SIDE COLLISION WARNING SYSTEMS FOR TRANSIT BUSES:

FUNCTIONAL GOALS

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ABSTRACT

A collaborative effort involving Carnegie Mellon University, the Port Authority Transit of Allegheny County, the Pennsylvania Department of Transportation, and the Federal Transit Administration is designing side collision warning systems for transit buses. The development of functional goals or changes to the situation that would help to eliminate or significantly reduce these types of incidents is a critical step in the development of the functional specifications for side collision warning systems for buses. This paper describes the "functional goals" that are based on an analysis of the circumstances and factors that precede and contribute to transit bus incidents. Based on a qualitative assessment of the effectiveness of a side collision warning system and an analysis of the type of incidents addressed by such a system, over 40% of Port Authority Transit incidents **may** positively impacted by a side collision warning system on transit buses.

INTRODUCTION

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) (www.fta.dot/research/safe/ivi/ivi/htm, www.its.dot/ivi/ivi.htm). 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 (4).

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 designing (SCWS) collision warning systems for transit buses. The design process builds on past research and development efforts focusing on light vehicles and long-haul trucks and the characteristics of incidents involving transit buses.

The goal of this work is to investigate, develop, and test performance specifications for a side collision warning system for transit buses that can reliably detect pedestrians, and bicycles as well as vehicles. The development of functional goals or changes to the situation that would help to eliminate or significantly reduce these types of incidents is a critical step in the development of the functional specifications for side collision warning systems for buses.

This paper describes the "functional goals" that are based on an analysis of the circumstances and factors that precede and contribute to transit bus incidents. The paper also presents a preliminary set of performance criteria for each of the functional goals.

BACKGROUND

In our analysis of incidents involving transit buses, interviews with drivers and observations (5,6), we have found that side collision incidents are fundamentally different from vehicle-vehicle collision of the type considered by Young et al, (7) and from the incidents involving class 8 trucks (8). 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 (5):

- 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 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.

Past studies have focused on lane changes and merges and have identified the following functional goals (7):

- 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

In our analysis of incidents we have found that few incidents mapped onto Young's functional goals. Specifically, 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" (5) 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 determine the functional goals we developed:

A) A taxonomy of collision subsets and collision related events that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash.

B) The application of the taxonomy to determine a set of potential functional goals, i.e., descriptions of system actions that are deemed necessary to avoid or mitigate a collision that would otherwise occur.

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, functional requirements are system specific specifications that reflect the balance between the ideal and the technologically achievable. An example of a functional requirement is the elimination of blind spot.

The functional goals are intended to allow consideration of changes to vehicles. These functional goals describe in this report are to guide the subsequent efforts for achieving the objectives of this project including developing functional requirements.

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 unpredictable manner and are much more likely to get injured in a collision than drivers of vehicles. The line between safe and dangerous situations is very narrow and a Collision Warning System (CWS) could be rendered useless by giving off too many false alarms. 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:

1. Detect objects underneath the bus (at least in front of the tires).
2. Full 360-degree coverage around the bus at very short distances, especially in front and to the right side.
3. Side and rear coverage for lane change maneuvers.
4. High resolution - approximately 1 inch at 6 feet for curb detection.
5. Distinguish cars from pedestrians.
6. Spot rapidly approaching vehicles at longer distances.
7. Estimate velocity of vehicles and pedestrians.
8. The sensor system should not be too expensive, preferably less $5,000 (9).
9. Few sensors.
10. Reliable, easy to maintain, and easy to use.

Two further things have been found to be likely to reduce incidents and should be combined with a CWS:

1. Recording of the sensor data to reduce fraudulent claims and vandalism and to help the collision investigation.
2. Warnings/announcements to passengers and pedestrians.

DEVELOPING FUNCTIONAL GOALS

Functional goals may be developed around the type of accident that the goal is addressing, or the intended response. The type of incident is classified by objects making contact (bus, vehicle, pedestrian, cyclist, or fixed object) and the nature of the action (for example, lane change, merge or clearance). Alternatively, the intended response to information is classified by the party involved (the driver, the pedestrian, or the other vehicle) and the possible system actions defined as follows:

1 – Aware: Baseline Situational Awareness. The transit operator and pedestrian see strictly non-enhanced system outputs be it bumper stickers, running lights, video, or the lack of any active alerts, warnings, evasions, or notifications.

2 – Alert: Potential Obstacles. Alerts are non-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.

3 – Warn: High Likelihood of Collision. Warnings are semi-intrusive and intrusive information of varying intensity depending on the severity of the situation. Examples include a voice or melodic sound indicating, or vibrating the seat, brakes or steering wheel, or a loud buzzer.

4 – Evade: Imminent Collision. Evasive actions include intrusive interference such as controlling the steering, or applying the brakes.

5 – Notify: Collision has occurred. Notification involves informing the transit operator through an intrusive light or voice that a collision has occurred.

Table 1 shows some examples of the interactions between the collision warning systems and the driver, and the collision warning system and the pedestrian or other vehicle.

Examples of different classifications are as follows:
Type of incident

- Bus - pedestrian
  - Pedestrian approaching bus
  - Pedestrian in path of bus
  - Pedestrian under bus
- Vehicle - bus
  - Clearance
  - Lane change
  - Merge
- Vehicle - fixed object

Intended response

- Driver
  - Alert
  - Awareness
  - Warning
  - Notification
- Other vehicle
  - Alert
  - Awareness
  - Warning
  - Notification
- Pedestrian
  - Alert
  - Awareness
  - Warning
  - Notification

We propose to use a taxonomy based on the type of object and the intended response.

PROPOSED FUNCTIONAL GOALS

Our functional goals are classified using

- the type of object (pedestrian, other vehicle or fixed object) involved in the crash,
- the intended system action (situation awareness, alert, warning, or notification of an event),
- the intended audience of the system action (the driver, or the pedestrian), and
- the current status of the bus (stopped, turning).

The functional goals are summarized below.

Pedestrian

1. To provide situation awareness, alerts and warnings to the driver for pedestrians in the path of bus.
2. To provide situation awareness to the driver of stopped bus, prior to starting motion for pedestrians.
3. To provide alerts and warnings to the driver for pedestrians in blind spots.
4. To provide alerts and warnings to the driver of turning bus for pedestrians in cross walk ahead of turning bus.
5. To provide warnings to the driver for pedestrians under bus
6. To notify the driver and record data for pedestrian related events
7. To provide alerts and warnings to pedestrians in danger

Vehicle

1. To provide situation awareness, alerts and warnings to the driver for inadequate clearance for oncoming vehicles
2. To provide situation awareness, alerts and warnings to the driver for sideswiping parked car
3. To provide situation awareness, alerts and warnings to the driver for lane change/ merge
4. To notify the driver and record data for vehicle relate incidents

Cyclist

1. To provide warnings to the driver for cyclists going past bus[2]

Fixed object

1. To provide situation awareness to the driver for fixed objects in the vicinity of the bus.
2. To provide alerts and warnings to the driver for fixed objects in blind spots.

A qualitative assessment based on the expert judgment of the research team suggests that a significant proportion of the bus collisions would indeed be reduced or eliminated if these functional goals are implemented. Using the PAT database of claims and sampled records to provide more detailed incident report data, we identified the proportion of incidents related to each of the functional goals and then the proportion of these incidents that **may** be impacted by the use of 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 impact if the bus had a SCWS. This assessment using the PAT data is summarized in Table 2. Overall, around 43% of all incidents **may** be positively impacted by the use of a SCWS. This assessment should be considered to be an upper bound on the effectiveness of side

[2] This functional goal covers the case where the cyclist behaves differently than vehicles or pedestrian and the situation would not be addressed by other goals.

collision warning systems for transit buses, although we have not included the value of notification and recording of incidents in reducing fraudulent claims.

FUNCTIONAL GOALS, SENSOR SYSTEMS AND PERFORMANCE CRITERIA

To begin to translate the functional goals into a performance specification, we identify the required sensor systems and then appropriate performance criteria. The functional goals identified are applicable to specific sensor systems, although several sensor systems are used to meet different goals. These sensor systems represent the hardware, software and procedures required to accomplish the functional goals. There are ten possible systems:

- General 3-D object detection
- Person detection (and person motion prediction)
- Bus motion prediction
- Prediction of onset of bus motion from a stop
- Curb detection
- Oncoming and overtaking vehicle 3-D measurement
- Object detection along side of bus
- Cross-walk detection or mapping
- Specific sensing for objects under the bus
- Contact detection for notification

For each of the functional goals and sensor systems, performance criteria are also defined to address performance issues such as reliability, when the system should or should not be actuated, limits of operation, and required interfaces. The performance criteria will be refined by system type as the project progresses. Some general characteristics apply across the board, for example, false alarm rate, and operation in all types of weather. Accuracy requirements and range requirements can probably be set per system, and do not have to be different for the same system on different functions.

Table 3 shows the relationships among the functional goals, proposed sensor systems and preliminary performance criteria. The performance criteria are not part of functional goals, but are the first step in laying out the functional requirements. These systems could also offer an opportunity to record and archive data that is of value in investigating hit-run and fraudulent claims. This function builds on the proposed hardware and software and should be included as system requirements.

The performance requirements and the parameters related to the criteria described in Table 3 will be further refined as the functional requirements are developed. As the definition of functional requirements suggest, this stage of the research reflects the balance between the desirable, and the technically and economically feasible.

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Table 1: Examples of Responses to Different Levels of Interaction

Safety Level	Side Collision Warning System Operating Status	Transit Bus Driver Perception	Other Vehicle / Pedestrian Perception
1	Aware	System on light and baseline video	Passive bumper stickers and warning / running lights
2	Alert	Status lights, enhanced video	Active voice warning pedestrians of starting vehicle
3	Warn	Audio warning about specific area of collision, seat vibration, buzzer	Active Buzzer
4	Evade	Computer control of steering, brakes	Not Applicable
5	Notify	Audio message and/or light indicating incident has occurred and data has been saved	Not Applicable

Table 2. Qualitative Assessment of Impacts of Functional Goals Based on Analysis of PAT Data

Object Involved in Collision with Bus	Population [3]	Sample Source	Functional Goal	Sample Distribution	Potential Impact
Pedestrian	7.2%	70 unique records recorded as "Bus & Pedestrian" extracted from the PAT claim database for the period January 1997 to May 1999.	pedestrians in the path of bus	21.4%	80%
			stopped bus, prior to starting motion for pedestrians	17.1%	92%
			pedestrians in blind spots	15.7%	91%
			pedestrians in cross walk ahead of turning bus.	10.0%	100%
			pedestrians under bus	NA	NA
			pedestrian related events	NA	NA
			pedestrians in danger	NA	NA
Vehicle	90.2%	93 unique records representing a 30% sample of incidents in the period January 1, 1999 to May 6, 1999 recorded as "Bus & Vehicle"	inadequate clearance for oncoming vehicles	6.5%	50%
			sideswiping parked car	9.7%	89%
			lane change/ merge	47.3%	68%
			vehicle relate incidents	NA	NA
Cyclist	0.7%	7 unique records recorded as "Bus & Pedestrian" extracted from the PAT claim database for the period January 1997 to May 1999 and identified as involving a cyclist	cyclists going past bus	100%	29%
Fixed Object	1.9%	Detailed data not available. Distributions and impacts based on judgment.	fixed objects in the vicinity of the bus	33%	50%
			fixed objects in blind spots	33%	50%

[3] PAT Claims – January 1997- May 1999

Table 3: Functional Goals, Proposed Systems and Performance Criteria.

Collision Type	Functional Goal	System	Performance Criterion
Pedestrian	Situation awareness, alert, and warning **to driver** for pedestrians in path of bus	Person detection	Reliability of object detection, Reliability of person discrimination, Range, Driver interface, Reliability in weather and lighting conditions
	Specific: Situation awareness to driver of stopped bus, prior to start motion	Person detection, future bus motion indication	All the above, plus signal of impending motion (door closure?)
	Specific: Alert and warning for pedestrians in blind spots	Person detection, bus path prediction, curb detection	All of the above, plus bus motion prediction, increased range requirement
	Specific: Alert and warning for pedestrians in cross-walk ahead of turning bus	Person detection, turning bus path prediction, pedestrian path prediction	All of the above, with bus motion prediction is sharp turns, (possibly) cross-walk detection or mapping
	Warning for pedestrian under bus	Object detection under bus	Reliability, false alarm rate
	Notify and record all pedestrian collisions	Contact detection or driver activation	Contact detection reliability, recording time & interface
	Alert and warning **to pedestrian** of danger	Person detection, bus path prediction, future bus motion indication	Reliability of object detection, Reliability of person discrimination, Range, **Pedestrian** interface, Reliability in weather and lighting conditions
Vehicle	Situation awareness, alert, and warning for inadequate clearance of oncoming traffic	Shape and motion detection in front of the bus	Range, speed tolerated, accuracy
	Situation awareness, alert, and warning for sideswiping parked car	Proximity detection along side of bus	Completeness of coverage, 3-D sensing (not just 2-D) to account for mirrors and overhangs
	Situation awareness, alert, and warning for lane change / merge	Proximity detection along side of bus, shape and motion detection to rear to sense overtaking vehicles	Accuracy, reliability, utility to driver
	Notify and record collisions	Contact detection or driver activation	Contact detection reliability, recording time & interface

Cyclist	Alert to driver of cyclists going past bus	Moving object detection, especially on bus right side	Detection of moving object (faster than pedestrian, smaller than vehicle) Driver interface
	Notify and record all cyclist collisions	Contact detection or driver activation	Contact detection reliability, recording time & interface
Fixed objects	Situation awareness	Small object detection to sides and rear	Size of object detected, types of objects detected, driver interface
	Alert and warning for fixed objects in blind spots and in bus path	Above, plus bus motion prediction	Above
	Notify and record all fixed object collisions	Contact detection or driver activation	Contact detection reliability, recording time & interface