A PERFORMANCE SPECIFICATION FOR TRANSIT BUS SIDE COLLISION WARNING SYSTEM

TECHNICAL PAPER

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SUMMARY
A performance specification for a side collision warning system for transit buses has been developed in a collaborative effort involving Carnegie Mellon University, the Port Authority Transit (PAT) of Allegheny County, the Pennsylvania Department of Transportation, and the Federal Transit Administration (FTA). The specifications draw on an analysis of transit bus crash data, experience with side collision warning systems for light vehicles and heavy trucks, exploration of proximity systems and experiments with a variety of sensors. This paper describes how the performance specification was developed, provides some examples of the performance specifications and an assessment of their completeness and adequacy. Finally, the paper addresses the value of such systems in reducing crashes.

INTRODUCTION
Mass transit provides a safe mode of travel. However, transit buses are still involved in a large number of crashes as they travel many miles in congested urban areas. Advances in sensors, vehicle control and human-computer interfaces provide opportunities to make transit safer through vehicle based driver assistance. Side collision warning systems are a specific example of a system of hardware, software and decisions support rules to reliably detect pedestrians, bicycles and vehicles and provide information to the driver. Past research and development related to side collision warning systems has been directed at light vehicles and long-haul trucks.

A collaborative effort involving Carnegie Mellon University, the Port Authority Transit (PAT) of Allegheny County, the Pennsylvania Department of Transportation, and the Federal Transit Administration (FTA) has developed a performance specification for side collision warning systems (SCWS) for transit buses. The performance specification defines what data must be collected, the accuracy of the data and the necessary outputs of the system in terms of signals, reliability, consistency and robustness.

This paper describes how the performance specification was developed, provides some examples of the performance specification and an assessment of their completeness and adequacy. Finally, the paper addresses the value of such systems in reducing crashes.

BACKGROUND
Advances in sensors, vehicle control and human-computer interfaces provide opportunities to make surface transportation safer through vehicle based driver assistance. This subset of Intelligent Transportation System (ITS) technologies is intended to improve driving safety and efficiency. The National Automated Highway System Consortium (NAHSC) was able to demonstrate several of these technologies in Demo '97 in San Diego in 1997 (1,2,3) and several concepts from this project are now part of the operational tests for the Intelligent Vehicle Initiative (IVI) program sponsored by the National Highway Traffic and Safety Administration (NHTSA) (4). Other completed and ongoing projects have demonstrated the role these technologies play in

specific aspects of highway safety. For example, a project focusing on lane-change-merge maneuvers has developed performance specifications (5).

In our analysis of incidents involving transit buses, interviews with drivers and observations (6,7), we have found that side collision incidents are fundamentally different from vehicle-vehicle collisions of the type considered by Young et al, (8) and from the incidents involving class 8 trucks (9). In addition, the constrained spaces in which transit buses maneuver and the proximity between the bus and pedestrian as they board mean that the operating environment is significantly different from the typical vehicle. Based on an analysis of bus collision data from Pittsburgh and Washington state, and the fatal accident reporting system (FARS), we have found that (6):

- The passenger fatality rate per mile is about 15 times less for buses than for other vehicles.
- A bus is involved in 15 times more collisions or 25 times more injuries per year than other vehicles.
- 6% of collisions are not with another vehicle, 84% with one other vehicle and 10% with more than one other vehicle.
- Not counting bus collisions with more than one other vehicle, around 90% of incidences involve collisions with another car and around 5% each for collisions with people (pedestrian and cyclist) and objects. Variations among different databases are significant.
- All objects involved in collisions are relatively tall, but some of them are thin. The first fact makes detection easy; the second difficult.
- The number of fatalities resulting from bus-pedestrian collisions is only a little less than from bus-vehicle collisions.
- Property damage per incident is $2700; there is almost no property damage from pedestrian or cyclist collisions. Variations in damage severity with collision type are strong.
- The average claim is paid or settled with $3000.
- There are much more claims of being injured onboard, boarding, or alighting a bus than claims of being injured in a vehicle or bus collision.

In our analysis of incidents we found that:
1. Pedestrian incidents are more frequent than expected.
2. The driver was often not aware that the incident had occurred.
3. A significant number of incidents involve parked vehicles including drivers who open their door into a bus.
4. A significant number of incidents involve oncoming vehicles when there is not sufficient room for both vehicles on the road.
5. The majority of incidents involving a fixed object occur when the bus backs into an object.

The report "Facts and Data Related to Transit Buses" (6) documents the analysis of data from the Port Authority Transit (PAT) of Allegheny County, Washington State, the Fatal Accidents Reporting System (FARS) and the General Estimation System (GES). The analysis explores the relationships among the operating environment of transit buses and

causal factors related to bus collisions, and examines other relevant factors for side collision warning systems.

To develop the performance specification, we first developed a set of functional goals around our analysis of accidents. We define functional goals to be changes in the situation for each crash type that would help to eliminate crashes or decrease their frequency or severity. They should be system independent. Similarly, performance specifications are system specific specifications that reflect the balance between the ideal and the technologically achievable.

Transit buses usually drive at low speeds and are exposed to a great variety of targets. Collisions happen all around the bus, even underneath the bus. Especially tricky are pedestrians, which often behave in an unpredictable manner and are much more likely to get injured in a collision than drivers of vehicles. The line between a safe and dangerous situation is very narrow and a Collision Warning System (CWS) could be rendered useless by giving off too many false alarms. When a pedestrian steps off the sidewalk and onto the street, they have crossed one of those lines, and a CWS should therefore be able to detect the curb. The curb is one of those lines and a CWS should therefore be able to detect it. An ideal CWS for a transit bus should therefore have the following capabilities:
- Detect objects underneath the bus (at least in front of the tires).
- Full 360-degree coverage around the bus at very short distances, especially in front and to the right side.
- Side and rear coverage for lane change maneuvers.
- High resolution - approximately 1 inch at 6 feet for curb detection.
- Distinguish cars from pedestrians.
- Spot rapidly approaching vehicles at longer distances.
- Estimate velocity of vehicles and pedestrians.
- The sensor system should not be too expensive, preferably less $5,000 (9).
- Few sensors.
- Reliable, easy to maintain, and easy to use.

Recording of the sensor data to reduce fraudulent claims and vandalism, to help the collision investigation and provide warnings/announcements to passengers and pedestrians are also likely to reduce incidents and should be combined with a CWS.

PERFORMANCE SPECIFICATIONS
The performance specifications are based on safety levels derived from the crash analysis and experiments with a variety of sensors and systems. The definition for SCWS safety levels are broken into five categories:
Aware - Baseline Situational Awareness. The transit operator and pedestrian see strictly non intrusive indications, be they running lights, video or the lack of any active alerts, warnings, evasions, or notifications.
Alert - Potential Obstacles. Alerts are semi-intrusive information such as enhanced video indicating potential obstacles, lights indicating the close proximity of an obstacle, or a pleasant voice alerting a pedestrian to the presence of a moving bus.

Warn - High Likelihood of Collision. Warnings span the spectrum from intrusive information such as voice or melodic sounds to intrusive interference such as shaking the steering wheel and or seat, vibrating the brakes, or a loud buzzer all indicating a high likelihood of collision.

Evade - Imminent Collision. Evasive actions include active control of the transit bus such as steering or applying the brakes. The Evade safety level has not been included in the specifications since it is not considered an option for the near term SCWS.

Notify - Collision has occurred. Notification involves informing the transit operator through an intrusive light or voice that a collision has occurred and data (either computer and/or video) has been saved.

The basic configuration of the SCWS is shown in Figure 1. Based on this configuration the performance specification addresses:

- For the transit buses: motion, pose, status, and environmental context,
- For objects in close proximity to the side of the bus: motion, and pose,
- Collision probability
- Warning generation,
- Driver vehicle interface,
- Recording requirements, and
- Operational requirements

The specification describes the accuracy and precision of the sensors but not how the sensors must function. For example, the specification addressing the location of objects is stated as follows:

> *The SCWS shall detect stationary objects within 2 meters of the sides of the bus, and extending forward at least 1 meter ahead of the front corners of the bus along its trajectory.*

The most complex parts of the SCWS specification are the calculation of the collision probabilities and identification of the appropriate warning level. The specification defines the data collected and the accuracy and reliability of the data, but not how the probabilities are computed. The SCWS computes the probability of a collision 2 seconds, 3 seconds and 5 seconds into the future. One way to do this is to use a series of simulated trajectories. Warning levels differ for pedestrians, objects and other vehicles. The relationships are based on experience and expert judgment. Figure 2 shows a hypothetical relationship between probability of impact and safety level for pedestrians. For example, if the probability of impact at 2, 3 and 5 seconds is computed to be 0.2, 0.3 and 0.8, the system will generate a warn alarm.

Nuisance alarms have been found to be a significant problem. Therefore the specification explicitly addresses system reliability in terms of both false positives (nuisance alarms) and false negatives (failure to warn). False positives and false negatives are limited to 5%.

These examples illustrate the concepts used in developing performance specifications. The complete specifications may be found in (10).
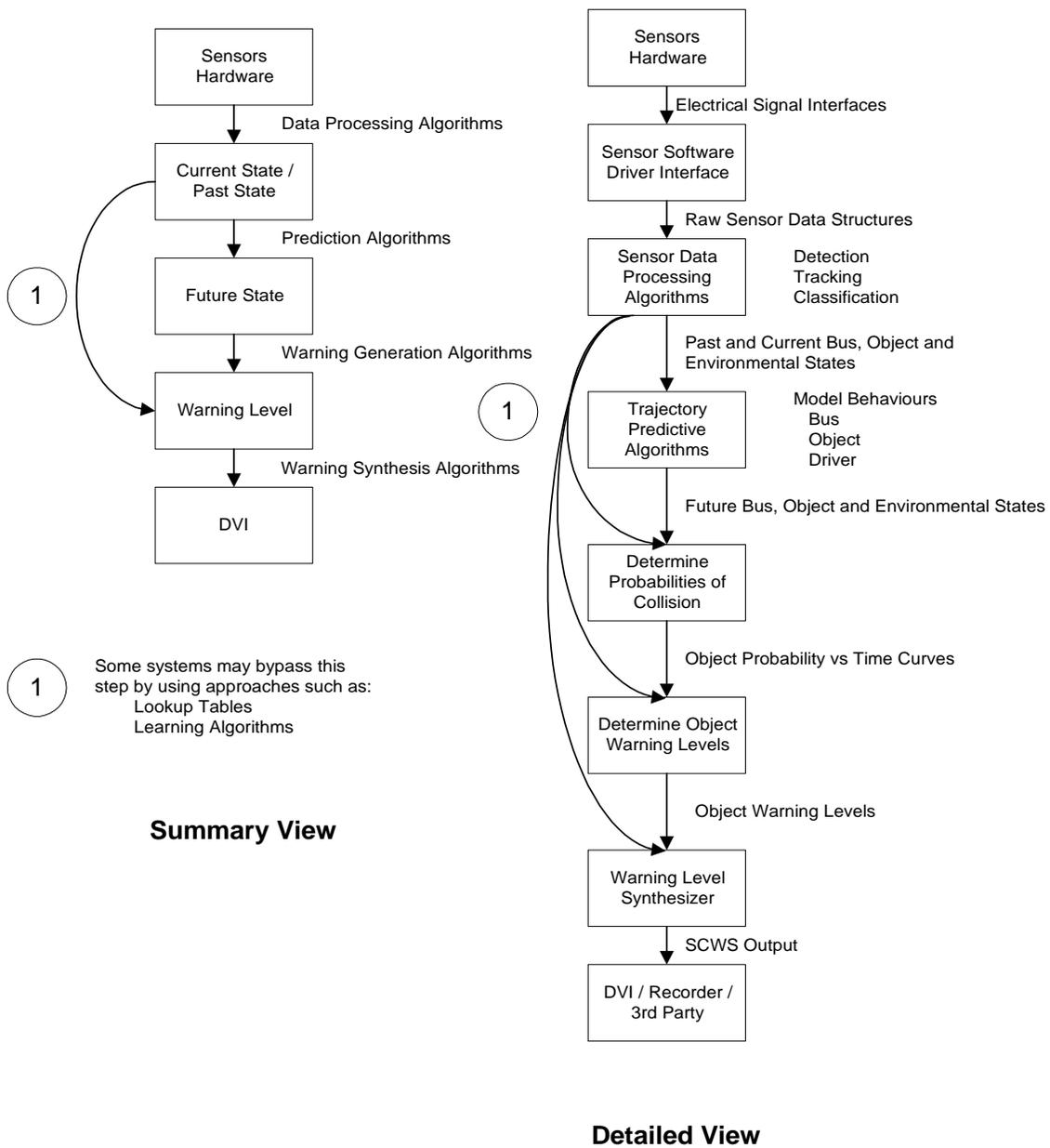
Summary View

Detailed View

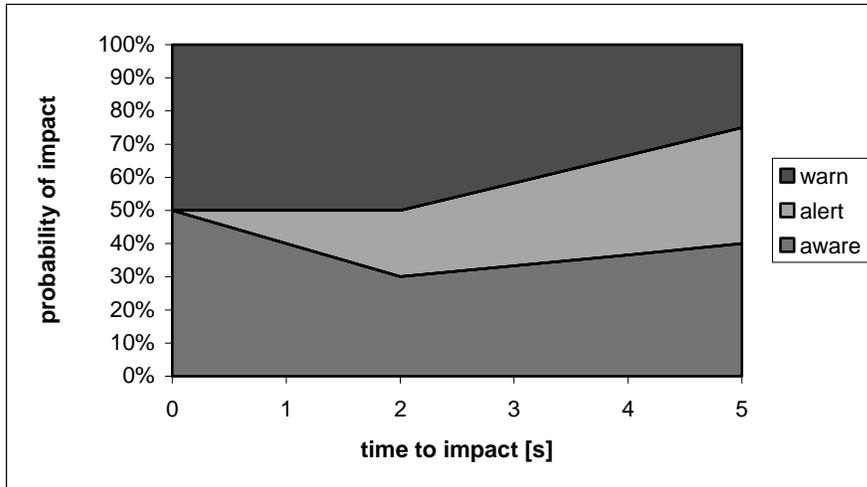**Figure 1: Side Collision Warning System Overview**

Figure 2: - Probability versus Safety Level Diagram for Pedestrians

THE VALUE OF SCWS FOR TRANSIT BUSES

Given the challenges facing a cost benefit evaluation of any technology, it is difficult to conduct a definitive cost benefit analysis for a side collision warning system for transit buses. It is also difficult to estimate the cost to develop and bring to market the system, the expected life of the system and most importantly the effectiveness of the system. Furthermore, there is considerable debate in the literature on the cost of accidents, for example, (11, 12). Given these limitations we explore the costs and benefits of a side collision warning system using a break-even analysis. We determine the cost of a side collision warning system to be equal to the benefits derived from the system.

Such an analysis of the break-even cost of a side collision warning system is useful as it provides an indication of whether or not such a system may be feasible. The analysis presented here for transit buses is based on many assumptions. These include:

- The cost of the SCWS consists of an initial cost, including acquisition and installation and some maintenance costs over its life, and it has a life of three years.
- The only benefits derived from the SCWS are in the form of the comprehensive costs of motor vehicle crashes eliminated and are measured in terms of the social costs of crashes in 2000 dollars.
- The real discount rate or MARR is 2.1%. (13,14).

The magnitude of the saving is highly dependent on the effectiveness of the system. The performance specifications for the SCWS typically require 95% detection of potentially dangerous situations. However, once a situation has been detected, the driver must recognize and respond. More important than the reliability of detection is the time available for the driver to respond. Eaton manufactures a commercially available SCWS for trucks. The system claims to have produced a 76% reduction in accidents (15). In this analysis we distinguished between preventing crashes and reducing their severity.

Based on our analysis of bus crash data for Pittsburgh and Washington State (9) and our experience in developing the performance specification for the SCWS for transit buses,

we estimate measures of effectiveness. We compute the break even cost for an SCWS factoring the number of crashes, the number of buses for the transit system, and the expected life of the SCWS. This cost includes purchase, installation, and maintenance and service of the system over its life.

The most appropriate values of life and costs of injury to use in cost-benefit analysis are the comprehensive cost. The comprehensive costs of crashes are based on the economic costs and loss of quality of life and are obtained from the National Safety Council (16):

Death	$ 3,214,290
Incapacitating Injury	$ 159,449
Non-incapacitating Evident Injury	$ 41,027
Possible Injury	$ 19,528
No Injury	$ 1,861

In reality, the average cost for death and injury is independent of the vehicles involved. However, the average property damage is likely to be dependent on the vehicle type. Buses are bigger and might inflict bigger damage, but at the same time buses drive on average much slower than other vehicles and therefore might inflict less damage. Buses have many more passengers and therefore the amount of lost wages due to lost time is likely to be bigger for buses than other vehicles.

In order to estimate the benefits derived from reducing the number and severity of crashes using a SCWS, we derive estimates for the number and severity of crashes involving buses from both Pittsburgh and Washington state data (10).

A qualitative assessment based on the expert judgment of the research team suggests that a significant proportion of the bus collisions would indeed be either less severe or eliminated using a SCWS based on our performance specifications. Using the PAT database of claims and a sample of detail accident records, we reviewed incidents by type and classified them as preventable or non-preventable using a SCWS. For example, 7.2% of incidents involve pedestrians. Just over 17% of these incidents occur when the bus is starting from a stopped position, and 92% of these incidents may be positively affected if the bus had a SCWS.

The effectiveness of the SCWS is derived from the overall effectiveness of 95% (from the performance specification that says there will be no more that 5% false negatives). The preventability is derived from the analysis of the PAT data, and the proportion of crashes that are side collisions. For vehicles and pedestrians the effectiveness ranges from 42% to 68%. This is consistent with NHTSA's 1996 estimate of 47% of lane change/ merge crashes avoided using a LCM CAS (17). Finally, we distribute the effectiveness between eliminating the crash and reducing the severity of the crash. This is done on the basis of the proportion of crashes that are preventable (approximately one third) and the proportion that may be preventable (approximately two thirds).

We also assume:
• The analysis is in constant dollars (ignoring the impact of inflation).

- The life of the system is 3 years.
- The focus is on social costs rather than agency costs.

Table 1 summarizes the values **assumed** for savings from prevention and reduction in severity for each of the various types of crashes, and the effectiveness in reducing crashes for PAT. These values are then used with the approximate annual number of crashes for PAT to produce total savings for each type of incident. Therefore, the crash savings to society (because we have used a social cost) are almost $4 million per year. PAT has approximately 900 buses, if each bus were fitted with an SCWS and the system had a life of 3 years, the system would cost under $12,500 to break even. This is based on the present value of a savings of over $3.9 million per year from incidents eliminated or reduced in severity by the SCWS over three years using a discount rate of 2.1%. We believe that it is feasible to develop, manufacture, install and maintain a system for under this amount. Therefore, with relatively modest reductions in incidents significant benefits can be gained.

Our assessment of effectiveness is very conservative but recognizes that we found approximately 25% of pedestrian incidents were not preventable and approximately 50% may not be preventable. Combined with a system effectiveness of 95% we have assumed that 30% of vehicle incidents are positively affected by the SCWS system and 20% of pedestrian incidents. This analysis could be considered to provide a lower bound. That is, from a social welfare point of view, it is worth spending at least $12,000 on an SCWS for a transit bus.

We repeated that analysis for a best-case scenario in which the system is more effective in both preventing crashes and reducing the severity of the crash. We also repeated the analysis using the Washington State data. The results are summarized in Table 2. The Washington state data uses an estimated number of buses for Washington State of 1658 derived from the APTA performance indicator statistics for 2000. These are derived from the National Transit Database (18).

Case	Effectiveness		PAT		Washington	
	Pedestrian	Vehicle	Cost Savings	Break Even Cost	Cost Savings	Break Even Cost
Worst	0.18	0.14	$3,963,670	$12,676	$10,092,650	$17,521
Best	0.23	0.2	$5,289,642	$16,917	$11,888,407	$20,638

Table 1 - Sensitivity Analysis

An analysis of crash data from Pittsburgh and Washington State and an assessment of opportunities for preventing or eliminating side collisions for transit buses has demonstrated that the savings in the social costs of accidents will be recouped if the costs of development, production, installation and maintenance of an SCWS is less than $12,000 and the system lasts at least 3 years. Additional saving can be realized by accounting for fraudulent claims, and reduced driver stress.

Type of Incident	Savings		Effectiveness		Annual # of Crashes	Total Savings
	Prevented	Reduced	Prevented	Reduced		
Pedestrian - fatality	$3,214,290	$3,054,841	0.18	0.36	0.44	$749,814
Pedestrian - incapacitating injury	$159,449	$118,422	0.18	0.36	10.12	$725,597
Pedestrian – nonincapacitating injury evident	$41,027	$21,499	0.18	0.36	14.33	$217,795
Pedestrian - possible injury	$19,528	$17,667	0.18	0.36	37.78	$375,010
Vehicle collision - fatality	$3,214,290	$3,054,841	0.14	0.28	0.44	$578,012
Vehicle - incapacitating injury	$159,449	$118,422	0.14	0.28	11.80	$652,019
Vehicle - nonincapacitating injury evident	$41,027	$21,499	0.14	0.28	16.70	$195,722
Vehicle - possible injury	$19,528	$17,667	0.14	0.28	15.95	$122,045
Vehicle collision - PDO	$1,861	$931	0.14	0.28	664.00	$344,717
Fixed object - PDO	$1,861	$931	0.05	0.10	15.11	$2,939
						$3,963,670

Table 2 - Hypothesized Worst Case Savings by Incident Type for Side Collision Warning Systems For PAT

CONCLUSIONS AND FUTURE RESEARCH

At the highest level, an SCWS for the transit environment requires:

- Sensing and predicting bus motion. Cues to the bus's future trajectory come not only from the steering wheel and current velocity, but also from the turn signal, door open or closed; from environmental cues such as the location of curbs; and even potentially from knowing the bus's current location along its route.
- Sensing and predicting object motion. The current location and motion of an object in the environment is the first important cue, but should be supplemented with other cues (is this a car? A lamppost? A pedestrian? Is it in the roadway or on the sidewalk?).
- Assessing the likelihood of a future collision. Once the bus and surrounding objects have been sensed and modeled, software needs to assess the chance of a collision with each object over time.
- Generating appropriate interfaces. This involves different levels of warnings, as well as various human factors issues in the driver interface.

Future research will focus on the development of a prototype system and validation of these performance specifications through both simulation and field-testing.

ACKNOWLEDGEMENTS

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