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Final Report

DEVELOP PERFORMANCE SPECIFICATIONS FOR A REAR IMPACT COLLISON WARNING SYSTEM FOR TRANSIT BUSES (RICWS)

November 2003

RICWS

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by the Federal Transit Administration.

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GENERAL DYNAMICS
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Final Report

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November 2003

Prepared for the

U.S. Department of Transportation
Federal Transit Administration

by

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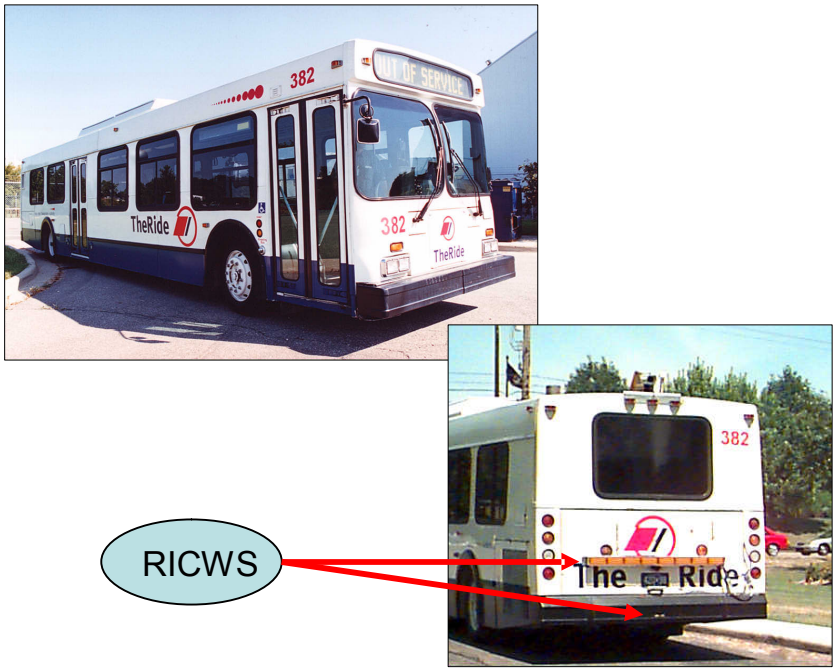

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16. Abstract

The goal of this research is to assist the Federal Transit Administration in facilitating the deployment of systems to mitigate transit bus rear-end collisions. This program specifically focused on active sensor rear impact collision warning systems (RICWS).

Transit bus rear-end crashes are the most frequent occurring type of collision, accounting for approximately 36 percent of all incidents, with an associated average cost of $54,455 per crash. The preponderance of crashes occurred with buses stopped during daylight hours, good weather conditions, traversing a straight path, and the striking vehicle attempting no corrective action.

A testbed RICWS data collection system was designed and built which included a recording system, digital video, a laser front-end sensor, and a light bar warning system to get the following vehicles attention. The RICWS was mounted on two Ann Arbor Transportation Authority buses which collected data from March – October 2003 over the regular bus routes.

Three warning algorithms (CAMP, 0.225 G and 0.3 G threshold) were field tested. All algorithms were effective in causing the following vehicle drivers to modify their driving behavior to a safer manner. As a result of this program, a set of comprehensive RICWS specifications were generated as well as recommended next steps.

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ABSTRACT

The goal of this research is to assist the Federal Transit Administration in facilitating the deployment of systems to mitigate transit bus rear-end collisions. This program specifically focused on active sensor rear impact collision warning systems (RICWS).

Transit bus rear-end crashes are the most frequent occurring type of collision, accounting for approximately 36 percent of all incidents, with an associated average cost of $54,455 per crash. The preponderance of crashes occurred with buses stopped during daylight hours, good weather conditions, traversing a straight path, and the striking vehicle attempting no corrective action.

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Three warning algorithms (CAMP, 0.225 G and 0.3 G threshold) were field tested. All algorithms were effective in causing the following vehicle drivers to modify their driving behavior to a safer manner. As a result of this program, a set of comprehensive RICWS specifications were generated as well as recommended next steps.

SUMMARY OF FINDINGS

The findings are categorized into Transit Bus Accident Profile findings and Rear Impact Collision Warning System (RICWS) performance findings. This encompasses the majority of the relevant findings from this effort.

The following table summarizes the findings for police reported accidents where the rear-end of a bus is struck by another vehicle.

Summary of Rear-end Transit Bus Crash Data

Feature	Most common (%)	Second most common (%)	Third most common or unknown (%)
Number of lanes	Two (41.7%)	More than two (39.1%)	Unknown (18.3%)
Relation to junction	Non-junction (62.7%)	Approach to intersection (22.2%)	Within intersection (8.0%)
Grade	Level (59.6%)	Grade (15.4%)	Unknown (23.6%)
Alignment	Straight (89.1%)	Curve (7.6%)	Unknown (3.3%)
Speed limit	30-45 (55.3%)	50-75 (15.8%)	10-25 (10.5%) Unknown (18.3%)
Following Vehicle speed	<=25 mph (47.3%)	26-40 mph (34.4%) [Largest single 5 mph bin is 31-35 mph, 15.1%)	>40 mph (18.3%)
Lighting	Daylight (85.5%)	Dark but lighted (6.7%)	dawn & dusk (4.0%) Dark & unknown (3.9%)
Weather	Clear (77.3%)	Rain or snow (18.7%)	Unknown (2.2%) Other (1.8%)
Bus motion	Stopped (67.2%)	Slowing in lane (13.5%)	Going straight (10.3%)
Following Vehicle movement prior to critical event	Going straight (82.1%)	Slowing or starting (6.6)	Lane change, passing, or turn (3.8%)
Corrective action attempted by striking vehicle	None (67.3%)	>2 vehicles involved (15.4%)	Braked/slowed (11.5%

From this table it can be seen that this type of collision happens most often with clear weather, daylight, straight road, bus stopped, striking vehicle approaches in same lane at constant 31–35 mph with no corrective action.

Also from our analysis of the transit bus crash data, the average cost of each transit bus crash is $54,455. Applying the economic cost of each crash to the entire population of buses in operation yields a value of $9,661 for each bus. So this becomes reference cost per bus that should be used in doing a return on investment analysis (ROI) for a RICWS system that mitigates rear-end collisions.

The findings from our Phase III proof-of-concept field operational testing did indicate that there is a trend that drivers respond to RICWS warnings (activated light bar) and stop at a lower braking required threshold. This conclusion is for all three warning activation algorithms we field tested. These three approaches were: 1.) A fixed threshold of braking required at 0.3Gs, 2.) A fixed threshold of 0.225 Gs, and 3.) The more sophisticated CAMP (Crash Avoidance Metrics Partnership – see Appendix E-3.2 for detailed explanation) warning algorithm that takes into account driver reaction times and closing velocity. This program successfully did show a trend that RICWS systems in transit bus operations did modify follow vehicle driving behavior in a positive manner. We feel that RICWS is a technology with great application in not only transit buses, but potentially other vehicle segments too. However, our proof-of-concept research effort did not collect sufficient data to statistically quantify the expected safety enhancements. In addition, our research uncovered some areas that need further development and research before RICWS systems are ready for full commercialization. This needed research addressed in Section 4.2, Research and Next Steps.

1.0 INTRODUCTION AND RESEARCH APPROACH

This final report is prepared for the U.S. Department of Transportation, Federal Transit Administration for the development of performance specifications for Rear Impact Collision Warning Systems (RICWS) for transit buses. This research was conducted in this area since one of the most frequent accidents in transit bus operation is when a vehicle collides with a bus from behind: a "rear impact." This type of collision is responsible for significant costs including damage to the bus, injuries to the occupants, and disruption of the operation of the transit agency. In addition, damage to following vehicles (FVs) and injury to their drivers is usually significantly greater than to the bus or its occupants.

In 1994, transit buses were involved in 3,119 rear-end collisions, nationwide. By 1996, that number increased 56 percent. For the same period, the number of injuries increased 161 percent.

Table 1. Crashes and Injuries for Transit Bus Rear-end Collisions

Year	1994	1995	1996
Crashes	3,119	3,668	4,868
Injuries	1,403	3,262	3,661

Data courtesy of Volpe National Transportation Systems Center, N. Burke, 2/99

Transit buses are particularly susceptible to rear impact collisions because of their frequent stops. Adding to the problem, some bus stops do not allow the bus to pull out of a lane of moving traffic. The DOT Draft Transit IVI Baseline Statistics Study (personal communication, N. Burke, February 2, 1999) indicates that the majority of collisions occur when the bus is decelerating or stopped.

This type accident is common with transit companies all over the country. Nationally, rear-end crashes account for 21.5 percent of all collisions involving buses for 1994 to 1996 (personal communication, N. Burke, February 2, 1999).

According to the 1998 Transit Fact Book, although casualty and liability costs comprise only an average of 2.9 percent of transit companies operating budgets, efforts to reduce the risk exposure, and therefore premiums and claims, by operating fewer miles, having fewer accidents, and/or fewer employees are "often overwhelmed by litigation awards, inflation and state- or region-wide premium increases to cover insurer losses elsewhere." In rear impact crashes, due to the mass of the bus, the resulting collision can be severe for the occupants in the following vehicle, but not necessarily for the bus. Although, there is usually little cost associated with physical damage to the bus, there are costs associated with workman compensation, rider injury, litigation against the following vehicle driver, lost time of bus and driver, and possible drug testing of the driver.

1.2 Research Approach

The research approach was to divide the effort into three major phases. The first phase was an initial causation study and technology demonstration. Overall the Phase II effort provided a detailed accident profile report, an initial system specification for a RICWS system, and field data collection effort to establish the baseline parameters for a RICWS system. Phase III of this

contract provides for outfitting two buses with similar systems which include algorithms and warning lights to study and assess the reactions of following vehicle drivers in response to ignition of the warning light. Phase III also updated the system specifications for a rear impact collision warning system.

The detailed approach in each of the phases as identified below.
The approach for Phase II:

- Assessment of available crash data to characterize rear-end crashes involving buses.
- Completed a warning indicator study to arrive at an "optimal" design of a warning indicator.
- Establish requirements for a baseline data collection.
- Build two testbed Data Collection Systems (DCS) to be used on AATA buses to collect baseline data.
- Generate a "baseline" of on-the-road data to use in assessing the efficacy of the data collection system and to use in building and testing a warning algorithm.
- Build tools with which to analyze the collected baseline data.
- Assess and analyze following vehicle driver behavior as exposed in the baseline data collected.
- Evaluate crash scenarios and possible benefits of the warning system, refine performance specifications, and define evaluation strategies.

The approach and efforts for Phase III:

- Implementation of the code necessary to add the capability to the DCS system to provide ignition of a warning light at appropriate times.
- Algorithm development and validation testing.
- Light bar field testing.
- Replacement of degraded laser IR sensors.
- Human factors testing of drivers approaching the back of a bus under "normal" conditions.
- Collection of data from two buses fitted with the system with warning lights.
- Analysis of collected data.
- Update algorithms to signal the warning light based on field testing.
- Update system specifications.
- Complete the final report and recommendations for next steps.

2.0 FINDINGS

G. Optimal vs. Wigwag Settings (5% Intensity-Day)

In addition to all the tests above, a control test in which the optimal mode was compared with another moving signal (wigwag), that would have been expected to test the 'M' signal transduction pathway. This testing parameter was to make sure that the Optimal parameter was not a novelty effect. These results can be seen within figures 17-18.

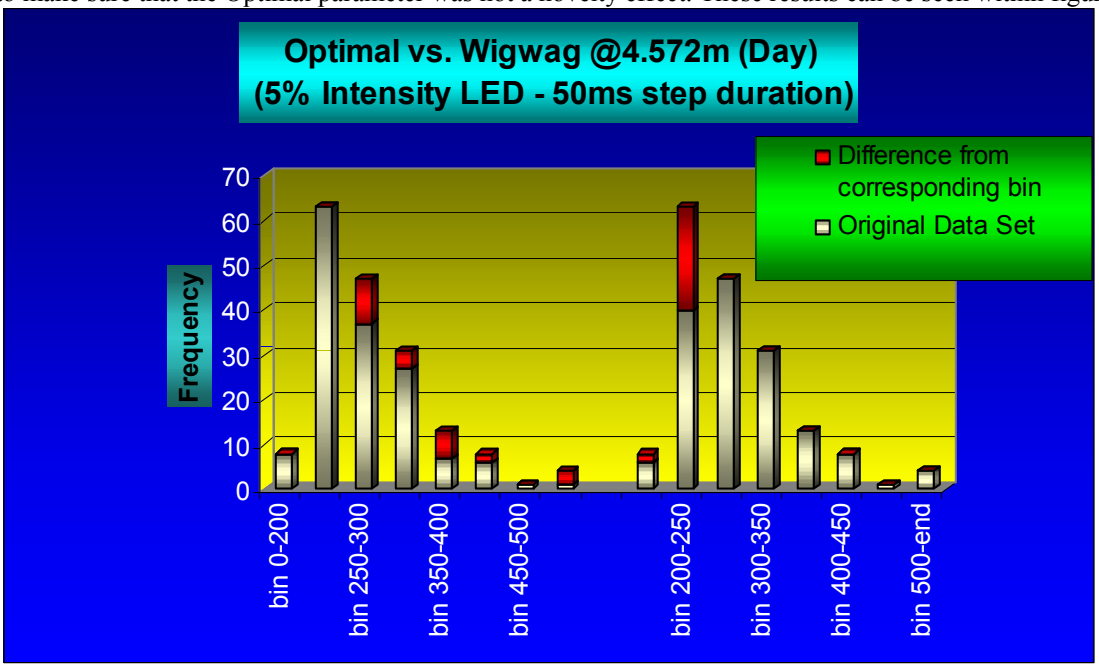

Figure 17 - This frequency table shows the results of the optimal vs. wigwag test at 4.572m, day conditions, 5% Intensity, and 50ms step duration for six subjects tested.

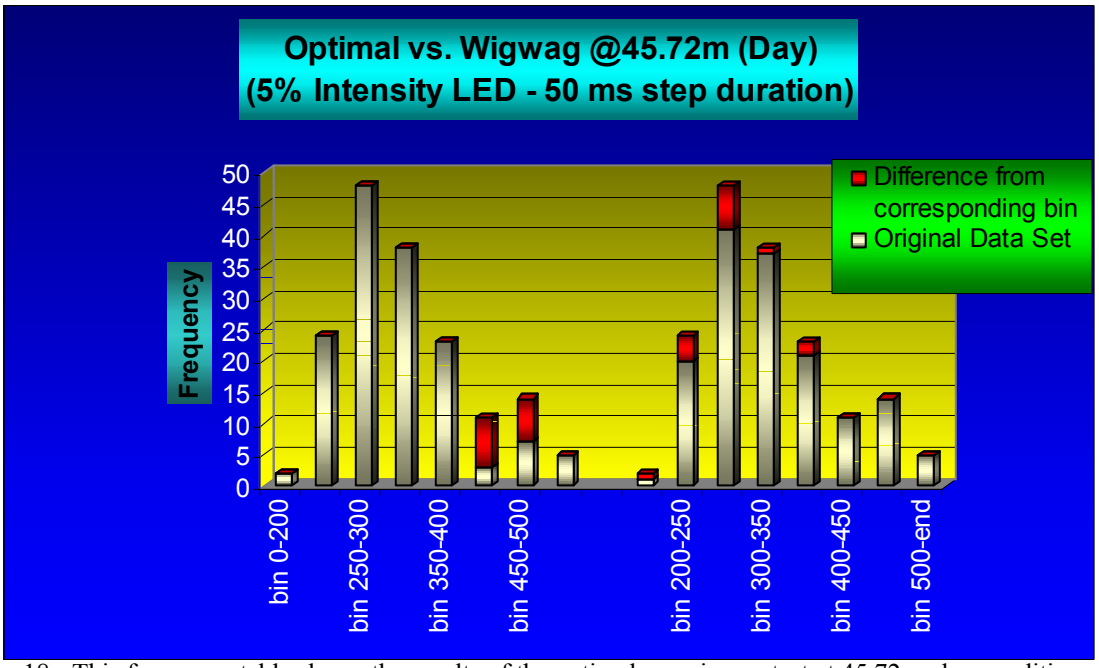

Figure 18 - This frequency table shows the results of the optimal vs. wigwag test at 45.72m, day conditions, 5% Intensity, and 50ms step duration for six subjects tested. The optimal was still superior, but not by as much.

H. LED vs. Incandescent Settings (Full Intensity-Day-40ms Turn-on Time)

The final round of testing conducted a simple comparison of the effect of the sluggish incandescent turn-on time versus the sudden LED turn-on time. The turn-on characteristic of the incandescent lamps was estimated and simulated in the second bus bar used for our testing. Initially, this was thought to be 40ms.

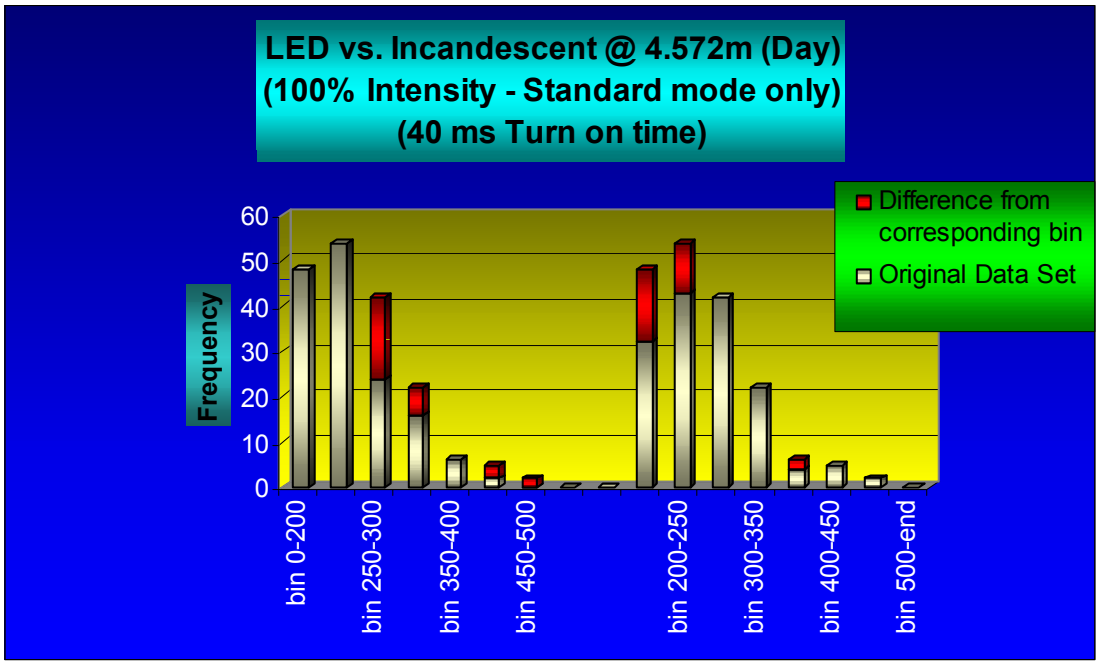

Figure 19 - This frequency table shows the results of the LED vs. Incandescent test at 4.572m, day conditions, 100% Intensity, and 40ms turn on time for six subjects tested.

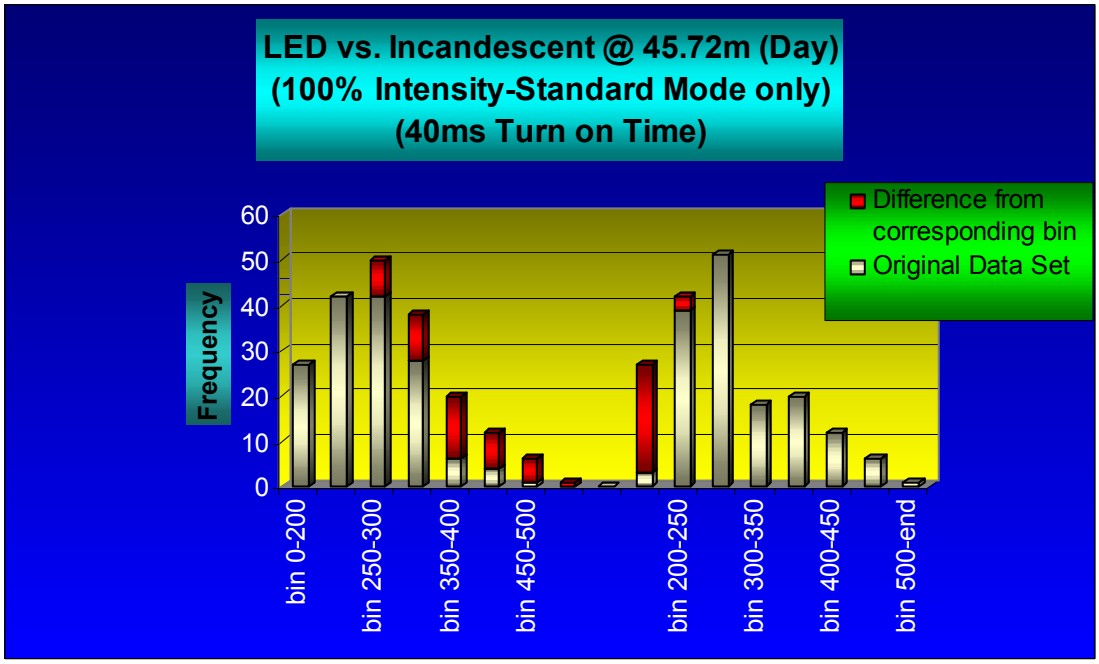

Figure 20 - This frequency table shows the results of the LED vs. Incandescent test at 45.72m, day conditions, 100% Intensity, and 40ms turn on time for six subjects tested.

I. LED vs. Incandescent Settings (Full Intensity-Day-250ms Turn-on Time)

Since the incandescent bus bar had a 250ms delay before being fully turned-on, as evident in Figure 4, the turn on time of the LED-simulated incandescent was simulated to match almost exactly, in order to achieve a proper comparison between the LED turn-on time and the Incandescent turn-on time.

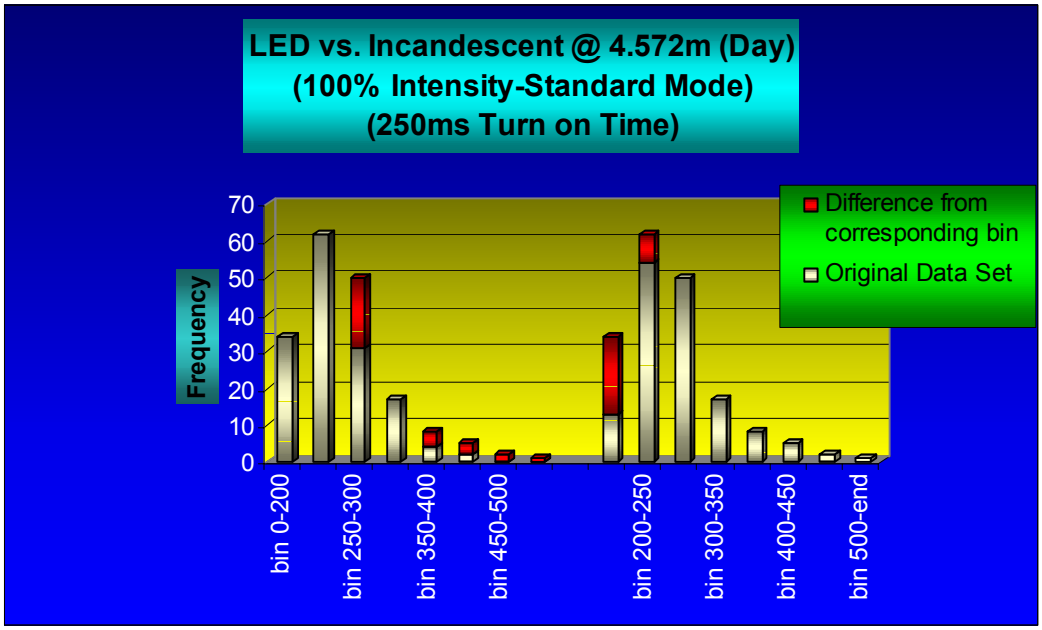

Figure 21 - This frequency table shows the results of the LED vs. Incandescent test at 4.572m, day conditions, 100% Intensity, and 250ms turn on time for nine subjects tested.

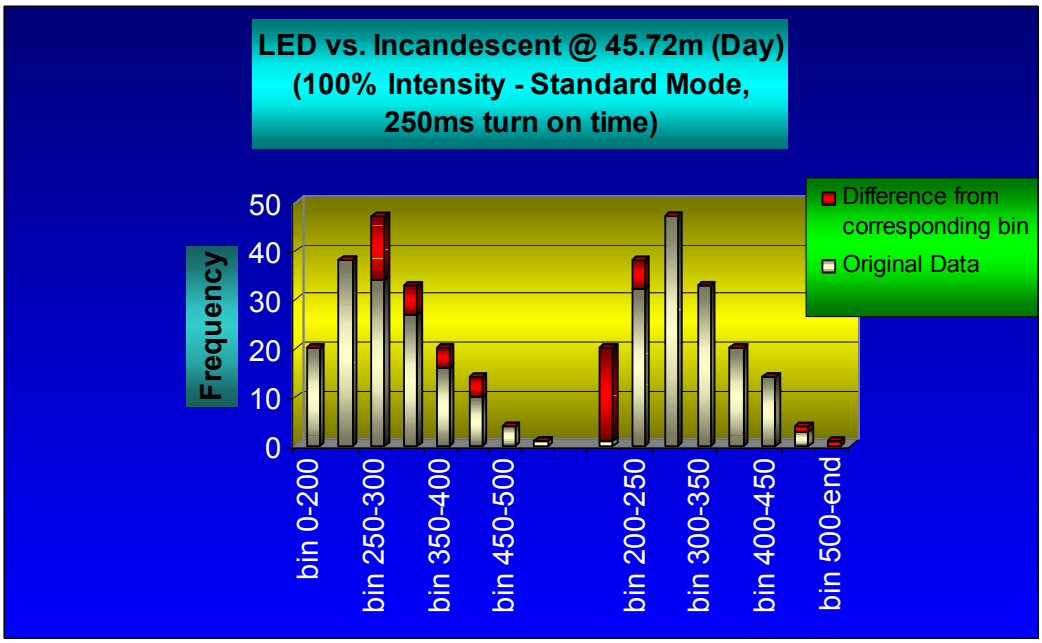

Figure 22 - This frequency table shows the results of the LED vs. Incandescent test at 45.72m, day conditions, 100% Intensity, and 250ms turn on time for nine subjects tested. The best case scenario with LED lights coming on at 50-150ms faster than the standard incandescent simulation lights.

Older subject testing were included within Test 2, 3, and 7. These parameters were the most important in determining the reaction times of the older subjects because these tests simulate most of the practical conditions that can be encountered on the road. In table 3, the data shows the minimum RT, average RT, and maximum RT for the older subjects(≥ 60 years old).

Table 3 – This table shows the summary values of Minimum RT and Maximum RT (upper half of table) with central tendency (mean and median – lower half of table) for the older subjects.

Testing Parameters (all values in ms)	Optimal (Min)	Standard(Min)	Optimal (Max)	Standard (Max)
Optimal vs. Standard Settings (5% Intensity-Day)@4.572m	195.6	162.6	836.6	587.5
@45.72m	205.9	197.2	454.2	722.7
Optimal vs. Standard Settings (5% Intensity-Night)@4.572m	199.5	191.5	589.7	733.5
@45.72m	212.7	205.7	601.3	525.3
Extreme Values for Max/Min of Optimal vs. Standard	195.6	162.6	836.6	733.5

	LED (Min)	Incandescent(Min)	LED(Max)	Incandescent(Max)
LED vs. Incandescent Settings (Full Intensity-Day-250ms Turn-on Time)@4.572m	165.3	170.2	549.9	526.1
@45.72m	197.6	185.6	487.4	3084.0
Extreme Values for Max/Min of LED vs. Incandescent	165.3	170.2	549.9	3084.0

Testing Parameters (all values in ms)	Optimal (Mean)	Standard (Mean)	Optimal (Median)	Standard (Median)
Optimal vs. Standard Settings (5% Intensity-Day)@4.572m	302.9	311.4	277.5	317.6
@45.72m	302.0	334.6	293.9	325.6
Optimal vs. Standard Settings (5% Intensity-Night)@4.572m	307.0	341.9	293.4	334.2
@45.72m	326.2	301.4	310.0	294.0
Mean Values for Mean/Median of Optimal vs. Standard	309.5 (4% decrease)	322.3	293.7 (7.6% decrease)	317.8

	LED (Mean)	Incandescent (Mean)	LED (Median)	Incandescent (Median)
LED vs. Incandescent Settings (Full Intensity-Day-250ms Turn-on Time)@4.572m	250.3	296.7	248.3	291.6
@45.72m	292.3	372.6	285.6	339.4
Mean Values for Mean/Median of LED vs. Incandescent	271.3 (18.9 % decrease)	334.6	267.0 (15.4% decrease)	315.5

This table below represents the summary values of minimum RT vs. average RT vs. maximum RT over all the 9 subjects.

Table 4 – Summary Table (young subjects and including older subjects when they were tested) of Minimum RT vs. Average RT vs. Maximum RT

Testing Parameters (all values in ms)	Optimal (Min)	Standard(Min)	Optimal (Max)	Standard (Max)
Optimal vs. Standard Settings (Full Intensity-Day)@4.572m	142.1	151.4	450.9	598.4
Same as above @ 45.72m	158.8	162.1	522.1	711.5
Optimal vs. Standard Settings (5% Intensity-Day)@4.572m	176.5	157.6	836.6	946.1
Same as above @45.72m	199.6	166.9	605.7	722.7
Optimal vs. Standard Settings (5% Intensity-Night)@4.572m	168.1	181.4	589.7	804.0
Same as above @45.72m	198. 8	205.7	636.7	550.3
Optimal vs. Standard Settings (5% Intensity-Day-No Fixation Point)@4.572m	168.2	190.8	601.7	850.6
Same as above @45.72m	193.7	246.3	862.1	1176.8
Extreme Values for Max/Min RT of Optimal vs. Standard	142.1	151.4	862.1	1176.8

	Optimal (Min)	Wigwag(Min)	Optimal (Max)	Wigwag(Min)
Optimal vs. Wigwag Settings (5% Intensity-Day)@4.572m	176.5	179.8	635.1	800.2
Same as above @45.72m	199.6	209.7	605.7	566.0
Extreme Values for Max/Min RTof Optimal vs. Wigwag	176.5	179.8	635.1	800.2

	LED (Min)	*Incandescent (Min)*	*LED(Max)*	*Incandescent (Max)*
LED vs. Incandescent Settings (Full Intensity-Day-40ms Turn-on Time)@4.572m	140. 5	153.8	440.0	487.0
Same as above @45.72m	149.8	191.3	453.1	517.5
LED vs. Incandescent Settings (Full Intensity-Day-250ms Turn-on Time)@4.572m	136.8	162.7	549. 9	526.1
Same as above @45.72m	155.8	185.7	515.8	3084.0
Extreme Values for Max/Min RT of LED vs. Incandescent	136.8	153.8	549. 9	3084.0

Testing Parameters (all values in ms)	*Optimal (Mean)*	*Standard (Mean)*	*Optimal (Median)*	*Standard (Median)*
Optimal vs. Standard Settings (Full Intensity-Day)@4.572m	237.0	269.6	224.3	259.3
Same as above @ 45.72m	277.9	302.9	265.1	290.9
Optimal vs. Standard Settings (5% Intensity-Day)@4.572m	282.9	292.9	267.2	280.4
Same as above @45.72m	311.7	322.3	300.7	305.9
Optimal vs. Standard Settings (5% Intensity-Night)@4.572m	287.7	317.6	278.8	298.6
Same as above @45.72m	330.3	334.1	321.9	325.8
Optimal vs. Standard Settings (5% Intensity-Day-No Fixation Point)@4.572m	322.8	377.1	308.8	356.4
Same as above @45.72m	401.9	442.4	381.1	388.3
Mean Values for Mean/Median RT of Optimal vs. Standard	306.5 (7.8% decrease)	332.4	293.5 (6.3% decrease)	313.2

	Optimal (Mean)	*Wigwag (Mean)*	*Optimal (Median)*	*Wigwag (Median)*
Optimal vs. Wigwag Settings (5% Intensity-Day)@4.572m	281.7	277.1	269.8	262.7
Same as above @45.72m	316.5	329.8	304.1	312.2
Mean Values for Mean/Median RT of Optimal vs. Wigwag	299.1 (1.4% decrease)	303.4	287.0 (0.01 % decrease)	287.4

	LED (Mean)	*Incandescent (Mean)*	*LED (Median)*	*Incandescent (Median)*
LED vs. Incandescent Settings (Full Intensity-Day-40ms Turn-on Time)@4.572m	233.4	257.4	224.1	245.7
Same as above @45.72m	259.7	302.0	255.9	287.0
LED vs. Incandescent Settings (Full Intensity-Day-250ms Turn-on Time)@4.572m	244.8	277.9	239.6	268.5
Same as above @45.72m	284.5	327.3	277.8	310.4
Mean Values for Mean/Median RTof LED vs. Incandescent	255.6 (12% decrease)	291.1	249.3(10.2 % decrease)	277.9

VI. Discussion / Data Analysis

The difference between a standard and an optimized bus bar under a variety of circumstances have been studied. All of the tests have been performed with observers alert and prepared. The only measure of performance that was used is the time to react, sometimes termed the 'reaction time'. This is defined as the time from the onset of the bus bar signal to the depression of a response button (a very sensitive microswitch) mounted in a small console held by the observer. By this means we are trying to separate motor, cognitive, motivational and other extraneous factors from a single factor, the speed with which the bus bar signal is coded in the visual nervous system and whether the standard bus bar is seen more or less quickly than the optimized bus bar.

The tests were designed to be 'best case'. A variety of observer-related circumstances or conditions (unalerted, unprepared, distracted, blinking, sneezing, coughing, poorly corrected, night myopia, glare) would have served to worsen the ability to see the signals and, we have evidence, would have enlarged the relative difference between standard and optimized bus bars.

We are thus in no position to say, based on these results, that such a signal will be understood, that it will cause drivers to brake sooner, that it will lessen the frequency of rear-end collisions, or any of a number of other desirable endpoints. We can only say how fast the signal is seen. Equally, we have no data on the question of the signature presented by the bus bar. Neither its color, its shape, its size, nor any of a number of other parameters that could have been varied were tested. These were all held fixed and were identical in each version of the bar.

In each test we have seen differences between the performances with the two signals. In general, and with only isolated exceptions, the optimized bus bar is seen more quickly than the standard bus bar. One way to study the difference and to appraise its impact is to examine the average RTs obtained by observers with each device. The average difference is small, ranging from 20 – 50 MSEC. A difference of 50 MSEC at 30 MPH, translates to a little more than four feet greater separation between bus and following vehicle. In other words, it is as if the bus has a virtual rear end on which the signal is mounted, and that lies four feet further behind the actual rear end. The following driver who would have come to a stop just touching the real bumper could, with the additional speed of seeing gained using the optimized signal, stop four feet earlier on average. The following driver whose vehicle stopped too late, and embedded itself a foot deep into the bus rear end, would have been enabled to stop with three feet to spare, enough room for an alighting passenger to walk safely between the two vehicles. A difference of as little as 20 MSEC, still translates to an extra foot and a half of leeway, a sort of safe cushion.

Another way to appraise the difference between the performances with the alternative light bars is to study the distributions of the reaction time events themselves. Figure 9 assists to illustrate this. The lowest RTs are in the range of 100-200 MSEC, as low as any ever reported in the literature.[10] Each bar proved capable of eliciting RTs this low, but in general the optimized bar did so more often. Thus the standard bar led to events that took longer. How many and how much longer is not revealed when one only looks at the average RT. The distribution of Figure 15 makes clear that as many as 20 % of the RTs for the standard signal are 50-150 MSEC longer than the ones that they have replaced for the optimized signal. In other words, the average difference quoted above, obscures a more important difference, one which does not occur in every instance, but which occurs with enough frequency to be rather important. The few occasions on which an additional delay of reaction amounting to 100-150 MSEC corresponds to 12 feet at 30 MPH or over half a car length. This ensues in best-case viewing conditions. Other work in our lab suggests that in worst case viewing conditions the differences will be larger and that the number of extremely long RTs will be greater.

This distinction can be seen in another way. If distributions were simply translations of one another (with, say, 26 msec added to each abscissa coordinate for RTs using the standard light bar, then their variances would be the same. Variance for the standard bar is significantly higher than for the 'optimal' bar. Table 5 shows F-test results for these comparisons.

Table 5: F-test results comparing variances in optimal and standard light bars by type of test

Testing Parameters (all values in ms)	*F-test (P-values)*
Optimal vs. Standard Settings (Full Intensity-Day)@4.572m	3.86E-06
@ 45.72m	0.0076
Optimal vs. Standard Settings (5% Intensity-Day)@4.572m	0.013
@45.72m	0.109 (ns)
Optimal vs. Standard Settings (5% Intensity-Night)@4.572m	4.97E-06
@45.72m	0.191 (ns)

Thus, while each type of light bar gives a few very much lower than average RTs, the standard bar gives many more higher than average RTs. This motivates one to state the advantage of the 'optimal' bar not so much in terms of the average speed up that it can supply in each instance, but rather the extreme speed-ups it actually exhibits in a small but important fraction of instances.

There is a second type of advantage of the bus bar design that we consider optimized. In that design, the luminous elements are light emitting diodes. The standard bus bar uses incandescent elements. These are known to turn on more slowly than LEDs. We have measured a physical turn-on time for the standard incandescent light bar and have simulated it using a gradual turn-on circuit in the second light bar populated by LEDs. The turn-on time of the simulated incandescent light bar can be seen in Figure 3 (40ms) and Figure 5(250ms). Those turn-on times can be compared with the LED turn on-time of Figure 2. The extra difference in time saved alone from this very data is translated into the time difference (50-150 msec) as seen in Figures 19-22.

By this means we have been able to quantify the extra perceptual time that is due solely to the slower turn-on (it will be appreciated that this is not known in advance from the physical measurement - even though the incandescent device requires approximately 250 MSEC to turn fully on, it is on enough to be seen considerably before then). Hence, we performed some additional measurements to discover the psychophysical difference, again in the best case. (In worst case viewing, more intensity might be required to achieve a particular level of performance and this would require additional delay). Our studies place the LED advantage at an average of about 36 MSEC in the best case. This 36 MSEC can be added to the RT difference (ca. 26 MSEC) recorded above for a net gain in the optimized device of as much as 62 MSEC.

Full intensity vs. 5% Intensity: Further tests were conducted with a lowered threshold intensity to test a less-than-best case scenario of detectability of the light bar. The data can be viewed in Figures 11-18 to see the results. The results showed similar delayed RT's for the standard mode when compared with the optimal in varying conditions as noted within each figure. This situation simulates a case where the illuminance of the light bar has become degraded, as it might under conditions of poor visibility, or with salt and dirt spray common in winter. There is very little difference in the advantage shown by the 'optimal' bus bar in these lowered intensity circumstances.

Minimum RT vs. Average RT vs. Maximum RT: These three summary numbers convey an interesting picture of the performance to be expected in comparing the 'optimal' to the standard bus bar as seen in Table 4. The minimum RTs that we have measured come close to the very best reported in the literature. This lends credence to the idea that there are no aspects of the conditions of testing that we are using that add delay or cause slowness. We do not expect to see significant difference in these minima between the two bus bars for a simple reason: the onset of each signal (at t=0) is identical in a restricted area of the bus bar (the center two panels) and the sight of this could be what triggers the reaction on a small fraction of the trials. If so, since the triggers are identical, the RTs will be. Seeking the minimum amongst our data is the most likely way of finding this particular circumstance. Moreover, differences between these minima are far less likely to be significant in a statistical sense so many fewer measurements are involved in the comparison -- one outlier can determine the entire result.

Average (or median) RT's tell a different sort of story. They describe the expected difference in performance to be achieved with optimal or standard bus bar. These averages (across six observers and including all trials at a given condition) suggest superiority for the 'optimal' bar that ranges from a low of 4 MSEC to a high of 54 MSEC with an average across conditions of 26 MSEC. 26 MSEC at 30 mph amounts to a reduced stopping distance of over one foot,

which, while useful, does not translate to a particularly large advance in safety.

It is when we study the maxima that we begin to see the real advantage of our 'optimal' signaling strategy. Maxima differ by a lot (although as in the case of minima, the statistical regularity of the result is smaller than that for the means). In seven of the eight test conditions the largest RT for the standard bus bar was over 100 MSEC slower than that for the 'optimal'. In three of the seven cases it was over 200 MSEC. Consider the practical significance of these findings: the maximum RT is extracted from a list of 150 such measurements. This means that about 1% of the time a driver can (at 30 mph) proceed as much as 9, 18 or even 27 feet down the road before his/her stopping algorithm is engaged. Coloration on the reaction time distributions in the several tests illustrates the magnitude of this advantage. In essence, the 'optimal' bus bar has significantly lower RT's. Higher RT's occur with the standard bar. In sum, these may amount to 10-20 % of the samples. But trading a few low times (for the optimal bar) for a few much higher times, which averages out to, say, 25 MSEC across 150 samples, may have been due to differences on the order of 100 MSEC or more in a small but significant portion of the samples. It is in those events that the use of the optimal light bar can prevent rear end collisions.

Optimal vs. Wigwag: The reader will note that we have studied an alternative signal configuration (termed 'wig-wag') in which illuminated segments proceed from left to right. While the data show a tiny advantage for the optimal bar in the case of RT there are two factors which cause us not to recommend its adoption:
1) the wig-wag signal is sided -- this means that it points right (or left) leaving the following driver with an interpretive conundrum ("Should I go that way? Is the bus going that way?)
2) The wig-wag does not incorporate the salience-inducing looming effect. While its motion enables it to achieve a suitably low RT, we cannot say that it will have the same salience as the optimal bar does.

LED vs. Incandescent: The original, light bar supplied to our project contained incandescent (automotive) light bulbs, two per segment for each of the eight segments. This light bar was not suitable for testing because it did not lend itself to the control or parameter variation needed for our tests. It happened also to be judged by our staff to be dangerously too intense (when illuminated, it was nearly impossible to look at it). In order to meet three essential criteria to (1) constrain all irrelevant parameters such as shape, color, intensity to be identical in standard and optimal configurations, (2) enable intensity control, and (3) have a flexible test system, we asked our collaborative partner, ElectroTechs, to fabricate a light bar that could be configured in either standard or optimal modes and which employed only LEDs for illumination. Thus, in order to fully complete a test that compares standard to optimal it was necessary to estimate the RT advantage that accrued solely due to the use of LEDs whose turn-on is virtually instantaneous. Figures 3 and 5 show the gradual turn-on quality of incandescent lights as simulated on the LED-based bus bar. This compares favorably to measurements of the actual incandescent standard bar. The LED turns on instantaneously compared to physiological delays. The incandescent turns on gradually. In this best case viewing situation, the question becomes 'when is the incandescent seen?' Our measurements are summarized in Table I. Thus the net advantage of employing the LED-based 'optimal' bus bar over the incandescent based standard bar is the sum of the differences in our standard vs. optimal tests and in our LED vs. incandescent tests. The former was about 26 msec. The latter averaged 36 msec. The sum of these is 62 msec. This represent the reduction of *average* time to react that out optimal bus bar would cause as compared to a standard bus bar of identical intensity. The difference amounts to over 2.5 feet lessened *average* stopping distance at 30 mph that could be achieved through the use of the optimal light bar.

Figure 5 reveals that our simulation of the incandescent turn-on is 'best case. The actual turn-on shows a roughly 35-40 msec dead time after activation. Our simulation, on the other hand, began a gradual (exponential) rise immediately upon ignition. Thus, one must add this dead time to the 62 msec average advantage cited above. In the net, we expect a roughly 100 msec average advantage for the optimal LED device.

Older vs. Younger Observers: We measured responses from six younger and three older observers. In the distributions above, their data are cumulated. We have studied the difference in reaction times in these two age groups. The result is that younger subjects react only slightly faster than the older subjects. Using table 3 and 4 median RT, young subjects' reaction times on a whole are only a few milliseconds faster than those of their older counterparts. However, the important difference may be seen in comparisons of the maximum and minimum reaction times. Older subjects tended to have alarmingly high RTs having slower hits at the higher ends of the RTspectrum. In fact, in one case, the older subject took almost 3 whole seconds to respond to a light ignition in the standard mode. Incidents like these are the ones with which we are most concerned and feel that the optimal mode would be better suited to eliciting faster reaction times for older subjects as well as younger subjects.

VII. Conclusions

We conclude that turning on some of the elements of a bus bar 50, 100, and 150 msec later than others brings about a paradoxical, but physiologically understandable speed-up in the time it takes an observer to "see" the ignition of the bus-bar. On the whole, the average advantage is small, on the order of 26 MSEC. But the average difference comes about due to a deletion of a few very short RT's and the inclusion of a few very long ones. It is not due to a simple translation of the RT distribution that might occur by simply adding 26 MSEC to each event. Thus, we predict that in deployment, one will measure a substantial number, perhaps 10-20%, of greatly altered reaction times, some larger that 100 or even 200 MSEC, if both optimal and standard bars are deployed and compared. In worst-case conditions we would expect the average difference, and also differences in individual instances, to be greater.

We also find that the gradual turn-on of incandescent lamps exerts its own slow-down in average RT. The measured average effect is on the order of 36 MSEC in best-case conditions. The difference would be expected to be larger in poor visibility conditions or for deficient or not-alerted observers. It may be as much as 40 msec underestimated owing to a dead time after ignition of incandescent lamps that we did not simulate. Light bars should thus be constructed with LED, not incandescent, lamps.

VIII. References

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IX. ADDENDUM

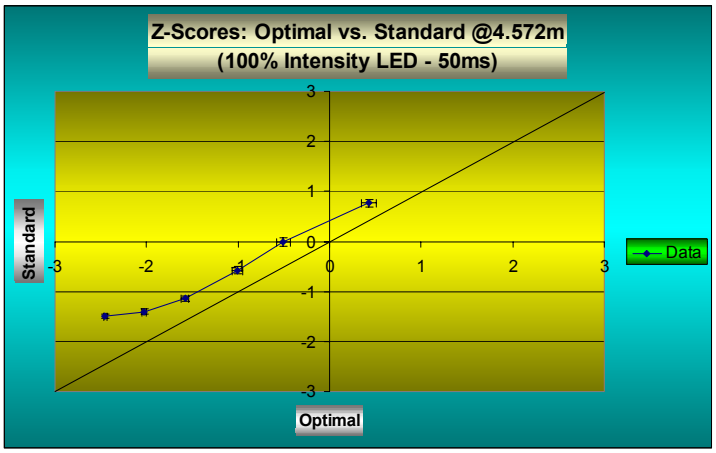
This addendum is intended to supply the reader with an 'at-a-glance' capability to appraise the difference between RT distributions obtained with the optimal and with the standard light bars. The display shows the ways in which, and the degree to which, the two RT distributions differ. This data display method is drawn from ROC analysis.

If distributions do not differ the resulting plot is a straight line through the origin. The degree to which they do differ is specified by the distance the ROC plot lies from the origin, said distance being in units of standard deviation. If the ROC plot is inclined with slope less than 1.0, it means that there is more variance in the standard RET distribution as compared to the optimal.

The plots below is for the set of conditions that are indicated:

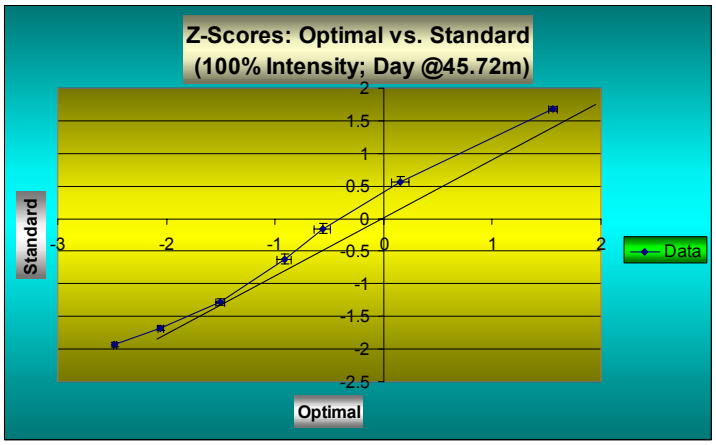
Testing Parameters

Lightbar Type	Old=LED only
Intensity	Full
Distance	4.572m
Step Duration	50ms
Turn-off Time	250ms
Test Type	Standard vs. Optimal
Condition	Day



Testing Parameters

Lightbar Type	Old=LED only
Intensity	Full
Distance	45.72m
Step Duration	50ms
Turn-off Time	250ms
Test Type	Standard vs. Optimal
Condition	Day



APPENDIX C: DATA COLLECTION SYSTEM (DCS)

C-1 Baseline Collection Requirements

The sensor and data collection system for this phase of this project were chosen and designed based on the following considerations and assumptions:

- Re-use of initial work done in "Phase I" demonstration system.
- Need for a low-cost range sensor with high lateral resolution.
- Video collection at the highest frame rate possible.
- A desire to limit development costs through re-use of code and expertise gained from other projects.

These considerations led to major design choices as follows:

- Continued use of the Mitsubishi LIDAR sensor used in the demonstration.
- DCS system built from PC-104 computer components running Linux and application code built in C++ (similar to hardware General Dynamics has designed into other projects, and a familiar programming environment for our programmers).

The project presumed a different DCS platform going into this work—one based on the demonstration system (PC laptop hardware and a Windows software environment), however, this system was later deemed to be unsuitable for the extended data collection periods and warning system operations contemplated for Phases II and III of the program.

Technical specifications for the data collection system were driven primarily by the a-priori chosen range sensor. A Data Collection System Requirements document was developed to guide construction of the system (Reference 4) and is available for review. The "top-level" requirements established for the DCS were:

- To be suitable for analyzing Following Vehicle (FV) driving behavior behind transit buses.
- To evaluate specific sensors for their ability to provide data that will allow automatic detection of a potential rear-impact collision.
- To allow development and testing of algorithms for detecting impending rear-impact collisions.
- To test rear impact collision warning indicators for their efficacy in alerting FV drivers of impending collision situations.
- To evaluate a complete RICWS utilizing the final algorithm and selected warning indicator and analyze the resulting FV driver behavior.

C-2 Data Collection System (DCS) Overview

The collection system as fielded for the baseline data collection, including sensor photographs, is shown in Figure C-1.

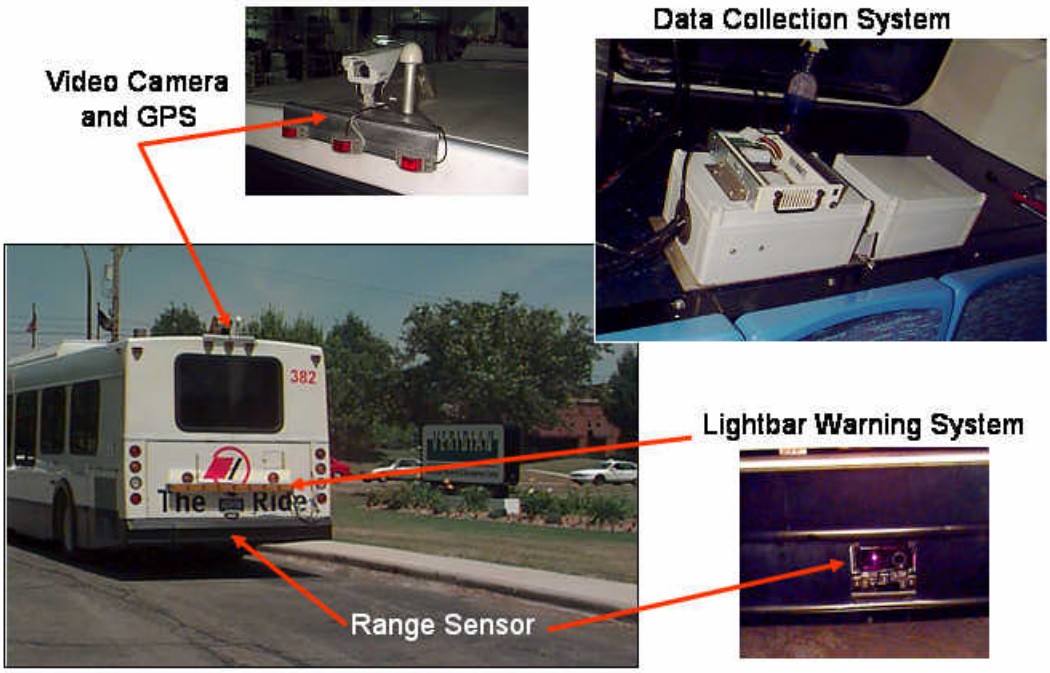


Figure C-1. DCS – Data Collection System

An initial design for the range and video sensor mountings on the bus included an environmental enclosure for these units to protect them from the elements. This design is shown in Figure C-2. Unfortunately, this approach was deemed to be unsafe from the perspective of pedestrian foot traffic behind the bus at stops, it did not allow towing of the bus (normally done from the rear) without removal of the unit, and the window covering of the range sensor significantly affected the performance of the sensor. This design was fielded initially, but later revised to the present mountings as shown in Figure C-2. The primary operational impacts of the revised design include a requirement for frequent (ideally, daily) washing of the range sensor front face to keep it clean, and a non-optimal video camera view angle—however, these impacts have not significantly affected operations or usability of the data.

Figure C-2. Initial Range and Video Sensor Mounting (Discarded)

Data is collected and recorded by the DCS at regular intervals (1/10 second) and includes the following:

- Range return data from the range sensor (serial port input).
- Video frame data from the video camera (memory-mapped data from frame buffer).
- Current GPS information (latitude, longitude, and GPS system time from serial port input).
- Yaw rate from a yaw sensor (a voltage measurement).
- Bus speed via transmission pulse counting over the 1/10 second range data update interval (parallel I/O signal input).
- Bus lamp state data (on/off) for brake light, right turn signal, left turn signal, deceleration lamps.

Data collection in this system is driven by the range sensor, which provides a constant 10 frames per second sweep update via its serial port connection to the DCS control computer. Each update sent from this sensor is used to initiate an interrogation of the state data, the GPS, bus speed, yaw, and at regular intervals (i.e., every five updates) a video frame collection.

C-3 Range Sensor

The range sensor utilized here is a Mitsubishi LIDAR, Model X4T25871H and control unit, Model E2Z561-04 or equivalent. This sensor was designed for forward collision warning and/or adaptive cruise control automotive applications and is in use in Japan. No current applications of this sensor are known in the U.S.

This sensor has the following technical characteristics:

- Scanned laser emitter at 850nm wavelength, time-of-flight ranging.
- Twelve degree horizontal field of view.
- Three degree vertical field of view.
- One hundred sixty-two byte data packet sent over serial interface every 1/10 second at 38.4K Baud, consisting of one status word (two bytes) and 80 range samples (two bytes each) containing 10 bits of dynamic range.
- Maximum range: 154.45 meters (dependent on optical cross section).

- Azimuth Resolution: 0.15 degrees (at 10m range: 2.6cm, at 50m range: 13cm).
- Range Resolution: 15 cm.
- Range accuracy: at 100m, + or – 1 meter (i.e., 1 percent).

The range sensor was installed on the bus in the rear bumper. Figure C-3 provides a graphical view of the resulting range sensor geometry.

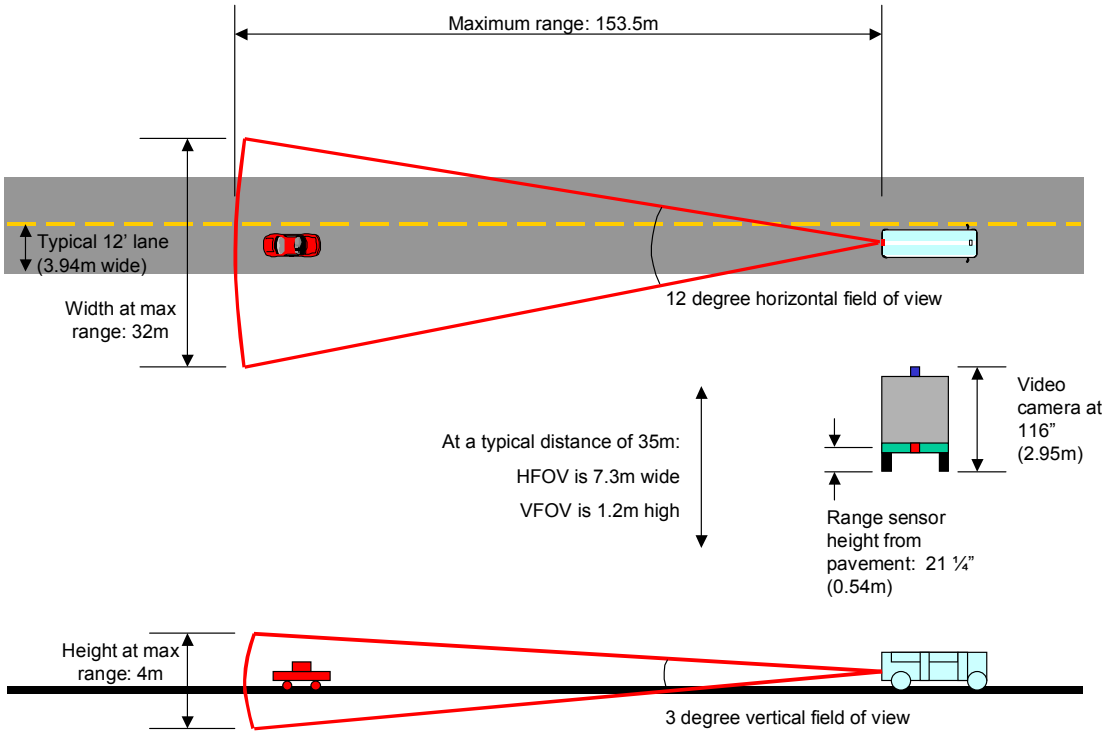


Figure C-3. Range Sensor Geometry

C-4 Data Collection System Details

A block diagram of the DCS system is provided below in Figure C-4.

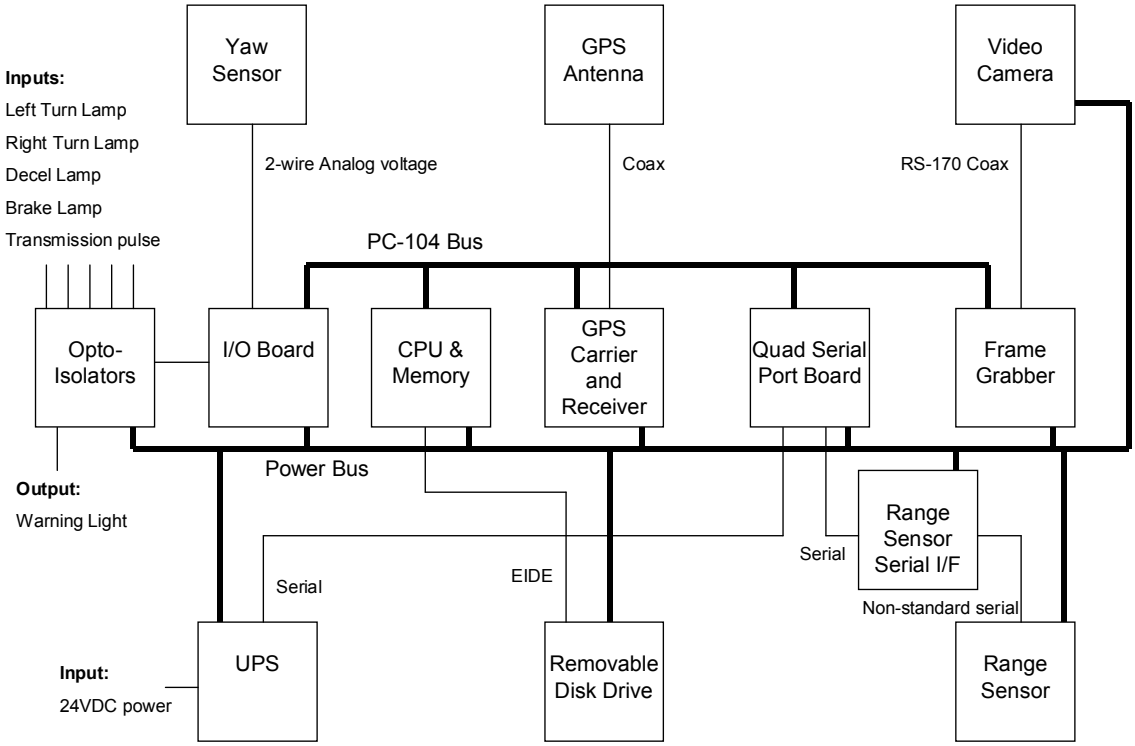


Figure C-4. DCS System Block Diagram

System software is described in the references "DCS System Description" and "DCS Data File Format Specification" (References 5 and 6, respectively). Each hour of data collected by the DCS is organized into a separate directory containing ".dcs" files, a Range subdirectory, and a Video subdirectory. Each ".dcs" file holds 100 records of timestamp, GPS, bus speed and yaw, and signal state data. Within the Range subdirectory the range return data is organized into files where each file holds 100 records of range return sweeps. Within the Video directory there is a sequentially numbered file (JPEG file format) for each video frame collected (every ½ second). Therefore, each hour of collection results in 36 ".dcs" files, 36 range sensor data files, and 7199 video frame files (one video frame collection is dropped every hour in the process of changing from one data storage directory to another).

A flow diagram of the operation of the DCS is shown below in Figure C-5.

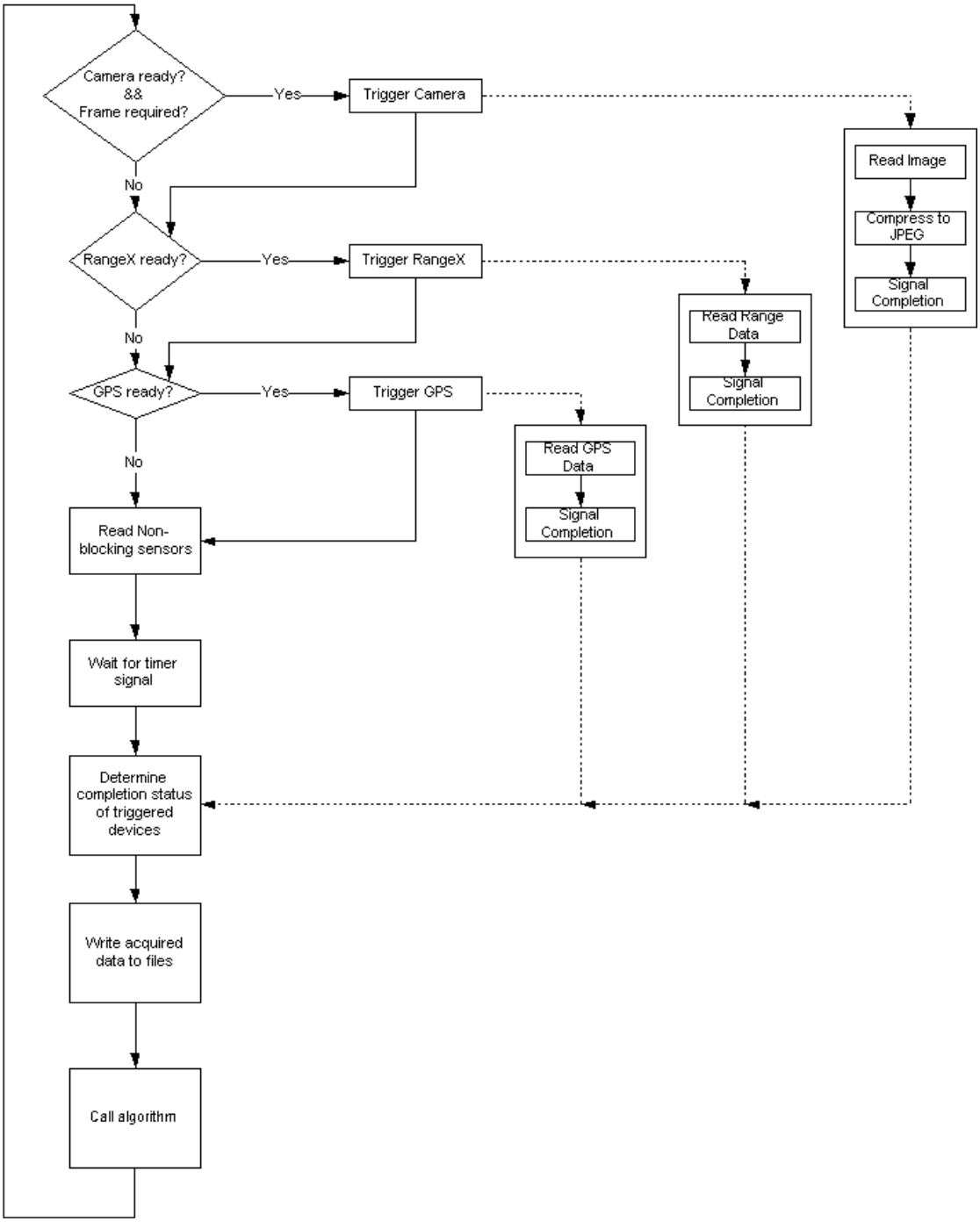


Figure C-5. DCS Operations Flow Diagram

In the diagram above, solid flow lines indicate single thread operations, while dashed lines indicate operations spawned and executable in parallel with the main control thread. The Mitsubishi sensor does not require re-triggering since it is free running. The timer signal utilized is the completion signal from the Mitsubishi interface. In other words, the collection cycle as diagrammed starts at the "Wait for timer signal" block, and proceeds through the loop starting from there at the end of every data packet arrival from the range sensor.

This system has proven to be somewhat reliable, despite the harsh conditions on-board the bus. The initial installation of the DCS experienced some unexplained loss of data due to file system corruptions. We theorized that this behavior was being caused by either shock and vibration—particularly as it affected the hard disk drive during writing operations, and/or electro-magnetic interference from a power control unit on the bus that was inches away from the DCS control electronics and hard drive. File system corruption problems were significantly reduced when the disk drive carrier was provided with shock mounts and encased in an EMI shield. Some system glitches have been observed since these corrective actions were taken, but the impact on collected data has been negligible. Further shock isolation for the hard disk drive should be provided in additional DCS units to eliminate this problem completely.

The DCS system is provisioned with a 20GB hard drive, of which approximately 18GB is available for collected data storage. An hour of collection data consumes approximately 60MB, so each disk drive can hold up to about 300 collection hours, or about 20 days (assuming 15 hours/day of operations).

C-5 Data Handling and Archiving

All data has been archived to DLT tapes on a Benchmark DLT1 tape drive in a backup format using NovaStor backup software. Data was collected off the bus on a weekly basis by swapping removable 20GB disk drives (replacing the one holding data with a "fresh" empty disk drive containing only the OS and application software). Each retrieved disk was returned to General Dynamics, inserted into the archive system, and the files copied to the archive system disks. Each collection disk was then emptied of data in preparation for the next swap. Further details on data handling and archiving can be found in Reference 7, "Data Flow Requirements and Data Handling Procedures".

APPENDIX D: DATA PROCESSING

D-1 Data Analysis Tools

Data analysis has been performed in the Windows 98 and NT environments on PCs, using Microsoft Access with General Dynamics-defined forms and queries, and custom-built C++ software tools for review of the data and running the algorithm code to generate track files. MatLab was also used for algorithm prototyping. Data examination and plotting is being done primarily using Microsoft Excel.

D-2 Tracker Algorithm Development

General Dynamics's prior experience in developing tracking algorithms was leveraged here and applied to the problem of creating code for this project. Two algorithms were independently coded and tested against the data to characterize their performance in recognizing objects in the data ("clustering") and their ability to track and generate accurate dynamic data representing the tracked object. Both used a Kalman filtering approach to model the track motion but the clustering methods were different. One used a "normalized innovation" approach, and the other a simpler agglomerative approach using a circular region. Initial experiments indicated that the agglomerative approach yielded better results (fewer instances of track splitting and multiple tracks on the same object). The discussion below describes the algorithm used for all subsequent data analysis.

D-2.1 Cluster Function

Clustering here is a modified agglomerative process. Beginning with the location of the first return in a scan, the function looks for all points within a cluster radius 'r_1' of the location to form the first cluster. The next return beyond the first cluster is the seed for the second cluster and so forth until all returns are associated with a cluster. A measurement is the centroid of the cluster (i.e., the mean range and azimuth of the measurements in the cluster). Some experimentation is required to determine an appropriate value for 'r_1'. After some experimentation the value of 'r_1' was chosen as 3 m for generation of data analysis results presented in this document.

D-2.2 Track Filter Function

The track filter is a fixed weight polynomial filter. This is essentially a Kalman polynomial filter with fixed values for the weighting matrix. This filter was chosen since no information was available to estimate the measurement error covariance. The target motion is modeled by second order polynomials in the radar polar coordinates (range and azimuth). This leads to a six variable state vector consisting of the range and azimuth, the range and azimuth rates, and the range and azimuth accelerations. Note that since the range of azimuth angles is limited to 12 degrees there is no problem with "wrap around". The choice of polar coordinates, which are statistically independent measurements, decouples the filter equations. That is, the measurement covariance is a diagonal matrix.

A track is initiated based on the nearest neighbor of a measurement in the current scan to a measurement from the preceding scan. The two measurements are assumed to be from the same target if the initial speed estimate is less than 'v_1'. This value was set to 30 m/s

for this analysis. The initial state for the track is (r, φ, r′, φ′, 0, 0) where r, φ are the current scan measurement (range and azimuth), r′, φ′ are the estimated range rate and angle rate and the accelerations are zero.

The initial estimated range and angle rates are calculated by differencing the first two range return observations and dividing by an empirically derived factor of two. The need for this modification arises due to the observed variability of first return ranges off of vehicles and the tendency for this variability to induce an erroneously large difference in range to the first two returns. These large differences produce correspondingly large, and erroneous—in most cases—first estimates of velocity. Dividing the first velocity estimate by an arbitrary factor is one of many ways to reduce the influence of noisy first returns off of following vehicles. Another technique to compensate for this sensor effect would be to simply wait for more observations before establishing the track. Either way, the net effect is to delay the recognition of a vehicle that is truly traveling extremely fast towards the bus—an undesirable but unavoidable consequence of poor sensor measurement reliability at the edges of its detection range.

Using the range coordinate as an example, the filter is updated by:

$$R_{k|k} = R_{k|k-1} + W_{rr} (r_k - R_{k|k-1})$$
$$R'_{k|k} = R'_{k|k-1} + W_{rr'} (r_k - R_{k|k-1})$$
$$R''_{k|k} = R''_{k|k-1} + W_{rr''} (r_k - R_{k|k-1})$$

where r_k is the measured range (cluster range center at time t_k) and the predicted range, range rate and range acceleration are determined from the equations of motion as:

$$R_{k|k-1} = R_{k-1|k-1} + R'_{k-1|k-1} \Delta t + ½ R''_{k-1|k-1} \Delta t^2$$
$$R'_{k|k-1} = R'_{k-1|k-1} + R''_{k-1|k-1} \Delta t$$
$$R''_{k|k-1} = R''_{k-1|k-1}$$

The weights are given by:

$$W_{rr} = 1 - \alpha^3$$
$$W_{rr'} = 1.5 (1 + \alpha) (1 - \alpha)^2 / \Delta t$$
$$W_{rr''} = (1 - \alpha)^3 / \Delta t^2$$

The measurement (r_k, φ_k) to associate with the track is determined as the nearest neighbor within a radius 'r_2' of the predicted measurement ($R_{k|k-1}$,$\Phi_{k|k-1}$). If no measurement is associated with the track in the current scan, the track is updated with the predicted measurement (ie: it coasts to the next scan). A track is dropped if it has not been updated by a measurement in time interval (Δt_{drop}). In the current analyses r_2 is set to 3 m and Δt_{drop} is set to 0.5 seconds, or 5 range sample intervals.

The filter constant 'α' represents the filter memory and can be defined in terms of a smoothing interval 'N' by:

$$\alpha = (N-1)/(N+1)$$

The smoothing interval determines the effect of past measurements on the current state estimate. In addition, the smoothing interval determines the dynamic (and random) errors for cases when the target motion is not described by the second order equation of motion. For the current data analysis N is 9 intervals, resulting in an α of 0.8.

D-3 Data Processing Methods and Tools

Data processing of the baseline data collected to date is being conducted with tools built in MS Access and MS Excel. Access forms and routines have been coded to enable execution of the tracking algorithm code on one hour of raw data at a time, or several hours at once. The Access forms-based execution of processing routines also include the automatic ingest of results into various tables for database query processing. Access database queries have been built to extract various parameters from the track summary statistics files produced for each hour of data, and from the raw track files themselves. These tools, in combination with ad-hoc Excel-based processing, statistics computations, plotting and analysis routines provide the infrastructure and basis for detailed examination, manipulation, organization and reduction of data produced by the baseline data collection system.

D-4 Parameter Calculations and Verification

All data produced by the collection system and derived based on this raw data has been checked for reasonableness and accuracy. Much time was spent in fine-tuning the algorithm processing to produce the most reasonable descriptors of following vehicle and bus velocities and accelerations, which in-turn are the input variables to all other derived parameters.

In addition to the attention paid to speed and velocity of the following vehicle as computed from the range data, two raw measurements in the collected data were found to exhibit characteristics that demand further attention. These were bus yaw, and bus speed.

Bus yaw is detected with a yaw sensor providing an analog voltage representing the magnitude of the angular velocity of the bus. This voltage is measured using a comparator and a reference voltage. System supply voltage serves as the reference. Since the reference can vary over time, the yaw measurement can be biased. A fairly constant bias in the yaw measurement was observed in the baseline data collections, so an offsetting bias constant was added to the raw yaw measurement to compensate. For the Phase III data collections, a dynamic biasing mechanism was be implemented in the DCS to ensure that the raw yaw data recorded is appropriately biased according to current system conditions so that downstream processing need not “second guess” this measurement. Part of the algorithm removes the error signal of the “natural” vibration of the bus coupling into the yaw measurements.

Bus speed is computed and recorded based on pulse counting of a signal originating in the transmission. This measurement was calibrated to within approximately + or – 1 mph by recording pulse counts while tailing the bus with a car having a calibrated speedometer. The DCS was originally fielded with this pulse counting occurring over a 1

second interval. When this was discovered during the collections it was deemed to provide too course a resolution on bus speed, so it was changed to a 0.1 second interval to correspond to the sensor update rate. Raw baseline collection data prior to 7/11/01, when this DCS change occurred, has been post processed to smooth the recorded bus speeds.

Processing Outputs

Although the tracker algorithm utilizes range and azimuth to maintain track state its position coordinates are translated to sensor X and Y coordinates for display and output. Figure D-1 provides a graphical representation of all the variables generated and/or passed through the algorithm processing code into track files. One track file is generated for each object recognized and tracked. Raw data is processed in one hour chunks.

Geometric data is relative to a coordinate system established by the range sensor on the back of the bus. The timestamp is relative to the beginning of the collection hour in which this track exists (0 origin). Raw range data consists of range values and (implicitly) azimuth for each range return by position of the data value with the 80-sample data packet provided every 1/10 second by the range sensor. All vehicle dynamics information is derived from the azimuth and range provided by the sensor and the measured bus speed. Raw bus speed information is filtered (smoothed) by the algorithms. Bus signal data is passed through from the raw data unaltered.

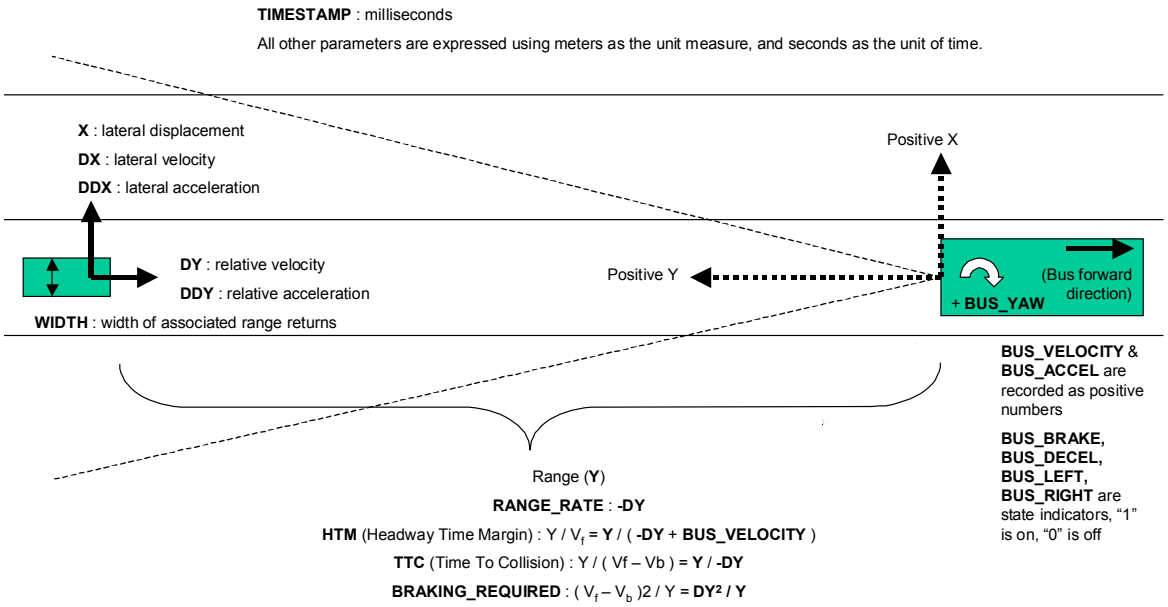


Figure D-1. Algorithm Output Data Description

TIMESTAMP	X	DX	DDX	Y	DY	DDY	WIDTH	RANGE_RATE	HTM	TTC	BRAKING_REQUIRED	BUS_VELOCITY	BUS_ACCEL
2354247	0.787687	-0.0948904	-0.000516141	50.8652	-6.12759	-0.03333	-1	6.12759	8.30101	8.30101	0.738174	0	0
2354347	0.828074	-0.123984	-0.016672	49.6618	-7.43563	-0.999862	-1	7.43563	6.67889	6.67889	1.1133	0	-0.609092
2354447	0.78355	-0.140726	-0.0300482	48.3915	-8.69112	-1.85576	-1	8.69112	5.56792	5.56792	1.56093	0	-0.609092
2354547	0.742008	-0.171583	-0.0520289	46.65	-10.7874	-3.27105	-1	10.7874	4.3245	4.3245	2.49448	0	-0.609092
2354647	0.717727	-0.174368	-0.051019	45.5742	-11.072	-3.2396	-1	11.072	4.11615	4.11615	2.6899	0	-0.609092
2354747	0.666778	-0.174682	-0.0511867	44.3506	-11.6189	-3.40468	-1	11.6189	3.8171	3.8171	3.04391	0	0
2354847	0.632907	-0.169587	-0.0459527	43.3298	-11.6102	-3.14599	-1	11.6102	3.73204	3.73204	3.11096	0	0
2354947	0.608271	-0.165645	-0.040981	42.3325	-11.528	-2.85206	-1	11.528	3.67213	3.67213	3.13933	0	0
2355047	0.585992	-0.170026	-0.0418728	41.1132	-11.929	-2.9378	-1	11.929	3.44649	3.44649	3.4612	0	0
2355147	0.541958	-0.165324	-0.0394405	39.9257	-12.1793	-2.90556	-1	12.1793	3.27815	3.27815	3.71531	0	0
2355247	0.537105	-0.166631	-0.035961	38.8776	-12.0614	-2.60299	-1	12.0614	3.22331	3.22331	3.74193	0	0

Figure 9. A Partial Listing of a Track File

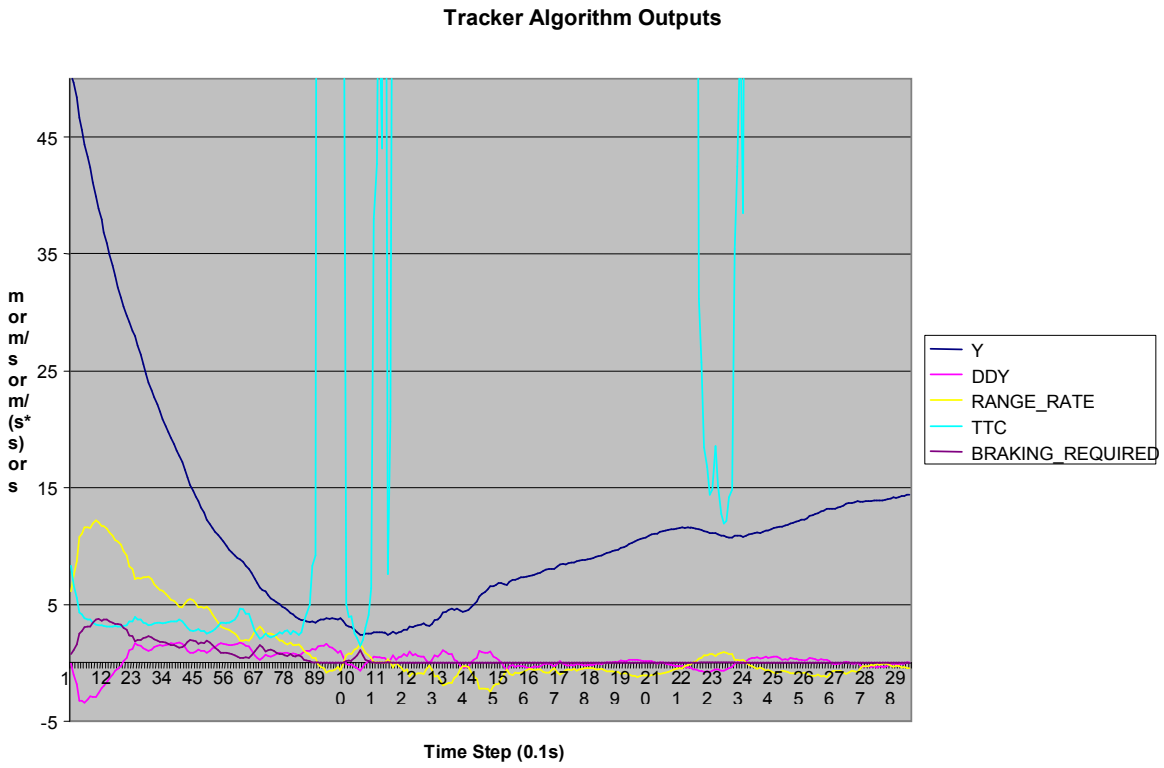


Figure 10. An Example Plot of Following Vehicle Dynamic Data

APPENDIX E: SIGNAL WARNING PARAMETERS AND ALGORITHM

E-1 Introduction

There are a number of conditions to be met along with the warning algorithm (based on range and velocity) calculations to be made that must be complied with before the warning light will be signaled. These calculations are performed on the track files, which are a result of the previously discussed tracking algorithm. These threshold conditions or qualifying parameters for signaling the warning will be discussed in the second section of this appendix. Then the algorithm for signaling the warning will be discussed in the third section.

Most of these qualifying parameters are not hard-coded in our testbed system, but rather are captured in a parameter file in the system to allow ease of manipulation as part of the intrinsic R&D aspects of this program. At each real-time sample of the RICWS system, each of qualifying parameters and the signaling the warning algorithm are calculated to see if it is time to turn on the warning lights at the back of the bus. So just to reiterate, even if all the calculations of the warning algorithm indicate the warning light should be signaled, the light will not be signaled if the qualifying parameters are not met. Within our process, the qualifying parameters were reasonably understood and fixed early in Phase II testing (however there were some adjustments at the end of Phase III testing), so the main area of research and testing was the algorithm area. As such, in this section the qualifying parameters will be discussed first, which will then set the stage for the algorithm development sections.

For this discussion, the following definitions will apply:
The RICWS-equipped vehicle is called the lead vehicle (LV), and the following vehicle representing the potential collision threat is called the following vehicle (FV). Let V_{FV} and V_{LV} denote the initial speeds of the FV and the LV, respectively, as shown in Figure E-1.

Let a_{FV} and a_{LV} denote the accelerations of the FV and the LV, respectively, at the moment of interest. (Acceleration is negative for braking).

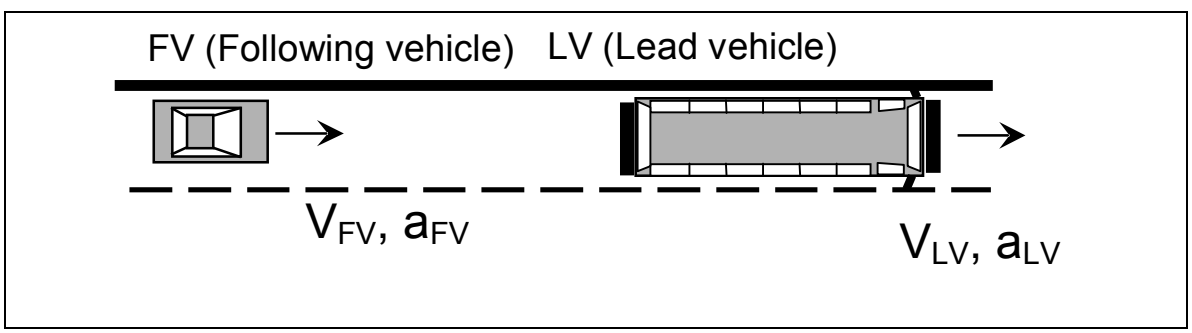


Figure E-1. Definition of Vehicles

E-2 Qualifying Parameters for Signaling the Warning

The set of parameters below are used in conjunction with the warning algorithm to enable the signaling of the warning. Note that all the parameters must be met before the warning is allowed to be signaled. Also, there are two categories of parameters. The first set of parameters is based on the history of the track file (single following vehicle). The second set is the category of instantaneous parameters that must be met at the point in time when it is desired to signal the warning light. If any of the parameters are false in either of the categories, then the warning will not be signaled. Note, that if at that instant in time all the parameters are not met, then the warning light will not be signaled, however on the very next time sample, the all the criteria could be met, and the warning lights would be signaled. So in some cases, the qualifying parameters tend to delay this signaling of the warning, which is in line with the concept of reducing the number of false positives. The list of parameters below is a rather comprehensive set to minimize false positive warnings. It is strongly felt that signaling too many false positives would significantly reduce the acceptance and effectiveness of the RICWS.

Since it is required that all the parameters be true before a warning can be signaled, there is not an implied greater importance to one parameter of another. Also, the identified parameters can be referenced to the Figure E-2 below.

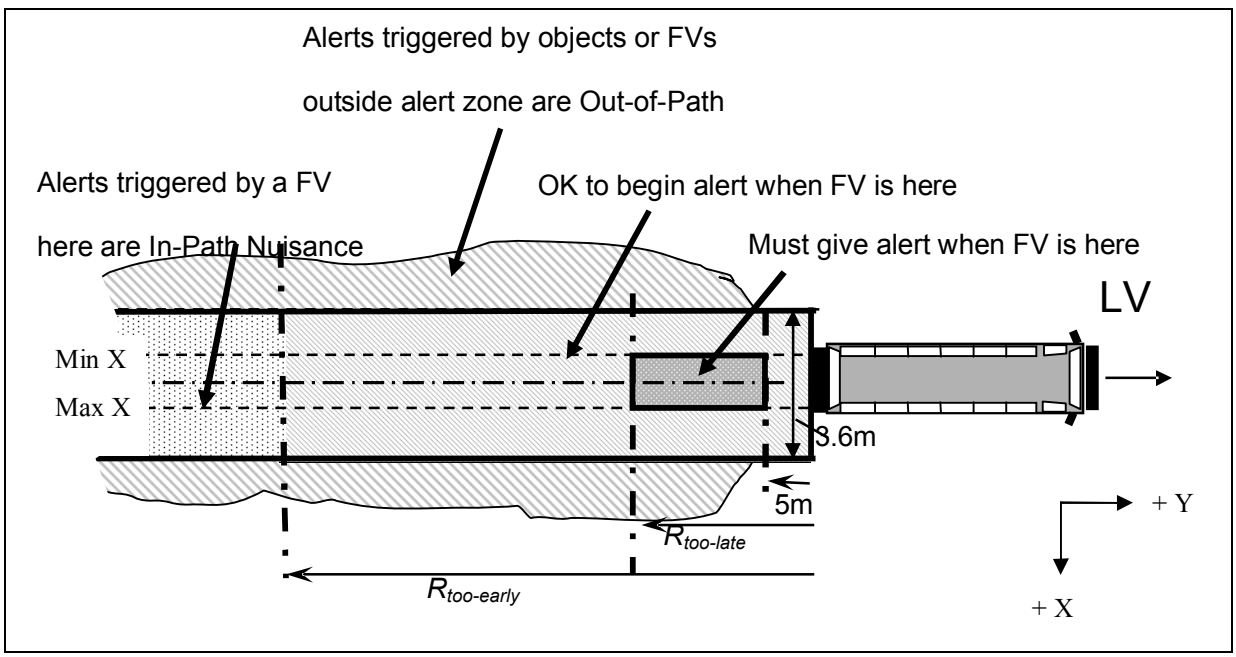


Figure E-2. Combining Alert Timing Rules and Alert Zone Requirements

The parameters and criteria and for this are:

A. Historical Parameters – The parameters which must be true over the history the track file

1. Min X (lateral position) < 0.8m, and Max X >-0.8m. It is required that the following vehicle have reflectors within this corridor at some point within the track file. During the collections, the corridor distance was held at this value as a way to minimize nuisance alarms. The goal was to filter out many "adjacent lane" passing vehicles that never approach the centerline of the bus axis, and therefore are not in the bus lane. However, during in the second to last set of data collections, we examined some track file cases where the reflectors were not within this narrow corridor (for example, headlight reflectors wider than ±0.8 meters) but still a concern. As identified on the video however, the following vehicle was offset and headed directly at the back of the bus and due to the offset, the warning was not signaled. It was a situation in which the warning light was defiantly needed to be signaled, but was prevented by this parameter. As such, we recommend for any subsequent or product that the corridor be set at the width of the leading vehicle (a bus is roughly plus and minus 1.29 meters). So in any case (track file) that following vehicle (reflector) is approaching the bus and at some point in time the reflector is in a corridor (the width of the bus) directly behind the bus, then there is a potential to signal the warning.
2. Min DX (lateral velocity) <>0. (Actually implemented with 0.05 meters of lateral velocity to facilitate comparisons of numbers within the C++ applications software.) This eliminates tracks that never have a zero crossing in lateral velocity (i.e., tracks which move consistently in one lateral direction or the other—not likely on a collision trajectory).

B. Instantaneous Parameters – The parameters related to the decision process at the instantaneous point of desiring to signal the warning. This point is arrived at when the real time warning algorithm calculates that it is time to signal the warning, based on the closing properties of the following vehicle with respect to the lead vehicle (bus).

1. -2m < X < 2m. This insures the following vehicle is within a corridor of plus or minus 2 meters behind the bus at the point it time when it is desired to signal the warning. This parameter is in conjunction with the similar corridor in the history set of parameters. The history parameters insures the following vehicle was in the collision corridor at some time during the history of the track of the following vehicle and the instantaneous parameter insures it is within this corridor when it is time to signal the warning.
2. Min Bus Yaw <1deg./sec, and Max Bus Yaw >-1deg./sec. These criteria eliminate tracks that occur while the bus is turning quickly. During all but the last set of collections, the threshold was set at 1 degree/second. During analysis of various track files, it was identified that the threshold was set too low, eliminating too many tracks where there was a slight swerve of the bus, so for the last collection testing the threshold was increased to 5 degrees/ second, which was more conservative and would

allow more vehicles to be warned. This value seems to be a good value for yaw.

3. Y > 8m. This criterion ensures that the braking required being looked for does not occur very close to the bus, where the range sensor output date is poor.
4. DX < 1 and DX > -1 (m/s). This criterion demands that a following vehicle has at most only a small lateral velocity indicating that it is not pulling around the bus.

E-3 Algorithm for Signaling the Warning Light

The algorithm is one of the primary areas of research for this program. Within the scope of the proposal, the "algorithms used to establish appropriate trigger conditions will be evaluated and enhanced to meet the new performance specifications." Our initial baseline collection and associated processing efforts indicated that a fixed threshold around 0.225 Gs would work as nicely. After some results with this algorithm, we performed some collections to evaluate a less conservative approach where fewer warnings would occur. For these data collections, we set the threshold at 0.3 Gs, which is consistent with industry evaluations of braking required for normal stops. This is a reasonably aggressive stop (intuitively, items sitting on the car seat begin to slide off at this braking level). After a fairly extensive collection period, no warning light were signaled, indication that this was to aggressive. And, related to our human factors testing, we identified that this aggressive braking algorithm does not provide a delay time for the motorist to recognizing the need to stop and the reaction time needed to begin braking. However, our background research indicated that the Crash Avoidances Metric Partnership (CAMP) studies addressed this situation. The CAMP algorithm modifies this criterion to include a delay time to account for the reaction time of the motorist seeing the system warning and the motorist's reaction time to apply the brakes and start the braking process. In addition, our human factors studies indicated that at higher following vehicle velocities the following vehicle driver would prefer a higher threshold be reached before the warning was signaled. The CAMP algorithms address this situation also. The details of all these conditions will be discussed in the following sections of this appendix.

E-3.1 Fixed Reference Threshold Warning

Basic Braking

To give an intuitive feel for braking rates, Figure E-3 shows the braking profiles vs. time for braking regimes from 0.2 Gs up to 0.7 Gs. Thirty miles per hour was selected as the initial velocity and is indicative of a closing rate that is commensurate with speeds in our accident study profile. The graph plots these profiles from the initial velocity to zero velocity where the vehicle has stopped. The braking regimes that we could expect a motorist are in the range of 0.2 G to 0.3 G for the 30 mph initial velocity, an up to 0.4 Gs considering the CAMP algorithm that will be discussed later. This equates to a stopping distance in the range of 4.5 seconds to 7 seconds. This correlates well to the 5 seconds of data we plot following the threshold warning as shown in the conclusion section. It should also be mentioned that no driver ever brakes as such constant values, but the plots are just indicative of the average braking the driver can do.

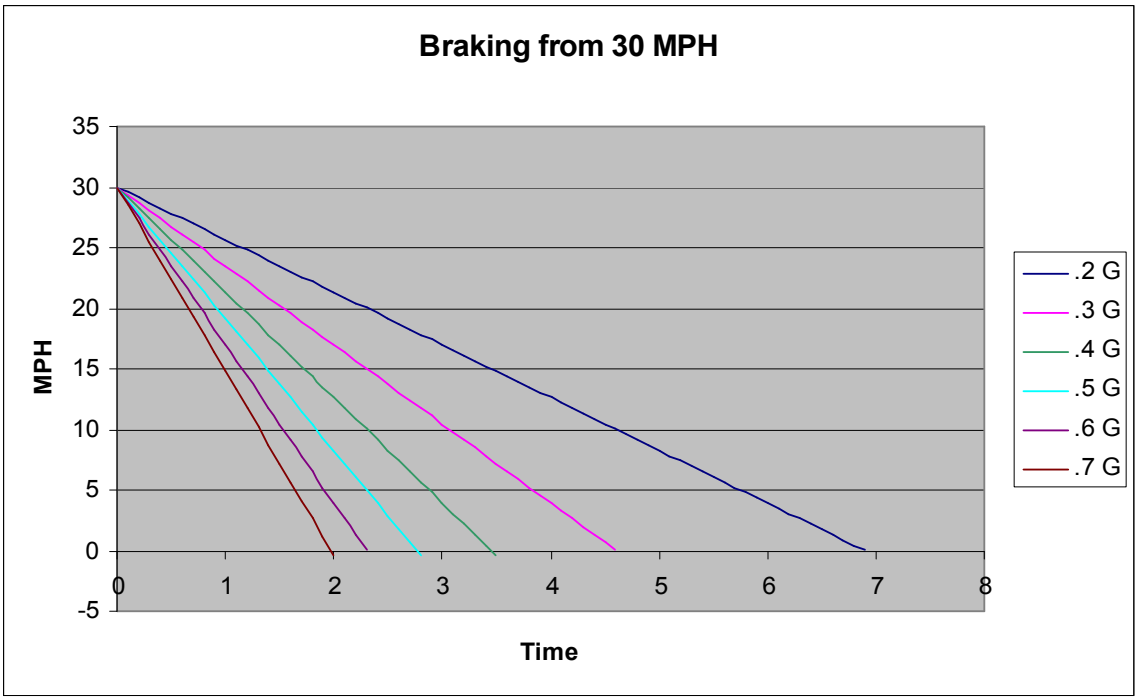


Figure E-3. Braking Rates from 30 mph

The first item to establish is the reference threshold value for signaling the warning. In the present system, the warning is signaled when the braking required first get to the value of 0.3 G braking required. However our new approach is different since the CAMP algorithm adds a 1.4 second time delay of the driver reaction and the brake system application. So the first step is to establish the reference threshold for the maximum total time allowed for braking based on the CAMP algorithm. After this total time had elapsed the following vehicle's velocity would have been reduced to zero. The equation below is based on closing velocity and a distance from the bus such that when the velocity goes to zero, the following vehicle is directly behind the bus.

Figure E-4 is a plot of velocity in meters/second and miles/hour and distance in meters versus time for a 0.3 G braking regime. This graph is included to help the reader decode easily from mph to M/S and to identify the distance traveled in a given amount of time for this braking rate. Note, the plots are all plotted for positive numbers, however in the real following vehicle scenario, the velocity goes from the initial velocity down to zero, and the distance is the closing distance traveled by the following vehicle behind the bus.

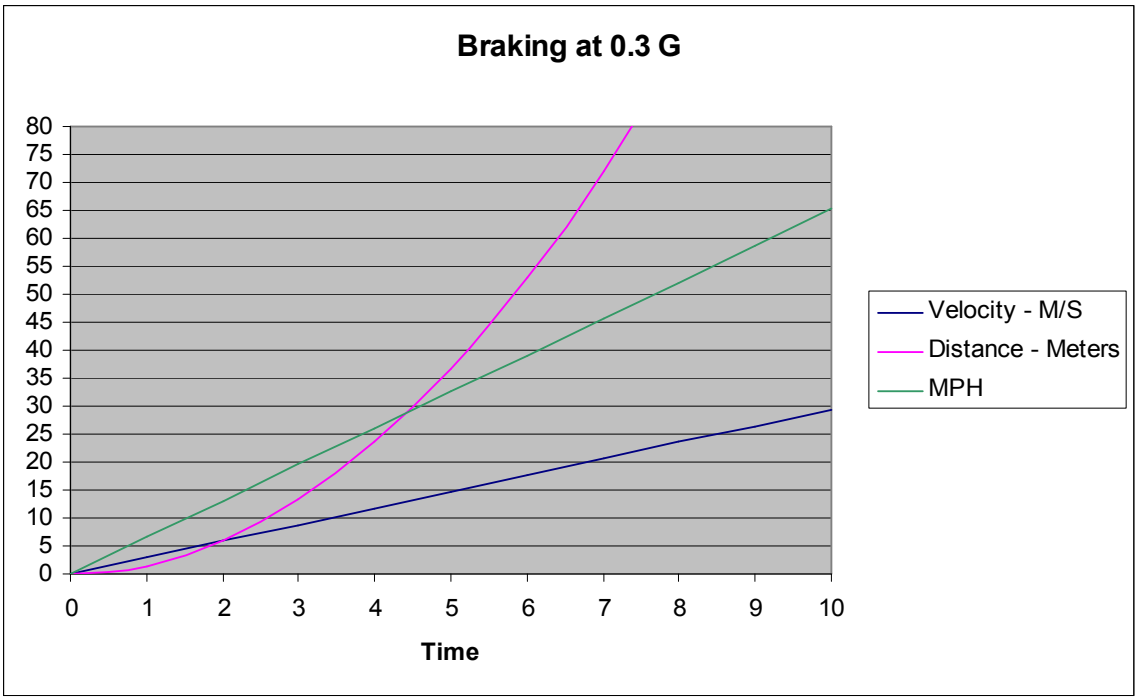


Figure E-4. Velocity and Distance Plots at 0.3G

Algorithms - Fixed Threshold Warning

For the initial data collections in Phase III RICWS data collection, it was selected to use fixed thresholds for signaling the warning lights to establish a baseline. Two values of threshold were selected, 0.3 G and 0.225 G. In addition to helping to establish the baseline, the 0.3 G value was selected based on industry literature search values indication that 0.3G was a "comfortable aggressive stop". The 0.225 G threshold was selected a lower fixed threshold to compensate a little for driver reaction time. It was also a number selected due to our human factors evaluation testing of following vehicles approaching a stationary bus.

The equations for implementing this fixed threshold can be viewed from either a distance (safe distance) behind the bus or a braking required parameter. Both parameters are intrinsically related by physics equations, and are just two different views of the same scenario. We will discuss both views, since each has its salient features. In the following examples we will us 0.3 G as the threshold for initiating braking.

First from a safe distance perspective, for any given approach speed by the following vehicle, there is a minimum distance at which a 0.3 G constant braking will stop the following vehicle just behind the bus. This is the minimum safe distance. If the following vehicle continues at its speed and moves closer than this minimum safe distance, then the algorithm should identify this and warn the following vehicle driver. This algorithm is based on the simple equation of motion:

(1) $y = \int (V_0 + a \cdot t)\, dt$ where y = distance between vehicles
V_0 = initial velocity = closing velocity
a = deceleration (0.3 Gs in our example)
t = time

This reduces to:

(2) $y = V_C \cdot t_D + \frac{1}{2} \cdot a \cdot t^2$ where t_D = delay time before braking which is set to zero for fixed threshold warning
V_C = closing velocity between vehicles

So from above

(3) $y = \frac{1}{2} \cdot a \cdot t^2$

Now (3) is the general equation for calculating the distance between the following vehicle and the bus. Our goal is to compare the distance measurement from our sensor to some calculated safe distance where the following vehicle can stop in time before hitting the bus. This safe distance changes with following vehicle speed. As would be expected, as the following vehicle has a higher speed, the distance needed to stop (at some constant braking rate) would increase. So the our algorithm needs to calculate the safe distance to the bus taking into account the instantaneous velocity and selected braking threshold and compare it to the actual distance between the following vehicle and the bus.

So to rewrite equation (3) to express safe distance as a function of velocity, we need the additional equation of motion from physics

(4) $a = dV / t$ or $t = dV/a$ where $dV = V_C - 0$, which is the change in velocity going from V_C to a stop

Substituting (4) into (3) and expressing y as a function of V and a (eliminating time)

(5) $y_s = V_C^{\,2} / (2 \cdot a)$ where y_s = safe distance between vehicle

So for the fixed warning threshold algorithm, on a pulse by pulse basis, the RICWS calculates the minimum safe distance between the following vehicle and the bus based on the RICWS sensor data for velocity, and compares it to the sensor data for distance between the bus and the following vehicle. If at any sample point, the sensor distance data is less than the calculated safe distance, then the following vehicle is too close (for the closing velocity) and the warning lights are signaled.

Now this is a very simple calculation for the RICWS system to implement, however since the safe distance changes with closing velocity there is not an intuitive understanding of the value for a safe distance, because it is not fixed. It would be nice to have some other way to look at the situation that was independent of the changing variables. For instance, we would not pick headway (time), because again, that is dependent on closing velocity, and so the time is always changing. From our basic research in the first phase, we

identified "braking required" as this key variable that is independent of closing velocity. So for our example, the threshold would be set to value of 0.3 Gs. If the following vehicle every had a closing speed and distance to the bus such that it needed to brake at a higher rate than our 0.3G threshold, then the RICWS would signal the warning light.

To do these calculations, we again start with the same distance calculation as in the "safe distance" based scenario. So, the starting equation is:

(6) $y = V_C \cdot t_D + \frac{1}{2} \cdot a \cdot t^2$

Again as in the previous fixed threshold approach, the time delay is zero. So the equation (6) reduces to equation (3).

Now solving for

(7) $t = \sqrt{(y \cdot 2/a)}$

Now eliminating t by using the equality $v = a \cdot t$ and applying it to equation (7)

(8) $V_C/a = \sqrt{(y \cdot 2/a)}$ where again, V_C = vehicle closing velocity

Solving for a, or the braking required, we have

(9) $a = V_C^{\,2}/(2 \cdot y)$

In this "braking required" equation, if the actual braking required (a) calculated from the distance to the bus and the velocity of the following vehicle (see equation 9) exceeds our set threshold (of 0.3 Gs in this example) then the warning light needs to be signaled. Note that equation is equivalent to equation 5, (just written in different forms) which says the safe distance algorithm is equivalent to the braking required algorithm.

In Table E-1 below, we have listed the safe braking distances for both 0.3 Gs and 0.225 Gs which were implemented in our Phase II data collections. So this is the distance from the bus that the following vehicle will be warned for each of the closing velocities identified. This distances will later be compared to the more conservative CAMP algorithm.

Table E-1. Safe Braking Distance vs. Closing Velocity

Closing Velocity mph	Safe Braking Distance .225G	Safe Braking Distance .3G
15 mph	10.2 meters	7.6 meters
20 mph	18.1 meters	13.6 meters
25 mph	28.3 meter	21.2 meters
30 mph	40.8 meters	30.6 meters
35 mph	55.5 meters	41.6 meters
40 mph	72.5 meters	54.3 meters
45 mph	91.7 meters	68.8 meters

Our implementation did not try to compensate for second order effects of bus acceleration or deceleration, it just looked at the relatively velocities between the two vehicles. Research could be conducted to optimize the parameters with respect to bus acceleration (+ or -), however it is expected that the resulting differences in warning would not be that significant. During bus acceleration from a stop, our simpler algorithm which does not take into account the second order bus acceleration effects (especially considering the normal acceleration of buses) would on be just be a little more conservative and signal the warning a little earlier or more often, but not enough to be considered a false positive. For the bus braking scenario, since buses do not normally brake at high rates of deceleration (passenger comfort), this second order effect is considered to be small. If a panic stop were initiated by the bus, our algorithm would not be as conservative as in the stopped bus scenario, however the intent of the RICWS is to address the predominate rear-end collision scenario, which is over 51 percent of the time the bus is stopped intending to go straight. As such we opted to focus on this scenario and not try to include mitigation of accidents where the bus is stopping at a high rate of deceleration with the potential to convolute the findings.

E-3.2 CAMP Warning Algorithm

As discussed above, two effects were not fully accounted for in the fixed threshold warning scenarios. First, the delay time of the driver to recognize the need to brake and the delay time to physically start the braking. This was partially addressed by evaluation of the lower 0.225 G braking required threshold to "effectively" allow greater time for the driver to reach. The second unaccounted scenario was that at higher velocities drivers preferred to have the threshold set higher. In our human factors testing, with the threshold set at 0.3 Gs, numerous drivers thought this threshold was too low (the light cam on too soon) at higher velocities (35 to 45 mph), even though these same drivers found the warning threshold appropriate for the 25 to 30 mph speed range. The researchers at CAMP also identified these effects, and applied significant research to the issues. We accepted their findings and results and applied them to our system. In applying their algorithm, we just called it the CAMP algorithm, even though their research was not specifically aimed at rear impact warning systems for transit buses, nor was it developed for a system where the sensor was mounded on the lead vehicle .

The implementation of the CAMP algorithm is again based on the basic equations of motion. We will again start with the initial equation from the fixed threshold scenario. Repeating the basic equation:

(10) $y_s = V_C \cdot t_D + \frac{1}{2} \cdot a \cdot t^2$ where y_s = safe following distance
t_D = delay time before braking is initiated
V_C = closing velocity between vehicles
a = following vehicle required braking

We will define this safe distance in the camp algorithm as Y_{CAMP}. In the first term of the equation, the variable t_D is the delay time before the brakes are applied. CAMP research identified this value as 1.38 seconds, which is what we used in the RICWS system. So now the equation now becomes:

(11) $Y_{CAMP} = V_C \cdot 1.38_{seconds} + ½ \cdot a \cdot t^2$

from substituting t = dv/a into equation (11)

(12) $Y_{CAMP} = V_C \cdot 1.38_{seconds} + ½ \cdot a \cdot (V_C / a)^2$

$Y_{CAMP} = V_C \cdot 1.38_{seconds} + (V_C)^2/(2 \cdot a)$

or

(13) $Y_{CAMP} = V_C \cdot (1.38 + V_C/2 \cdot a)$

Now as we identified above, one of the issues associated with our human factors testing and the CAMP research was that the braking required should be adjusted as a function of following vehicle closing velocity. As such a term is needed to be added to equation (13) that changes the value of "a" as a function of velocity. The particular expression for this variable is:

(14) $a_C = 0.26Gs + 0.00727 \cdot V_C$ where closing velocity V_C is in meters/second
Note: the coefficients are in Gs, but will need to
Converted to meter/second^2

A plot of this equation is shown in Figure E-5, comparing the previously fixed threshold of 0.3 Gs to the modified "braking required" value generated by the CAMP equation.

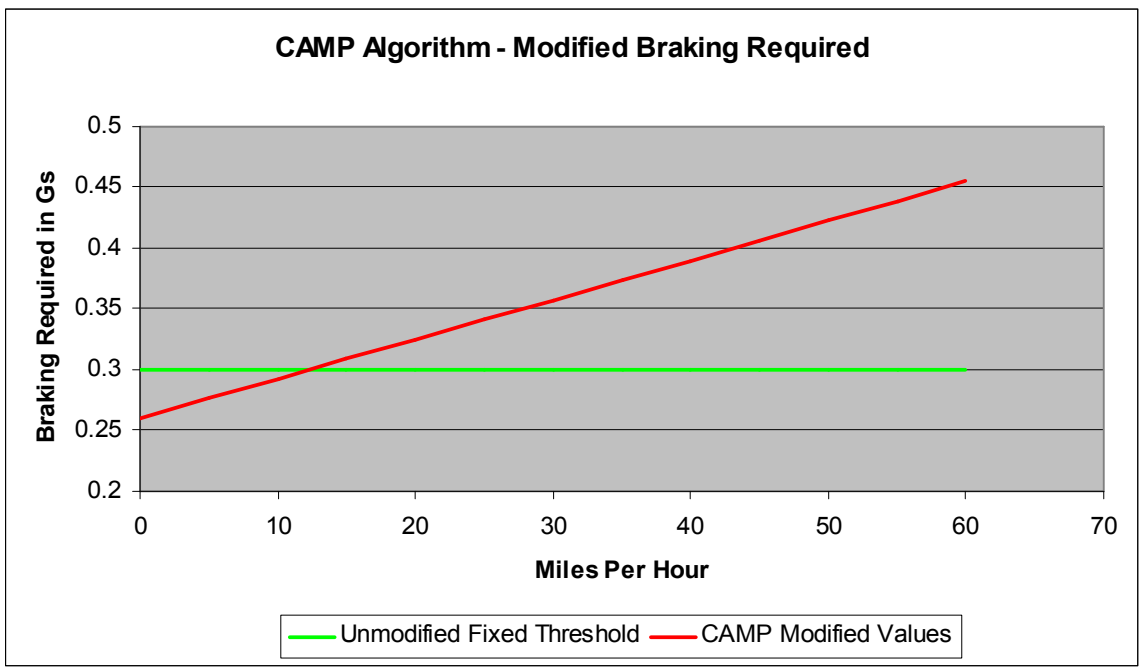


Figure E-5. CAMP Algorithm Modified Braking Required

Now to calculate our CAMP minimum safe distance we substitute a_C in equation (14) into equation (13) for acceleration "a", we get

(15) $Y_{CAMP} = V_C \cdot (1.38 + V_C/(2\cdot (0.26Gs + 0.00727\cdot V_C))$

Now converting the G variables into meters/second^2, equation (15) becomes

(16) $Y_{CAMP} = V_C \cdot (1.38 + V_C/(5.099458 + 0.142588691\cdot V_C))$

This is the shortest safe distance behind the bus and it the point where the warning lights would be signaled. Calculating these values for various miles per hour and putting them into table similar to table, we get Table E-2 below. Note that the CAMP algorithm is more conservative (more warnings and more braking distance allowed) than a 0.225 G fixed threshold up to about 35 mph and similarly is more conservative than a 0.3 G fixed braking threshold up to approximately 58 mph.

Table E-2. Comparison of CAMP Safe Braking Distance

Closing Velocity mph	Safe Braking Distance .225 G	Safe Braking Distance 0.3 G	CAMP Safe Braking Distance
15 mph	10.2 meters	7.6 meters	16.8 meters
20 mph	18.1 meters	13.6 meters	25.1 meters
25 mph	28.3 meter	21.2 meters	34.3 meters
30 mph	40.8 meters	30.6 meters	44.5 meters
35 mph	55.5 meters	41.6 meters	55.4 meters
40 mph	72.5 meters	54.3 meters	67 meters
45 mph	91.7 meters	68.8 meters	79.1 metes
50 mph	113.3 meters	84.9 meters	91.8 meters
55 mph	137.0 meters	102.7 meters	104.9 meters
60 mph	163.0 meters	122.3 meters	118.5 meters

The CAMP algorithm assumes a constant braking profile for its calculations. Related to these calculations and the distances provided in Table E-2, profiles of the CAMP braking/velocity profiles are graphically shown in Figure E-6.

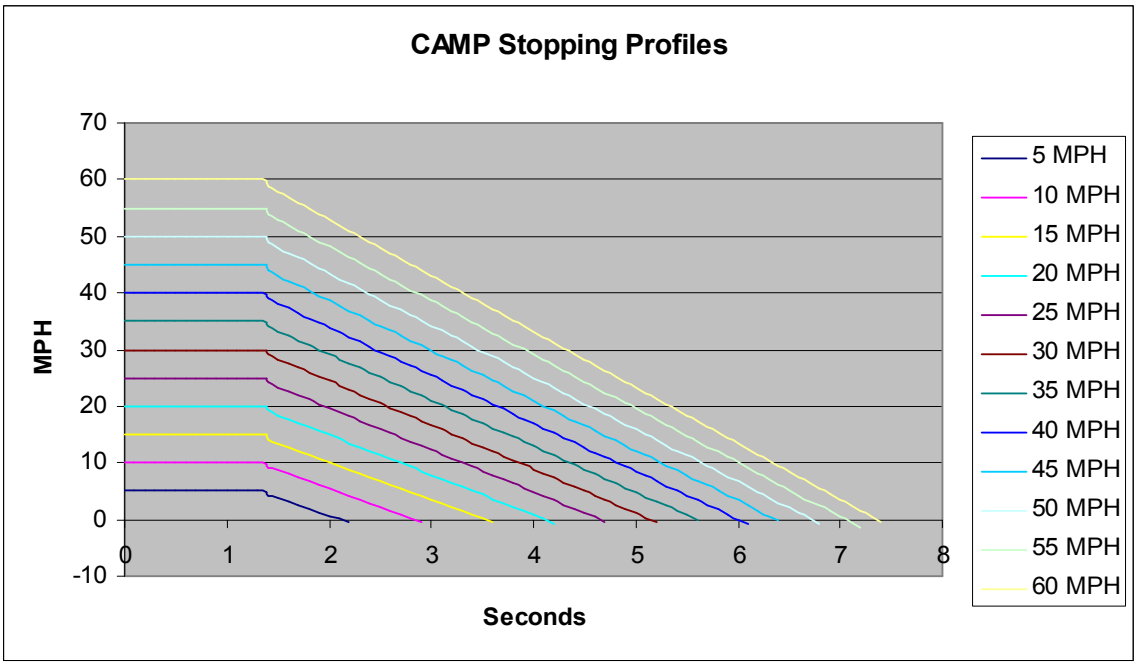


Figure E-6. CAMP Stopping Profiles

These profiles indicate that allowed safe time to stop is between 2 and 7.5 seconds with associated stopping distances of 3 meters (at 5 mph) to 118.5 meters at 60 mph. This algorithm as depicted here is implemented in the final set of Phase III data collection tests. Note, that because of the initial 1.38 seconds delay time in the CAMP equation, the overall effective braking required is less than the CAMP instantaneous modified braking required as shown in Figure E-6. This difference is depicted in Table E-3. So it would not be unexpected to have phase II warning signal plots with average braking required values as low as 0.126 Gs.

Table E-3. Effect of CAMP Delay Time on Effective Braking Required

Following Vehicle Closing Speed - mph	CAMP Modified Instantaneous Braking Required	CAMP Effective Braking Required
5 mph	0.276 Gs	0.126 Gs
10 mph	0.293 Gs	0.152 Gs
15 mph	0.309 Gs	0.185 Gs
20 mph	0.325 Gs	0.217 Gs
25 M,PH	0.341 Gs	0.240 Gs
30 mph	0.375 Gs	0.261 Gs
35 mph	0.374 Gs	0.280 Gs
40 mph	0.390 Gs	0.299 Gs
45 mph	0.406 Gs	0.317 Gs
50 mph	0.422 Gs	0.330 Gs
55 mph	0.439 Gs	0.348 Gs
60 mph	0.455 Gs	0.367 Gs

APPENDIX F: BASELINE DATA COLLECTION

F-1 Baseline Data Collection

One AATA bus (#382) was outfitted with the system described above and put into service on April 25, 2001. This bus was generally assigned to the same routes each day but did see service on other routes from time to time. The main routes traveled have been routes 5 and 3, shown below (Figure F-1). However, this bus has traversed many other routes during the course of this data collection.

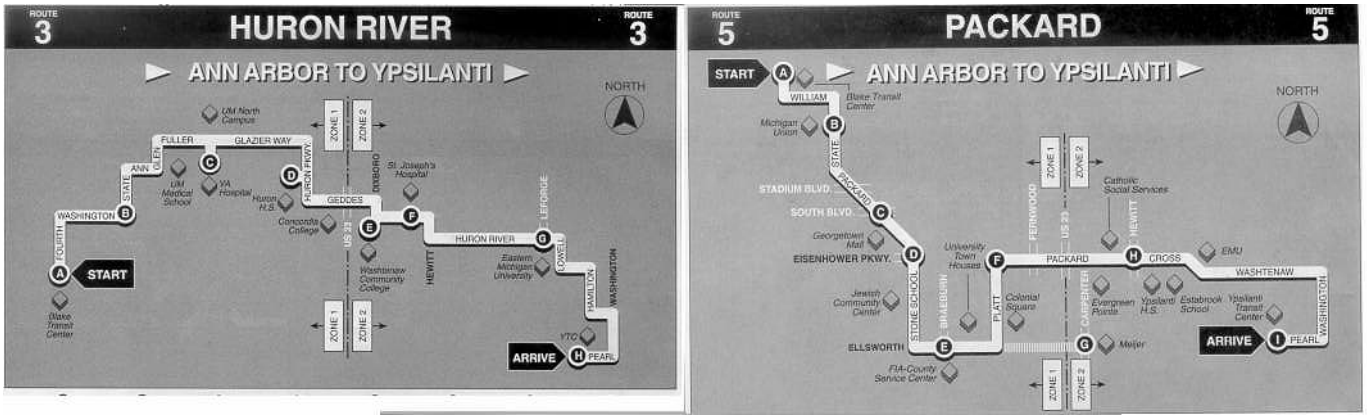


Figure F-1. Primary Routes Traveled by AATA Bus 382 with DCS

These routes consist of a mix of side streets, collectors, and main arterial roadways, including four and five lane roads with speed limits up to 40 mph.

F-2 Quantity

A total of 640 hours of run time has been collected between April 25, 2001 and August 31, 2001 inclusive. This corresponds to about 40 gigabytes of collected data.

A very small amount of data collected was corrupted by shock and/or EMI events as it was being collected (as noted in the previous section). Overall, data collections from about eight hours (1.25 percent) of the DCS run time was compromised due to these problems, but since the system modifications less data has been corrupted. Prior to the system changes, about 207 hours were collected, with about five hours (2.4 percent) lost due to file corruptions. After the system changes, an additional 434 hours were collected, with about three hours (0.7 percent) lost due to file corruptions.

Run time does not exactly correspond to actual time on the road. The buses are started up early in the morning and idle in the AATA garage for a significant period of time. Maintenance activities and daily washing in the garage account for still more time that is irrelevant to the study purpose. How much of the total time collection time is accounted for by these activities remains to be assessed. Based on qualitative review of a few days of data it is estimated that no more than about 7 percent of the data may be irrelevant. This still leaves approximately 587 hours of on-the-road collection time available for analysis.

F-3 Baseline Data Collection Data Analysis:

Initially the analyses that are presented in this section addressing the baseline data collection were based on a two stage filter (query) to find relevant "events" in the data where the tracks exhibiting Braking Required of >0.3g and >0.4g. During this entire phase of the program this is the scaling that was used. However during the human factors testing that was performed in April of 2003, we had human factors testing results that just did not agree with industry results, by a significant margin. Upon a detailed analysis of our processing algorithms, it was identified that there was a processing scaling error of a factor of two. Due to this, and some of the early results in the Phase III data collection, algorithms were modified accordingly and data analysis and planning were also adjusted accordingly. So the analysis presented below, originally based on the 0.3 G and 0.4 G thresholds were really at the 0.15 G and 0.2 G thresholds. The analysis values were modified in the results presented below.

These errors in scaling during the baseline calculation initially lead us to expect many more incidents that were actually finding. However, we quickly compensated from this misguidance and all the data results and conclusions in the Phase III data collection is based on correct scaling.

The analysis in the rest of this section has been corrected to utilize the corrected values.

A data filter has been constructed to cull out the information needed from the baseline data already collected to help quantify the size of the subsequent data collection necessary to assess the hypothesis above.

A two stage filter (query) is utilized to find relevant "events" in the data, i.e., tracks exhibiting Braking Required of >0.15 G and >0.2 G. The first filter step is a "pre-filter" that serves to minimize the amount of actual track data that must be examined to find relevant tracks. Since the criteria for the two filters are slightly different the results would be different if the second filter was used alone to scan all the track data. The filters work as follows:

A. Using track statistics (compilation of all parameter minimums, averages and maximums over the lifetimes of the tracks) a selected subset of tracks is produced. The criteria for this selection are:
    1. Max Braking Required >0.15 G or >0.2 G.
    2. Min X (lateral position) < 0.8m, and Max X >-0.8 meters. These criteria serve to filter out many "adjacent lane" passing vehicles that never approach the centerline of the bus axis, and therefore are not in the bus lane.
    3. Min Bus Yaw <1deg./sec, and Max Bus Yaw >-1deg./sec. These criteria eliminate tracks that occur while the bus is turning quickly.
    4. Max Y (range) > 8 meters. This eliminates tracks that are very close to the bus for their entire lifetimes.

5. Min DX (lateral velocity) <>0. This eliminates tracks that never have a zero crossing in lateral velocity (i.e,. tracks which move consistently in one lateral direction—not likely on a collision trajectory).

B. The track data records for the subset of tracks resulting from the selection above are then queried for the simultaneous presence of the following criteria:
   1. Braking Required >0.15 G or 0.2 G
   2. -2m < X < 2m. This provides a somewhat less restrictive test of track records for filtering adjacent lane passing vehicles.
   3. –1deg.sec < Bus Yaw < 1deg.sec. This provides the same filter on individual track records as that performed on the min/max track statistics records.
   4. Y > 8m. This criterion ensures that the braking required being looked for does not occur very close to the bus, where the range sensor outputs are suspect.
   5. DX < 1 and DX > -1 (m/s). This criterion demands that the vehicle be on a nearly true trajectory towards the bus.

Track records remaining from this second query represent portions of the tracks that are candidates for inclusion in the study group of incidents. These are vehicles exhibiting following behavior that could be deemed sufficiently threatening to warrant a warning light flash. Those tracks that meet the 0.15 G criteria would yield a warning light flash (or not, if the bus system observing that behavior was assigned to the "control" group), and those tracks that meet the 0.2 G criteria are the sub-set (of the first 0.15 G group) of samples by which this experiment will attempt to observe a behavioral change in the warned drivers. The expected observable effect is, therefore, a reduction in the number of tracks that ever reach 0.2 G Braking Required in the population of tracks observed while the warning light was operational versus the number of tracks reaching the 0.2 G threshold in the population of tracks obtained while the warning light was not operational. The measure to be used to quantify this effect is the time between occurrences of tracks exceeding the 0.2 G threshold.

The results of these interrogations of a particular day (8/17/01) of baseline data are as follows:

Number of "candidates" for warning (Braking Required excursions >0.15 G) = 123
Number of these candidates with subsequent excursions >0.2 G = 70

The collection of 8/17/01 spanned approximately 12.5 hours. Under the described conditions the warning light would have flashed 123 times (or almost 10 times per hour), with 70 of these vehicles exhibiting subsequent behavior that could cause them to be candidates for inclusion in this experiment as samples.

Further insight into these tracks' behavior is needed to ensure that these 70 samples would be capable of yielding relevant observable changes in behavior.

The further problem to be addressed here is driver reaction time as it relates to track length and Braking Required parameter behavior. The question that must be answered is whether the track length and duration of excessive Braking Required behavior is such that the driver's observation of the warning light has the potential to cause an observable reduction in the maximum Braking Required during the subsequent course of the track. In other words, do we see tracks in the baseline data that provide sufficient reaction time between the observation of 0.15 G Braking Required and the subsequent occurrence of the 0.2 G value? Such a track represents a candidate that could be observably influenced by the warning light.

For an observation to be useful, Braking Required should be an increasing function of time from the point at which the warning is to be flashed. Also, a vehicle tracked for less then a second (or whatever interval is appropriate to describe a typical reaction time) will yield no useful information on the behavior of the driver even if the warning light was flashed.

Based on the discussion above, a further filtering step was constructed that required the following to be true:

- The elapsed time from the 0.15 G reading to a 0.2 G reading was at least 1 second (to allow time to react).
- The first 0.2 G reading does not occur within 0.9 seconds of the end of the track (such tracks were found to be lane changing passing vehicles that had made it through the earlier filter criteria—this additional test eliminates remaining passing vehicle tracks from consideration).

This examination of the tracks for the 70 incidents previously located resulted in a finding that only three of these tracks met these additional requirements. These tracks represent viable "observations" of the behavior that is the target of this experiment. The first 10 seconds of each of these three tracks are plotted below (Range and Braking Required as functions of time, Figures F-2 and F-3.)

Note that all the criteria defined above for identification of "events" for the purposes of this experiment are objective and can be programmed as database queries and/or track selection algorithms on the recorded track data and summary statistics.

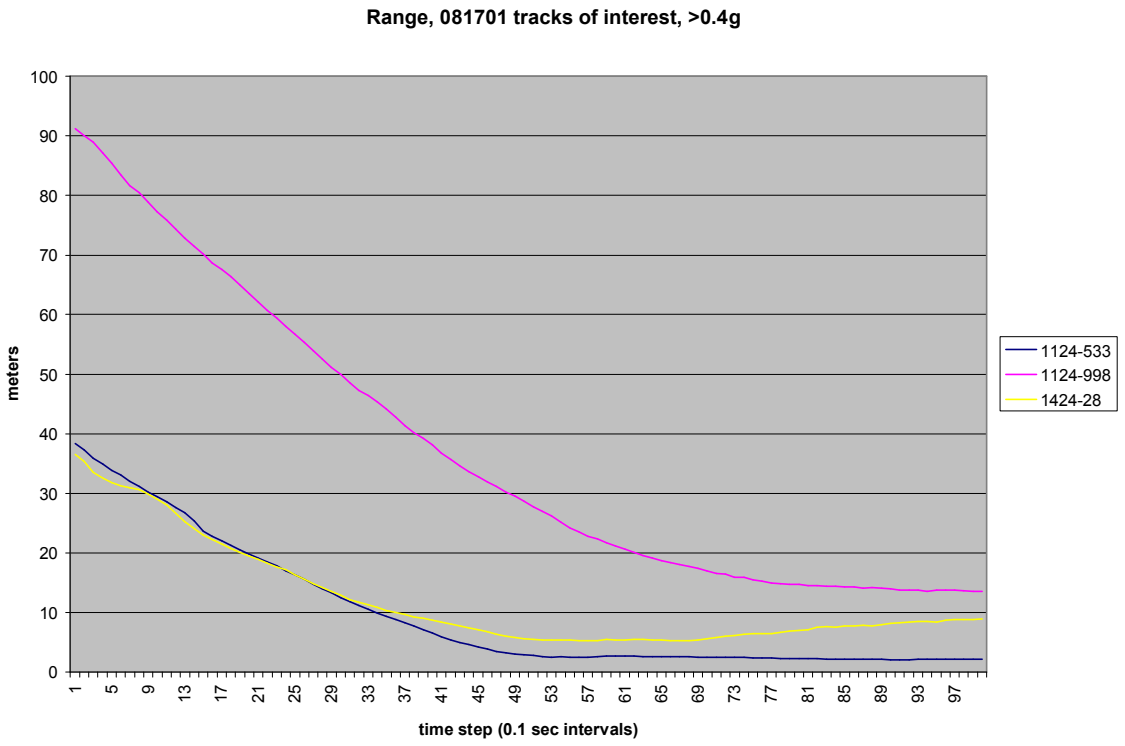


Figure F--2. Range for Tracks of Interest.

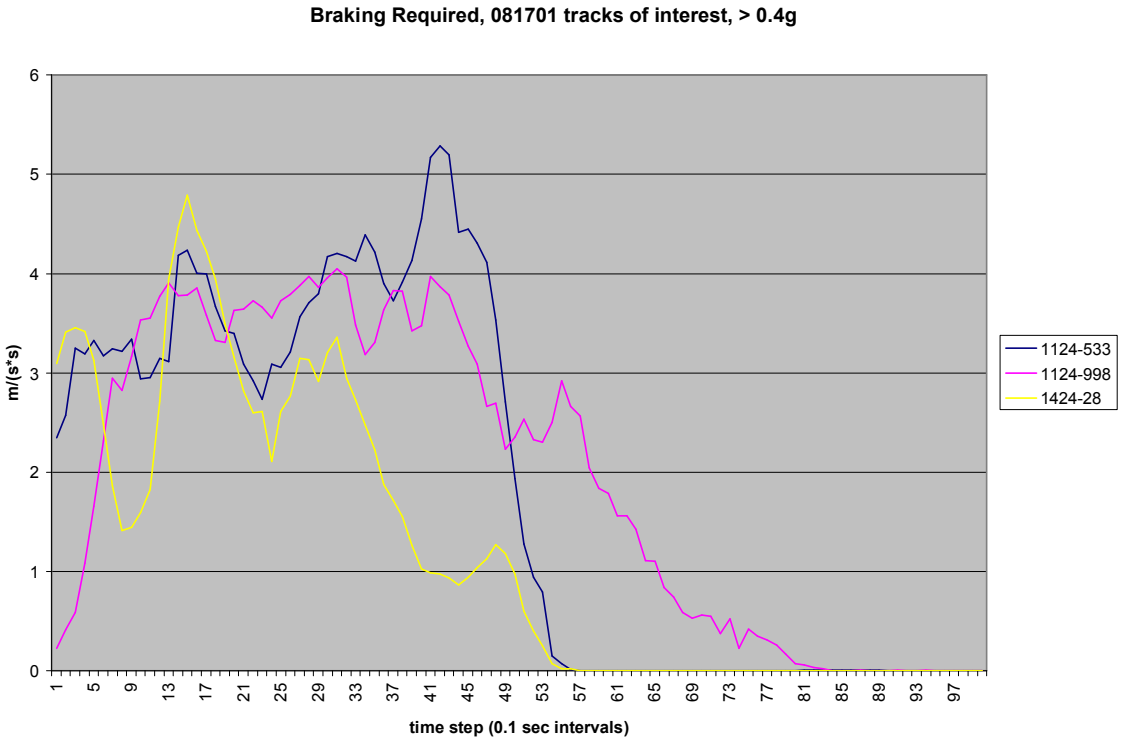


Figure F-3. Braking Required (times 2) -- for Tracks of Interest.

The tracking algorithm that generates this data uses a conservative "weighting" of the initial range sample differencing that determines initial velocities. This is the origin of the initially low value for Braking Required for track 1124-998, and to a lesser extent the other tracks. A less conservative weighting would result in more numerous tracks with high initial Braking Required measurements and therefore more "false alarm" flashes of the warning light. This represents tunable trade-off between early detection of the true threats and more flashes at drivers who do not deserve them. Another tunable characteristic of the tracker is evident by the "rise time" visible in these measurements. The time constant (currently set at 1 second) of the tracker can be adjusted to yield faster response, at the potential expense of more noisy measurements.

The methodology and criteria described above was applied to three more days adjacent to the 17th of August to verify the frequency of occurrence of relevant events for this experiment definition, and the accumulate enough samples to quantify the mean and standard deviation for a meaningful size sample population. This data is presented in the Table F-1 (note the mean and standard deviation on the last two lines of this table).

Table F-1. Selected Data on 10 Relevant Tracks in Baseline Data, 8/15/01 – 8/18/01

ALGO_ID	SEGMENT_ID (date & time)	TRACK_ID	TIMESTAMP (milliseconds)	BRAKING_REQUIRED (m/(s^s))	Y (m)	DX (m/s)	BUS_YAW_RATE (degrees/s)	X (m)	Delta time (seconds)	start (milliseconds)	end (milliseconds)	delta start->.4g (milliseconds)	-> end (milliseconds)	.3g start (milliseconds)	delta .3->.4 (milliseconds)
day start	8150531		142561												
1	8150931	908	2447307	4.024640083	14.995	0.06842	0.037160002	-0.469	15425	2444308	2461606	2999	14299	2446108	1199
1	8151031	58	339552	4.303380013	14.755	-0.2613	0.067160003	0.0342	1492	337752	394768	1800	55216	338352	1200
day end	8152231		0						42860						
day start	8160620		1868715												
1	8160720	1057	2053837	4.092470169	22.564	0.8946	0.057160001	-0.46	3785	2052337	2072944	1500	19107	2052737	1100
1	8161659	120	161099	4.180280209	25.36	0.99184	0.157159999	-1.368	31911	156199	187397	2900	26298	160099	1000
1	8161659	358	595341	4.416510105	10.46	-0.35602	-0.072839998	0.1411	434	590441	602240	4900	6899	594241	1100
day end	8162240		0						20321						
day start	8170624		0												
1	8171124	533	1549515	4.181369781	25.305	0.45219	-0.06284	0.6866	19550	1548115	1603712	1400	54197	1548415	1100
1	8171124	998	2670603	3.973809958	52.515	-0.19146	-0.082840003	1.7924	1121	2667804	2668492	2799	17889	2668504	2099
1	8171424	28	40957	3.943269968	25.179	0.26397	-0.022840001	-0.514	8170	39557	60256	1400	19299	39657	1300
day end	8171859		0						15619						
day start	8180715		0												
1	8180815	934	3122377	4.150100231	23.405	0.50695	-0.06284	1.173	6722	3120177	3123477	2200	1100	3120777	1600
1	8181015	666	1644871	4.052209854	26.636	0.0041	-0.032839999	0.8556	5722	1642178	1663070	2693	18199	1642472	2399
day end	8181912		0						30647						
								mean	9433						
								stdev	10062						

<u>Experiment Design and Parameters for Phase III</u>:
The following assumptions and calculations are provided to quantify the scope of the proposed experiment. The parameters of this experiment are:

1. Study group: Two buses will be equipped to flash the light at any vehicle that reaches 0.3 G Braking Required (with all other dynamic conditions holding as described in the data filtering as above—this provides an initial definition of the warning light activation algorithm to be coded into the collection system). For a control group, each bus will be run at a 50 percent duty cycle, where 50 percent of the time the signaling the warning light is enabled and 50 percent of the time it is not (and only data is collected).
2. Calculate average time between tracks reaching 0.4 G Braking Required for both groups.
3. Expect to see a change (an increase) in the mean time between occurrences of 0.4 G braking events observed in the study population (warning light active) as compared to the control group (warning light inactive).

From the 10 tracks identified from the baseline data for 8/15–8/18 as "samples" in this formulation of the experiment, the following parameters were calculated:

Mean time between 0.2 G braking required "events": 9433 seconds (157 minutes)
Standard deviation of this mean: 10062 seconds (168 minutes)

The control group distribution is assumed to be normal, and the study group distribution is assumed normal with a different mean and a somewhat larger standard deviation. This assertion is borne out by studies on the data set identified above where one or more 0.2 G events is eliminated from the sample set (which indeed would be the effect of the warning light if it does cause drivers to brake harder and/or quicker causing their maximum braking required variable to never reach 0.2 G). Another assumption needed for the statistics to work out is independence of samples. This definition of the random variable does not really meet the requirement of independence of samples. All these assumptions will be further examined through more in-depth expert analysis and study of larger portions of the baseline data.

Two more assumptions are needed to quantify the scope of the experiment: effect size and the relationship of this effect to the practical issue being addressed: rear-end collision avoidance. The effect size is unknown at this point and must be arbitrarily estimated based on some rationale related to "practical significance". The assumption needed to connect this experiment to the goal of reducing rear-end collisions is that a particular relationship exists between "time between braking required parameter excursions" and "time between rear-end collisions". We assume this relationship to be directly proportional—that is, a doubling of the time between 0.2 G braking required occurrences will cause a doubling in the time between actual rear-end collisions. Whether this assumption is valid or not is the subject of current and planned future research. Then, the nature of what is practically significant must be established. We have concluded (for now) that a reduction of at least 25 percent in frequency of (or, correspondingly, an increase of 33 percent in the time between) rear-end collisions would be viewed by most people as an important result.

Using an assumption (i.e., a requirement) of 33 percent (at least) expected increase in time between events as a result of the warning light, we would then make the following predictions for the mean and standard deviation for the study group of samples:

Mean time between 0.2 G relevant braking required "events": 12577 seconds
Standard deviation of this mean: 12224 seconds

This estimated mean and standard deviation for the "warned" group is scaled from the numbers obtained (presented above) for the sample group found in the baseline data. Sample point deletion experiments with this small set of data show that if the effect is present, these numbers are representative of the numbers that would be observed.

With all these assumptions and parameters the number of samples required for statistical significance of the result can be calculated. Utilizing a normal distribution, two-sample, unequal variances set of assumptions and the following experiment requirements:

H_0 : $mean_{warned} - mean_{no\ warning} = 0$
H_a : $mean_{warned} - mean_{no\ warning} > 0$

One approach to quantify the number of samples needed is to apply the following sample size formula for a two-sample procedure designed to measure the difference in population means ($\mu_1 - \mu_2$), where the required confidence level and the allowable "accuracy" or bounds (B) of the interval must be specified:

$$n_1 = n_2 = \frac{(z_{\alpha/2})^2 (\sigma_1^2 + \sigma_2^2)}{B^2}$$

Here:
$n_1 = n_2$ = number of samples (control and study sample populations equal)
$z_{\alpha/2}$ is the "Z-statistic" that specifies the confidence level
σ_1^2 and σ_2^2 are the (estimated) population variances
B is the required margin of error ("($\mu_1 - \mu_2$) must be accurate to within B units")

The difference in the sample means (obtained from baseline data, above) is
12577 – 9433 = 3144 seconds

Using a 90 percent confidence requirement and a bound of one-half the observed difference or
½ * 3144 = 1572

And looking up the z-statistic in a table we then obtain the following formula:

$$n_1 = n_2 = \frac{1.645^2 * (10062^2 + 12224^2)}{1572^2} = 275 \text{ samples}$$

This experiment would show (assuming the measured sample population mean and variance were approximately equal to the estimates given above) that the warning light had indeed had an effect, and that effect was (with a 90 percent confidence) an increase of between 16 percent and 50 percent in the time between tracks showing a 0.2 G braking required value.

Another approach used to determine the number of samples needed was to access a web-based power calculation tool provided by the statistics department at UCLA. For a two-sample, unequal variance, normal distributions experiment, this calculator (http://www.stat.ucla.edu/index.php) yields the following results (plugging in the means and standard deviations obtained from baseline data above):

Control group samples: 205
Study group samples: 273

The problem here, in both approaches, is the use of means and standard deviations obtained from a very small sample to represent the overall population means and standard deviations. Further work will be conducted to establish the control group mean from the

baseline data by reviewing the entire data set. Also, further expert consultation will be obtained to verify and/or modify these calculations to ensure accuracy and appropriate application of theory.

Based on the results above, for the purposes of estimating run time needed for the secondary data collection, an assumption will be made that each sample population must consist of at least **300 samples**. As will be seen in the Phase III Data Collection results, we did not flag anywhere near 300 incidents which were need to make finding statistically significant. A little further explanation of this is below.

Using the four days of collection reviewed so far, 10 relevant tracks were observed in 56.6 hours of bus run time, or an average of one event per 5.66 hours. For the number of samples desired the run time required would be:

Bus with no warning activations: 1698 hours, or about 142 days (12-hour days)
Bus with warning activated: same

This conclusion is based upon one event of 0.15 Gs every 5.66 hours. As we pointed out in the initial portion of this section, since our original scaling was incorrect, this conclusion is based upon the rather low value of braking required of 0.15 Gs. If we would have used higher value for braking required, then the number of events per unit of time would be less, and that would mean that we would need to collect more than 1698 hours of data to flag 300 events. So based on these new conclusions, it appears that two buses running for five months would not be sufficient to generate a statistically significant enough data set to absolutely prove the effectiveness. However, our data collection operations for each of the warning algorithms show the positive trend of results. So though we fully feel that our results are correct indications of performance, the absolute performance enhancement have not been quantified with a high degree of statistically confidence. .

APPENDIX G: HUMAN FACTORS TESTING

G-1 Human Factors Test Planning

The need for human factors testing was identified as a critical element of the project early in the program. During March of 2003, the critical question that needed answering was where to set the threshold for triggering the warning signal. As such, we wrapped our human factors testing around this question.

Ideally, we would have set up the experiment such that a distracted driver would have approached the stopped bus and the RICWS would calculate the braking required based on closing velocity and distance and at the selected threshold, activate the light bar. Hopefully, the subject drivers would stop before hitting the bus and would then indicate if the warnings were too soon, too late, or just right. This ideal testing regime however would put test subjects at risk, and hence was unacceptable. The evaluation here was to test the performance of a distracted driver.

Not willing to put distracted drivers at risk with a potential collision into the back of a bus, we opted to conduct the human factors test with non-distracted drivers braking behind the bus. With the bus stopped on a two-lane road, daylight, clear weather and no other traffic, the subject drivers would come straight at the back of the bus. These conditions were selected to be the same conditions as identified in Appendix A from our accident analysis. The subject drivers would approach the bus at various speeds and brake at a rate that they felt was "comfortable" hard braking. We asked then to brake as hard as they could, but still feel absolutely safe. This would give us an analysis of this comfortable hard braking level. Then in our RICWS algorithm, we would need to add driver reaction time into the equation.

G-2 Human Factors Testing

For our testing, we used seven different drivers, each in their own vehicles except for subject #7, who used a corporate vehicle. We wanted the drivers to use their own vehicles so they would feel comfortable in driving the car and would have a good feel how as to how the vehicle would respond.

One of the columns in Table G-1 is "Reflector?" During this time period, we were also evaluating the performance of our laser sensor to be able to see the approaching vehicles. We had used a bicycle reflector as a target for verifying the alignment of the sensor before starting the testing. So in some of the test runs, we taped the reflector to the front of the vehicle to insure the RICWS sensor would see the vehicle for a significant distance (typically greater than 100 meters).

For the first run, driver #1 approached the bus slowly and the RICWS did not activate the light bar, which is what the subject thought was appropriate. Runs #2 and #3 were at higher speeds and the driver thought the system should have activated the warning. Another similar run was made, and a test operator was in the bus viewing the processing display so we could understand what the system was doing. For this run, the observer noted that the RICWS did not start to see the Camry until late into the run. The RICWS system did pick up the Camry and did signal the warning at what the driver thought was

an appropriate level of 0.3 Gs. This fourth run did indicate the RICWS was having difficulty seeing the following vehicle. So, for the fifth run, the calibration bicycle reflector was taped to the front of the car. The driver repeated the last three runs at the same moderate speed (~ 25 to 30 mph). The system tracked the Camry in from 100 meters and activated the warning at the appropriate point with a 0.3 G threshold. So driver #1 felt the appropriate warning threshold was 0.3 Gs.

Driver #2 was driving a 2003 Ford Explorer. Following the same pattern, approaching first at slower speeds, then faster, driver #2 completed seven runs. The first run was very slow, and the driver did not expect the RICWS to warn him, and the system did not. The second two runs were sorting out the sensor seeing the vehicle. So the set was repeated with adding the reflector to the front of the Explorer. Run # 4 was at higher speed (~> 30 mph), and the subject driver thought the threshold value of 0.3 Gs caused the warning to go off too soon. Run #5 was at slow speed, the light bar did not signal, and the driver did not think it should. The seventh run was at a moderate speed and driver though the light bar warning was correct, but maybe a little too easy. So Driver #2 thought the 0.3 G threshold was basically correct, but maybe should be a little higher.

Subject #3 was driving a silver 2003 Sable which showed up well with the laser sensor. (This is contrasted with vehicle #5 which was a 1997 Taurus with basically the same body style, but in black, which did not show up well with the laser sensor.) Overall, driver #3 thought the light bar threshold of 0.3 Gs was a little conservative at nominal 30 mph speeds.

Driver #4 with a Saturn was the most conservative driver. The first run was slow and the driver thought the signal should not have signaled. Runs #2 through #7 were coming at a moderate rate, and the vehicle was stopped well back of the bus. The driver thought the light should have been activated, and it was not. Run #9 repeated the threshold setting of 0.195 Gs, the driver came stopped closer to the bus, and the driver felt it was too easy. This is direct conflict with run #7. The last run was at 0.25 Gs, and the driver thought this warning level was correct.

Drive #5 was the most aggressive driver and felt comfortable with warning distances that would require a 0.35 G braking required. Driver #5 confirmed earlier suspicions that at higher speeds, drivers preferred higher braking thresholds.

Driver #6 identified that at higher speeds (runs #5 and #6) that a 0.3 G threshold is too low. Driver #6 was one of the more conservative drivers and preferred a threshold value of 0.25 Gs at approximate 25 mph.

Table G-1. Human Factors Testing Data

Driver	Vehicle Type	Run #	Reflector	Warning Threshold	Light bar Triggered?	Driver Evaluation	Comments
#1	Camry	1	No	0.3 Gs	No	Correct	Came in slow, shouldn't have triggered
		2	No	0.3 Gs	No	Too hard	Swerved out of lane
		3	No	0.3 Gs	No	Too hard	Swerved out of lane
		4	No	0.3 Gs	Yes	Correct	Stopped in lane
		5	Yes	0.3 Gs	Yes	Correct	Caught him much further out
#2	Explorer	1	No	0.3 Gs	No	Correct	Easy run, shouldn't have triggered
		2	No	0.3 Gs	No	Too hard	Stopped
		3	No	0.3 Gs	No	Too hard	Stopped. Not seeing it?
		4	Yes	0.3 Gs	Yes	Too easy	
		5	Yes	0.3 Gs	No	Correct	Shouldn't have triggered
		6	Yes	0.3 Gs	No	Too hard	
		7	Yes	0.3 Gs	Yes	Correct	Maybe too easy, but okay
#3	Sable	1	No	0.3 Gs	No	Correct	Shouldn't have triggered. Car shows up well
		2	No	0.3 Gs	Yes	Correct	
		3	No	0.3 Gs	Yes	Too easy	
		4	Yes	0.3 Gs	Yes	Correct	Maybe a bit too easy
		5	Yes	0.3 Gs	Yes	Correct	Maybe a bit conservative
#4	Saturn	1	No	0.3 Gs	No	Correct	Shouldn't have triggered
		2	No	0.3 Gs	No	Too hard	
		3	No	0.3 Gs	No	Too hard	
		4	Yes	0.3 Gs	No	Too hard	
		5	Yes	0.3 Gs	No	Too hard	
		6	Yes	0.25 Gs	No	Too hard	
		7	Yes	0.195 Gs	No	Too hard	
		8	Yes	0.15 Gs	Yes	Too easy	
		9	Yes	0.195 Gs	Yes	Too easy	
		10	Yes	0.25 Gs	Yes	Correct	
#5	Taurus	1	No	0.3 Gs	Yes	Too easy	Comfortable stop. Loose car at 30 meters.
		2	No	0.3 Gs	Yes	Too easy	Comfortable stop. Comes on too soon.
		3	Yes	0.3 Gs	Yes	Too easy	Still too easy
		4	Yes	0.35 Gs	Yes	Too easy	Was going 40, flashed way back, maybe okay.
		5	Yes	0.35 Gs	No	Correct	
		6	Yes	0.35 Gs	No	Correct	
		7	Yes	0.35 Gs	No	Too hard	Should have flashed
		8	Yes	0.35 Gs	Yes	Too hard	Came on late
		9	Yes	0.325 Gs	Yes	Correct	
		10	Yes	0.325 Gs	Yes	Too hard	Maybe okay though
		11	Yes	0.325 Gs	Yes	Too easy	Good at speeds ~35

Driver	Vehicle Type	Run #	Reflector	Warning Threshold	Light bar Triggered?	Driver Evaluation	Comments
		12	Yes	0.35 Gs	Yes	Correct	Good at high speed (~50)
#6	Ranger	1	No	0.3 Gs	No	Too hard	Bus out of battery power, range = 18 meters
		2	Yes	0.3 Gs	Yes	Too hard	Light bar not flashing, but should have – system problem
		3	Yes	0.3 Gs	Yes	Too hard	Light bar not flashing, but should have – system problem
		4	Yes	0.3 Gs	No	Correct	Solution for system problem. Shouldn't have activated. Braked normal.
		5	Yes	0.3 Gs	Yes	Too easy	High speed
		6	Yes	0.3 Gs	Yes	Too easy	High speed
		7	Yes	0.25 Gs	Yes	Correct	Braked normal, low speed (~25)
#7	F-350	1	No	0.3 Gs	Yes	Correct	High speed. Swerved.
		2	No	0.3 Gs	Yes	Too easy	High speed. Stopped.
		3	No	0.3 Gs	Yes	Too easy	High speed. Stopped.
		4	No	0.325 Gs	No	Correct	High speed. Stopped.
		5	No	0.325 Gs	Yes	Correct	High speed. Swerved.
		6	No	0.325 Gs	Yes	Too hard	Lower speed. Stopped.
		7	No	0.3 Gs	Yes	Correct	Lower speed. Stopped.

Driver #7 in the test was driving a Ford F350 corporate pick up truck. So this driver was driving a large unfamiliar vehicle. In run #1, the driver tested the system response to a high-speed approach with a planned swerve. Driver #7 thought the warning on the swerve was correct at the setting of 0.3 Gs. Run # 2 and #3 were high-speed straight on (no swerve) runs with a planned stop. Driver # 7 thought the threshold of 0.3 Gs warned too early. This agreed with drivers #5 and #6 for high-speed approaches. In runs #4 and #5, the subject thought a better threshold for high speed was 0.325 Gs. Then in runs #6 and #7, the subject driver confirmed that the correct threshold was 0.3 Gs.

G-3. Testing Conclusions

The average braking required threshold preferred for most drivers at speeds of 25 to 30 mph was approximately 0.3 Gs. Two drivers preferred values lower (0.25 Gs) than the average and two drives at the average, and two drivers slight higher than the average, and one driver significantly higher that the average. In our test group, three of the six drivers evaluate the system at higher speed. All three thought that a higher threshold was needed for higher speeds.

Since all the test runs were with drivers focused on the bus, the actual algorithm will need to take into account an delay time for the driver to respond to the warning lights. Also, the algorithm will need to modulate the threshold value with following vehicle speed.

APPENDIX H: PHASE III DATA COLLECTION

H-1 Designing the Phase III Data Collection Experiment

H-1.1 Primary Purpose of Phase III Data Collection Experiment

To show (with reasonable certainty) that the activation of a warning on the back of the bus actually influences driver behavior in a way that will reduce the incidence of rear-end collisions.

H-1.2 Key Metric for Evaluating RICWS Performance

Drivers exhibit following behavior that result in a distribution of a simple "Braking Required" descriptor of following vehicle dynamic behavior (see below). The frequency of events where this descriptor exceeds certain thresholds (or, alternatively, the average time between such excursions) can be considered a measure of the risk-taking behavior of the following vehicle population. It is assumed that activating the warning light with an appropriate algorithm will reduce the frequency of events where higher "Braking Required" thresholds are exceeded. This assumes drivers will respond to the light by beginning to brake sooner or, if they were already slowing—to brake harder than they otherwise would have with no warning light flash.

Braking Required descriptor of driver behavior:
Braking required is defined here as the longitudinal velocity of the following vehicle minus longitudinal velocity of the bus, quantity squared, divided by the range. $((V_f - V_b)^2 / 2*\text{Range})$. The difference in velocities is simply the relative (closing) velocity, which is easily computed from successive outputs of the range sensor.

Hypothesis:
Activating the warning light at 0.3 G Braking Required will cause the number of occurrences of a Braking Required value of 0.4 G to decrease.

H-1.3 Phase III Data Collection System Setup

For the Phase III data collection, two AATA transit buses, #382 and #385, were outfitted with full RICWS systems. The full RICWS system included all the data acquisition aspects of the Phase II data collection system as well as the driver warning subsystem. The original Phase II collection system included the laser sensor subsystem, the video subsystem, and the acquisition software and hardware data. This foundation system allows full analysis capability of the Phase III data collection. So we have not lost capability as we progress from Phase II to Phase III collections. For the Phase III collection, we also added the collision warning algorithms and the warning light bar system. Also, the data that is recorded on the bus includes when the warning light is enabled and when the warning light is activated. It was planned to collect all data at a 50 percent duty cycle. This meant the 50 percent of the time the warning lights would be enabled and would be activated if an incident would occur. The other 50 percent of the time the warning portion of the subsystem would be disabled. The disabled portion of the data would provide the "untainted" reference data or ground truth of how follow drivers act with no warning in normal conditions. A benefit of collecting untainted data is that it

provided a testing ground to evaluate how often and in what conditions a new algorithm would identify potential warning incidents

H-2 Secondary Data Collection

Unlike the Phase II efforts with the planned shorter data collection time and a desire to evaluate the buses in a more controlled environment (limited number of routes), the Phase III collection was intended to statistically capture RICWS performance in all conditions. As such, there was no attempt to restrict the test buses to any particular routes. The collection dates identified are identified in Table H-1 below. In the March 14–19 timeframe, the buses were operating with a fixed threshold for activating the warning lights set at 0.225 Gs. This value gave a reasonable number of warning incidents; however, our research indicated that the 0.3 G warning level was more in line with the maximum comfortable level for driver braking. To confirm this, we ran some preliminary human factors test with drivers approaching a parked bus and applying the brakes at a comfortable level. This short test confirmed the 0.3 G level and as such, we changed the threshold to 0.3 G on March 20.

Table H-1. Phase III Data Collections.

Dates	Algorithm Description
March 14–19	0.225 G braking required
March 20–July 2	0.3 G braking required
July 3–27	0.3 G braking required with CAMP delay time
July 28–September 3	System hardware and algorithm implementation issues
September 4–30	Full CAMP algorithm

The collection from March 20th to July 2nd was our largest data collection. Early April we ran our more extensive human factors testing. One of the human factors test participants was Dr. James P. Foley from Mitretek. With his human factors expertise and background, he was able to point out the need to take into account the drivers' response time in our warning approach. This pointed us towards using the CAMP warning algorithm developed for front automotive collision avoidance systems. We analyzed this approach and embarked upon modifying and testing our algorithm utilizing the 1.38 second driver response (delay) time of the CAMP algorithm. We tested the algorithm on the data that was collected during the 50 percent of the time when the warning light was disabled. This provided the untainted following vehicle driving data set we needed.

With this successful testing completed, we implemented the new algorithm with the 1.38-second CAMP delay time on both buses and started collecting data with this approach. During this same collection time period we also began reviewing our human factors test data and identified the trend that at higher speeds, drivers thought the fixed threshold of 0.3 Gs was too low. This prompted us to go back and reevaluate the full CAMP algorithms that included both the time delay and velocity components. We did some initial quick testing on existing data and found it to be reasonable. We concluded that the full CAMP algorithm was the correct approach. For our analysis we have ignored the July 3–27 data set with the 0.3 G braking required and the 1.38 second delay as being an

intermediate data set with no real relevance. Considering this conclusion, we updated our algorithm on both bus data collection systems to the full CAMP algorithm that incorporated the time delay and added the closing velocity modulation factor. This was implemented on July 28, 2003, however due to implementation issues and system hardware (disk and sensor) issues; we did not start collecting good CAMP data until September 4. At this point we knew our collection time was limited, so we changed the warning duty cycle from 50 percent to 100 percent to allow all of the bus operation time to be used to evaluate CAMP algorithm performance. Since all the September data was configured with warnings enable, we needed to process another reference data set without warnings enabled. We selected the late March through early April as the data timeframe. This data was processed and is presented in Section 2.2.3, *Camp Warning Algorithm Effectiveness*. All data collections were stopped at the end of September, and the systems were disabled.