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BRAKING ANALYSIS FOR COLLISION AVOIDANCE - AUTONOMOUS BRAKING SYSTEM PERFORMANCE MODELING AND BENEFITS ANALYSIS

Report No. 95-007

Contract No. DTNH22-94-Y-07016

AUTHORS: Thomas A. Gee, Daniel G. Smedley, Andy Suri

DATE: May 24, 1996

This report was prepared for the U.S. Department of Transportation, National Highway Traffic Safety Administration, Office of Crash Avoidance Research, Washington, D.C 20540. Covering activity over the time period of April, 1994 to October, 1995.

Corporate R&D-Detroit Center

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Executive Summary

This report is an analysis of the benefits of a collision avoidance system in reducing rear-end crashes. The collision avoidance system considered in this study utilizes the signal from a forward looking sensor to activate the traction control valve in an anti-lock brake system with a traction control option, to autonomously apply the service brakes in a heavy duty vehicle equipped with air brakes.

Baseline stopping distance simulations for five different vehicle configurations over a range of conditions were done using a computer model. Different brake activation strategies were analyzed to determine how stopping distances could be reduced for a specific set of vehicle, road, and load conditions. A combination statistical and modeling method was used to predict how an active braking strategy could reduce the number and severity of rear-end collisions. Data taken from statistics researched by the University of Michigan Transportation Research Institute, is used in our methodology to support the validity of the modeling. The methodology is used to predict the percentage reduction in rear-end collisions possible for heavy commercial vehicles where the lead vehicle is stationary. While the original work plan called for applying the methodology also to the condition where the lead vehicle is moving, it was agreed that there would be more value in applying the resources toward actual vehicle testing. The results of the vehicle testing is reported on in a separate report.

The accident reduction simulations presented in this report indicate that a potential exists for reducing the stopping distances of heavy commercial vehicles equipped with a collision warning system and an autonomous braking system. The accident reduction modeling also predicts that such a system could be responsible for preventing a large percentage of certain types of rear end crashes where the lead vehicle is stationary. The simulation effort shows that over 78% of these crashes could be prevented with a collision warning system and some measure of autonomous braking. The target number of collisions that this system could affect on a per year basis, based on three years of NASS GES data, is estimated to be about 24,500, or up to 12% of all tractor collisions.

The cost/benefits ratio of only the target collisions indicates a favorable return on investment for such a system, on an industry-wide basis. Many fleets are now assessing the cost effectiveness of a collision warning system, with no autonomous braking. Some fleets have determined that the system will help change drivers' behavior to change toward a safer driving style, and therefore, will reduce accidents.

The analysis has yielded a database and a methodology that is capable of analyzing the benefits of collision avoidance systems relative to truck rear-end collisions. Using the analysis to predict accident and severity reductions is very dependent upon the design of the activation algorithm. A wide range of accident reduction projections can be made just by changing the activation algorithm. However, the design of the activation algorithm is also critical the driveability and acceptability of the system to the user. Rigorous accident analysis was not performed because of this sensitivity, and effort on the program shifted to exploring the driver's reaction to different activation strategies.

1.0 Introduction

This report is one part of a two-part final report prepared as part of the research efforts on the cooperative agreement DTNH22-94-Y-07016, entitled "Braking Analysis for Collision Avoidance: Heavy Commercial Vehicles." This report covers the analysis of the benefits of a collision avoidance system in reducing rear-end crashes. The other report is titled "Braking Analysis for Collision Avoidance - Autonomous Braking System Development and Test Report" and documents the development and testing of a prototype autonomous braking system implemented on a heavy duty vehicle.

The collision avoidance system considered in this study utilizes the signal from a forward looking sensor to activate the traction control valve in an anti-lock brake system (with a traction control option), to autonomously apply the service brakes in a heavy duty vehicle equipped with air brakes. Normally a traction control valve is used to apply air pressure to the brakes of the truck during traction control operation The ABS valves are used to hold off the air to all brake sites except the one(s) that are spinning. Thus, tractive force is increased to the non-spinning wheels due to the characteristics of the differentials connecting the wheels. In the autonomous braking mode, the traction control valve will apply a controlled air pressure to all the service brakes when requested, thereby initiating control of the vehicle braking that is independent of the driver's actions.

This report starts with a description of a model for calculating stopping distance, which includes the distance traveled during the time it takes the driver to react to the situation. This is different than the normally referenced stopping distance in NHTSA testing because it includes this distance. The report then presents the results of the baseline stopping distance simulations. This part looks at the baseline stopping distances for five different vehicle configurations over a range of conditions. The next section examines how different brake activation strategies can reduce stopping distances for a specific set of vehicle, road, and load conditions. A combination statistical and modeling method is described that predicts how an active braking strategy could reduce the number and severity of rear-end collisions. Data taken from statistics researched by the University of Michigan Transportation Research Institute, (UMTRI), is used in our methodology to support the validity of the modeling. The methodology is used to predict the percentage reduction in rear-end collisions possible for heavy commercial vehicles where the lead vehicle is stationary.

2.0 Stopping Distance Model

Stopping distances for all analyses were calculated using UMTRI's Phase IV heavy vehicle simulation program; a computerized model for simulating the braking and steering dynamics of trucks, articulated vehicles and tractor/trailer combinations. This Fortran-based model allows the user to modify many vehicle parameters to determine the effects of these parametric changes on the performance of the vehicle. Phase IV was used to predict stopping performance, calculate stopping distances, impact speeds, and determine lateral stability. The stopping distance referred to in this report is not the traditional stopping distance as referred to in the FMVSS 121 standard because the driver's response/reaction time is included.

The stopping distance model used is shown in Figure 1 below:

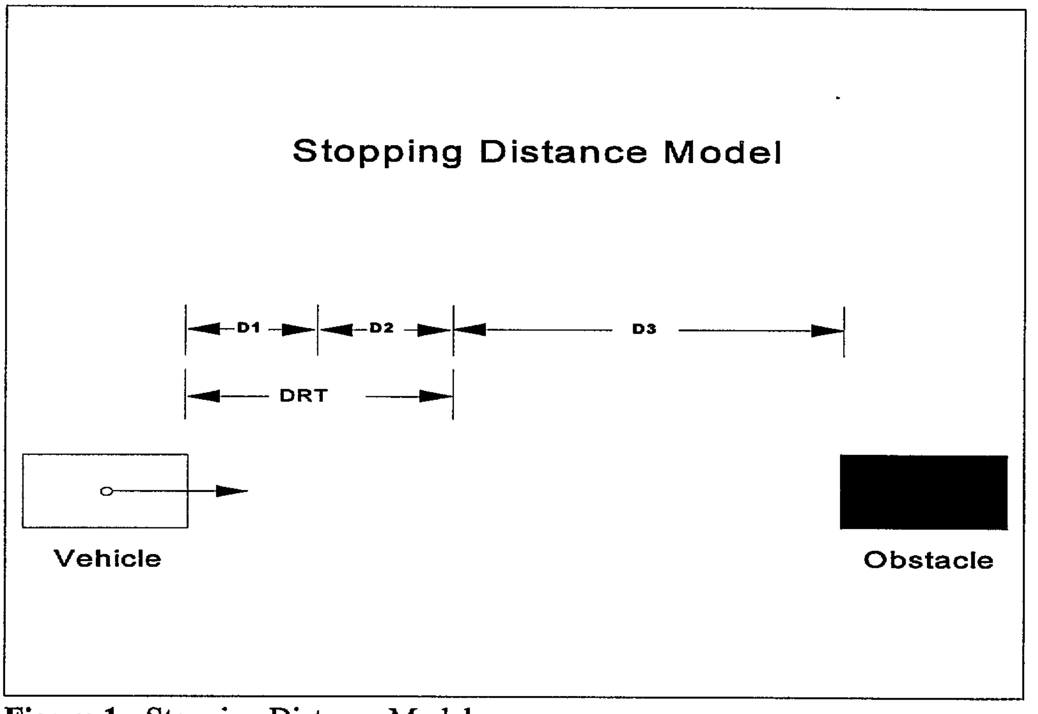

Figure 1 - Stopping Distance Model

Where D1 = the distance traveled during the cognizance time (t_c), the time it takes the driver to recognize a situation that needs a braking reaction.

D2 = the distance traveled during the reaction time (t_r), the time it takes the driver to react to the condition that exists and apply the brakes.

DRT = Driver Reaction Time

D3 = the distance traveled during the braking time (t_b), the time it takes the system to react to the brake pedal input and decelerate the vehicle to a stop.

The tire and brake models used within Phase IV for all the analyses are described in Appendices A and B, respectively. The tire model input into Phase IV is a table of entries of various μ-slip values and different tire loads and vehicle speeds. In order to obtain realistic braking response in the simulation, an empirically derived brake model was implemented and an anti-lock control system was included. The brake model is explained in Appendix B. Additional Phase IV inputs to define the vehicle models are explained in Appendix C.

3.0 Baseline Modeling

The variable parameters used in this analysis are listed below:

1. The vehicle types to be simulated are shown in Figure 1.

   A two-axle straight truck, a three-axle straight truck, a tractor/trailer with a 4x2 tractor and a one-axle trailer, a double with a 4x2 tractor, two one-axle trailers and a dolly, and a tractor/trailer with a 6x4 tractor and a two-axle trailer.

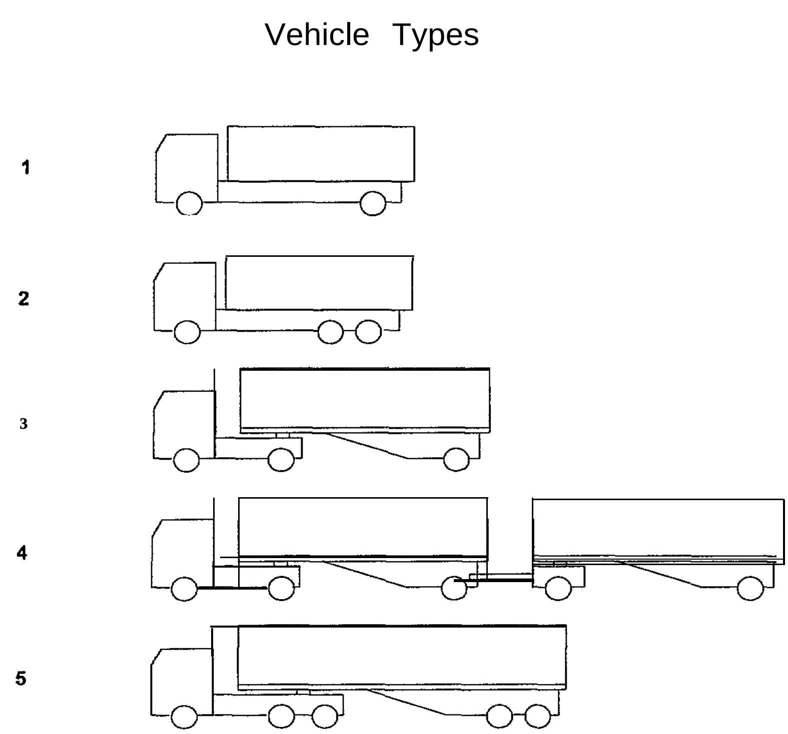

Figure 2 - Vehicle Configurations

2. Only air brake systems were examined. Two levels of braking and brake effectiveness were tested:
   a. Normal brakes, full pressure, full effectiveness braking
   b. 80% of the normal braking

3. Initial speeds were:
   a. 35 MPH
   b. 60 MPH

4. The gross vehicle weight was varied over the three conditions below:
    a. Empty load
    b. Half load
    c. Full load

    The vehicle loading conditions used in the Phase IV modeling for the five vehicle types is included as Appendix C.

5. Road surfaces
    a. Wet pavement (skid number 0.50)
    b. Dry pavement (skid number 0.75)

<u>Results:</u>

The data from this portion of the analysis indicate that, like all braking scenarios, the stopping distance is mostly dependent upon tire traction limits and/or brake torque limits and that brake system response (i.e. time to build up pressure in the various brakes to generate braking torques) can be a small factor. In these simulations, the brake torque and tire traction properties are basically identical for the various vehicles. The greatest simulation differences to impact braking are weight shifts, suspension characteristics, and brake timing. Even so, the stopping distances for the 5 vehicle types were substantially similar. As a result, one vehicle type (type 5) was eventually selected for the remaining simulations in this analysis.

4.0 Reduced Reaction Time Modeling

The main principle of this type of collision avoidance system is to compensate for poor driver cognizance, decision or physical reaction times of the braking process in cases of driver inattention or poor visibility. To evaluate the plausible effectiveness of such a collision avoidance system, candidate braking configurations and strategies were devised.

Three different tractor trailer braking configurations were simulated:

1. Tractor and trailer equipped with ABS and the assisted braking function applied to all the brakes,
2. Tractor and trailer equipped with ABS and the assisted braking function applied to only the tractor brakes.
3. Tractor and trailer equipped with ABS and the assisted braking function applied to only the drive axles of the tractor.

For each of these three configurations, five different automatic braking strategies with two different driver reaction responses were simulated.

1. The collision avoidance system recognizes that a braking condition exists, warns the driver and steps the brake command pressure up to the crack pressure for the brakes in these simulations; crack pressure = 5 psi in 150 milliseconds. The stopping distances for two different driver responses are simulated:
   a. The driver is alerted by the system and reacts promptly to apply full pressure braking.
   b. The driver is not alerted and doesn't react until he recognizes the situation.

2. The collision avoidance system recognizes that a braking condition exists, warns the driver and steps the brake command pressure up to 20 psi by 150 milliseconds. The stopping distances for two different driver responses are simulated:
   a. The driver is alerted by the system and reacts promptly to apply full braking.
   b. The driver is not alerted and doesn't react until he recognizes the situation.

3. The collision avoidance system recognizes that a braking condition exists, warns the driver and, by 150 milliseconds, begins to ramp the command pressure up at 75 psi/second toward 100 psi. The stopping distances for two different driver responses are simulated:
   a. The driver is alerted by the system and reacts promptly to apply full braking.
   b. The driver is not alerted and doesn't react until he recognizes the situation.

4. The collision avoidance system recognizes that a braking condition exists, warns the driver and, by 150 milliseconds, begins to ramp the command pressure up at 150 psi/second toward 100 psi. The stopping distances for two different driver responses are simulated:
   a. The driver is alerted by the system and reacts promptly.
   b. The driver is not alerted and doesn't react until he recognizes the situation.

5. The collision avoidance system recognizes that a braking condition exists, warns the driver and the command pressure is applied fully by 150 milliseconds. The stopping distances for two different driver responses are simulated:
   a. The driver is alerted by the system and reacts promptly to apply full braking.
   b. The driver is not alerted and doesn't react until he recognizes the situation.

The above brake configurations and strategies were applied to a subset of the total possible combinations of vehicle variables. Simulations were performed on all five vehicle types but only with:

- full braking effectiveness
- 60 mph initial speed
- full load
- road surface coefficient of 0.75

cognizance and recognition time are also commenced at t=0 and driver braking override of the autonomous strategy eventually occurs. This is shown schematically in Figure 3.

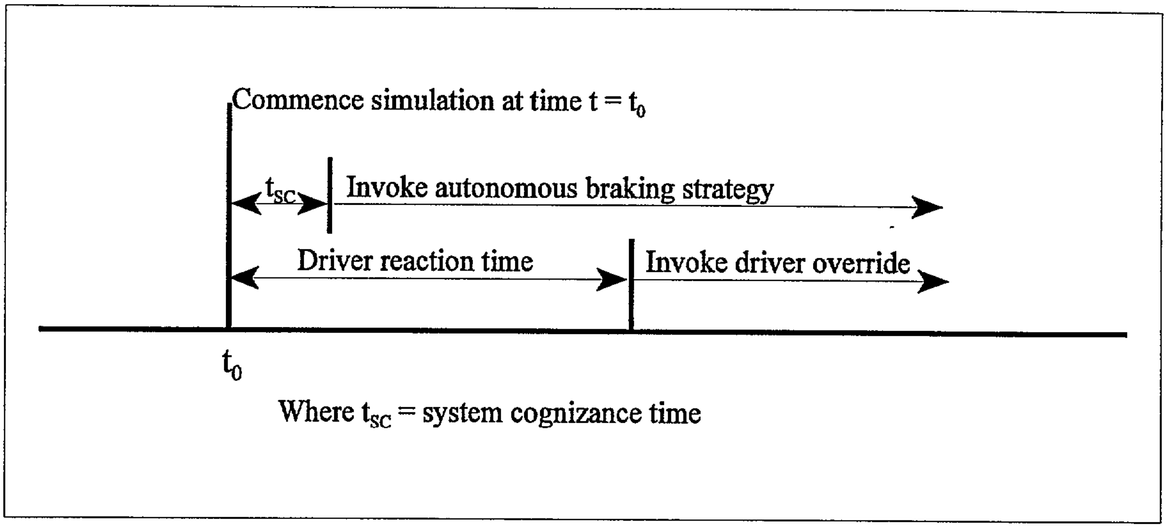

Figure 3 - Model for Simulating Brake Commands

Results:

The results are included as Appendix D. The brake command tables are Tables D1 through D36. The reduced reaction simulation results are included as Figures D1 to D6. These show graph-ically how the stopping distances varied for the different assisted braking conditions modeled. Table D37 shows the numerical stopping distance data from the simulations. Table D38 shows the percent reduction in stopping distance each strategy exhibited compared to the baseline stopping distance. Table D39 shows the actual reduction in stopping distance from the baseline.

The data indicate that the activation strategy and the alertness of the driver have significant effects on the stopping distance. Referring to Figure D1, the situation where the driver reaction time is 1.5 seconds, the stopping distance variability between the different braking strategies is clear. Full braking, Strategy 5 is the best with an average 35% reduction in stopping distance, or about 130 feet. Strategy 1, bringing the pressure up to crack pressure, provides the least reduction, less than 1% or around 2 feet.

Compare Figure D1 to Figure D2. The conditions are the same except that in Figure D1 the driver reaction is only 0.5 seconds. The variability between the different strategies has narrowed. This shows that a system that improves the driver's reaction time has the best effect on improving the stopping distance. The faster the driver reacts, the less important the assisted braking strategy is. The converse of this also applies. If the driver reacts slowly, a more aggressive brake application strategy needs to be applied, such as strategies 3, 4 or 5.

best effect on improving the stopping distance. The faster the driver reacts, the less important the assisted braking strategy is. The converse of this also applies. If the driver reacts slowly, a more aggressive brake application strategy needs to be applied, such as strategies 3,4 or 5.

Since Strategy 1, the strategy that applied air pressure just up to the crack pressure, shows little improvement in stopping distance for the longer driver reaction time, it was eliminated from further analysis. Since the driver's reaction time is a significant contributor to stopping distance, it was decided that in the benefits analysis modeling, the driver reaction time should be a randomly selected variable covering a range of times that have been observed and reported in the literature. Also, as was found in the first series of simulations - the baseline modeling - the differences in stopping distance between the vehicle types was minor. Thus, it was decided that only the tractor trailer combination unit depicted as type 5 will be modeled in the next series of analyses.

5.0 Stopping Distance Reduction Analysis - Lead Vehicle Stationary

The benefits analysis of this section is based on the concept of modeling the known accident situations where rear-end collisions occur to determine the new outcome if the proposed collision avoidance techniques were to be used.

The determination of accident situations and circumstances was estimated fi-om statistical data supplied by our subcontractor, UMTRI. They utilized data from a variety of sources but the crash situation statistics are drawn from North Carolina police reports of 1990 to 1993. This database is the only one known to definitively include truck accident circumstances. The UMTRI statistics are included in this report as Appendix F.

One of the major pieces of information drawn from these statistics is the distribution of vehicle speeds in rear-end collisions. The simulations are arranged to have the pre-crash speeds of both vehicles as the starting point where the distribution of speed in the group of simulations is the same as the distribution in actual rear-end collisions. The simulations in each group also include situational variables other than speed. They are randomly selected from distributions determined, or considered, to be representative of actual accidents. So, for example, if 80% of the simulation runs for a certain group indicate no collision would occur; the premise is that 80% of the actual accidents of the type represented in the simulation would be eliminated.

There are two distinct types of rear-end accidents that are important to modeling the accident situation. When the lead vehicle is stationary, both prior to and upon being struck, the modeling task is different than when the lead vehicle is moving. In the former case, called lead vehicle stationary (LVS), the dynamics of only the striking vehicle need be considered. For the lead vehicle moving (LVM), both the vehicles movements must be considered. The accident statistics are detailed enough to provide pre-crash and speed-at-impact values. Only the accidents with pre-crash= 0 and speed-at-impact= 0 were deemed LVS types of accidents.

This study performed only the LVS simulations for a variety of good reasons. Foremost is that the LVS was performed first and it revealed the very strong influence of the systems' "activation distance" on the number of avoided collisions. On the other hand, it was known that it also inversely impacted the driveability. It was agreed part way into the contract, that more effort would be applied to exploring the activation algorithms in a test truck with an active radar obstacle sensor and that the LVM simulations would be left uncompleted. The sensor and system work with driver reaction feedback is reported in the second part of this final report.

Also, only one vehicle configuration, the type 5 tractor trailer combination was simulated because the stopping analysis of the whole range of vehicles only revealed small differences in braking capability and because the type 5 truck is in such high usage on American highways.

In the simulations:

- Four random variables in braking a vehicle were considered to affect the result:
  - vehicle weight,
  - vehicle road surface coefficient of friction limitation (u),
  - vehicle braking capability, and
  - driver reaction time to system override,
- Two different tractor/trailer assisted braking configurations were modeled,
- Five different braking strategies were modeled,
- A random sample size for the modeling was selected to limit the time and cost of the modeling effort,
- The pre-crash LVS speed distributions were estimated and used as "mock" values. They were later adjusted when the real distributions were obtained.
- The vehicle configuration was limited to the 6x4 tractor with a tandem axled semi-trailer, and
- Two different activation distance algorithms were examined to explore how effective they were at reducing the number of rear-end collisions.

1 Random variables

Each of the 4 variables, vehicle weight, road surface condition, brake effectiveness, and driver reaction time, were independently randomly chosen. The variables and how they were determined is described below:

a) <u>Vehicle Weight</u> — UMTRI's 1986 National Truck Trip Information Survey (NTTIS) was used to generate load distributions of truck-tractor combinations on U.S. roads. UMTRI reviewed their NTTIS data and data from 334 trucks involved in fatal rear-end accidents from their "Trucks Involved in Fatal Accidents" (TIFA-

199 l-92 file). It shows the fatal involvements have higher vehicle weights than the NTTIS distribution of vehicle weights in general. The median GVW from the TIFA is about 60,000 pounds and the median of the NTTIS is about 50,000. This difference seems in the expected direction. Heavier trucks have more momentum, so more fatalities could occur when they strike another vehicle.

What is not revealed here, is whether heavier trucks are more likely to be involved in rear-end accident incidents. Lacking any further information, the weight distribution universe from the UMTRI 1986 NTTIS data was used on the basis that any truck in use is equally likely to be involved in trying to avoid a rear-end collision. Furthermore, the data were grouped to fit the empty, half-load, or full-load models.

The usage data and the assigned distributions are as follows:

TCW	Single	Group	%
0 (empty)	9,741,981	empty	29.31
< 10K 10-20K 20 - 30K	2,95 1,750 4,299,579 2,999,917	Half-load	30.85
30 - 40K 40 - 50K 50 - 60K 60 - 70K 70 - 80K 80K +	3,296,619 8,245,5 12 1,397,938 145,948 48,605 106,615	Full-load	39.84

Table 1 - Weight Distribution Grouping

Where: TCW is Total Cargo Weight
Single refers to the number of single trailer combination unit usage miles identified in 1986 survey.

Source: University of Michigan Transportation Research Institute, National Truck Trip Information Survey, 1986.

b) Surface mu — UMTRI also provided a breakdown of road surface conditions. They used the road conditions in all police-reported truck-tractor accidents from the 1992 General Estimates System file with the following filter:

- power unit type is truck-tractor

- rear-end collision
- truck is striking vehicle
- truck did not have brake failure
- truck was not changing lanes, merging, or maneuvering to avoid something else (an animal, pedestrian, other vehicle, etc.)

UMTRI's review of GES data involving heavy trucks revealed:

Dry:	15,891 involvements
Wet:	3,237 involvements
Snow/Ice:	474 involvements

From this information we conceded the snow/ice conditions as non-preventable. The mu distribution for the modeling was then:

Condition	mu	Percent
Dry	.75	83.1%
Wet	.50	16.9%

Table 2 - Coefficient of Friction Distribution

Reference: Correspondence from Dawn Massey, University of Michigan Transportation Research Institute, October 24, 1994.

c) Vehicle braking: canability — To account for brake capability variations that might exist for reasons related to low mu or high temperature linings, defective adjustments, low air pressure reserves, or actuator chambers below par, the brake effectiveness was evenly distributed from 80 to 100% effectiveness. This arrangement places the 50th percentile truck at 90% of its full braking capability. This roughly corresponds to reports of brake defect inspection results on U.S. highways. [1]

d) Driver reaction time — The subject of driver reaction time (DRT) for the collision avoidance system braking benefits analysis is an important variable because some of the braking strategies are not full braking. Therefore, the driver can override the system braking with his own action. Indeed, the benefits analysis is predicated on such an override of the system braking level. DRT to override will affect the likely stopping distance, so it is an important factor in the benefits analysis.

[1] SAE 922443., Air Brake Inspections on Five-axle Combinations, Ronald B. Heusser, 1992.

In our preliminary modeling of stopping distance, a 1.5 second value of DRT was used to simulate unalerted drivers. Since the preliminary modeling was only meant to establish the process and to generally sort the braking scenarios, the value chosen for DRT was not critical. In a paper that analyzes the collision avoidance potential of systems in passenger cars, Knipling et al.' utilizes the DRT from Sivak et al. and applies it to a hypothetical collision warning system. The DRTs for warning systems or collision avoidance systems can be critical to the results of either.

The pertinent issue for a heavy duty truck collision avoidance system is: what reaction time will trained commercial drivers exhibit to a visual, audible, and/or tactile warning of an impending threat? DRT has been characterized as a collection of driver perception, decision and response initiation times. It seems reasonable that the several modes of warning, as planned, will improve perception time, and familiarity with the warning will reduce the decision time.

The reasonableness seems to be supported by at least two studies of DRT: one by Johansson, et al[3], and one by Olson et al.[4] In the Johansson report, he estimates that DRT's can be reduced by 26% through "anticipation" which is at least partially due to pre-knowledge of how to react. In the Olson paper, DRT to an external obstacle which is located in the roadway following a hill crest is measured as a "surprise" DRT. After the surprise trial, five more measurements were taken under identical conditions. These are called "alerted" DRT measurements. The 95th percentile DRT dropped from 1.55 seconds in the "surprise" tests to 1,15 seconds in the "alerted" tests - a 0.4 second reduction. This corresponds well with the Johansson 26% reduction. Another part of the Olson study tested the reaction time to apply brakes in response to a red light signal on the front of the vehicle's hood. This showed an additional reduction of 0.3 second for the 95th percentile and a 0.15 second reduction for the 50th percentile from the "alerted" reaction times and seems to support reductions related to speed of identification.

At 40 MPH, a 0.4 second interlude could account for about 23 feet of stopping distance or, stated another way, about 20 MPH of impact velocity; so the DRT is a significant issue.

These studies indicate that substantial reductions of DRT that would result in improved benefits could be achieved with the proper presentation to the driver.

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[2] Assessment of IVHS Countermeasures for Collision Avoidance: Rear-end Crashes, May, 1993, DOT HS 807995, R. Knipling, et al.

[3] Driver's Brake Reaction Times, Johansson & Rumar, published in Human Factors, 197 1, 13(l), Pg. 23-27.

[4] Parameters Affecting Stopping Sight Distance, Olson & et al., Transportation Research Board report #270,1984.

However, the conditions tested in the studies do not really simulate the expected warnings of a collision avoidance system, especially since they were all visual or audible warnings. Good DRT data with high applicability for our analysis is not known to exist. The Olson study with the red light on the hood seems the most applicable, but even then, signal and location differences, plus the untested effects of "cry-wolf' syndrome from false signals, fatigue, boredom and overload can negatively impact the results. The most applicable DRTs for this analysis would be somewhere between the "hood signaled" response of the Olson study and the unalerted response of the Knipling/Sivak study. In this analysis, considering the uncertainties, the more conservative Knipling/Sivak data are used.

The reaction time distribution as discerned from the Knipling report is as follows.

Driver Reaction Time (sec)	Probability %	Driver Reaction Time (sec)	Probability %
.3	2.2901	2.1	3.0534
.5	10.1781	2.3	2.0356
.7	15.7761	2.5	1.5267
.9	17.3028	2.7	1.0178
1.1	14.2494	2.9	.7634
1.3	11.1959	3.1	.6361
1.5	8.6514	3.3	.5089
1.7	6.1069	3.5	.3817
1.9	4.0712	3.7	.2545

Table 3 - Driver Reaction Time Distribution

2. The two different tractor trailer braking configurations that were modeled are:
   a. Tractor and trailer are equipped with ABS and the assisted braking function applies to the brakes on the tractor and trailer.
   b Tractor and trailer are equipped with ABS and the assisted braking function applies to only the tractor brakes.

   Another option is possible, which is to equip the drive axle brakes only. This was not modeled in this analysis because the actual test vehicle (reported in the second part of this final report) was equipped such that all the vehicle brakes were autonomously applied. Also, in the reduced reaction time modeling reported in section 2 of this report, stopping distances for the type 5 vehicle with full tractor brakes averaged only about 1% shorter than with drive axle brakes alone.

3. The five different braking strategies that were modeled are:
   a. The collision avoidance system recognizes that a braking condition exists, warns the driver but does not apply the brakes autonomously. The driver is alerted by the system and reacts promptly with a full treadle brake application.

b. The collision avoidance system recognizes that a braking condition exists, warns the driver and steps the brake pressure up to 20 psi. The driver is alerted by the system and reacts promptly with a full brake application.

c. The collision avoidance system recognizes that a braking condition exists, warns the driver and ramps the brake pressure up at 75 psi/second toward 100 psi. The driver is alerted by the system and reacts promptly with a full application.

d. The collision avoidance system recognizes that a braking condition exists, warns the driver and ramps the brake pressure up at 150 psi/second toward 100 psi. The driver is alerted by the system and reacts promptly with a full application.

e. The collision avoidance system recognizes that a braking condition exists, warns the driver and the brakes are automatically applied fully. The driver is alerted by the system and reacts promptly with a full application.

These strategies were implemented in Phase IV by changing the brake pressure command (i.e., the control line pressure at the treadle valve) at certain times in the stop. The model allows independent control of the braking command to each of the axles. To illustrate how the brakes were controlled, Tables 4 to 8 show the time sequence of brake pressure commands for the condition of applying the assisted braking function to all axles, with the driver reacting to the warning after t_r seconds. For example, in Table 4 at time t=0.0, the brake pressure is 0, at time t=0.15 the brake pressure command steps to 20 psi, at time $t=t_r$=reaction time, the driver reacts and commands full brake pressure and the command stays there for the balance of the stop. The reaction time (t_r) is selected from Table 3.

Step pressure to 20 psi. Assisted braking function applied to all brakes

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	**20.0**	**20.0**	**20.0**
0.5	**20.0**	**20.0**	**20.0**
0.65	**20.0**	**20.0**	**20.0**
t_r	full_psi	full_psi	full_psi

Table 4 - Brake Command Table - Strategy 2

Ramp pressure up at 75 psi/sec to 100 psi. Assisted braking function applied to all brakes.

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	11.25	11.25	11.25
0.5	37.5	37.5	37.5
1.333	fullgsi	fullgsi	full_psi
t_r	fullqsi	fullgsi	full_psi

Table 5 - Brake Command Table - Strategy 3

Ramp pressure up at 150 psi/sec to 100 psi. Assisted braking function applied to all brakes.

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	22.5	22.5	22.5
0.5	75.0	75.0	75.0
0.667	fullgsi	fullgsi	ful_psi
t_r	fullqsi	fullqsi	fullqsi

Table 6 **-** Brake Command Table **-** Strategy 4

Bring pressure to 100 psi. Assisted braking function applied to all brakes.

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	full_psi	full_psi	fullgsi
0.5	fullqsi	fullgsi	fullgsi
0.65	fullqsi	full_psi	fullqsi
t_r	full_psi	fullgsi	full_psi

Table 7 **-** Brake Command Table - Strategy 5

Driver is warned but brakes are not applied automatically.

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
t_r	fullqsi	fullqsi	fullqsi

Table 8 **-** Brake Command Table - Baseline

4. Random Sample Size

The choice of the random sample size was of interest to us to limit the time and cost of running Phase IV cases, but it needed to be large enough to allow reasonable reliability of the results.

From the sample size charts for a single variable[5] shown in Figure 4, and with an expectation that the system would prevent all but about 20% of the accidents, a sample size with 1000 random selections of variables implied that we could be 90% confident of the projected effectiveness within ± a couple of percent of error. This seemed accurate enough for this analysis and within a reasonable range of working cases for the matrix we intended to run in the lead vehicle stationary study.

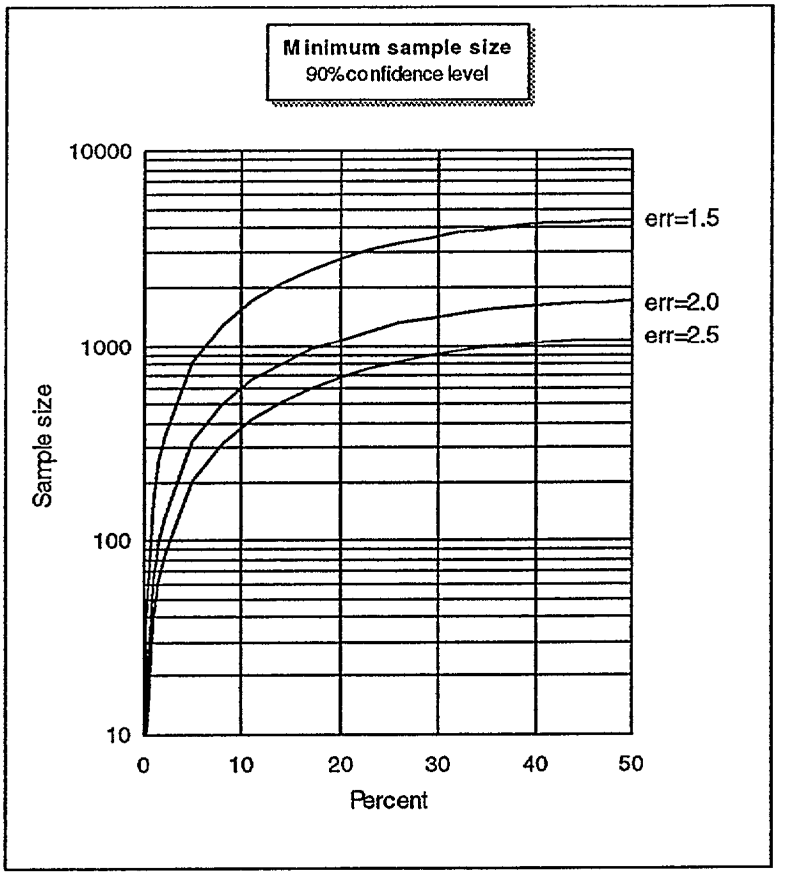


Figure 4 - Sample Size Chart

[5] "Volume 12 - How to Choose the Proper Sample Size", Gary G. Brush, American Society for Quality Control, Statistics Division.

Therefore, 1,000 cases with random selection of the four variables x 5 braking strategies x 2 braking configurations equals 10,000 runs. The 10,000 cases were archived in files to allow the five braking strategies and two braking configurations to be directly comparable to each other.

5. Pre-crash Speeds (mock LVS values)

The 1000 cases for each run were distributed according to a pre-crash speed. The pre-crash speed distribution in the simulations was from the distribution reported in the referenced Knipling report. The distribution was treated as a mock value. When the statistically accurate speed distribution became known, the crash results could be weighted to accommodate a changed distribution.

Pre-crash Speed	5	10	15	20	25	30	35	40	45	50	55	60	65	70
# of Cases	135	110	95	112	106	112	148	68	57	27	23	5	2	0

Table 9 **-** Pre-crash Mock Speed Distribution

For example, Knipling reported that 13.5% of rear-end crashes occurred at pre-crash speeds in the speed interval of 5 MPH. Accordingly, 1000x0.135=135 cases were selected with an initial speed of 5 MPH and with a randomly selected brake level, coefficient of friction, reaction time and weight per the procedure described above.

6. LVS Corrected Speed Distribution

As outlined in Appendix F, the North Carolina data were received from UMTRI and then, after review, some of the "unlikely" data points were corrected. Then the UMTRI comparisons were used to "nationalize" this corrected LVS speed distribution (in fact, a redistribution was not deemed necessary). Table 10 shows the mock and corrected percentages for each of the pre-crash speed intervals.

Speed Interval	5	10	15	20	25	30	35	40	45	50	55	60	65	Total
% of Total Mock	13.5	11.0	9.5	11.2	10.6	11.2	14.8	6.8	5.7	2.7	2.3	0.5	0.2	100.0
% of Total Corrected	40.7	8.8	4.0	3.8	3.6	5.8	10.2	7.2	6.8	3.0	5.0	0.6	0.4	100.0

Table 10 - Pre-Crash Corrected Speed Distribution

The procedure to correct the number of cases that crash, for instance would be to take the number from the simulation and multiply it by the ratio of corrected/mock. For example, if 125 cases of the 5 mph simulations crash, then the corrected number of crashes should be 125 x 40.7/13.5 = 376.9. And, if 25 of the 35 mph simulations indicate a crash, then the corrected number would be 25 x 10.2/14.8 = 17.22.

7. Vehicle Configuration:

From the previous work where five vehicle configurations were studied, the 6x4 tractor with a tandem axled trailer was selected as the host vehicle to reduce the modeling work load. However, it should also be noted that it was -determined in the earlier modeling that there was generally little difference in stopping performance between the five different configurations. (Note: the exception to this is the doubles unit with tractor-only braking.]

8. Activation Distance Algorithm:

There are a number of parameters that may be desirable to consider when creating the activation distance algorithm. For instance, it may improve the system driveability in city traffic conditions if collision avoidance is skewed to emphasize long-range sensing and high-speed accident avoidance. However, the activation distance algorithm chosen for these simulations is based on two parameters only; the full load stopping capability of the vehicle and vehicle speed. This basically creates the simplest of an "at the last moment" activation distance that aims to minimize false triggering events. In hindsight, now at the time of writing this report, the algorithm is obviously too optimistic. It does not allow for any off-peak performance or situations. Even so, we continue our explanation of our derivation of the algorithm for the sake of completeness.

Each of the five braking strategies has a different expectation of stopping distance. This is evident from the modeling reported earlier and is related not only to the reaction time and/or steady state decel capability, but also to the brake build-up time differences. Air brakes inherently have a prolonged build-up time. Moreover, the braking strategies chosen have intentional build-up time differences. Therefore, the stopping capability for each will be different. For these different capabilities, the activation distances need to be matched. Longer stopping requirements need the brake initiation distance from the target to be longer if the accident is to be avoided.

To account for the build-up time differences, it seemed appropriate to design an activation distance for each braking strategy. The model for this algorithm is based upon an idealized velocity versus time profile as shown in Figure 5. The area under the profile represents the stopping distance.

The profile is characterized by three parameters:

t_1 - Delay period to the onset of braking. It is the period of time from the moment a threat occurs to the first detectable braking induced decel. Engine defueling during this period could cause some decel, but the values are usually quite small. Idealized, the vehicle will maintain constant speed during this time period. Delays in braking of actual air braked trucks are caused by system response lag associated with plumbing, valves, actuators and brakes such as the charging time for the pressurization of clearance volumes and/or the overcoming of spring preloads, component inertia and friction. In the simulations, brake system response lag is modeled as described in Appendix B. Additionally, this delay period also includes the collision target sensor's recognition time which can consist of send and receive time, data processing time, and control valve actuation time.

t_2 - Brake build-up period. This is generally the period from decel initiation to final deceleration capability. It can be associated with the flow time and energy losses to pressurize all of the brake system volumes. At least one part of this period arises due to the brakes at various places having different timing characteristics, i.e., the slower brakes commence their braking contribution during this time. More importantly, however, for autonomous braking situations, this period includes the driver override time which includes the reaction time and any additional associated charging time required to reach full pressure conditions. In reality, the deceleration during this period could have a complicated shape. In the idealization, the deceleration for the period is selected as half the final value.

a_r - The level of deceleration that can be achieved by the following vehicle.

Incidentally, these values need not be static. In a real dynamic system they can be continuously or periodically updated to reflect historical response, vehicle weight, traffic density, driver alertness, road surface, reservoir pressure, etc.

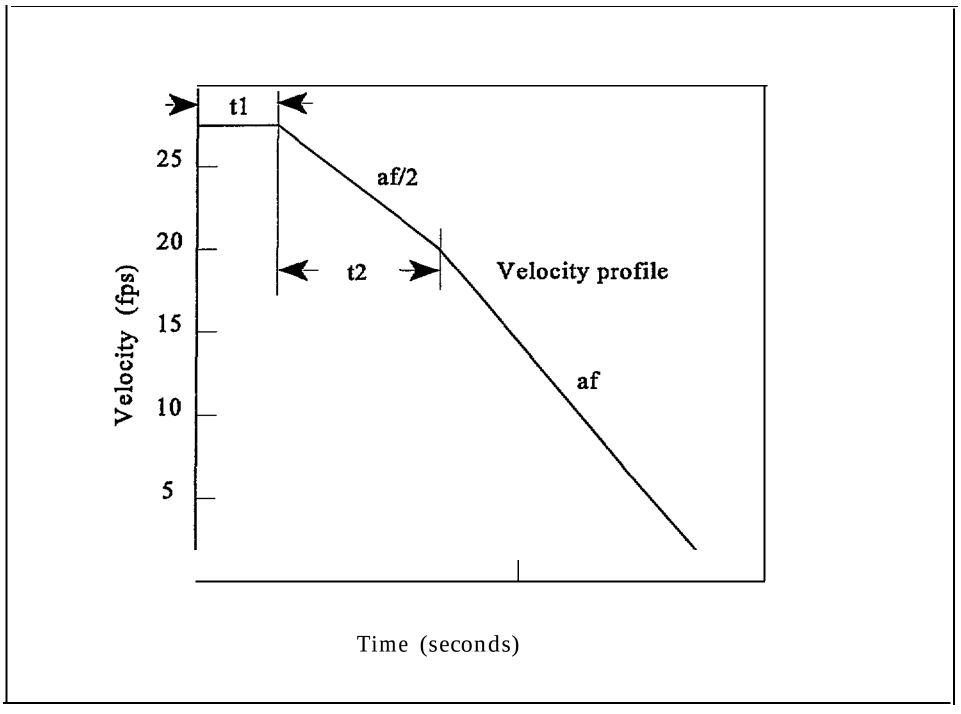


Figure 5 - Velocity Profile

From the idealized stopping profile, a crossover velocity, v_1, can be calculated. It is the velocity when decel a_r is achieved. Then, the 'safe' activation distance, D, can be made equal to the area under the velocity profile. The algorithm for determining its value is:

$v_I = v_f - (a_f/2) * t_2$
if v, < = 0 then
D = v_f*t_1 + vf2/af
else
D = vf*t1 + .5*(vf+v1)*t2 +.5*vf2/af

where v_f is the velocity of the following vehicle.

To obtain values for t,, t_2, and a_f for the different activation distance approaches, the Phase IV simulation was exercised with the different braking strategies to determine a stopping velocity profile for each (with tractor and trailer brakes applied). The driver reaction time was fixed at 1.50 sec (the 75th percentile from the Olsen report). Also, the sensor's target recognition time was selected as .06 sec and included as an initial braking delay in the simulations. The values for the activation distances corresponding to the braking strategies 2 through 5 were obtained by analyzing the velocity profiles from simulations. They are indicated in Table 11. Also shown in Table 11 is the activation distance based on braking Strategy 6 which presumes the system issuing a warning but with only the driver providing the braking level.

It is interesting to note that the t_1 period for Strategy 2 is less than for strategies 3 or 4. This happens because the air system response to a 20 psi command step is faster, at least initially, than it is for 75 or 150 psi/sec ramp commands.

In Strategy 6, the 75th percentile value of driver reaction time was added to the fastest target recognition + brake response times (i.e., a total of 0.15 sec from the t_1 of Strategy 5) to arrive at its effective t_1 of 1.65 sec.

Since all of the strategies arrive at full braking by design or driver override, the final a_f values are all equal for this simulated vehicle.

The activation distance algorithm and coefficients can be used to generate a variety of activation distances for different speeds and the associated braking strategies. Table 12 and Figure 6 compare these activation approaches.

Although Table 12 has the activation distances calculated to 70 mph initial speeds, it is uncertain that the 460+ ft. indicated for activation 6 can be reliably achieved by sensors within the near future.

Activation Distance	**Braking Strategy**	**Description**	**t_1 sec**	**t_2 sec**	**a_f ft/sec^2**
2	2	20 psi	0.22	1.91	19.76
3	3	75 psi/sec	0.35	1.19	19.76
4	4	150 psi/sec	0.29	0.91	19.76
5	5	full braking	0.15	0.50	19.76
6	6	warning only	1.65	0.50	19.76

Table 11 - Activation Time Coefficients

Initial Speed (mph)	0	5	10	15	20	25	30	35
Activ. Distance 2	0.0	4.3349	14.113	29.086	47.228	68.092	91.677	117.98
Activ. Distance 3	0.0	5.2882	15.805	29.539	45.995	65.172	87.07	111.69
Activ. Distance 4	0.0	4.8482	14.324	26.592	41.58	59.291	79.722	102.88
Activ. Distance 5	0.0	3.6766	10.692	20.429	32.888	48.069	65.97	86.594
Activ. Distance 6	0.0	14.677	32.692	53.429	76.888	103.07	131.97	163.59

Initial Speed (mph)	40	45	50	55	60	65	70
Activ. Distance 2	147.01	178.76	213.23	250.43	290.34	332.98	378.33
Activ. Distance 3	139.03	169.09	201.88	237.39	275.61	316.56	360.23
Activ. Distance 4	128.75	157.35	188.67	222.80	259.47	298.95	341.15
Activ. Distance 5	109.94	136.01	164.79	196.30	230.53	267.49	307.16
Activ. Distance 6	197.94	235.01	274.79	317.30	362.53	410.49	461.16

Table 12 - Activation Distance Values

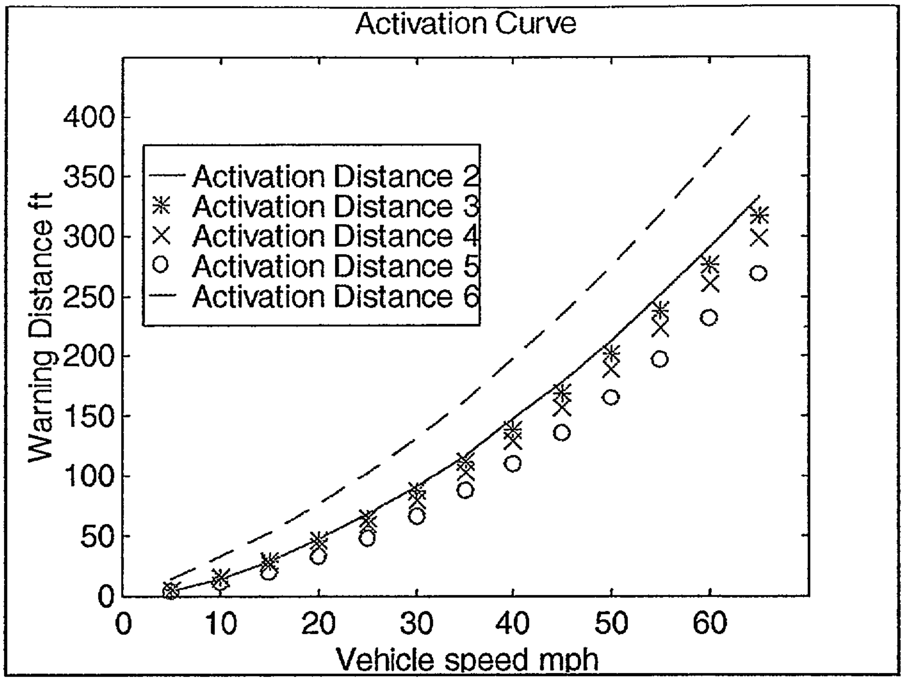


Figure 6 - Activation Distance Curves

Results:

The detailed output of this analysis is shown and discussed in Appendix E. In summary:

When the Activation Distance 6 is used for each of the strategies, a significant reduction in the number of target LVS accidents occurs. Figure 7 illustrates the findings.

- When there is no automatic activation but only a warning to the driver, 78.6% of the target accidents are prevented. Coincidentally, this is consistent with the findings of Knipling, et al. in the previously referenced report. It is highly dependent upon the selection of actuation distance.
- When Strategy 2 is used to control just the tractor brakes automatically at the activation distance 6, accidents are prevented in 93.7% of cases.
- When Strategy 2 is used to control both the tractor and trailer brakes automatically at the activation distance 6, accidents are prevented in 97.3% of cases.

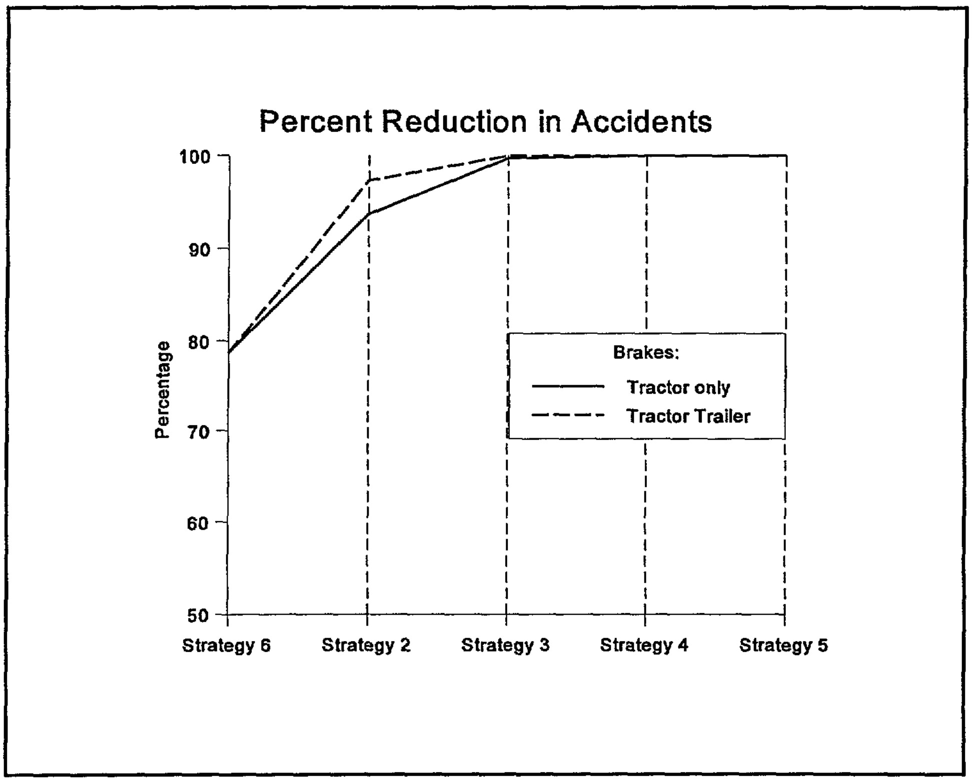
- When Strategy 3 is used to control only the tractor brakes automatically at the activation distance 6, accidents are prevented in 99.7% of cases.

- When Strategy 3 is used to control both the tractor and trailer brakes automatically at the activation distance 6, all the accidents are prevented.

- For Strategies 4 and 5, and regardless of whether the tractor only or tractor and trailer brakes are automatically applied, 100% are prevented using activation distance 6.

Appendix E includes graphs of the data for the conditions where the reduction was less than 100%.

Although the results outlined in Figure 7 appear to be very beneficial, they also are probably impractical; specifically, the autonomous braking strategies. Trying to drive a vehicle that applies high pressures to the brakes at the activation distances (i.e., 362 feet at 60 mph) would be very unappealing.



Note: activation distance 6 for all cases.

Figure 7 - Reduction in the Number of Accidents

To explore the shift in accident rates the simulations were also performed for autonomous braking with activation distances 2 and 3. The accident reduction results are shown in Tables 13 and 14.

	Braking Strategy 2	**Braking Strategy 3**	**Braking Strategy 4**	**Braking Strategy 5**
Tractor Applied	22.3%	30.17%	41.1%	87.7%
Tractor & Trailer Applied	30.7%	45.0%	56.6%	100%

Table 13 - Reduction in Accidents Predicted with Distance 2 Warning and Activation.

	Braking Strategy 2	**Braking Strategy 3**	**Braking Strategy 4**	**Braking Strategy 5**
Tractor Applied	19.6%	27%	51.6%	92.9%
Tractor & Trailer Applied	34.3%	40%	83.8%	100%

Table 14 - Reduction in Accidents Predicted With Distance 3 Warning and Activation

Some conclusions can be drawn from these results.

- Light braking strategies, like 20 psi, do not outperform a warning-only system because the driver override is presumed to occur later.

- Severe braking strategies, like full pressure, can outperform warning-only systems.

- Although activation distance 3 is generally a shorter distance than 2, it is actually longer at the low speeds. It is believed to cause the nonuniform shifting around of the reductions between the two tables.

This leads to the most important conclusion of the analysis: the accident reduction benefit is almost totally dependent upon the activation scheme. Within the limits of the sensors, the activation distance can be set at any value. Therefore, the accident reduction capability can be manipulated to eliminate 100% of the targeted collisions. The penalty for designing such a system is loss of vehicle driveability; the greater the activation distance, the more frequently the system will warn the driver to do something when the driver does not want the warning.

As mentioned previously, the activation could be designed to accentuate accident reduction at certain speeds, i.e., favor reductions of high speed collisions since they are usually more lethal and expensive. Or, the simulation techniques presented here might be used to generate the design of the activation, i.e., with the activation designed to achieve some uniform reduction at all speeds. Or, as recently suggested,[6] use empirical traffic data in a traffic simulator to help select an activation scheme. Whatever design criteria are finally used, there is no doubt the customer will be involved in the process.

Also, in actual practice, an autonomous braking vehicle, with sensors for activation, would probably warn the driver at some distance from a target before any brake application. Then, if he did not take some action before some shorter target distance was measured, the automatic braking would ensue.

The Phase IV techniques presented here would need to be modified to allow simulations of such systems. Specifically, the pressure command tables would need to reflect that the driver reaction time period should commence at the warning. It should be displaced by the time elapsed to travel the warning distance to the activation distance difference. See Figure 8. This observation was made after the simulations were completed and the results analyzed. No subsequent simulations were done with the model.

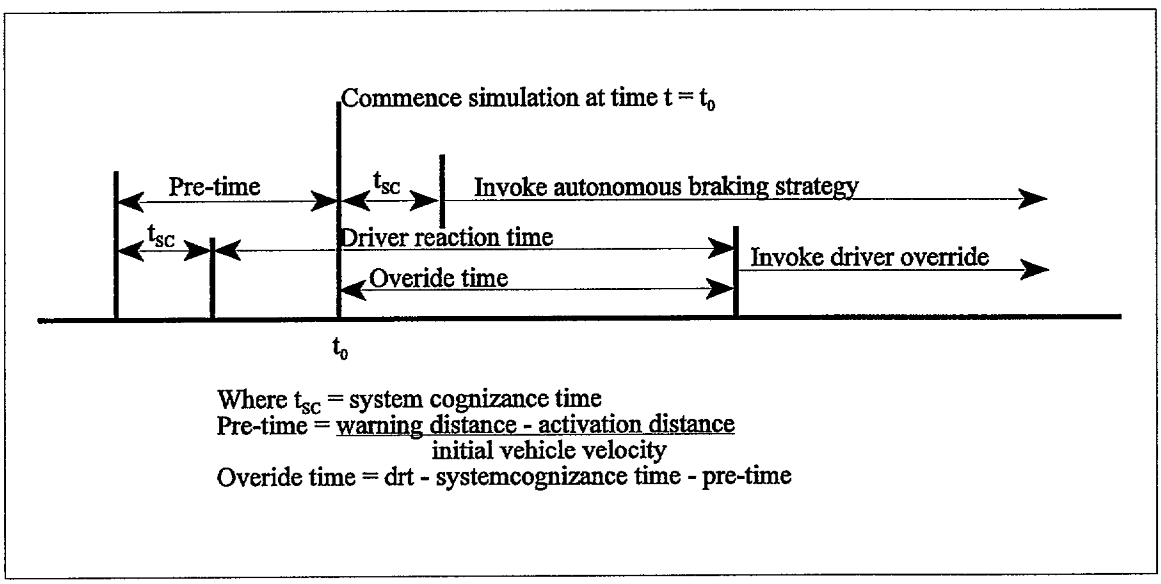


Figure 8 - Model for Simulating Driver Prewarning into Brake Commands

6 Farber & Paley, proceedings of International Conference On Strategic Research Program and Traffic Safety on Two Continents, The Hague (Netherlands), September, 1993.

6.0 Number of Target Collisions

The collision avoidance system studied here, would only be expected to function well in collisions involving forward obstacles. Generally, it would be most functional in preventing rear-end collisions. Accordingly, the analysis focused on target collisions that meet the following criteria:

- rear-end collision involving exactly two vehicles
- accident involves a truck-tractor as the striking vehicle
- both vehicles moving straight-no lane changes, merges, or avoidance maneuvers
- truck did not experience brake failure
- accident took place on straight section of roadway
- accident did not occur on snowy/icy roadway

Screening the cases is a method of removing the causal factors that the system may not be able to ameliorate. Multiple-vehicle accidents are certainly amenable to collision avoidance. Restricting the target collisions to “exactly two vehicles” was included to gain insight into potential severity reductions. Single-vehicle accidents with stationary objects also have some real-world applicability.

The target collision data were assembled by the University of Michigan Transportation Research Institute’s Center for National Truck Statistics. This information was provided in a memo by Dawn Massey of UMTRl, dated March 10, 1995.

Because the annual number of target collisions in any single year of NASS, GES is small, therefore three years of data were combined for this analysis. They are the three most recent years available to UMTRI, 1990-1992.

Table 15 shows the average annual number of target collisions. Of the 12,048 total crashes, 5,056 (42%) are in the LVS subtype and 6,992 (58%) are in the LVM subtype.

Accident Severity	Rear-end Subtype		Total
	LVS	LVM	
PDO	3,429	4,725	8,153
C Injury	1,229	1,056	2,285
B Injury	197	729	926
A Injury	163	365	528
Fatal	19	111	131
Unknown	19	7	25
Total	5,056	6,992	12,048

Table 15 - Target Collisions (Snowy/Icy Roads and Curves Excluded) 1990-1992 GES/Weighted Frequencies/Annual Averages)

The GES files were also used to estimate the number of all police-reported accidents involving at least one truck-tractor. Table 16 shows the annual average. About 174,000 collisions involving at least one truck-tractor are estimated to occur each year. This means that the group of target collisions comprises about 6.9% of all truck-tractor involved collisions.

Table 16 also tabulates tractor accidents by collision type and injury severity. Rear-end collisions account for 33,347 truck-tractor accidents each year. The group of target collisions, all of which are rear-end crashes, comprise 36% of all of the rear-end tractor accidents. This relatively low percentage is primarily due to limiting rear-end collisions to those where the tractor was the striking vehicle and those involving only two vehicles.

	Manner of Collision									
Accident Severity	Non-Collision	Rear-end	Head-on	Rear-rear	Angle	Sideswipe Same Dir.	Sideswipe Opp. Dir.	Other	Unknown	Total
PDO	39,292	21,447	672	189	41,639	20,532	2,050	165	880	126,867
C Injury	3,263	5,731	314	1	7,575	2,662	377	101	10	20,035
B Injury	3,719	3,553	142	0	4,991	1,218	329	0	64	14,016
A Injury	2,132	2,164	324	0	4,064	397	179	11	39	9,310
Fatal	433	408	388	0	1,069	6	1	0	0	2,304
Unknown	1,185	44	43	0	165	8	0	0	11	1,456
Total	50,024	33,347	1,884	190	59,503	24,823	2,937	277	1,005	173,990

Table 16 - Collisions Involving at Least One Truck-Tractor 1990-1992 GES/Weighted Frequencies/Annual Averages.

GES may slightly underestimate the total number of truck-tractor collisions that occur each year. The "truck-tractor" level of the Body Type variable in GES was used to identify tractor collisions for this work. There is also an "unknown medium/heavy truck type" level on that variable. Data checks suggested that most vehicles coded with this level are probably straight trucks, but a few are probably tractors. It is estimated that there may be 5-10% more tractor collisions annually than the 174,000 stated above. The proportion of these accidents that are target collisions would probably not change, so the number of target collisions would probably show a similar 5-10% increase.

Target collisions were restricted to those involving exactly two vehicles to facilitate data analysis. If target collisions were allowed to involve three or more vehicles, their absolute number would increase by an estimated 60-65%. So, if target collisions involved any number of air braked vehicles, they would comprise 10-12% of all truck collisions instead of the 6.9% figure cited above.

7.0 System Cost Estimate

The autonomous braking system as considered in this research is presumed to consist of a radar-based collision warning system, a J1939 communications bus or equivalent, an anti-lock brake system with traction control, a pressure sensor, and some modifications to the air system. The system has three possible implementations: one that controls the brakes of the drive axle alone, one that controls the brakes on all axles of the tractor, and one that controls all the brakes on the tractor and trailer. The following cost analysis is a simplistic estimate of what the selling price might be for the autonomous braking system. It is assumed that this system would be installed in a vehicle where ABS is required or is already installed. The cost estimate does not include the cost of the ABS.

There are two areas in this cost analysis that are difficult to assess. First, without further development work, it is difficult to estimate the cost impact on the integration of the autonomous braking control algorithm into the ABS/TCS and/or the collision warning system. One of the systems needs to have an added analog input, with the appropriate hardware and software signal conditioning to read the signal from the pressure sensor. Secondly, the added costs that an OEM will include in the base vehicle cost that are associated with the installation of such a system creates further assessment inaccuracies.

The cost of the major components is estimated in Table 17 below. This cost is based on an estimate of the suggested fleet selling price with a 10% premium added to cover the cost to accomplish the system integration.

Collision warning system	$2300
Modifications to ABS ECU	$25
Traction control valve (or TC option to ABS)	$240
Pressuresensor	$25
Additional air lines and fittings	$10
TOTAL	..$2600

Table 17 - System Components Cost

There will also be additional cost to the vehicle OEM to equip the vehicle for installation of these components. The OEM selling price for the complete system would have to cover these costs, which include the cost increase to the vehicle wiring harness, the added cost of installing the components and any warranty, shrinkage, etc. costs associated with the product, plus some profit.

The estimated time to install the system, assuming the vehicle is prewired is about 1.5 hours. This includes alignment of the radar system. The cost estimate for installation is the labor rate times 1.5 hours times burden rate. Using a labor rate of $20.00 per hour and a burden rate of 4, the cost is about $120. The additional cost to the vehicle wiring harness is estimated to be $80. Thus, the estimated selling price of the base product is: (Cost of the major component + cost of installation + wiring harness cost) times an OEM factor.

Here the OEM factor is a number that captures warranty, shrinkage, selling expenses, profit, and other costs. A reasonable estimate for this number is 1.75.

Therefore, for a base system that only applies the brakes to the drive axle of the tractor, the selling price would be $2,800 x 1.75 = $4,900.

For a system that applies all the tractor brakes, the addition of an additional traction control valve, a relay valve, a double check valve, and some additional air lines is needed. These items would probably add about $300 to the installed system cost, bringing the cost to about $5,425.

For a system that applies the tractor brakes and the trailer brakes, the selling price is slightly more than the previous example due to an additional check valve and different air system configuration. This is estimated to total about $5,700.

8.0 Cost of Accidents Analysis

The UMTRI data of Table 16, also contains GES assignments for accident severity in various accidents. UMTRI noted that the target collisions represent 36% of the total GES rear-end collisions.

Table 18 is a scale of costs/MATS injury derived from Blincoe and Fagin and referenced in an appendix of the Knipling report, previously referenced. Table 19 is a worksheet that estimates cost/benefit and payback period.

The benefit in terms of reduced accident costs is derived by expanding the KABCO scale for the rear-end collisions and applying the Blincoe and Fagin derived willingness to pay values. The severities are from Table 15 values for the GES target collision. The LVS collisions are factored at a conservative 80% and the LVM collisions (analysis not completed) are factored at a guessed value of 50%.

The resulting cost/benefit ratio of 0.88 would represent a fleet payback period of eleven months; a very favorable value.

“Fatal Equivalents” Injury Severity Scale		
Injury Severity (MAIS)	**“Willingness to Pay” $ Value Per Injury**	**“Fatal Equivalents”**
Fatality (K)	$2,620,5 16	1.0000
Critical (5)	$2,122,642	0.8100
Severe (4)	$1,017,331	0.3882
Serious (3)	$400,3 10	0.1528
Moderate (2)	$107,638	0.0411
Minor (1)	$6,180	0.0024
Not injured (0)	------	0.0000

Table 18 - Conversion Table for Deriving “Fatal Equivalents” from MAIS (Derived from Blincoe and Fagin, 1992)

REAR-END ACCIDENTS

LVS Accident Reduction Benefits(Table 15)

Severity	Number/Year	1992 Projected $1000's	Sub-total $1000's
PDO	3,429.0	2	6,858.0
C1	614.5	6	3,687.0
C2	614.5	107	65,751.5
B	197.0	400	78,800.0
A1	81.5	1,000	81,500.0
A2	81.5	2,100	171,150.0
Fatal	19.0	2,600	49,400.0
Unknown	19.0	10	190.0
			457,336.5
		LVS Portion @ 80% EFF =	365,869.0

LVM Accident Reduction Benefits(Table 15)

Severity	Number/Year	1992 Projected $1000's	Sub-Total $1000's
PDO	4,725.0	2	9,450
C1	528.0	6	3,168
C2	528.0	107	56,496
B	729.0	400	291,600
A1	182.5	1,000	182,500
A2	182.5	2,100	383,250
Fatal	111.0	2,600	288,600
Unknown	7.0	10	70
			1,215,134
		LVM Portion @ 50% EFF =	607,567
		Benefit to Transportation Industry	973,436
Systems Cost:	Vehicles/Year	$1000's	$1000's
	150,000	5.7	855,000
	Yearly Cost($) =		855,000
		COST/BENEFIT RATIO =	0.88
		PAYBACK PERIOD (MONTHS) =	11

Table 19 - Cost/Benefit Worksheet

9.0 Conclusion

The stopping distance simulations in this analysis indicate that for all the major combination unit types, a braking system that can react to dangers in the road ahead and can initiate some form of autonomous braking at a time earlier than the driver can initiate braking, will result in shorter stopping distances.

The accident reduction simulations presented in this report indicate that a potential exists for reducing the stopping distances of heavy commercial vehicles equipped with a collision warning system and an autonomous braking system. The accident reduction modeling also predicts that such a system could be responsible for preventing a large percentage of certain types of rear end crashes where the lead vehicle is stationary. The simulation effort shows that over 78% of these crashes could be prevented with a collision warning system and some measure of autonomous braking. The analysis shows very clearly that the benefits arise from the reduction in braking reaction time to a potential danger ahead of the vehicle. Just having the collision warning system alarm the driver of an obstacle ahead was shown to help reduce accidents by 78.5%. One system approach, that applies full braking at the first sign of an obstacle ahead, was shown to eliminate all of the target accidents, although it is doubtful if such an approach is acceptable from a driveability viewpoint.

The target number of collisions that this system could affect on a per year basis, based on three years of NASS GES data, is estimated to be 12,048, or up to about 6.9% of all truck-tractor collisions involving one or more combination units. This is a rather small number and the selection criteria may have eliminated some additional number of target collisions that could be prevented. If target collisions were allowed to include rear-end collisions involving two or more vehicles, the numbers would be about 24,500, or up to 12% of all tractor collisions.

The cost of an autonomous braking system is estimated at about $5,700. The cost/benefits ratio of only the target collisions indicates a favorable return on investment for such a system, at least on an industry-wide basis. The real accident reduction undoubtedly includes an even larger share of the estimated 174,000 annual number of truck collisions. Many fleets are now assessing the cost effectiveness of a collision warning system (which can identify stationary objects out to about 250 feet and moving objects out to about 350 feet, and also has a side-looking sensor and thus will eliminate another category of accidents), with no autonomous braking. This system is less expensive, about $2,300 as an uninstalled, retrofit kit to the fleet. Some fleets have determined that the system will help change drivers' behavior toward a safer driving style, and therefore, will reduce accidents. The combination of these factors broadens the industry-wide benefits. Of course, the accident experience of individual fleets is not necessarily the same as industry-wide values. It is suspected that the fleets with a willingness to invest in collison avoidance technology already have low accident rates. So, on an individual basis, the benefits may become more difficult to sell.

The analysis has yielded a database and a methodology that is capable of analyzing the benefits of collision avoidance systems relative to truck rear-end collisions. The use of Phase IV as a simulator in the methodology creates a system that is somewhat cumbersome to use. -On the other hand, it has the potential to simulate situations other than straight line rear-end collisions when expanded applications are explored. Using the analysis to predict accident and severity reductions is very dependent upon the design of the activation algorithm. Since the design viability has not been determined or tested in any way, rigorous accident analysis has not been performed.

APPENDIX A

Tire Model

Tire Model

The nonlinear longitudinal tire table format was selected to be used for the longitudinal stiffness parameter in the input file. This option requires the entries of the various u-slip[7] curves under the different tire loads and the different vehicle speeds.

Three p-slip curves of a 10X20/F tire on dry asphalt with 2126 lbs, 5570 lbs and 9195 lbs of vertical load were obtained from the above article. From these three curves, six more curves were derived by using the velocity-sensitivity data from the same article. There is a total of 9 p-slip curves - each corresponding to a specific vertical load (2126 lbs, 5570 lbs or 9 195 lbs) and a specific vehicle speed (10 mph, 40 mph or 55 mph). This set of 9 p-slip curves is used in the simulation as the high-p surface condition. The plot of these curves is shown in Figure A.:

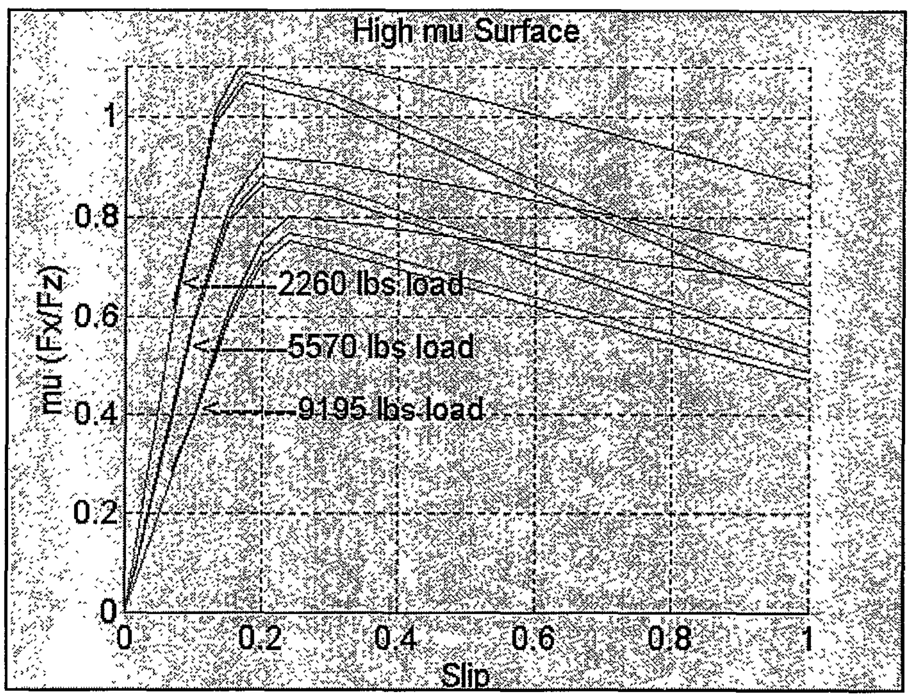


Figure Al - High u surface p-slip curves

The plot clearly shows there are three groups of curves with different slopes in the low slip region (slip < 0.2). They correspond to three different vertical tire loads as indicated on the figure. Within each group of curves there are three curves that correspond to different vehicle speeds. The curve that corresponds to the higher vehicle speed has the lower u value in the higher slip region (slip > 0.3).

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7 The u-slip curves used in our simulation were obtained and derived from the following article: Ervin, R. D. ***"Mobile Measurements of Truck Tire Traction".*** Proceedings of a Symposium on Commercial Vehicle Braking and Handling, Highway Safety Research Institute, The University of Michigan, May 5-7, 1975.

APPENDIX B

Brake Model

Brakes and Brake Systems in Simulations

The Phase IV simulation program basically simulates vehicle air systems by converting driver command pressures to brake chamber pressures. It then converts the brake chamber pressures to brake torques that are applied to the associated, simulated wheel/tire.

Air Brake Control System

The conversion of command to chamber pressure has the general form of a first order exponential lag with a delay. The iteration algorithm has the form:

P_driv = (P_driv) from a previous time, (t-t_del)
P_inc = (P_driv-P_brake) X (1 -e* *(-t_inc/t_rise))
P_brake=P_brake + P_inc

where P_inc is the incremental change in the brake application pressure over the time increment, t_inc, of interest and t-rise is a time constant parameter. Delay is introduced by utilizing the command pressure, P_driv, from a previous time that is offset by a delay time, t_del The values of delay time and time constant are input parameters to the simulation for each brake site.

The above parameter values are grouped by brake site for simulations here. Each of the brakes in the tractor steer, tractor drive, and semi-trailer rear brakes are given identical parameter values as a group. Generally, these brakes are plumbed in similar groups in real trucks.

The values were selected to attempt to approximate the brake actuation times of vehicles designed to meet the requirements defined in FMVSS 121, part S5.3.3-Brake actuation time, where each brake must reach 60 psi in .45, or .60 sec for trucks or trailers, respectively. Since the simulations are meant to simulate collision avoidance scenarios, where brake applications have greater importance than brake releases; these approximation criteria seem appropriate.

Parameter	Steer	Drive	Trailer
Lagtime delay (sec)	.050	.075	.175
Risetime constant (sec)	.250	.250	.250
Simulated actuator response to 100 psi command step	80 psi @ .45 sec	77 psi @ -45 sec	81 psi @ .60 sec

Brake Torque

The relationship of brake torque to actuator pressure is generally nonlinear so the Phase IV option of using a table input is exercised. The brake relationships for the simulations were obtained from Eaton dynamometer tests performed to FMVSS 121, part S5.4, especially S5.4.1, the brake retardation force portion. These tests are frequently performed for performance certification to North American truck and trailer OEM's. New brakes generally perform within several percent of each other and the values presented here represent a five percent below normal level. FMVSS 121 requires that retardation forces be sized relative to gross axle weight rating (GAWR). The North American practice of sizing drive and trailer brakes for 20,000 GAWR, irrespective of any actually lower GAWR's, allows the use of a single set of brake torque tables to be used for all the vehicles in this study. Steer axle brakes have been sized for 12,000 lb GAWR for all cases here. In addition, air systems and brakes exhibit pushout and crack pressure values that must be attained before braking commences. The simplest way to introduce such typical offsets between command pressure and torque output in the Phase IV simulation is to add the crack pressure to the torque tables. Accordingly, about four psi has been added to the brake tables.

Actuator press (psi)	15x4 Steer (in-lb)	16.5x7 Drive (in-lb)	16.5x7 Trailer (in-lb)
0.0	0	0	0
2.0	0	0	0
4.0	0	0	0
4.5		0	
10.0	6216	11688	15084
20.0	14508	25908	32124
30.0	23280	40908	46944
40.0	31968	55020	59820
60.0	50544	76308	82944
80.0	66504	94644	100056
100.0	81084	110100	110448

To improve the simulation of stopping in anticipation of ABS cycles, brake hysteresis typical of real S-cam brakes (i.e., about 7 psi of hysteresis at 100 psi) has been included.

Phase IV Parameter	15x4 Steer	16.5x7 Drive	16.5x7 Trailer
KHYST	1	1	1
HY	1.04	1.007	1.007
HY2	86.33	177.1	209.5
RESBRK	4.0	4.5	4.0
RESID	179.6	445.8	421.9
HYL	1.04	1.007	1.007

To illustrate the effect of these values, typical drive axle rising and falling torque values are shown in Figure Bl and the simulation values for a ‘pumped’ brake command are plotted in Figure B2. This test indicates a reasonably good simulation of brake hysteresis.

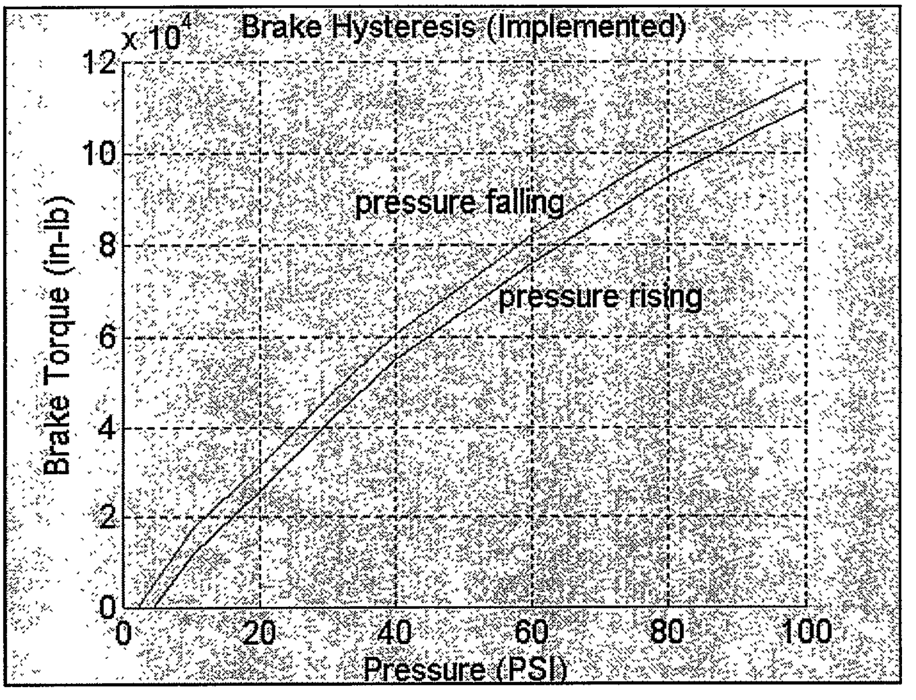

Figure Bl - Brake Hysteresis Model

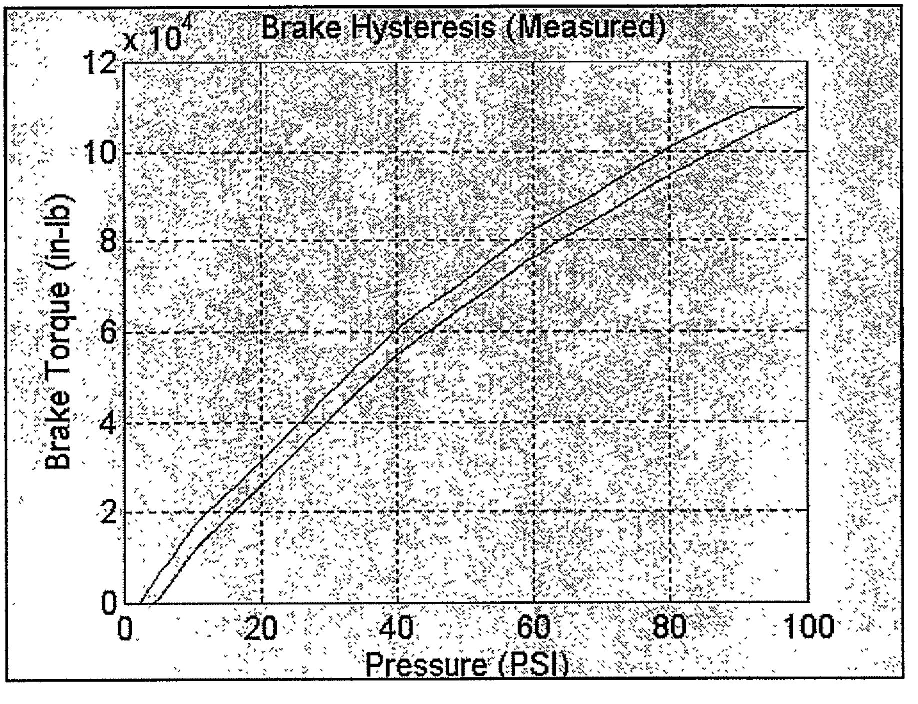

Figure B2 - Brake Hysteresis Simulation Results

ABS Simulation

An Anti-lock Brake System is simulated here as an axle based system with worst wheel logic. The control logic is a state type where the brakes are released if the wheel deceleration is too great. The brake pressure is reinstated when the accel becomes positive. It is a rudimentary approach that provides realistic directional control and stopping distance for the uniform, medium to high friction surface conditions of these simulations.

APPENDIX C

Additional Phase IV Modeling Inputs and Definitions

Additional Phase IV Modeling Inputs and Definitions

This appendix describes the vehicle parameters used in the UMTRI Phase IV model for the purposes of modeling vehicle stopping behavior. In all, five Class 8 vehicles were modeled for braking performance. The five vehicle configurations can be described in general terms as (see also Figure 2):

1. 4x2 Straight Truck
2. 6x4 Straight Truck
3. 4x2 Tractor plus one single axle Semi-trailer
4. 4x2 Tractor plus two single axle Semi-trailers
5. 6x4 Tractor plus one tandem axle Semi-trailer

For the five vehicle configurations chosen for this study, an engineering mock design was performed. Major components were selected and then the weights, inertias, etc. were looked up, estimated or calculated. The parameters are contained in Tables Cl through C6. The NHTSA technical report, DOT HS 807 125, ‘A Factbook of the mechanical properties of the components for single-unit and articulated heavy trucks’, Fancher et al., Univ. of Mich. Transportation Research Institute, Dec. 1986, was used extensively to obtain component parameters.

VEHICLE #1-4x2 STRAIGHT TRUCK. THIS VEHICLE WAS CHOSEN TO REPRESENT A LOCAL DELIVERY TRUCK.

A. 1994 CF 8000-FORD CARGO WITH WHEELBASE (INCHES) = 225

B. BARE CHASSIS CHARACTERISTICS (DIESEL HANDBOOK) =

a.	FRT CHASSIS CURB ST (LBS) =	7113
b.	FRT DRIVER, FIFTH WHL, & FUEL PACKAGE WT =	300
c.	REAR CHASSIS CURB WT =	3993
d.	REAR DRIVER, FIFTH WHL, & FUEL PACKAGE WT =	0
e.	TOTAL CURB WT =	11406
f.	FRT UNSPRUNG ST (ESTIMATED) =	1000
g.	REAR UNSPRUNG ST (ESTIMATED) =	2000
h.	CHASSIS SPRUNG MASS (LBM) =	8406

C. VAN BOX CHARACTERISTICS

a.	LENGTH(INCHES) =				312
b.	HEIGHT =				100
c.	WIDTH =				96
	ELEMENT	SQ.FT.	DENSITY	WT(LBS)	
d.	TOP	208	3	520	
e.	FLOOR	208	10	2080	
f.	L.SIDE	217	4	758	
g.	R.SIDE	217	4	758	
h.	FRT END	67	4	233	
j.	REAR END	67	4	233	
k.	TOTAL ST (LBS) =				4583
l.	BOX CG ABOVE THE FLOOR (INCHES =				33
m.	BOX CG AHEAD OF REAR AXLE =				50
n.	BOX WT. ON FRT SUSP (LBS) =				1019
p.	BOX WT. ON REAR SUSP =				3565

Table C1 – Vehicle Type 1

D. SPRUNG MASS POSITIONS (CG,& ETC)

a.	FRT SUSP LOAD (LBS)=					7432
b.	REAR SUSP LOAD=					5558
c.	PITCH CG AHEAD OF REAR AXLE(INCHES)=					129
d.	CHASSIS PITCH & ROLL CG ABOVE R'WAY (EST)=					40
e.	BOX MOUNTED FLOOR ABOVE ROADWAY=					41
f.	COMBINED CG ABOVE ROADWAY=					52
g.	YAW CG AHEAD OF THE REAR AXLE=					166

E. ROLL MOMENTS OF INERTIA (Ixx)

a.	CHASSIS RADIUS OF GYRATION (INCHES)(ESTIMATED)=					40
b.	CHASSIS Ixx=.5*M*R^2 =SLUG-FT2=FT-LB-SEC2=					1450
	=IN-LB-SEC2=					17404
c.	ADDITIONAL TO TRANSLATE TO CG =					3128
d.	COMBINED CHASSIS Ixx (IN-LB-SEC2)=					20531
BOX	ELEMENT	SHP. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
e.	FRT END	0.3	7.2	33.4	12.0	967
f.	TRANSLATE	1.0	7.2	10.6	12.0	919
g.	REAR END	0.3	7.2	33.4	12.0	967
h.	TRANSLATE	1.0	7.2	10.6	12.0	919
j.	L. SIDE	0.3	23.6	17.4	12.0	1635
k.	C.L. TRANS	1.0	23.6	16.0	12.0	4522
l.	CG TRANS	1.0	23.6	10.6	12.0	2986
m.	R. SIDE	0.3	23.6	17.4	12.0	1635
n.	C.L. TRANS	1.0	23.6	16.0	12.0	4522
p.	CG TRANS	1.0	23.6	10.6	12.0	2986
q.	TOP	0.3	16.1	16.0	12.0	1034
r.	CG TRANSLA'	1.0	16.1	55.0	12.0	10662
s.	FLOOR	0.3	64.6	16.0	12.0	4134
t.	CG TRANSLA'	1.0	64.6	0.8	12.0	650
u.	BOX Ixx ABOUT ROLL CG=					38539
v.	COMBINED TOTAL Ixx ABOUT ROLL CG(IN-LB-SEC2)=					59071

Table C1 - Vehicle Type 1 (continued)

F. PITCH MOMENT OF INERTIA (Iyy)

SIMPLE CHASS. MODEL USES LUMPED MASSES AT FRT & REAR

a.	CHASSIS FRT PORTION Iyy=M*R^2=					153824
b.	CHASSIS REAR PORTION Iyy=M*R^2=					85471
c.	COMBINED CHASSIS Iyy=					239294
BOX	ELEMENT	SHP. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
d.	FRT END	0.3	7.2	17.4	12.0	503
e.	LG TRANS	1.0	7.2	41.5	12.0	3606
f.	HT.. TRANS	1.0	7.2	10.6	12.0	919
g.	REAR END	0.3	7.2	17.4	12.0	503
h.	LG TRANS	1.0	7.2	382.6	12.0	33271
j.	HT.. TRANS	1.0	7.2	10.6	12.0	919
k.	L. SIDE	0.3	23.6	186.4	12.0	17538
l.	LG TRANS	1.0	23.6	43.0	12.0	12164
m.	HT.. TRANS	1.0	23.6	10.6	12.0	2986
n.	R. SIDE	0.3	23.6	186.4	12.0	17538
p.	LG TRANS	1.0	23.6	43.0	12.0	12164
q.	HT.. TRANS	1.0	23.6	10.6	12.0	2986
r.	TOP	0.3	16.1	169.0	12.0	10906
s.	LG TRANS	1.0	16.1	43.0	12.0	8341
t.	HT.. TRANS	1.0	16.1	55.0	12.0	10662
u.	FLOOR	0.3	64.6	169.0	12.0	43623
v.	LG TRANS	1.0	64.6	43.0	12.0	33365
x.	HT.. TRANS	1.0	64.6	0.8	12.0	650
y.	TOTAL BOX Iyy=					212645
z.	TOTAL VEHICLE Iyy=					451939

Table C1 - Vehicle Type 1 (continued)

G. YAW MOMENT OF INERTIA (Izz)

a.	SPRING CHASSIS (MAKE SAME AS Lyy)=				239294
	ELEMENT	MASS	RAD(INCH)		IN#SEC^2
b.	F.AX/SUSP	1000	45		5241
c.	CG TRANS	1000	59		9132
d.	R. AX/SUSP	2000	40		8282
e.	CG TRANS	2000	166		141940
f.	COMBINED CHASSIS Izz=				403888
BOX	ELEMENT	SHP.FACT	WEIGHT	RAD(INCH)	INSEC^2
g.	FRT END	0.3	233.3	48.0	464
h.	CL TRANS	1.0	233.3	156.0	14696
j.	REAREND	0.3	233.3	48.0	464
k.	CL TRANS	1.0	233.3	156.0	14696
l.	L. SIDE	0.3	758.3	48.0	15920
m.	CL TRANS	1.0	758.3	156.0	4522
n.	R. SIDE	0.3	758.3	156.0	15920
p.	CL TRANS	1.0	758.3	48.0	4522
q.	TOP	0.3	520.0	163.2	11950
r.	FLOOR	0.3	2080.0	163.2	47801
s.	BOX Izz ABOUT ITS OWN CENTER=				130964
t.	TRANSLATE TO YAW CG(RAD)=				158506
u.	TOTAL BOX Izz=				289460
v.	COMBINED TOTAL Izz=				693349

Table C1 – Vehicle Type 1 (continued)

H. PAYLOAD CHARACTERISTCS

a.	ALLOW. Fr AXLE LOAD (LBS)=	12000
b.	ALLOW. Rr AXLE LOAD (LBS)=	19000
c.	TOTAL VEH CAP (LBS)=	31000
d.	VEH WT=	15989
e.	FULL LOAD CAP=	15011
f.	98% LOAD CAP==PAYLOAD=	14710
g.	% TOTAL VEH. CAP=	99.0
h.	ALLOW. Rr AXLE PAYLOAD=	11258
j.	PAYLOAD CG AHEAD OF Rr AXLE(IN)	52.8
70% PAYLOAD IN BOTTOM HALF OF BOX		
k.	LOAD IN BOTTOM HALF(LBS)=	10297
l.	LOAD IN TOP HALF(LBS)=	4413
m.	CG HEIGHT ABOVE GRD (IN.)=	810
LENGTH OF UNIF, LOAD TO FIT CGX REQUIRMENT		
n.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	50
o.	LENGTH OF UNIFORM LOAD (IN.)=	306
p.	BOTTOM HALF Ixx(in-lb-sec2)=	26019
q.	RANSLATE CG=	5996
r.	TOP HALF Ixx=	11151
s.	TRANSLATE CG=	13991
t.	TOTAL ROLL Ixx(IN-LB-SEC2)=	57157
u.	BOTTOM HALF Iyy=	214032
v.	TRANSLATE CG=	5996
w.	TOP HALF Iyy=	91728
x.	TRANSLATE CG=	13991
y.	TOTAL PITCH Iyy (IN-LB-SEC2)	325747
z.	TOTAL YAW Izz OF PAYLOAD	327067

Table C1 – Vehicle Type 1 (continued)

J. HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT TO HALF AND LENGTH AND HEIGHT TO .707

a.	PAYLOAD=	7355
b.	% TOTAL VEH. CAP=	75.3
c.	ALLOW. Rr AXLE PAYLOAD=	6750
d.	PAYLOAD CG AHEAD OF Rr AXLEw FORW EDGE HELD(IN.)=	97.7
70% PAYLOAD IN BOTTOM HALF OF LOAD		
e.	LOAD IN BOTTOM HALF(LBS)=	5149
f.	LOAD IN TOP HALF(LBS)=	2207
g.	CG HEIGHT ABOVE GRD (IN.)=	69.3
h.	LENGTH OF UNIFORM LOAD(IN.)=	217
j.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	11621
k.	TRANSLATE CG=	1499
l.	TOP HALF Ixx=	4980
m.	TRANSLATE CG=	969
n.	TOTAL ROLL Ixx(IN-LB-SEC2)=	19069
o.	BOTTOM HALF Iyy=	53492
p.	TRANSLATE CG=	1499
q.	TOP HALF Iyy=	22925
r.	TRANSLATE CG=	969
s.	TOTAL PITCH Iyy (IN-LB-SEC2)=	78884
t.	TOTAL YAW Izz OF PAYLOAD	89054

Table C1 - Vehicle Type 1 (continued)

VEHICLE #2-6X4. THIS VEHICLE WAS CHOSEN TO REPRESENT A FLAT BED, LOCAL DELIVERY TRUCK AS USED IN STEEL DELIVERY.

A.1989 FREIGHTLINER FLC11264S WITH WHEELBASE (INCHES)=					232
B. BARE CHASSIS CHARACTERISTICS (DIESEL HANDBOOK)					
a.	FRT CURB WT (LBS)=				7725
b.	FRT DRIVER & FUEL PACKAGE WT=				420
c.	REAR CURB WT=				6825
d.	REAR DRIVER&FUEL PACKAGE WT=				300
e.	TOTAL CURB WT=				15270
f.	FRT UNSPRUNG WT(ESTIMATED)=				1200
g.	REAR UNSPRUNG WT(ESTIMATED)=				4900
h.	CHASSIS SPRUNG MASS(LBM)=				9170
C. FLAT BED CHARACTERISTICS					
a.	LENGTH(INCHES)=				240
b.	HEIGHT=				48
c.	WIDTH=				96
BED	ELEMENT	SQ.FT.	DENSITY	WT(LBS)	
d.	TOP	160.0	0.0	0.0	
e.	FLOOR	160.0	13.0	2080.0	
f.	L. SIDE	80.0	0.0	0.0	
g.	R. SIDE	80.0	0.0	0.0	
h.	FRT END	32.0	15.3	489.9	
j.	REAR END	32.0	4.7	150.4	
k.	TOTAL WT (LBS)=				2720
l.	BOX CG ABOVE THE FLOOR (INCHES)=				3
m.	BOX CG AHEAD OF REAR AXLE=				45
n.	BOX WT. ON FRT SUSP(LBS)=				528
p.	BOX WT. ON REAR SUSP=				2193

Table C2 - Vehicle Type 2

D. SPRUNG MASS POSITIONS (CG,& ETC)

a.	WT ON FRT SUSP (LBS)=					7473
b.	WT ON REAR SUSP =					4418
c.	PITCH CG AHEAD OF REAR AXLE(INCHES)=					146
d.	CHASSIS PITCH & ROLL CG ABOVE R'WAY (EST)=					40
e.	BOX MOUNTED FLOOR ABOVE ROADWAY=					45
f.	COMBINED CG ABOVE ROADWAY=					42
g.	YAW CG AHEAD OF THE REAR AXLE=					131

E. ROLL MOMENTS OF INERTIA (Ixx)

a.	CHASSIS RADIUS OF GYRATION (INCHES)(ESTIMATED)=					40
b.	CHASSIS Ixx=.5*M*R^2 =SLUG-FT2=FT-LB-SEC2=					1582
	=IN-LB-SEC2=					18986
c.	ADDITIONAL TO TRANSLATE TO CG =					70
d.	COMBINED CHASSIS Ixx (IN-LB-SEC2)=					19055
BOX	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
e.	FRT END	0.3	15.2	20.0	12.0	1217
f.	TRANSLATE	1.0	15.2	5.0	12.0	910
g.	REAR END	0.3	4.7	20.0	12.0	374
h.	TRANSLATE	1.0	4.7	5.0	12.0	279
j.	L. SIDE	0.3	0.0	4.0	12.0	0
k.	C.L. TRANS	1.0	0.0	16.0	12.0	0
l.	CG TRANS	1.0	0.0	5.0	12.0	0
m.	R. SIDE	0.3	0.0	4.0	12.0	0
n.	C.L. TRANS	1.0	0.0	16.0	12.0	0
p.	CG TRANS	1.0	0.0	5.0	12.0	0
q.	TOP	0.3	0.0	16.0	12.0	0
r.	CG TRANSLA'	1.0	0.0	17.9	12.0	0
s.	FLOOR	0.3	64.6	16.0	12.0	4134
t.	CG TRANSLA'	1.0	64.6	0.1	12.0	42
u.	BOX Ixx ABOUT ROLL CG=					6956
v.	COMBINED TOTAL Ixx ABOUT ROLL CG("#SEC^2)=					26011

Table C2 - Vehicle Type 2 (continued)

F. PITCH MOMENT OF INERTIA (Iyy)

SIMPLE CHASS. MODEL USES LUMPED MASSES AT FRT & REAR

a.	CHASSIS FRT PORTION Iyy=M*R^2=					133540
b.	CHASSIS REAR PORTION Iyy=M*R^2=					122414
c.	COMBINED CHASSIS Iyy=					255954
BOX	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
d.	FRT END	0.3	15.2	4.0	12.0	243
e.	LG TRANS	1.0	15.2	2.6	12.0	467
f.	HT.. TRANS	1.0	15.2	5.0	12.0	910
g.	REAR END	0.3	4.7	4.0	12.0	75
h.	LG TRANS	1.0	4.7	338.6	12.0	18977
j.	HT.. TRANS	1.0	4.7	5.0	12.0	279
k.	L. SIDE	0.3	0.0	104.0	12.0	0
l.	LG TRANS	1.0	0.0	70.6	12.0	0
m.	HT.. TRANS	1.0	0.0	5.0	12.0	0
n.	R. SIDE	0.3	0.0	104.0	12.0	0
p.	LG TRANS	1.0	0.0	70.6	12.0	0
q.	HT.. TRANS	1.0	0.0	5.0	12.0	0
r.	TOP	0.3	0.0	100.0	12.0	0
s.	LG TRANS	1.0	0.0	70.6	12.0	0
t.	HT.. TRANS	1.0	0.0	17.9	12.0	0
u.	FLOOR	0.3	64.6	100.0	12.0	25813
v.	LG TRANS	1.0	64.6	70.6	12.0	54699
x.	HT.. TRANS	1.0	64.6	0.1	12.0	42
y.	TOTAL BOX Iyy=					101504
z.	TOTAL VEHICLE Iyy=					357458

Table C2 - Vehicle Type 2 (continued)

G. YAW MOMENT OF INERTIA (Izz)

a.	SPRUNG CHASSIS(MAKE SAME AS Iyy)=					255954
	ELEMENT	MASS	RAD(INCH)			IN#SEC^2
b.	F. AX/SUSP	1200	45			6289
c.	CG TRANS	1200	101			31443
d.	R. AX/SUSP	4900	40			20290
e.	CG TRANS	4900	131			218879
f.	COMBINED CHASSIS Izz=					532855
BOX	ELEMENT	SH.FACT	WEIGHT	RAD(INCH)		IN#SEC^2
g.	FRT END	0.3	489.9	48.0		974
h.	CL TRANS	1.0	489.9	120.0		18258
j.	REAREND	0.3	150.4	48.0		299
k.	CL TRANS	1.0	150.4	120.0		5605
l.	L. SIDE	0.3	0.0	120.0		0
m.	CL TRANS	1.0	0.0	48.0		0
n.	R. SIDE	0.3	0.0	120.0		0
p.	CL TRANS	1.0	0.0	48.0		0
q.	TOP	0.3	0.0	129.2		0
r.	FLOOR	0.3	2080.0	129.2		29973
s.	BOX Izz ABOUT ITS OWN CENTER=					55108
t.	TRANSLATE TO YAW CG(RAD=			86	) =	52528
u.	TOTAL BOX iZZ=					107636
v.	COMBINED TOTAL Izz=					640491

Table C2 - Vehicle Type 2 (continued)

H. PAYLOAD CHARACTERISTICS

a.	FRONT AXLE CAP (LBS)=	12000
b.	Rr AXLE CAP (LBS)=	38000
c.	TOTAL VEH CAP (LBS)=	50000
d.	VEH. WT=	17990
e.	FULL LOAD CAP=	32010
f.	95% LOAD CAP==PAYLOAD=	30409
g.	% TOTAL VEH. CAP=	96.8
h.	ALLOW. Rr AXLE PAYLOAD=	27466
j.	PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	22.5
UNIFORMLY SPREAD LOAD AT HALF THE DENSITY OF STEEL		
k.	LOAD VOLUME (IN3)=	194106
l.	LOAD HEIGHT (IN.)=	9.0
m.	CG HEIGHT ABOVE GRD (IN.)=	49.0
LENGTH OF UNIF. LOAD TO FIT CGX REQUIRMENT		
n.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	30.0
o.	LENGTH OF UNIFORM LOAD(IN.)=	225
p.	ROLL Ixx OF PAYLOAD(IN-LB-SEC2)=	55069
q.	PITCH Iyy OF PAYLOAD (IN-LB-SEC2)=	332273
r.	YAW Izz OF PAYLOAD(IN-LB-SEC2)=	392184

J. HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT AND HEIGHT TO HALF		
a.	PAYLOAD=	15205
b.	% TOTAL VEH. CAP=	66.4
c.	ALLOW. Rr AXLE PAYLOAD=	15910
d.	PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	22.5
UNIFORMLY SPREAD LOAD AT HALF THE DENSITY OF STEEL		
e.	LOAD HEIGHT (IN.)=	4.5
f.	CG HEIGHT ABOVE GRD (IN.)=	46.7
g.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	30.0
h.	LENGTH OF UNIFORM LOAD(IN.)=	225
j.	ROLL Ixx (IN-LB-SEC2)=	30287
k.	PITCH Iyy (IN-LB-SEC2)=	165938
l.	TOTAL YAW Izz OF PAYLOAD	196092

Table C2 - Vehicle Type 2 (continued)

VEHICLE #3-4X2 TRACTOR WITH A 28FT SINGLE AXLE TRAILER.
THIS VEHICLE WAS CHOSEN TO REPRESENT A LOCAL DELIVERY TRUCK.

A. 1994 WG42T VOLVO-WHITE-GMC WITH WHEELBASE (INCHES)=					146
B. BARE CHASSIS CHARACTERISTICS (DIESEL HANDBOOK)					
a.	FRT CURB WT (LBS)=				7489
b.	FRT DRIVER , FIFTH WHL , & FUEL PACKAGE WT=				400
c.	REAR CURB WT=				4263
d.	REAR DRIVER, FIFTH WHL, &FUEL PACKAGE WT=				600
e.	TOTAL CURB WT=				12752
f.	FRT UNSPRUNG WT(ESTIMATED)=				1300
g.	REAR UNSPRUNG WT(ESTIMATED)=				2300
h.	TOTAL CHASSIS SPRUNG MASS(LBM)=				9152
C. SPRUNG MASS POSITIONS (CG,& ETC)					
a.	FRT SUSP LOAD (LBS)=				6589
b.	REAR SUSP LOAD=				2563
c.	PITCH CG AHEAD OF REAR AXLE(INCHES)=				105.1
d.	CHASSIS PITCH & ROLL CG ABOVE R'WAY (EST)=				40.0
e.	YAW CG AHEAD OF THE REAR AXLE=				90.3
D. TRACTOR ROLL MOMENTS OF INERTIA (Ixx)					
a.	CHASSIS RADIUS OF GYRATION (INCHES)(ESTIMATED)=				40.0
b.	CHASSIS Ixx=.5*M*R^2 =SLUG-FT2=FT-LB-SEC2=				1579
	=IN-LB-SEC2=				18948
E. TRACTOR PITCH MOMENT OF INERTIA (Iyy)					
	SIMPLE CHASS. MODEL USES LUMPED MASSES AT FRT & REAR				
a.	CHASSIS FRT PORTION Iyy=M*R^2=				28507
b.	CHASSIS REAR PORTION Iyy=M*R^2=				73287
c.	COMBINED CHASSIS Iyy=				101794
F. TRACTOR YAW MOMENT OF INERTIA (Izz)					
a.	SPRUNG CHASSIS(MAKE SAME AS Iyy)=				101794
	ELEMENT	MASS		RAD(INCH)	IN*LB*SEC2
b.	F. AX/SUSP	1300		45.0	6813
c.	CG TRANS	1300		55.7	10430
d.	R. AX/SUSP	2300		40.0	9524
e.	CG TRANS	2300		90.3	48561
f.	COMBINED CHASSIS Izz=				177120

Table C3 - Vehicle Type 3

G. 28 FT. VAN TRAILER

a.	Rr AXLE CL TO KINGPIN LENGTH=WHEELBASE(IN)=					27
b.	LENGTH(IN)=					33
c.	HEIGHT(IN)=					10
d.	WIDTH(IN)=					10
e.	Rr AXLE AHEAD OF Rr DOOR(IN)=					3
f.	LAND GEAR CG AHEAD OF Rr DOOR(IN)=					26
g.	LAND GEAR CG BELOW FLOOR(IN)=					1
h.	SUSP CG AHEAD OF Rr DOOR(IN)=					4
j.	SUSP CG BELOW FLOOR(IN)=					1
k.	ELEMENT	SQ.FT.	DENSITY	WT(LBS)		
l.	TOP	238	2.0	476		
m.	FLOOR	238	11.0	2618		
n.	L. SIDE	252	3.5	882		
o.	R. SIDE	252	3.5	882		
p.	FRT END	76.5	4.0	306		
q.	REAR END	76.5	7.0	535.5	BOX WT=	570
r.	LAND GEAR			250		
s.	SUSP			450		
t.	Rr. AXLE			1700		
u.	TOTAL SPRUNG WT (LBS)=					640
v.	BOX FLOOR ABOVE GRD(IN.)=					4
w.	PITCH & ROLL CG ABOVE THE GRD (IN.)=					7
x.	PITCH CG AHEAD OF REAR DOOR=					15
y.	WT. ON KINGPIN(LBS)=					334
z.	WT. ON REAR SUSP=					305
aa.	WT ON GRD AT Rr AXLE=					475
ab.	TOTAL TRAILER WT=					810
ac.	YAW CG AHEAD OF REAR DOOR=					14

H. TRAILER ROLL MOMENTS OF INERTIA (Ixx)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	38.3	12.0	145
b.	TRANSLATE	1.0	9.5	4.5	12.0	51
c.	REAR END	0.3	16.6	38.3	12.0	254
d.	TRANSLATE	1.0	16.6	4.5	12.0	89
e.	L. SIDE	0.3	27.4	20.3	12.0	221
f.	C.L. TRANS	1.0	27.4	18.1	12.0	593
g.	CG TRANS	1.0	27.4	4.5	12.0	147
h.	R. SIDE	0.3	27.4	20.3	12.0	221
j.	C.L. TRANS	1.0	27.4	18.1	12.0	593
k.	CG TRANS	1.0	27.4	4.5	12.0	147
l.	TOP	0.3	14.8	18.1	12.0	106
m.	CG TRANS	1.0	14.8	43.8	12.0	776
n.	FLOOR	0.3	81.3	18.1	12.0	587
p.	CG TRANS	1.0	81.3	5.7	12.0	554
q.	LAND GEAR	1.0	7.8	6.3	12.0	58
r.	CG TRANS	1.0	7.8	0.8	12.0	7
s.	SUSP	1.0	14.0	6.3	12.0	104
t.	CG TRANS	1.0	14.0	2.4	12.0	40
u.	TOTAL TRAILER Ixx ABOUT ROLL CG("#SEC^2)=					4702

Table C3 - Vehicle Type 3 (continued)

J. TRAILER PITCH MOMENT OF INERTIA (Iyy)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	20.3	12.0	770
b.	CG TRANS	1.0	9.5	227.7	12.0	25963
c.	REAR END	0.3	16.6	20.3	12.0	1347
d.	CG TRANS	1.0	16.6	175.0	12.0	34934
e.	L. SIDE	0.3	27.4	216.3	12.0	23693
f.	CG TRANS	1.0	27.4	5.4	12.0	1761
g.	R. SIDE	0.3	27.4	216.3	12.0	23693
h.	CG TRANS	1.0	27.4	5.4	12.0	1761
j.	TOP	0.3	14.8	214.1	12.0	12658
k.	CG TRANS	1.0	14.8	44.6	12.0	7920
l.	FLOOR	0.3	81.3	214.1	12.0	69617
m.	CG TRANS	1.0	81.3	6.6	12.0	6408
n.	LAND GEAR	1.0	7.8	0.0	12.0	0
p.	CG TRANS	1.0	7.8	95.0	12.0	8851
q.	SUSP	1.0	14.0	6.3	12.0	1048
r.	CG TRANS	1.0	14.0	105.0	12.0	17604
s.	TOTAL TRAILER Iyy ABOUT THE PITCH CG("#SEC^2)=					238029

K. TRAILER YAW MOMENT OF INERTIA (Izz)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	18.1	12.0	687
b.	TRANSLATE	1.0	9.5	262.9	12.0	29975
c.	REAR END	0.3	16.6	18.1	12.0	1202
d.	TRANSLATE	1.0	16.6	138.9	12.0	27727
e.	L. SIDE	0.3	27.4	196.0	12.0	21475
f.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
g.	CG TRANS	1.0	27.4	4.9	12.0	1609
h.	R. SIDE	0.3	27.4	196.0	12.0	21475
j.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
k.	CG TRANS	1.0	27.4	4.9	12.0	1609
l.	TOP	0.3	14.8	214.1	12.0	12658
m.	CG TRANS	1.0	14.8	4.9	12.0	869
n.	FLOOR	0.3	81.3	214.1	12.0	69617
p.	CG TRANS	1.0	81.3	4.9	12.0	4777
q.	LAND GEAR	1.0	7.8	6.3	12.0	582
r.	CG TRANS	1.0	7.8	104.3	12.0	9717
s.	SUSP	1.0	14.0	6.3	12.0	1048
t.	CG TRANS	1.0	14.0	71.5	12.0	11985
u.	TOTAL TRAILER Izz ABOUT YAW CG("#SEC^2)=					228887

Table C3 - Vehicle Type 3 (continued)

L. TRAILER PAYLOAD CHARACTERISTICS

a.	TRACTOR Frt AXLE CAP (LBS)=	10000
b.	TRACTOR Rr AXLE CAP (LBS)=	20000
c.	TOTAL TRACTOR CAP (LBS)=	30000
d.	TRACTOR WT=	12752
e.	KINGPIN CAP=TRACTOR CAP (LBS)=	17248
f.	EMPTY TRAILER KINGPIN WT=	3343
g.	ALLOW PAYLOAD ON KINGPIN=	13905
h.	TRAILER REAR AXLE CAP=	20000
j.	ALLOW. PAYLOAD ON REAR SUSP=	15244
k.	FULL LOAD CAP=	29149
l.	95% LOAD CAP==PAYLOAD=	27691
m.	% TOTAL VEH. CAP=	97.1
n.	REQUIRED PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	128.8
70% PAYLOAD IN BOTTOM HALF OF BOX		
o.	LOAD IN BOTTOM HALF(LBS)=	19384
p.	LOAD IN TOP HALF(LBS)=	8307
q.	CG HEIGHT ABOVE GRD (IN.)=	88.2
LENGTH OF UNIF. LOAD TO FIT CGX REQUIREMENT		
r.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	138
s.	LENGTH OF UNIF. LOAD TO FIT CGX REQUIRMENT=	318
t.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	55683
u.	TRANSLATE CG=	13165
v.	TOP HALF Ixx=	23864
w.	TRANSLATE CG=	30719
x.	TOTAL ROLL Ixx(IN-LB-SEC2)=	123432
y.	BOTTOM HALF Iyy=	433862
z.	TRANSLATE CG=	13165
aa.	TOP HALF Iyy=	185941
ab.	TRANSLATE CG=	30719
ac.	TOTAL PITCH Iyy (IN-LB-SEC2)=	663687
ad.	TOTAL YAW Izz OF PAYLOAD	664521
ae.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	18.8
af.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	11.1
ag.	SELECTED KINGPIN POSITION=	12.0

Table C3 - Vehicle Type 3 (continued)

M. HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT TO HALF AND LENGTH AND HEIGHT TO .707

a.	PAYLOAD(LBS)=	13846
b.	PAYLOAD ON KINGPIN=	8193
c.	PAYLOAD ON REAR SUSP=	7241
d.	% TOTAL VEH. CAP=	69.4
e.	PAYLOAD CG AHEAD OF Rr AXLEw FORW EDGE HELD(IN.)=	175.3
70% PAYLOAD IN BOTTOM HALF OF LOAD		
f.	LOAD IN BOTTOM HALF(LBS)=	9692
g.	LOAD IN TOP HALF(LBS)=	4154
h.	CG HEIGHT ABOVE GRD (IN.)=	75.5
j.	LENGTH OF UNIF. LOAD (IN)=	225
k.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	24793
l.	TRANSLATE CG=	3290
m.	TOP HALF Ixx=	10626
n.	TRANSLATE CG=	7677
o.	TOTAL ROLL Ixx(IN-LB-SEC2)=	46387
p.	BOTTOM HALF Iyy=	108433
q.	TRANSLATE CG=	3290
r.	TOP HALF Iyy=	46471
s.	TRANSLATE CG=	7677
t.	TOTAL PITCH Iyy (IN-LB-SEC2)=	165872
u.	TOTAL YAW Izz OF PAYLOAD	181618
v.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	37.6
w.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	-123.7
x.	SELECTED KINGPIN POSITION=	12.0

Table C3 - Vehicle Type 3 (continued)

VEHICLE #4-4X2 TRACTOR WITH 28FT DOUBLE TRAILERS.
THIS VEHICLE WAS CHOSEN TO REPRESENT A DOUBLE TRAILER COMBINATION.

A. 1994 INTERNATIONAL 9600 SERIES WITH WHEELBASE (INCHES)=					120
B. BARE CHASSIS CHARACTERISTICS (DIESEL HANDBOOK)					
a.	FRT WT (LBS)=				6997
b.	FRT DRIVER , FIFTH WHL , & FUEL PACKAGE WT=				600
c.	REAR WT=				4131
d.	REAR DRIVER, FIFTH WHL, &FUEL PACKAGE WT=				800
e.	TOTAL WT=				12528
f.	FRT UNSPRUNG WT(ESTIMATED)=				1400
g.	REAR UNSPRUNG WT(ESTIMATED)=				2300
h.	TOTAL CHASSIS SPRUNG MASS(LBM)=				8828
C. SPRUNG MASS POSITIONS (CG,& ETC)					
a.	FRTCURB LOAD (LBS)=				6197
b.	REAR CURB LOAD=				2631
c.	PITCH CG AHEAD OF REAR AXLE(INCHES)=				84
d.	CHASSIS PITCH & ROLL CG ABOVE R'WAY (EST)=				40
e.	COMBINED CG ABOVE ROADWAY(EST)=				41
f.	YAW CG AHEAD OF THE REAR AXLE=				73
D. TRACTOR ROLL MOMENTS OF INERTIA (Ixx)					
a.	CHASSIS RADIUS OF GYRATION (INCHES)(ESTIMATED)=				40
b.	CHASSIS Ixx=.5*M*R^2 =SLUG*FT^2=FT*LB*SEC^2=				1523
	=IN*LBS*SEC**2=				18277
E. TRACTOR PITCH MOMENT OF INERTIA (Iyy)					
	SIMPLE CHASS. MODEL USES LUMPED MASSES AT FRT & REAR				
a.	CHASSIS FRT PORTION Iyy=M*R^2=				20513
b.	CHASSIS REAR PORTION Iyy=M*R^2=				48315
c.	COMBINED CHASSIS Iyy=				68828
F. TRACTOR YAW MOMENT OF INERTIA (Izz)					
a.	SPRUNG CHASSIS(MAKE SAME AS Iyy)=				68828
	ELEMENT	MASS		RAD(INCH)	IN#SEC^2
b.	F. AX/SUSP		1400	45	7337
c.	CG TRANS		1400	47	8083
d.	R. AX/SUSP		2300	40	9524
e.	CG TRANS		2300	73	31519
f.	COMBINED CHASSIS Izz=				125291

Table C4 - Vehicle Type 4

G. 28 FT. VAN SEMI-TRAILER

a.	Rr AXLE CL TO KINGPIN LENGTH=WHEELBASE=					270
b.	LENGTH(INCHES)=					336
c.	HEIGHT=					108
d.	WIDTH=					102
e.	Rr AXLE AHEAD OF DOOR=					30
f.	LAND GEAR CG AHEAD OF Rr DOOR=					264
g.	LAND GEAR CG BELOW FLOOR=					18
h.	SUSP CG AHEAD OF Rr DOOR=					40
j.	SUSP CG BELOW FLOOR=					10
k.	ELEMENT	SQ.FT.	DENSITY	WT(LBS)		
l.	TOP	238	2.0	476		
m.	FLOOR	238	11.0	2618		
n.	L. SIDE	252	3.5	882		
o.	R. SIDE	252	3.5	882		
p.	FRT END	77	4.0	306		
q.	REAR END	77	6.0	459	BOX WT=	5623
r.	LAND GEAR			250		
s.	SUSP			400		
t.	Rr. AXLE			1800		
u.	TOTAL SPRUNG WT (LBS)=					6273
v.	BOX FLOOR ABOVE GRD(IN.)=					45
w.	PITCH & ROLL CG ABOVE THE GRD (IN.)=					74
x.	PITCH CG AHEAD OF REAR DOOR=					160
y.	WT. ON KINGPIN(LBS)=					3337
z.	WT. ON REAR SUSP=					2936
aa.	WT ON GRD AT Rr AXLE=					4736
ab.	TOTAL TRAILER WT=					8073
ac.	YAW CG AHEAD OF REAR DOOR=					142

H. SEMI-TRAILER ROLL MOMENTS OF INERTIA (Ixx)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	38.3	12.0	1456
b.	TRANSLATE	1.0	9.5	4.5	12.0	510
c.	REAR END	0.3	14.3	38.3	12.0	2185
d.	TRANSLATE	1.0	14.3	4.5	12.0	766
e.	L. SIDE	0.3	27.4	20.3	12.0	2219
f.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
g.	CG TRANS	1.0	27.4	4.5	12.0	1471
h.	R. SIDE	0.3	27.4	20.3	12.0	2219
j.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
k.	CG TRANS	1.0	27.4	4.5	12.0	1471
l.	TOP	0.3	14.8	18.1	12.0	1068
m.	CG TRANS	1.0	14.8	43.8	12.0	7764
n.	FLOOR	0.3	81.3	18.1	12.0	5874
p.	CG TRANS	1.0	81.3	5.7	12.0	5546
q.	LAND GEAR	1.0	7.8	6.3	12.0	582
r.	CG TRANS	1.0	7.8	15.1	12.0	1406
s.	SUSP	1.0	12.4	6.3	12.0	932
t.	CG TRANS	1.0	12.4	10.4	12.0	1543
u.	TOTAL TRAILER Ixx ABOUT ROLL CG("#SEC^2)=					48887

Table C4 - Vehicle Type 4 (continued)

J. SEMI-TRAILER PITCH MOMENT OF INERTIA (Iyy)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	20.3	12.0	770
b.	CG TRANS	1.0	9.5	220.6	12.0	25162
c.	REAR END	0.3	14.3	20.3	12.0	1155
d.	CG TRANS	1.0	14.3	181.3	12.0	31011
e.	L. SIDE	0.3	27.4	216.3	12.0	23693
f.	CG TRANS	1.0	27.4	5.0	12.0	1634
g.	R. SIDE	0.3	27.4	216.3	12.0	23693
h.	CG TRANS	1.0	27.4	5.0	12.0	1634
j.	TOP	0.3	14.8	214.1	12.0	12658
k.	CG TRANS	1.0	14.8	44.3	12.0	7852
l.	FLOOR	0.3	81.3	214.1	12.0	69617
m.	CG TRANS	1.0	81.3	6.2	12.0	6028
n.	LAND GEAR	1.0	7.8	0.0	12.0	0
p.	CG TRANS	1.0	7.8	90.8	12.0	8462
q.	SUSP	1.0	12.4	6.3	12.0	932
r.	CG TRANS	1.0	12.4	109.6	12.0	16343
s.	TOTAL TRAILER Iyy ABOUT THE PITCH CG("#SEC^2)=					230643

K. SEMI-TRAILER YAW MOMENT OF INERTIA (Izz)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	18.1	12.0	687
b.	TRANSLATE	1.0	9.5	262.5	12.0	29931
c.	REAR END	0.3	14.3	18.1	12.0	1030
d.	TRANSLATE	1.0	14.3	139.2	12.0	23814
e.	L. SIDE	0.3	27.4	196.0	12.0	21475
f.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
g.	CG TRANS	1.0	27.4	4.8	12.0	1592
h.	R. SIDE	0.3	27.4	196.0	12.0	21475
j.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
k.	CG TRANS	1.0	27.4	4.8	12.0	1592
l.	TOP	0.3	14.8	214.1	12.0	12658
m.	CG TRANS	1.0	14.8	4.8	12.0	859
n.	FLOOR	0.3	81.3	214.1	12.0	69617
p.	CG TRANS	1.0	81.3	4.8	12.0	4726
q.	LAND GEAR	1.0	7.8	6.3	12.0	582
r.	CG TRANS	1.0	7.8	104.1	12.0	9695
s.	SUSP	1.0	12.4	6.3	12.0	932
t.	CG TRANS	1.0	12.4	71.7	12.0	10684
u.	Rr AXLE	1.0	55.9	12.3	12.0	8217
v.	CG TRANS	1.0	55.9	86.5	12.0	58007
w.	TOTAL TRAILER Izz ABOUT YAW CG("#SEC^2)=					289447

Table C4 - Vehicle Type 4 (continued)

L. 28 FT TRAILER #2 WITH DOLLY

a.	DOLLY SUSP CL TO PINTLE HOOK(IN)=	72.0
b.	DOLLY KINGPIN AHEAD OF SUSP(IN)=	0.0
c.	WHEELBASE(IN)=	270
d.	BOX LENGTH(INCHES)=	336
e.	BOX HEIGHT=	108
f.	BOX WIDTH=	102
g.	BOX CG AHEAD OF REAR DOOR(FROM SEMI-TRAILER)(IN)=	163
h.	BOX CG ABOVE FLOOR(FROM SEMI-TRAILER)(IN)=	33
j.	Rr AXLE AHEAD OF DOOR=	30
k.	LAND GEAR CG AHEAD OF Rr DOOR=	264
l.	LAND GEAR CG BELOW FLOOR=	18
m.	DOLLY FRAME AND SUSP CG AHEAD OF Rr DOOR(IN)=	310
n.	DOLLY FRAME AND SUSP CG BELOW THE FLOOR(IN)=	15
o.	RrSUSP CG AHEAD OF Rr DOOR=	40
p.	RrSUSP CG BELOW FLOOR=	10
q.	BOX WT (FROM SEMITRAILER)(LBS)=	5623
r.	LAND GEAR WT=	250
s.	DOLLY FRAME AND SUSP WT=	1000
t.	Rr. SUSP WT=	450
u.	Fr. AXLE WT=	1700
w.	Rr. AXLE WT=	1700
x.	TOTAL SPRUNG WT (LBS)=	7323
y.	BOX FLOOR ABOVE GRD(IN.)=	45
z.	PITCH & ROLL CG ABOVE THE GRD (IN.)=	67
aa.	PITCH CG AHEAD OF REAR DOOR=	179
ab	WT. ON Frt SUSP(LBS)=	4377
ac.	WT. ON REAR SUSP=	2946
ad.	WT ON GRD AT Fr AXLE=	6077
ae.	WT ON GRD AT Rr AXLE=	4646
af.	TOTAL TRAILER WT=	10723
ag.	YAW CG AHEAD OF REAR DOOR=	175

Table C4 - Vehicle Type 4 (continued)

M. TRAILER #2 ROLL MOMENT OF INERTIA (Ixx)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	38.3	12.0	1456
b.	TRANSLATE	1.0	9.5	6.9	12.0	791
c.	REAR END	0.3	14.3	38.3	12.0	2185
d.	TRANSLATE	1.0	14.3	6.9	12.0	1187
e.	L. SIDE	0.3	27.4	20.3	12.0	2219
f.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
g.	CG TRANS	1.0	27.4	6.9	12.0	2281
h.	R. SIDE	0.3	27.4	20.3	12.0	2219
j.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
k.	CG TRANS	1.0	27.4	6.9	12.0	2281
l.	TOP	0.3	14.8	18.1	12.0	1068
m.	CG TRANS	1.0	14.8	50.9	12.0	9028
n.	FLOOR	0.3	81.3	18.1	12.0	5874
p.	CG TRANS	1.0	81.3	3.5	12.0	3397
q.	LAND GEAR	1.0	7.8	6.3	12.0	582
r.	CG TRANS	1.0	7.8	11.3	12.0	1056
s.	Rr SUSP	1.0	12.4	6.3	12.0	932
t.	CG TRANS	1.0	12.4	7.3	12.0	1086
u.	DOLLY FRAM	1.0	31.1	6.3	12.0	2329
v.	CG TRANS	1.0	31.1	9.7	12.0	3618
w.	TOTAL TRAILER Ixx ABOUT ROLL CG("#SEC^2)=					55462

N.TRAILER #2 PITCH MOMENT OF INERTIA (Iyy)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	20.3	12.0	770
b.	CG TRANS	1.0	9.5	220.6	12.0	25162
c.	REAR END	0.3	14.3	20.3	12.0	1155
d.	CG TRANS	1.0	14.3	181.3	12.0	31011
e.	L. SIDE	0.3	27.4	216.3	12.0	23693
f.	CG TRANS	1.0	27.4	5.0	12.0	1634
g.	R. SIDE	0.3	27.4	216.3	12.0	23693
h.	CG TRANS	1.0	27.4	5.0	12.0	1634
j.	TOP	0.3	14.8	214.1	12.0	12658
k.	CG TRANS	1.0	14.8	44.3	12.0	7852
l.	FLOOR	0.3	81.3	214.1	12.0	69617
m.	CG TRANS	1.0	81.3	6.2	12.0	6028
n.	LAND GEAR	1.0	7.8	0.0	12.0	0
p.	CG TRANS	1.0	7.8	90.8	12.0	8462
q.	SUSP	1.0	12.4	6.3	12.0	932
r.	CG TRANS	1.0	12.4	109.6	12.0	16343
s.	DOLLY FRAM	1.0	31.1	20.0	12.0	7453
t.	CG TRANS	1.0	31.1	128.4	12.0	47833
u.	TOTAL TRAILER Iyy ABOUT THE PITCH CG("#SEC^2)=					285929

Table C4 - Vehicle Type 4 (continued)

O. TRAILER #2 YAW MOMENT OF INERTIA (Izz)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	9.5	18.1	12.0	687
b.	TRANSLATE	1.0	9.5	262.5	12.0	29931
c.	REAR END	0.3	14.3	18.1	12.0	1030
d.	TRANSLATE	1.0	14.3	139.2	12.0	23814
e.	L. SIDE	0.3	27.4	196.0	12.0	21475
f.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
g.	CG TRANS	1.0	27.4	4.8	12.0	1592
h.	R. SIDE	0.3	27.4	196.0	12.0	21475
j.	C.L. TRANS	1.0	27.4	18.1	12.0	5937
k.	CG TRANS	1.0	27.4	4.8	12.0	1592
l.	TOP	0.3	14.8	214.1	12.0	12658
m.	CG TRANS	1.0	14.8	4.8	12.0	859
n.	FLOOR	0.3	81.3	214.1	12.0	69617
p.	CG TRANS	1.0	81.3	4.8	12.0	4726
q.	LAND GEAR	1.0	7.8	6.3	12.0	582
r.	CG TRANS	1.0	7.8	104.1	12.0	9695
s.	SUSP	1.0	12.4	6.3	12.0	932
t.	CG TRANS	1.0	12.4	71.7	12.0	10684
u.	Rr AXLE	1.0	55.9	12.3	12.0	8217
v.	CG TRANS	1.0	55.9	86.5	12.0	58007
w.	DOLLY FRAM	1.0	31.1	20.0	12.0	7453
x.	CG TRANS	1.0	31.1	118.6	12.0	44214
y.	FR AXLE	1.0	52.8	12.3	12.0	7761
z.	CG TRANS	1.0	52.8	101.2	12.0	64103
aa.	TOTAL TRAILER Izz ABOUT YAW CG("#SEC^2)=					412979

Table C4 - Vehicle Type 4 (continued)

P. TRAILER #1 PAYLOAD CHARACTERISTICS

a.	TRACTOR Frt AXLE CAP (LBS)=	10500
b.	TRACTOR Rr AXLE CAP (LBS)=	20000
c.	TOTAL TRACTOR CAP (LBS)=	30500
d.	TRACTOR WT=	12528
e.	KINGPIN CAP=TRACTOR CAP (LBS)=	17972
f.	EMPTY TRAILER KINGPIN WT=	3337
g.	ALLOW PAYLOAD ON KINGPIN=	14635
h.	TRAILER REAR AXLE CAP=	20000
j.	ALLOW. PAYLOAD ON REAR SUSP=	15264
k.	FULL LOAD CAP=	29899
l.	95% LOAD CAP==PAYLOAD=	28404
m.	% TOTAL VEH. CAP=	97.0
n.	REQUIRED PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	132.2
70% PAYLOAD IN BOTTOM HALF OF BOX		
o.	LOAD IN BOTTOM HALF(LBS)=	19883
p.	LOAD IN TOP HALF(LBS)=	8521
q.	CG HEIGHT ABOVE GRD (IN.)=	88.2
LENGTH OF UNIF. LOAD TO FIT CGX REQUIREMENT		
r.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	138
s.	LENGTH OF UNIF. LOAD TO FIT CGX REQUIRMENT=	324
t.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	57117
u.	TRANSLATE CG=	13504
v.	TOP HALF Ixx=	24479
w.	TRANSLATE CG=	31510
x.	TOTAL ROLL Ixx(IN-LB-SEC2)=	126610
y.	BOTTOM HALF Iyy=	463559
z.	TRANSLATE CG=	13504
aa.	TOP HALF Iyy=	198668
ab.	TRANSLATE CG=	31510
ac.	TOTAL PITCH Iyy (IN-LB-SEC2)=	707242
ad.	TOTAL YAW Izz OF PAYLOAD	708097
ae.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	20.4
af.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	14.1
ag.	SELECTED KINGPIN POSITION=	16.0

Table C4 - Vehicle Type 4 (continued)

Q.TRAILER #1 HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT TO HALF AND LENGTH AND HEIGHT TO .707

a.	PAYLOAD(LBS)=	14202
b.	PAYLOAD ON KINGPIN=	8537
c.	PAYLOAD ON REAR SUSP=	7256
d.	% TOTAL VEH. CAP=	68.9
e.	PAYLOAD CG AHEAD OF Rr AXLEw FORW EDGE HELD(IN.)=	179.7

70% PAYLOAD IN BOTTOM HALF OF LOAD

f.	LOAD IN BOTTOM HALF(LBS)=	9941
g.	LOAD IN TOP HALF(LBS)=	4261
h.	CG HEIGHT ABOVE GRD (IN.)=	75.5
j.	LENGTH OF UNIF. LOAD (IN)=	229
k.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	25431
l.	TRANSLATE CG=	3375
m.	TOP HALF Ixx=	10899
n.	TRANSLATE CG=	7875
o.	TOTAL ROLL Ixx(IN-LB-SEC2)=	47581
p.	BOTTOM HALF Iyy=	115855
q.	TRANSLATE CG=	3375
r.	TOP HALF Iyy=	49652
s.	TRANSLATE CG=	7875
t.	TOTAL PITCH Iyy (IN-LB-SEC2)=	176757
u.	TOTAL YAW Izz OF PAYLOAD	192905
v.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	81.1
w.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	-91.8
x.	SELECTED KINGPIN POSITION=	16.0

Table C4 - Vehicle Type 4 (continued)

R. TRAILER #2 PAYLOAD CHARACTERISTICS

a.	Fr AXLE CAP(LBS)=	20000
b.	DOLLY WT ON PINTLE HOOK=	139
c.	ALLOWABLE PINTLE HOOK STATIC VERT. LOAD(LBS)=	139
d.	DOLLY WT=	2700
e.	ALLOW. DOLLY KINGPIN LOAD(LBS)=	17439
f.	TRAILER REAR AXLE CAP=	20000
g.	BASE TRAILER KINGPIN LOAD=	3012
h.	BASE TRAILER Rr SUSP LOAD=	2946
j.	ALLOW. PAYLOAD ON KINGPIN=	14427
k.	ALLOW. PAYLOAD ON REAR SUSP=	15354
l.	FULL LOAD CAP=	29780
m.	95% LOAD CAP==PAYLOAD=	28291
n.	% TOTAL VEH. CAP=	97.2
o.	REQUIRED PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	130.8
70% PAYLOAD IN BOTTOM HALF OF BOX		
p.	LOAD IN BOTTOM HALF(LBS)=	19804
q.	LOAD IN TOP HALF(LBS)=	8487
r.	CG HEIGHT ABOVE GRD (IN.)=	88.2
LENGTH OF UNIF. LOAD TO FIT CGX REQUIREMENT		
s.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	138
t.	LENGTH OF UNIF. LOAD TO FIT CGX REQUIRMENT=	322
u.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	56890
v.	TRANSLATE CG=	13451
w.	TOP HALF Ixx=	24381
x.	TRANSLATE CG=	31385
y.	TOTAL ROLL Ixx(IN-LB-SEC2)=	126107
z.	BOTTOM HALF Iyy=	454186
aa.	TRANSLATE CG=	13451
ab.	TOP HALF Iyy=	194651
ac.	TRANSLATE CG=	31385
ad.	TOTAL PITCH Iyy (IN-LB-SEC2)=	693672
ae.	TOTAL YAW Izz OF PAYLOAD	694525

Table C4 - Vehicle Type 4 (continued)

S.TRAILER #2 HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT TO HALF AND LENGTH AND HEIGHT TO .707

a.	PAYLOAD(LBS)=	14146
b.	PAYLOAD ON KINGPIN=	6853
c.	PAYLOAD ON REAR SUSP=	7293
d.	% TOTAL VEH. CAP=	62.0
e.	PAYLOAD CG AHEAD OF Rr AXLEw FORW EDGE HELD(IN.)=	177.9
70% PAYLOAD IN BOTTOM HALF OF LOAD		
f.	LOAD IN BOTTOM HALF(LBS)=	9902
g.	LOAD IN TOP HALF(LBS)=	4244
h.	CG HEIGHT ABOVE GRD (IN.)=	75.5
j.	LENGTH OF UNIF. LOAD (IN)=	227
k.	BOTTOM HALF Ixx=(IN-LB-SEC2)=	25331
l.	TRANSLATE CG=	3362
m.	TOP HALF Ixx=	10856
n.	TRANSLATE CG=	7844
o.	TOTAL ROLL Ixx(IN-LB-SEC2)=	47392
p.	BOTTOM HALF Iyy=	113512
q.	TRANSLATE CG=	3362
r.	TOP HALF Iyy=	48648
s.	TRANSLATE CG=	7844
t.	TOTAL PITCH Iyy (IN-LB-SEC2)=	173366
u.	TOTAL YAW Izz OF PAYLOAD	189453

Table C4 - Vehicle Type 4 (continued)

VEHICLE #5-6X4 TRACTOR WITH A TANDEM 48FT TRAILER.
THIS VEHICLE WAS CHOSEN TO REPRESENT A TYPICAL HIGHWAY COMBINATION.

A. 1994 FREIGHTLINER FLD120 WITH WHEELBASE (INCHES)=				210
B. BARE CHASSIS CHARACTERISTICS (DIESEL HANDBOOK)				
a.	FRT WT (LBS)=			7990
b.	FRT DRIVER , SLEEPER CAB, FIFTH WHL , & FUEL PACKAGE WT=			950
c.	REAR WT=			6140
d.	REAR DRIVER, SLEEPER CAB, FIFTH WHL, &FUEL PACKAGE WT=			1000
e.	TOTAL WT=			16080
f.	FRT UNSPRUNG WT(ESTIMATED)=			1200
g.	REAR UNSPRUNG WT(ESTIMATED)=			4900
h.	TOTAL CHASSIS SPRUNG MASS(LBM)=			9980
C. SPRUNG MASS POSITIONS (CG,& ETC)				
a.	FRTCURB LOAD (LBS)=			7740
b.	REAR CURB LOAD=			2240
c.	PITCH CG AHEAD OF REAR AXLE(INCHES)=			163
d.	CHASSIS PITCH & ROLL CG ABOVE R'WAY (EST)=			40
e.	COMBINED CG ABOVE ROADWAY(EST)=			41
f.	YAW CG AHEAD OF THE REAR AXLE=			117
D. TRACTOR ROLL MOMENTS OF INERTIA (Ixx)				
a.	CHASSIS RADIUS OF GYRATION (INCHES)(ESTIMATED)=			40
b.	CHASSIS Ixx=.5*M*R^2 =SLUG*FT^2=FT*LB*SEC^2=			1722
	=IN*LBS*SEC**2=			20663
E. TRACTOR PITCH MOMENT OF INERTIA (Iyy)				
SIMPLE CHASS. MODEL USES LUMPED MASSES AT FRT & REAR				
a.	CHASSIS FRT PORTION Iyy=M*R^2=			44502
b.	CHASSIS REAR PORTION Iyy=M*R^2=			153770
c.	COMBINED CHASSIS Iyy=			198271
F. TRACTOR YAW MOMENT OF INERTIA (Izz)				
a.	SPRUNG CHASSIS(MAKE SAME AS Iyy)=			198271
	ELEMENT	MASS	RAD(INCH)	IN#SEC^2
b.	F. AX/SUSP	1200	45	6289
c.	CG TRANS	1200	93	27003
d.	R. AX/SUSP	4900	40	20290
e.	CG TRANS	4900	117	172862
f.	COMBINED CHASSIS Izz=			424715

Table C5 - Vehicle Type 5

G. 48 FT. VAN SEMI-TRAILER

a.	Rr AXLE CL TO KINGPIN LENGTH=WHEELBASE=						488
b.	LENGTH(INCHES)=						576
c.	HEIGHT=						108
d.	WIDTH=						102
e.	Rr AXLE AHEAD OF DOOR=						52
f.	LAND GEAR CG AHEAD OF Rr DOOR=						511
g.	LAND GEAR CG BELOW FLOOR=						18
h.	SUSP CG AHEAD OF Rr DOOR=						62
j.	SUSP CG BELOW FLOOR=						14
k.	ELEMENT	SQ.FT.	DENSITY	WT(LBS)			
l.	TOP	408	2.5	1020			
m.	FLOOR	408	11.5	4692			
n.	L. SIDE	432	3.5	1512			
o.	R. SIDE	432	3.5	1512			
p.	FRT END	77	6.0	459			
q.	REAR END	77	6.0	459	BOX WT=		9654
r.	LAND GEAR			350			
s.	SUSP			750			
t.	TWO Rr. AXLES			3600			
u.	TOTAL SPRUNG WT (LBS)=						10754
v.	BOX FLOOR ABOVE GRD(IN.)=						45
w.	PITCH & ROLL CG ABOVE THE GRD (IN.)=						73
x.	PITCH CG AHEAD OF REAR DOOR=						279
y.	WT. ON KINGPIN(LBS)=						5566
z.	WT. ON REAR SUSP=						5188
aa.	WT ON GRD AT Rr AXLE=						8788
ab.	TOTAL TRAILER WT=						14354
ac.	YAW CG AHEAD OF REAR DOOR=						241

Table C5 - Vehicle Type 5 (continued)

H. SEMI-TRAILER ROLL MOMENTS OF INERTIA (Ixx)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	14.3	38.3	12.0	2185
b.	TRANSLATE	1.0	14.3	4.5	12.0	774
c.	REAR END	0.3	14.3	38.3	12.0	2185
d.	TRANSLATE	1.0	14.3	4.5	12.0	774
e.	L. SIDE	0.3	47.0	20.3	12.0	3803
f.	C.L. TRANS	1.0	47.0	18.1	12.0	10178
g.	CG TRANS	1.0	47.0	4.5	12.0	2549
h.	R. SIDE	0.3	47.0	20.3	12.0	3803
j.	C.L. TRANS	1.0	47.0	18.1	12.0	10178
k.	CG TRANS	1.0	47.0	4.5	12.0	2549
l.	TOP	0.3	31.7	18.1	12.0	2289
m.	CG TRANS	1.0	31.7	43.9	12.0	16694
n.	FLOOR	0.3	145.7	18.1	12.0	10528
p.	CG TRANS	1.0	145.7	5.6	12.0	9846
q.	LAND GEAR	1.0	10.9	6.3	12.0	815
r.	CG TRANS	1.0	10.9	15.0	12.0	1957
s.	SUSP	1.0	23.3	6.3	12.0	1747
t.	CG TRANS	1.0	23.3	12.5	12.0	3502
u.	TOTAL TRAILER Ixx ABOUT ROLL CG("#SEC^2)=					86355

J. SEMI-TRAILER PITCH MOMENT OF INERTIA (Iyy)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	14.3	20.3	12.0	1155
b.	CG TRANS	1.0	14.3	615.0	12.0	105207
c.	REAR END	0.3	14.3	20.3	12.0	1155
d.	CG TRANS	1.0	14.3	547.0	12.0	93569
e.	L. SIDE	0.3	47.0	596.3	12.0	111991
f.	CG TRANS	1.0	47.0	5.0	12.0	2832
g.	R. SIDE	0.3	47.0	596.3	12.0	111991
h.	CG TRANS	1.0	47.0	5.0	12.0	2832
j.	TOP	0.3	31.7	594.1	12.0	75273
k.	CG TRANS	1.0	31.7	44.4	12.0	16885
l.	FLOOR	0.3	145.7	594.1	12.0	346254
m.	CG TRANS	1.0	145.7	6.1	12.0	10724
n.	LAND GEAR	1.0	10.9	0.0	12.0	0
p.	CG TRANS	1.0	10.9	387.2	12.0	50502
q.	SUSP	1.0	23.3	6.3	12.0	1747
r.	CG TRANS	1.0	23.3	341.0	12.0	95320
s.	TOTAL TRAILER Iyy ABOUT THE PITCH CG("#SEC^2)=					1027436

Table C5 - Vehicle Type 5 (continued)

K. SEMI-TRAILER YAW MOMENT OF INERTIA (Izz)

	ELEMENT	S. FACT.	MASS	RAD^2	CONV. F'R	IN*LB*SEC2
a.	FRT END	0.3	14.3	18.1	12.0	1030
b.	TRANSLATE	1.0	14.3	778.3	12.0	133125
c.	REAR END	0.3	14.3	18.1	12.0	1030
d.	TRANSLATE	1.0	14.3	404.1	12.0	69128
e.	L. SIDE	0.3	47.0	576.0	12.0	108188
f.	C.L. TRANS	1.0	47.0	18.1	12.0	10178
g.	CG TRANS	1.0	47.0	-15.2	12.0	8558
h.	R. SIDE	0.3	47.0	576.0	12.0	108188
j.	C.L. TRANS	1.0	47.0	18.1	12.0	10178
k.	CG TRANS	1.0	47.0	15.2	12.0	8558
l.	TOP	0.3	31.7	594.1	12.0	75273
m.	CG TRANS	1.0	31.7	15.2	12.0	5773
n.	FLOOR	0.3	145.7	594.1	12.0	346254
p.	CG TRANS	1.0	145.7	15.2	12.0	26557
q.	LAND GEAR	1.0	10.9	6.3	12.0	815
r.	CG TRANS	1.0	10.9	505.4	12.0	65918
s.	SUSP	1.0	23.3	6.3	12.0	1747
t.	CG TRANS	1.0	23.3	223.1	12.0	62354
u.	Rr AXLE	1.0	111.8	12.3	12.0	16435
v.	CG TRANS	1.0	111.8	248.7	12.0	333629
w.	TOTAL TRAILER Izz ABOUT YAW CG("#SEC^2)=					1392914

L. SEMI-TRAILER PAYLOAD CHARACTERISTICS

a.	TRACTOR Frt AXLE CAP (LBS)=	11000
b.	TRACTOR Rr AXLE CAP (LBS)=	34000
c.	TOTAL TRACTOR CAP (LBS)=	45000
d.	TRACTOR WT=	16080
e.	KINGPIN CAP=TRACTOR CAP (LBS)=	28920
f.	EMPTY TRAILER KINGPIN WT=	5566
g.	ALLOW PAYLOAD ON KINGPIN=	23354
h.	TRAILER REAR AXLE CAP=	34000
j.	ALLOW. PAYLOAD ON REAR SUSP=	25212
k.	FULL LOAD CAP=	48566
l.	95% LOAD CAP==PAYLOAD=	46138
m.	% TOTAL VEH. CAP=	96.9
n.	REQUIRED PAYLOAD CG AHEAD OF Rr AXLE(IN.)=	234.7
UNIFORM PAYLOAD T0 96% OF VAN HEIGHT		
o.	CG HEIGHT ABOVE GRD (IN.)=	96.8
p.	CENTERLINE OF BOX AHEAD OF Rr AXLE(IN)=	236
q.	LENGTH OF UNIF. LOAD TO FIT CGX REQUIRMENT=	573
r.	ROLL Ixx ON PRINC AXIS(IN-LB-SEC2)=	210485
s.	PITCH Iyy ON PRINC AXIS(IN-LB-SEC2)=	3377687
t.	YAW Izz ON PRINC AXIS(IN-LB-SEC2)=	3374249
u.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	15.7
v.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	4.7
w.	SELECTED KINGPIN POSITION=	6.0

Table C5 - Vehicle Type 5 (continued)

M. SEMI-TRAILER HALF PAYLOAD CHARACTERISTICS

BASED ON REDUCING WEIGHT AND HEIGHT TO HALF

a.	PAYLOAD(LBS)=	23069
b.	PAYLOAD ON KINGPIN=	13737
c.	PAYLOAD ON REAR SUSP=	11976
d.	% TOTAL VEH. CAP=	67.7
e.	PAYLOAD CG AHEAD OF Rr AXLEw FORW EDGE HELD(IN.)=	234.7
UNIFORM PAYLOAD T0 48% OF VAN HEIGHT		
f.	CG HEIGHT ABOVE GRD (IN.)=	70.9
g.	LENGTH OF UNIF. LOAD (IN)=	573
h.	ROLL Ixx ON PRINC AXIS(IN-LB-SEC2)=	65132
j.	PITCH Iyy ON PRINC AXIS(IN-LB-SEC2)=	1648733
k.	YAW Izz ON PRINC AXIS(IN-LB-SEC2)=	1687125
l.	MAX. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	59.8
m.	MIN. FORW. KINGPIN POS AHEAD OF TRACTOR REAR AXLE(IN)=	-200.6
n.	SELECTED KINGPIN POSITION=	6.0

Table C5 - Vehicle Type 5 (continued)

MISC. PARAMETERS FOR UMTRI PHASE4 MODEL

	VEH 1	VEH 2	VEH 3	VEH 4	VEH 5
FIFTH WHEEL HEIGHT(IN)=	N.A.	N.A.	45	45	45
TR'CT FRAME TORS. STIFF(IN-LB/DEG)=	10000	10000	10000	10000	10000
FRAME TORS. AXIS HT ABOVE GRD(IN)=	38	38	38	38	38
FR SUSP AND AXLE(UNITS/SIDE/AXLE)					
SPRING RATE(LB/IN)=	1200	1250	1200	1200	1200
VISC. DAMPING(LB-SEC/IN)=	5	5	50	50	50
COUL. FRICTION(LB)=	200	400	350	350	350
AXLE Ixx (IN-LB-SEC2)=	3420	4100	3420	3420	3420
ROLL CTR HT(IN ABOVE GRD)=	20	20	20	20	20
ROLL STEER COEFF=	0.1	0.01	0.01	0.01	0.01
AUX.ROLL STIFFNESS(IN-LB/DEG)=	2000	2000	2000	2000	2000
LAT'R'L DIST BETW'N SPRINGS(IN)=	36	36	36	36	36
TRACK WIDTH(IN)=	79.5	79.5	79.5	79.5	79.5
TIRE SPRING RATE(LB/IN)=	4700	6000	4700	4700	4700
TIRE ROLLING RAD(IN)=	20	22.5	20	20	20
POLAR INERTIA(IN-LB-SEC2/WHEEL)=	140	254	140	140	140
Rr SUSP AND AXLE(UNITS/SIDE/AXLE)					
SUSP KEY=	0	1	0	0	1
TANDEM AX. SEPARAT'N SP'G(IN)=	N.A.	52	N.A.	N.A.	52
% STATIC LOAD ON FORW.AXLE=	N.A.	50	N.A.	N.A.	50
% BRAKE TRQ LOAD TRANSFER=	N.A.	-50	N.A.	N.A.	0
SUSP SPR'G RATE(LB/IN)=	5500	5000	1000	1000	1000
VISC. DAMPING(LB-SEC/IN)=	5	5	100	100	100
COUL. FRICTION(LB)=	800	600	50	50	50
AXLE Ixx (IN-LB-SEC2)=	6000	6000	6000	6000	6000
ROLL CTR HT(IN ABOVE GRD)=	29.6	29.6	29.6	29.6	29.6
ROLL STEER COEFF=	0.01	0.01	0.01	0.01	0.01
AUX.ROLL STIFFNESS(IN-LB/DEG)=	5000	5000	5000	5000	5000
LAT'R'L DIST BETW'N SPRINGS(IN)=	40.75	40.75	38	38	38
TRACK WIDTH(IN)=	72	72	72	72	72
DUAL TIRE SEPARATION(IN)=	12.8	12.8	12.8	12.8	12.8
TIRE SPRING RATE(LB/IN/TIRE)=	4700	5700	4700	4700	4700
TIRE ROLLING RAD(IN)=	20	20	20	20	20
POLAR INERTIA(IN-LB-SEC2/WHEEL)=	145	145	145	145	145

Table C6 - Miscellaneous Parameters

SEMI-TRAILER PARAMETERS					
SUSP KEY=	N.A.	N.A.	0	0	1
TANDEM AX. SEPARAT'N SP'G(IN)=	N.A.	N.A.	N.A.	N.A.	50
% STATIC LOAD ON FORW.AXLE=	N.A.	N.A.	N.A.	N.A.	50
% BRAKE TRQ LOAD TRANSFER=	N.A.	N.A.	N.A.	N.A.	-50
SUSP SPR'G RATE(LB/IN)=	N.A.	N.A.	5000	5000	5000
VISC. DAMPING(LB-SEC/IN)=	N.A.	N.A.	5	5	5
COUL. FRICTION(LB)=	N.A.	N.A.	500	500	500
AXLE Ixx (IN-LB-SEC2)=	N.A.	N.A.	5500	5500	5500
ROLL CTR HT(IN ABOVE GRD)=	N.A.	N.A.	29.6	29.6	29.6
ROLL STEER COEFF=	N.A.	N.A.	0.01	0.01	0.01
AUX.ROLL STIFFNESS(IN-LB/DEG)=	N.A.	N.A.	5000	5000	5000
LAT'R'L DIST BETW'N SPRINGS(IN)=	N.A.	N.A.	38	38	38
TRACK WIDTH(IN)=	N.A.	N.A.	71.25	71.25	71.25
DUAL TIRE SEPARATION(IN)=	N.A.	N.A.	12.8	12.8	12.8
TIRE SPRING RATE(LB/IN/TIRE)=	N.A.	N.A.	5700	5700	5700
TIRE ROLLING RAD(IN)=	N.A.	N.A.	20.2	20.2	20.2
POLAR INERTIA(IN-LB-SEC2/WHEEL)=	N.A.	N.A.	132	132	132

Table C6 - Miscellaneous Parameters (continued)

TRAILER #2 PARAMETERS					
DOLLY KEY=	N.A.	N.A.	N.A.	1	N.A.
DIST -PINTLE HOOK TO SUSP(IN)=	N.A.	N.A.	N.A.	72	N.A.
KINGPIN AHEAD OF SUSP(IN)=	N.A.	N.A.	N.A.	0	N.A.
K'PIN TURNTABLE HT ABOVE GRD(IN)=	N.A.	N.A.	N.A.	45	N.A.
FR SUSP AND AXLE(UNITS/SIDE/AXLE)					
SUSP KEY=	N.A.	N.A.	N.A.	0	N.A.
TANDEM AX. SEPARAT'N SP'G(IN)=	N.A.	N.A.	N.A.	N.A.	N.A.
% STATIC LOAD ON FORW.AXLE=	N.A.	N.A.	N.A.	N.A.	N.A.
% BRAKE TRQ LOAD TRANSFER=	N.A.	N.A.	N.A.	N.A.	N.A.
SUSP SPR'G RATE(LB/IN)=	N.A.	N.A.	N.A.	5000	N.A.
VISC. DAMPING(LB-SEC/IN)=	N.A.	N.A.	N.A.	5	N.A.
COUL. FRICTION(LB)=	N.A.	N.A.	N.A.	500	N.A.
AXLE Ixx (IN-LB-SEC2)=	N.A.	N.A.	N.A.	5500	N.A.
ROLL CTR HT(IN ABOVE GRD)=	N.A.	N.A.	N.A.	29.6	N.A.
ROLL STEER COEFF=	N.A.	N.A.	N.A.	0.01	N.A.
AUX.ROLL STIFFNESS(IN-LB/DEG)=	N.A.	N.A.	N.A.	5000	N.A.
LAT'R'L DIST BETW'N SPRINGS(IN)=	N.A.	N.A.	N.A.	38	N.A.
TRACK WIDTH(IN)=	N.A.	N.A.	N.A.	71.25	N.A.
DUAL TIRE SEPARATION(IN)=	N.A.	N.A.	N.A.	12.8	N.A.
TIRE SPRING RATE(LB/IN/TIRE)=	N.A.	N.A.	N.A.	5700	N.A.
TIRE ROLLING RAD(IN)=	N.A.	N.A.	N.A.	20.2	N.A.
POLAR INERTIA(IN-LB-SEC2/WHEEL)=	N.A.	N.A.	N.A.	132	N.A.
Rr SUSP AND AXLE(UNITS/SIDE/AXLE)					
SUSP KEY=	N.A.	N.A.	N.A.	0	N.A.
TANDEM AX. SEPARAT'N SP'G(IN)=	N.A.	N.A.	N.A.	N.A.	N.A.
% STATIC LOAD ON FORW.AXLE=	N.A.	N.A.	N.A.	N.A.	N.A.
% BRAKE TRQ LOAD TRANSFER=	N.A.	N.A.	N.A.	N.A.	N.A.
SUSP SPR'G RATE(LB/IN)=	N.A.	N.A.	N.A.	5000	N.A.
VISC. DAMPING(LB-SEC/IN)=	N.A.	N.A.	N.A.	5	N.A.
COUL. FRICTION(LB)=	N.A.	N.A.	N.A.	500	N.A.
AXLE Ixx (IN-LB-SEC2)=	N.A.	N.A.	N.A.	5500	N.A.
ROLL CTR HT(IN ABOVE GRD)=	N.A.	N.A.	N.A.	29.6	N.A.
ROLL STEER COEFF=	N.A.	N.A.	N.A.	0.01	N.A.
AUX.ROLL STIFFNESS(IN-LB/DEG)=	N.A.	N.A.	N.A.	5000	N.A.
LAT'R'L DIST BETW'N SPRINGS(IN)=	N.A.	N.A.	N.A.	38	N.A.
TRACK WIDTH(IN)=	N.A.	N.A.	N.A.	71.25	N.A.
DUAL TIRE SEPARATION(IN)=	N.A.	N.A.	N.A.	12.8	N.A.
TIRE SPRING RATE(LB/IN/TIRE)=	N.A.	N.A.	N.A.	5700	N.A.
TIRE ROLLING RAD(IN)=	N.A.	N.A.	N.A.	20.2	N.A.
POLAR INERTIA(IN-LB-SEC2/WHEEL)=	N.A.	N.A.	N.A.	132	N.A.

Table C6 - Miscellaneous Parameters (continued)

Brake Command Tables

Table D1 Assisted braking function applied to all brakes, driver does not react to warning. Strategy 1 - Bring pressure to crack pressure (crack = 5.0 psi) (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	crack	crack	crack
0.5	crack	crack	crack
0.65	crack	crack	crack
1.5	crack	crack	crack
1.65	full_psi	full_psi	full_psi

Table D2 Assisted braking function applied to all brakes, driver does not react to warning. Strategy 2 - Bring pressure to 20 psi (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	20.0	20.0	20.0
0.5	20.0	20.0	20.0
0.65	20.0	20.0	20.0
1.5	20.0	20.0	20.0
1.65	full_psi	full_psi	full_psi

Table D3 Assisted braking function applied to all brakes, driver does not react to warning. Strategy 3 - Ramp pressure up at 75 psi/sec to 100psi (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	11.25	11.25	11.25
0.5	37.5	37.5	37.5
1.333	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D4 Assisted braking function applied to all brakes, driver does not react to warning. Strategy 4 - Ramp pressure up at 150 psi/sec to 100psi (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	22.5	22.5	22.5
0.5	75.0	75.0	75.0
0.667	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D5 Assisted braking function applied to all brakes, driver does not react to warning. Strategy 5 - Bring pressure to 100psi (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	full_psi	full_psi	full_psi
0.5	full_psi	full_psi	full_psi
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D6 Baseline - Driver is not warned and brakes are not applied automatically (See Figure D1)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D7 Assisted braking function applied to all brakes, driver reacts to warning
Strategy 1 - Warn the driver and bring pressure to crack pressure (crack = 5.0 psi)
(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	crack	crack	crack
0.5	crack	crack	crack
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D8 Assisted braking function applied to all brakes, driver reacts to warning
Strategy 2 - Warn the driver and bring pressure to 20 psi
(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	20.0	20.0	20.0
0.5	20.0	20.0	20.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D9 Assisted braking function applied to all brakes, driver reacts to warning
Strategy 3 - Warn the driver and ramp pressure up at 75 psi/sec to 100psi
(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	11.25	11.25	11.25
0.5	37.5	37.5	37.5
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D10 Assisted braking function applied to all brakes, driver reacts to warning Strategy 4 - Warn the driver and ramp pressure up at 150 psi/sec to 100psi

(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	22.5	22.5	22.5
0.5	75.0	75.0	75.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D11 Assisted braking function applied to all brakes, driver reacts to warning Strategy 5 - Warn the driver and bring pressure to 100psi

(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	full_psi	full_psi	full_psi
0.5	full_psi	full_psi	full_psi
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D12 Baseline - Driver is not warned and brakes are not applied automatically

(See Figure D2)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D13 Assisted braking function applied only to tractor brakes, driver does not react to warning. Strategy 1 - Bring pressure to crack pressure (crack = 5.0 psi)

(See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	crack	crack	0.0
0.5	crack	crack	0.0
0.65	crack	crack	0.0
1.5	crack	crack	0.0
1.65	full_psi	full_psi	full_psi

Table D14 Assisted braking function applied only to tractor brakes, driver does not react to warning. Strategy 2 - Bring pressure to 20 psi

(See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	20.0	20.0	0.0
0.5	20.0	20.0	0.0
0.65	20.0	20.0	0.0
1.5	20.0	20.0	0.0
1.65	full_psi	full_psi	full_psi

Table D15 Assisted braking function applied only to tractor brakes, driver does not react to warning. Strategy 3 - Ramp pressure up at 75 psi/sec to 100psi

(See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	11.25	11.25	0.0
0.5	37.5	37.5	0.0
1.33	full_psi	full_psi	0.0
1.5	full_psi	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D16 Assisted braking function applied only to tractor brakes, driver does not react to warning. Strategy 4 - Ramp pressure up at 150 psi/sec to 100psi (See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	22.5	22.5	0.0
0.5	75.0	75.0	0.0
0.667	full_psi	full_psi	0.0
1.5	full_psi	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Table D17 Assisted braking function applied only to tractor brakes, driver does not react to warning. Strategy 5 - Bring pressure to 100psi (See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	full_psi	full_psi	0.0
0.5	full_psi	full_psi	0.0
0.65	full_psi	full_psi	0.0
1.5	full_psi	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Table D18 Baseline - Driver is not warned and brakes are not applied automatically (See Figure D3)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D19 Assisted braking function applied only to tractor brakes, driver reacts to warning. Strategy 1 - Warn the driver and bring pressure to crack pressure (crack = 5.0 psi)

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	crack	crack	0.0
0.5	crack	crack	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D20 Assisted braking function applied only to tractor brakes, driver reacts to warning. Strategy 2 - Warn the driver and bring pressure to 20 psi

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	20.0	20.0	0.0
0.5	20.0	20.0	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D21 Assisted braking function applied only to tractor brakes, driver reacts to warning Strategy 3 - Warn the driver and ramp pressure up at 75 psi/sec to 100psi

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	11.25	11.25	0.0
0.5	37.5	37.5	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D22 Assisted braking function applied only to tractor brakes, driver reacts to warning. Strategy 4 - Warn the driver and ramp pressure up at 150 psi/sec to 100psi

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	22.5	22.5	0.0
0.5	75.0	75.0	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D23 Assisted braking function applied only to tractor brakes, driver reacts to warning. Strategy 5 - Warn the driver and bring pressure to 100psi

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	full_psi	full_psi	0.0
0.5	full_psi	full_psi	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D24 Baseline - Driver is not warned and brakes are not applied automatically

(See Figure D4)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D25 Assisted braking function applied only to drive axles, driver does not react to warning. Strategy 1 - Bring pressure to crack pressure (crack = 5.0 psi)

(See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	crack	0.0
0.5	0.0	crack	0.0
0.65	0.0	crack	0.0
1.5	0.0	crack	0.0
1.65	full_psi	full_psi	full_psi

Table D26 Assisted braking function applied only to drive axles, driver does not react to warning. Strategy 2 - Bring pressure to 20 psi

(See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	20.0	0.0
0.5	0.0	20.0	0.0
0.65	0.0	20.0	0.0
1.5	0.0	20.0	0.0
1.65	full_psi	full_psi	full_psi

Table D27 Assisted braking function applied only to drive axles, driver does not react to warning. Strategy 3 - Ramp pressure up at 75 psi/sec to 100psi

(See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	11.25	0.0
0.5	0.0	37.5	0.0
1.33	0.0	full_psi	0.0
1.5	0.0	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D28 Assisted braking function applied only to drive axles, driver does not react to warning. Strategy 4 - Ramp pressure up at 150 psi/sec to 100psi (See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	22.5	0.0
0.5	0.0	75.0	0.0
0.667	0.0	full_psi	0.0
1.5	0.0	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Table D29 Assisted braking function applied only to drives axles, driver does not react to warning. Strategy 5 - Bring pressure to 100psi (See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	full_psi	0.0
0.5	0.0	full_psi	0.0
0.65	0.0	full_psi	0.0
1.5	0.0	full_psi	0.0
1.65	full_psi	full_psi	full_psi

Table D30 Baseline - Driver is not warned and brakes are not applied automatically (See Figure D5)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D31 Assisted braking function applied only to drive axles, driver reacts to warning. Strategy 1 - Warn the driver and bring pressure to crack pressure (crack = 5.0 psi)
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	crack	0.0
0.5	0.0	crack	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D32 Assisted braking function applied only to drive axles, driver reacts to warning. Strategy 2 - Warn the driver and bring pressure to 20 psi
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	20.0	0.0
0.5	0.0	20.0	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D33 Assisted braking function applied only to drive axles, driver reacts to warning. Strategy 3 - Warn the driver and ramp pressure up at 75 psi/sec to 100psi
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	11.25	0.0
0.5	0.0	37.5	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Brake Command Tables (continued)

Table D34 Assisted braking function applied only to drive axles, driver reacts to warning. Strategy 4 - Warn the driver and ramp pressure up at 150 psi/sec to 100psi
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	22.5	0.0
0.5	0.0	75.0	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D35 Assisted braking function applied only to tractor brakes, driver reacts to warning. Strategy 5 - Warn the driver and bring pressure to 100psi
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	full_psi	0.0
0.5	0.0	full_psi	0.0
0.65	full_psi	full_psi	full_psi
1.5	full_psi	full_psi	full_psi
1.65	full_psi	full_psi	full_psi

Table D36 Baseline - Driver is not warned and brakes are not applied automatically
(See Figure D6)

Brake Command:

Time (sec)	Pressure at Steer Axle	Pressure at Drive Axle(s)	Pressure at Trailer Axle(s)
0.0	0.0	0.0	0.0
0.15	0.0	0.0	0.0
1.0	0.0	0.0	0.0
1.15	0.0	0.0	0.0
1.5	0.0	0.0	0.0
1.65	full_psi	full_psi	full_psi

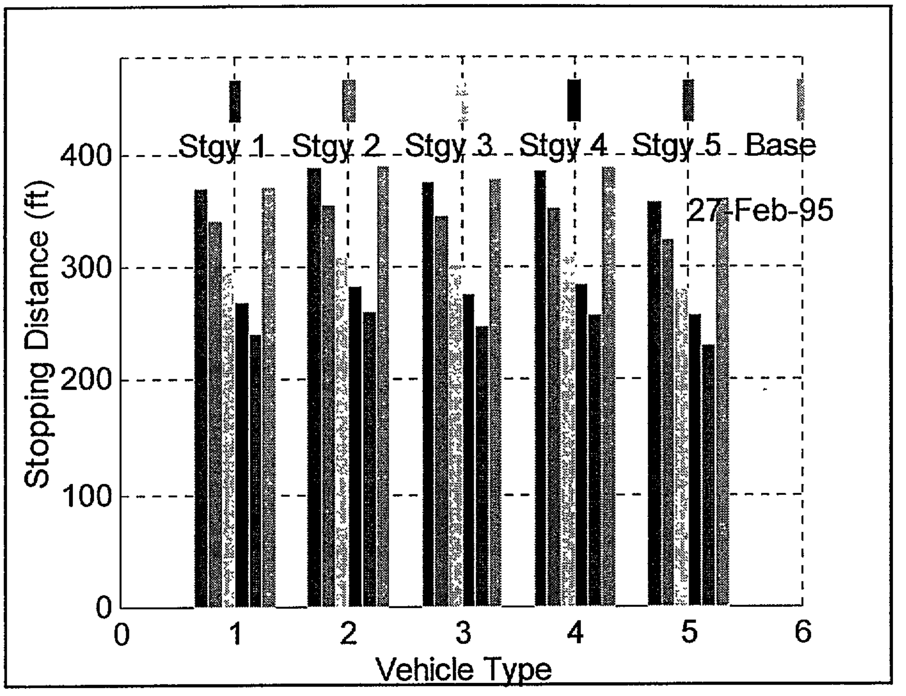

Figure D1 - Stopping Distance - Full assist with driver not reacting to warning

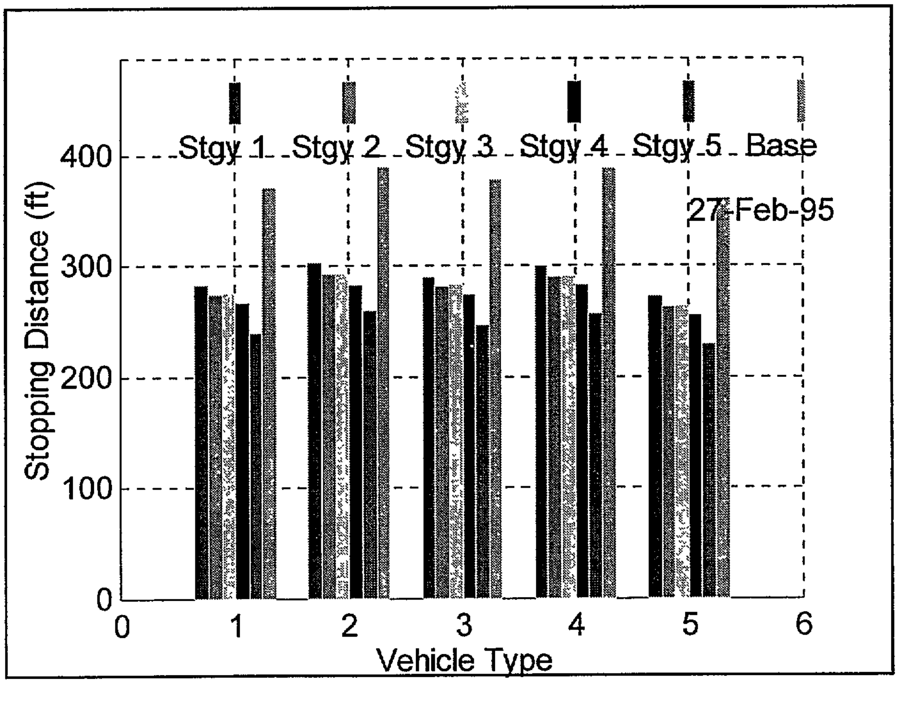

Figure D2 - Stopping Distance - Full Assist with driver reacting to warning

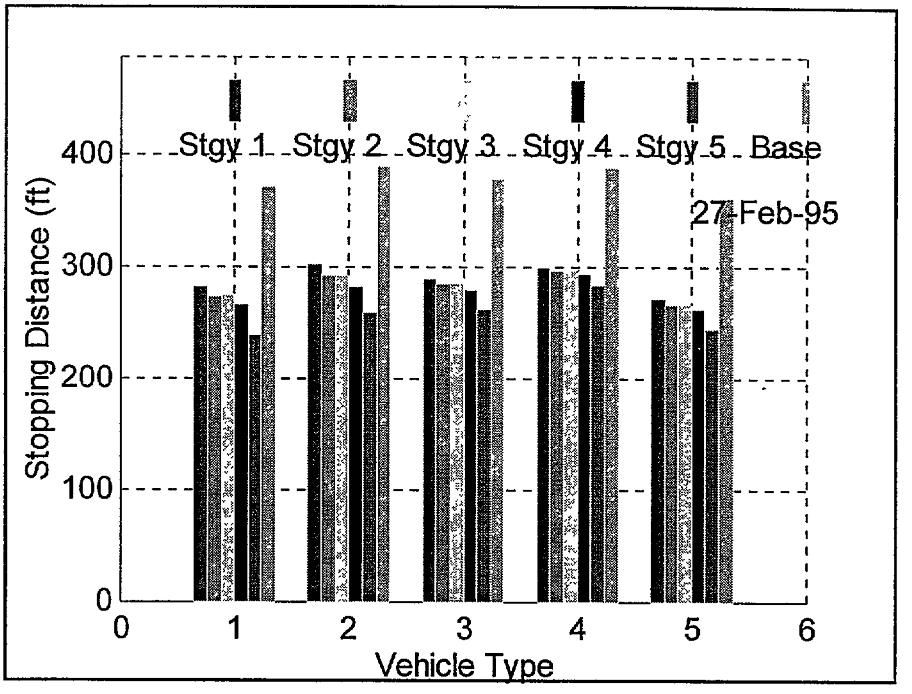

Figure D3 - Stopping Distance - Tractor assist with driver not reacting to warning

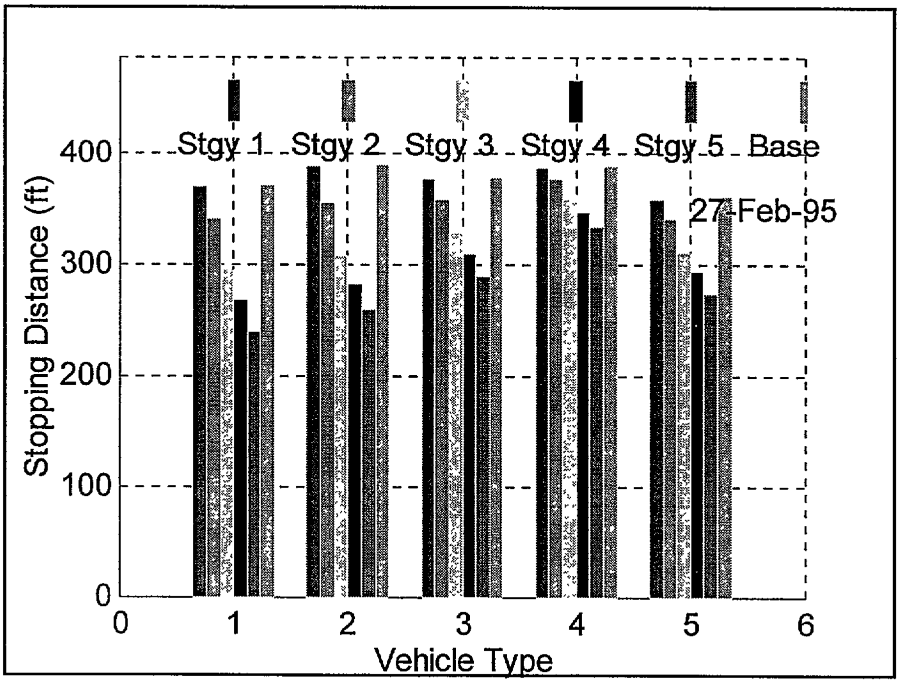

Figure D4 - Stopping Distance - Tractor Assist with driver reacting to warning

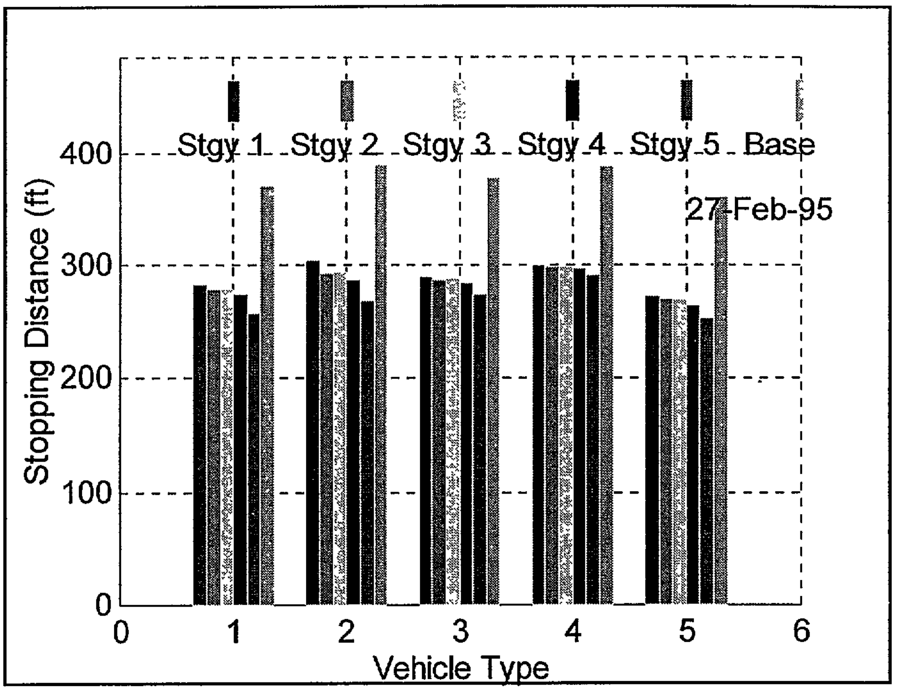

Figure D5 - Stopping Distance - Drive axle assist with driver not reacting to warning

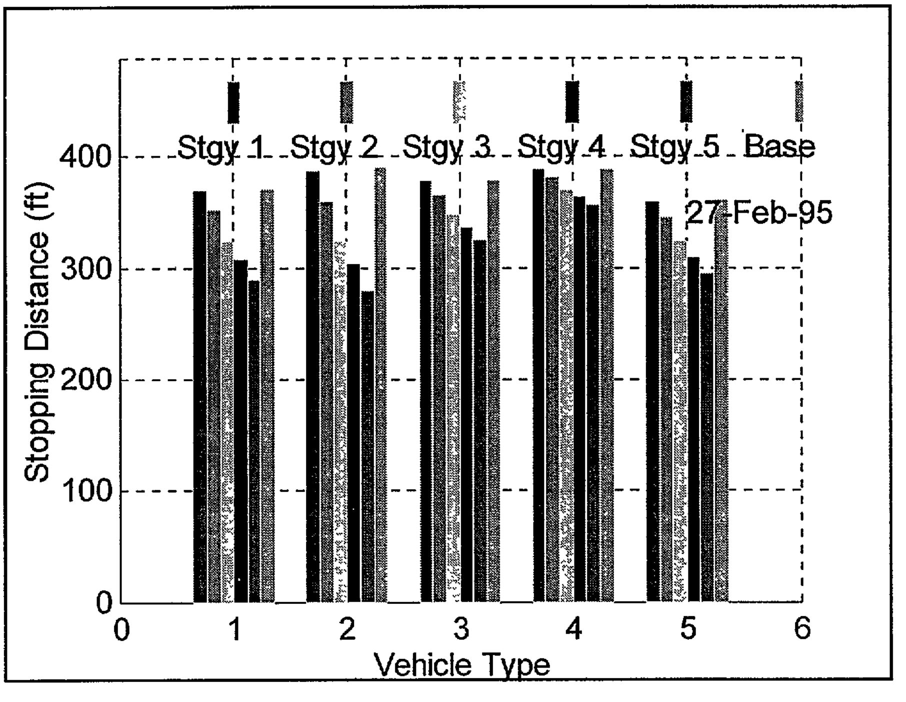

Figure D6 - Stopping Distance - Drive axle assist with driver reacting to warning

Table D37 - Stopping Distance Data for Reduced Reaction Time Simulations

Full assist with driver not reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	369.85	341.53	295.66	268.77	240.03	371.81
Veh. Type 2	388.38	356.35	309.13	283.81	259.64	390.07
Veh. Type 3	376.75	345.57	301.33	275.46	247.32	379.10
Veh. Type 4	386.14	352.91	309.83	284.70	256.99	388.77
Veh. Type 5	358.81	324.18	280.94	256.77	229.76	361.94
Full assist with driver reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	283.05	275.17	276.01	267.18	240.03	371.81
Veh. Type 2	302.87	292.58	292.81	283.09	259.64	390.07
Veh. Type 3	290.33	281.79	282.91	273.99	247.32	379.10
Veh. Type 4	299.99	290.96	292.29	283.31	256.99	388.77
Veh. Type 5	272.93	263.33	263.92	255.51	229.76	361.94
Tractor assist with driver not reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	369.85	341.53	295.66	268.77	240.03	371.81
Veh. Type 2	388.38	356.35	309.13	283.81	259.64	390.07
Veh. Type 3	377.85	359.61	328.87	310.28	289.99	379.10
Veh. Type 4	388.05	377.42	359.02	347.67	335.15	388.77
Veh. Type 5	359.21	341.31	311.66	294.08	274.70	361.94
Tractor assist with driver reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	283.05	275.17	276.01	267.18	240.03	371.81
Veh. Type 2	302.87	292.58	292.81	283.09	259.64	390.07
Veh. Type 3	290.69	285.64	286.18	280.48	262.65	379.10
Veh. Type 4	300.62	297.69	298.00	294.67	284.13	388.77
Veh. Type 5	273.11	267.63	267.45	262.44	245.90	361.94
Drive axle assist with driver not reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	370.79	352.50	325.15	308.83	290.59	371.81
Veh. Type 2	387.41	360.73	325.14	304.07	280.42	390.07
Veh. Type 3	378.45	366.72	348.77	337.91	325.66	379.10
Veh. Type 4	388.39	381.58	370.99	364.52	357.20	388.77
Veh. Type 5	360.85	345.47	323.89	310.69	296.18	361.94
Drive axle assist with driver reacting to warning						
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Baseline
Veh. Type 1	283.47	278.58	279.21	273.95	258.07	371.81
Veh. Type 2	304.03	293.27	294.52	287.18	269.50	390.07
Veh. Type 3	290.96	287.83	288.23	284.85	274.55	379.10
Veh. Type 4	300.78	298.97	299.20	297.23	291.19	388.77
Veh. Type 5	273.55	269.64	269.57	265.22	253.11	361.94

Table D38 - Percent Reduction in Stopping Distance for Different Stopping Strategies

% Reduction in Stopping Distance - Full assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	0.53%	8.14%	20.48%	27.71%	35.44%
Veh. Type 2	0.43%	8.65%	20.75%	27.24%	33.44%
Veh. Type 3	0.62%	8.84%	20.51%	27.34%	34.76%
Veh. Type 4	0.68%	9.22%	20.30%	26.77%	33.90%
Veh. Type 5	0.86%	10.43%	22.38%	29.06%	36.52%
% Reduction in Stopping Distance - Full assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	23.87%	25.99%	25.76%	28.14%	35.44%
Veh. Type 2	22.36%	24.99%	24.93%	27.43%	33.44%
Veh. Type 3	23.42%	25.67%	25.37%	27.72%	34.76%
Veh. Type 4	22.84%	25.16%	24.82%	27.13%	33.90%
Veh. Type 5	24.59%	27.25%	27.08%	29.41%	36.52%
% Reduction in Stopping Distance - Tractor assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	0.53%	8.14%	20.48%	27.71%	35.44%
Veh. Type 2	0.43%	8.65%	20.75%	27.24%	33.44%
Veh. Type 3	0.33%	5.14%	13.25%	18.15%	23.51%
Veh. Type 4	0.19%	2.92%	7.65%	10.57%	13.79%
Veh. Type 5	0.75%	5.70%	13.89%	18.75%	24.10%
% Reduction in Stopping Distance - Tractor assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	23.87%	25.99%	25.76%	28.14%	35.44%
Veh. Type 2	22.36%	24.99%	24.93%	27.43%	33.44%
Veh. Type 3	23.32%	24.65%	24.51%	26.02%	30.72%
Veh. Type 4	22.67%	23.43%	23.35%	24.21%	26.92%
Veh. Type 5	24.54%	26.06%	26.10%	27.49%	32.06%
% Reduction in Stopping Distance - Drive axle assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	0.27%	5.19%	12.55%	16.94%	21.84%
Veh. Type 2	0.68%	7.52%	16.65%	22.05%	28.11%
Veh. Type 3	0.17%	3.27%	8.00%	10.87%	14.10%
Veh. Type 4	0.10%	1.85%	4.57%	6.24%	8.12%
Veh. Type 5	0.30%	4.55%	10.51%	14.16%	18.17%
% Reduction in Stopping Distance - Drive axle assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	23.76%	25.07%	24.90%	26.32%	30.59%
Veh. Type 2	22.06%	24.82%	24.50%	26.38%	30.91%
Veh. Type 3	23.25%	24.07%	23.97%	24.86%	27.58%
Veh. Type 4	22.63%	23.10%	23.04%	23.55%	25.10%
Veh. Type 5	24.42%	25.50%	25.52%	26.72%	30.07%

Table D39 - Reduction in Stopping Distance for Different Stopping Strategies

Reduction in Stopping Distance - Full assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	1.96	30.28	76.15	103.04	131.78
Veh. Type 2	1.70	33.72	80.95	106.27	130.43
Veh. Type 3	2.35	33.53	77.77	103.64	131.78
Veh. Type 4	2.63	35.86	78.94	104.07	131.78
Veh. Type 5	3.12	37.76	81.00	105.17	132.17
Reduction in Stopping Distance - Full assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	88.76	96.64	95.80	104.63	131.78
Veh. Type 2	87.20	97.49	97.26	106.98	130.43
Veh. Type 3	88.77	97.31	96.19	105.10	131.78
Veh. Type 4	88.78	97.80	96.48	105.45	131.78
Veh. Type 5	89.01	98.61	98.01	106.43	132.17
Reduction in Stopping Distance - Tractor assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	1.96	30.28	76.15	103.04	131.78
Veh. Type 2	1.70	33.72	80.95	106.27	130.43
Veh. Type 3	1.25	19.49	50.22	68.82	89.11
Veh. Type 4	0.72	11.35	29.75	41.10	53.62
Veh. Type 5	2.73	20.63	50.28	67.85	87.24
Reduction in Stopping Distance - Tractor assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	88.76	96.64	95.80	104.63	131.78
Veh. Type 2	87.20	97.49	97.26	106.98	130.43
Veh. Type 3	88.41	93.46	92.92	98.62	116.45
Veh. Type 4	88.14	91.08	90.77	94.10	104.64
Veh. Type 5	88.82	94.31	94.48	99.50	116.04
Reduction in Stopping Distance - Drive axle assist with driver not reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	1.02	19.31	46.66	62.98	81.22
Veh. Type 2	2.67	29.34	64.93	86.01	109.65
Veh. Type 3	0.65	12.38	30.32	41.19	53.44
Veh. Type 4	0.38	7.18	17.78	24.25	31.57
Veh. Type 5	1.09	16.46	38.04	51.25	65.76
Reduction in Stopping Distance - Drive axle assist with driver reacting to warning					
	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
Veh. Type 1	88.34	93.23	92.60	97.86	113.74
Veh. Type 2	86.04	96.80	95.56	102.89	120.58
Veh. Type 3	88.14	91.27	90.86	94.25	104.54
Veh. Type 4	87.99	89.80	89.57	91.54	97.58
Veh. Type 5	88.38	92.29	92.37	96.72	108.83

APPENDIX E

Benefits Analysis Data

1000 Stop Simulation Groups

For each assisted braking stopping strategy there are four attendant graphs in Appendix E. The first of these shows the modeled stopping distance for the 1000 cases with the activation distance overlayed. Stopping distance “stars” that are above the line are cases that would have impacted the target. The second graph shows the impact velocity distribution. These impact velocities will figure into the severity reduction estimates. The third and fourth graphs are distributions to better illustrate the effectiveness versus speed by plotting both the numbers of collisions and the percent of cases at each speed. Figure El shows the modeled stopping distance for the 1000 cases with no automatic braking. The solid line shows the distance at which above the line there will still be an accident. For all the starred stopping distances above the line, the vehicle impacted the target. As stated previously, this was 78.5%. Figure E2 shows the resulting impact speed for the resulting accidents. Figure E3 shows the number of accidents at each of the starting speeds, and Figure E4 shows the percentage of cases at each starting speed that an accident occurred.

Figure E5 displays the modeled stopping distances when Braking Strategy 2 is autonomously applied to just the tractor brakes. Strategy 2 is the assisted braking function that applies the brakes to the 20 psi level at the activation time. As you can see, there are fewer “stars” above the line; in fact, only 8.4% of the 1000 cases are predicted to be involved in accidents. Figure E9 shows the modeled stopping distance when Braking Strategy 2 is autonomously applied to both the tractor and trailer brakes. In this case, all but 2.7% of the accidents are eliminated. Figure El 3 displays the modeled stopping distances when Braking Strategy 3 is autonomously applied to just the tractor brakes. Strategy 3 is the assisted braking function that applies the brakes by ramping the brake pressure up from 0 psi to 100 psi at 50 psi/second at the activation time. In this case, all but 0.3% of the accidents are eliminated.

There are no graphs included for Strategy 3 with the tractor and trailer brakes automatically applied, or for Strategies 4 and 5 for both braking configurations because there were no stopping distances above the activation line. In all of these cases the autonomous system stopped the vehicle before an accident could occur.

The next series of Figures, El7 through E46, show the same data if the activation line is defined by the coefficients for Strategy 2 from Table 10. In these cases, the time in which the brakes are activated is delayed from the time that they would have been activated in the case of Strategy 6. This time difference is primarily explained because of the difference in coefficient t_1, which varies from 0.22 seconds for Strategy 2 to 1.65 seconds for Strategy 6. This delayed automatic actuation may be desirable in order to reduce the effects of false alarms or other conditions that the driver may be able to react to without assistance of the system.

We also assume that the driver is still warned at the warning time indicated by Strategy 6, therefore, approximately 78.6% of the accidents will be eliminated. However, at the warning time associated with the activation Strategy 2, the brakes are automatically applied. This analysis shows that of the 78.6% not prevented by warning alone, additional accidents could have been prevented by applying the different braking strategies. Table 12 shows the further reductions, over the warning alone, that are predicted will be achieved when activation Strategy 2 is used to automatically apply the brakes after the warning has been issued.

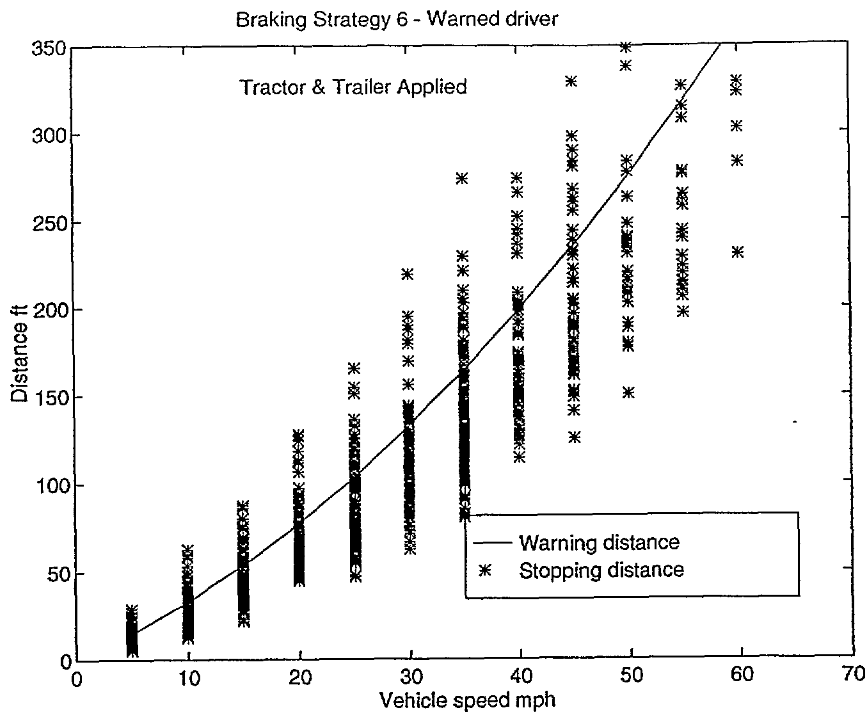

Figure E1 - Accident Reduction Model

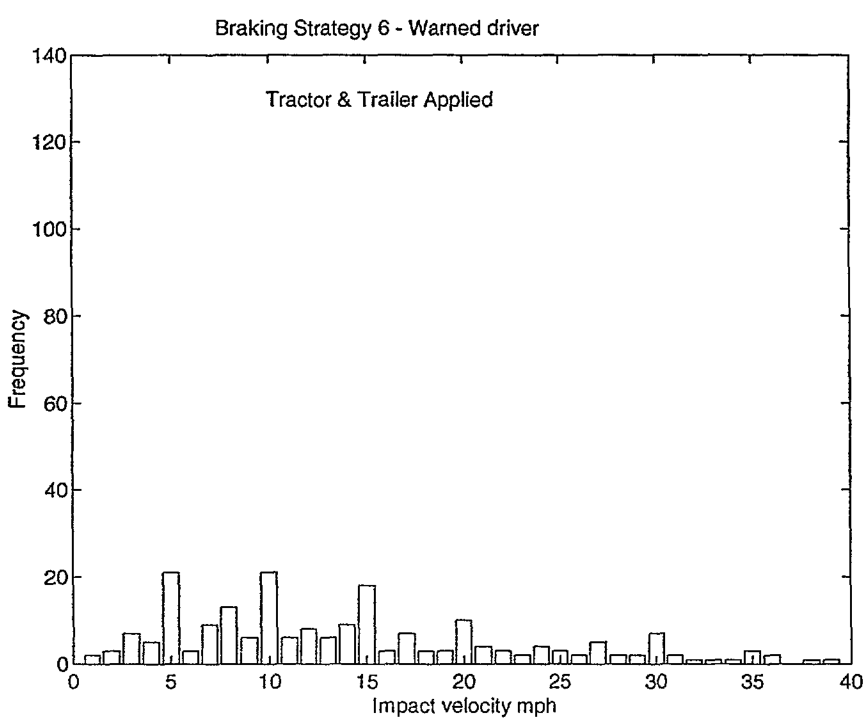

Figure E2 - Impact Velocity

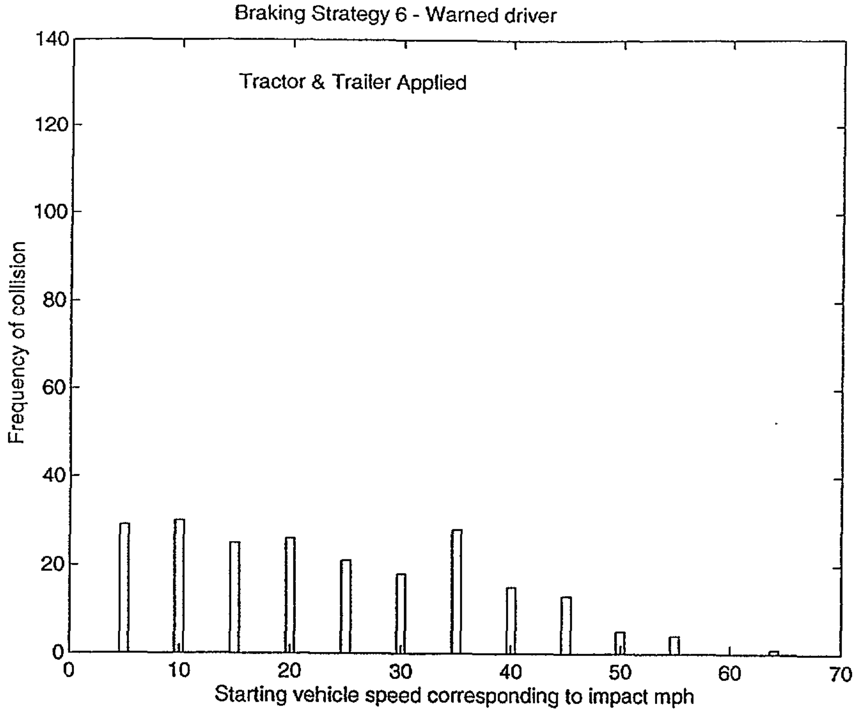

Figure E3 - Number of Collisions at each Starting Vehicle Speed

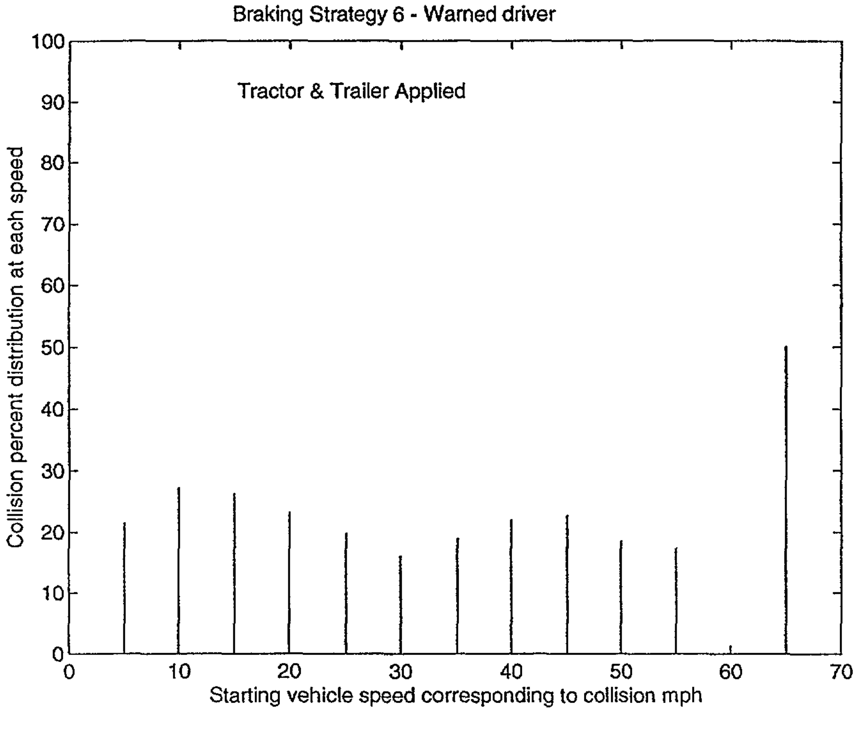

Figure E4 - Percent of Collisions for each Starting Vehicle Speed

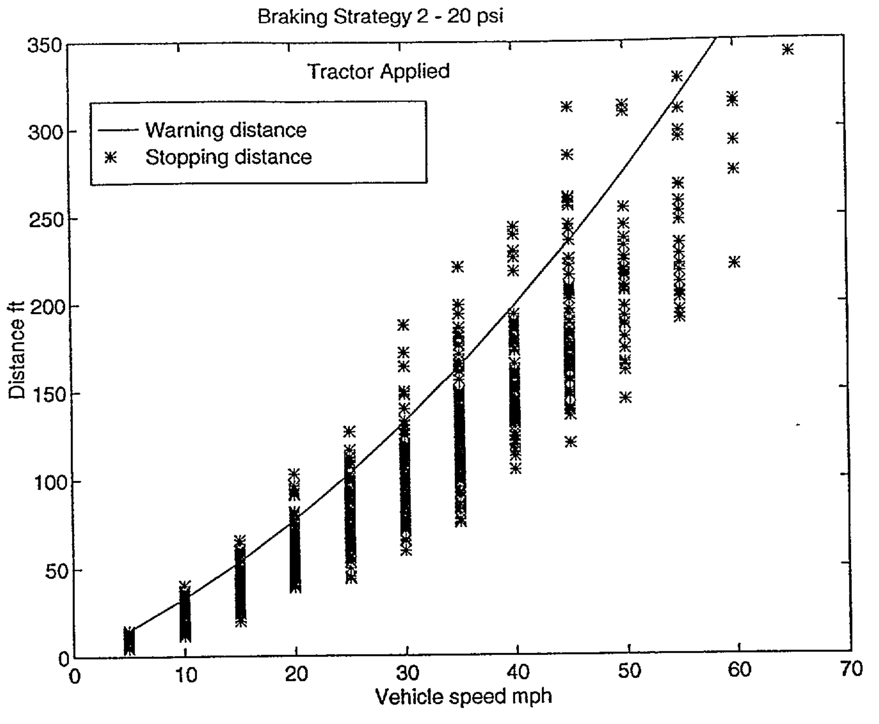

Figure E5 - Accident Reduction Model

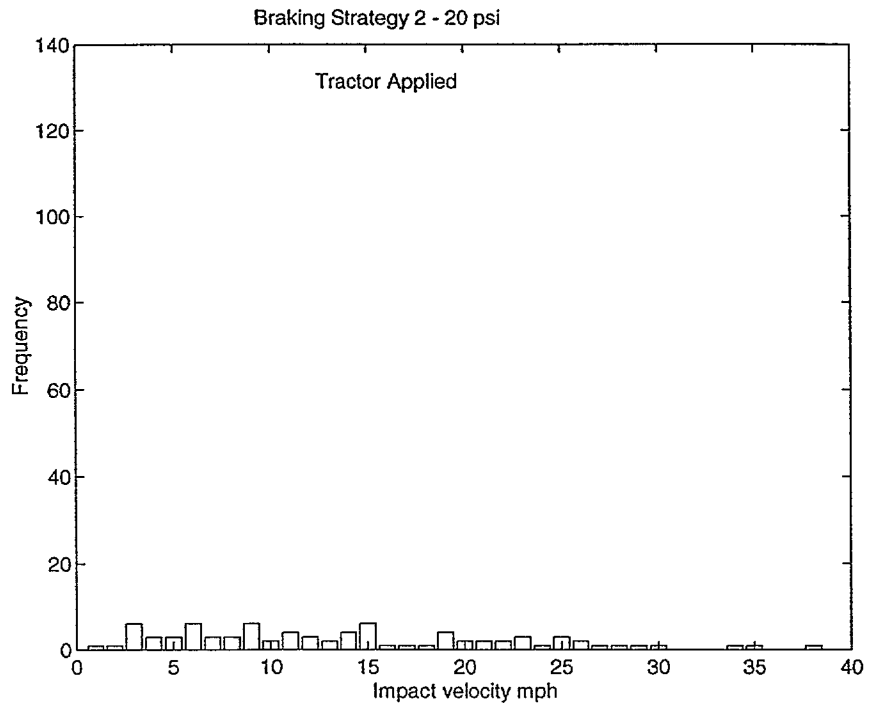

Figure E6 - Impact Velocity

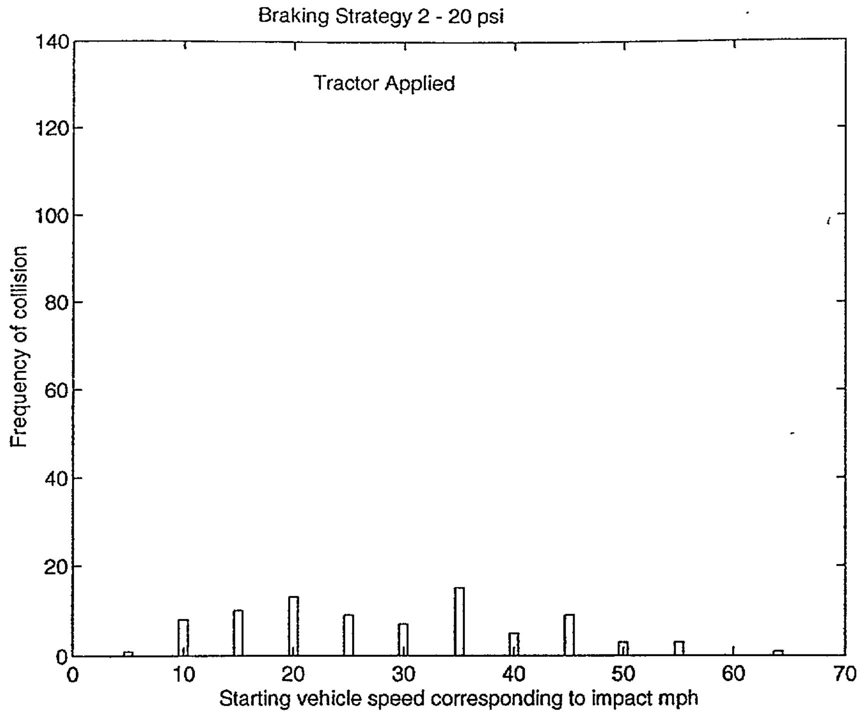

Figure E7 - Number of Collisions at each Starting Vehicle Speed

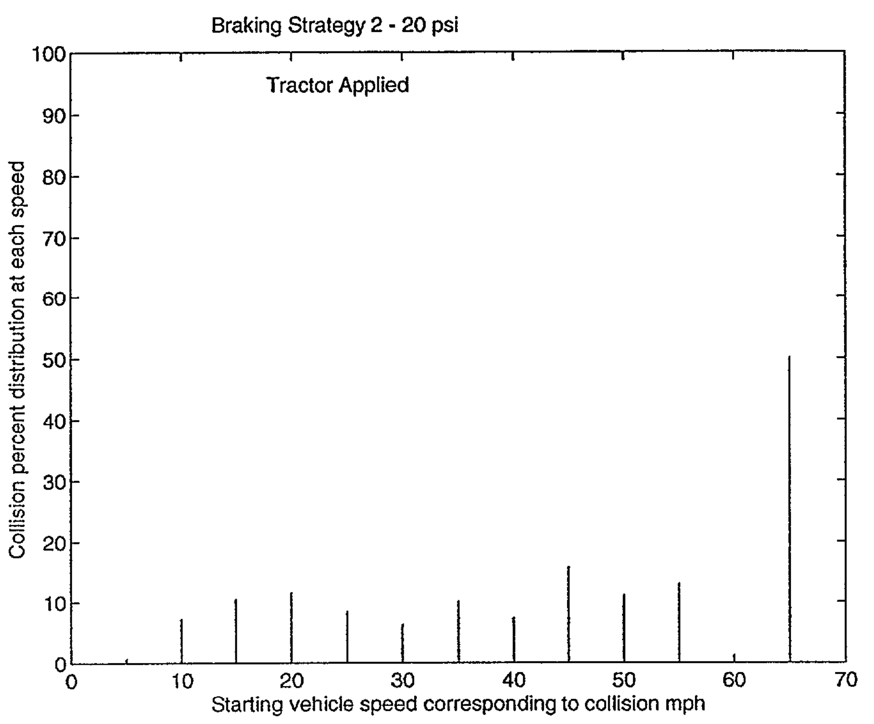

Figure E8 - Percent of Collisions for each Starting Vehicle Speed

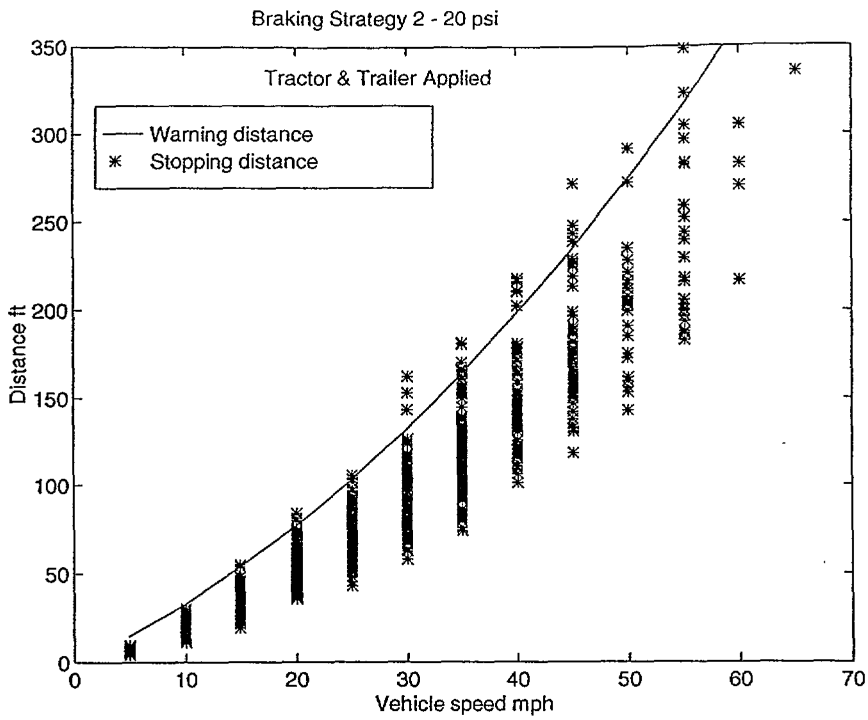

Figure E9 - Accident Reduction Model

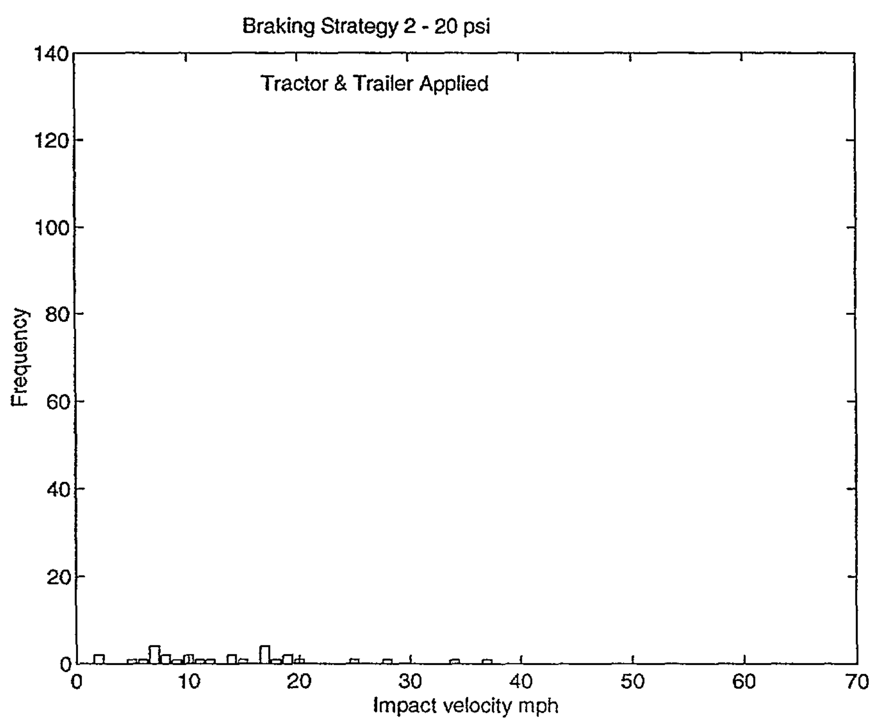

Figure E10 - Impact Velocity

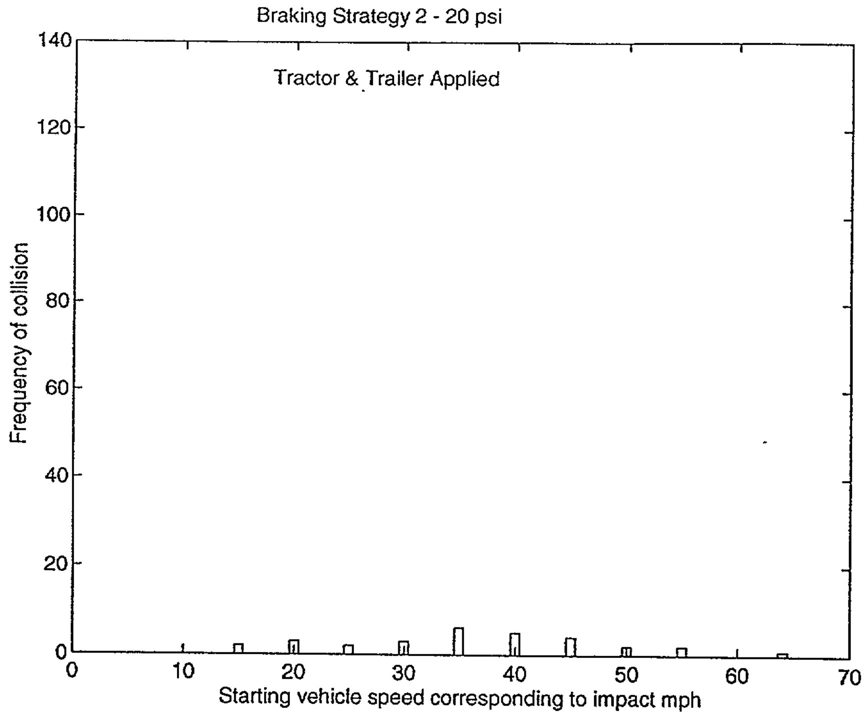

Figure E11 - Number of Collisions at each Starting Vehicle Speed

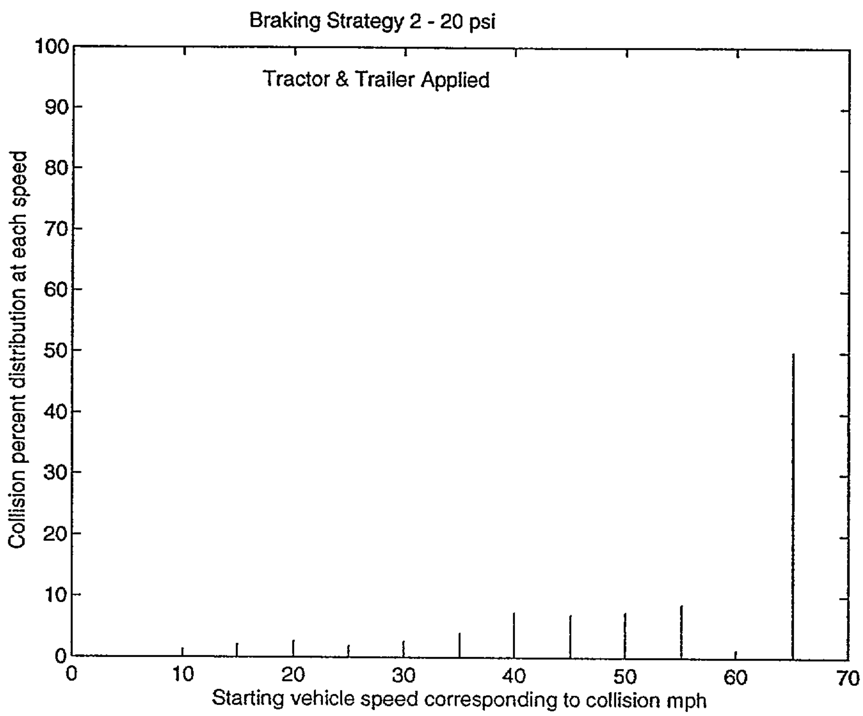

Figure E12 - Percent of Collisions for each Starting Vehicle Speed

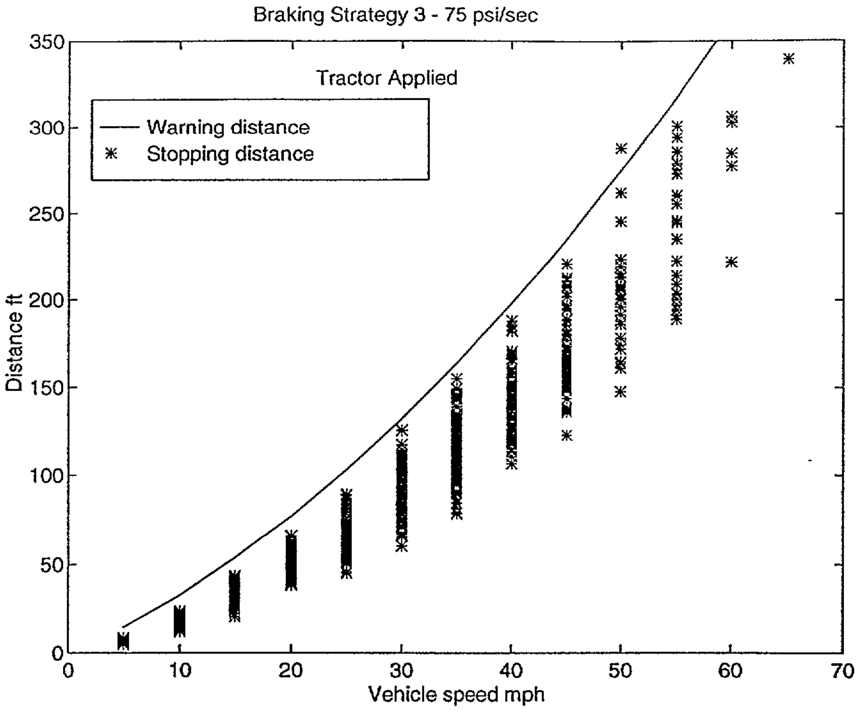

Figure E13 - Accident Reduction Model

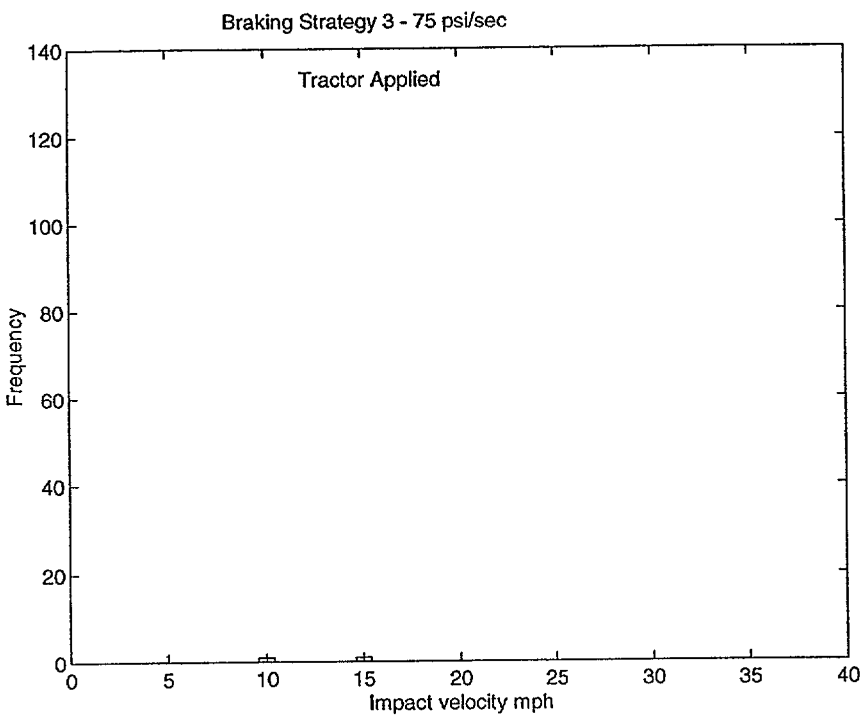

Figure E14 - Impact Velocity

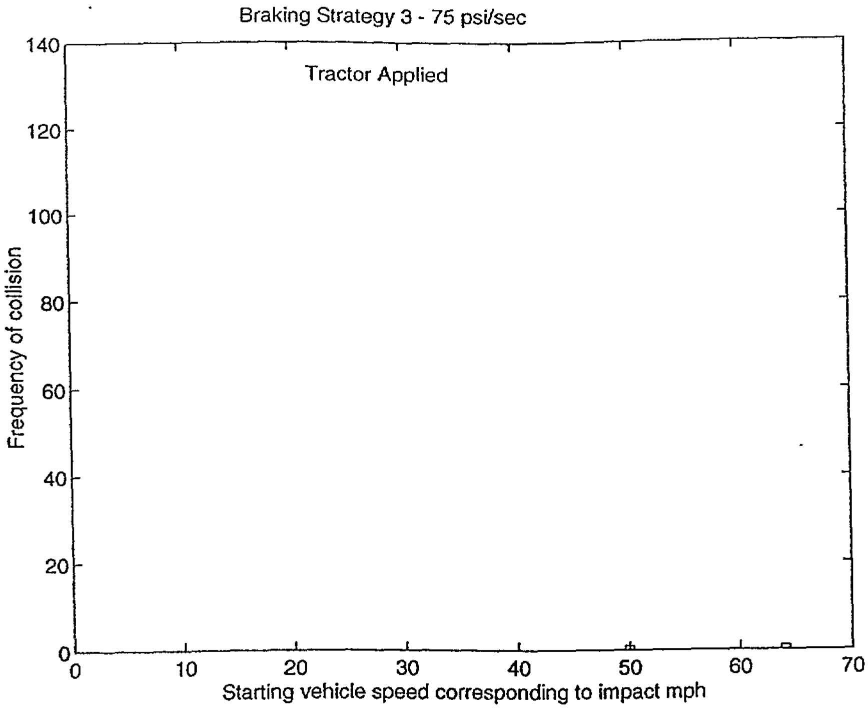

Figure E15 - Number of Collisions at each Starting Vehicle Speed

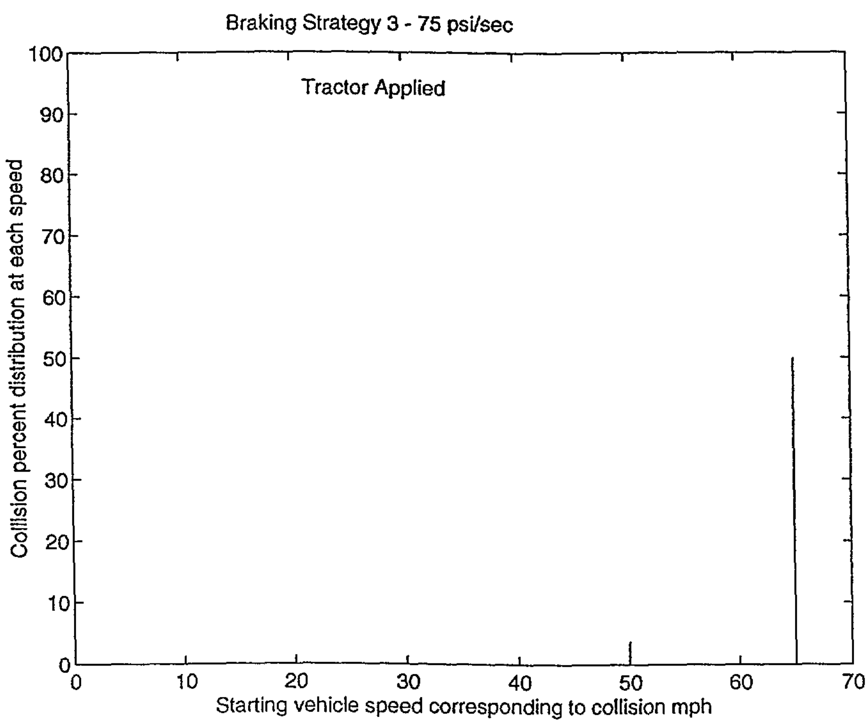

Figure E16 - Percent of Collisions for each Starting Vehicle Speed

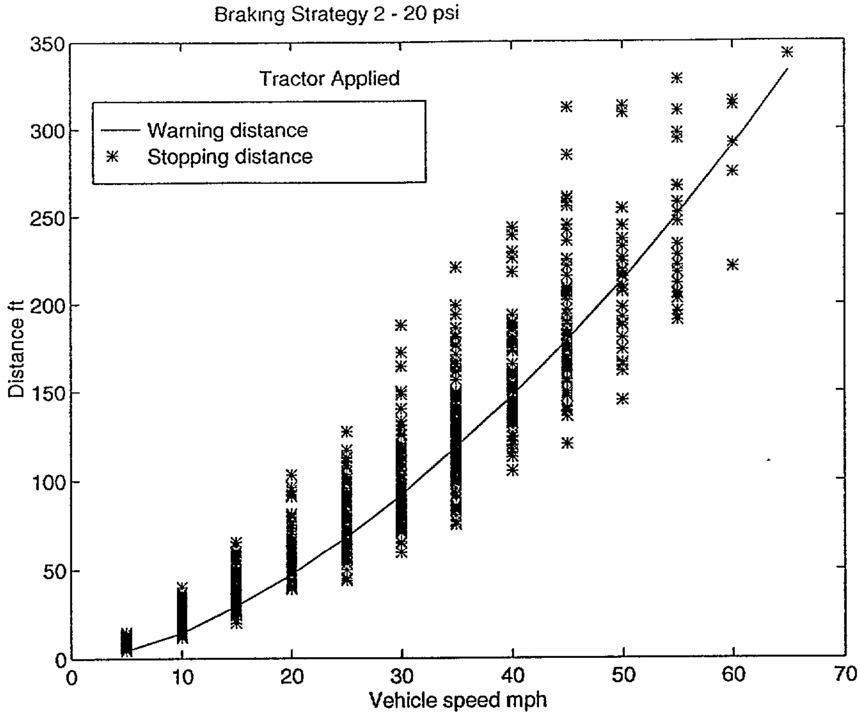

Figure E17 - Accident Reduction Model

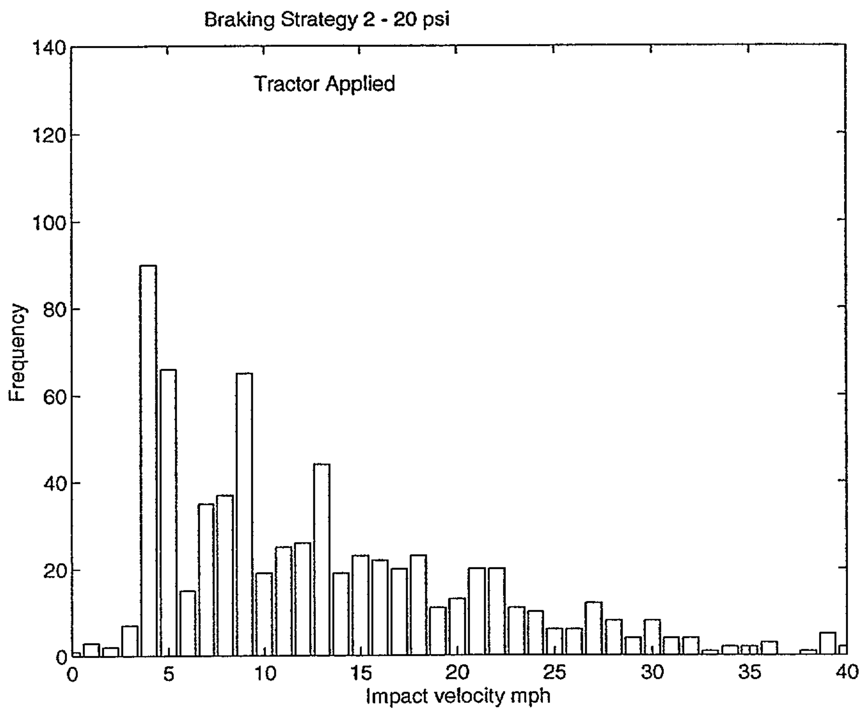

Figure E18 - Impact Velocity

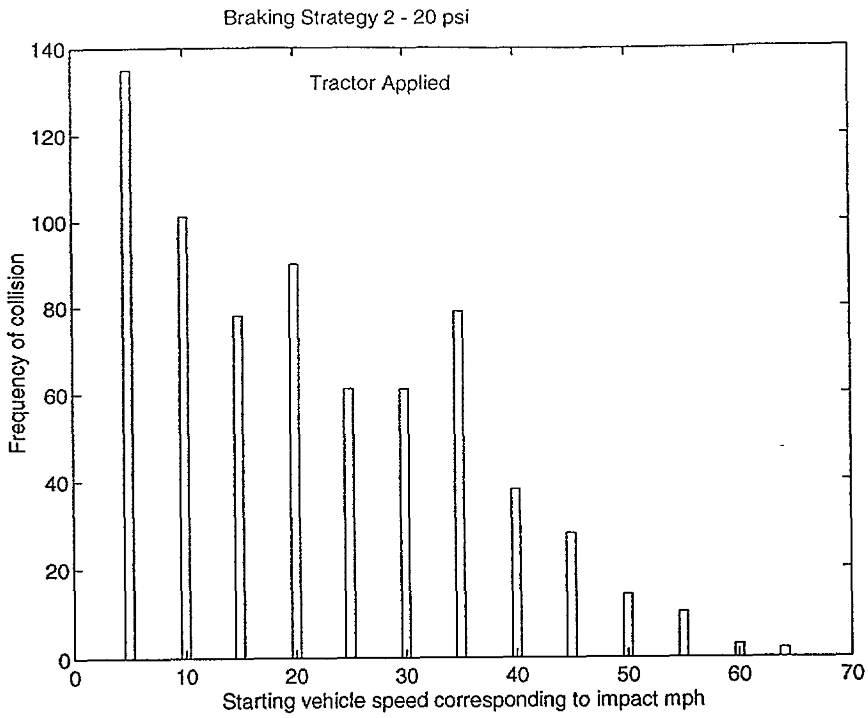

Figure E19 - Number of Collisions at each Starting Vehicle Speed

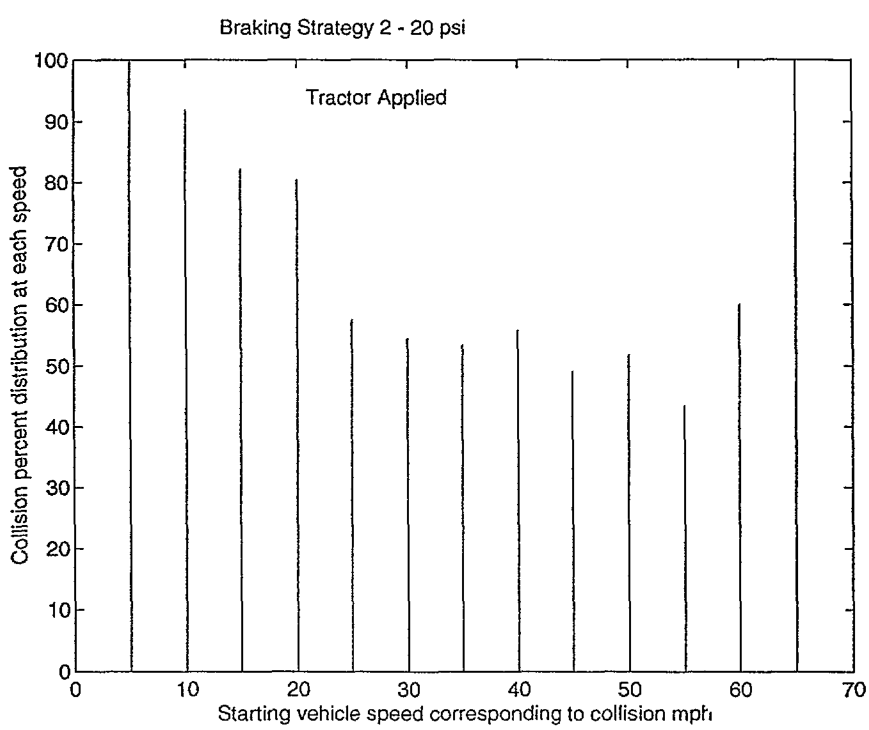

Figure E20 - Percent of Collisions for each Starting Vehicle Speed

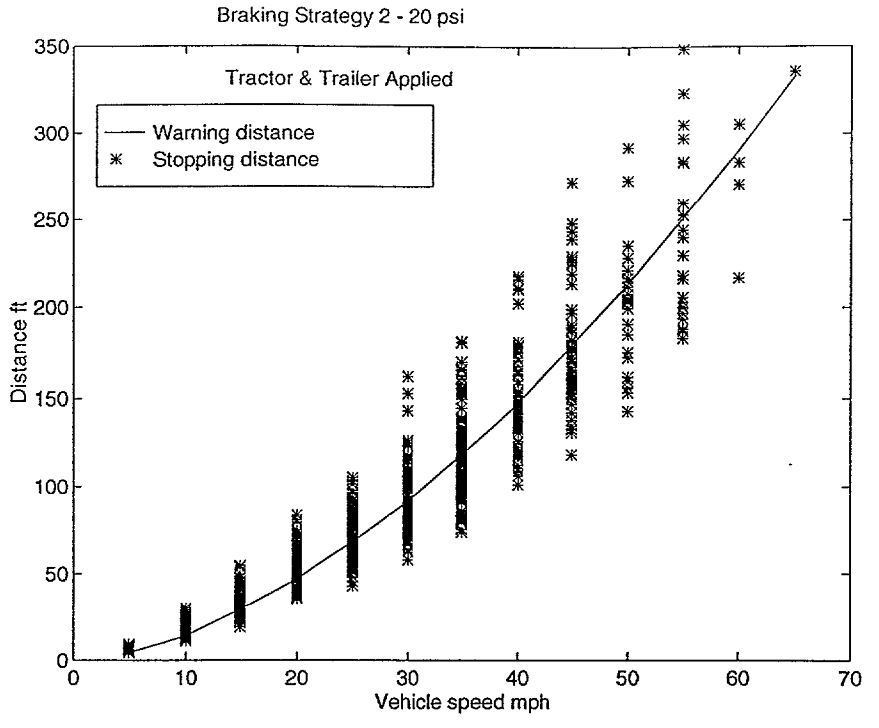

Figure E21 - Accident Reduction Model

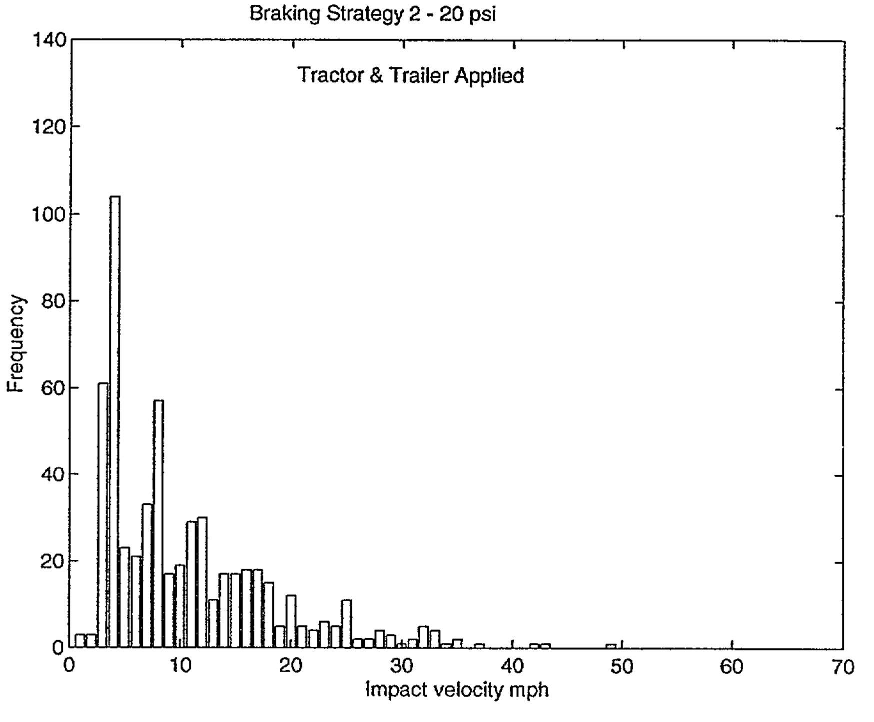

Figure E22 - Impact Velocity

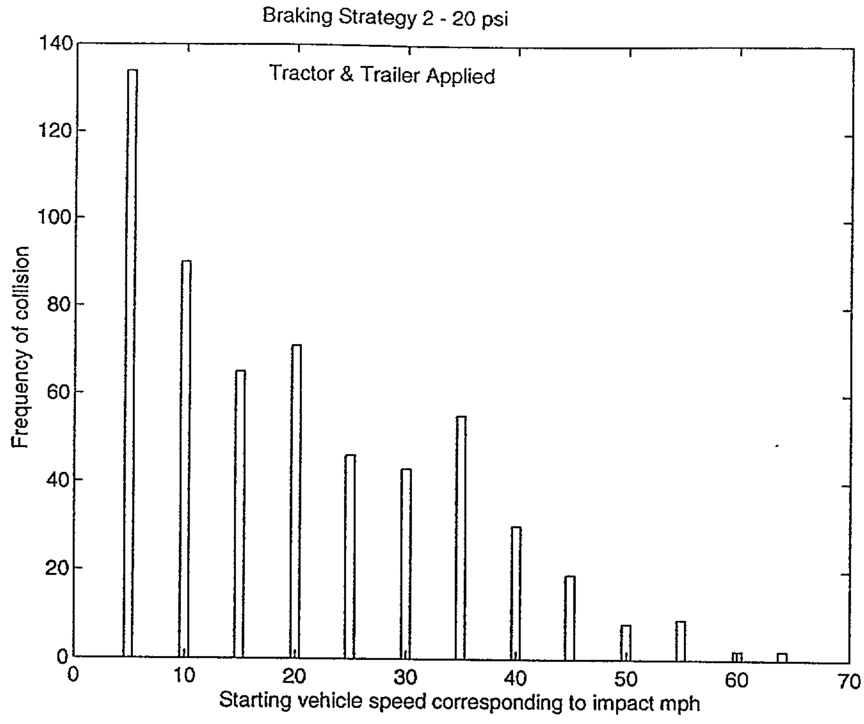

Figure E23 - Number of Collisions at each Starting Vehicle Speed

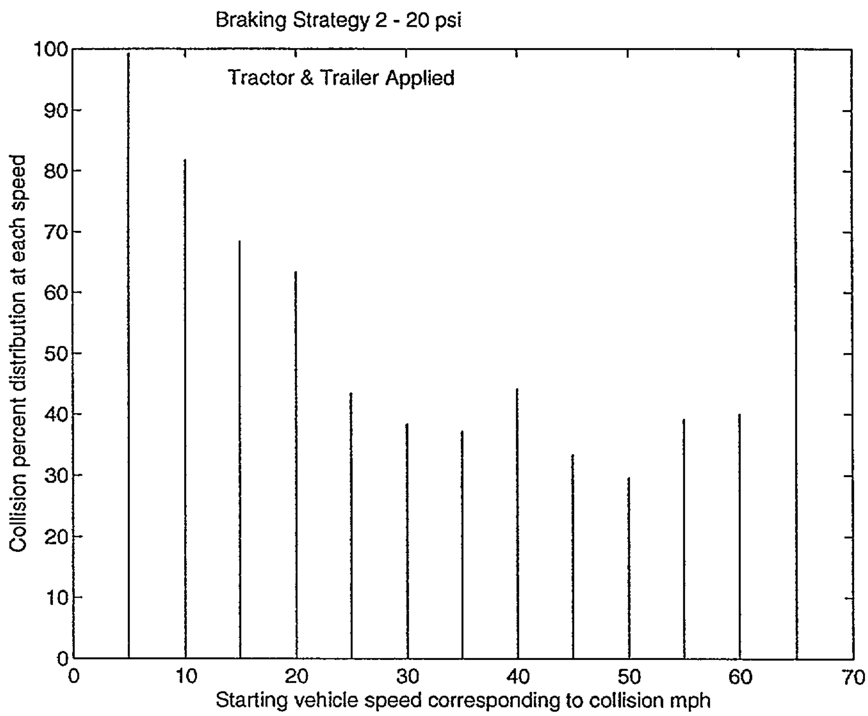

Figure E24 - Percent of Collisions for each Starting Vehicle Speed

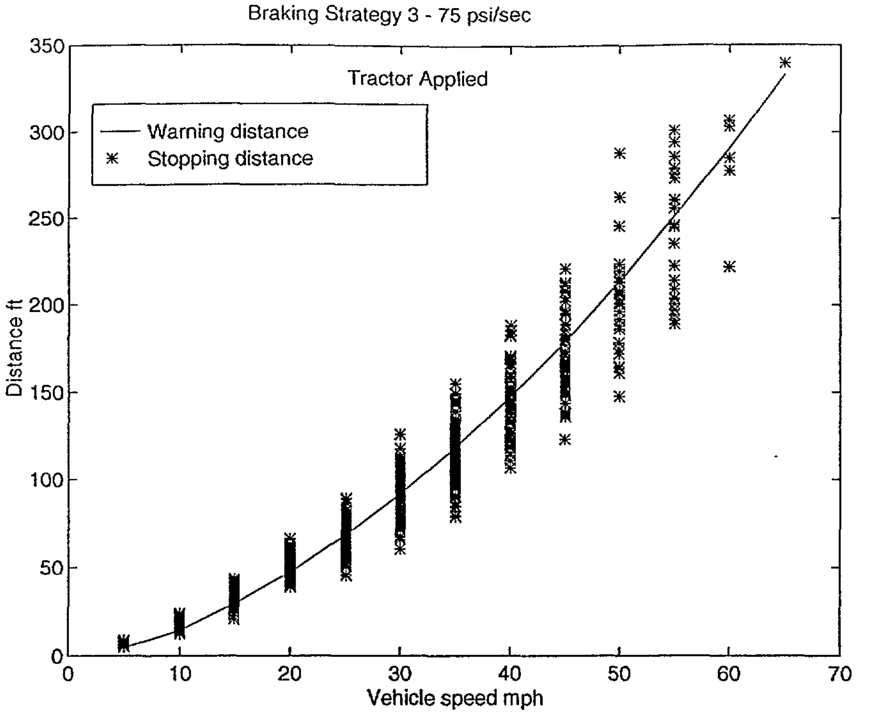

Figure E25 - Accident Reduction Model

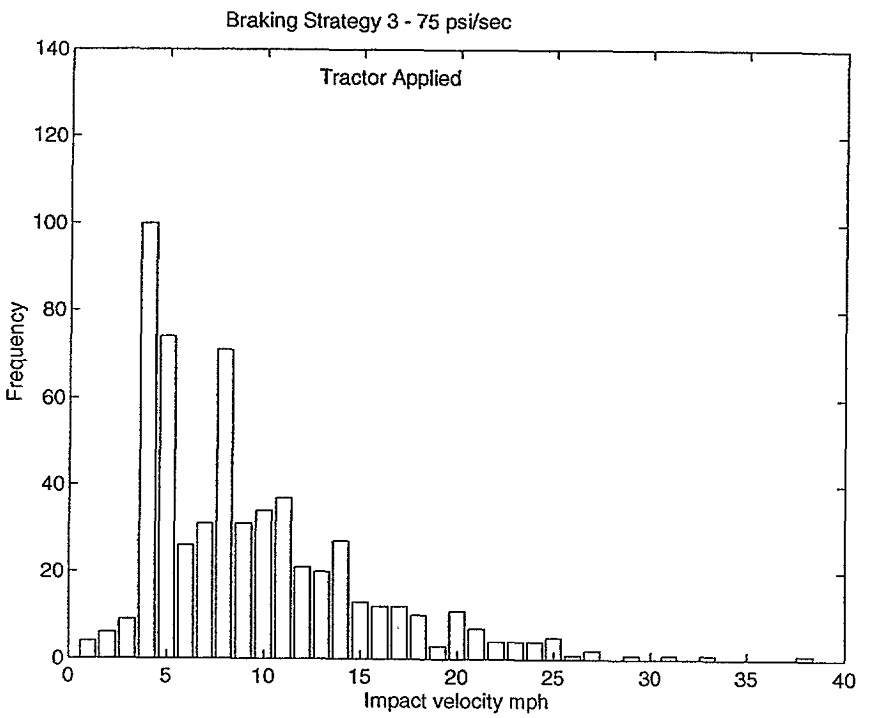

Figure E26 - Impact Velocity

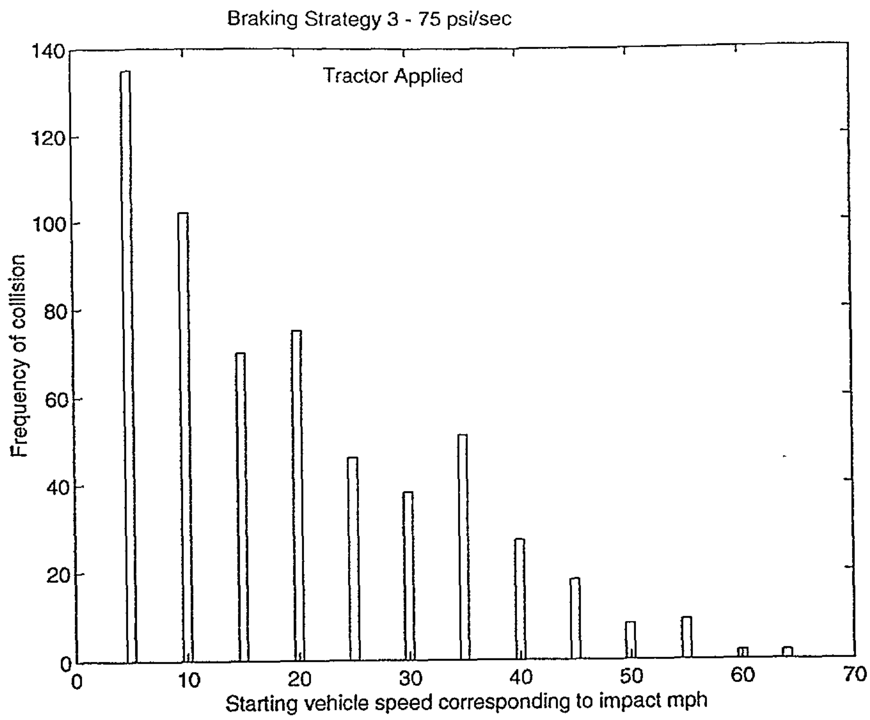

Figure E27 - Number of Collisions at each Starting Vehicle Speed

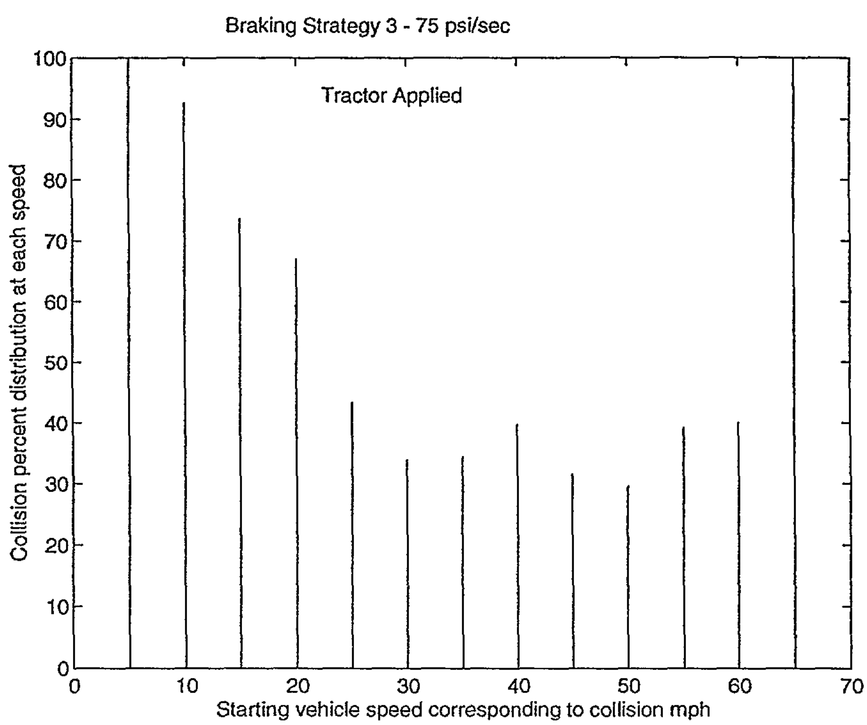

Figure E28 - Percent of Collisions for each Starting Vehicle Speed

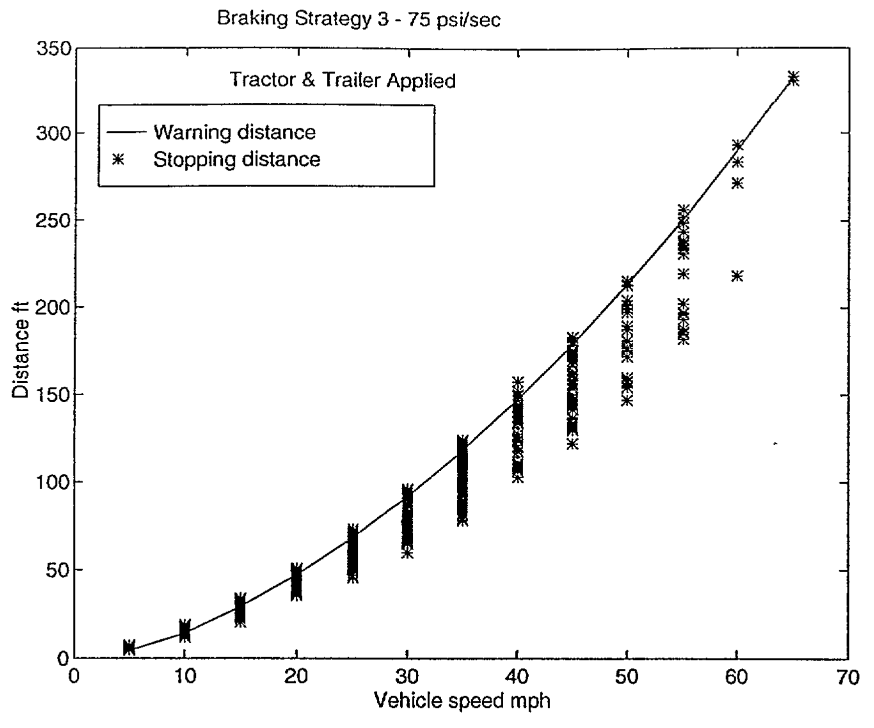

Figure E29 - Accident Reduction Model

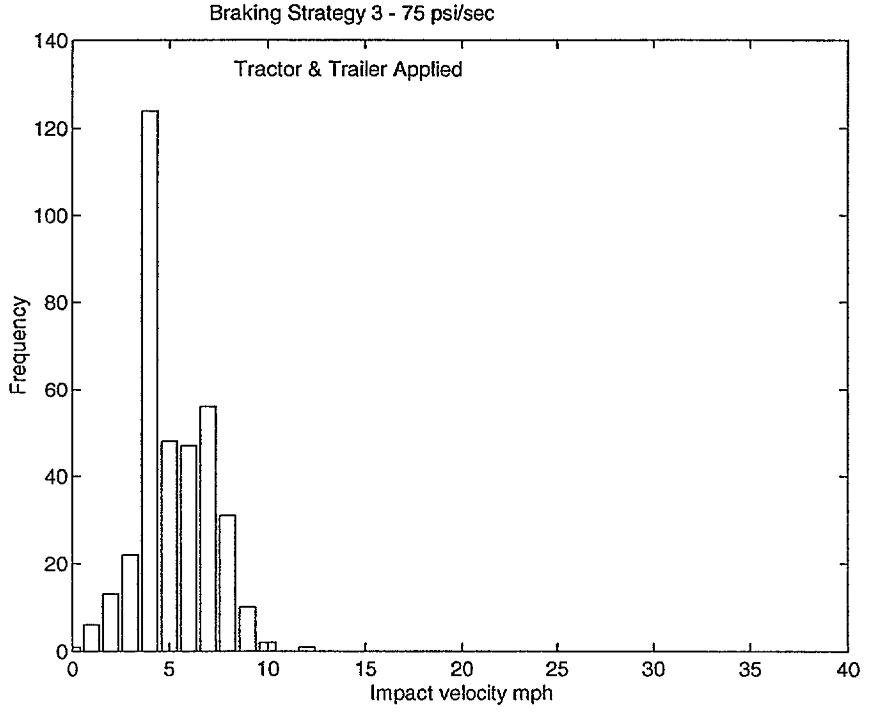

Figure E30 - Impact Velocity

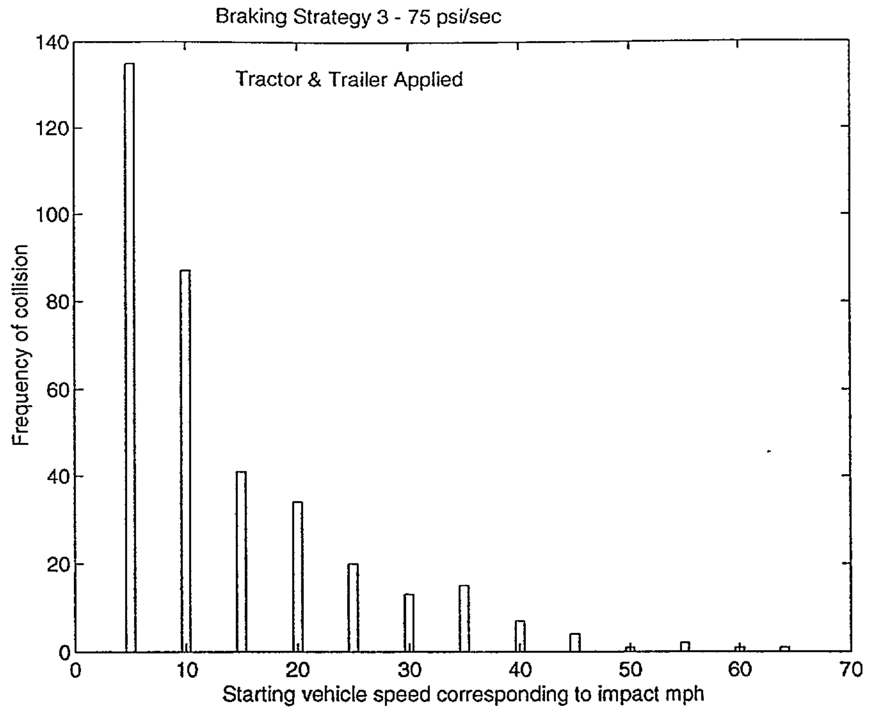

Figure E31 - Number of Collisions at each Starting Vehicle Speed

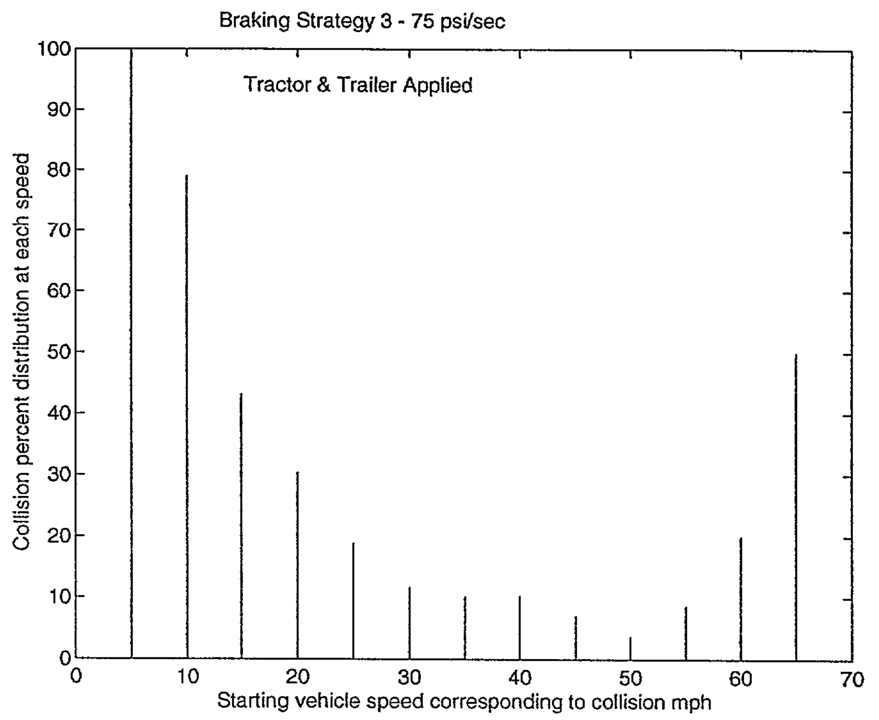

Figure E32 - Percent of Collisions for each Starting Vehicle Speed

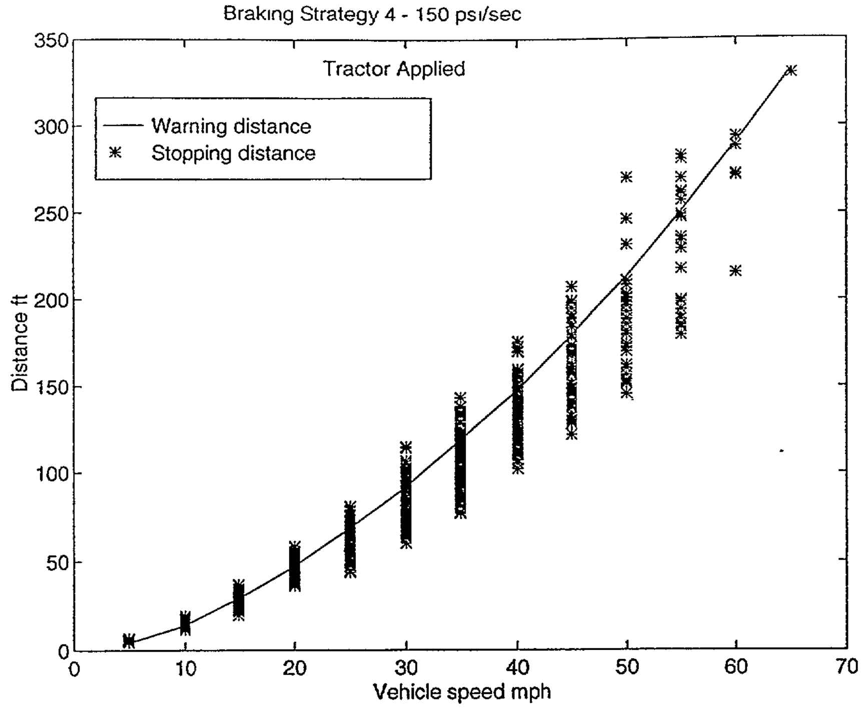

Figure E33 - Accident Reduction Model

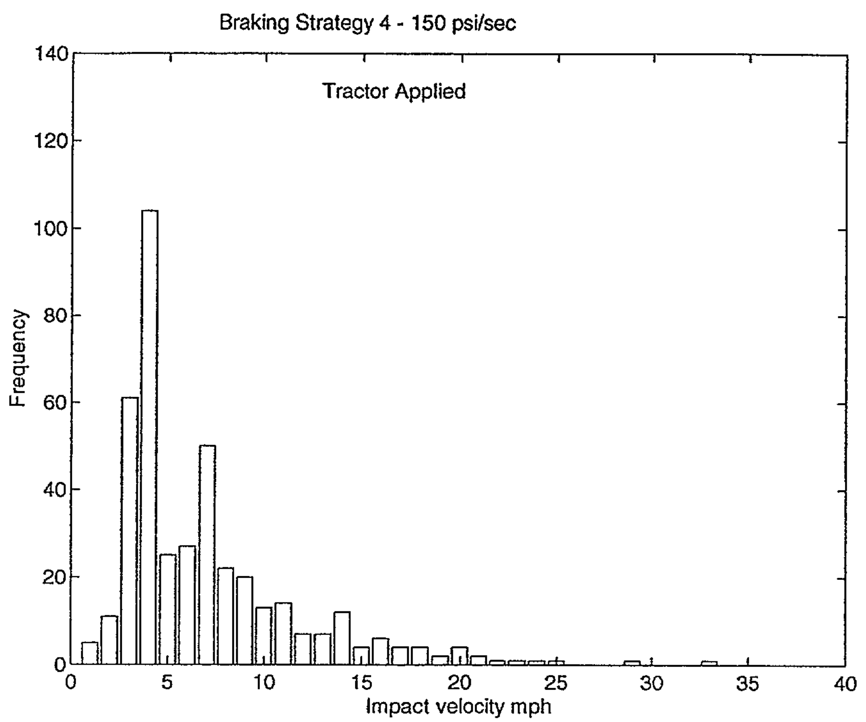

Figure E34 - Impact Velocity

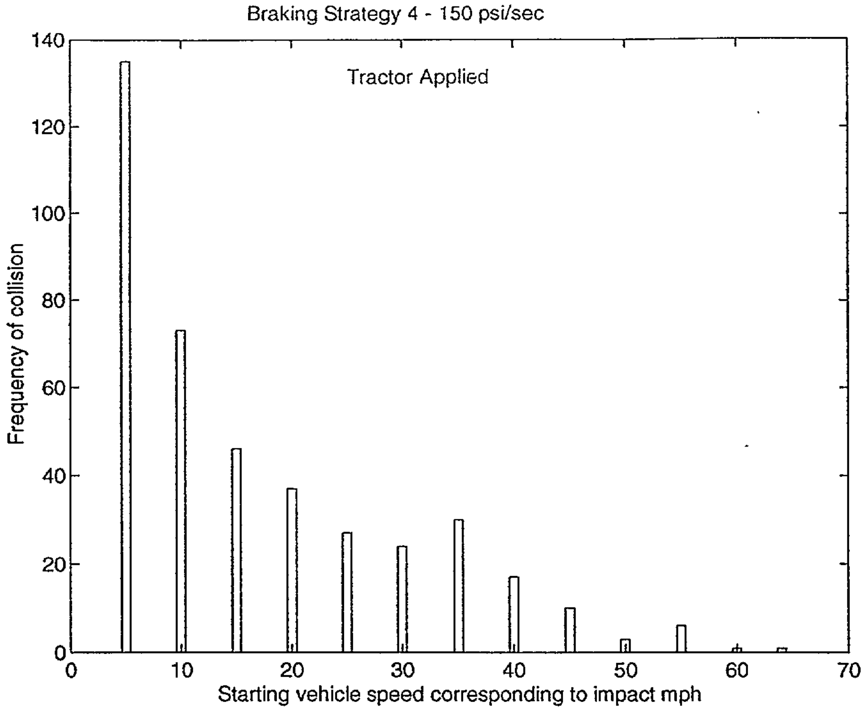

Figure E35 - Number of Collisions at each Starting Vehicle Speed

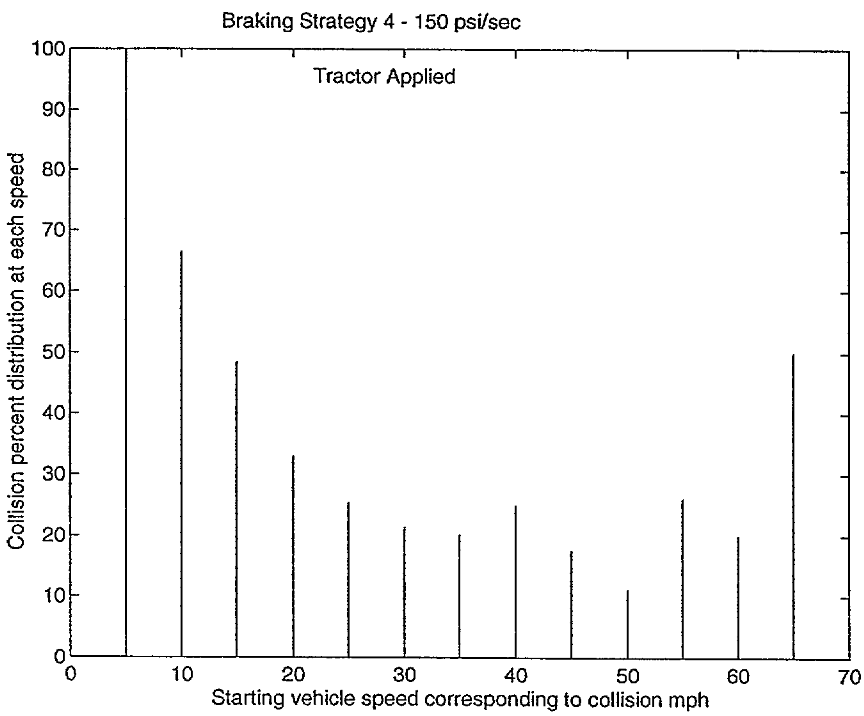

Figure E36 - Percent of Collisions for each Starting Vehicle Speed

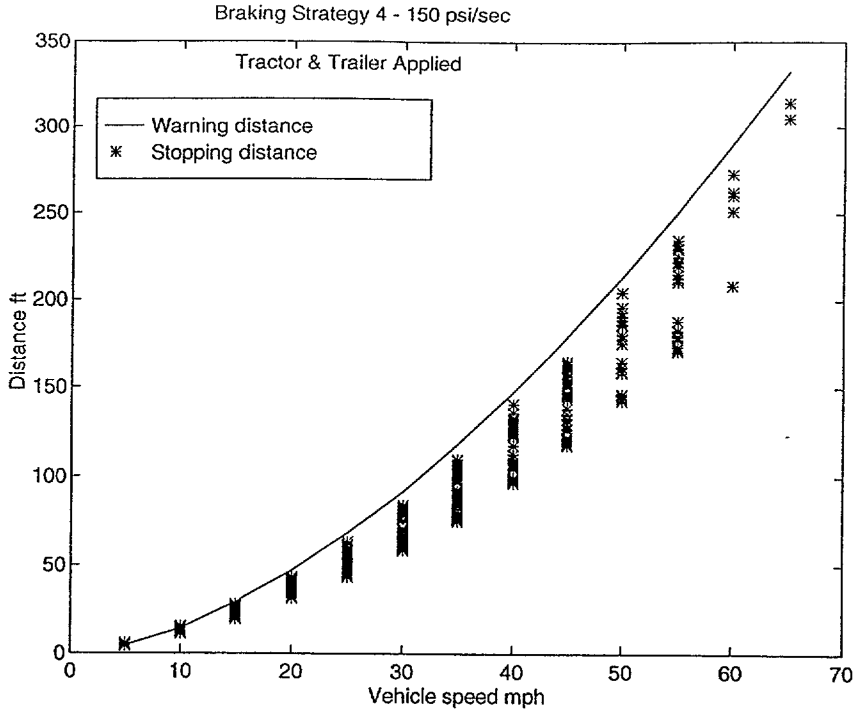

Figure E37 - Accident Reduction Model

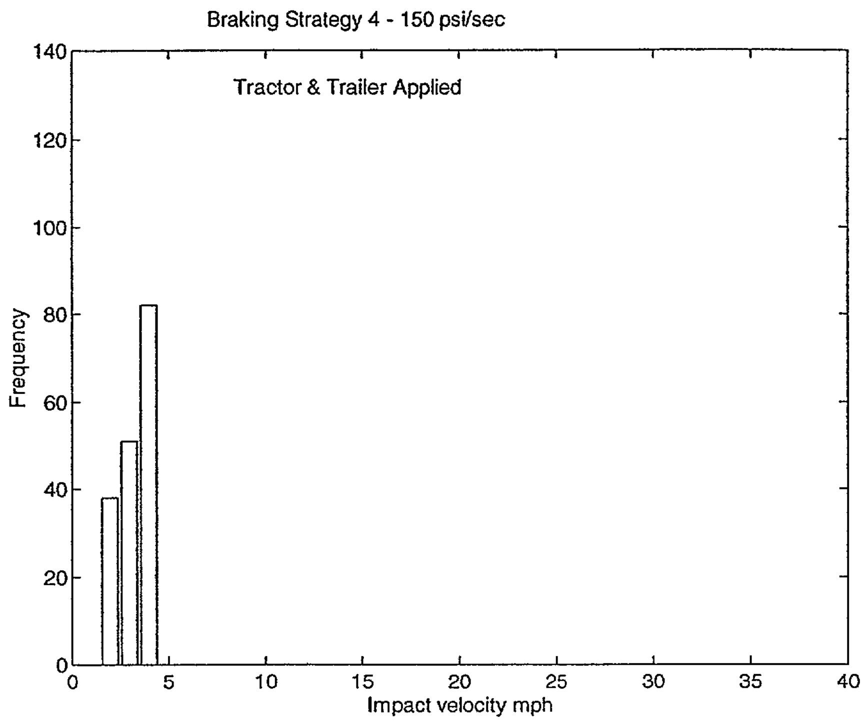

Figure E38 - Impact Velocity

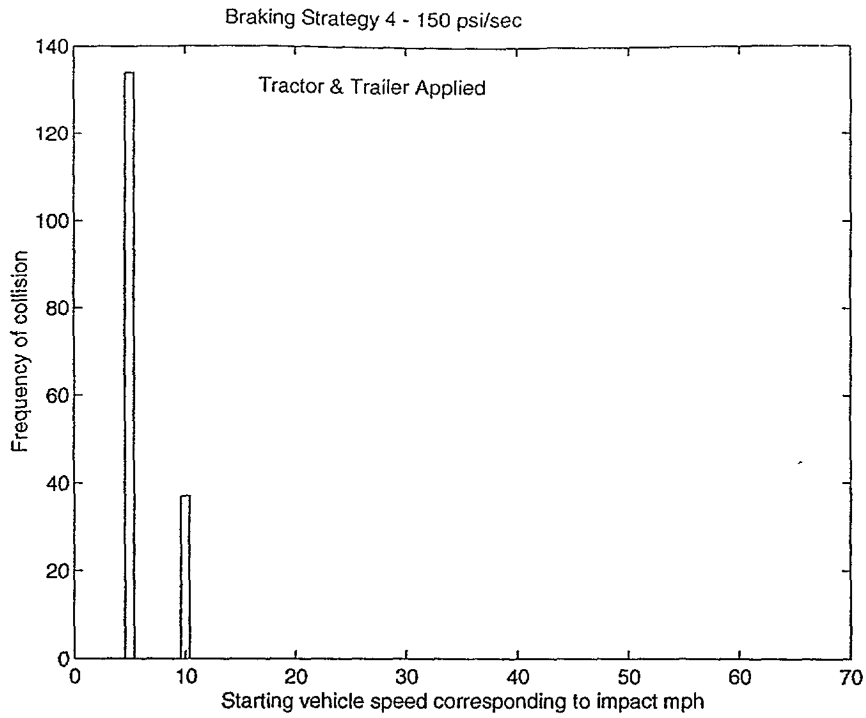

Figure E39 - Number of Collisions at each Starting Vehicle Speed

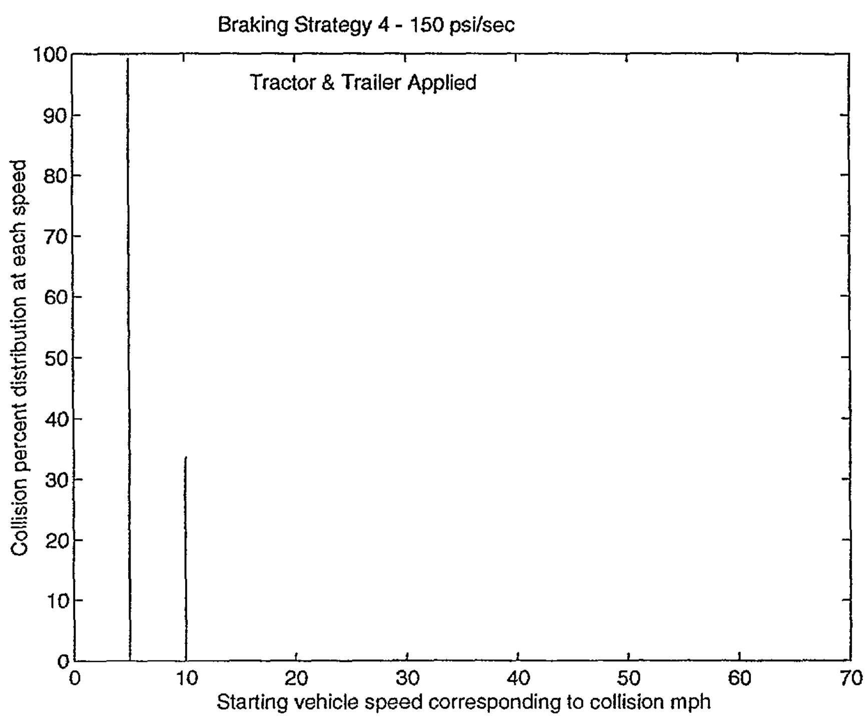

Figure E40 - Percent of Collisions for each Starting Vehicle Speed

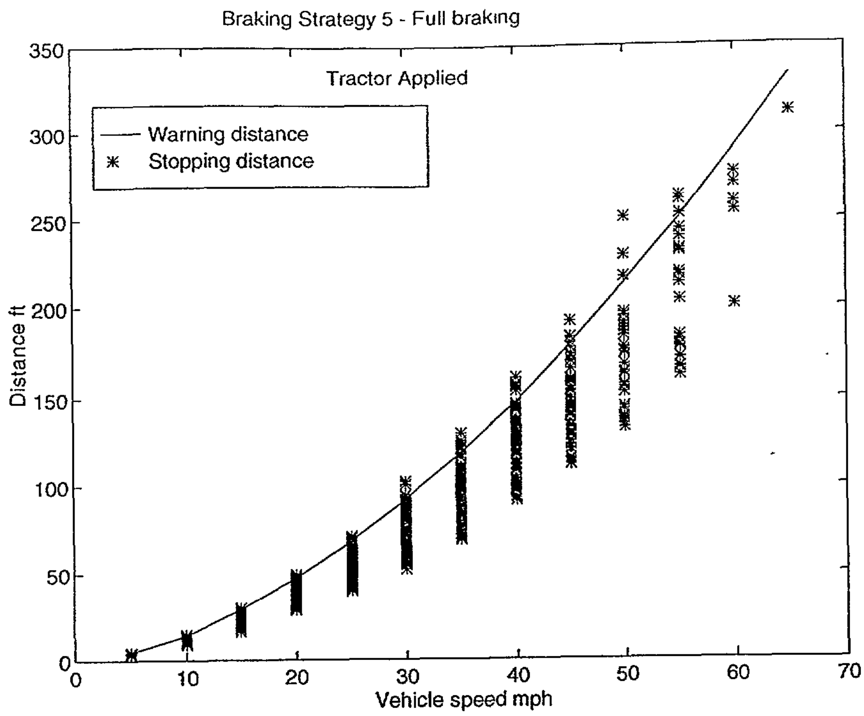

Figure E41 - Accident Reduction Model

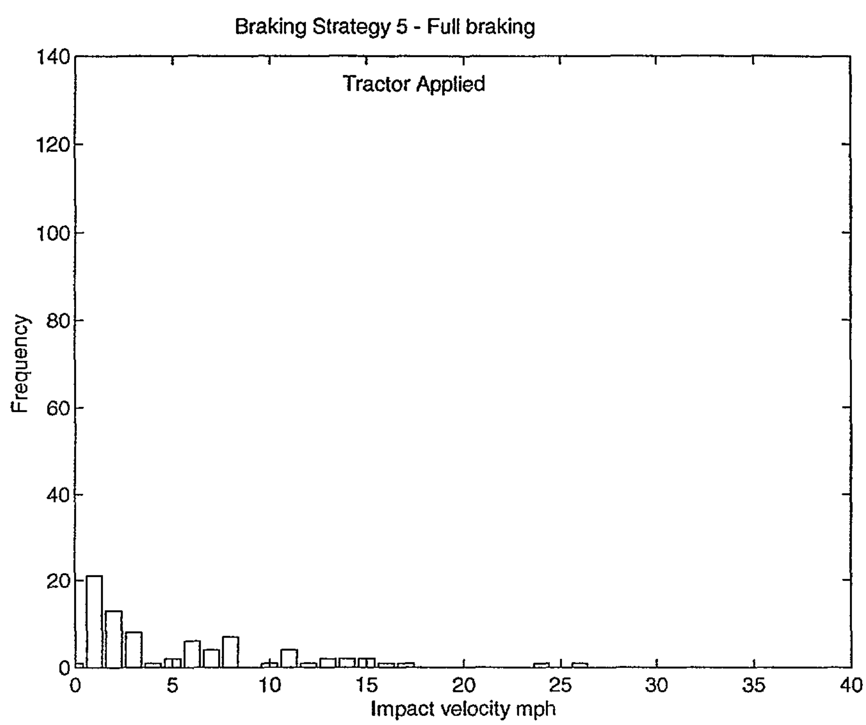

Figure E42 - Impact Velocity

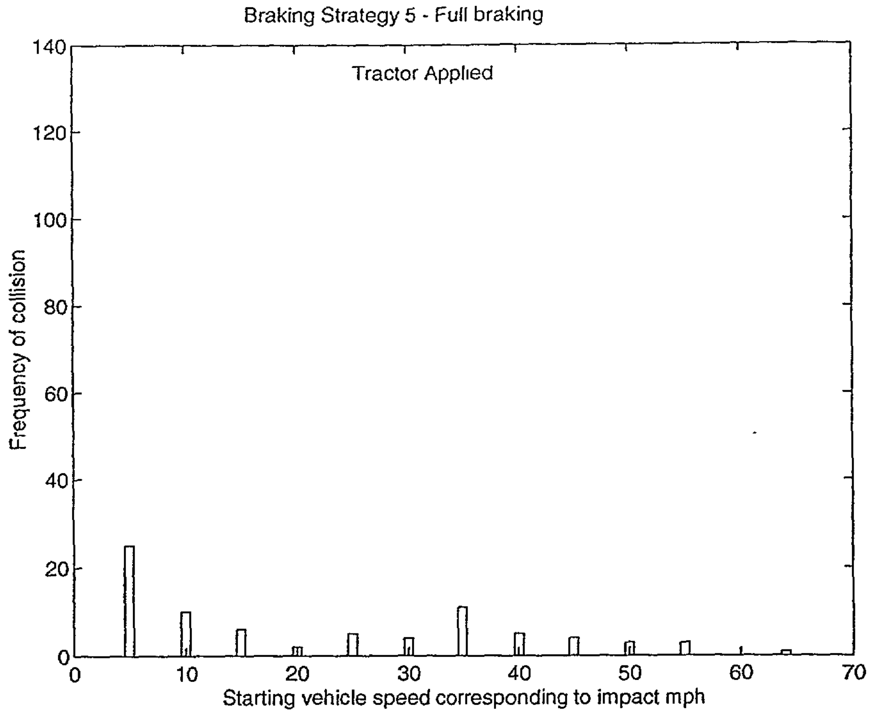

Figure E43 - Number of Collisions at each Starting Vehicle Speed

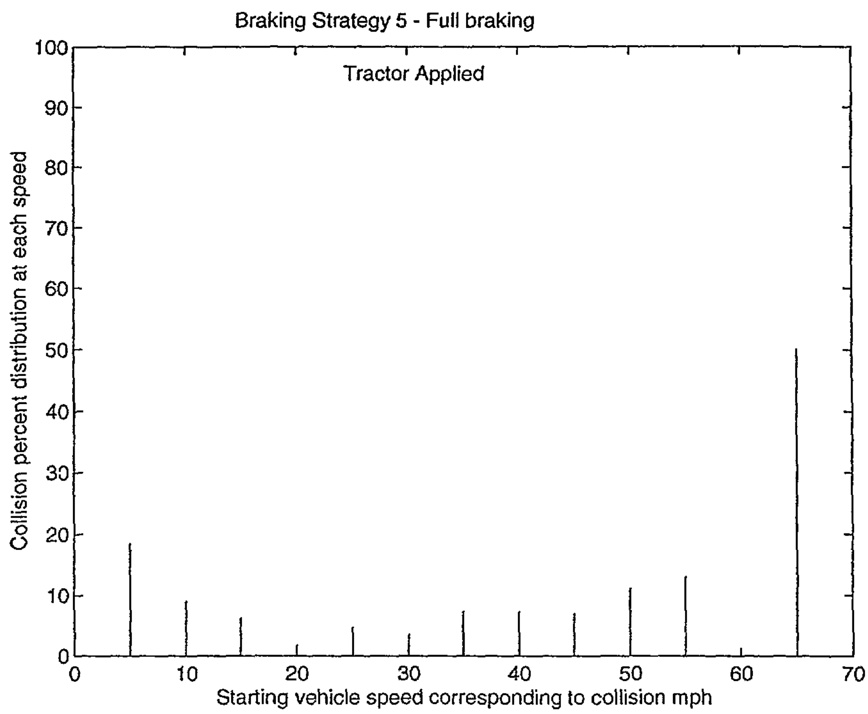

Figure E44 - Percent of Collisions for each Starting Vehicle Speed

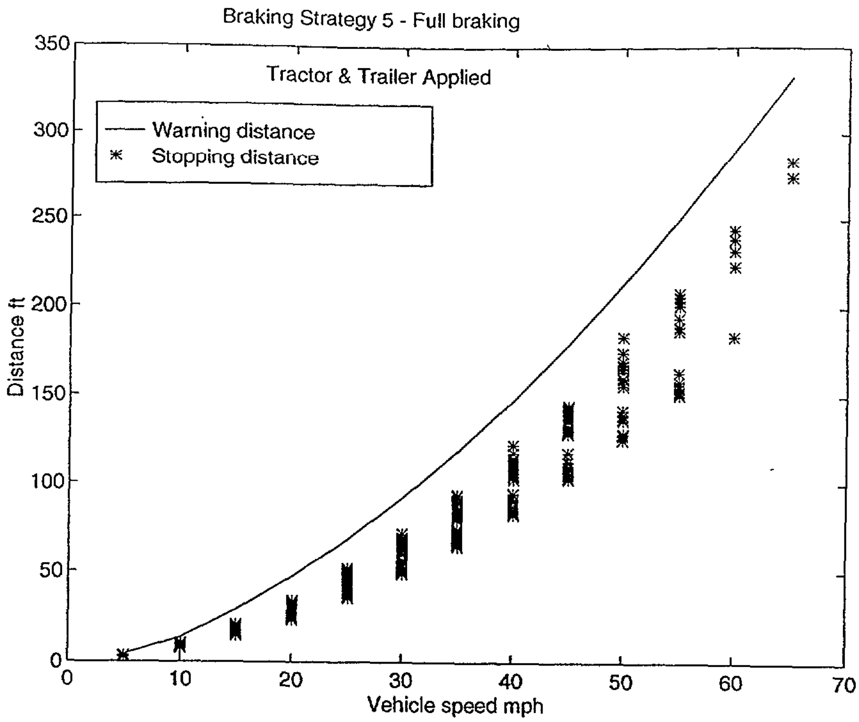

Figure E45 - Accident Reduction Model

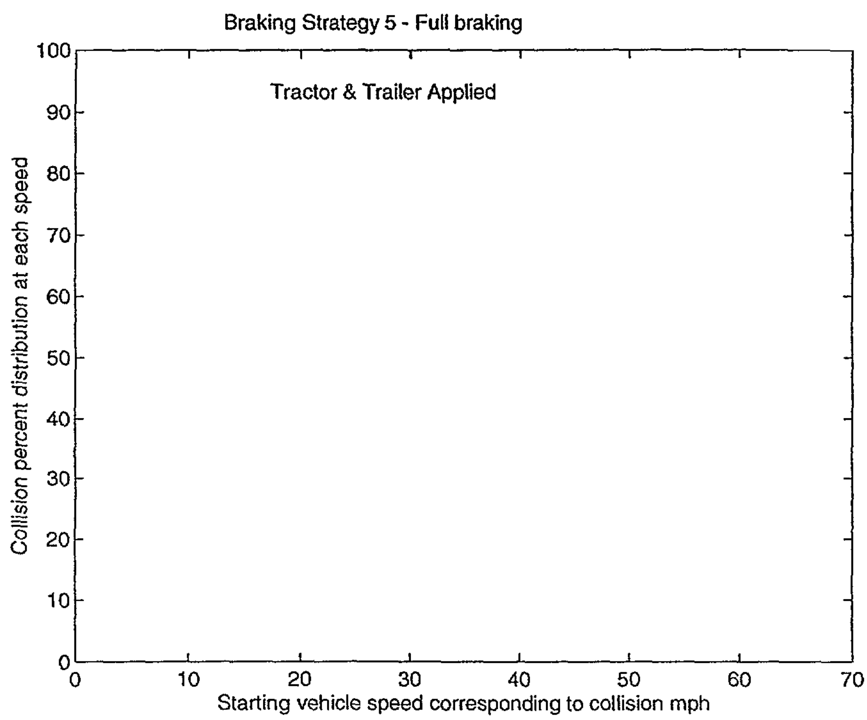

Figure E46 - Impact Velocity

APPENDIX F

North Carolina Police Report Accident Statistics

North Carolina Target Collisions

The North Carolina target collisions as received from UMTRI were matrices similar to Tables F1 and F2. The LV and truck travel speeds shown are pre-crash speeds. The matrix allowed the ready identification of many "unlikely" elements. For example, some cases indicated a high speed lead vehicle and a low speed truck with the lead vehicle's speed at impact = 0. Admittedly, these could be cut-in-front-then-stop accidents; but not all seemed so unlikely. One hundred police reports of these unlikely cases were obtained and reviewed. It turned out that many had been miscoded in one or more variables in transferring them from the policeman's report to the database. Some had the LV and the truck speed entries flipped on the report. About 10 were actually unknown and about 40 were real situations. They generally were one of two types. A lead vehicle changing lanes and then slowing in front of the striking vehicle is one type. The other is where the lead vehicle was stopped then started and then stopped or slowed down when it was struck. Not all of the unlikelies were obtained for review. The reviewed cases were repositioned, but based on the experience from the review process, several points were presumed to be erroneous and simply removed from the dataset.

Tables Fl and F2 are the corrected matrices. The shaded areas represent the target collision set. They are situations that are easy to understand where the truck travel speed was at least as great as the lead vehicle's speed before the collision occurred. The light gre area, where the lead vehicle's pre-accident speed was zero and its speed at impact was zero, are referred to as te lead vehicle stationary subtype, LVS. The remainder are lead vehicle moving subtypes, LVM.

UMTRI noted that the LVS/LVM split of 48%/58% for GES (and 32%/68% for North Carolina) was basically reversed from the 70/30 split of GES data derived for all vehicle types. They offered the explanation that the GESs and North Carolina splits (which were for truck-tractors as the striking vehicle) were quite possibly the result of the "increased braking distances for (these) trucks compared with passenger vehicles and the not infrequent practice of passenger vehicle drivers cutting off trucks in traffic." The relatively large number of cases lying along the diagonal of the matrix could support such a contention. Case reviews were not performed to further establish a cause for the high ratio of LVM cases.

Several cases of truck speeds > 70 mph have been arbitrarily excluded from the target collisions on the basis that the required radar ranging distances will remain marginal for such speeds (given the truck braking capabilities).

1990-1993 North Carolina Data (with 100 'unliklies' verified/corrected)

TRAVEL SPEEDS/LV MOVING(LV IMPACT SPEED>0)

LV Travel Speed(mph)	Truck Travel Speed(mph) 0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	>70	Total
0	6	2	0	0	0	0	2	2	2	3	1	1	2	0	0	0	21
1-5	0	18	8	5	2	2	4	4	4	3	2	6	3	0	1	0	60
6-10	0	0	7	7	4	4	3	6	4	8	8	2	1	1	0	0	55
11-15	0	0	1	2	1	1	2	2	4	3	3	7	0	0	0	0	26
16-20	0	0	0	0	7	1	5	2	6	6	0	11	3	0	0	0	40
21-25	0	0	0	0	0	11	2	1	4	6	1	3	2	2	0	0	32
26-30	0	0	0	0	0	1	17	6	5	6	3	4	1	4	0	0	47
31-35	0	0	0	0	0	0	1	25	2	13	5	5	3	6	0	0	60
36-40	0	0	0	0	0	1	0	0	24	11	8	13	5	7	1	2	72
41-45	0	0	0	0	0	0	0	0	1	64	9	22	8	13	1	0	118
46-50	0	0	0	0	0	0	0	0	0	2	31	33	12	15	2	1	96
51-55	0	0	0	0	0	0	0	0	1	0	3	79	12	35	7	0	137
56-60	0	0	0	0	0	0	0	0	0	0	2	0	6	17	2	2	29
61-65	0	0	0	0	0	0	0	0	0	0	0	0	0	17	5	5	27
66-70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	6	18	16	14	14	21	36	48	56	125	76	186	58	117	19	10	820

Table F1

1990-1993 North Carolina Data (with 100 'unliklies' verified/corrected)

TRAVEL SPEED/LV STOPPED (LV IMPACT SPEED=0)

LV Travel Speed(mph)	Truck Travel Speed(mph) 0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	>70	Total
0	73	130	44	20	19	18	29	51	36	34	15	25	3	2	0	499
1-5	1	12	6	0	2	0	1	1	1	3	0	0	0	0	0	27
6-10	0	3	5	4	2	0	1	2	1	1	0	0	0	0	0	19
11-15	0	0	0	5	0	1	0	0	0	0	1	0	0	0	0	7
16-20	0	0	0	0	6	1	1	1	2	1	0	0	0	0	0	12
21-25	0	0	0	0	0	11	3	0	0	1	0	1	0	0	0	16
26-30	0	0	0	0	2	0	17	4	1	0	2	0	0	0	0	26
31-35	0	0	0	0	1	0	1	35	5	7	1	1	0	0	0	51
36-40	0	0	0	0	1	0	0	0	20	9	3	1	0	0	0	34
41-45	0	0	0	0	0	1	0	0	2	45	3	2	0	0	0	53
46-50	0	0	0	0	0	0	0	0	0	0	14	3	0	0	0	17
51-55	0	0	0	0	0	0	0	0	0	0	4	21	0	0	0	25
56-60	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
61-65	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
110	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	74	145	55	29	33	32	53	94	68	101	43	54	5	5	0	791

National Representation of Target Collisions

Since this analysis is meant to project National benefits, the degree of representation of the target collisions to the accident situations across the nation are important. National speed distributions are not available, so the potential differences must be assessed on the basis of other criteria. The following characteristics were considered influential:

- road surface condition (dry, wet, snow/ice)
- roadway alignment (straight vs. curved)
- roadway profile (level vs. hill)
- road class (interstate vs. non-interstate)

Several tests on GES screened data showed that the variables were stable on a year-to-year basis. Then the North Carolina and GES files were screened and compared. The summary findings and proposed data modification follow.

	1990-92 GES			1990-93 North Carolina		
	Dry	Wet	Total	Dry	Wet	Total
LVS frequency percent	 13,513 87.1	 2,005 12.9	 15,518 100.0	 460 82.4	 98 17.5	 558 100.0
LVM frequency percent	 18,073 80.3	 3,809 19.7	 22,512 100.0	 1,014 84.8	 181 15.2	 1,195 100.0
ALL frequency percent	 31,586 84.5	 5,814 15.5	 37,400 100.0	 1,474 84.1	 279 15.9	 1,753 100.0

Two-vehicle rear-end collision with tractor striking, both vehicles straight, truck did not have brake failure, roads dry or wet only.

Table F3 - Road Surface Condition

The North Carolina data had fewer snowy/icy rear-end collisions than the GES national average. However, the target collisions excluded snowy/icy conditions and the wet vs. dry comparisons from Table F3 are very close. No speed distribution change is called for.

	1990-92 GES			1990-93 North Carolina		
	Straight	Curve	Total	Straight	Curve	Total
LVS frequency percent	 16,164 97.5	 411 2.5	 16,575 100.0	 525 93.6	 36 6.4	 561 100.0
LVM frequency percent	 22,533 96.1	 921 3.9	 23,454 100.0	 1,122 93.0	 85 7.0	 1,207 100.0
ALL frequency percent	 38,698 96.7	 1,332 3.3	 40,030 100.0	 1,647 93.2	 121 6.8	 1,768 100.0

Two-vehicle rear-end collisions with tractor striking, both vehicles straight, truck did not have brake failure.

Table F4 - Roadway Alignment

Table F4 shows that North Carolina has a higher percentage of curved road accidents. However, the target collisions excluded curved road accidents, so the speed distributions are not affected at all.

	1990-92 GES			1990-93 North Carolina		
	Level	Grade	Total	Level	Grade	Total
LVS frequency percent	 10,978 79.0	 2,917 21.0	 13,895 100.0	 403 71.8	 158 28.2	 561 100.0
LVM frequency percent	 15,495 78.1	 4,339 21.9	 19,834 100.0	 848 70.3	 359 29.7	 1,207 100.0
ALL frequency percent	 26,474 78.5	 7,256 21.5	 33,730 100.0	 1,251 70.8	 517 29.2	 1,768 100.0

Two-vehicle rear-end collisions with tractor striking, both vehicles straight, truck did not have brake failure.

Table F5 - Road Profile

Table F5 shows that North Carolina has a higher percentage of rear-end collisions on grades than the national average. To ascertain the effect upon the speed profile, the speed distributions for level and grade situations were compared. They are illustrated in Figures F1 and F2.

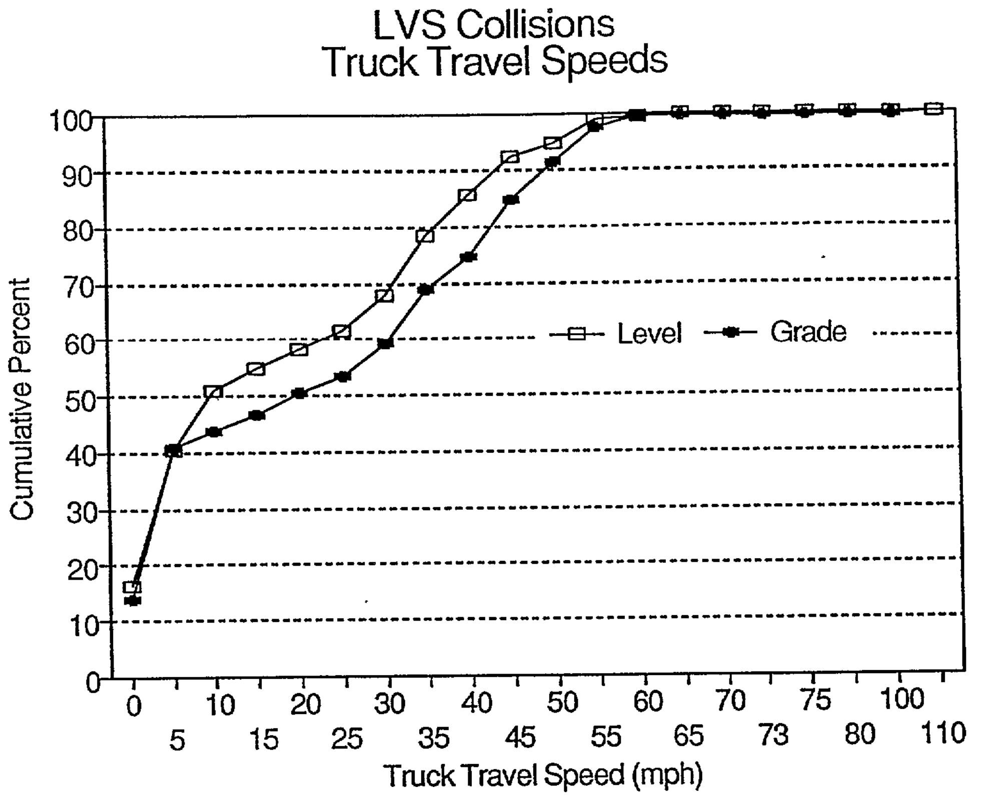

Figure F1 - Memo, March 10, D. Massie, UMTRI

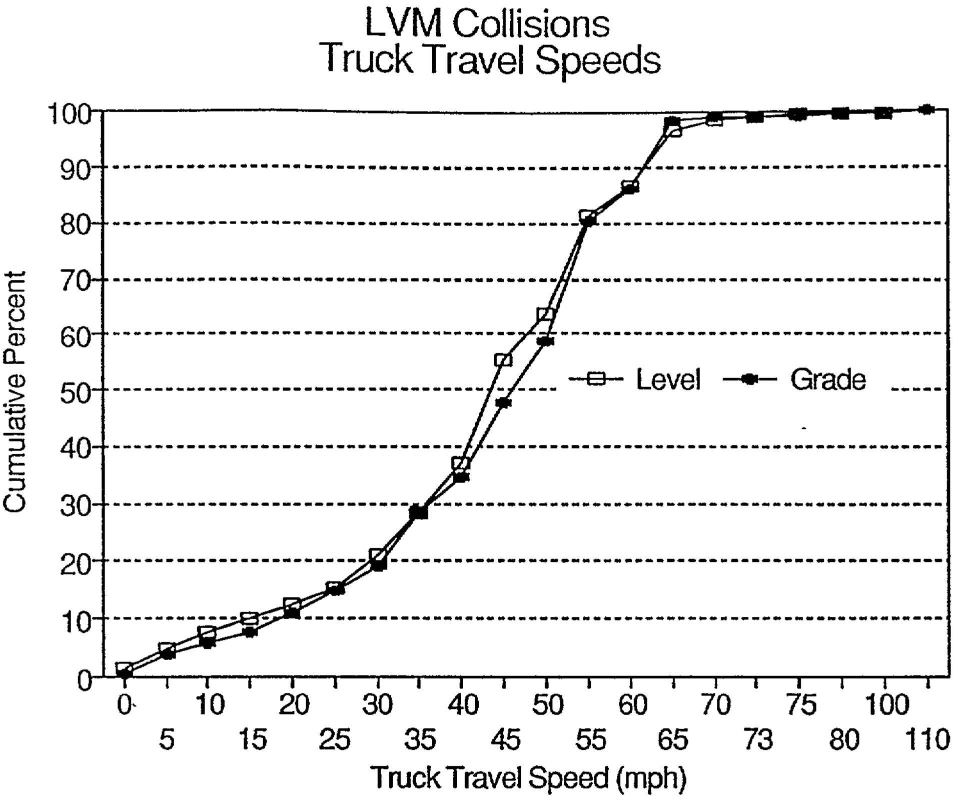

Figure F2 - Memo, March 10, D. Massie, UMTRI

From the LVS cases, it appears that the grade accidents have a higher median speed, i.e., 20 mph vs. 10 mph. So, the North Carolina LVS speed distributions are probably high by approximately 0.8 mph. The LVM cases have a much smaller exaggeration, not worthy of correction since the redistribution methods would most likely generate a greater error than this.

	1990-92 GES			1990-93 North Carolina		
	Interstate	Non-Interstate	Total	Interstate	Non-Interstate	Total
LVS frequency percent	2,747 16.2	14,195 83.8	16,942 100.0	44 7.8	518 92.2	562 100.0
LVM frequency percent	9,433 40.1	14,084 59.9	23,517 100.0	374 31.0	833 69.0	1,207 100.0
ALL frequency percent	12,180 30.1	28,279 69.9	40,459 100.0	418 23.6	1,351 76.4	1,769 100.0

Two-vehicle rear-end collision, tractor striking both vehicles straight, truck did not have brake failure.

Table F6 - Road Class

The Table F6 data shows that North Carolina has a lower percentage of accidents on interstates than the national average. To study the effect this might have on the speed profiles, the speed distributions for the two road classes were compared. They are illustrated in Figures F3 and F4. In the case of the LVS, the number of cases for the interstate class is rather small, 38 cases. This does not provide a high confidence result. However, the LVM group shows significant differences of the non-interstate vs interstate median speeds, i.e., 41 vs. 54 mph respectively.

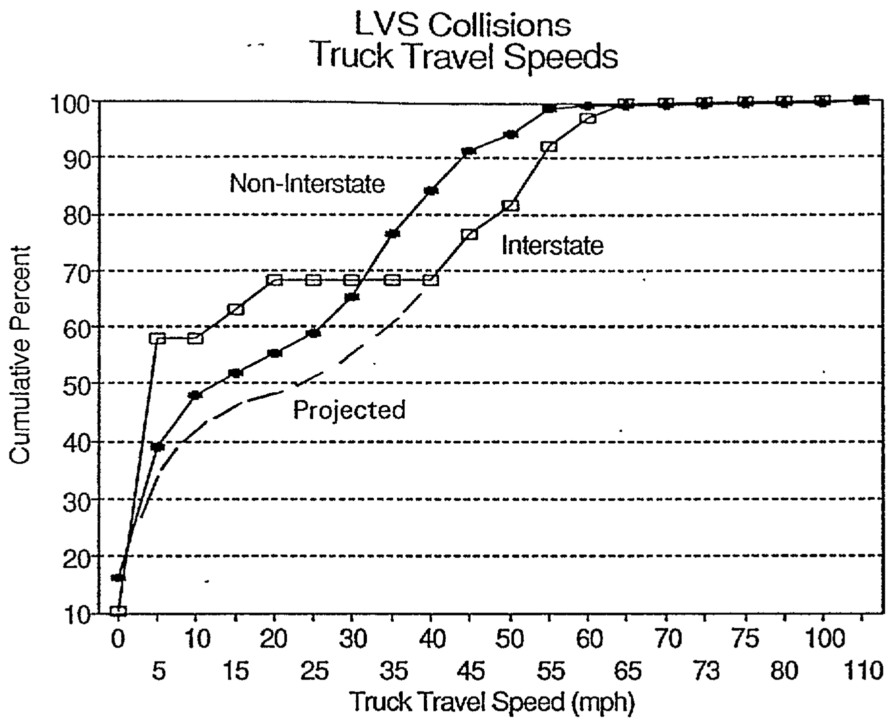

Figure F3 - LVS Speed Distribution

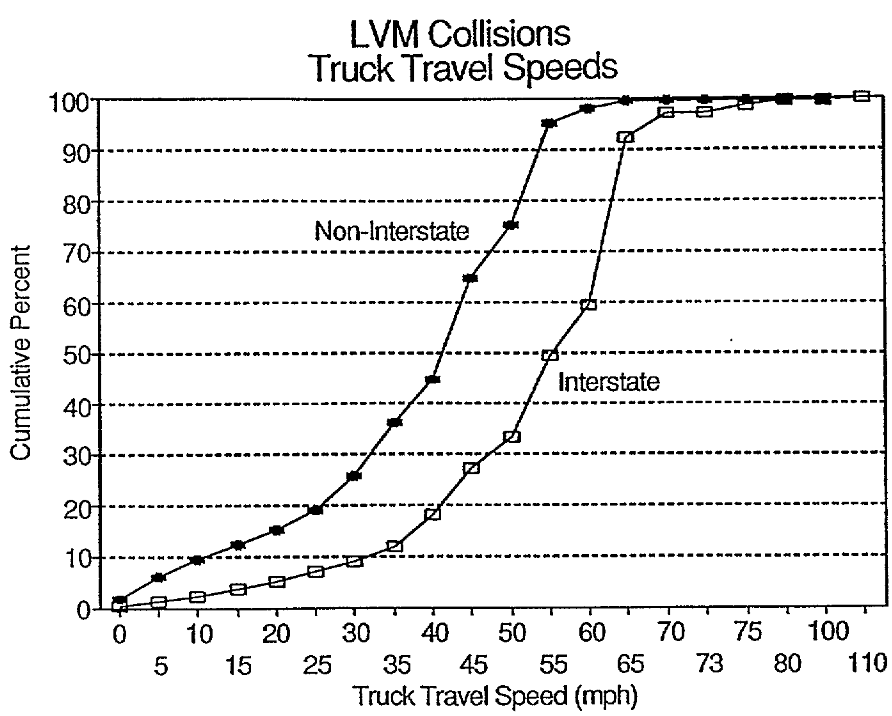

Figure F4 - LVM Speed Distribution

Since the LVS interstate group seems adequate, and since it is intuitive that interstate accident speeds would be higher, the shift of value from the LVM group is assumed to also apply to the LVS grouping. Accordingly, the median speed for the North Carolina LVS interstate group needs to be higher by 54-41=13 mph.

The "projected" cumulative distribution for an adequate group size is also illustrated in Figure F3.

The necessary increase of the North Carolina speed distribution for correspondence to the national level of interstate accidents is about 1.1 mph. (So, the net correction needed to the speed distribution is to increase the median by 1.1 mph for the road class effects and to decrease it by .8 for the road profile effects.) This net change level of 0.3 mph is not worthy of reweighting the speed distribution of the data.

In the previous section, UMTRI's comments on the LVS/LVM splits of 42%/58% GES data and 32%/68% for North Carolina were noted. The differences are not fully known. The North Carolina LVS cases are defined as a lead vehicle pre-crash speed a.nJ speed at impact equal to zero. The GES cases are defined as lead vehicle "stopped in traffic lane" as the coded vehicle maneuver variable. It is probable that the different definitions account for the discrepancy.

The North Carolina definition with its expanded speed information fits the simulation scheme well and its use is prefered fr this analysis.

When referencing the totality of target collisions, the discrepancy is not important, i.e., all the accidents will be counted.

In an LVS only analysis, however, the use of 32% of target collisions may underestimate the population and lead to benefits that are on the conservative side.

Accident Rate Correction for North Carolina Speed Distributions

The original simulations were performed with a mock value for the speed distribution. The mock value was extracted from the Knipling report referenced elsewhere. The use of the mock values facilitated the initiation of the simulation work prior to completion of the search review and nationalization of the North Carolina data. The final speed distributions for LVS accidents can be extracted from Figure Fl and are detailed in Table F7.

														Totals
init speed (mph)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	
target coll's from n.c.	73	130	44	20	19	18	29	51	36	34	15	25	3	2	499
% of total		40.7	8.8	4.0	3.8	3.6	5.8	10.2	7.2	6.8	3.0	5.0	0.6	0.4	100
# of stops of 1000		407	88	40	38	36	58	102	72	68	30	50	6	4	1000

Table F7 - North Carolina LVS Speed Distribution

Eaton Corporation
Corporate R&D-Detroit Center
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Southfield, MI 48037-0766
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