary threshold and purchase insurance to cover extraordinary losses. In several states, transit agencies have organized transit insurance pools, which handle claims and combine the purchasing power of a number of properties to receive better rates from insurance providers.

Dollars spent on casualty and liability expenses are wasted dollars, arguably spent to mitigate the effects of collisions that should not have happened. The best way to reduce those wasted dollars is to prevent collisions from happening, and that is what will be discussed in subsequent sections of this paper.

Trends in Bus Injuries and Casualty and Liability Expenses

Figure 1 shows that the rate of injuries per million passenger miles fluctuates over the period 2003 to 2013, but the trend is generally downward, which is good. Figure 2, however, shows that the number of injuries per has been trending upward. Figure 3 shows sharp fluctuations in casualty and liability expenses with a significant upward trend over the period. The research roadmap will include an examination of these trends and underlying factors that drive them.

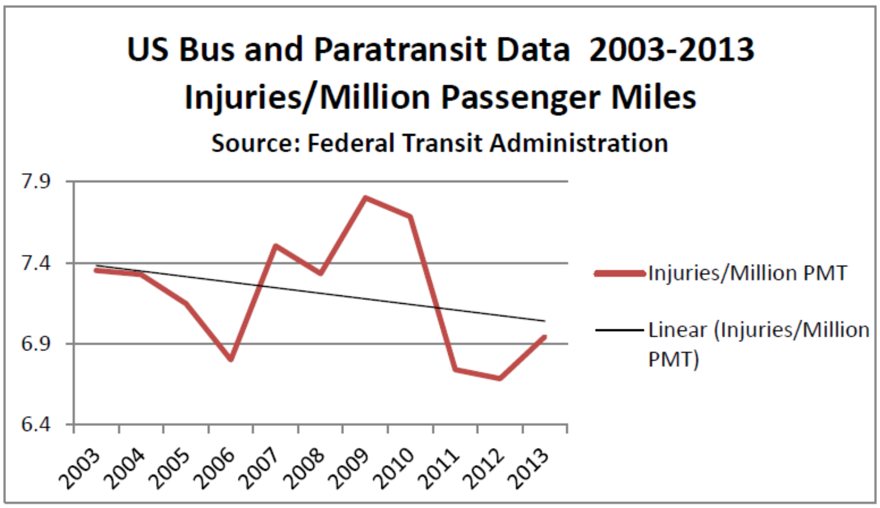

Figure 1 US Bus and Paratransit Injuries per Million Passenger Miles

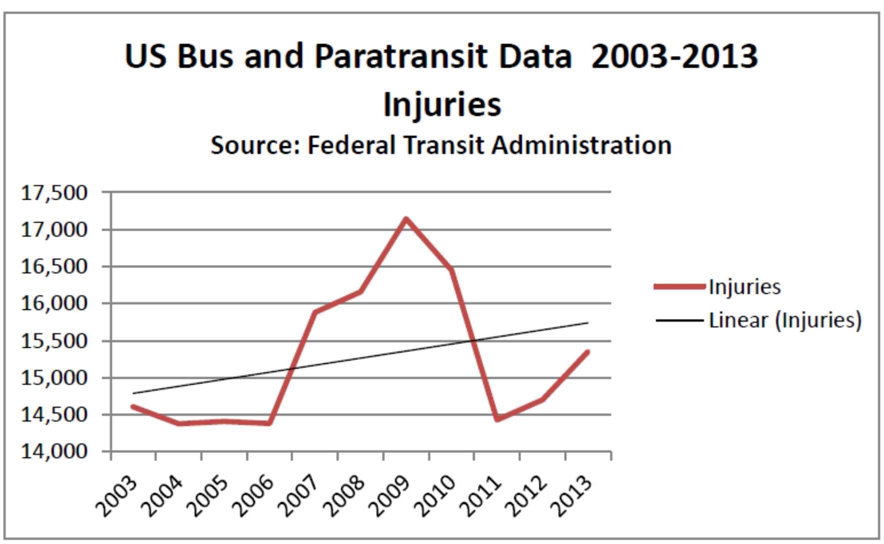

Figure 2 US Bus and Paratransit Injuries per Year

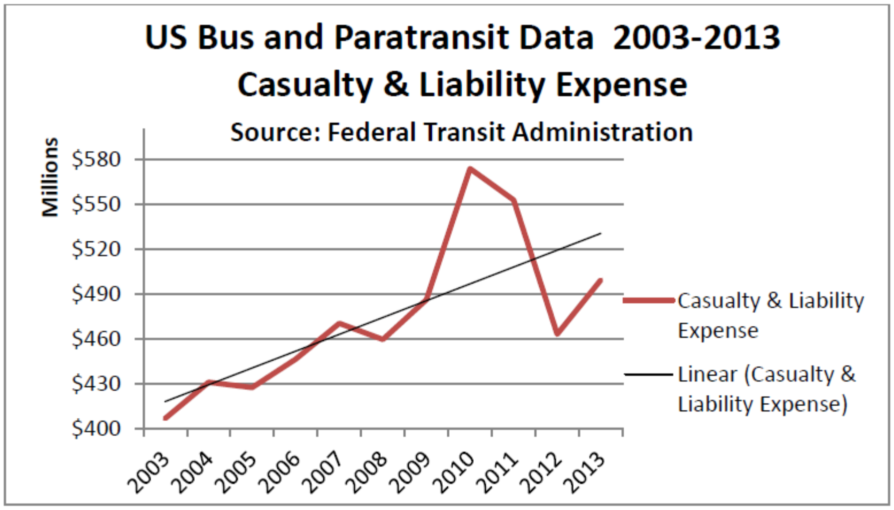

Figure 3 US Bus and Paratransit Casualty and Liability Expenses

AN ANALYSIS OF BUS COLLISION CLAIMS

Three major transit insurance organizations, the California Transit Indemnity Pool, the Ohio Transit Risk Pool, and the Washington State Transit Insurance Pool, together with King County Metro Transit, collaborated on an analysis of bus claims to determine the potential for claims reduction through application of autonomous collision avoidance and autonomous emergency braking.[4] The analysis was based on claims resolved during the period 2004 to 2014. Of the total $191million in gross incurred losses, $113 million were for claims less than $100 thousand and $78 million were for claims greater than $100 thousand. The analysis focused on claims greater than $100 thousand.

The majority of losses, 74 percent, were collision-related. Collisions with pedestrians, bicyclists, and motorcyclists accounted for 46 per cent. Forward collisions with vehicles accounted for another 15 percent. Ten percent of the collision losses were considered “non-preventable” by forward warning systems, and three percent were categorized as “other.” Based on the transit risk pool analysis, forward collision avoidance systems with autonomous emergency braking have the potential to prevent 61 percent of claims greater than $100 thousand. An analysis of the top five large claims, ranging from $3.3 million to $5 million, showed that four of the five could have been prevented by autonomous collision avoidance technology, for a savings of $18 million.

COLLISION AVOIDANCE TECHNOLOGY

In 2004, 2007, and 2013 the Federal Transit Administration released research reports on the potential for technology to reduce bus crashes.[5,6,7] These reports concluded that the systems envisioned at the time, which would warn bus drivers of impending collisions, could be effective in reducing costs.

Several vendors are offering collision avoidance warning systems for buses. Roscoe Vision Systems and Mobileye are offering a camera-based pedestrian detection system for buses that recognizes when a bus is at risk of colliding with a pedestrian and provides both audible and visual warnings to the operator.[8] CycleEye is testing a system that uses cameras and radar to detect cyclists in blind spots close to a bus.[9] Other vendors including Clever Devices and Protran Technology offer systems that broadcast audible warnings to pedestrians that a bus is turning. [10,11]

Although intended for trucks rather than buses, Soterea, Inc. has teamed with Klam America, Inc. to develop a promising radar-based system, "Autonobox" which detects vehicles, pedestrians and obstacles in the path of a truck and activates an electromagnetic driveshaft retarder to slow and stop the vehicle prior to a collision.[12,13]

The Need for Autonomous Driver Assistance

Although driver warnings may be effective, in the time it takes to respond to an imminent collision, a bus typically can travel as much as six times its own length before the brakes are applied. Chang and Chang presented an experimental study in which bus driver perception-reaction times were measured.[14] They found that the average perception-reaction times for the various trials ranged from 1.6 to 2.32 seconds with a standard deviation of 0.54 to 0.88 seconds. Autonomous braking and maneuvering could reduce that delay significantly, reducing the potential for collisions and injuries, and saving lives.

Automobiles are now entering the market with automated systems that not only sense that a collision is imminent, but actually take control of throttle, steering and braking functions to avoid or mitigate collisions. In particular, systems for autos are available that will initiate autonomous braking to bring a vehicle to a stop prior to collision with a pedestrian or vehicle, even if the vehicle operator does not apply the brakes manually.[15] The Insurance Institute for Highway Safety (IIHS) has concluded that forward collision avoidance technologies have reduced claims. According to IIHS, Volvo XC60 SUV's equipped with autonomous braking experienced 33 percent fewer bodily injury claims, 15 percent fewer property damage claims, and 20 percent fewer collision claims. [16]

The National Transportation Safety Board (NTSB) has called for immediate action to require these systems on new vehicles. The NTSB reported that forward collisions were reduced by 71 percent for trucks equipped with collision avoidance systems (CAS) that included autonomous emergency braking (AEB) and electronic stability control (ESC). That test spanned 30 months and included 12,600 truck-tractors.[17]

The Need for Standards and Specifications

Because transit buses typically can stay in service for 12 to 18 years and often carry standees, their technology requirements will differ from those for trucks and autos. Emergency braking rates for transit buses must consider that standing passengers may be thrown off balance if the jerk and deceleration rates are too high. Abernethy, et al, reported only two known human studies of effects of deceleration on public transit passengers.[18] One of the studies cited was conducted in 1932 and measured the deceleration forces that would cause standing passengers to lose balance.[19]

Buses and vans purchased with FTA funds are expected to remain in service for at least 12 years.[20] Digital technology often becomes obsolete in a matter of months. Autonomous collision avoidance systems should not be expected to last for the life of the bus. Software and electronic components in the systems will be replaced by newer versions over time as the original versions will no longer be available. Sensors and processors are subjected to harsh environmental conditions in the transit operating environment. It is expected that components and even entire systems will need to be replaced over the life of the vehicle.

When system maintenance or replacement is required, vehicles must be taken out of service and spend time in a maintenance facility. Fleet availability and the impact on maintenance resources will be a concern. For those reasons, component change outs need to be done quickly and multiple sources will be needed to insure that replacement component prices are competitive.

With slightly over 60,000 vehicles, the transit bus industry in the United States is a niche market compared with automobiles and trucks. Bus manufacturers have told us that they act as systems integrators for new technology by purchasing and installing systems that are specified by their transit agency customers. As a result there is little financial incentive for bus manufacturers to undertake development of these systems. Consequently, the push for innovation and standards in this area must come from transit agencies and those government bodies charged with oversight of transit safety.

Purchasing buses for a transit authority is not a simple task. Buses are usually purchased under a competitive procurement process in which an agency issues a request for proposals to bus manufacturers that specifies what the agency wishes to buy. Bus manufacturers then submit proposals that contain technical information on the buses they propose to supply along with the prices for the buses and optional features. The agencies will evaluate each proposal and generally award a contract to the manufacturer that meets the agency's technical requirements and offers the lowest price.

Integral to the process is the need for the agency to develop a detailed specification for the features it wants on the buses. Specifications range from the color scheme, to the type of engine and fuel, to small details like the location of drain plugs. The American Public Transportation Association (APTA) has developed guidelines for bus procurement that agencies can use in their requests for proposals. [21] The APTA outline runs 284 pages long and includes more than 300 alternatives for technical requirements from which an agency can choose.

The APTA guidelines contain extensive technical detail, but they do not include information on, or specifications for, collision avoidance systems and autonomous emergency braking. Although other standards bodies are beginning to work on standards for autos and trucks, standards for buses will need to address unique bus characteristics such as the following:

- Blind spot locations
- Component replacement and maintenance requirements
- Forces acting on seated and standing passengers
- Operator training and workload
- Proximity of pedestrians and waiting passengers
- Sensor placement
- Vehicle lifespan

RESEARCH AND DEVELOPMENT ROADMAP

The draft research roadmap presented here includes a statement of the research objectives as questions to be answered, and four separate research phases. The phases are generally sequenced in chronological order, but may overlap. Once this general outline has been reviewed by stakeholders, it is expected that changes will be incorporated and each phase will be divided into tasks, with a schedule and budget.

Research Objectives and Outcomes

- Why have casualty and liability expenses trended upward?

- How can the industry more accurately account for the total costs of bus collisions?
- What is the correlation between costs and type of collision?
- What types of autonomous collision avoidance technologies have the greatest potential to reduce casualty and liability expenses?
- What requirements and standards are needed to allow transit operators to specify autonomous collision avoidance technology for new bus procurements and retrofits?
- Given that buses may remain in service for 15 to 18 years, and digital technology can become obsolete within 18 months to two years, how should buses be configured to allow rapid and cost-effective replacement of components and retrofit with updated technology?
- What is the process for testing and certifying autonomous collision avoidance systems?

Phase 1

- Create a broad, inclusive stakeholder group of transit agencies and other members of the transit industry, and achieve a comprehensive view of the problem and potential solutions from all sides.

Phase 1 will establish an effective project management structure and create an industry-wide stakeholder group including representatives of transit agencies, risk management and insurance providers, consultants, vehicle manufacturers, systems developers, standards organizations, vendors, motor vehicle regulators, and USDOT officials. Volunteers from the stakeholder group will be asked to participate in expert technical working groups to assist in the development and balloting of consensus standards for autonomous collision avoidance technology for transit buses. These standards will make it possible to install life-saving advanced technology on new transit buses and to retrofit exiting buses.

Expert Technical Working Groups (ETWG's) – ETWG's are working groups charged with the development of functional requirements and standards through a consensus process and balloting. Each ETWG will be chaired by a subject matter expert who will develop an initial white paper to articulate specific technical issues that need to be addressed in the standards development process. ETWG membership will be publicly and broadly solicited throughout the transit industry. Announcements will be sent to interested parties and the creation of the working groups will be advertised in APTA publications to recruit volunteers. ETWG members will include volunteers representing stakeholder groups such as transit agency staff, risk management and insurance providers, consultants, vehicle manufacturers, systems developers, standards organizations, and vendors. The project includes the following ETWG's:

- Claims analysis and data collection
- Human factors/operations/safety
- Bus interfaces/systems/maintainability
- Autonomous systems and controls
- Testing and certification

Phase 2

- Conduct a research assessment of why casualty and liability claims are increasing and determine the potential for automated collision avoidance systems to reduce fatalities, injuries and claims.

Phase 2 will provide transit agencies with an accurate and comprehensive understanding of the total costs of bus collisions, the reasons that the costs of collisions are increasing, and the relationship between costs and types of accidents. Using the National Transit Database (NTD), we will provide a detailed examination of the historical trends of steadily rising casualty and liability expenses and provide insights through statistical analysis of factors that are shown to be correlated with the increases in costs. In addition to NTD data, participating transit agencies and insurers will provide detailed data that will allow the researchers to link individual claims and other expenses with individual incidents to assemble an accurate record of the total agency cost of each collision. Although this data will be used in the project to identify cost-effective autonomous collision avoidance technologies, it is expected that transit agency safety and risk managers immediately will be able to increase bus operator awareness of high risk situations and improve their ability to reduce the frequency and severity of collisions.

Phase 3

- Develop functional requirements and standards to allow installation of collision avoidance and driver assist technology on new transit buses and retrofit of existing buses.

Phase 3 of the project will use expert technical working groups created in Phase 1 to develop functional requirements, specifications and standards that will: 1) define the capabilities and performance requirements for autonomous collision avoidance technology for buses, and 2) allow collision autonomous collision avoidance technologies to be retrofitted to buses, using competitive procurements and "plug and play" interfaces. The major deliverables of this task will be a balloted set of standards for autonomous collision avoidance technology and for the electromechanical on-board interfaces needed to host the technology.

Phase 4

- Develop a prototype test bed that would allow developers of innovative collision avoidance and driver assist technologies to work with transit agencies and researchers to expedite development and deployment.

Phase 4 involves development and testing of the following elements: 1) an on-board test-bed network using electromechanical interface standards developed in Phase 3, that will accommodate the installation and testing of prototype autonomous collision avoidance technologies, 2) a collision avoidance system simulator that can be installed to test the bus's ability to host, and autonomously respond to inputs from, a collision avoidance system, and 3) a data logger and analyzer to monitor multiple performance parameters of both the bus and the autonomous collision avoidance technology and produce reports that can be used to certify compliance with the performance requirements and standards. Phase 4 will include an extensive field operational test of all three elements.

Research Products

This program would develop the following products: 1) a review and analysis of the comprehensive costs to transit agencies of various types of bus collisions, 2) functional requirements and performance specifications for autonomous collision avoidance technology for buses, 3) standards for interfaces between buses and autonomous collision avoidance technology, 4) an on-board test-bed network using the performance and interface standards, that will accommodate the installation and testing of prototype autonomous collision avoidance technologies, 5) a collision avoidance system simulator that can be installed on a new or retrofitted bus to test the bus's ability to host, and autonomously respond to inputs from, a collision avoidance system, and 6) a data logger/analyzer that will monitor multiple performance parameters of both the bus and the autonomous collision avoidance technology and produce reports that can be used to certify compliance with the performance requirements and standards.

CONCLUSION

This paper documents a serious problem for the transit bus industry, rising numbers of injuries and a sharp increase in casualty and liability expenses for buses. We show that bus lags behind rail transit in these key safety metrics. The paper presents a work program for the development of functional standards and certification procedures for autonomous bus collision avoidance systems and autonomous emergency braking that draws on a partnership among various stakeholders including the American Public Transportation Association (APTA), Princeton University Autonomous Vehicle Engineering (PAVE), and the Washington State Transit Insurance Pool (WSTIP).

The missing piece is how to communicate the message to transportation decision-makers that a relatively small investment in research and development could yield major savings in lives, injuries and dollars. Current policies at the federal level have focused discretionary spending on programs that emphasize job creation rather than research. However, data show that the research and development of autonomous collision avoidance and autonomous emergency braking for buses have the potential to reduce annual casualty and liability expenses and allow scarce transit funds to be reallocated in ways that would not only create jobs, but would save lives and reduce injuries, as well. This paper is a starting point for the educational process of communicating the value of this research and building a coalition to seek funding and get it done.

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