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Supplementary Notes

16. Abstract

The purpose of this study is the evaluation of a radar-based anti-collision system developed by Radar Control Systems, Inc. (RCS). The tests were divided into two categories: quantitative and qualitative. The quantitative test involved the verification of the system's displayed speed, range and closing rate; system's sensitivity to various vehicle types; i.e., motorcycles, bicycles and pedestrians; the system's ability to target through environmental conditions (such as rain). Qualitative tests were under normal driving conditions on approximately 1300 miles of interstate highways, 275 miles of major arterial roadways, 275 miles of minor arterial roadways, 250 miles of residential roadways, 250 miles of rural roadways and 300 miles of other roads (i.e., dirt, parking lots, etc.).

An independent contractor, Systems Technology, Inc. (STI) conducted the tests under the direction of the Program on Advanced Technology for the Highway (PATH) and the California Department of Transportation (Caltrans). Funding was provided by the National Traffic Safety Administration.

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NHTSA EDITORIAL NOTE:

The results reported here reflect the performance of a hand-built unit designed in 1989. Subsequent to the production of this prototype, the supplier of the device continued with additional product development. Thus, the results reported here should be taken in the context of the system that was tested and do not necessarily apply to other systems. Irrespective of the results, the aspects of performance presented here are important considerations for future designs of such systems.

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INTRODUCTION

The purpose of this study is the evaluation of a radar-based anti-collision system developed by Radar Control Systems, Inc. (RCS). In this configuration, the system is intended to provide a warning to the driver when the equipped vehicle is in danger of being involved in a collision with another vehicle or object. This is achieved by reflecting a radar signal from vehicles or objects ahead and using this information to calculate range. Changes in range over time (closing rate), range to the object, and vehicle speed are then used to activate the alarms.

The idea of warning drivers of an impending collision is not new. Previous research has been conducted on the Rashid system (unpublished), and on the Nissan laser based system (Stein, Ziedman & Parseghian, 1989). Both of these systems had implementation problems. Some of the problems were due to the technology being used, and some were related to decisions made by the designers of the systems.

The current study was conducted from April through July of 1990, and was divided into two segments. The first segment analyzed *quantitative* measures of the system. These tests involved verification of the system's displayed speed and range; obtaining repetitive alarm activation data at various closing rates on several types of vehicles; testing the system's sensitivity to pedestrians, bicycles and motorcycles; testing the interference resistance of the unit itself; and testing the system's capability under degraded atmospheric conditions.

The second segment involved the *qualitative* evaluation of the anti-collision system under normal driving conditions. Varying traffic, roadway, and surrounding environmental conditions were chosen to provide a thorough analysis of the system.

APPARATUS

The system was provided by RCS in April 1990, and was mounted in a 1989 Ford LTD. The system is installed so that it is active whenever the vehicle is running. It has a detection range of approximately 500 feet.

The normal system includes the following apparatus:

- A pivoting ***microwave radar head,*** mounted in the front grill of the vehicle. The radar head moves as the vehicle's steering wheel is turned, following the direction of the front tires. The head emits a microwave radar signal which is reflected from vehicles and objects in the beam's path. The reflected beam is received by the head and the resulting data is sent to the signal processing unit.

- A ***signal processing unit*** receives the data from the radar head. The data are processed using the system's algorithms, and when required, the processing unit activates the auditory alarms.

- A dashboard mounted ***driver*** *interface* which allows the driver to change system parameters by moving various slide switches. The driver may indicate the roadway type (e.g., highway, normal), the atmospheric condition (e.g., rain, normal), and the alarm onset mode (e.g., normal, early). For these tests the system was left in the "normal" setting except for the freeway testing where the range switch was set at "highway."

- A ***speaker*** which provides the driver the auditory alarm.

Because various data elements were required to carry out the analysis of the system, additional equipment was added to the test vehicle. This included:

- A dashboard mounted ***video camera*** which provided an out-of-the-window view. This information was recorded so that when the data were analyzed it was possible to view the conditions of the roadway environment at the time of the event.

- ***An Amiga microcomputer*** which received data output from the system and presented the data elements on a video output. These data elements included vehicle speed, target range and closing rate. The system data were combined with the video camera picture to provide a complete data set.

- A ***video recorder and monitor*** were used to record the combined video camera and system data. The monitor provided the researcher a view of the data being recorded, insuring that data was actually present.

- A ***micro-cassette recorder*** was used to record the tape location and event type when an event was encountered during the qualitative portion of the tests. This allowed the data to be more easily reduced. Without this data, it would have been necessary to view ALL of the video taped data to complete the analysis. The recorded log allowed the analyst to search for those portions of tape which had relevant data.

QUANTITATIVE TESTS

The first phase of the project tested the system under controlled conditions. All tests during this phase of the project were conducted on the HOV lanes of I-15 in the San Diego, California area. This facility is separated from the normal freeway by Jersey barriers on either side. There are two lanes and medians on the outside of the lanes. The length of the facility is approximately eight miles. Access is controlled on the facility, and during the testing no other traffic was allowed on the roadway.

Speed Verification

The first tests determined the accuracy of the raw data provided by the system (i.e., speed and range). Because a police radar gun was used to determine the system's speed accuracy, the possibility of interference by the gun was first eliminated. This was accomplished by aiming the radar gun at the system's radar head as the test vehicle approached at a constant speed. The gun's radar signal was turned on and off, and the speed display was observed. No effect was noted when the police radar gun signal was aimed at the radar head, and it was determined that interference was not a problem.

The accuracy of the RCS system's speed display was verified using the radar gun (certified $\pm$ 1 MPH). An experimenter held the radar gun out of the vehicle's side window and aimed it at the ground several hundred feet ahead. The gun then displays the speed of the vehicle. The experimenter called out the speed of the vehicle, and the driver's job was to maintain speed for several ten second periods. Data were gathered at speeds ranging from 10 to 70 miles per hour in 10 miles per hour increments (16-112 KPH in 16 KPH increments). The accuracy of the system was very good as shown in Figure 1.

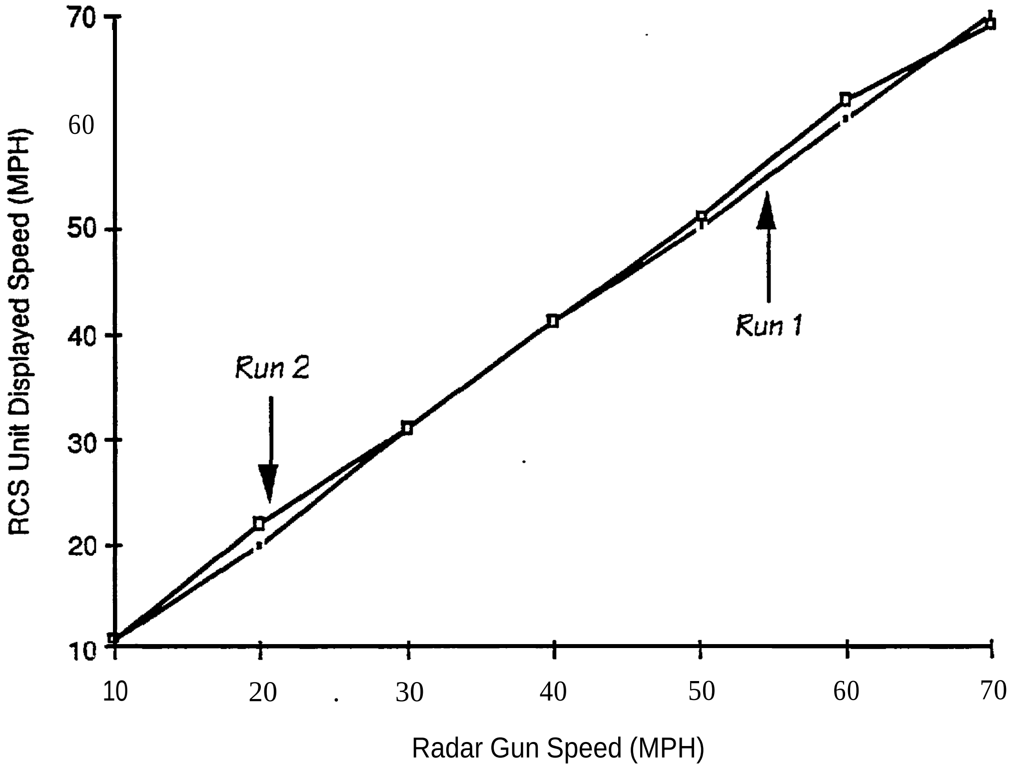

Figure 1. RCS System Speed Calibration Data.

Closing Rate Verification

The radar gun was also used to verify the system's displayed closing rate. This was accomplished by having the test vehicle close on a 1989 Thunderbird travelling at a constant speed of 15 MPH. Measurements were taken at closing rates varying between 3 MPH and 16 MPH. The closing rate of the RCS system equalled that of the radar gun. The data are found in Figure 2.

Range Verification

The next tests were to determine the accuracy of the RCS system's displayed range data. Initially it was planned to place "candle" type cones at successive one-second intervals from the target, and test the system at various speeds. This plan was aborted when we found that the system was not expected to 'lock" onto the target at ranges greater than 500 feet. We modified this plan so that the cones would never be farther than the 500 foot point. The cones were placed on either side of the lane, approximately four feet from the sides of the test vehicle.

To locate the cones, a target vehicle was placed in the lane in front of the test vehicle. The test vehicle was then located a known distance from the target vehicle, and the cones were located so that their image just disappeared off the edge of the camera display. By locating each set of cones in this manner, the tape can be used to reduce the data As the tape is viewed, it is advanced one frame at a time. When the cone disappears from the scene, the range is read from the display, and compared with the actual range.

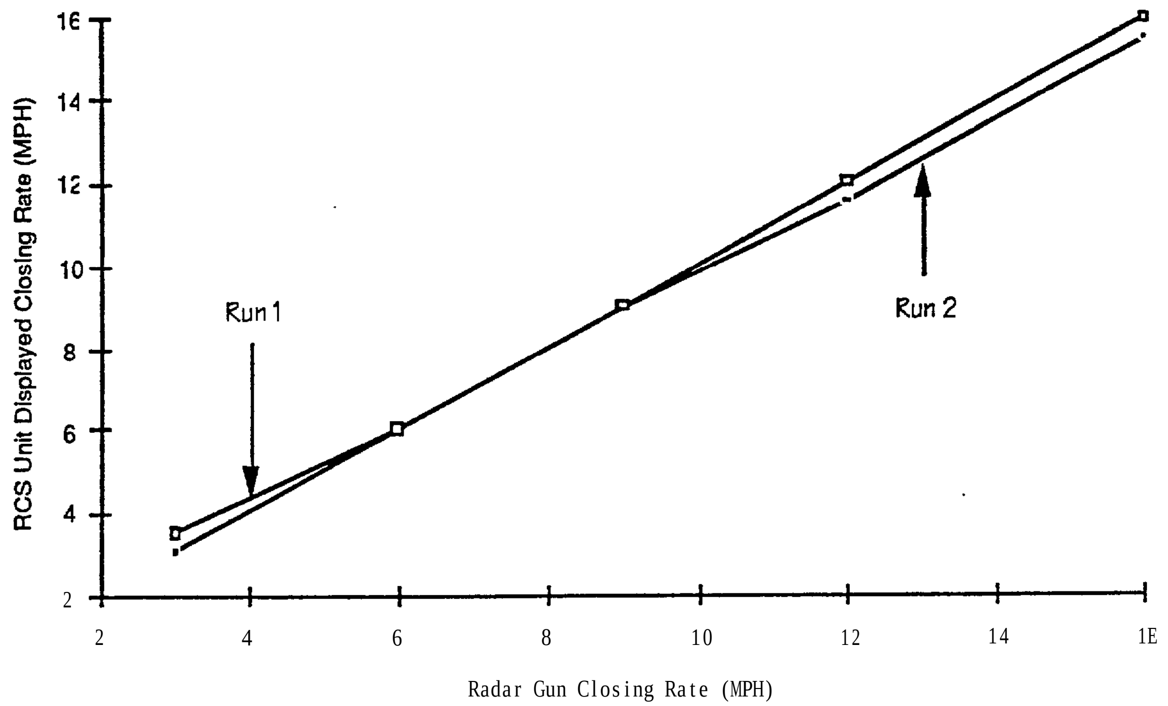

Figure 2. RCS System Closing Rate Calibration Data.

As with the speed verification, data were gathered at speeds ranging from 10 MPH to 70 MPH in 10 MPH increments. Ten runs were made at each speed to determine the repeatability of the measurements.

Analysis of these data during the evening following the tests revealed several problems. It appeared that the system may have been picking up the cones, or in some way was compromised by the cones. Because of this the range tests were repeated. This time only one set of cones were used. They were located on the far right of the lane, next to the Jersey barrier keeping them out of the area where they may interfere with the system. Instead of placing the cones at one-second intervals from the target, they were placed at 50 foot intervals starting at 100 feet and ending at 300 feet. The method used for locating the cones was similar to that used earlier.

The results of the tests are found in Table 1, and a graphic representation of the means is found in Figure 3. Data were not considered valid unless at least five of the 10 test runs resulted in range data. Several problems were noted in the displayed range. The most notable was the inability of the system to provide range data at the higher speeds, with the failure of the system to detect data in proportion to the speed of the test vehicle. Specifically, sparse data were obtained for speeds of 40 and 50 miles per hour, and the system provided NO data at speeds of 60 and 70 MPH (Figure 4). At first there was concern that the system was not operating properly. Because the opposing unit interference tests were conducted on the same day, another RCS equipped vehicle was available. This vehicle was also driven at the stationary target vehicle at the higher speeds, and the system failed to "lock" onto the target vehicle resulting in no alarm being given.

The second problem noted was the large variability in the data. Table 1 shows both the means and standard deviations for the data. (The raw data are found in Appendix A) The variability noted in the table was also observed in the data. It appeared as if the range data was "jumping" from one value to the next rather than showing a reduction consistent with approaching the target. One of the causes for the variance in the data could be the acquisition and analysis techniques. The RCS system updates the range data at 10 hertz. It is possible that the data displayed at the instant the target cone disappeared was one data cycle behind. At higher speeds this could account for a fairly large distance (e.g., at 40 MPH this would be 5.9 feet). If, however, the standard deviations were reduced by the appropriate distance for each speed, the variability would still be quite high.

Finally, we found that in all cases the system indicated a range which was further away than the measured distance from the target. Again, the methods used to gather the data may have influenced the measurements, however if the data were corrected for the possible 10 hertz sampling rate discrepancy, the problem will still exist. Having the system display incorrect range data can create a potential safety problem. If the system alerts the driver based on the range obtained from the system, the alarm may occur too late. In one case, the mean value for the measured range is over 100 feet in error, which would certainly create problems in providing a timely warning.

System interference Tests

System interference tests were conducted to determine if the system could be compromised by another RCS unit in an opposing vehicle, or by a police radar gun. The radar gun tests were described above, and no interference was noted. The opposing unit tests were conducted using another PATH provided vehicle. The RCS system was installed in the vehicle, and was operational. The two vehicles were driven at each other at a speed of 35 MPH a total of 10 times. Half of the runs were conducted on a curve where, for a moment at least, the two radar heads were directly facing each other. The data were analyzed by observing the displayed data to determine if interference caused any changes in the data output. As with the police radar gun, no interference was noted.

One problem with interference was observed, but we were unable to document the problem. One end of the HOV facility is very near the Miramar Naval Air Station, and landing aircraft fly directly over the roadway at very low levels. Occasionally, when an aircraft was directly overhead and the vehicle was at this end of the facility, some interference was noted. It appeared particularly prevalent when there were AWACS operations. If there is some problem with the system being interfered with by advanced military electronic equipment, it would not appear to be much of a traffic safety problem. However, there are a number of roads which are in close proximity to major airports, and it is possible that the system has interference problems with radar systems other than the AWACS. Also, this problem may be indicative of some design flaw (i.e., the system is not affected by police radar or other RCS units, but is affected by more powerful radar installations such as boats, weather stations, airports, etc.)

		DISTANCE (feet)				
		100	150	200	250	300
10 MPH						
	Mean	114.10	166.00	209.60	282.20	320.50
	SD	1.45	3.46	11.58	17.25	24.56
20 MPH						
	Mean	122.30	167.70	231.29	296.63	333.71
	SD	2.36	14.46	57.35	59.11	43.15
30 MPH						
	Mean	129.45	191.50	219.00	285.20	341.71
	SD	5.24	26.33	40.60	67.56	45.23
40 MPH						
	Mean	137.56	102.22	303.43		
	SD	6.65	. 12.49	65.50		
50 MPH						
	Mean		194.40	274.50		
	SD		0.46	39.00		

Table 1. Means and Standard Deviations for Range Verification Data

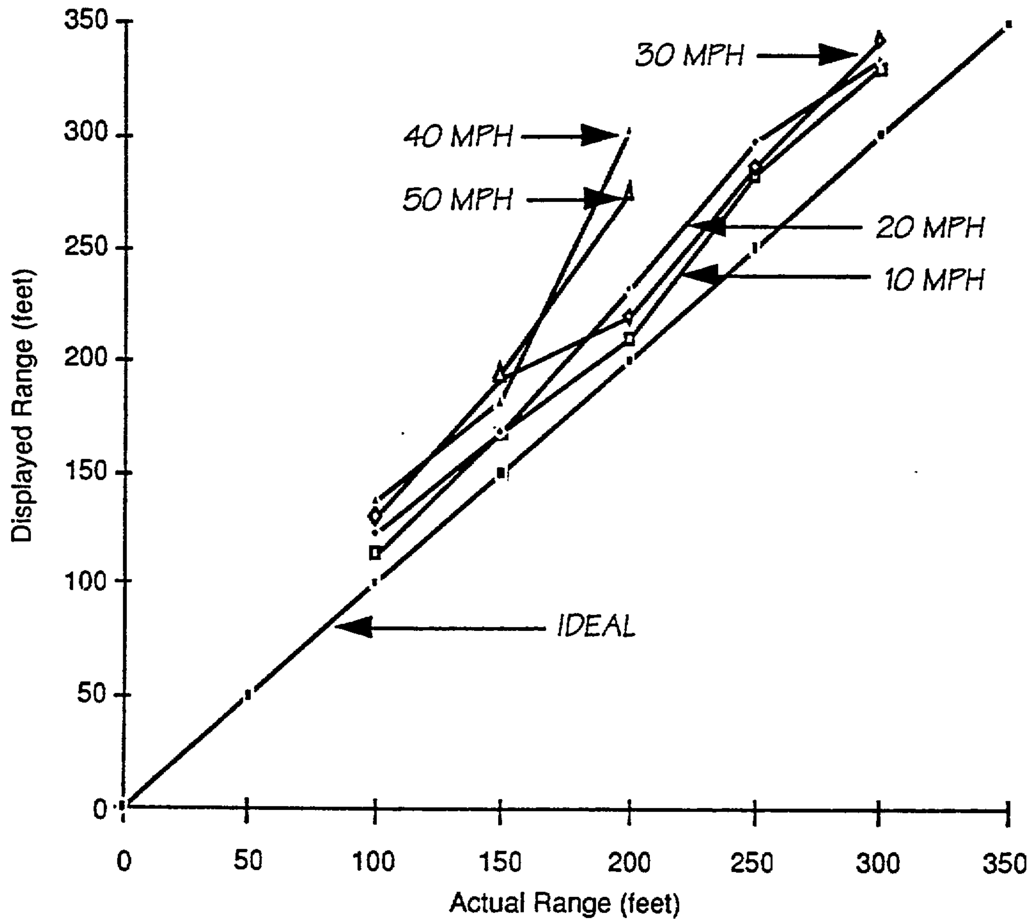

Figure 3. Range Verification Data

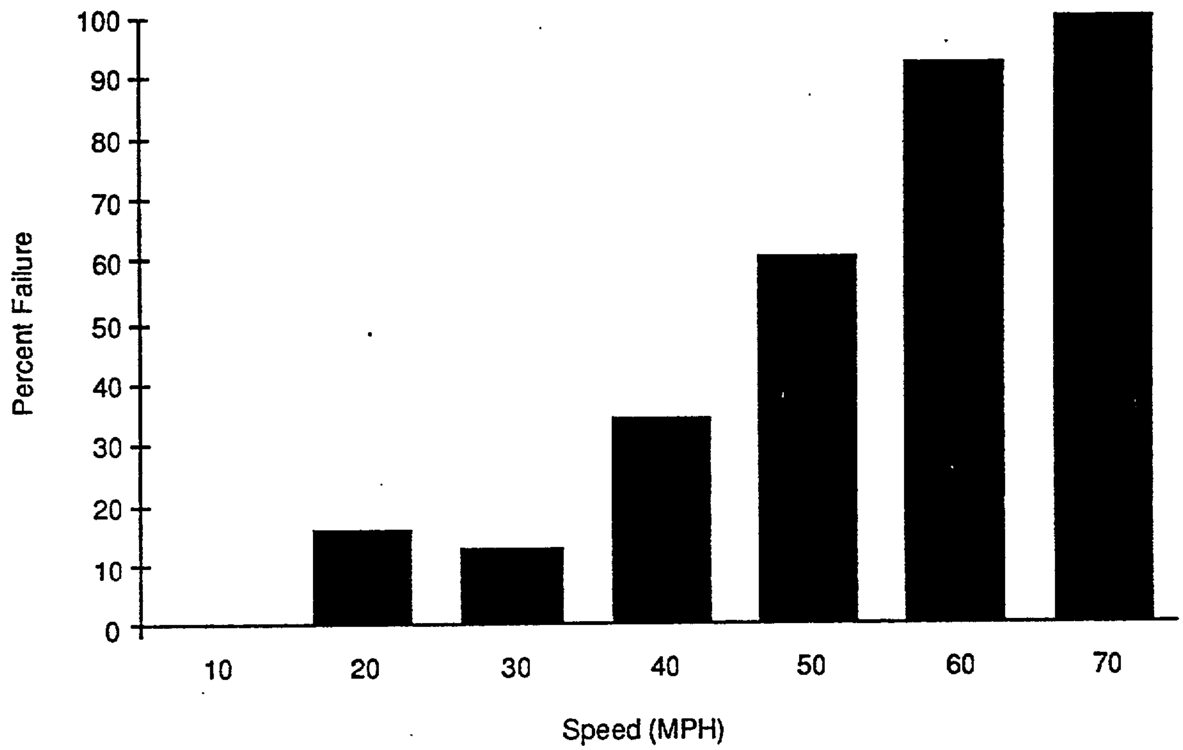

Figure 4. Percent Failure of the RCS System in Providing Range Data During Closing Rate Tests

Degraded Atmospheric Condition Tests

As with an opposing unit, the range accuracy of the system might be compromised by either changes in atmospheric reflectivity or transmissivity. Because of the climate in Southern California, the only condition that could be tested was simulated rain. The rain was simulated using 10 impulse sprinklers located 15 feet apart, and provided both large and small droplets at a rate of approximately 3/4 inch per hour. The sprinklers were located approximately five feet above the road surface, and provided a "rain" area approximately 16 feet wide, covering the entire lane, and 150 feet long.

A target vehicle was located approximately 10 feet beyond the rain area. To establish a baseline for these tests 10 runs were made prior to turning on any water. These runs were made at speeds ranging from 41 MPH to 49 MPH. In general, the system functioned properly, and system alarms were noted.

The water was then turned on and the tests repeated. If the radar signal was reflected by the rain, then early alarms would result. Conversely, if the rain attenuated the signal the alarms would either be late or would not occur. The latter proved true. Only one alarm was given by the system, and an analysis of the closing rate data found extreme variability. (The raw data for these tests are found in Appendix A.)

These tests were limited in both duration and scope. For example, the RCS engineers indicated that the rainfall rates used would not require changing the sensitivity of the system. Doing so may improve the system's performance. There was also no attempt to measure other environmental factors such as fog, dirt, or dust. To completely evaluate the impact of the environment on the system these tests should be conducted.

Difficult Target Tests

One of the problems with a radar based system is that the signal needs a good reflector for the system to operate properly. The roadway environment does not include only cars and trucks, but also motorcycles, bicycles and pedestrians. These latter targets provide poor reflectance of the signal, and the system would not be expected to perform very well with these targets. Tests were conducted, however, to determine the system's sensitivity to these targets.

Two different bicycle rider positions were tested. The first is a semi-crouching position typical of a rider on a "road" type derailleur bicycle. The bicycle used was a high-end racing type bicycle. It had no reflectors pointing toward the rear of the bicycle, which might have helped the system performance. As expected, the system performed poorly. A total of 15 approaches were made to the rear of the bicycle. The bicycle was travelling approximately 30 MPH, and the test vehicle approximately 45 MPH. Of the 15 attempts only two alarms were recorded.

The second rider position had the cyclist upright on a "mountain" bike. This bike had a rear reflector which might have helped return the radar signal. Again 15 attempts were made, however in these tests the cyclist was travelling only 20-25 MPH. Of the 15 passes, no alarms were recorded.

The motorcycle test used a California Highway Patrol Harley-Davidson motorcycle. This vehicle has additional reflectors and lights mounted on the rear, and would be more likely to be "seen" by the system than a less equipped motorcycle. A total of 30 tests were run, 10 each with the motorcycle on the right, in the middle and on the left of the lane. The motorcycle maintained a constant 35 MPH and the test vehicle approached at 45 MPH. The system provided appropriate alarms only when the motorcycle was in the center of the lane. When the motorcycle was on the right or left of the lane no alarms were recorded. This is an unfortunate deficiency because motorcycle riders are trained that riding in the center of the lane is not a good idea because they are less visible to motorists, and because of oil drips which accumulate in that area.

Pedestrian tests were done in a manner similar to the motorcycle tests. Again the target was located at the right and left, and in the center of the lane. The pedestrian remained stationary, facing the test vehicle as it approached. The test vehicle approached at 20 MPH. Again, 30 trials were run. The system did not detect the pedestrian in any location.

Alarm Activation Tests

Data were gathered on repetitive encounters where the test vehicle was closing on a target vehicle. To control for possible target reflectivity differences, seven classes of target vehicle were used: sub-compact, mid-size, and full-size passenger cars, a Volkswagen "beetle", a mini-van, a full-size pick up truck, and a large water truck with a cross section similar to a tractor-trailer.

Test vehicle closing rates ranged from 3 to a maximum of 38 feet per second, and at least 10 repeat runs were conducted at each closing rate. The tests were accomplished by having the target vehicle drive at 25 MPH. The test vehicle approached the target vehicle at the appropriate speed, and the experimenter's assistant called out the displayed closing rate. The test vehicle approached the target vehicle until an alarm was recorded, or until it was no longer safe to continue if there was no alarm. At the onset of the alarm the experimenter slowed the vehicle and began the next trial.

While 10 runs were made at each of the closing rates for each vehicle, some of the runs were eliminated during an inspection of the data. In some cases this inspection was done on-line, and an additional run was made; in other cases the problem arose during the data analysis and the data from the run were not used in the analysis.

Figures 5 through 11 show the data for the point of alarm onset for each of the vehicles. A strong correlation exists between the closing rate and range at alarm onset. There are several interesting factors to note in these data. First, as with the other tests, there is a great deal of variability in the data. Differences in range at alarm onset were as great as 25 to 30 feet in some cases, and rarely were the differences in range at alarm onset within five feet.

The second factor to notice is the problem the system encountered with unique vehicle configurations. The Volkswagen, which presents a curved surface to the radar beam, created difficulty for the system at closing rates greater than 30 feet per second. The truck proved even worse than the VW. In this case the system would not operate at closing rates greater than 28 feet per second.

When braking is the only means for preventing a collision, minimum warning distances may be calculated; and three assumptions can be made to assess the capability of the system to provide adequate warning. One assumption has the target vehicle maintaining a constant speed (equation 1); the second assumes the target vehicle is braking at the time of alarm onset (equation 2); while the third assumes both vehicles start decelerating at the same time (equation 3).

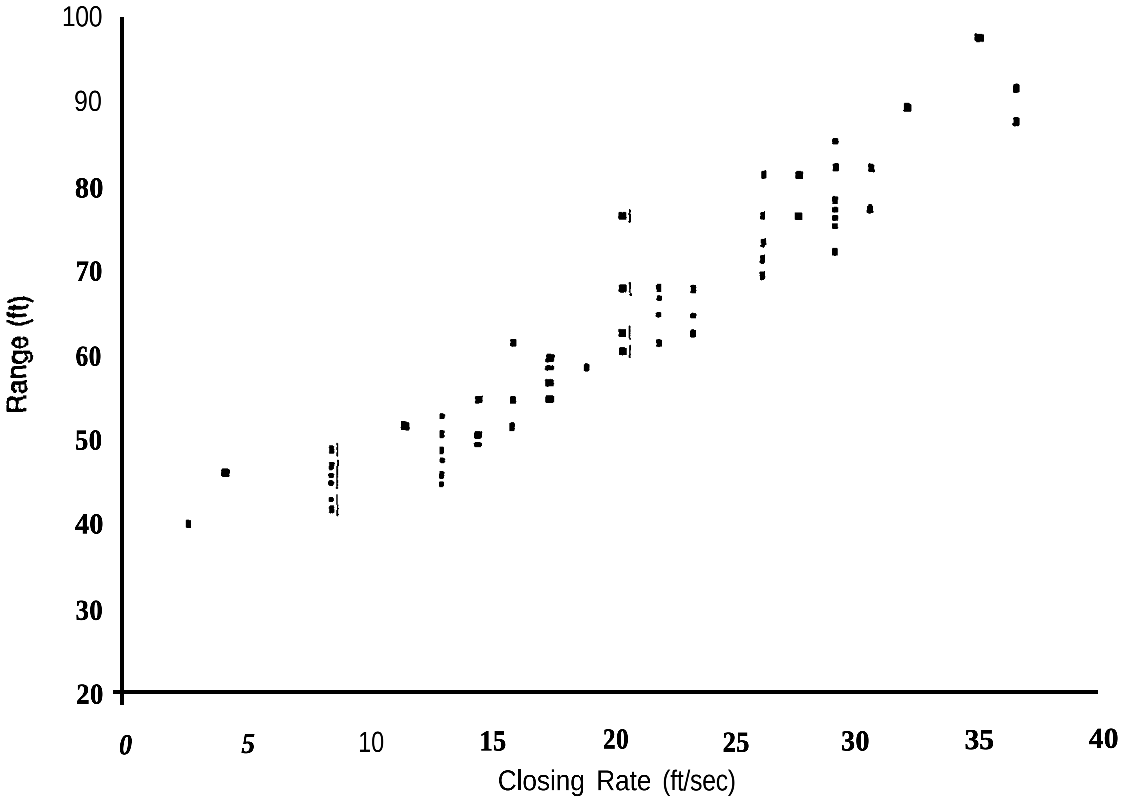

Figure 5. Alarm Onset Data for Sub-Compact Car

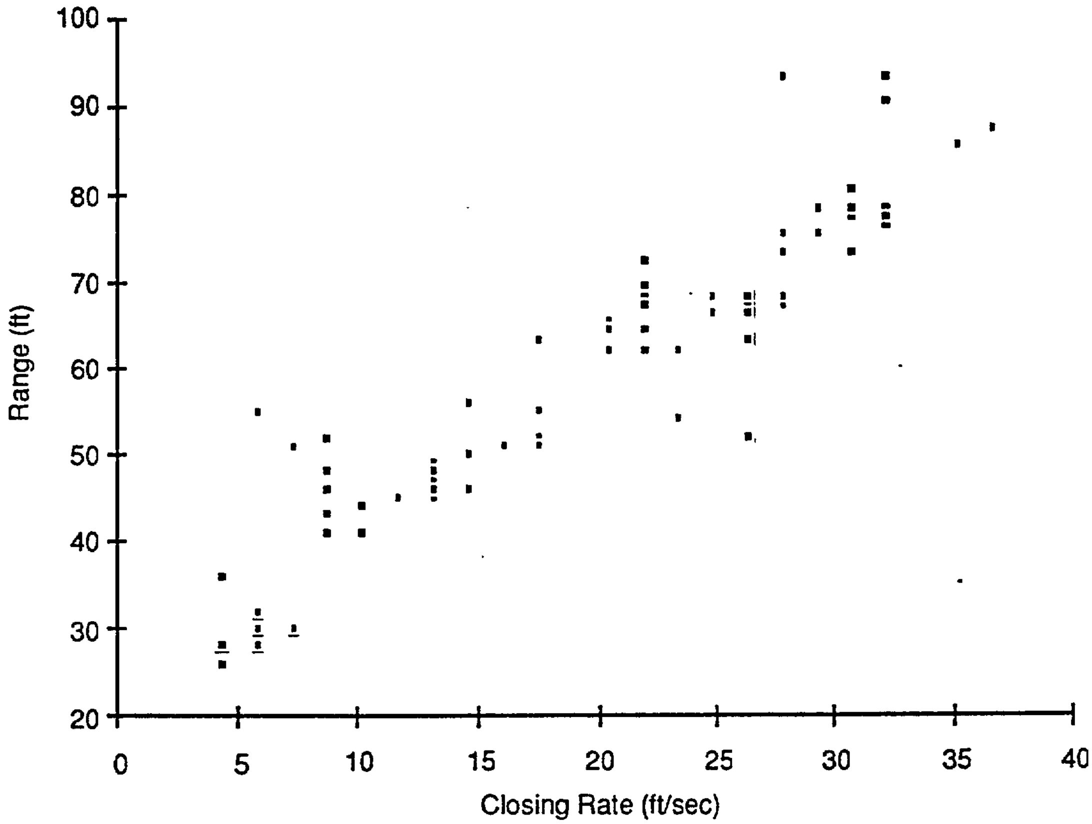

Figure 6. Alarm Onset Data for Mid–Size Car

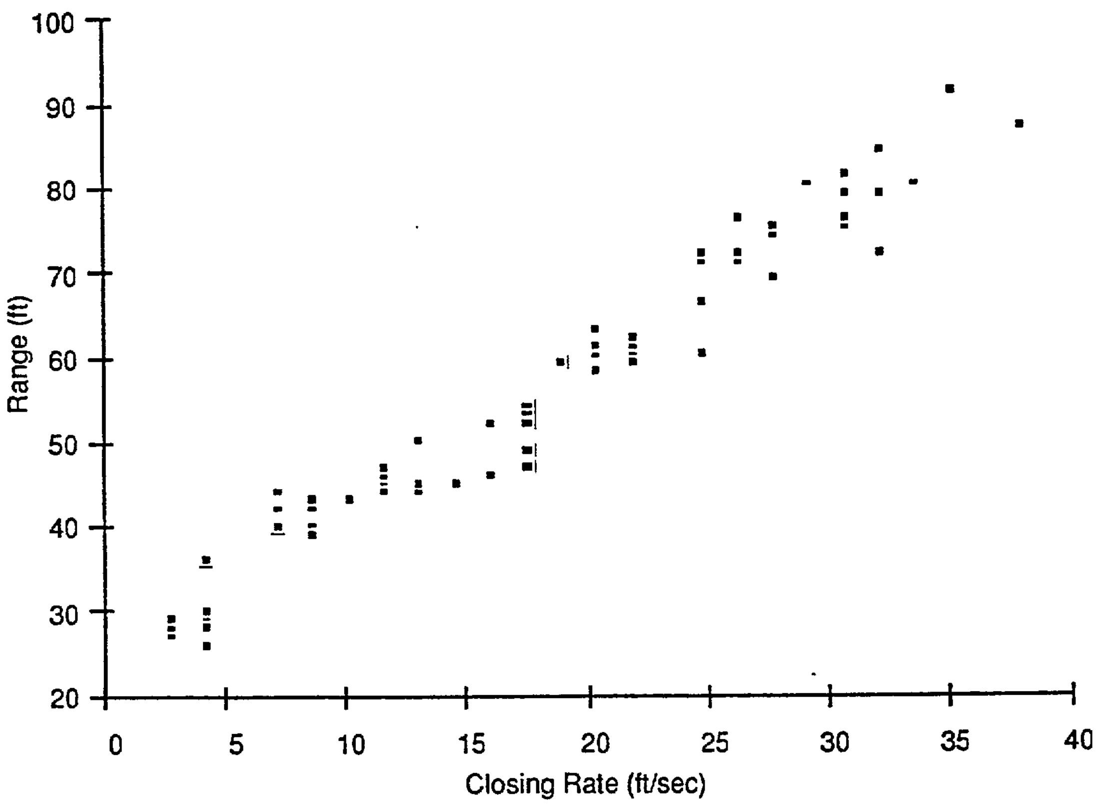

Figure 7. Alarm Onset Data for Full–Size Car

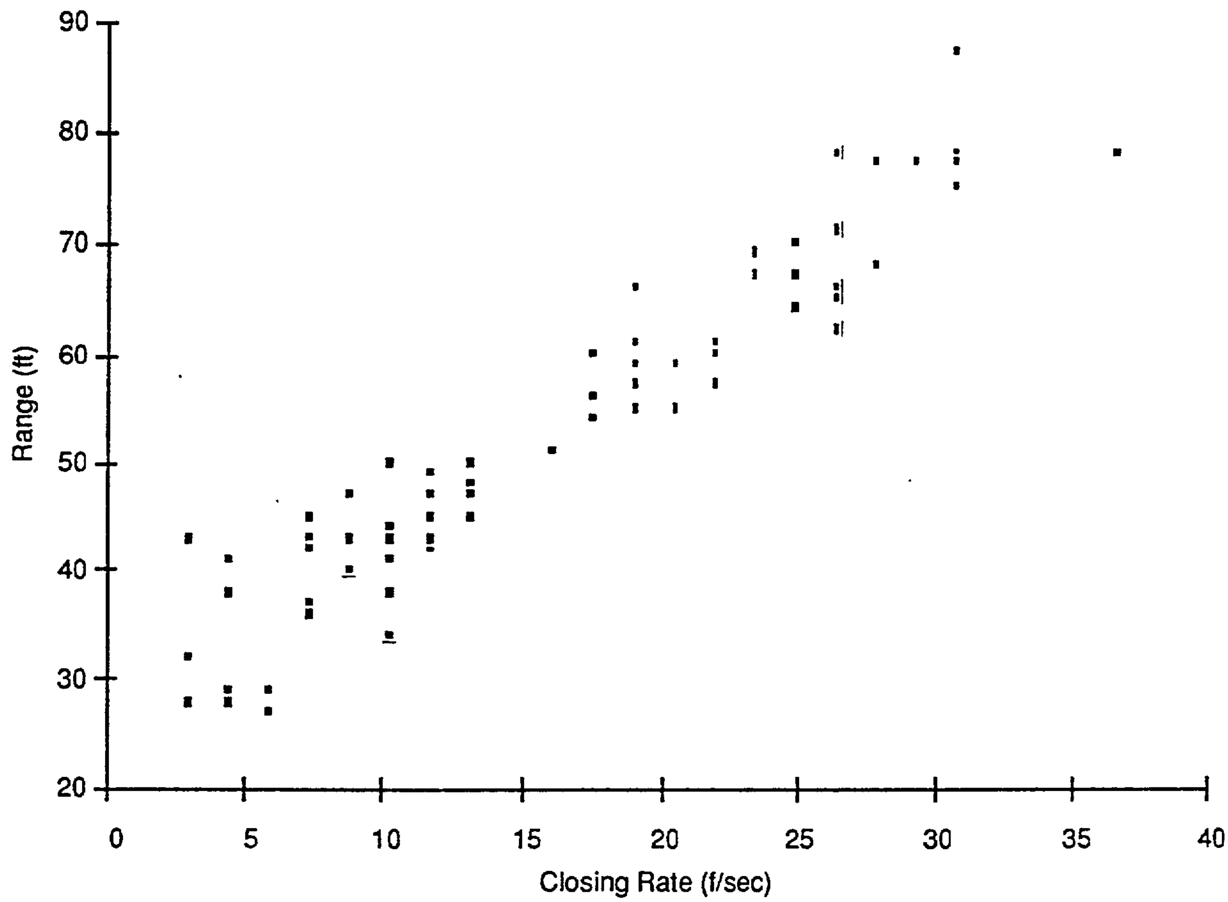

Figure 8. Alarm Onset Data for Volkswagen

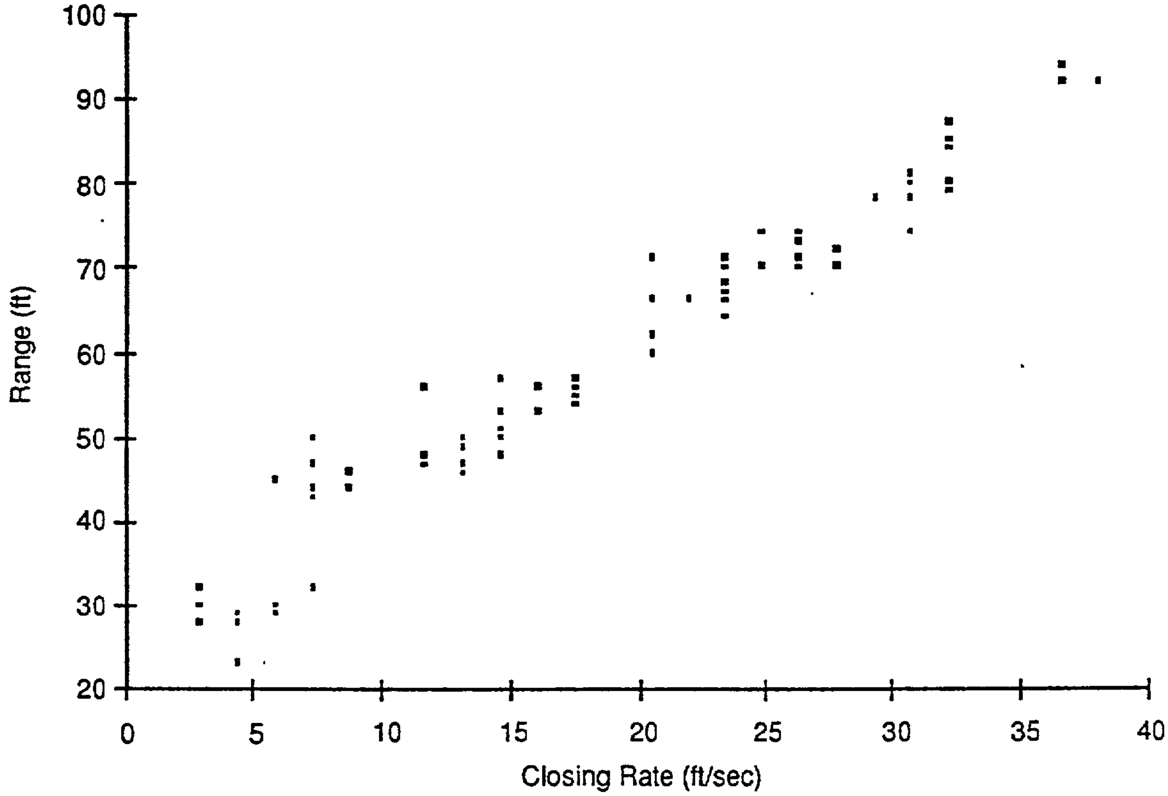

Figure 9. Alarm Onset Data for Full Size Pick–up Truck

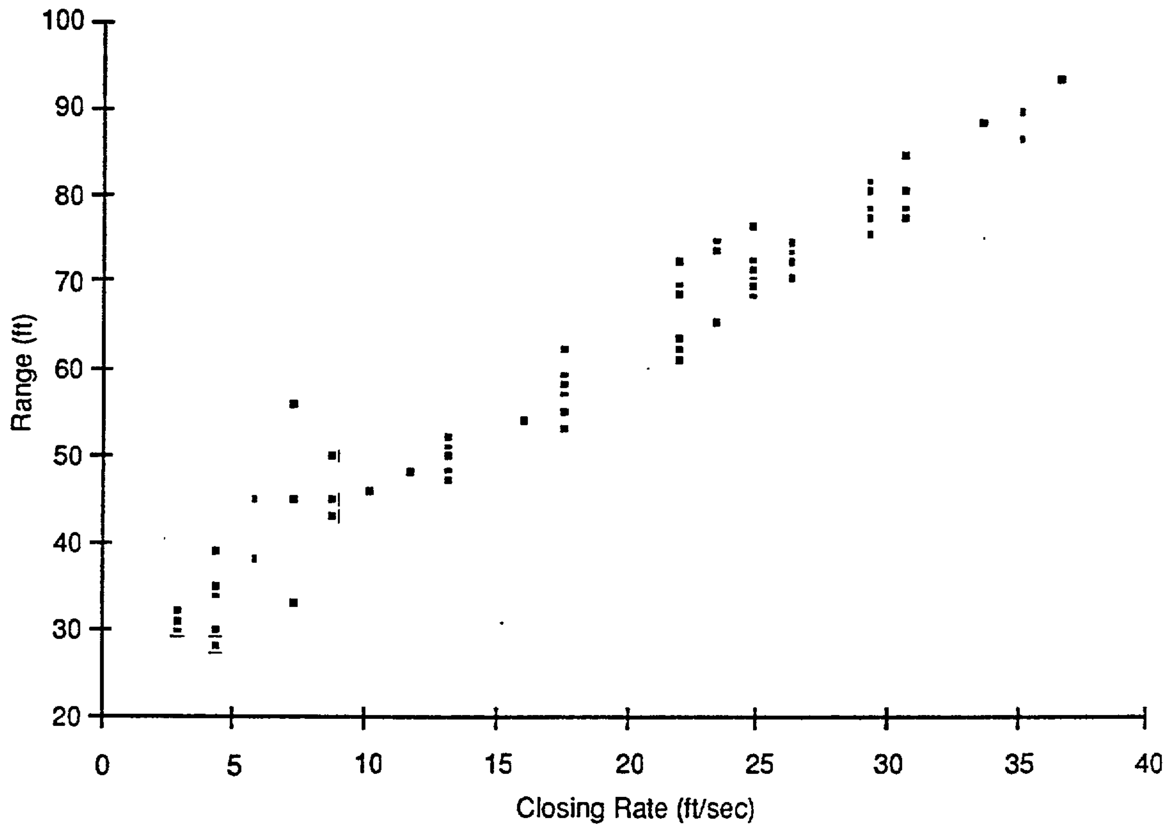

Figure 10. Alarm Onset Data for Mini–Van

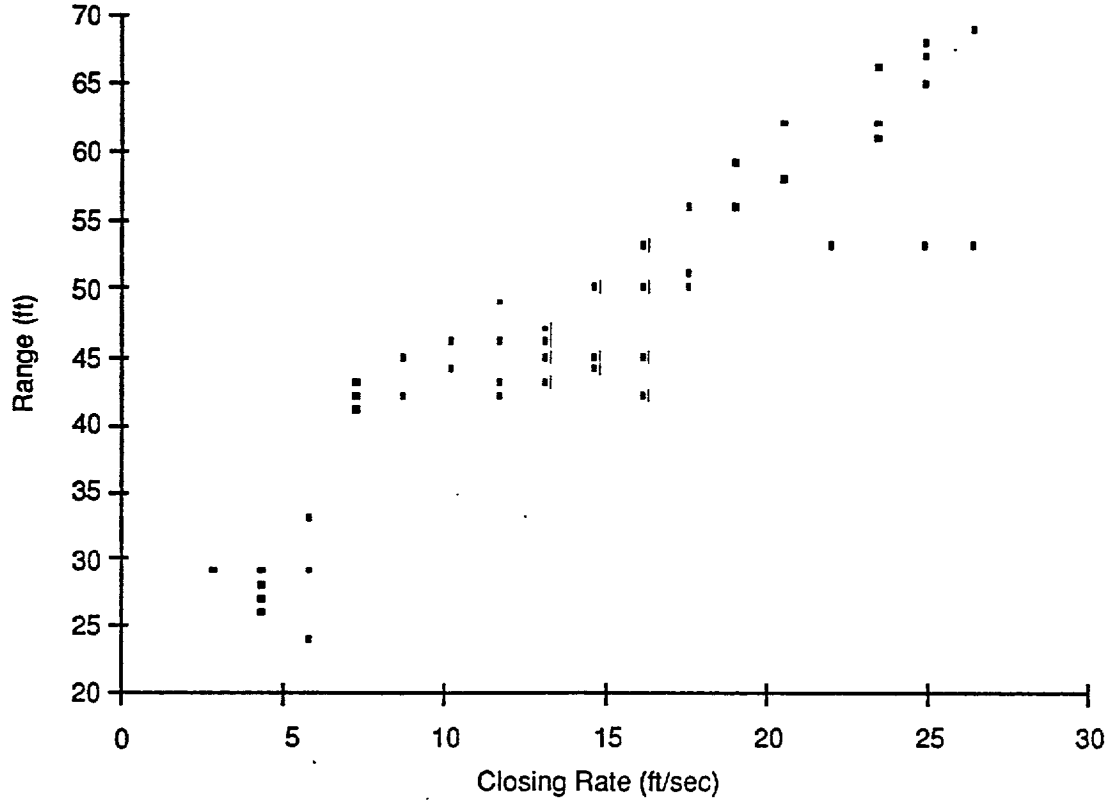

Figure 11. Alarm Onset Data for Large Truck

Following are the equations used to perform the minimum warning distance calculations

$$Dm = (Vv - Vt) * Tr + \frac{(Vv - Vt)^2}{2a} \qquad (1)$$

$$Dm = (Vv * Tr) + \frac{(Vv^2 - Vt^2)}{2a} \qquad (2)$$

$$Dm = (Vv - Vt) * Tr + \frac{(Vv^2 - Vt^2)}{2a} \qquad (3)$$

where

Dm = minimum warning distance (assumes no collision if brakes applied at this distance and vehicle decelerates at rate a)
Vv = velocity of test vehicle
Vt = velocity of target vehicle
Tr = reaction time for driver and braking system (1.5 sec.)
a = braking deceleration (0.5g for dry pavement)

These assumptions were tested with data from each of the seven test vehicles. The comparisons are seen in Figures 15 through 21. Tbe first assumption, constant speed of the target vehicle, requires the test vehicle to slow only to the speed of the target vehicle prior to collision (Figure 12). This assumption is the most liberal, and the system appears to provide ample warning. In all cases, the system performs better at lower closing rates.

The most conservative assumption has the target vehicle braking at the time of alarm activation, followed by test vehicle braking ***Tr*** seconds later (Assumption 2, Figure 13). Using this assumption the system fails to provide adequate warning at any closing rate, and again, as closing rate increases the system error also increases.

The third assumption falls between the two previous assumptions. Here both vehicles are proceeding at constant speeds, with the test vehicle gaining on the target vehicle, causing alarm activation. The target vehicle, however, begins braking at some time after alarm activation, requiring the test vehicle to further reduce speed (Figure 14). Using this assumption there are several timing scenarios which can be calculated. For this analysis, an assumption was made that the target vehicle braking began at the same time as the test vehicle braking. Using this assumption, the system performs adequately at closing rates below 15 to 20 feet per second (10 to 14 MPH). Above these closing rates the system fails to provide adequate warning, and again the error increases with increasing closing rate. Other assumptions concerning the timing would yield similar results, with the difference being the "cross over" speed.

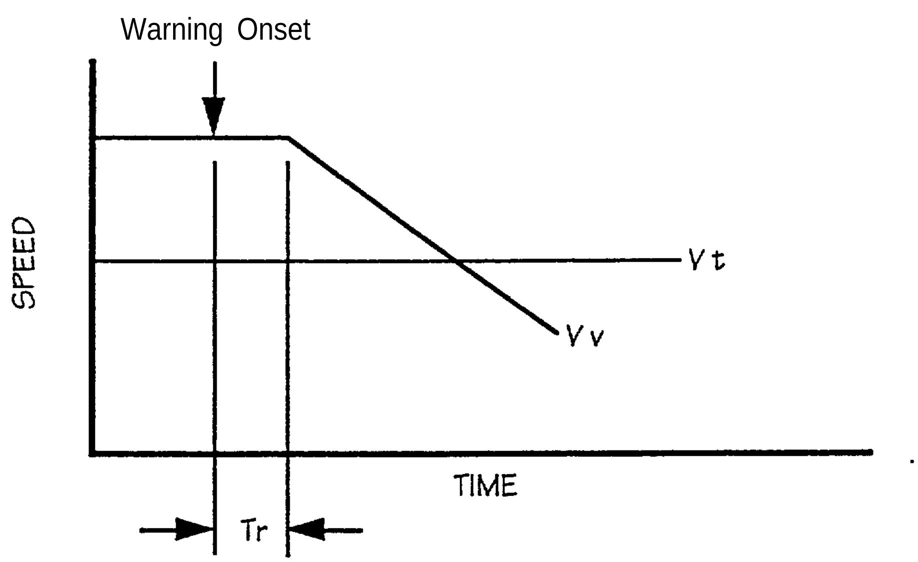

Figure 12. Graphic Description of Assumption 1

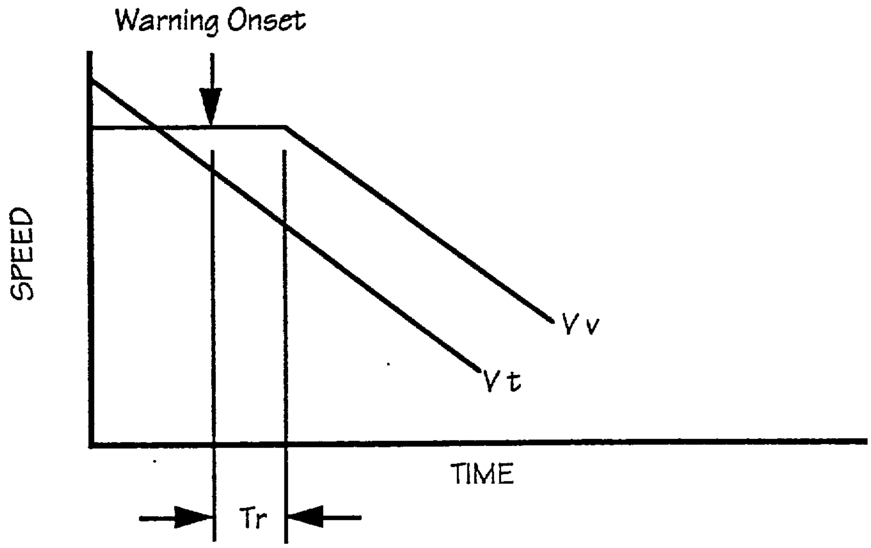

Figure 13. Graphic Description of Assumption 2

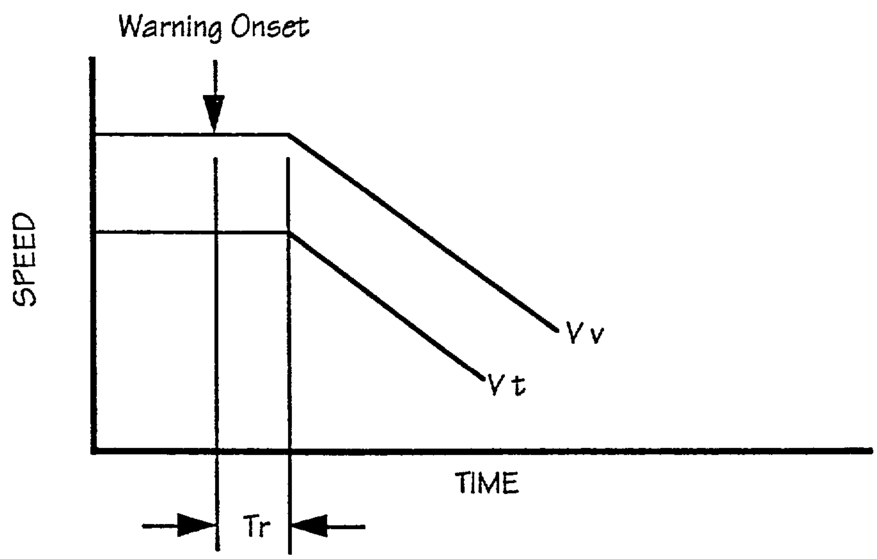

Figure 14. Graphic Description of Assumption 3

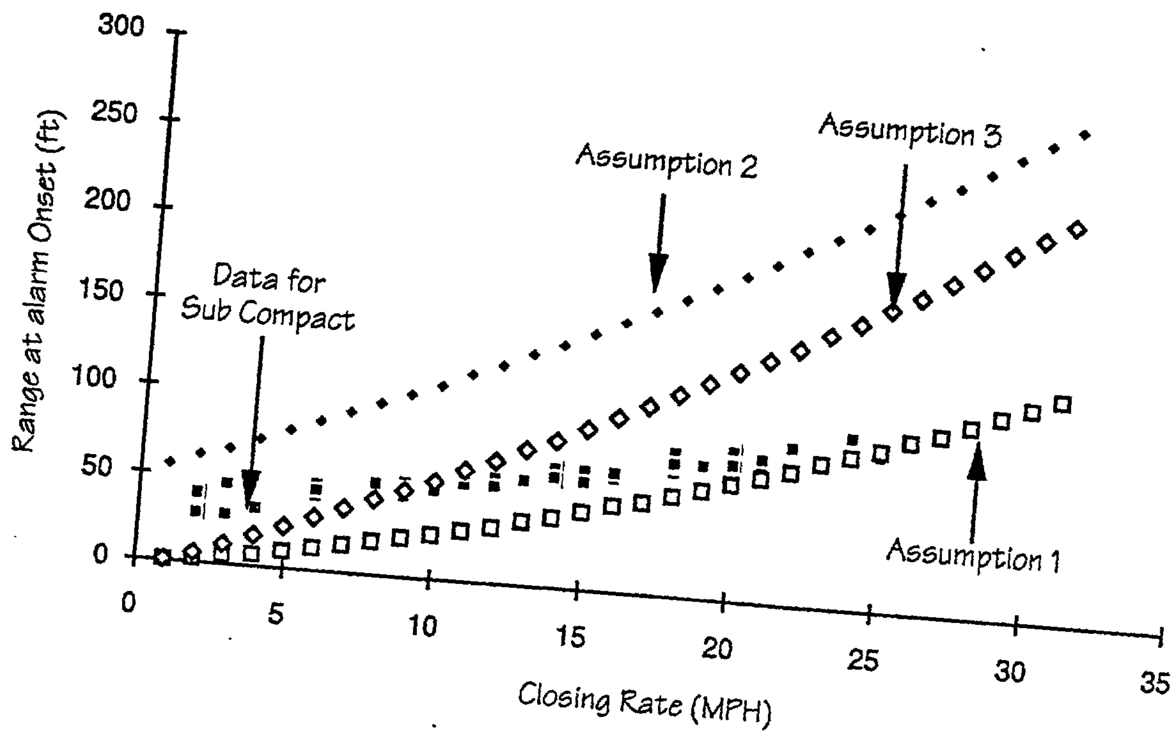

Figure 15. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Sub-Compact Target Vehicle

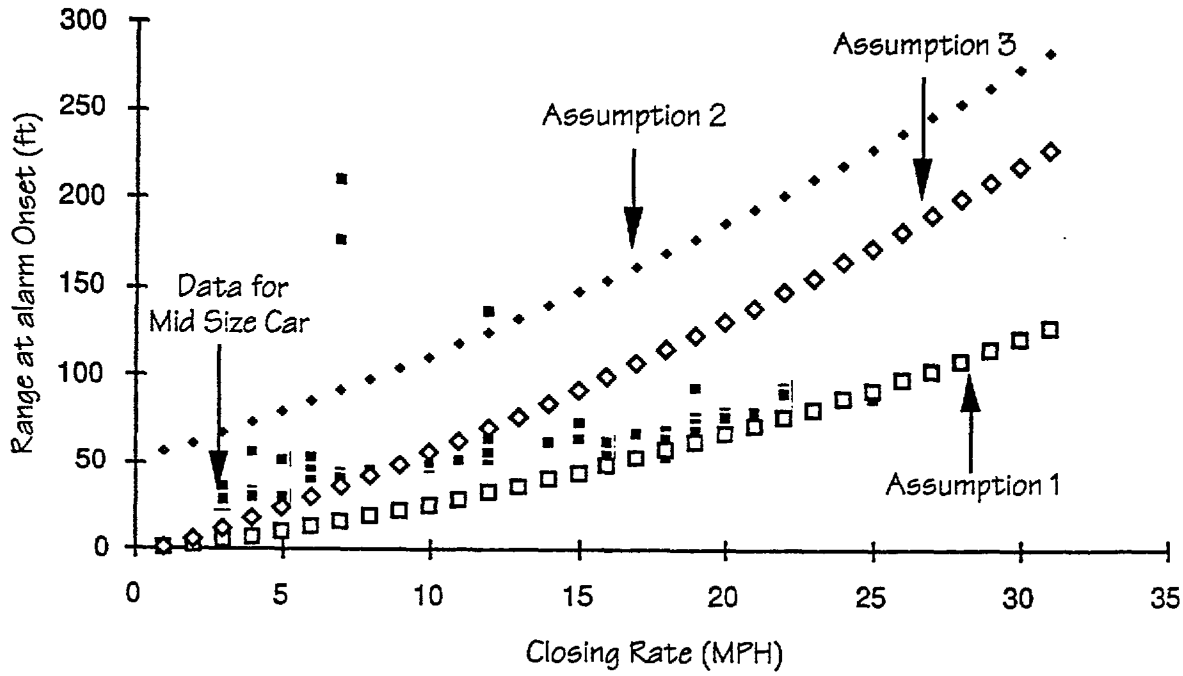

Figure 16. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Mid–Size Target Vehicle

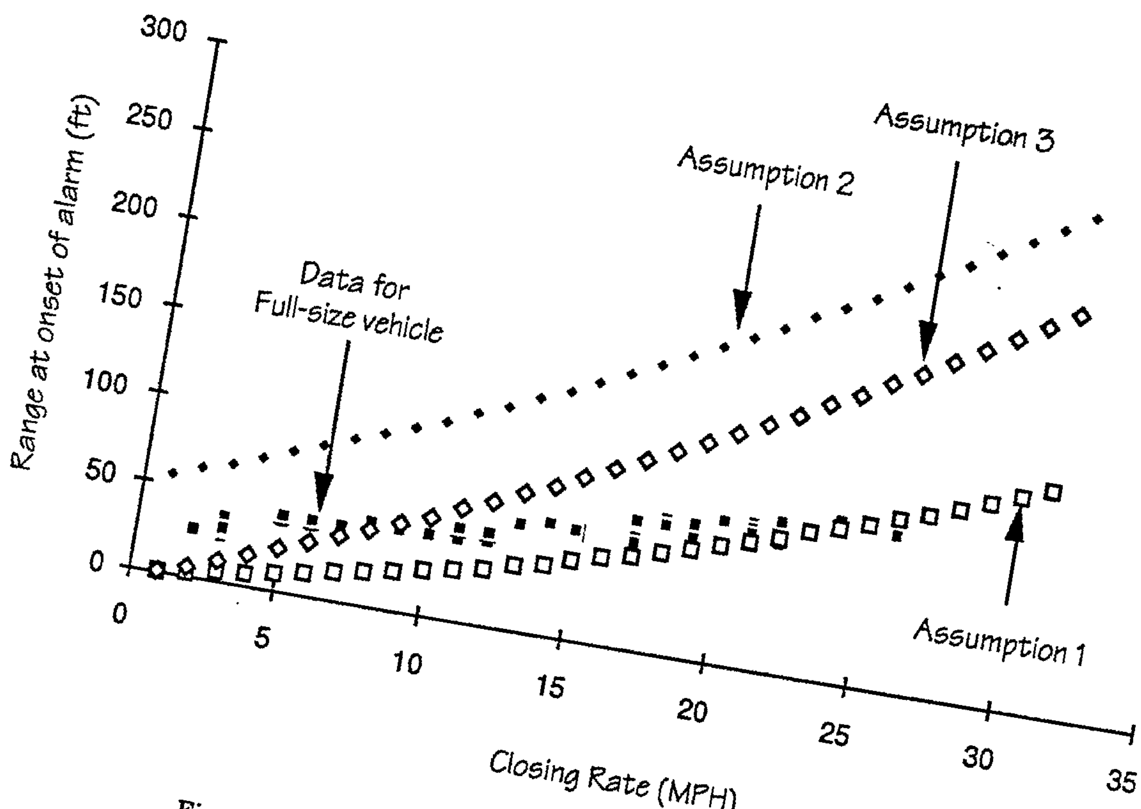

Figure 17. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Full-Size Target Vehicle

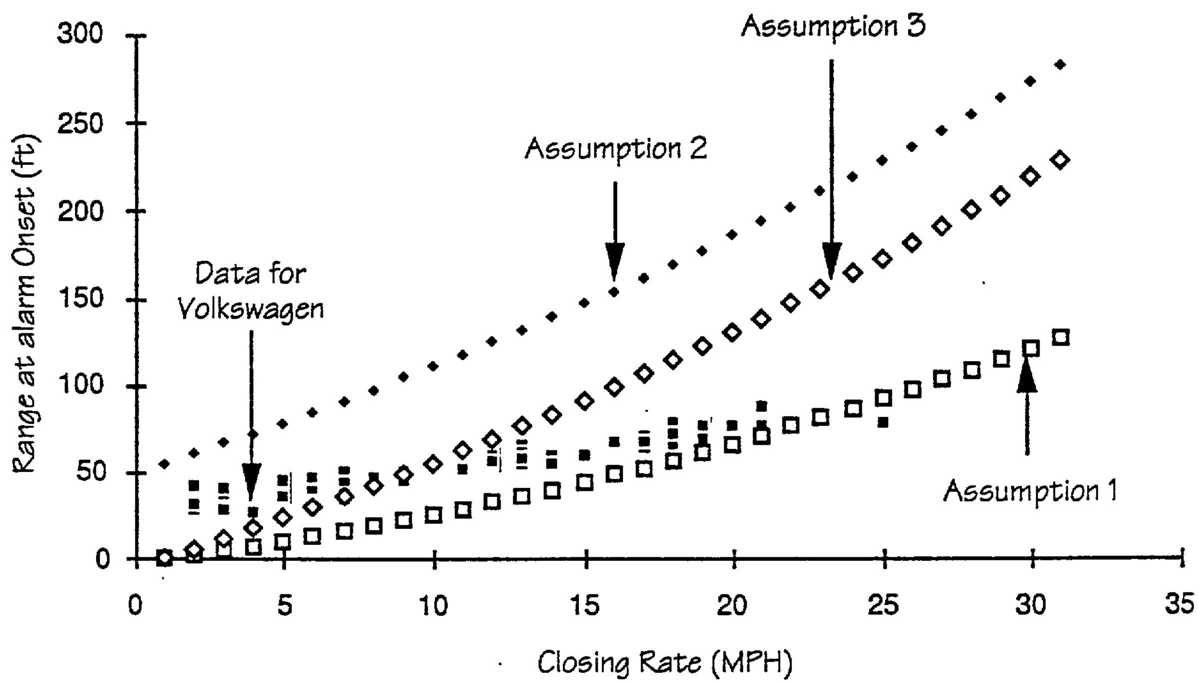

Figure 18. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Volkswagen Target Vehicle

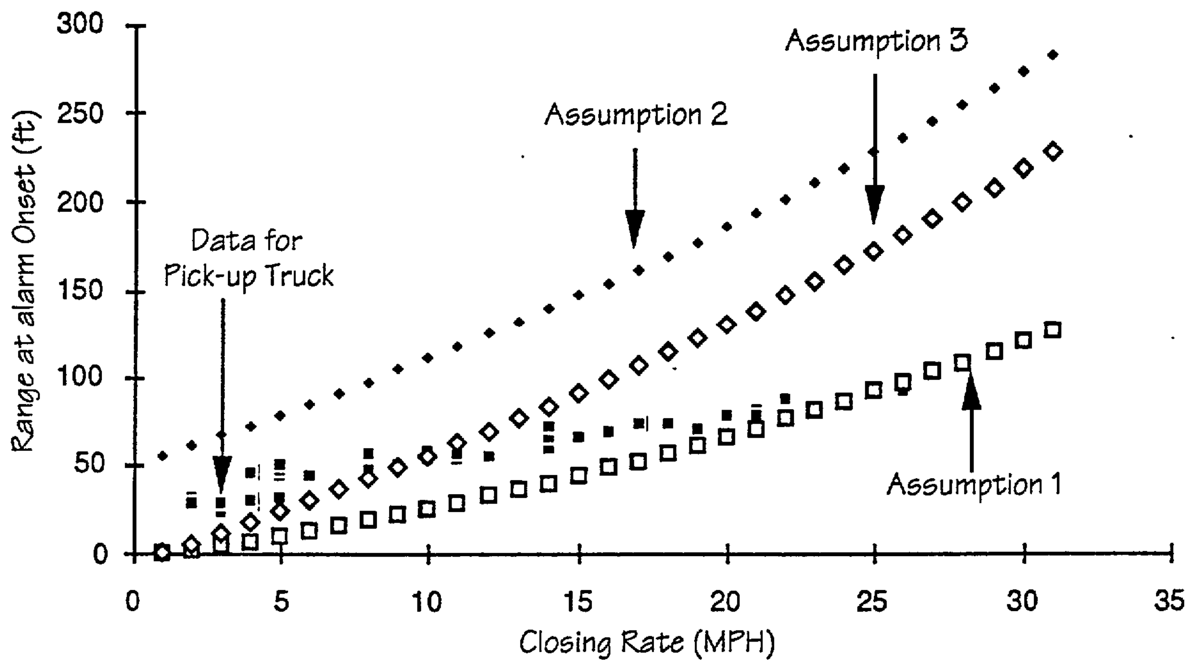

Figure 19: Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Pick–Up Truck Target Vehicle

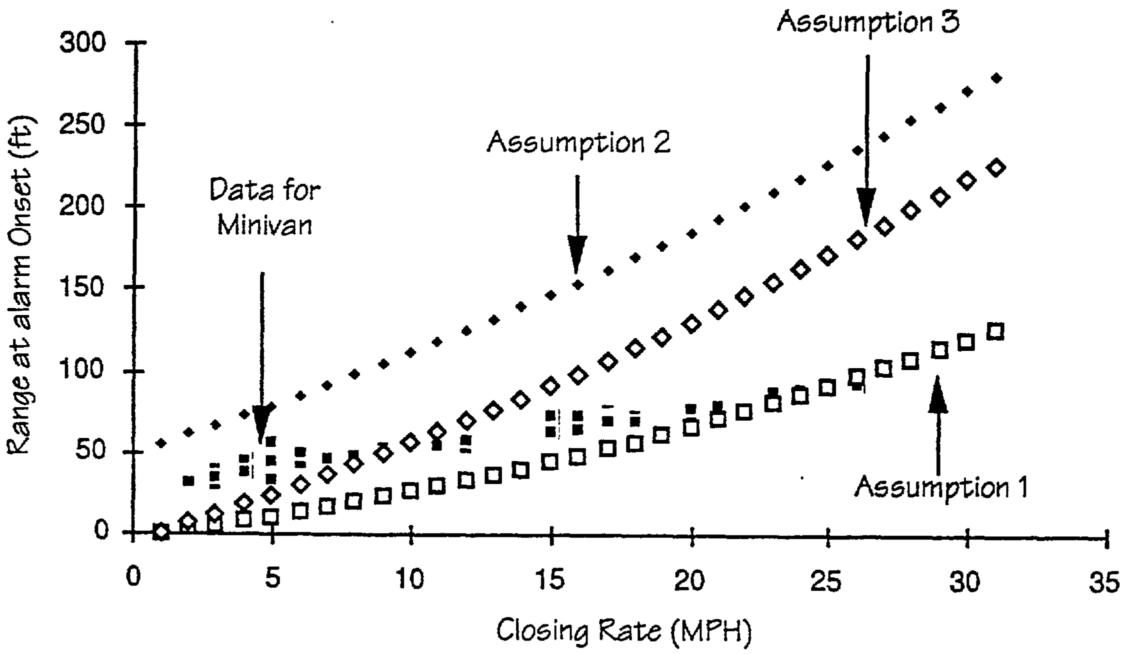

Figure 20. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Mini–Van Target Vehicle

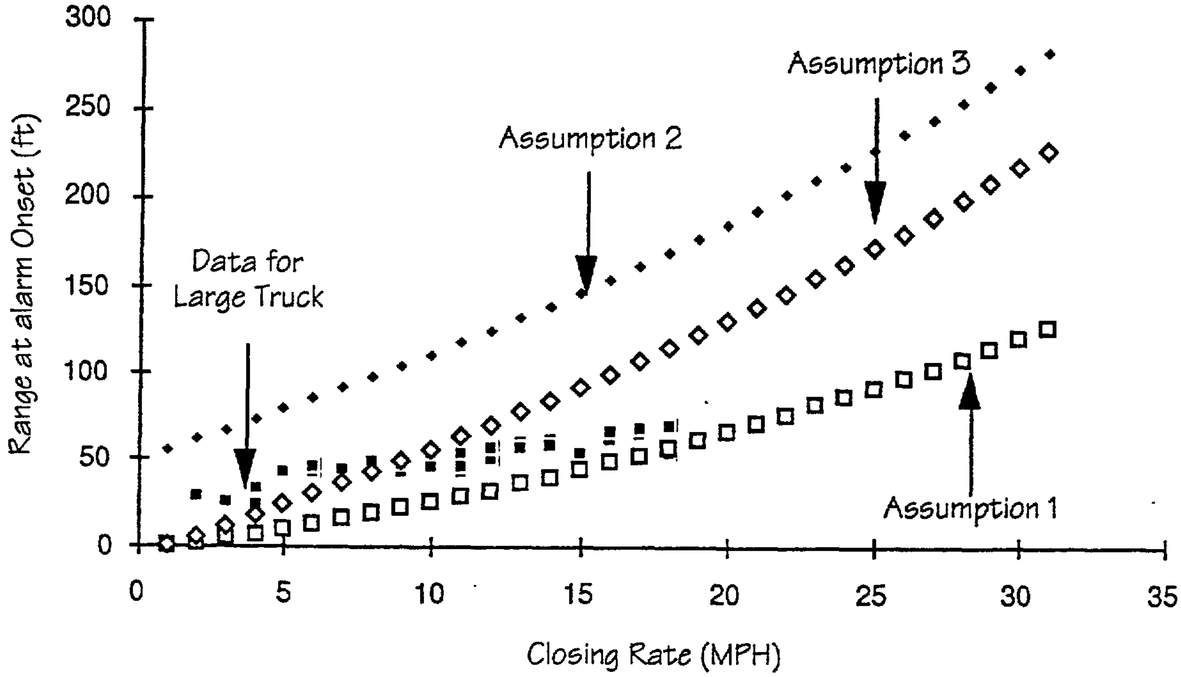

Figure 21. Comparison Between Actual Alarm Onset and Required Alarm Onset Distance Based on the Assumptions in Equations 1–3, Large Truck Target Vehicle

QUALITATIVE TESTS

Methods

Qualitative tests were conducted on over 2500 miles of actual roadway. The purpose of these tests was to determine how the RCS system functioned in the “real world." The evaluation took place on the following types of roadways:

- ***Interstate highways (1327*** miles, as defined by the MUTCD), where conditions varied from low-volume to rush-hour traffic.
- ***Major*** arterial ***roadways (274*** miles), distinguished by multiple lanes of same direction traffic divided from opposing vehicles with median dividers or delineated islands.
- ***Minor arterial roadways (265*** miles), having single or multiple lanes of same direction traffic, but not divided from opposing vehicles.
- ***Residential roadways*** (256 miles, self-explanatory), which allowed testing the system’s interaction with pedestrians and bicyclists.
- ***Rural roadways (259*** miles), including mountain roads, and flat terrain found in agricultural areas.
- ***Other Roadways*** (294 miles), which included all of the above types of roadways, as well as dirt roads, parking lots, etc.

As seen above, the breakdown of data acquisition, by roadway type, was: approximately 50% interstate highway, and 10% each for the other categories. While most of the testing was conducted during daylight, limited nighttime data were also obtained.

Data were gathered during “normal” driving. Two types of events were recorded by the experimenter. The first type of event was a system alarm, the second was a lack of alarm for a situation where the experimenter felt that an alarm would have been appropriate. When an event was encountered the experimenter recorded the video counter number on the micro-cassette recorder to allow easy access to the event on the video tape; then the type of event, possible cause, and other pertinent information was recorded on the audio track of the video recorder. The video tapes were then reviewed to verify and categorize the event.

Results

A total of 573 events were recorded during the testing. Data analysis required reviewing the video taped data for each of these events. A slightly disproportionate number of events occurred on the Interstate Highway portion of the tests as shown in Table 2. The events fall into three major categories: ***false alarms, appropriate events,*** and ***system misses.*** All of these categories are subjective and are based on the experimenter’s driving experience and assessment of the situation as it was encountered. Also, the category assigned to a given event is based on the experimenter’s interpretation of the event as depicted in the video tape. ***False alarms*** were events when the alarm was activated, but where immediate braking was not required. ***Appropriate events*** were those events where the alarm was activated and immediate braking was required to avoid a collision, ***System misses*** were events where the driver felt immediate braking was required, but where no alarms were activated. Appendix B contains the data breakdown for event types, causes and frequency.

	EVENTS			
	NUMBER			PERCENT
ROAD TYPE	A PPROPRIATE ALARMS	FALSE ALARMS	SYSTEM MISSES	
Interstate Highway	125	185	13	56.37
Major Arterial	8	4 0	1	8.38
Minor Arterial	8	30	5	7.50
Residential	3	4 0	9	9.08
Rural	3	13	11	4.71
Other	3 8	3 5	7	13.96
TOTAL	185	343	4 6	100.00

Table 2. Breakdown of Events By Road Type

False Alarms

False alarms were the most frequently occurring event (N=343). The highest proportion were caused by Interstate Highway dividers when the test vehicle was proceeding straight (N=108). This was followed, in order, by false alarms caused by: unknown factors (N=79), freeway dividers when the test vehicle was in a curve (N=45), and signs and objects in the left hand median (N=27). Causes of false alarms with between 10 and 20 occurrences included Objects in the roadside when the test vehicle was proceeding straight (N=14), parked vehicles while the vehicle was proceeding straight (N=12), objects in the road while the test vehicle was in a curve (N=ll), and parked vehicles when the test vehicle was in a curve (N=l0). A variety of causes accounted for the remainder of the recorded false alarms.

False alarms were most prevalent on the freeway, with the freeway divider accounting for 83 percent of these alarms, and 45 percent of all false alarms. The balance of the false alarms were divided fairly evenly among the other road types. Among the balance of the false alarms unknown factors accounted for 23 percent of the false alarms, and signs or objects in the median accounted for 7 percent. No other category accounted for any significant number of false alarms.

Appropriate Alarms

Appropriate alarms accounted for over 32 percent of all events (N=185). The highest frequency occurrences were when the test vehicle was proceeding straight and the vehicle **in** front slowed (N=ll2), when the test vehicle changed lanes (N=30), when the vehicle in front applied its brakes causing the test vehicle to close too rapidly (N=13), and when other vehicles changed lanes in front of the test vehicle (N=12). In the second and fourth cases the lane change action resulted in an excessive closing rate.

Again, freeways accounted for the majority of the appropriate alarms (N=125), although in the case of appropriate alarm the percentage breakdown is not as close to the driving breakdown as with the false alarms. Sixty eight percent (68%) of the appropriate alarms occurred on the freeway. Thirty eight percent (38%) were in the "other" category, but much of this driving was also freeway. None of the other road categories accounted for even 10% of the appropriate alarms.

System Misses

Events involving system misses occurred with relatively low frequency (N=46), and accounted for less than 8% of all events. The most frequent missed event was when a vehicle in an adjacent lane changed lanes in front of the test vehicle (N=13). The second most common cause was when the test vehicle was closing too fast and the system failed to respond (N=ll). The most critical missed event was when a vehicle was stopped in front of the test vehicle (N=3). This occurred one time on the freeway when there was barely enough time to avoid the stopped vehicle by changing lanes, had the adjacent lane been occupied there would have been a collision.

The distribution of system misses was fairly even across all types of roadways, with the exception of major arterials which had a very low frequency.

CONCLUSIONS

It appears that the RCS system produced a high number of false alarms. These occurred primarily on the freeway during normal driving. The most common cause of the false alarms was the Jersey barrier divider, and more of these alarms occurred if there was no vehicle in front of the test vehicle.

The quantitative tests revealed two major problems with the system's operation. A fault was found in the system's ability to accurately determine the range of a target. In this area there were two problems, an unusually high variability in the displayed range of an object, and a tendency to display a range which was greater than it should have been. The other area which created a problem was the system's inability to recognize objects in the vehicle's path if the closing rate was high. This problem means that the system will not warn the driver of a stopped vehicle when traveling at moderately high speeds. This could prove to be a flaw, and during the qualitative tests this error almost resulted in a collision.

Additionally, the analysis of the alarm onset tests found that using all but the most liberal assumptions concerning other traffic resulted in a high probability of inadequate warning time. Unfortunately, in the authors' opinion, changing the algorithm to provide adequate warning using other assumptions may result in the user ***losing*** faith in the system because the alarm appears to be "too early., This may be an unsolvable human factors problem because drivers are accustomed to driving too close.

On the positive side, the system provided alarms in situations which may have resulted in collisions. These events accounted for almost one-third of all events. If the Jersey barrier interference were eliminated as a cause of false alarms, appropriate alarms would represent almost half of all events.

Reference was made earlier to the tests conducted on the Nissan laser based system. A comparison of the basic results of the two systems is found in Table 3.

	SYSTEM	
EVENT TYPE	RCS	NISSAN
False Alarm	59.76%	83.57%
Appropriate Alarm	32.23%	12.79%
System Miss	0.01%	3.64%

Table 3. Comparison of RCS and Nissan System Performance

As the table shows, the RCS system has made a substantial improvement over the Nissan system. The Nissan system's false alarm rate made system use impractical except for driver training or limited use. The RCS system has reduced the false alarm rate substantially, and if the Jersey barrier problem is corrected the change would be even more dramatic. The RCS system has also improved appropriate alarm incidence almost threefold. The unfortunate comparison is with the system misses. Here the RCS system has over two times the system misses of the Nissan system. It is interesting that the most common cause of false alarms in the Nissan system, vehicles changing lanes, was the most common cause of system misses in the RCS system. The Nissan system provided an alarm each time a lane change maneuver was completed and the vehicle in front of the test vehicle was closer in distance than the previous vehicle had been. Most of the time there was no collision danger. The RCS system missed those occasions when a vehicle changed lanes in front of the test vehicle requiring braking to avoid a collision. This shows that problems cannot be corrected in a vacuum.

This project was limited in scope, and only called for the research described above. No research was conducted on the impact of the system on driver behavior, or on accident rates.

The reader of this report should be aware that advances in the technology are taking place as this report is being written. For example, during the conduct of the quantitative tests RCS developed methodologies which should help reduce the range variability noted. They are also working on technologies which will assist in deciding what objects really pose a threat. It is hoped that the results of these tests will not inhibit further development of these systems.

REFERENCE

Stein, A.C., Ziedman, D. and Parseghian, Z. ***Field Evaluation of a Nissan Laser Collision Avoidance System.*** Washington, D.C.: U.S. Department of Transportation, 1989 (NTIS, DOT-HS-807 375).

APPENDIX A

QUANTITATIVE TESTING DATA

Range Measurement Data

1

Target Speed	Run Number	Actual Speed	Measured Distance @ 100	Actual Speed	Measured Distance @ 150	Actual Speed	Measured Distance @ 200'	Actual Speed	Measured Distance @ 250'	Actual Speed	Measured Distance @ 300
1.0	1	11	116	11	169	11	202	11	295	11	288
	2	11	115	11	169	11	213	10	298	10	330
	3	11	113	11	164	11	206	11	276	11	302
	4	10	115	10	162	11	236	11	265	11	305
	5	10	115	9	169	10	200	10	272	11	340
	6	10	116	10	164	10	219	10	255	10	369
	7	10	113	10	173	10	214	10	266	10	343
	8	10	112	10	168	10	205	10	301	10	321
	9	10	113	10	163	10	196	10	301	10	337
	10	10	113	9	167	10	205	10	293	10	350
2.0	1	20	124	20	173	20	257	20	235	20	393
	2	20	121	20	174	21	244	20	300	20	250
	3	20	126	20	177	20	192	20	303	21	351
	4	20	119	20	179	20	245	20	182	20	336
	5	20	124	20	174	21	230	20	'346	20	336
	6	20	120	20	168	20	133	20	325	20	322
	7	20	120	20	186	20	318	20	329	20	348
	8	20	125	20	155	20		20	353	20	
	9	19	122	20	146	20		19		20	
	10	20	122	2 0	145	20		20		20	

Range Measurement Data

Target Speed	Run Number	Actual Speed	Measured Distance @ 100'	Actual Speed	Measured Distance @ 150'	Actual Speed	Measured Distance @ 200'	Actual Speed	Measured Distance @ 250'	Actual Speed	Measured Distance @ 300'
30	1	30	132	29	142	30	222	30	316	30	368
	2	30	124	30	177	29	264	30	306	30	325
	3	30	136	30	189	30	236	30	362	30	366
	4	30	126	30	199	30	159	30	367	30	351
	5	30	126	30	177	30	324	30	198	30	340
	6	30	130	31	219	31	212	31	369	30	391
	7	29	126	29	236	30	167	30	220	30	251
	8	30	140	30	214	30	201	30	233	30	
	9	30	129	30	172	30	222	30	213	30	
	10	30	132	29	190	30	183	30	268	30	
	11	30	123	30		30		30		30	
40	1	40	132	40	176	40	276	40	320	40	323
	3	40	136	40	159	40	426	39	583	40	
	4	39	138	39	180	39	264	39		39	
	5	40	138	40	171	40	254	40		40	
	6	40	139	40	191	40	363	40		40	
	7	39	126	39	202	39	258	40		40	
	8	39	151	40	188	40	283	40		40	
	9	39	139	39	187	39		40		40	
	10	39	139	39	186	40		40		40	

Range Measurement Data

Target **Speed**	Run Number	Actual Speed	Measured Distance @ 100’	Actual **Speed**	Measured Distance @ 150’	Actual Speed	Measured Distance @ 200'	Actual Speed	Measured Distance @ 250'	Actual Speed	Measured Distance @ 300'
5(	1	50	148	5c	191	50	233	50	324	50	
	2	50	148	5c	185	50	340	50	232	50	
	3	51		51	204	51	250	50		50	
	5	49		49	195	49	299	49		50	
	6	49		49	180	49	277	49		49	
	7	50		50	204	49	248	49		49	
	8	50		50	189	50		50		49	
	9	50		50	201	50		50		50	
	10	49		49	192	49		49		50	
	11	50		50	203	50		49		49	
6(	1	60		60		60		60		61	
	2	60		60		60	286	60		60	
	3	59		59		60		60		59	
	4	59		59		59		60		60	
	5	61		61		61		61		61	
	6	60		60		60	332	59		60	
	7	60		60		60		60		60	
	8	61		61	288	61		61		61	
	9	60		60		60	525	60		60	
	10	59		59		60		60		6 0	

Range Measurement Data

Distance	100	150	200	250	300
10 MPH					
Mean	114.10	166.80	209.60	282.20	328.50
SD	1.45	3.46	11.58	17.25	24.65
20 MPH					
Mean	122.30	167.70	231.29	296.63	333.71
SD	2.36	14.16	57.35	59.11	43.15
30 MPH					
Mean	129.45	191.50	219.00	285.20	341.71
SD	5.24	26.99	48.68	67.56	45.29
40 MPH					
Mean	137.56	182.22	303.43		
SD	6.65	12.49	65.58		
50 MPH					
Mean		194.40	274.50		
SD		8.46	39.80		

Closing Rate Test Data

Run Number	Radar Gun Closing Rate (MPH)	RCS Displayed Closing Rate Trial Set 1	Trial Set 2
1	3	3.0	3.5
2	6	6.0	6.0
3	9	9.0	9.0
4	12	11.5	12.0
5	16	15.5	16.0

Simulated Rain Tests

Dry Trials

Run Number	Range at Alarm Onset	Closing Rate at Alarm Onset	Speed at Alarm Onset	Analysis
1	106	31	30	Appropriate alarm
2	122	34	34	Appropriate alarm
3	132	25	32	Suspect range
4		30	29	Missed Target, no alarm
5	111	34	34	Appropriate alarm
6	97	31	31	Appropriate alarm
7	115	10	3c	Suspect Closing Rate, not related to speed
8	109	26	33	Appropriate alarm
9	171	28	28	Appropriate alarm
10	98	11	31	Suspect Closing Rate, not related to speed

Rain Trials

Run Number	Range at Alarm Onset	Closing Rate at Alarm Onset	Speed at Alarm Onset	Analysis
1			29	Missed Target, no alarm
2	30		29	Appropriate Alarm
3			20	Missed Target, no alarm
4			31	Missed Target, no alarm
5			29	Missed Target, no alarm
6			33	Missed Target, no alarm
7			28	Missed Target, no alarm
a			29	Missed Target, no alarm
9			30	Missed Target, no alarm
10			32	Missed Target, no alarm

Radar Gun Interference Tests

Run Number	Radar Gun Speed (MPH)	Direction of Travel	Comments	Analysts
1	44.0	N		RCS behaved normally
2	42.0	S		RCS behaved normally
3	41.0	N	Locked in	RCS behaved normally
4	41.0	S		Closing rate read 11 and 5, no range displayed
5	39.0	N		RCS behaved normally
6	41.0	S		RCS behaved normally
7	42.0	N		RCS behaved normally
8	40.0	S		RCS behaved normally
9	40.0	N		RCS behaved normally
10	41 .0	S		RCS behaved normally
11		S	Direct at car with closing rate	Hard to say anything
12	48.0	N	Direct at car with closing rate	Hard to say anything
13	15.0	S	Direct at car with closing rate	Negative closing rates
14		S	No radar gun	RCS behaved normally
15	15.5		All radar	Negative closing rates

Opposing Unit Interference Tests

Run Number	Speed of Test Vehicle (MPH)	Comments	Analysis
1	35		
2	35		
3	35		
4	35	No opposing unit, run aborted	
5	35	Aimed at stationary vehicle, no	
6	35	opposing unit, run aborted	
7	60	Aimed at stationary target, alarm	False Alarm, not related to other unit
8	20	Alarm	Appropriate alarm
9	20	Alarm	False Alarm, not related to other unit

Bicycle Tests

"Road" Bike

Run Number	Range to Target (ft)	Closing Rate (MPH)	Speed of Test Vehicle (MPH)	Appropriate Closing Rate ?	Alarm Activation ?
1	none			No	No
2	none			No	No
3	none			No	No
4	40	10	29	Yes	Yes
5	none			No	No
6	75	11	28	Yes	Yes
7	none			No	No
8	none			No	No
9	none			No	No
10	none			No	No
11	none			No	No
12	none			No	No
13	none			No	No
14	none			No	No
15	none			No	No

"Mountain" Bike

Run Number	Range to Target (ft)	Closing Rate (MPH)	Speed of Test Vehicle (MPH)	Appropriate Closing Rate	Alarm Activation ?
1	none			No	No
2	none			No	No
3	none			No	No
4	none			No	No
5	none			No	No
6	none			No	No
7	none			No	No
8	none			No	No
9	none			No	No
10	none			No	No
11	none			No	No
12	none			No	No
13	none			No	No
14	none			No	No
15	none			No	No

Pedestrian Tests

Pedestrian Test — Test vehicle traveling from 15 MPH to stop prior to striking pedestrian

Pedestrian in Center of Raod

Run Number	Range at Alarm Onset (ft)	Closing Rate at Alarm Onset (MPH)	Speed of Test Vehicle @ Alarm (MPH)	Appropriate Closing Rate ?	Alarm Activation ?
1				No	No
2				No	No
3	77	14	13	Yes	Yes
4				No	No
5				No	No
6				No	No
7				No	No
a				No	No
9				No	No
10				No	No

Pedestrian on Left Side of Road

Run Number	Range at Alan Onset (ft)	Closing Rate at Alarm Onset (MPH)	Speed of Test Vehicle @ Alarm (MPH)	Appropriate Closing Rate ?	Alarm Activation ?
1				No	No
2				No	No
3				No	No
4				No	No
5				No	No
6				No	No
7				***No***	***No***
8				No	No
9				***No***	***No***
10				No	No

Pedestrian Tests

Pedestrian on Right Side of Road

Run Number	Range at Alarm Onset (ft)	Closing Rate at Alarm Onset (MPH)	Speed of Test Vehicle @ Alarm (MPH)	Appropriate Closing Rate ?	Alarm Activation ?
1				No	No
2				No	No
3				No	No
4				No	No
5				No	No
6				No	No
7				No	No
8				No	No
9				No	No
10				No	No

Motorcycle Tests

Motorcycle Test 1988 Harley Davidson 1349cc Highway Patrol

Motorcycle in Middle of Lane

Run Number	Range at Alarm Activation (ft)	Ctosing Rate at Alarm Activation {MPH)	Speed at Alarm Activation (MPH)
1	44	5	33
2	31	3	31
3	33	4	31
4	32	3	29
5	31	3	29
6	36	5	30
7	31	4	29
8	34	4	28
9	31	5	30
10	2E	4	29

Motorcycle at Left of the lane

Run Number	Range at Alarm Activation (ft)	Ciosing Rate at Alarm Activation (MPH)	Speed at Alarm Activation (MPH)
1	No alarm		30
2	No alarm		28
3	No alarm		30
4	No alarm		30
5	No alarm		30
6	No alarm		30
7	No alarm		31
8	47	5	31
9	No alarm		30
10	No alarm		30

Motorcycle at Right of the lane

Run Number	Range at Alarm Activation (ft)	Closing Rate at Alarm Activation {MPH)	Speed at Alarm Activation (MPH)
1	No alarm		30
2	38	-4	30
3	43	2	30
4	45	-1	31
5	No alarm		30
6	31	4	32

Motorcycle Tests

7	No alarm		30
8	No alarm		31
9	No alarm		30
10	No alarm		31

Sub-compact Closing Rate Data Runs

Closing Rate Sub Compact Run Number	Desired Closing Rate (MPH)	Actual Closing Rate {MPH)	Range (ft)	Speed (MPH)	Comments
1	3	3	29	30	
2	3	2	29	29	
3	3	3	29	30	
4	3	4	33	30	
5	3	3	32	30	
6	3	3	31	30	
7	3	3	30	30	
8	3	3	28	30	
9	3	2	40	30	
10	3	3	29	29	
1	6	6	42	32	
2	6	6	43	33	
3	6	6	47	33	
4	6	6	45	32	
5	6	6	49	33	
6	6	6	46	33	
7	6	6	43	32	
8	6	6	46	33	
9	6	6	46	33	
10	6	6	45	33	
11	6	3	46	33	

Sub-compact Closing Rate Data Runs

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments .
1	9	9	51	36	
2	9	9	48	36	
3	9	9	53	36	
4	9	9	49	36	
5	9	9	51	36	
6	9	9	46	36	
7	9	8	52	34	
8	9	9	46	36	
9	9	9	45	36	
10	9	9	49	36	
11	9	10	50	38	
1	12	12	57	39	
2	12	13	59	38	
3	12	12	55	39	
4	12	11	55	38	
5	12	11	62	38	
6	12	12	60	38	
7	12	10	51	38	
8	12	12	59	38	
9	12	11	52	38	abnormal closing rate variability
10	12	12	55	38	
11	12	10	55	38	abnormal closina rate variability

Sub-compact Closing Rate Data Runs

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	15	15	68	41	
2	15	15	65	41	
3	15	14	61	41	
4	15	16	63	41	
5	15	14	68	41	
6	15	16	65	42	
7	15	14	63	40	abnormal closing rate variability
8	15	14	63	41	
9	15	15	67	41	
10	15	15	62	41	
1	18	18	81	44	
2	18	19	76	45	
3	18	18	71	44	
4	18	16	68	45	
5	18	19	81	45	
6	18	18	69	44	abnormal closing rate variability
7	18	18	71	44	
8	18	18	73	44	
9	18	18	76	44	
10	18	14	76	44	abnormal closing rate variability
1	21	21	77	46	
2	21	20	82	47	
3	21	20	85	46	
4	21	20	77	46	
5	21	21	77	46	
6	21	20	76	46	
8	21	20	72	47	
9	21	20	78	47	
10	21	21	82	47	
11	21	20	75	46	
12	21	20	77	46	
13	21	22	a9	48	

Sub-compact Closing Rate Data Runs

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate {MPH)	Range (ft)	Speed (MPH)	Comments
1	25	25	91	50	
2	25	24	97	50	
3	25	25	87	50	

Mid-size Closing Rate Data

Closing Rate Mid-size Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	3	4	28	28	
2	3	4	30	28	
3	3	5	30	28	
4	3	4	32	27	
5	3	4	30	27	
6	3	3	28	27	
7	3	3	36	27	
8	3	3	26	27	
9	3	3	28	27	
10	3	3	28	27	
1	6	5	51	29	
2	6	6	43	30	
3	6	6	41	30	
4	6	7	41	31	
5	6	6	48	30	
6	6	7	44	30	
7	6	6	48	30	
8	6	6	46	30	
9	6	6	52	30	
10	6	-3	40	30	
11	6	7	41	30	

Mid-size Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	9	9	46	32	
2	9	9	45	33	
3	9	10	46	33	
4	9	9	47	33	
5	9	9	46	32	
6	9	9	49	33	
7	9	9	46	33	
8	9	8	45	32	
9	9	9	49	33	
10	9	10	50	33	
11	9	9	48	32	
1	12	12	52	35	
2	12	11	51	35	
3	12	12	51	36	
4	12	10	56	36	
5	12	11			No alarm
6	12	12	136	36	
7	12	7	175	36'	
8	12	7	209	36	
9	12	12	55	36	
10	12	12	55	36	
11	12	12	63	36	
12	12	4	55	36	

Mid-size Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	15	14	65	38	
2	15	16	54	38	
3	15	15	69	39	
4	15	14	64	38	
5	15	15	68	38	
6	15	15	64	39	
7	15	14	62	38	
8	15	15	62	39	
9	15	15	67	39	
10	15	15	72	39	
11	15	16	62	39	
12	15	15	64	38	
1	18	19	75	42	
2	18	17	68	41	
3	18	19	73	42	
4	18	18	67	41	
5	18	19	67	41	
6	18	18	67	41	
7	18	18	66	41	
8	18	18	68	41	
9	18	18	52	40	
10	18	18	63	41	
11	18	17	66	40	
12	18	19	68	41	

Mid-size Closing Rate Data

Run Number	Desired Closing Rate {MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	21	22	93	45	
2	21	22	78	45	
3	21	22	90	44	
4	21	20	78	43	
5	21	21	73	44	
6	21	21	77	45	
7	21	22	76	45	
8	21	22	77	45	
9	21	21	80	44	
10	21	21	78	45	
11	21	20	75	45	
1	25	19	93	48	
2	25	25	87	48	
3	25	24	85	48	
1	25				Run Aborted
2	25			46	No alarm
3	25			49	No alarm

Full-size Closing Rate Data

Closing Rate Full Size Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH}	Range (ft)	Speed (MPH)	Comments
1	3	2.00	28.00	27	
2	3	2.00	27.00	27	
3	3	3.00	29.00	29	
4	3	2.00	27.00	26	
5	3	3.00	28.00	28	
6	3	2.00	27.00	28	
7	3	3.00	36.00	29	
8	3	2.00	29.00	27	
9	3	3.00	30.00	30	
10	3	3.00	26.00	27	
1	6	5.00	40.00	31	
2	6	6.00	40.00	32	
3	6	6.00	42.00	32	
4	6	8.00	45.00	33	
5	6	5.00	42.00	32	
6	6	6.00	43.00	30	
7	6	5.00	44.00	30	
8	6	6.00	39.00	31	
9	6	7.00	43.00	31	
10	6	6.00	39.00	29	

Full-size Closing Rate Data

Run Number	Desired Closing Rate {MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	9	8.00	47.00	32	
2	9	8.00	46.00	33	
3	9	9.00	45.00	34	
4	9	9.00	50.00	34	
5	9	9.00	44.00	35	
6	9	8.00	44.00	33	
7	9	10.00	45.00	33	
8	9	8.00	47.00	33	
9					Aborted run
10	9	9.00	45.00	35	
1	12	12.00	49.00	35	
2	12	12.00	47.00	36	
3	12	12.00	54.00	36	
4	12	12.00	53.00	36	
5	12	11.00	46.00	37	
6	12	12.00	52.00	36	
7	12	13.00	59.00	37	
8	12	12.00	52.00	36	
9	12	11.00	52.00	37	
10	12	12.00	52.00	36	

Full-size Closing Rate Data

Run Number	Desired Closing Rate {MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	15	15.00	60.00	39	
2	15	17.00	60.00	41	
3	15	17.00	66.00	40	
4	15	14.00	58.00	39	
5	15	15.00	59.00	40	
6	15	14.00	60.00	39	
7	15	15.00	61.00	40	
8	15	14.00	61.00	40	
9	15	14.00	63.00	41	
10	15	15.00	62.00	36	
1	18	19.00	74.00	42	
2	18	17.00	66.00	39	
3	18	19.00	74.00	43	
4	18	17.00	71.00	42	
5	18	18.00	72.00	44	
6	18	19.00	69.00	43	
7	18	17.00	72.00	43	
8	18	19.00	75.00	44	
9	18	18.00	76.00	42	
10	18	18.00	71.00	43	
11	18	18.00	72.00	43	

Full-size Closing Rate Data

Run Number	Desired Closing Rate {MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	21	21.00	76.00	46	
2	21	22.00	72.00	46	
3	21	22.00	79.00	46	
4	21	22.00	84.00	46	
5	21	21.00	81.00	45	
6	21	21.00	81.00	45	
7				46	Aborted Run
8	21	21.00	75.00	45	
9	21	21.00	76.00	46	
10	21	21.00	79.00	45	
11	21	20.00	80.00	46	
1	25	24.00	91 00	49	
2	25	26.00	87.00	45	
3	25	23.00	80.00	44	

Volkswagen Closing Rate Data

Closing Rate Votkswagen Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed {MPH)	Comments
1	3	2	28	27	
2	**3**	2	28	27	
3	**3**	3	28	27	
4	**3**	3	38	26	
5	**3**	2	32	28	
6	**3**	2	43	30	
7					Aborted Run
8	**3**	5	42	29	
9	**3**	4	27	29	
10	**3**	3	29	27	
11	**3**	4	29	28	
12	**3**	3	28	27	
1	**6**	5	43	30	
2	**6**	6	47	31	
3	**6**	6	43	30	
4	**6**	6	40	30	
5	**6**	7	50	31	
6	**6**	5	45	30	
7	**6**	5	37	30	
8	**6**	7	41	30	
9	**6**	8	42	31	
10	**6**	5	42	29	
11	**6**	7	43	30	
12	**6**	7	44	31	

Volkswagen Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate {MPH)	Range (ft)	Speed (MPH)	Comments
1					Aborted Run
2	9	8	49	34	
3	9	8	45	33	
4	9	5	36	34	
5	9	9	48	35	
6	9	7	34	34	
7	9	9	50	36	
8	9	8	43	32	
9	9	7	38	33	
10	9	3	41	34	
11	9	9	47	33	
12	9	9	45	37	
1					Aborted Run
2	12	12	54	36	
3	12	8	47	34	
4	12	13	61	38	
5	12	12	56	37	
6	12	11	51	36	
7	12	12	60	36	
8	12	12	56	37	
9	12	13	55	38	
10	12	13	57	38	
11	12	13	66	37	

Volkswagen Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1					Aborted Run
2	15	14	55	39	
3	15	16	69	40	
4					Aborted Run
5	15	13	59	36	
6					Aborted Run
7	15	16	67	40	
8					Aborted Run
9	15	14	59	38	
10	15	17	67	40	
11	15	15	61	39	
12	15	15	57	39	
13	15	15	60	41	
1	18	18	66	43	
2	18	18	78	43	
3	18	18	62	43	
4	18	18	71	43	
5	18	18	65	43	
7	18	19	77	42	
8	18	17	67	43	
9	18	17	64	42	
10	18	17	70	42	
11	18	19	68	43	

Volkswagen Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate {MPH)	Range (ft)	Speed (MPH)	Comments .
1	21	21	75	45	
2	21	21	78	46	
3					Aborted Run
4	21	21	77	45	
5	21	21	77	46	
6	21	21	75	45	
7					Aborted Run
a	21	20	77	46	
9	21	18	71	45	
10	21	21	a7	45	
11					Aborted Run
1					Aborted Run
2	25	25	78	48	
3					Aborted Run

Pick up Truck Closing Rate Data

Closing Rate Pick-up Truck					
Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	3	3	23	29	
2	3	2	30	29	
3	3	4	29	28	
4	3	2	28	27	
5	3	3	29	29	
6	3	2	32	28	
7	3	5	32	30	
a	3	2	28	27	
9	3	3	29	29	
10	3	3	28	29	
11	3	5	43	30	
12	3	3	29	30	
13	3	4	30	29	
1	6	a	56	33	
2	6	6	46	31	
3	6	5	44	31	
4	6	6	46	32	
5	6	5	47	32	
6	6	6	44	31	
7	6	6	44	31	
8	6	5	50	31	
9	6	6	44	32	
10	6	4	45	31	

Pick up Truck Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	9	10	48	35	
2	9	9	46	35	
3	9	10	50	35	
4	9	8	48	35	
5	9	10	51	35	
6	9	9	46	36	
7	9	9	46	36	
a	9	9	47	36	
9	9	8	47	36	
10	9	9	49	36	
11	9	9	50	36	
1	12	12	56	37	
2	12	12	55	38	
3	12	12	55	37	
4	12	11	53	38	
5	12	12	57	38	abnormal closing rate variability
6	12	12	54	38	abnormal closing rate variability
7	12	12	54	38	
8	12	12	54	38	
9	12				Aborted run
10	12	11	56	37	
11	12	10	53	37	
12	12	10	57	37	

Pick up Truck Closing Rate Data

Run Number	Desired Closing Rate {MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	15	16	67	40	
2	15	16	71	41	
3	15	16	64	41	abnormal closing rate variability
4	15	16	70	41	
5	15	16	70	41	
6	15	16	66	40	abnormal closing rate variability
7	15	14	62	40	
8	15	14	60	40	
9	15	15	66	40	
10	15	14	66	40	
11	15	14	71	40	
1	18	17	74	42	
2	18	16	68	43	
4	18	19	72	44	
5	18	19	70	44	
6	18	17	70	43	abnormal closing rate variability
7	18	18	73	44	
8	18	18	70	43	
9	18	18	71	44	
10	18	18	74	43	
11	18	18	73	43	
1	21	21	80	46	
2	21	21	78	46	
3	21	22	80	46	
4	21	22	84	46	
5	21	21	74	46	
6	21	22	79	46	
7	21	21	al	47	
8	21	21	78	47	
9	21	22	85	46	
10	21	22	87	46	
11	21	20	78	46	

Pick up Truck Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	25	25	92	51	
2	25	26	92	51	
3	25	25	94	51	abnormal closing rate variability

Mini Van Closing Rate Data

Closing Rate Mini Van Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	3	5	33	26	
2	3	3	34	29	
3	3	2	32	29	
4	3	3	39	29	
5	3	2	30	28	
6	3	3	30	29	abnormal closing rate var
7	3	3	28	29	
8	3	3	30	28	
9	3	3	35	29	
10	3	2	31	29	
1	6	4	45	31	
2	6	6	45	32	
3	6	6	43	31	
4	6	6	50	32	
5	6	7	46	32	
6	6	5	45	32	
7	6	4	38	32	
a	6	5	45	32	
9	6	5	45	32	
10	6	5	56	31	
1	9	9	.51	35	
2	9	9	48	35	
3	9	9	48	35	
4	9	9	48	35	
5	9	a	48	35	
6	9	9	48	35	
7	9	9	51	35	
8	9	9	52	35	
9	9	9	47	35	
10	9	9	50	36	

Mini Van Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	12	12	58	38	
2	12	12	62	38	abnormal closing rate variability
3	12	12	57	38	
4	12	11	54	37	
5	12	12	55	38	
6	12	12	58	38	
7	12	12	53	38	
8	12	12	53	38	
9	12	12	59	38	abnormal closing rate variability
10	12	12	58	38	
1	15	17	70	41	
2	15	15	69	41	
3	15				Aborted Run
4	15	15	68	42	
5	15	16	65	41	
6	15	16	74	41	
7	15	15	72	41	
8	15	15	62	41	
9	15	15	63	41	
10	15	15	63	41	
11	15	16	73	41	

Mini Van Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	18	17	76	44	
2	18				Aborted Run
3	18	17	72	43	
4	18	15	61	41	abnormal closing rate variability
5	18	18	73	43	
6	18	17	71	44	
7	18	18	72	44	
a	18	18	70	43	
9	18	17	69	43	
10	18	17	68	43	
11	18	18	74	44	abnormal closing rate variability
12	18	17	69	43	
1	21	20	75	46	
2	21	21	80	46	
3	21	20	81	46	
4	21	21	78	47	
5	21	20	77	46	
6	21	20	80	46	
7	21	20	78	46	
a	21	20	77	47	
9	21	21	77	47	abnormal closing rate variability
10	21	21	a4	48	abnormal closing rate variability
11	21	21	80	47	
1	25	25	93	51	
2	25	23	88	50	
3	25	24	89	50	
4	25	24	86	51	
1	25	25	92	51	
2	25	26	92	51	

3

Large Truck Closing Rate Data

Closing Rate Truck					
Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	connments
1	3	3	29	29	
2	3				Aborted Run
3	3	3	29	29	
4	3	2	29	27	
5	3	3	28	29	
6	3	3	28	28	
7	3	3	27	29	
8	3	4	29	29	
9	3	4	33	31	
10	3	3	26	26	
11	3				Aborted Run
1	6	7	46	34	
2	6	6	42	30	
3	6	6	42	32	
4	6	7	44	33	
5	6	5	41	30	
6	6	5	43	31	
7	6	5	43	31	
8	6	5	42	31	
9	6				Aborted Run
10	6	6	45	32	
11	6				Aborted Run
12	6	4	24	30	

Large Truck Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	9	9	45	34	
2	9	11	50	36	
3	9	9	46	35	
4	9	8	46	34	
5	9	a	42	33	
6	9	9	43	33	
7	9	9	47	36	
8	9	8	43	32	
9	9	10	44	35	
10	9	8	49	34	
11	9	6	45	32	
12	9				Aborted Run
1	12	12	50	36	
2	12	11	53	36	
3	12	10	50	35	
4	12	11	53	36	
5	12	11	42	36	
6	12	12	51	36	
7	12	13	59	38	
a	12				Aborted Run
9	12	12	56	37	
10	12	11	45	37	
11	12	10	45	37	

Large Truck Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range	Speed (MPH)	Comments
1	15	13	56	39	
2	15			40	No alarm
3	15	15	53	39	
4	15	16	62	41	
5	15			39	No alarm
6	15			39	No alarm
7	15				Aborted Run
8	15	46	58	41	
9	15			39	No alarm
10	15	14	62	41	
11	15	14	58	41	
1	18			44	No alarm
2	18				Aborted Run
3	18			45	
4	18	16	61	42	
5	18	17	53	42	
6	18			44	No alarm
7	18			45	No alarm
8	18			45	No alarm
9	18				
10	18			43	No alarm
11	18				Aborted Run
12	18	16	66	40	
13	18			43	No alarm
14	18	17	65	41	

Large Truck Closing Rate Data

Run Number	Desired Closing Rate (MPH)	Actual Closing Rate (MPH)	Range (ft)	Speed (MPH)	Comments
1	21				Aborted Run
2	21	18	53	43	
3	21			45	No alarm
4	21				No alarm
5	21				No alarm
6	21				No alarm
7	21				No alarm
8	21				No alarm
9	21	18	69	44	
10	21	17	67	42	
11	21	17	68	43	
1	25				No alarm
2	25			46	No alarm
3	25			49	No alarm

APPENDIX B

QUALITATIVE TESTING DATA

APPROPRIATE ALARM DATA

CAUSE OF ALARM	FREEWAY COUNT	FREEWAY %	MAJOR COUNT	MAJOR %	MINOR COUNT	MINOR %	RESIDENTIAL COUNT	RESIDENTIAL %	RURAL COUNT	RURAL %	OTHER COUNT	OTHER %	TOTAL COUNT	TOTAL %
TEST VEHICLE STRAIGHT	63	50	7	88	7	88	2	67	3	100	30	79	112	61
TEST VEH CHANGING LANES	26	21									4	11	30	16
ADJ VEH CHANGING LANES	10	8			1	13					1	3	12	6
TEST/ADJ VEH CHANGING LN	5	4											5	3
NO DATA	4	3											4	2
VEH IN FRONT BRAKING	12	10					1	33					13	7
VEH IN FRONT STOPPED	1	1											1	1
VEH IN FRONT CHG LANES	2	2											2	1
TEST VEH IN CURVE	2	2	1	13							3	8	6	3
TOTAL	**125**	**68**	**8**	**4**	**8**	**4**	**3**	**2**	**3**	**2**	**38**	**21**	**185**	**100**

FALSE ALARM DATA

CAUSE Of ALARM	FREEWAY COUNT	%	MAJOR COUNT	%	MINOR COUNT	%	RESIDENTIAL COUNT	%	RURAL COUNT	%	OTHER COUNT	%	TOTAL COUNT	%
FWY DIVIDER/VEH STRAIGHT	108	58											108	31
FWY DIVIDER/VEH TURNING	45	24											45	13
UNKNOWN	23	12	13	33	10	33	8	20			25	71	79	23
TEST VEH BRAKING	1	1			3	10					1	3	5	1
TEST VEH STOPPED/NO DATA	1	1	1	3									2	1
,VEH IN ADJACENT LANE	3	2	2	5							2	6	7	2
TEST VEH CHANGING LANES	2	1	1	3									3	1
OBJECT IN ROAD/VEH TURNING	2	1					4	10					6	2
SIGN OR OBJECT IN LT MEDIAN			21	53			1	3	2	15	3	9	27	8
'OPPOSING VEH/TEST VEH TURN			2	5			1	3					3	1
OBJECT IN ROAD I							1	3					1	0
TEST VEH TURN RT/OTH VEH LT							1	3					1	0
OBJECTS ON ROADSIDE I					8	27	3	8	1	8	2	6	14	4
PARKED VEHICLE/TEST VEH STRAIGHT							10	25	1	8	1	3	12	3
OPPOSING VEHICLE					7	23	1	3	1	8			9	3
OBJECT IN ROAD/TEST VEH TURN					1	3	1	3	8	62	1	3	11	3
PARKED VEH/TEST VEH TURN					1	3	9	23					10	3
TOTAL	185	54	40	12	30	9	40	12	13	4	35	10	343	100

SYSTEM MISSES

CAUSE OF ALARM	FREEWAY COUNT	%	MAJOR COUNT	%	MINOR COUNT	%	RESIDENTIAL COUNT	%	RURAL COUNT	%	OTHER COUNT	%	TOTAL COUNT	%
TEST VEH/ADJ VEH CHG LN	1	8											1	2
ADJ VEH CHG LANES	7	54			3	60			2	18	1	14	13	28
STOPPED VEHICLE	2	15							1	9			3	7
SHOULD OCCUR EARLIER														
TEST VEH CLOSING TOO FAST	2	15			1	20	1	11	3	27	4	57	11	24
TEST VEH CHANGING LANES	1	8											1	2
VEH IN FRONT CHANGED LN							1	11					1	2
VEH IN FRONT LEFT TURN							3	33	2	18	1	14	6	13
OPP VEH CURV/TEST VEH LT TN							1	11	1	9			2	4
PEDESTRIANS			1	100	1	20	2	22			1	14	5	11
BICYCLES							1	11	2	18			3	7
TOTAL	13	28	1	2	5	11	9	20	11	24	7	15	46	100