A NEW FOCUS FOR SIDE COLLISION WARNING SYSTEMS FOR TRANSIT BUSES

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ABSTRACT

Research and development related to side collision warning systems has been directed at light vehicles and long-haul trucks. In this paper, we present evidence that supports our hypothesis that the side collision warning systems for transit buses are very different as they must focus on detecting pedestrians. This includes a preliminary analysis of pedestrian- bus accident claims data for the Port Authority of Pittsburgh, interviews with bus drivers, and an evaluation of what a driver can actually see. Past research, as well as experience with a collision warning system developed for long-haul trucks and installed on a bus, provides some partial solutions to these problems. A review of relevant literature and an evaluation of existing systems are presented. Based on the results of this preliminary research, a plan for developing a performance specification for a side collision warning systems for buses is presented.

INTRODUCTION

The design of collision warning systems recognizes the relative speed, orientation, and distance between the instrumented vehicle and nearby objects, and the influence of environmental factors, such as weather, lighting, and roadway conditions. However, research and development efforts to date have focused on light vehicles and long-haul trucks ignoring the particular needs of transit, such as the requirement to operate in restricted spaces and the presence of pedestrians. Existing side collision warning systems are typically unable to resolve smaller objects that are common in the transit buses' operational domain, such as pedestrians, bicycles, and baby carriages. Furthermore, existing systems require multiple sensors for adequate coverage of the side of a 40ft transit bus.

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) is addressing these issues. The goal of this work is to investigate, develop, and test performance specifications for a side collision warning system that can reliably detect these smaller objects using, preferably, a single sensor per side of the bus.

A preliminary review of publicly available data and informal interviews of bus drivers suggests that pedestrians present a significant problem. For example, a study in Washington State (1) found that 127 out of 11,160 pedestrian collisions in the five-year period 1990-1995 were bus related. While this only represents 1.1% of pedestrian collisions, it is significant, as nationally only 0.26 % of vehicle miles of travel are by bus (2). Furthermore, an even larger proportion (3.1%) of the bus related pedestrian collisions resulting in fatalities is reported in the Washington State study (1) suggesting that the bus pedestrian accidents may be more severe. The high cost of accidents, the importance of safety in the public perception of transportation alternatives, and recent advances in sensors, automated and intelligent vehicles, vehicle control and driver interfaces mean that there is an opportunity to address this problem. This paper reviews past efforts at safety related transit improvements, and related studies for light vehicles and long-haul trucks. The paper also evaluates experiences on Port Authority buses in Pittsburgh in terms of observing pedestrian incidents and experiences with an existing sensor for side collision warning. Finally the paper summarizes opportunities related to improving side collision warning systems and describes a plan for future research.

THE PROBLEM: BUS PEDESTRIAN CRASHES

What we know About Bus Pedestrian Crashes

The Washington State study found that bus pedestrian incidents had some common themes (1):

– Bus collisions are highest during morning and evening rush hours.

– They are predominantly on city streets.

– Most pedestrians are in the roadway when struck; small percentages are on the sidewalk or shoulder.

– In the most common case, there was no violation by the pedestrian; second most common was inattention; third was alcohol.

– In the most common case, there was no violation by the driver; inattention and fail to yield were also significant contributing circumstances.

– Distribution of crashes by bus driver age peaks in 35-44 and 45-54 decades, which may indicate that inexperience is not the major factor.

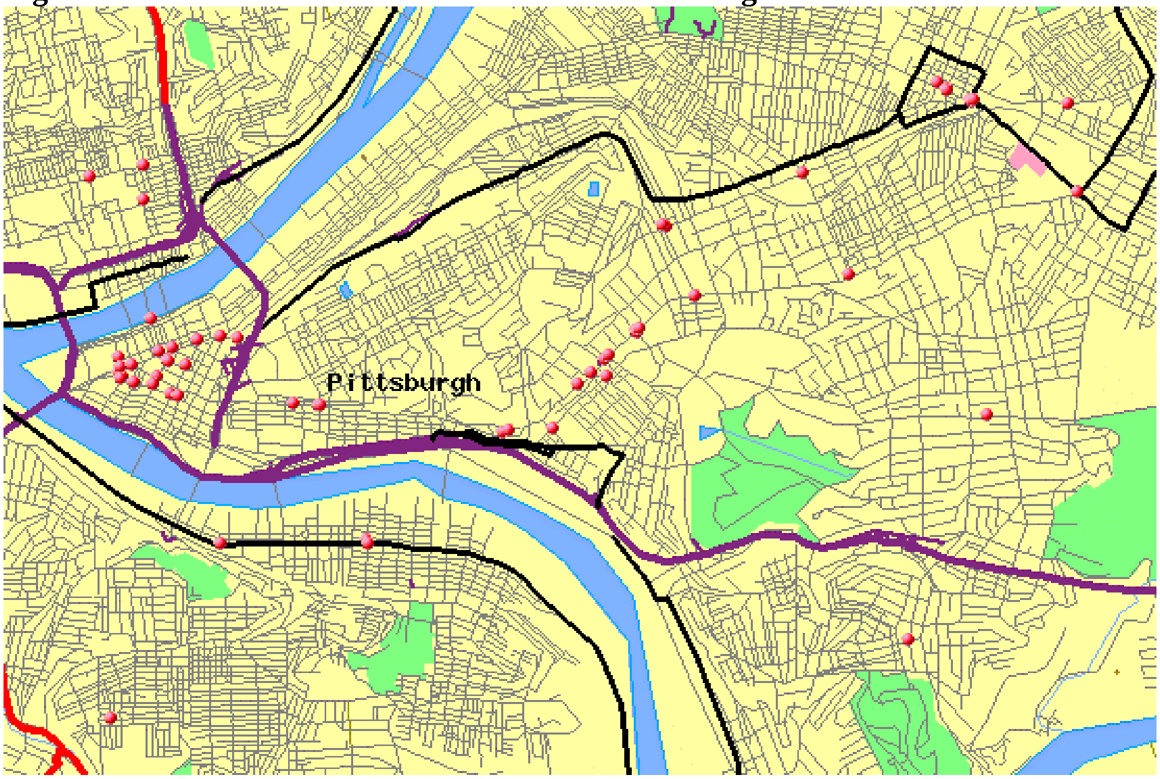
Interviews with PAT drivers also tell us something about the nature of crashes involving buses. The theme in these conversations is a major concern with preventing pedestrian accidents. Although there are relatively few pedestrian accidents, they are the most likely to cause serious injury. They are also among the hardest to prevent. Bus drivers do not trust the common sense of pedestrians – the anecdotal evidence is full of people walking in front of busses, even people walking into the side of a bus, knocking themselves down, and being run over by the rear wheels. Pedestrians are significantly harder to see than vehicles since they are smaller, move unpredictably, and can be found in areas close to the bus where the driver has limited visibility. Such areas include the front of the bus in the area blocked from view by the electronic fare box, and the area immediately behind the front passenger door. Beyond pedestrians, there is concern with bicycles (including fast riders going around the bus on the curbside). There is some concern with hitting fixed objects, but the general feeling is that those accidents are most likely due to driver inexperience. There is more need for sensors along the front half of the side of the bus, short-range sensors looking forward, and perhaps sensors watching the ground in front of the rear wheels; and less need for sensors at the rear corners.

To enable us to go beyond the anecdotal evidence, PAT has provided us with their database of liability claims. This database includes comprehensive data for claims and crashes since 1997. For the period January 1997 to May 1999 the database includes over four thousand records. In 1999, PAT added a field "Nature of Accident" to their claim record. Claims categorized as "Bus & Pedestrian" in this field were extracted. A total of 141 records were extracted representing 90 unique incidents. These incidents are largely clustered in Downtown Pittsburgh and Oakland (an area with universities and hospitals and heavy pedestrian traffic) as shown in Figure 1. Recognizing that the downtown area is less than one square kilometer, the concentration of approximately 19 incidents in a 29-month period in this area suggests that the center-city is an area of particular concentration for pedestrian incidents.

What we are Investigating

Our current understanding is that pedestrian strikes are the most worrisome bus related incidents, both because of the serious consequences, and because people move

Figure 1. Pedestrian Bus Related Incidents in Pittsburgh



unpredictably and are therefore harder to track. Drivers voice pedestrian related concerns during interviews that fall into one of two categories:

– Interactions with the bus when the bus is just starting to move after having stopped. When the bus is moving at speed, the driver can see pedestrians as he or she approaches, and they are unlikely to move fast enough to get into the bus blind spots before the bus clears the area. When the bus is stopped, pedestrians can more easily move into blind spots, and are less likely to be concerned about the bus moving.

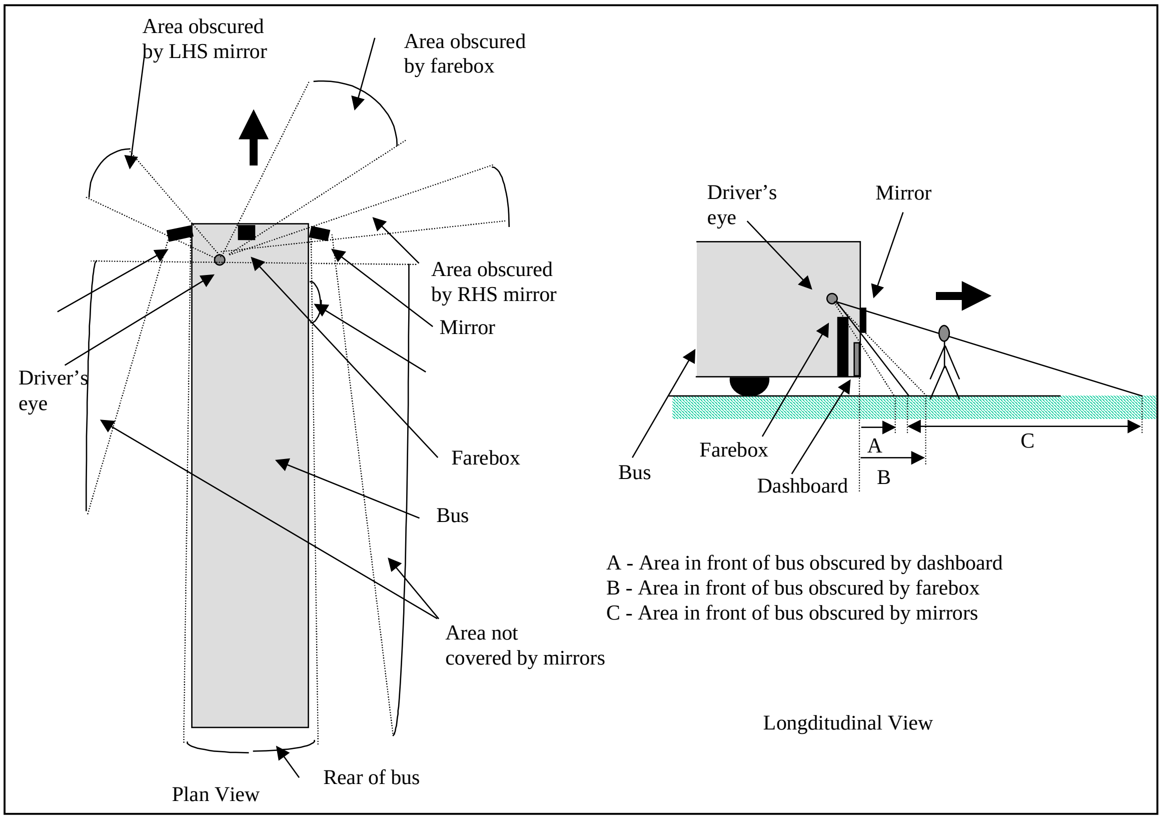
– Moving objects (people) when the bus is stationary. This is significant, because moving object detection from a static platform is a much easier problem than generic person detection.

To better understand these issues we identified what the driver sees. Based on these results, the literature review and past experiences we then identified opportunities for address this problem.

Blind Spots

Buses have quite limited visibility along the right side, and areas of limited visibility in front where the driver's view is obscured by mirrors, the farebox and a high dashboard. Unfortunately, these areas of limited visibility correspond to the locations where pedestrians are likely to be. Using approximate techniques based on sight lines, areas of limited visibility around a bus were identified. Figure 2 is a schematic showing the "blind spots around the bus". The left side of the figure is a plan view showing areas obscured by the mirrors and farebox and the areas behind the driver not covered by the mirrors. A person standing or moving in any of the areas defined by straight lines and arcs will not

Figure 2. Blind Spots Around a Bus



be seen by the driver unless the driver moves his or her head, or the person moves part of their body out of that zone. In reality, this is a three dimensional problem and the right side of the figure presents a longitudinal view showing areas obscured by the mirrors, farebox and dash of the bus. For example, a person of typical height is often partially visible. However, the farebox or dashboard of the bus can easily obscure a short person. This again reinforces our view that concern for pedestrian safety is paramount, and is a much different problem than lane-change-merge countermeasures.

Opportunities for Warnings

This emphasis on pedestrian accidents corresponds with our initial intuition, but is somewhat different from the emphasis suggested in other studies and discussion. We believe that the operating environment of a transit bus is very different from the environment of a light vehicle or long-haul trucks and that the emphasis of this project should be quite different than the emphasis of the NHTSA lane-change/merge countermeasures program. However, there are also many opportunities to build on past and on-going work.

PARTIAL SOLUTIONS

Related literature

The literature on pedestrian detection, lane-change / merge collision detection, and human factors includes applications to vehicle-vehicle collisions, pedestrian detection, object detection and avoidance, and specific applications related to school buses. This section presents a brief synopsis of the state of the art organized in terms of an overview, sensors and detection, interfaces, and commercially available collision warning systems (CWS).

Overview

Several reports and papers address experience with existing systems or system components. Other reports present results from testing commercial and prototype systems. For example, eleven CWS for lane change, merge and backing were evaluated using operational and performance data. The data were obtained on a controlled test track and on public roads. Performance capabilities varied widely (3).

The foundation of much of the relevant research related to vehicle-vehicle side collisions is the functional (high level) goals (for both vehicles and infrastructure) for eliminating lane change, merge and backing crashes (4). To understand side collisions, they develop a taxonomy for vehicle-vehicle crashes as follows:

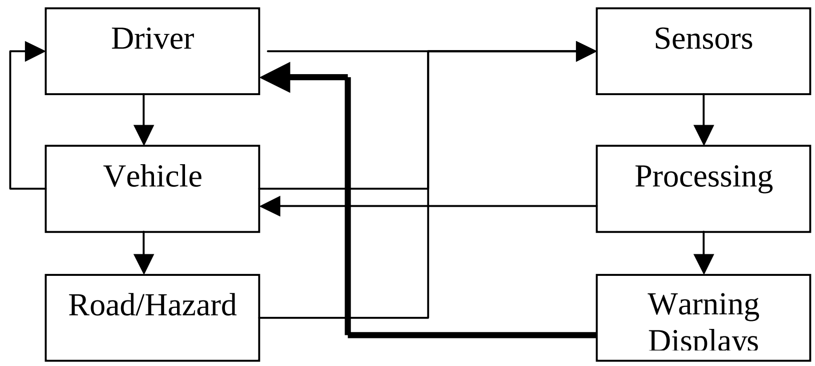
- angle striking
- angle struck
- drifting
- rear-end struck
- leaving a parking place
- both changing lanes
- sideswipe
- rearend striking

They then derived the following functional goals:

- Lane change
  1. To alert the driver to the presence of vehicles in adjacent lanes prior to initiation of lane change maneuvers
  2. To alert the driver of drifting vehicle motion.
  3. To alert the driver to the presence of rapidly approaching vehicle in adjacent lanes.
  4. To alert the drive to the presence and movement of vehicle two lanes over.
- Merge
  1. To heighten the awareness of drivers as they approach a merge
  2. To provide situational awareness during merging

These functional goals have been translated into preliminary performance specifications (5). These specifications build on the concept of a CWS as shown in Figure 3, and address the goals identified above as shown in Table 1. The concepts used are relevant to this problem since buses also change lanes and merge, but need to be expanded to reflect the importance of bus pedestrian crashes. For example, transit operators concerns center around: 1) buses leaving the bus zone, 2) bus entering the bus zone, 3) buses making a left turn - pedestrian in crosswalk, 4) buses making a right turn - pedestrian stepping off the curb after the bus has entered the crosswalk and started to turn, 5) uses making a right turn when the signal turns green and a pedestrian is in the crosswalk, 6) pedestrian running after a bus as it leaves the bus zone, 7) bicyclist in the bike lane.

Figure 3. Collision Warning Systems Concepts
Modified from (4)



Sensors and Detection

Pedestrian detection has been the focus of several studies. While few studies have addressed the side collision problem, they provide some insights on the variety of relevant technology:

- The City of Portland tried three different kinds of sensors for monitoring pedestrians in crosswalks. They had limited success with sonar, mostly due to their mounting angles. They preferred infrared for narrow-beam short-range detection and microwave Doppler radar for longer range detections, and engineered a system that gave nearly 100% coverage (6).
- The Society of Automotive Engineers (SAE), with sponsorship from NHTSA, used Doppler radar to detect children around school buses. Because the technology detects movement, it only works with a stopped bus and a moving child. Two different systems were tested; both included forward and sideways looking components. The results are regarded as generally encouraging (7).
- Sonar was used to detect walking people by looking for rhythmic patterns of the frequency expected in typical gaits (8).
- The Nissan Advanced Safety Vehicle includes an infrared camera to detect pedestrians in front of the vehicle. If a hot spot is detected, one of several LEDs on the dash lights up, drawing the driver's attention to the right direction (9).
- A detailed description of how thermal sensors work is presented (10) in a review of the physics of sensors. The most interesting discussion is that most sensors are better at detecting changes in temperature, rather than absolute temperature, so detecting moving objects is easier than detecting stationary bodies.
- A NHTSA study focuses on radar and lidar as technologies, as well as determining the state of the art in digital signal processing, for lane change, merging and backing. This study uses the preliminary performance specifications from other tasks of the NHTSA study as a benchmark (11).
- Carnegie Mellon researchers are developing a stereo based pedestrian detection device that uses neural networks to process the data (12).
- Cadillac is using an infrared imaging system for night vision enhancement. The system identifies pedestrians and displays an enhanced image on a heads-up display (http://archive.abcnews.go.com/sections/tech/CarTech/cartech980902.html.)

Table 1. Performance Criteria for CAS
Modified from (5)

Collision Types	Functional Goal	System	Performance Criteria
Lane change	To alert the driver to the presence of vehicles in adjacent lanes prior to initiation of lane change maneuvers	Minimal System	• Function • Coverage • Target • Platform • Accuracy/Reliability • Interference • Duty Cycle • Driver Interface
	To alert the driver of drifting vehicle motion.	Lane Keeping	• Function • Measurement range • Accuracy • Vehicle velocity • Interface • Duty Cycle
	To alert the driver to the presence of rapidly approaching vehicle in adjacent lanes.	Counter-Fast Approach	• Coverage • Function • Relative Velocity • Number of Targets • Measurement Accuracy
	To alert the drive to the presence and movement of vehicle two lanes over.	Counter Convergence/ Situational Awareness	• Coverage • Function • Measurement Accuracy • Concept • Duty Cycle
Merge	To heighten the awareness of drivers as they approach a merge	Driver Advisory/ Warning	• Function • Concept of Operation • Vehicle Interface
	To provide situational awareness during merging	Merging Aid	• Coverage

Interfaces

The literature on interfaces includes discussion of concepts and configurations, and presentation of results from experiments to evaluate different devices. For example, Campbell *et al.* (13) identified and evaluated driver vehicle interface designs for side object detection systems using static mock-ups and displays in a driving simulator.

Variables included format, location, and symbols. The study concluded that three types of information are valuable:

- status indication at vehicle start-up,
- caution alert under “no intent to turn’ situations, and
- hazard alert under “intent to turn” situations (including directional information.)

Some basic common sense points are worth noting as follows:

- color of indicator alone is not sufficient, because there may be color blind drivers;
- brightness of indicators needs to vary from high (in direct sunlight) to more subdued (at night); and
- hold time and response time are critical parameters, and depend both on the sensor and on driver behavior (14).

Similarly experiments for rear end collisions were used to develop some general principles including the value of the concept of a two-stage alert; alternative sizes, shapes, and colors of icons; and sound specifications (15). More specifically, a NHTSA study puts different visible and audible interfaces on two different vehicles, and drove them in a variety of traffic conditions. Specific recommendations for how much the driver should be able to adjust loudness, how bright LEDs should be, etc. are included in the paper (16). In another study, driver interfaces for side looking collision-warning systems, rear looking collision-warning systems and systems that enhance the driver’s ability to see objects in the rear of the vehicle were assessed. The assessment was used to develop a preliminary set of driver interface performance specifications (17).

Of a more general nature is a summary of human factors research to date and human factors research needs related to lane-change and merge collision avoidance, including obstacle and pedestrian detection presented in (18).

Commercially Available Side Collision Warning Systems.

A summary of vendor-supplied information about their most current warning systems as of November 1998 is provided in (19). The data was collected specifically for application to transit buses. ITS America data and Internet searches were used to identify vendors who were then asked to respond to a questionnaire that documented:

- the operation of the system,
- the applicability of the system to transit,
- the sensing technology used,
- previous experience with using the technology for side collision warning, and
- lead-time and warranty information.

Table 2 provides a summary of the responses.

Demonstration Systems

Over the past three years demonstrations of sensors, systems, controls, and driver interfaces related to side collision warning systems have been undertaken.

Demo 97

Demo 97 was held in San Diego in August 1997 under the sponsorship of the National Automated Highway System Consortium (20). Carnegie Mellon and Houston Metro demonstrated a multi-platform free agent in a scenario including two sedans, a minivan,

Table 2. Commercially Available Side Collision Warning Systems Modified from (19).

	Alirt™	Ameriguard ™	BlindSight™	BlindSpot ™	EchoVision™	SCAN™	SideMinder™
Sensor Type	Infrared	Radar	Sonar	Sonar	Sonar	Sonar	Infrared
Sensors Per Side	2-3	2	10	5	4	4	N/A
Mounting Height (in)	30	36	40	24-42	50	42	N/A
Connection Method	TBD	Daisy Chained	Daisy Chained	Direct	Direct	Daisy Chained	N/A
Temperature	-40°-85° C	-40°-85° C	-40°-85° C	-20°-44° C	?	-40°-85° C	-40°-85° C
Installed Sensor Base	~200	<100	>2000	~2500	~10,000	>250	N/A
Modifications	Yes	Yes	Yes	Yes	Yes		
Lead Time (weeks)	8-12	12-16	None	None	2-4	8	N/A
Warranty (yr)	3	1	1	2	1	2	N/A

and two New Flyer buses (21, 22). The scenario requires no infrastructure modification and works on existing roadways and facilitates evolutionary deployment. All computing and sensing was located onboard the vehicles. The demonstration took place on the high occupancy vehicle lanes (HOV) of I-15. On the HOV lane, the bus driver demonstrated lane departure warning to show driver assist features. The driver then engaged auto control on the fly, and the bus automatically participated in maneuvers involving the other bus and other vehicles. The bus changed lanes to avoid obstacles (construction zone) based on prior knowledge and then demonstrated automatically maintaining constant headway. Based on information obtained from the car in front the bus changed lanes again. This time the lane change is to avoid another obstacle (debris on the road). At the end of the demonstration the bus braked under automated control to come to a complete stop as the end of the AHS was reached.

In Demo 97, the bus demonstrated fully automated driving including:

- Lane departure warning
- Lane keeping
- Headway keeping
- Lane changing
- Constant speed control
- Obstacle avoidance
  - lane changing
  - stopping

This was accomplished using a forward camera, and forward and side radar. All processing was accomplished using a single Pentium™ Pro PC. Actuators were used for steering, throttle and the brake. The driver interface was a simple on-off button.

"Demo 98"

In August, 1998 Pennsylvania Department of Transportation sponsored "Demo 98" at State College. Carnegie Mellon University demonstrated a side collision warning system fitted to a Port Authority Transit (PAT) bus. The bus has four sensors installed along the right side of the bus. The commercial sonar sensors manufactured by EchoVision™ were selected on the basis of availability and coverage. The sensors were activated when the four-way hazard lights were on, or the right-turn indicator was on. If an object was identified in the "field of view" of any one of the sensors, an audible warning signal was generated. A rear-looking system was also installed on the bus.

Demo 99

Demo 99 was held in East Liberty, Ohio in July 1999 under the sponsorship of ITS America, IT Ohio, and the Transport Research Center. Several collision-warning systems were shown for commercial trucks, demonstrating that the technologies have advanced past the purely experimental stage. Some sensors have been proven to work on snowploughs in severe weather conditions, showing that sensors are available which work under condition worse than what a normal transit bus will ever encounter. The demonstrations all involved trucks, snowplows, cars, and vans, but no buses. This emphasizes the need for research specifically focused on buses.

Evaluation of the System Used In "Demo 98"

The research team used driver comments sheets, informal interviews and a "test ride" to obtain informal feedback on the system used in Demo 98.

Driver Comments

While only four evaluation sheets were received because of the limited opportunity for drivers to use the bus, these comments were insightful and sent a clear message. The questionnaires asked the drivers:

- to identify when and where they drove the bus, and the weather conditions,
- to provide comments and
- to answer the following question "During your run, did you encounter anything about the system's operation that you did not understand or that you would like to see changed which would make your driving task easier or more comfortable."

The responses are summarized in Table 3.

The biggest concern was that the system, as configured, was too sensitive, and the buzzer went off too frequently and too loudly. A second concern was that the sensors as configured only covered the right side of the bus, and left the left side uncovered. (These responses give an inconsistent impression, that the drivers didn't completely like the system, but still wanted it on both sides of the vehicle). It is clear that the drivers have to be helped by the system rather than annoyed, so the system sensitivity and driver interface are crucial.

The informal driver interviews, described earlier, also stressed the importance of the driver interface.

Table 3. Bus Driver Responses to Side Collision Warning System

Date	Comments	Issues
9-21-98	None	Buzzer goes off too often, it is irritating to driver. I feel buzzer is not needed because driver is always looking to right and all around at all times anyway.
9-23-98	None	Warning system is only partially effective. With RTS on all 4 ways on, system signals are too sensitive. It signals at poles, fire plugs, even stop signs. Alert sounds after you have passed a person. Drive becomes insensitive after a short time because warning signs sounds much too often and defeats its own purpose. System in my opinion isn't worth the time it takes for installation. Passengers are annoyed at the constant sound of the warning signal going off.
10-9-98	Only when the four ways are on the buzzer alarms. Need to alarm when four ways are off also. People attend to go along side of bus as they get off. Left turn signal does not trigger alarm.	The buzzer is too loud.
10-22-98	Would like to have driver side (left) sensors. We do have a bad blind spot. It could help when making left turn, especially when another vehicle gets too close to left rear blind spot.	Sensors on right and left.

Riding the bus

The research team also did a "test ride" of the bus with the sensors and warning system operational. The bus was driven, out of service, on a loop down Pittsburgh's east busway, down Fifth Avenue, through the downtown lunch-hour congestion, up the counter-flow bus lane on Fifth Avenue in Oakland, and back to the East Liberty Garage.

The main conclusion is that the driver interface needs to be fixed, desperately. The system installed on the demo bus was designed for long-haul trucks. As a result, the range of sensitivity of the side-looking sensors was set to be large, to cover most of an adjacent lane. In bus operations, the side-looking sensors are continually picking up parked cars, phone poles, and other roadside obstructions, so the visual obstacle indicator is often illuminated. Worse, the sensor system assumes that when the turn signals are activated, the truck driver is intending to change lanes; and if anything is picked up by the sensors at that point, the driver must be alerted quickly to avoid an accident.

Therefore, the audible alert is enabled. In the bus scenario, for the 98 Demo installation, the audible alert was enabled by either the turn signals or the four-way flashers. When the vehicle was sitting at a red light, waiting to turn, if there was an object near the bus the audible alert was constantly on. More critically, every time the bus prepares to stop to pick up or discharge passengers, the driver engages the 4-way flashers, which then enables the audible alarm. Just when the driver is pulling over to the edge of the road to pick up passengers, the sensors find objects (the waiting passengers) within their range, and the audible alert goes off. This is at best annoying; at worst, it distracts the driver from more important tasks, and rapidly desensitizes the driver to the alarm so that true emergencies no longer attract attention.

PLAN FORWARD

Characterize the Operating Environment

To date, our research has supported our hypothesis that side collision warning systems for transit buses must be able to detect pedestrians. To design and develop an appropriate systems we need to better understand the operating environment. This includes pedestrian behavior, the constraints placed on the driver (for example, field of view, and ability to respond to situations), and the extent and severity of the problem. We are doing this through videotaping of bus and pedestrian movements, review and analysis of PAT accident reports involving buses and pedestrians, additional driver interviews, and bus related accident data from other sources.

Ongoing PAT Field Test

Collision Avoidance Systems Inc. (CAS) is installing commercial sensors, BlindSight™, initially on 10 buses and eventually on a fleet for PAT. CAS has already taken into account several of the limitations of the “Demo 98” system: they use more sensors, so they have a tighter control over the range; and their audible alert is triggered by turn signals but not by the 4-way flashers. This study will add to the base of experience on side collision warning systems.

Sensor Development

Our research, so far, has shown that there are two main requirements on sensors. First, they have to be able to distinguish pedestrians from other objects. Second, they need to be able to determine the distance and movement of the pedestrians with respect to the bus accurately to be able to discriminate dangerous situations from normal ones. At the high-cost end of the spectrum of sensors are infrared cameras, which can distinguish people from other objects by their heat radiation while at the same time providing a picture from which distances and movements can be determined. Laser range finders are very accurate in determining distances, but it is much more problematic to distinguish between people and other objects. In the medium range are video cameras, which are similar to the infrared cameras but provide much less contrast and might be problematic at night. The usefulness of video cameras can be greatly enhanced if one makes use of stereo cameras (12). At the low-cost end of the spectrum are motion detectors of the kind that can be found in everyday light switches. We are now in the process of developing a practical way to use each of those sensors on the bus and test if they are able to perform as a useful sensor in a collision warning system.

CONCLUSION

Given our new focus on pedestrian accidents, important design decisions have to be made including:

- What area to cover? Could include one or more of:
  - Within the mirror coverage, serving as a reminder to the driver
  - Below / inside mirror coverage in proximal blind spots
  - For either of the above, base coverage on planar mirror or convex mirror
  - Area along side of entire bus out to a fixed distance (say, 2 feet)
  - Area in front of bus, especially below dash height and blind spots from mirror and farebox
- When to sound an audio alert, if there is a target in the area? Could include:
  - When doors are just closed after a stop
  - When an object is really close to the bus
  - When an object is close in front and the bus is starting to move
  - Never
- When to light the visible alert? When objects are within the Field of View and:
  - Bus stopped
  - Bus coming to a stop
  - Bus just starting after a stop
  - Any time
- Phenomenon to detect:
  - Anything close
  - Anything moving
  - Only people

Based on our research to date and past studies (4,5) some general performance goals are defined to include:

- Functional goals for the collision warning system being tested.
- Sensor requirements
- Electronic processor requirements
- Alternatives within pertinent technologies (different types of radar, for example)
- Permissible electromagnetic frequencies
- Electromagnetic compatibility with in vehicle and external systems.
- Maintenance requirements including durability, and vandalism-proof,
- False alarm causes and probability
- Tradeoff between collision warning systems effectiveness and false alarm probability.
- How to best warn driver of the impending collision, elicit his/her needed attention, and instruct him/her about proper action(s).
- Compatibility and priority order of the warnings and instructions if more than one countermeasure system or information sources are activated simultaneously.
- Vehicle type
- Costs
- Technical feasibility and reliability.
- Fail-safe operation.
- Implementation practicability.

Preliminary analysis of available data and driver interviews has placed additional emphasis on pedestrians. We have focused on warning drivers, rather than pedestrians or modifying the infrastructure at high incident locations. These approaches may be valuable, but were outside the scope of our work. As the project proceeds we will use an interative process to develop and evaluation performance specifications including:

- Analysis of available crash data
- Modification of functional goals
- Assessment of existing systems
- Development of preliminary performance specifications
- Investigation of state-of-the-art technology
- Construction/acquisition of collision warning systems
- Testing to validate performance specifications
- Revision of performance specifications

The end result will not only be the performance specifications but cost benefit analyses and a series of "lessons learned."

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