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**National Highway
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NHTSA Technical Report

The Effectiveness of Retroreflective Tape on Heavy Trailers

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16. Abstract

This report evaluates the effectiveness of retroreflective tape in enhancing the visibility of heavy trailers and reducing side and rear impacts by other vehicles into these trailers during dark conditions. It is based on a statistical analysis of 10,959 crash cases investigated by the Florida Highway Patrol and the Pennsylvania State Police in 1997 - 1999.

The tape is quite effective. It reduced side and rear impacts into trailers, in dark conditions (including "dark-not-lighted," "dark-lighted," "dawn," and "dusk") by 29 percent. In "dark-not-lighted" conditions, the tape reduced side and rear impact crashes by 41 percent. Tape is especially effective in reducing injury crashes. In dark conditions, it reduced side and rear impacts that resulted in fatalities or injuries to drivers of any vehicle by 44 percent.

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TABLE OF CONTENTS

TABLE OF CONTENTS iii

ACKNOWLEDGMENTS iv

EXECUTIVE SUMMARY v

INTRODUCTION AND BACKGROUND 1
1.1 HISTORY AND RESULTS OF EARLIER EFFECTIVENESS STUDIES 2
1.2 FMCSA RETROFIT STANDARD 4
1.3 CURRENT STATUS OF TAPE 5

CONSPICUITY DATA 7
2.1 SUPPLEMENTARY FORM 7
2.2 CONSPICUITY DATA BASE 11
2.3 CRASHES NOT INVESTIGATED BY STATE POLICE 20

BASIC ANALYSIS 23
3.1 DEFINITIONS 23
3.2 THE BASIC ANALYSIS 26
3.3 STATISTICAL SIGNIFICANCE AND CONFIDENCE BOUNDS 29
3.4 TAPE EFFECTIVENESS IN SPECIFIC DARK CONDITIONS 32
3.5 COMBINED EFFECTIVENESS AND “BEST” ESTIMATES 33

TAPE EFFECTIVENESS IN SPECIFIC SITUATIONS 39
4.1 EFFECTIVENESS BY COLLISION TYPES 40
4.2 EFFECTIVENESS BY ENVIRONMENTAL/ROADWAY CONDITIONS . . . 42
4.3 EFFECTIVENESS BY TRACTOR/TRAILER CHARACTERISTICS 44
4.4 EFFECTIVENESS BY OTHER DRIVER/VEHICLE CHARACTERISTICS 46
4.5 EFFECTIVENESS BY CRASH-LEVEL INJURY SEVERITY 48
4.6 TAPE EFFECTIVENESS DURING THE DAYLIGHT 49

BENEFITS OF CONSPICUITY TAPE 51
5.1 CRASHES AVOIDED PER YEAR 51
5.2 NONFATAL INJURIES AVOIDED PER YEAR 52
5.3 LIVES SAVED PER YEAR 52

REFERENCES 55

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EXECUTIVE SUMMARY

All heavy trailers manufactured on or after December 1, 1993 must be equipped with red-and-white retroreflective tape, sheeting and/or reflex reflectors around the sides and rear to make them more conspicuous. The National Highway Traffic Safety Administration (NHTSA) established this requirement, with its various options, in December 1992 by amending Federal Motor Vehicle Safety Standard (FMVSS) No. 108, "Lamps, Reflective Devices, and Associated Equipment." However, retroreflective tape has been used almost exclusively for meeting the standard, and it is the subject of this evaluation. Heavy trailers are at least 80 inches wide and have a Gross Vehicle Weight Rating over 10,000 pounds.

The purpose of retroreflective tape is to increase the visibility of heavy trailers to other motorists, especially in the dark. At those times, the tape brightly reflects other motorists' headlights and warns them that they are closing on a heavy trailer. In the dark, without the tape, many trailers do not become visible to other road users until they are dangerously close. The alternating red-and-white pattern flags its bearer as a heavy trailer and at the same time helps other road users gauge their distance and rate of approach. This report evaluates the effectiveness of the tape in reducing side and rear impacts into heavy trailers - primarily in dark conditions where even a vigilant motorist might not see an untreated trailer in time to avoid a crash, and secondarily in daylight, where the tape might alert inattentive drivers that they are approaching a trailer.

In March 1999, the Federal Highway Administration extended the application of this important protection to the entire on-road trailer fleet by directing motor carriers engaged in interstate commerce to retrofit heavy trailers manufactured before December 1993 with tape or reflectors. These older trailers must have some form of conspicuity treatment, by June 1, 2001, in the locations specified by the NHTSA standard for new trailers, except on the rear impact guard. In other words, as of June 2001, almost all heavy trailers on the road will have some form of conspicuity treatment. This Federal Motor Carrier Safety Regulation furthermore gives motor carriers until June 1, 2009 to retire their pre-1993 trailers or retrofit them with treatments that conform exactly to the NHTSA standard (again, with the exception of the rear impact guard).

Since none of NHTSA's crash data at hand (FARS, NASS, or State files) identified whether crash-involved heavy trailers had retroreflective tape, NHTSA worked out agreements with the Florida Highway Patrol (FHP) and the Pennsylvania State Police (PSP) to collect data for this analysis. For a two-year period, each time these agencies investigated a crash involving a tractor-trailer and filed a crash report, they also filled out an "Investigator's Supplementary Truck-Tractor Trailer Accident Report" on every trailer in the crash. The FHP collected 6,095 crash cases from June 1, 1997, through May 31, 1999. The PSP collected 4,864 crash cases from December 1, 1997, through November 30, 1999.

The analysis estimates the reduction of side and rear impacts by other vehicles into tape-equipped trailers in dark conditions - relative to the number that would have been expected if the trailers had not been equipped. It is based on tabulating and statistically analyzing crash involvements of tractor-trailers by three critical parameters: (1) whether or not the trailer is tape-equipped; (2) the light condition - dark (comprising "dark-not-lighted," "dark-lighted," "dawn" and "dusk") vs. daylight; and (3) relevant vs. control-group crash involvements. Relevant crash involvements are those where another vehicle crashed into the side or rear of a heavy trailer, because the tape can help the other driver see and possibly avoid hitting the trailer. The control group consists of single-vehicle crashes of tractor-trailers (where visibility of the tractor-trailer to other road users is not an issue at all) and impacts of the front of the tractor into other vehicles (where conspicuity of the side and rear of the trailer is also not an issue).

The principal conclusion of the study is that retroreflective tape is quite effective, and it significantly reduces side and rear impacts into heavy trailers in the dark. Other findings and conclusions are the following:

ANNUAL BENEFITS OF CONSPICUITY TAPE

- When all heavy trailers have conspicuity tape, the tape will be saving an estimated 191 to 350 lives per year, preventing approximately 3,100 to 5,000 injuries per year, and preventing approximately 7,800 crashes per year, relative to a hypothetical fleet in which none of the trailers have the tape.

CRASH REDUCTIONS BY LIGHTING CONDITIONS

- In dark conditions (combining the subsets of "dark-not-lighted," "dark-lighted," "dawn," and "dusk"), the tape reduces side and rear impacts into heavy trailers by 29 percent. The reduction is statistically significant (confidence bounds: 19 to 39 percent).

- However, the tape is by far the most effective in dark-not-lighted conditions. Here, the tape reduces side and rear impacts into heavy trailers by 41 percent. The reduction is statistically significant (confidence bounds: 31 to 51 percent).

- In dark-lighted, dawn, and dusk conditions, the tape did not significantly reduce crashes. The tape also did not significantly reduce crashes during daylight.

CRASH REDUCTIONS FOR SPECIFIC SUBGROUPS IN DARK CONDITIONS

The effectiveness estimates here are the percentage reductions of various subgroups of the side and rear impacts into heavy trailers in dark conditions. As stated above, tape reduces these crash involvements by 29 percent, overall.

- The tape is especially effective in preventing the more severe crashes, specifically, injury crashes. Impacts resulting in fatal or nonfatal injuries to at least one driver are reduced by 44 percent.

- The tape is more effective when the driver of the impacting vehicle is young. The crash reduction is 44 percent when the driver of the impacting vehicle is 15 to 50 years old, but only 20 percent when that driver is more than 50 years old. A possible explanation of this difference is that older drivers are less able to see, recognize and/or react to the tape in time to avoid hitting the trailer.

- The tape may be somewhat more effective in preventing rear impacts (43 percent) than side impacts (17 percent) into trailers; however, this difference is not consistent in the two states.

- The tape is effective in both clear (28 percent) and rainy/foggy weather conditions (31 percent).

- The tape is especially effective on flatbed trailers (55 percent). These low-profile vehicles must have been especially difficult to see in the dark before they were treated with tape.

- Dirt on the tape significantly diminished its effectiveness in rear impacts. Clean tape reduces rear impacts by 53 percent but dirty tape by only 27 percent.

STATUS OF TAPE IN THE 1997-1999 CRASH DATA

- Almost 50 percent of the pre-standard trailers in the study had retroreflective tape. The retrofit of these older, pre-1993 trailers was already well underway in 1997 - 1999.

- More than 60 percent of the trailers with retroreflective tape had clean tape at the time of the study. About 30 percent of the trailers with tape had some dirt and less than 5 percent had “very dirty” tape.

- About 96 to 99 percent of the retroreflective tape on the side of trailers was intact, while 92 to 95 percent of the tape on the rear of trailers was intact.

CHAPTER 1

INTRODUCTION AND BACKGROUND

In September 1992, the National Highway Traffic Safety Administration (NHTSA) amended Federal Motor Vehicle Safety Standard (FMVSS) No. 108, "Lamps, Reflective Devices, and Associated Equipment," by adding a Conspicuity Systems provision. This revision, effective December 1, 1993, requires that heavy trailers (i.e., those 80 or more inches in width with a Gross Vehicle Weight Rating over 10,000 pounds) manufactured on and after this date be equipped with reflective material. Two types of material are permitted -- (1) retroreflective sheeting, or tape, and (2) reflex reflectors. A combination of the two types is also permissible. However, retroreflective tape has been used almost exclusively for meeting the standard, and it is the subject of this evaluation. Essentially, the tape must outline the bottom of the sides of the trailers and the top corners, bottom and underride guard of the rear of the trailers. The tape must be applied in a pattern of white and red color segments to the sides and rear of the trailer and in white to the upper rear corners of the trailer. Specifications for affixing the tape to the sides and rear of the trailers are contained in Title 49, Part 571, Section 108 of the Code of Federal Regulations (i.e., 49 CFR 571.108).

The purpose of the regulation is to make heavy trailers more conspicuous to other motorists. Studies of highway crashes where other motor vehicles collide with combination trucks (truck tractor plus heavy trailer) have indicated that, in a number of these crashes, the operator of the other vehicle may not have seen the combination truck in time to avoid a collision. Such crashes are more likely to occur in dark conditions or under other conditions of decreased visibility -- i.e., adverse weather conditions such as rain, snow, or fog. The light reflection qualities of the tape, particularly from sources such as automobile headlamps, enhance the conspicuousness of the heavy trailer, thereby also increasing the chances that the attention of other drivers in the vicinity will be directed to the combination truck. It is hoped that the tape, with its alternating red-white pattern, will also help those drivers more accurately assess the closing rate and distance between their vehicle and the combination truck.

The tape is expected to be more effective in dark conditions, when combination trucks are harder to see, than during daylight. The amount of light should also influence the effectiveness of the tape. The tape should be more effective on unlighted dark roads than on lighted roads, or during dawn or dusk when some light is available.

The tape should also reduce collisions into the rear and side of combination trucks especially in dark conditions, since the tape is on the side and rear of trailers. In rear impacts, your headlights will shine on the rear of the trailer and illuminate the tape, so you can detect the vehicle and avoid a collision. In side impacts where you are moving exactly or nearly perpendicular to the combination truck and especially if the combination truck is moving slowly or stopped, the tape is expected to be highly effective. In this case, your headlights will illuminate the side of the trailer and you may have enough time to avoid the collision. The tape may be less effective in preventing sideswipe crashes where you are moving parallel to the combination truck. In this case, the angle between your headlights and side of the trailer may be too small to illuminate the tape. The tape is unlikely to have an effect in collisions with the front of the combination truck or on any single-vehicle crashes of combination trucks.

The Government Performance and Results Act of 1993 and Executive Order 12866 (October 1993) require agencies to conduct periodic evaluations to assess the effectiveness of their existing vehicle safety standards. This report evaluates the effectiveness of retroreflective tape on heavy trailers required by FMVSS 108 (Lamps, Reflective Devices, and Associated Equipment). This evaluation will show if the tape reduces the number of side and rear impacts to trailers in dark conditions.

Throughout the remainder of the report, a truck tractor pulling one or more trailers -- i.e., tractor with semi-trailer, full trailer, or two trailers will be referred to as a combination truck, retroreflective tape will sometimes be referred to as tape, and heavy trailers will sometimes be referred to as trailers.

1.1 HISTORY AND RESULTS OF EARLIER EFFECTIVENESS STUDIES

Several early studies of combination truck crashes concluded that increasing the conspicuity of heavy trailers in dark conditions would reduce some of these crashes. Minahan and O'Day analyzed fatal car into combination truck crashes in Michigan and Texas and found that such crashes usually occur in the dark with frequent car underrides[1]. They concluded that the driver of the other vehicle did not detect the presence of the combination truck in time to avoid a collision. On the basis of these findings, it was concluded that improvements in the conspicuity of heavy trailers might reduce the frequency and severity of these crashes. Another analysis of the collisions of cars with tractor-semitrailers, based on the 1977 Fatality Analysis Reporting System (FARS), also found that such collisions are overrepresented in dark conditions and concluded the addition of lights or reflective paints on trucks and trailers would reduce the frequency of collisions[2].

In 1980, the agency initiated a three-phase research project to develop and evaluate an optimal configuration of heavy-truck and truck-trailer markings and lights. Phase I of this project entailed

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[1]Minahan, D. J. and O'Day, J., *Car-Truck Fatal Accidents in Michigan and Texas,* University of Michigan Highway Safety Research Institute, Report No. UM-HSRI-77-49, Ann Arbor, MI, 1977.

[2]Green, P., et al., *Accidents and the Nighttime Conspicuity of Trucks*, University of Michigan Highway Safety Research Institute, Report No. UM-HSRI-79-92, Ann Arbor, MI 1979.

analyzing the problem of other vehicles striking large trucks and trailers.[3] The work included interviewing trucking company representatives, analyzing crash data, modeling driver behavior, and analyzing active lighting and passive reflective material. The results indicated that crashes in which conspicuity might conceivably have been a factor were equally distributed between daylight and dark conditions and involved collisions with both the sides and rear of the trailer. Rear impacts tend to occur when the combination truck is traveling straight ahead and moving slowly, stopping or stopped on the roadway. The following driver either 1) does not see the combination truck at all, 2) sees the combination truck but misjudges its motion and/or distance, or 3) correctly perceives the combination truck's dynamics and distance, but too late. Moreover, collisions of this sort are more severe in dark conditions. Side impacts most often occur when the combination truck is turning or being astride lanes, e.g. backing, making U-turns, etc. Sideswipe crashes often occur while the combination truck is traveling straight.

Phase II entailed conducting a series of laboratory and field studies to determine the best way to mark heavy trailers and improve other drivers' abilities to: 1) quickly and accurately identify combination trucks in the traffic stream, 2) judge their rate of closure, and 3) estimate their distance from combination trucks.[4] The most effective marking scheme identified in these studies consisted of a strip of alternating colors outlining the side and rear perimeters of the trailers and a U-shaped outline of the mudflaps.

Phase III of the research project was a fleet study to evaluate the crash reduction effectiveness of the reflective tape to the sides and rears of commercial trailers.[5] The study, conducted by Vector Enterprises, Inc., took place over a 23-month period in 1983-1985. A total of 3,820 van trailers were selected for participation; half were treated with retroreflective tape; the other half served as a control group against which the performance of the treated trailers was compared. However, because of cost considerations, 1,910 treated van trailers in the study were equipped with less reflectorized material than that recommended by the Phase Two study. The Vector conspicuity scheme used alternately hatched red and white or blue and white, two-inch wide strips of retroreflective tape to outline the lower side rail on both sides of the trailer and the rear perimeter of the trailer. Each of the two groups accumulated 106 million miles of exposure during the study period. The study concluded that tractor-trailer combinations in the treated fleet were struck by

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[3]Burger, W. J., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task I – Accident Analysis and Functional Requirements*, NHTSA Report No. DOT HS 806 100, Washington, DC, 1981.

[4]Ziedman, K., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task II – Analyses, Experiments and Design Recommendations*, NHTSA Report No. DOT HS 806 098, Washington, DC, 1981.

[5]Burger, W. J., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task III – Field Test Evaluation of Vehicle Reflectorization Effectiveness,* NHTSA Report No. DOT HS 806 923, Washington, DC, 1985.

other vehicles 15 percent fewer times than were combinations in the control fleet; the report did not distinguish side from rear impacts.

The results of the fleet study were found to vary somewhat according to the number of crashes considered to be relevant -- that is, the number of crashes whose occurrence could be considered to have been affected by the conspicuousness of the trailer. After extensive review and reanalysis of the fleet test results, including solicitation of viewpoints from the public, NHTSA concluded that the potential benefits from retroreflective marking of heavy trailers were sufficient to warrant such a requirement under FMVSS 108. From its final review of the field test analyses, the agency estimated that the use of the material would reduce crashes into the side and rear of combination trucks in dark conditions by 15 percent and 25 percent, respectively.[6] It was also estimated that injuries and fatalities in these crashes would be reduced by 15 percent.

A study[7] sponsored by NHTSA defined the large truck conspicuity enhancements that ought to be used as a basis for the revised Federal regulations. The study recommended the retroreflective tape width, color, pattern, and placement. The study also recommended the appropriate retroreflective efficiency level, taking into account the effects of environmental dirt, aging, and orientation of the marked vehicle. The current NHTSA standard generally incorporates these recommendations.

1.2 FMCSA RETROFIT STANDARD

On March 31, 1999, the Federal Highway Administration (FHWA) published a final rule amending the Federal Motor Carrier Safety Regulations (FMCSRs) to require motor carriers engaged in interstate commerce to install retroreflective tape or reflex reflectors on the sides and rear of trailers manufactured prior to December 1, 1993. The final rule gives motor carriers until June 1, 2001, to install some form of conspicuity treatment in the same locations that NHTSA requires manufacturers to install such treatments, with the exception of the rear impact guard. Motor carriers have until June 1, 2009, to install conspicuity treatments identical to that required on new vehicles, with the exception of the rear impact guard. Effective January 2000, the authority for issuing and enforcing FMCSRs was transferred to a new agency within the Department of Transportation, the Federal Motor Carrier Safety Administration (FMCSA)

There are two notable differences between NHTSA's standard for new trailers manufactured on or after December 1, 1993 and FMCSA's retrofit requirement for trailers manufactured before

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[6] *Preliminary Regulatory Evaluation - Proposed Amendment to FMVSS No. 108 to Require Retroreflective Material on the Side and Rears of Heavy Trailers*, NHTSA, Washington, DC, 1991.

[7] Olsen, P. L., et al., *Performance Requirements for Large Truck Conspicuity Enhancements*, NHTSA Report No. DOT HS 807 815, Washington, DC, 1992

December 1, 1993. The NHTSA standard requires an alternating red and white pattern. FMCSA encourages the use of a red-and-white pattern, but allows flexibility in terms of colors or color combinations from June 1, 2001 through June 1, 2009. After June 1, 2009, these trailers, if they are still in service, will have to have the red-and-white pattern. The second difference is that on the rear, NHTSA requires two red and white applications, one the full width of the vehicle and the other the full width of the underride guard. The FMCSA requires only the full width of the vehicle.

A standardized appearance will assist motorists so that they can quickly recognize the image of the reflective tape in the dark and associate it with a trailer. Therefore, it alerts motorists to the presence or motion of the trailer, even if the body of the trailer is not visible.

1.3 CURRENT STATUS OF TAPE

Table 1-1 shows the percentage of trailers that have tape and the percentage of trailers with FMVSS 108 tape by state and calendar year. The percentage of trailers with tape is increasing over time. This suggests that the retrofitting of trailers with tape is proceeding. An observational study by NHTSA staff in 1996 found about 60 percent of the combination trucks had trailers with tape. The vehicles were observed at a weigh station along a major interstate in two states, Florida and Pennsylvania. By 1999, almost 70 percent of the trailers had tape in Florida and almost 80 percent in Pennsylvania. The 1997-1999 data is from a recent study of truck-trailer crashes collected to evaluate the effectiveness of conspicuity tape. Florida collected data from June1, 1997, through May 31, 1999 and Pennsylvania from December 1, 1997, through November 30,1999. Therefore, the Florida 1999 data is from only the first five months of the year, while the Pennsylvania 1999 data is from almost the full year, January through November. (See Chapter 2 for more information about the conspicuity data.)

TABLE 1-1
Observational and Conspicuity Crash Data
Trailers by Tape Configuration, State, and Calendar Year

	Total Trailers	Trailers With Tape		With FMVSS 108 Tape		% of Trailers w/Tape that meet FMVSS 108
Florida						
1996 (Observed)	453	271	60%	181	40%	67%
1997 (Crashes)	1,904	1,060	56%	962	51%	91%
1998	3,224	2,002	62%	1,864	58%	93%
1999	1,275	863	68%	811	64%	94%
Pennsylvania						
1996 (Observed)	1,116	632	57%	500	45%	79%
1997 (Crashes)	298	206	69%	191	64%	93%
1998	2,457	1,745	71%	1,612	66%	92%
1999	2,430	1,908	79%	1,776	73%	93%

Table 1-2 shows the percentage of pre-standard trailers (trailer model year less than 1993 that are not required to have tape until June 1, 2001) that have tape and the percentage of pre-standard trailers with FMVSS 108 tape by state and calendar year. The observational data cannot be separated by model year and are not included in this table. Here, there is a 10 percentage point increase in the trailers with tape in Florida from 1997 to 1999. In Pennsylvania, there is an 8 percentage point increase from 1998 to 1999. The 1997 Pennsylvania data is from only one month, December, and is not a large enough sample to accurately represent the status of trailers with tape.

TABLE 1-2
Pre-1993 Trailers by Tape Configuration, State, and Calendar Year

	Total Trailers	With Tape		With FMVSS 108 Tape		% of Trailer w/Tape that meet FMVSS 108
Florida						
1997	1,091	417	38%	349	32%	84%
1998	1,711	715	42%	622	36%	87%
1999	660	317	48%	283	43%	89%
Pennsylvania						
1997	108	60	56%	54	50%	90%
1998	725	339	47%	289	40%	85%
1999	654	360	55%	310	47%	86%

Table 1-1 and 1-2 also shows the percentage of trailers with tape that meet FMVSS 108 requirements. In Table 1-1, the 1996 data is noticeably different than the later years in the percentage of trailers with tape that meet the 108 standard. In the 1996 observational survey, the tape had to meet the NHTSA standard exactly, while the tape had to meet or be similar to the standard in the 1997-1999 crash data. The criteria the police officers used to judge whether the tape was similar or dissimilar to FMVSS 108 is not known. In 1999, about 93 percent of all trailers with tape have tape that meets the NHTSA standard or is similar to the standard.
Table 1-2 shows that about 86 percent of the retrofitted trailers with tape in 1999 have tape complying with FMVSS 108 although not required until 2009. Thus, a large majority of trailers with tape already have a standardized appearance.

CHAPTER 2

CONSPICUITY DATA

Typically, studies to assess the effectiveness of a vehicle safety standard consist of the collection and analysis of highway crash data which compare the experience of vehicles that meet the safety standard with the experience of vehicles that do not meet the standard. For most evaluation studies, this is a comparison of the crash experience of vehicles built before the effective date of the given standard with the crash experience of the vehicles built subsequent to the effective date of the standard. All trailers manufactured on and after December 1, 1993, are required to be equipped with the retroreflective material. Retroreflective tape was the primary choice of material. However, many trucking firms equipped their new trailers with the special tape prior to the December 1993 effective date of the NHTSA requirement. Companies have added reflective tape to their older (i.e., pre-December 1, 1993, manufacture) trailers since the NHTSA conspicuity requirement was issued and in response to FMCSA retrofit standard. Therefore, it was necessary to obtain more information on the crash-involved trailer than just its date of manufacture (which can be derived from the trailer Vehicle Identification Number or VIN). It was necessary to observe directly whether or not the trailers were equipped with retroreflective tape. None of the existing NHTSA crash data sets (FARS, NASS CDS, NASS GES, or the State data) identify whether or not a crash involving heavy trailers had this tape. NHTSA had to collect and create a new data set containing this essential data element.

2.1 SUPPLEMENTARY FORM

NHTSA created the "Investigator's Supplementary Truck-Tractor Trailer Accident Report" form to collect the necessary tape information on trailers. Most of the supplementary elements pertain only to the trailer (or trailers) being pulled by the truck tractors. Other data items collected on the form besides the presence of retroreflective tape are:

(1) whether or not the application pattern conforms to the FMVSS 108 requirement,
(2) the color(s) of the tape,
(3) the condition of the tape with respect to the presence/accumulation of dirt or other agents which could degrade the reflectivity,
(4) whether the tape is damaged or has missing segments,
(5) the weather conditions at the time of the crash,
(6) the light conditions (i.e., dark, daylight, dusk, etc.) at the time of the crash,
(7) the date, time, and day of week of the crash,
(8) the county, city, road and speed limit of the crash, and
(9) the state accident report number, to allow eventual linkage to the state crash file.

The supplementary form was commonly referred to as the "NHTSA Green" because it was printed on green paper. A copy of the NHTSA Green form is on Page 9 and the instructions for the form are on Page 10.

Other data elements describing the crash are also required for this analysis such as:

(1) the crash configuration (i.e., other vehicle into combination truck rear, other vehicle into combination truck side, etc.).
(2) a diagram/narrative explanation of the crash.
(3) estimates of damage to the other vehicle, and to the combination truck, in descriptive terms.
(4) injuries and fatalities resulting from the crash.
(5) contributing factors or other conditions surrounding the crash (alcohol, speeding, fail to yield, etc.).

These data elements are routinely collected on Police Accident Report (PAR) forms. Therefore, data from both the NHTSA Green and the basic PAR forms were necessary for this analysis.

The Florida Highway Patrol (FHP) and the Pennsylvania State Police (PSP) agreed to collect the necessary data for this analysis. For a two-year period, each time they investigated a crash involving a tractor-trailer and filed a PAR, they also completed a NHTSA Green form on every trailer in the crash. A tractor-trailer combination was defined as a truck tractor pulling one or more trailers -- i.e., tractor with semi-trailer, full trailer, or two trailers. Only crashes investigated and reported by these agencies were included in the study. Crashes where the PAR was filed by local police, sheriffs, other police agencies, or the drivers themselves were not included. In 1998, the FHP collected 59 percent and the PSP collected 60 percent of all crashes involving a tractor trailer in their States. See Section 2.3 for a discussion on crashes not investigated by state police and how this will not significantly affect our effectiveness estimates.

For each crash reported, the FHP and the PSP provided NHTSA with a copy of the State PAR and the respective NHTSA Green stapled together, with the NHTSA Green displaying the same accident report number as the State report. The FHP collected data from June 1, 1997, through May 31, 1999. The PSP collected data from December 1, 1997, through November 30, 1999.

OMB No. 2127-0585
Expiration Date: 1/31/2000

U.S. Department of Transportation
National Highway Traffic Safety Administration

Investigator's Supplementary Truck-Tractor Trailer Accident Report

National Highway Traffic Safety Administration Special Study

(To be completed for all accidents involving a truck-tractor pulling one, or more, trailers)

(See Instructions on reverse side)

1

Date of Accident	Day of Accident	Time of Accident	**ACCIDENT REPORT NUMBER** *(from state accident report)*
___ / ___ / ___	❑ Sun ❑ M ❑ T ❑ W ❑ T ❑ F ❑ Sat	________ ❑ a.m. ❑ p.m.	

Address *(Place where accident occurred)*

County *City, Town or Township*

Road on which accident occurred *(Give name of street or highway no.)* | Posted Speed Limit

2

Light Condition: ❑ Daylight ❑ Dark ❑ Dark, Lighted ❑ Dawn ❑ Dusk

Weather Condition: ❑ Clear ❑ Rain ❑ Fog ❑ Snow/Sleet

3

TRAILER—UNIT 1

Trailer Type: ❑ Van ❑ Flatbed ❑ Tanker ❑ Dump ❑ Auto Transporter ❑ Other *(Specify)* ________

Trailer Vehicle Identification No. (VIN):

Retroreflective Tape: ❑ Yes ❑ No

Tape Pattern: ❑ Side/Rear, per FMVSS 108 or similar *(See Figure below)* ❑ Other Pattern

Tape Color: ❑ Red/White, per FMVSS 108 ❑ Solid White ❑ Solid Orange ❑ Solid Blue ❑ Other *(Specify)* ________

TAPE CONDITION *(Check all that apply)* ❑ Tape peeling, missing segments: ❑ Underride guard ❑ Other rear

Trailer Rear: ❑ Clean ❑ Some Dirt ❑ Very Dirty If tape missing, give estimated percent: Underride guard ___% Other rear ___%

Trailer Sides: ❑ Clean ❑ Some Dirt ❑ Very Dirty ❑ Tape peeling, missing segments

4

TRAILER—UNIT 2

Trailer Type: ❑ Van ❑ Flatbed ❑ Tanker ❑ Dump ❑ Auto Transporter ❑ Other *(Specify)* ________

Trailer Vehicle Identification No. (VIN):

Retroreflective Tape: ❑ Yes ❑ No

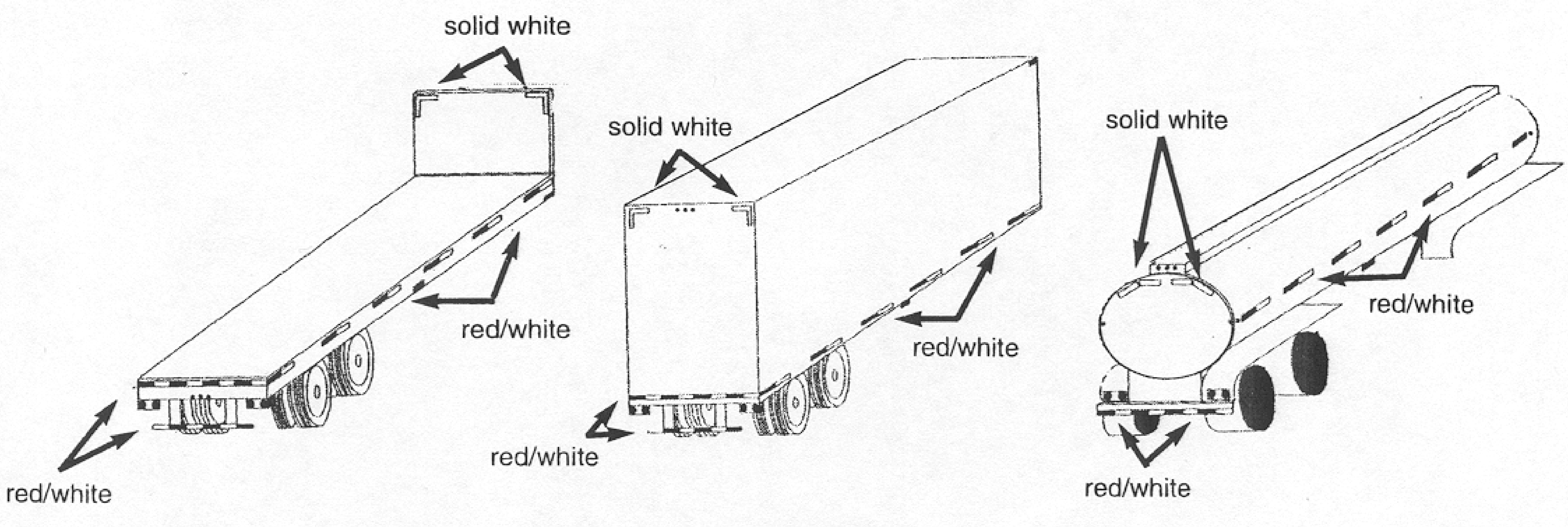
Tape Pattern: ❑ Side/Rear, per FMVSS 108 or similar *(See Figure below)* ❑ Other Pattern

Tape Color: ❑ Red/White, per FMVSS 108 ❑ Solid White ❑ Solid Orange ❑ Solid Blue ❑ Other *(Specify)* ________

TAPE CONDITION *(Check all that apply)* ❑ Tape peeling, missing segments: ❑ Underride guard ❑ Other rear

Trailer Rear: ❑ Clean ❑ Some Dirt ❑ Very Dirty If tape missing, give estimated percent: Underride guard ___% Other rear ___%

Trailer Sides: ❑ Clean ❑ Some Dirt ❑ Very Dirty ❑ Tape peeling, missing segments



Typical Retroreflective Tape Markings

Instructions for Completing Supplementary Report on Truck-Tractor Trailer Accidents

National Highway Traffic Safety Administration Special Study

When To Use Form

If the accident involved a truck-tractor pulling one or more trailers—i.e., tractor with semi-trailer, or tractor with double trailers. Both single vehicle and multi-vehicle accidents are to be reported. *NOTE:* The vehicle data to be reported concerns only **trailers**.

DATA ELEMENT INSTRUCTIONS

Accident Information

Block 1

Date of Accident: Enter month, day, and year.

Day of Accident: Enter day of week.

Time of Accident: Enter the time

Place Where Accident Occurred: Enter county, city *(town or township)*.

Road on Which Accident Occurred: Enter Street, or State Highway Number.

Posted Speed Limit: Enter speed limit in m.p.h.

Accident Report Number: enter Number of the state accident report.

Block 2

Light Condition: Check the appropriate light condition.

Weather Condition: Check the appropriate weather condition.

Vehicle (Trailer) Information

Complete the trailer information corresponding to the respective traffic UNIT—i.e., "1" or "2"—as recorded on the state report form. NOTE: If a tractor was pulling more than 1 trailer, complete the information for each trailer, numbering the trailers "1", "2", with "1" being the lead trailer. If more than 2 trailers were involved in the accident, use additional **SUPPLEMENTARY REPORT** Forms, as needed, to record information on all trailers.

Block 3/Block 4

Trailer Type: Check the trailer type.

Trailer VIN: Enter the Vehicle Identification No. (VIN) of the trailer.

Retroreflective Tape: Check whether or not the trailer was equipped with retroreflective tape. If "yes", complete the following items.

Tape Pattern: Check whether or not the tape pattern was similar to FMVSS 108 requirement *(refer to illustration)*. Examples of "Other Pattern" are "tape on rear, but not on sides," or "tape on side, but not on rear."

Tape Color: Check the tape color–red/white per FMVSS 108 requirement *(refer to illustration),* or other.

Tape Conditon, Rear: Check the box(es) which best describe the condition of the tape on the rear of the trailer. For "tape peeling, missing segments," check the appropriate area(s)–i.e., "underride guard", "other area." For tape missing, give estimated percent missing.

Tape Conditon, Sides: Check the box(es) which best describe the condition of the tape on the sides of the trailer.

Comments

2.2 CONSPICUITY DATA BASE

A contractor created a data base with the necessary information to evaluate the safety benefits of retroreflective tape. The contractor entered all the data elements on the NHTSA Green and some of the elements on the PAR. Only the pertinent data elements on the PAR were entered such as: initial point of impact, vehicle type, vehicle maneuver, first harmful event, driver age, driver sex, etc. The most important data elements were coded directly from the hard-copy data to avoid a delay in analyzing the data, since the states' automated PAR files are usually not available at NHTSA until 6 to 9 months after the end of the year. The remaining elements on the PAR could be analyzed later, if needed, by linking the conspicuity data to the automated state data files at NHTSA. The state accident report number on the NHTSA Green permits us to match the conspicuity cases to the corresponding state data cases for this purpose.

The conspicuity data contain one derived element, besides the elements on the forms. The derived element identifies the specific location on the vehicle of the first impact if it was not identified on the PAR. In both states, the point of impact is an element on the PAR. In Florida, the police can mark "Trailer," or "Unknown" if applicable. Point of impact is "Trailer" in 16 percent of the tractor-trailer combinations and is "Unknown " in 5 percent. In Pennsylvania, point of impact is "Towed Unit" in 5 percent and is "Unknown " in 1 percent of the tractor-trailer combinations. These codes are too general for this analysis and do not say if the trailer was hit in the rear or the side, a crucial distinction for this report. Thus, if the point of impact is "Trailer," "Towed Unit," or "Unknown," the data coder used all available information on the PAR including the diagram and the narrative to classify the specific location on the trailer of the first impact as one of the following:

No Damage, No Impact, Non Collision or Not Applicable

Front

Right Side

Rear

Left Side

Top

Undercarriage

Other

Unknown

The conspicuity data base was organized into three files for each state: the crash file, the vehicle file, and the pedestrian file. The crash file contains information describing the environmental conditions and roadway characteristics at the time of the crash. The vehicle file contains information describing the vehicles and their drivers involved in the crashes. The pedestrian file contains information describing any pedestrians involved in the crashes. Table 2-1 shows the number of crashes, vehicles, and pedestrians on the conspicuity data base by state.

TABLE 2-1
Conspicuity Data Base: The Number of Cases by State and File

	Crashes	Vehicles	Pedestrians
Florida	6,095	12,380	51
Pennsylvania	4,864	9,134	25
Total	10,959	21,514	76

Since each crash had to include at least one tractor-trailer combination, more than half of the vehicles are tractor-trailer combinations. Table 2-2 shows that 52 percent of the Florida vehicles are combination trucks and 59 percent of the Pennsylvania vehicles are combination trucks.

TABLE 2-2
Vehicle Types by State

	Florida		Pennsylvania		Total
Tractor-Trailer Combination	6,444	52%	5,349	59%	11,793
Other Vehicles	5,936	48%	3,785	41%	9,721
Total Vehicles	12,380	100%	9,134	100%	21,514

State regulations in both Florida and Pennsylvania allow truck tractors traveling in their state to pull one or two trailers. Table 2-3 shows that most tractors pulled one trailer.

TABLE 2-3
Tractor-Trailer Combinations by Number of Trailers and State

Number of Trailers	Florida		Pennsylvania		Total
One Trailer	6,363	99%	5,191	97%	11,554
Two Trailers	81	1%	158	3%	239
Total Vehicles	6,444	100%	5,349	100%	11,793

Table 2-4 compares the characteristics of the trailers in Florida and Pennsylvania. For the most part, the trailers were similar: vans were the most common type, followed by flatbeds. The trailer model years were also similar: slightly more that half of the trailers in Florida are pre-standard, not required to have tape. (Most of the unknown model years in Pennsylvania are probably model years before 1981. In Pennsylvania, trailer model year is decoded from the trailer VIN. Model years earlier than 1981 cannot be decoded from the VIN since the VIN was not standardized before 1981.)

The most noteworthy difference is that 60 percent of the trailers in Florida were equipped with tape, while 70 percent in Pennsylvania were equipped with tape. This is partly due to the data collection starting and ending six months later in Pennsylvania, by which time more trailers had been retrofitted.

TABLE 2-4
Number and Percent of Trailers by Trailer Characteristics and State

	Florida		Pennsylvania	
Trailer Type				
Van	3,414	52%	3,655	66%
Flatbed	1,174	18%	847	15%
Tanker	580	9%	348	6%
Dump	550	8%	218	4%
Auto Transporter	163	2%	60	1%
Other/Unknown	644	10%	379	7%
Trailer Year				
Pre-Standard < MY 1993	3,504	54%	1,504	27%
Transition Year MY 1993	349	5%	254	5%
Transition Year MY 1994	442	7%	376	7%
Post-Standard > MY 1994	2,022	31%	1,865	34%
Unknown	208	3%	1,508	27%
Treatment				
Tape	3,925	60%	3,859	70%
No Tape	2,478	38%	1,326	24%
Unknown	122	2%	322	6%

Table 2-5 shows the characteristics of the trailers with tape by state. Almost all have the tape applied to the side and rear of the trailer as required by FMVSS 108 or similar to the standard. (The criteria the police officers used to judge whether the tape was similar or dissimilar to FMVSS 108 is not known.) About 90 percent or more have the required alternating red and white tape. Very few trailers have tape that is “very dirty.” About 30 percent of the trailers have tape that is somewhat dirty. The extent, if any, to which dirt on the tape may reduce its effectiveness will be analyzed in Chapter 4.

TABLE 2-5
Tape Characteristics on Trailers Equipped with Tape

	Florida		Pennsylvania	
Tape Pattern				
FMVSS 108 or Similar	3,627	92%	3,579	93%
Other	223	6%	202	5%
Unknown	75	2%	78	2%
Tape Color				
Red/White	3,676	94%	3,477	90%
White, Orange, or Blue	157	4%	267	7%
Other/Unknown	92	2%	115	3%
Tape Condition Rear				
No Tape*	10	0%	22	1%
Clean	2,575	66%	2,440	63%
Some Dirt	1,103	28%	1,226	32%
Very Dirty	167	4%	117	3%
Unknown	70	2%	54	1%
Tape Peeling/Missing on Rear of Trailer				
No Tape*	10	0%	22	1%
Not Peeling, Missing	3,565	91%	3,612	94%
Peeling, Missing	330	8%	196	5%
Unknown	20	1%	29	1%
Tape Peeling/Missing on Rear Underride Guard of Trailer				
No Tape*	11	0%	22	1%
Not Peeling, Missing	3,634	93%	3,654	95%
Peeling, Missing	250	6%	131	3%
Unknown	30	1%	52	1%
Tape Peeling/Missing on Rear of Trailer, Other than Underride Guard				
No Tape*	16	0%	26	1%
Not Peeling, Missing	3,698	94%	3,691	96%
Peeling, Missing	182	5%	89	2%
Unknown	29	1%	53	1%
Tape Condition Side				
No Tape*	54	1%	96	2%
Clean	2,570	65%	2,384	62%
Some Dirt	1,071	27%	1,164	30%
Very Dirty	111	3%	82	2%
Unknown	119	3%	133	3%
Tape Peeling/Missing Side				
No Tape*	54	1%	104	3%
Not Peeling, Missing	3,664	93%	3,590	93%
Peeling, Missing	139	4%	50	1%
Unknown	68	2%	115	3%

* Trailers has tape in some locations, but not on this component (e.g. tape on side only– no tape on rear or underride guard).

There are two small but notable differences between the two states. The percentage of trailers with tape that have some dirt is slightly higher in Pennsylvania than in Florida. In Pennsylvania, more dirt and grime may be splashed up on roads treated with salt or other chemicals to reduce snow, slush and ice on the roads during the winter. The other difference is the percentage of trailers with peeling or missing tape. The percentages are slightly lower in Pennsylvania than Florida. It is unknown why this happened. It is possible that combination trucks in Pennsylvania travel further between loading/unloading, thus reducing the chances that the tape will be damaged. It is also possible that Pennsylvania has more recently retrofitted trailers since data collection started and ended six months later in Pennsylvania than Florida. These trailers may not have had enough time to develop any peeling or missing segments.

Table 2-5 also shows that peeling or missing segments of tape occur more often on the rear of the trailer than the side, as expected. The rear of the trailer is more susceptible to scraping and damage when the trailer is loaded and unloaded. Eight percent of the trailers in Florida and five percent in Pennsylvania had peeling or missing segments on the rear of the trailer. Only four percent of the trailers with tape in Florida and one percent in Pennsylvania had peeling or missing segments on the side. The tape on the rear other than the underride guard appears to be just as vulnerable as tape on the rear underride guard.

Table 2-6 shows the percentage of missing tape on the rear by state for trailers with missing tape. The 100 percent missing at a particular location may represent trailers that never had tape at that particular location but had tape elsewhere on the trailer. The form is not entirely clear and some officers may have misunderstood the information requested. A large proportion of the trailers coded with 100 percent missing tape on the rear underride guard were pre-standard trailers. Seventy percent (50 cases) in Florida and 64 percent (16 cases) in Pennsylvania are pre-standard trailers, which are not required to have tape on the rear underride guard according to the FMCSA retrofit standard. Similar results were found for elsewhere on the rear of the trailer. Seventy-eight percent (31 cases) in Florida and 50 percent (6 cases) in Pennsylvania of the trailers coded with 100 percent missing tape are pre-standard trailers. These may be trailers that were partially retrofitted with tape before FMCSA announced its final rule and have not yet added the missing tape to make it compliant.

If you only consider the 1 to 99 percent categories, then 55 percent (84/152 = 55 % in Florida and 42/77 = 55% in Pennsylvania) of the trailers with missing tape on the underride guard have 75 percent or more of the tape intact. This amount of tape missing will probably not seriously diminish its conspicuity effectiveness. On the other hand, tape that is missing on more than 25 percent of the guard may reduce the effectiveness of the tape. In this case, 45 percent (68/152 = 45 percent in Florida and 35/77 = 45 percent in Pennsylvania) of the trailers with missing tape on the underride guard have more than 25 percent of the tape missing. Elsewhere on the rear, 46 percent in Florida of the trailers with missing tape and 48 percent in Pennsylvania have 75 percent or more of the tape intact and 54 and 52 percent, respectively, have more than 25 percent of the tape missing.

TABLE 2-6
Number and Percent of Trailers with Missing Tape
by Percentage of Missing Tape and State

	Florida		Pennsylvania	
Percentage of Missing Tape on Rear Underride Guard				
1-25 %	84	35%	42	32%
26-50%	46	19%	20	15%
51-75%	10	4%	8	6%
76-99%	12	5%	7	5%
100%	71	30%	25	19%
Unknown Percentage	14	6%	28	22%
Percentage of Missing Tape on Rear - Other than Underride Guard				
1-25 %	61	34%	32	37%
26-50%	45	25%	25	29%
51-75%	13	7%	3	3%
76-99%	13	7%	6	7%
100%	40	22%	12	14%
Unknown Percentage	7	4%	8	9%

Overall, missing tape was not a big problem when this data was collected. Most trailers with tape either had no tape missing at all or they had 75 percent or more of the tape intact on the rear. Less than two percent of the 3,925 (68/3,925 = 1.7 percent) trailers with tape in Florida had tape missing on more than 25 percent of the rear guard. In Pennsylvania, less than a percent (35/3,859 = 0.9 percent) had tape missing on more than 25 percent of the rear guard. The same percentages were found for elsewhere on the rear in each state. However, this could increase as the trailers get older.

Table 2-7 shows the percentage of trailers treated by trailer model year. Model year is the best available surrogate for date of manufacture. NHTSA requires all trailers manufactured on and after December 1, 1993 to have tape. Model years 1993 and 1994 are considered transition years because most 1993 and some 1994 trailers were manufactured before December 1, 1993. In this table, model year was decoded from "good" trailer VINs that yielded a valid model year and valid trailer make.

As expected, the percentage of trailers with tape is increasing by model year. Most of the post-standard trailers have tape. More than 80 percent of the model year 1994 trailers have tape and more than half of the model year 1993 trailers have tape. Slightly fewer than half of the pre-standard trailers have tape.

Also as expected, more pre-standard and transition-year trailers have tape in Pennsylvania than in Florida. Pennsylvania's data collection period was 6 months later than the Florida period and ended on November 30, 1999, eight months after the FMCSA published a retrofit regulation on

March 31, 1999. Although the regulation gives motor carriers two years from June 1, 1999 to install the material on trailers manufactured prior to December 1, 1993, it appears that motor carriers were quickly retrofitting their trailers with tape.

Table 2-7 also shows a small portion of post-standard trailers do not have tape (5 percent in Florida and 3 percent in Pennsylvania). These could be coding errors but not necessarily. Possible coding errors included miscoding of the tape presence/absence or inaccurate copying of the VIN. On the other hand, some of these trailers may be exempt from the tape requirement. Trailers designed exclusively for living or office space are not required to have conspicuity treatment. Pole trailers, trailers that carry logs, are also exempt. Some of these trailers may have reflex reflectors, instead of tape, an option allowed by the standard. Finally, some of these trailers may be non-compliant, although this is unlikely. Probably some combination of these possibilities or errors in the data account for the post-standard trailers that do not have tape.

TABLE 2-7
Trailer Treatment by Trailer Model Year and State
Model Year Decoded from Good VINs

	Pre-Standard < MY 1993		Transition Year MY 1993		Transition Year MY 1994		Post-Standard > MY 1994	
Florida								
Tape	747	48%	144	59%	246	84%	1,180	94%
No Tape	787	51%	99	41%	46	16%	66	5%
Unknown	13	1%	1	0%	1	0%	11	1%
Pennsylvania								
Tape	540	49%	113	66%	261	89%	1,255	95%
No Tape	540	49%	56	33%	29	10%	43	3%
Unknown	12	1%	2	1%	2	1%	19	1%

Table 2-8 shows some of the crash characteristics of combination truck crashes. Most of the crashes occur on a weekday, when the weather is clear, and involve two or more vehicles. More than two-thirds of the crashes occur on roads with speed limits of 50 mph or higher. It appears that most of the crashes occur on roadways with limited access. In Pennsylvania, 67 percent occur on limited access roadways and in Florida the exact percentage is hard to estimate since most of the interstates and turnpikes and some of the U.S. and State roads have limited access. For the most part, combination trucks are on major roads when they are involved in crashes.

There are two minor differences between the crash experience of combination trucks in Florida and Pennsylvania. Pennsylvania has more adverse weather cases than Florida. This is no surprise since the climate is different there. Snow is common in Pennsylvania during the late fall and winter, but rare in Florida. Pennsylvania also has proportionately more single-vehicle crashes than Florida. This disparity is mostly due to reporting differences. Crashes are reported in Florida if there is $500 worth of property damage. In Pennsylvania, crashes are reported if there is at least one vehicle towed from the scene because of damage. Therefore, there are more low-damage, multiple vehicle fender-benders reported in Florida than Pennsylvania.

TABLE 2-8
Number and Percent of Crashes by Crash Characteristics and State

	Florida			Pennsylvania	
Day of Crash					
Weekday	5,334	88%		4,184	86%
Weekend	756	12%		679	14%
Unknown	5	0%		1	0%
Weather Conditions					
Clear	5,004	82%		3,416	70%
Adverse	973	16%		1,374	28%
Unknown	118	2%		74	2%
Number of Vehicles					
1	864	14%		1,348	28%
2	4,375	72%		2,973	61%
3 or more	856	14%		543	11%
Speed Limit					
0 to 49 mph	1,743	29%	*	1,205	25%
50 - 70 mph	4,187	69%		3,581	74%
Unknown	165	3%		78	2%
Roadway Access Type					
Unlimited				1,487	31%
Limited				3,245	67%
Other/Unknown				132	3%
Roadway Type					
Interstate & Turnpike/Toll	2,461	40%			
U.S. & State	2,548	42%			
County & Local	767	13%			
Other/Unknown	319	5%			

* Total percentages may not add to 100 percent due to rounding.

Table 2-9 compares the driver's age in the other vehicle involved in combination truck crashes. There is little difference between the driver's age in Florida and Pennsylvania except for the older drivers. There are slightly more 61-70 year old and 70 and older drivers in Florida than in Pennsylvania. This is not surprising since Florida has an older population.

TABLE 2-9 The Driver's Age in the Other Vehicle Involved in a Crash with Combination Truck by State	Florida		Pennsylvania	
Driver's Age				
15-20	303	7%	194	8%
21-25	449	11%	332	13%
26-30	471	11%	267	11%
31-50	1,612	38%	962	38%
51-60	446	11%	288	12%
61-70	304	7%	136	5%
70 +	324	8%	132	5%
Unknown	298	7%	193	8%

Table 2-10 shows the distribution of driver's age for passenger vehicles in two vehicle crashes investigated by State police that do **not** involve combination trucks. This data is from the NHTSA Florida and Pennsylvania State data files. The percentage of 15-20 year old drivers in Table 2-10 is twice that in Table 2-9. Younger drivers are underrepresented as drivers of other vehicles involved in crashes with a combination truck. A possible explanation is that younger drivers, especially 15-18 year old drivers, less frequently encounter combination trucks because their driving habits are different than combination truck drivers. Young drivers drive a lot on local roads to and from school and work. The percentage of all the other age groups is fairly consistent between the two tables.

TABLE 2-10 Driver's Age of Passenger Vehicles Involved in Two-Vehicle Crashes Investigated by State Police that do not Involve a Combination Truck by State	Florida			Pennsylvania	
Driver's Age					
15-20	15,387	14%	*	5,055	18%
21-25	13,226	12%		3,278	12%
26-30	12,680	12%		2,845	10%
31-50	41,835	39%		9,792	36%
51-60	10,692	10%		2,747	10%
61-70	6,878	6%		1,625	6%
70 +	6,772	6%		1,919	7%
Unknown	0	0%		273	1%

* Total percentages may not add to 100 percent due to rounding.

2.3 CRASHES NOT INVESTIGATED BY STATE POLICE

The previous section gave a general overview of the crashes investigated by the FHP and PSP. But the conspicuity data do not include combination truck crashes investigated by local law enforcement agencies, other state agencies, or reported by the drivers themselves. This section is an overview of those crashes. Specifically, this section will address the following: What type of crashes do local law enforcement officers investigate? Are they different from the ones that state law enforcement officers investigate? If they are different, how will these differences influence our effectiveness estimates?

The State Police investigate more than half of all the crashes that involve a combination truck. The FHP investigated 59 percent of the combination truck crashes in Florida during 1998. The PSP investigated 60 percent of the crashes in Pennsylvania during 1998. Table 2-11 shows the percent of crashes investigated by the State police and others in Florida and Pennsylvania for various crash characteristics. The FHP and the PSP investigate almost all of combination truck crashes that occur on major roads where they have jurisdiction. The PSP investigate 93 percent of the crashes on limited access roads and the FHP investigate 93 percent on interstates and turnpikes/toll roads. These agencies also investigate more than half of all the crashes for most of the crash characteristics in Table 2-11. They investigate more than half of the weekday, weekend, clear, adverse, daylight, dark, high speed, rural, etc. crashes that involve a combination truck.

The conspicuity data underrepresents crashes that occur in urban areas, on county and local roads, or on roadways with lower speed limits. The majority of these crashes are investigated by local police, sheriffs, or other police agencies that have jurisdiction in these areas or are reported by the drivers themselves. The local police agencies investigate somewhere between 64 and 74 percent of the crashes that occur in urban areas, 68 percent on county and local roads, and about 65 percent on roads with speed limits less than 50 miles per hour.

There is little difference between what the FHP and PSP investigate in their respective states. The only exceptions appear to be single-vehicle crashes and crashes that occur in urban areas. The PSP investigates 74 percent of the single-vehicle crashes that involve a combination truck, while the FHP investigates only 60 percent of these crashes. The local agencies in Florida also investigate more crashes that occur in urban areas than their counterparts in Pennsylvania. The reporting threshold differences between these states probably account for these discrepancies. A crash in Florida is investigated if it involved at least $500 worth of damage. In Pennsylvania, a crash is investigated if at least one of the vehicles is towed away. Therefore, local police agencies in Florida will investigate more low-speed, single-vehicle crashes or low-speed crashes in urban areas than the local police agencies in Pennsylvania.

The fact that a proportion of crashes are not investigated by the State police will not significantly affect our effectiveness estimates. In Chapter 4, we will see no consistent difference in the effectiveness in rural vs. urban areas or on low vs. high speed limit roads, so the state police effectiveness estimates are also appropriate for the groups of crashes investigated by other agencies. When we complete benefits in Chapter 5, we will include non-state police investigated crashes in the "size of the problem" estimate, so as not to underestimate the benefits.

TABLE 2-11
Percent of Crashes Reported by Enforcement Agency and State

	Florida		Pennsylvania	
Day of Crash	FHP	Other	PSP	Other
Weekday	58%	42%	59%	41%
Weekend	64%	36%	72%	28%
Weather Conditions				
Clear	56%	44%	58%	42%
Adverse	65%	35%	67%	33%
Number of Vehicles				
1	60%	40%	74%	26%
2	57%	43%	55%	44%
3 or more	67%	33%	57%	43%
Speed Limit				
0 to 49 mph	35%	65%	34%	66%
50 to 70 mph	89%	11%	84%	16%
Roadway Access Type				
Unlimited			55%	45%
Limited			93%	7%
Other/Unknown			61%	39%
Roadway Type				
Interstate & Turnpike/Toll	93%	6%		
U.S. & State	63%	37%		
County & Local	31%	68%		
Other/Unknown	19%	81%		
Light Condition				
Daylight	57%	43%	55%	45%
Dark Conditions	64%	36%	70%	30%
Rural/Urban				
Rural	77%	23%	83%	17%
Urban	26%	74%	36%	64%

CHAPTER 3

BASIC ANALYSIS

Tractor-trailer combinations in which trailers are equipped with retroreflective tape ought to experience a reduction of side and rear impacts into the trailer by other vehicles in dark conditions - relative to the number that would have been expected if the trailers had not been equipped. The analytic challenge is to compute the "expected" number of impacts and quantify the reduction. The critical parameters are: (1) whether or not the trailer is tape-equipped; (2) the light condition - dark (comprising "dark-not-lighted," "dark-lighted," "dawn" and "dusk") vs. daylight; and (3) relevant vs. non-relevant crash involvements. Relevant crash involvements are those where another vehicle crashed into the side or rear of a heavy trailer, because the tape can help the other driver see and possibly avoid hitting the trailer. The non-relevant group consists of single-vehicle crashes of tractor-trailers (where visibility of the tractor-trailer to other road users is not an issue at all) and impacts of the front of the tractor into other vehicles (where conspicuity of the side and rear of the trailer is also not an issue). Each of these parameters defines a sort of control group. The vehicles without tape are a control group that can be compared to the vehicles equipped with tape. Since the tape ought to have substantially less effect (if any) by daylight than in dark conditions, daylight crashes are a control group relative to crashes in the dark. The most satisfactory definition of the "expected" number of side/rear impacts in the dark uses all three of these control groups.

3.1 DEFINITIONS

The data base for this analysis is a vehicle-oriented file, with one record for each tractor-trailer combination that was involved in a crash. Initially, Florida and Pennsylvania data will be analyzed separately. The Florida file includes 6,444 tractor-trailer combinations and the Pennsylvania file includes 5,349.

The critical parameters that must be defined for this analysis are tractor-trailer combinations, trailer treatment, light conditions and crash mode/point of impact. Some of the parameters can be defined from data elements on the NHTSA Green and some from data elements the state PAR. The definitions for the parameters that are defined from elements on the NHTSA Green are the same in Florida and Pennsylvania. But each state has it own unique way of coding elements on its PAR, so the definitions for parameters that are defined from elements on the state PAR cannot be exactly the same. For these parameters, the definitions ought to be made as similar as possible. The States also differ in the exposure and crash characteristics of combination trucks. Below are the definitions and the differences found in the conspicuity data for these critical parameters.

First, it is necessary to define "tractor-trailers." The vehicle type and number of trailers were used to identify heavy trucks pulling at least one trailer. "Vehicle type" is a data element on the state PAR and identifies the body style of a vehicle. "Number of trailers" is on the NHTSA Green form and identifies the number of trailers that were attached to a vehicle. (Small trailers typically pulled by light vehicles are not included in the analysis.) Tractor-trailer combinations were defined as follows:

State	Definition
Florida	veh_type = 4, 5, 6, 77 and trlno = 1, 2
Pennsylvania	body_type=70, 73, 74, 75, 76, 77, 79 and trlno = 1, 2

The trailer treatment[8] (the presence or lack of retroreflective tape) is easily identified by a variable collected on the NHTSA Green. If the truck tractor was pulling only one trailer and the trailer had tape, then the combination truck was classified as treated. If the trailer had no tape, then the combination truck was classified as untreated. Few tandem trailers were found in the conspicuity data although both Florida and Pennsylvania allow heavy trucks to pull up to 2 trailers. In these cases, the presence or lack of tape was defined for both trailers. If both trailers had tape, then it was classified as treated and if both trailers did not have tape, then it was classified as untreated. A truck pulling two trailers where one trailer had tape and the other one did not were classified as unknown, as are combinations with unknown tape conditions on a single trailer or at least one of the tandem trailers. Table 2-3 shows that fewer than 5 percent of the combination trucks are pulling two trailers and very few cases were classified as unknown because the tape was inconsistent on the two trailers. Table 3-1 shows that 60 percent of truck trailer combination trucks have tape in Florida and 70 percent have tape in Pennsylvania. Combination trucks with "unknown" trailer treatment were excluded from the analyses.

TABLE 3-1
Retroreflective Tape by State for Tractor-Trailer Combinations

	Florida		Pennsylvania		Total
Treated	3,880	60%	3,751	70%	7,631
Untreated	2,443	38%	1,283	24%	3,726
Unknown	121	2%	315	6%	436
Total Vehicles	6,444		5,349		11,793

The light conditions at the time of the crash were classified into "dark" and "daylight" conditions for the analysis using a variable on the NHTSA Green. Table 3-2 shows the different levels of light conditions along with the number and percentage of these cases. Note the difference in the

[8]Conspicuity treatment of truck tractors is arguably a neutral factor in evaluating the effectiveness of the treatment in preventing crashes involving truck tractor-trailer combinations. There is no side treatment applied to truck tractors, while the rear treatment is masked by the trailer being towed.

percentage of daylight and "dark-not-lighted" conditions between Florida and Pennsylvania. Although there is no exposure data to support this premise, this suggests that combination trucks are driven more often at nighttime in Pennsylvania than in Florida.

TABLE 3-2
Light Conditions by State for Tractor-Trailer Combinations

	Florida		Pennsylvania		Total
Daylight	4,408	68%	3,139	59%	7,547
Dark-Not-Lighted	1,245	19%	1,628	30%	2,873
Dark-Lighted	505	8%	334	6%	839
Dawn	179	3%	147	3%	326
Dusk	91	1%	86	2%	177
Unknown	16	0%	15	0%	31
Total Vehicles	6,444		5,349		11,793

The basic analysis compares dark conditions to daylight conditions. "Dark" conditions include "dark-not-lighted," "dark-lighted," "dawn," and "dusk." Other analyses will compare dark-not-lighted to daylight; and dark-lighted, dawn, and dusk to daylight. Cases with unknown light conditions are excluded from the analysis.

Crash mode/point of impact were used to identify single-vehicle cases and frontal, side, and rear initial impacts. Single-vehicle cases were identified first, regardless of their initial point of impact. A single-vehicle case involves only a tractor-trailer combination and no other vehicle.

Frontal, side, and rear initial impacts were identified from the remaining cases. The remaining cases involved two or more vehicles where at least one of the vehicles is a tractor-trailer combination. The initial impact area refers to the initial point of impact for the tractor-trailer combination. The analysis used a combination of the PAR's "point of impact" and the NHTSA Green's derived "impact point" to identify the initial impact area. If the PAR's "point of impact" is "Trailer," "Towed Unit," or "Unknown" then the derived impact point from the NHTSA Green is used to classify the area. In the conspicuity data base, the variable from the PAR is called "impact" and the variable from the NHTSA Green is called "impactpt." The definitions for the four categories are as follows:

Category	State	Definition
Single-Vehicle	FL	the number of vehicles involved by counting is 1
	PA	num_veh = 1
Front	FL	impact = 1,2,14 or (impact = 22, 99 and impactpt = 1)
	PA	impact = 11,12,1 or (impact = 15, 99 and impactpt = 1)

Side	FL	impact = 3,4,5,6,10,11,12,13 or (impact = 22, 99 and impactpt = 2,4)
	PA	impact = 2,3,4,8,9,10 or (impact = 15, 99 and impactpt = 2,4)
Rear	FL	impact = 7,8,9 or (impact = 22, 99 and impactpt = 3)
	PA	impact = 5,6,7 or (impact = 15, 99 and impactpt = 3)

Let us refer to these categories as damage areas, since three of the four categories are damage areas. Table 3-3 shows that Pennsylvania has a higher percentage of single-vehicle crashes than Florida and that Florida has a higher percentage of other/unknown crash types. But the percentage of frontal impacts is about the same in both states. Florida has fewer rear impacts but more side impacts than Pennsylvania. However, the sum of the side and rear impacts is the same in both States, 39 percent. The basic analysis compares side and rear damage areas to single-vehicle and front damage areas. Cases with unknown damage areas are excluded from the analysis.

TABLE 3-3
Damage Area by State for Tractor-Trailer Combinations

	Florida		Pennsylvania		Total
Single-Vehicle	846	13%	1,335	25%	2,181
Front	2,240	35%	1,758	33%	3,998
Side	1,768	27%	992	19%	2,760
Rear	774	12%	1,063	20%	1,837
Other/Unknown	816	13%	201	4%	1,017
Total Vehicles	6,444		5,349		11,793

After excluding cases with unknown trailer treatment, light condition or damage area, there remain 5,535 cases in Florida and 4,871 in Pennsylvania available for the analysis because they have known values for each of the three critical parameters. In all, 14 percent of the Florida cases and 9 percent of the Pennsylvania cases are excluded because of unknowns.

3.2 THE BASIC ANALYSIS

The basic analysis tabulated tractor-trailer combination involvements in crashes by trailer treatment (treated; untreated) and damage area (side and rear impacts; single-vehicle and frontal impacts) and light conditions (dark; light). The basic contingency table is:

Number of Crash Involvements

Treated	Side & Rear Impacts	Single-Vehicle & Frontal Impacts
Dark	N_{111}	N_{112}
Daylight	N_{121}	N_{122}
Untreated		
Dark	N_{211}	N_{212}
Daylight	N_{221}	N_{222}

In Florida, the numbers in the basic contingency table are:

Number of Crash Involvements in Florida

Treated	Side & Rear Impacts	Single-Vehicle (SV) & Frontal Impacts
Dark	526	632
Daylight	1,024	1,231
Untreated		
Dark	285	314
Daylight	648	875

First, let us consider only the **untreated** vehicles. There are 648 side/rear impacts in the daylight. Based on the involvements in SV/frontal impacts, which act as a control group or measure of induced exposure, we might have expected (314/875)648 = 232.5 side/rear impacts in the dark. In fact, there are 285. Because untreated vehicles are harder to see in the dark (except from the front), they are excessively impacted in the side and rear, relative to exposure, by a factor of 285/232.5, i.e.

$$(285/648) / (314/875) = (N_{211} / N_{221})/(N_{212} / N_{222}).$$

Now, let us consider the **treated** vehicles. There are 1024 side/rear impacts in the daylight. Again using the SV/frontal impacts as a control group, we would expect (632/1231)1024 = 525.7 side/rear impacts in the dark. And that is almost exactly what happened: 526. Because the treated vehicles are quite visible in the dark, they have no more side/rear impacts in the dark than might have been expected based on their exposure. Clearly, there is a reduction of side/rear impacts in dark conditions relative to the pattern in the untreated vehicles.

Finally, the data on the untreated and the treated vehicles can be combined to estimate the reduction in side/rear impacts for the treated vehicles in dark conditions. As stated above, the excess of side/rear crashes in the dark for the untreated trailers is 285/232.5 = 1.23. If the treatment were of no value at all, we would expect the same excess of side/rear impacts in the dark as in the untreated vehicles. The effectiveness of the treatment is the extent to which that excess is reduced - i.e., the relative difference of the actual-to-expected ratios in the treated and the untreated vehicles:

$$1 - \frac{(526/1024) / (632/1231)}{(285/\ 648) / (314/\ 875)} = 18 \text{ percent}$$

The expected number of side and rear impacted treated tractor-trailer combinations in dark conditions is

$$N_{121} * (N_{112} / N_{122}) * [(N_{211} / N_{221})/(N_{212} / N_{222})].$$

In fact, there are only N_{111} side and rear impacted treated tractor-trailer combinations in dark conditions. That is a reduction of

$$1 - \frac{\left[\left(N_{111}/N_{121}\right) \big/ \left(N_{112}/N_{122}\right)\right]}{\left[\left(N_{211}/N_{221}\right) \big/ \left(N_{212}/N_{222}\right)\right]}$$

dark, side and rear impact involvement rate.   All three variables (trailer treatment, damage area, and light conditions) are needed for this analysis of effectiveness. An analysis missing any one of these variables would not give accurate effectiveness estimates and should be avoided.

In Pennsylvania, the basic contingency table is:

Number of Crash Involvements in Pennsylvania

Treated	Side & Rear Impacts	Single-Vehicle & Frontal Impacts
Dark	512	977
Daylight	873	1,271
Untreated		
Dark	214	283
Daylight	282	459

Here, the reduction in side/rear impacts for treated combination trucks in dark conditions is

$$1 - \frac{\left[\left(512/873\right) \Big/ \left(977/1{,}271\right) \right]}{\left[\left(214/282\right) \Big/ \left(283/459\right) \right]} = 38 \text{ percent.}$$

Tractor-trailer combination with treated trailers in Pennsylvania had a 38 percent lower risk of being involved in a side or rear impact collision in the dark than combination trucks with untreated trailers.

3.3 STATISTICAL SIGNIFICANCE AND CONFIDENCE BOUNDS

Statistical significance is tested using the CATegorical data MODeling (CATMOD) procedure in SAS.[9] This procedure is similar to the chi-square test in that it estimates the predicted values from the observed values and tests to see if at least one of the observed values is different from its predicted value. The simple chi-square test cannot be used because we have three categorical variables. The CATMOD procedure allows us to analyze categorical data that can be represented by a contingency table. It fits linear models to functions of response frequencies and tests the likelihood ratio. The likelihood ratio tests if the variables are independent.

Table 3-4 shows the results of the CATMOD procedure using the basic contingency table on Page 27 for dark conditions in Florida. A log-linear model was specified to reproduce the predicted cell frequencies. The model included all main effects (DAMAGE, LIGHT, and TREAT) and two-variable interactions (DAMAGE*LIGHT, DAMAGE*TREAT, and LIGHT*TREAT). The three-variable interaction was not included in the model. The null hypotheses is that the three variables are independent. In other words, the number of side and rear combination truck crashes in dark conditions with or without tape are the same and that tape effectiveness is zero. The model is weighted by N, the number of combination trucks in each cell.

[9]*SAS/STAT Users's Guide: Volume1, ACECLUS-FREQ*, Version 6, Fourth Edition, SAS Institute Inc., Cary, NC, 1990.

TABLE 3-4 Florida Data Log-linear Model Without Three-variable Interaction Maximum-likelihood analysis-of-variance table			
Dependent Variables: DAMAGE, LIGHT, and TREAT			
Model: DAMAGE, LIGHT, TREAT, DAMAGE*LIGHT, DAMAGE*TREAT, and LIGHT*TREAT			
N of Observations: 5,535			
Weighting Factor: N (Number of Combination Trucks)			
Source	DF	Chi-Square	Prob
DAMAGE	1	44.52	0.0000
LIGHT	1	692.23	0.0000
DAMAGE*LIGHT	1	1.60	0.2063
TREAT	1	304.76	0.0000
DAMAGE*TREAT	1	0.95	0.3295
LIGHT* TREAT	1	19.43	0.0000
Likelihood Ratio	1	2.81	0.0937

The analysis-of-variance table above shows that the model of independence does not fit since the likelihood-ratio test for the three-variable interaction is significant. NHTSA's evaluations of safety standards customarily use a one-tailed 95 percent test (or a two-tailed 90 percent test) as the criterion for statistical significance. Chi-square is a two-tailed test and a value of 2.81 with its associated probability of 0.0937 is significant at the two-tailed 90^{th} percentile (or one-tailed 95^{th} percentile). Therefore, we reject the null hypotheses. We conclude that the tape is 18 percent effective under dark conditions in Florida and this is significantly greater than zero.

The tape effectiveness estimate is also significantly greater than zero in Pennsylvania for dark conditions. Here, the tape was 38 percent effective. The CATMOD procedure fit the same log-linear model for the Pennsylvania data. The analysis-of-variance table showed that the likelihood-ratio is 12.13 with a probability of 0.0005. Again, we conclude that the three-variable interaction is significant and it is significant at the 99^{th} percentile.

In order to calculate the confidence bounds around our effectiveness estimates, let N_{ijk} represent each cell in the basic contingency table where i = trailer treatment, j = light conditions, and k = damage area. Each N_{ijk} is Poisson distributed and independent from the others. The relative variance of N_{ijk} is

$$\mathrm{Var}\ (N_{ijk}) / N^2_{ijk} \ = \ N_{ijk} / N^2_{ijk} = 1 / N_{ijk}.$$

10

$$Var(r)/r^2 = 1/N_{111} + 1/N_{112} + \ldots + 1/N_{222}$$

$$Var(r) = r^2\left(1/N_{111} + 1/N_{112} + \ldots + 1/N_{222}\right)$$

$$s.d.(r) = r\left(\sqrt{1/N_{111} + 1/N_{112} + \ldots + 1/N_{222}}\right)$$

and the standard deviation of e is

$$s.d.(e) = (1-e)\left(\sqrt{1/N_{111} + 1/N_{112} + \ldots + 1/N_{222}}\right).$$

For the Florida data, the standard deviation of e is

$$s.d.(e) = (1-.18)\left(\sqrt{1/1231 + 1/1024 + 1/632 + 1/526 + 1/875 + 1/648 + 1/314 + 1/285}\right) = .099.$$

Using a 90 percent confidence interval, the upper and lower confidence bounds for effectiveness in Florida are 18% ± (1.645)*0 .099 = 18 ± 16 percent. Thus, the lower bound is 2 percent and the upper bound is 34 percent.

There is slightly less variation in the Pennsylvania data than the Florida data resulting in a slightly smaller standard deviation and smaller bounds. The standard deviation in Pennsylvania is .085 and the confidence bounds are 38% ± (1.645)*0 .085 = 38 ± 14 percent. The lower bound is 24 percent and the upper bound is 52 percent.

Hansen, Morris H., Hurwitz, William N., and Madow, William G., *Sample Survey* , John Wiley & Sons, New York, 1953, pp. 512-514.

3.4 TAPE EFFECTIVENESS IN SPECIFIC DARK CONDITIONS

The effective estimates calculated in Section 3.2 are for a combination of four dark conditions including dark-not-lighted, dark-lighted, dawn, and dusk. Is the tape equally effective in each of these four conditions? If not, which conditions make it more effective and which conditions make it less effective?

Table 3-5 shows the basic contingency table and effectiveness estimates for dark-not-lighted conditions. These are crashes that occur at night where the roadway is not illuminated by street lights. The tape should be the most beneficial in these conditions since the contrast reflectivity of the tape should be brightest. The tape is 37 percent effective at reducing crashes in Florida and 44 percent in Pennsylvania. The results are both statistically significant at the .01 level, so the tape is highly effective on dark unlighted roads.

Table 3-6 shows the basic contingency table and effectiveness estimates for the combination of dark-lighted, dawn, and dusk conditions. Here the results are mixed. The tape has a negative effect in Florida and a positive effect in Pennsylvania. Neither result is significantly different from zero, so the tape has no substantial benefit when some light is available.

TABLE 3-5
Effectiveness of Tape in Dark-Not-Lighted Conditions by State

	Florida		Pennsylvania	
Treated	Side & Rear	SV & Front	Side & Rear	SV & Front
Dark-Not-Lighted	272	417	357	768
Daylight	1,024	1,231	873	1,271
Untreated				
Dark-Not-Lighted	190	207	157	213
Daylight	648	875	282	459
Effectiveness		37%		44%

TABLE 3-6
Effectiveness of Tape in Dark-Lighted, Dawn, and Dusk Conditions by State

	Florida		Pennsylvania	
Treated	Side & Rear	SV & Front	Side & Rear	SV & Front
Dark-Lighted, Dawn & Dusk	254	215	155	209
Daylight	1,024	1,231	873	1,271
Untreated				
Dark-Lighted, Dawn & Dusk	95	107	57	70
Daylight	648	875	282	459
Effectiveness		-18%		19%

Table 3-7 shows the effectiveness of the tape at three different lighting conditions for comparison. The tape is most effective in dark-not-lighted conditions. The dark-not-lighted conditions have the largest effectiveness estimates. The tape is somewhat beneficial in the combination of all four dark conditions. Here, the effectiveness estimates are less than the dark-not-lighted estimates, but significantly greater than zero. At dark-lighted, dawn, or dusk conditions, the effectiveness estimates are not statistically different from zero. Pennsylvania's estimate suggests there may be some benefit, but Florida's estimate suggests no benefit from the tape under these conditions.

TABLE 3-7
Tape Effectiveness by Light Conditions and State

	Florida		Pennsylvania	
Dark	18%	S*	38%	S
Dark-Not-Lighted	37%	S	44%	S
Dark-Lighted, Dawn, & Dusk	-18%	NS	19%	NS

S - Statistically Significant at .01 level.
S* - Statistically Significant at .05 level.
NS - Not Statistically Significant.

3.5 COMBINED EFFECTIVENESS AND "BEST" ESTIMATES

Ideally, the analysis should produce a single estimate of the effectiveness of the tape in both states, combined. One way to do this is to simply combine the Florida and Pennsylvania data and calculate the effectiveness by the method described in Section 3.2 with the pooled data. Table 3-8 shows the effectiveness estimates under the three different lighting conditions using the pooled Florida and Pennsylvania data. The individual Florida and Pennsylvania results are also included in the table.

TABLE 3-8
Tape Effectiveness by Light Conditions

	Pooled		Pennsylvania		Florida	
Dark	29%	S	38%	S	18%	S*
Dark-Not-Lighted	41%	S	44%	S	37%	S
Dark-Lighted, Dawn, & Dusk	-3%	NS	19%	NS	-18%	NS

S - Statistically Significant at .01 level.
S* - Statistically Significant at .05 level.
NS - Not Statistically Significant.

The tape is highly effective in preventing crashes in dark conditions and especially in dark-not-lighted conditions using the combined data. These pooled effectiveness estimates are statistically significant. The tape does not appear to prevent crashes in dark-lighted, dawn, and dusk conditions. All of the pooled effectiveness estimates are in between the ones found in each state. In the dark and dark-not-lighted conditions, the pooled effectiveness is almost exactly equal to the average of the two states' effectiveness.

But the simple method of pooling the data may not be the most accurate. It is possible that some other factors in the states may be confounded with the effectiveness of the tape and therefore simply pooling the data may not be appropriate.

The CATMOD procedure was used on the combined data sets to test if the effectiveness estimate for dark conditions varies by State. The variable STATE was added to the log-linear model (described in Section 3.3) and the data were tested for interactions between the four variables (STATE, DAMAGE, TREAT, and LIGHT). The model includes all the main effects, all the two-variable interactions, and all the three-variable interactions. It does not include the four-variable interaction.

Table 3-9 shows the results of the CATMOD Procedure. The analysis-of-variance table shows that the likelihood-ratio test for the four-variable interaction is non-significant but the three-variable interaction DAMAGE*LIGHT*TREAT is significant. In other words, the tape significantly reduces side and rear impacts in dark conditions, but by about the same amount in the two states. Since the four-variable interaction term is non-significant, it is unnecessary to include the STATE variable in the analysis. The data can simply be pooled and the pooled effectiveness estimate for dark conditions shown in Table 3-8 is a good estimate.

TABLE 3-9
Florida and Pennsylvania Data
Log-linear Model Without Four-variable Interaction
Maximum-likelihood analysis-of-variance table

Dependent Variables: STATE, DAMAGE, LIGHT, and TREAT

Model: DAMAGE, LIGHT, TREAT, STATE, DAMAGE*LIGHT, DAMAGE*TREAT, LIGHT*TREAT, STATE*DAMAGE, STATE*LIGHT, STATE*TREAT, STATE*DAMAGE*LIGHT, STATE*DAMAGE*TREAT, STATE*LIGHT*TREAT, and DAMAGE*LIGHT*TREAT

N of Observations: 10,406

Weighting Factor: N (Number of Combination Trucks)

Source	DF	Chi-Square	Prob
DAMAGE	1	193.71	0.0000
LIGHT	1	673.05	0.0000
DAMAGE*LIGHT	1	0.31	0.5788
TREAT	1	1213.90	0.0000
DAMAGE*TREAT	1	1.77	0.1835
LIGHT* TREAT	1	7.47	0.0063
STATE	1	74.46	0.0000
STATE*DAMAGE	1	33.67	0.0000
STATE*LIGHT	1	77.61	0.0000
STATE*TREAT	1	138.41	0.0000
STATE*DAMAGE*LIGHT	1	4.96	0.0260
STATE*DAMAGE*TREAT	1	1.41	0.2358
STATE*LIGHT*TREAT	1	7.92	0.0049
DAMAGE*LIGHT*TREAT	1	12.68	0.0004
Likelihood Ratio	1	2.26	0.1325

We also conclude from the table that the model is a good predictor of the data. But a model excluding the non-significant term STATE*DAMAGE*TREAT would be an even better predictor of the data. The other non-significant terms (DAMAGE*LIGHT and DAMAGE*TREAT) cannot be excluded because these terms are contained in significant three-variable interactions. Table 3-10 shows the results of the CATMOD procedure using this better model. Again, likelihood-ratio test is non-significant, so effectiveness does not vary significantly from state to state. The three-variable interaction DAMAGE*LIGHT*TREAT is significant, so the overall effectiveness estimate is significant. This model fits the data better than the model in Table 3-9, because it has fewer interaction terms yet still produces a likelihood ratio with higher probability (0.1598 in Table 3-10 vs. 0.1325 in Table 3-19). Thus, this model “best” predicts the effectiveness in dark conditions.

TABLE 3-10
Florida and Pennsylvania Data
Best Log-linear Model
Maximum-likelihood analysis-of-variance table

Dependent Variables: STATE, DAMAGE, LIGHT, and TREAT

Model: DAMAGE, LIGHT, TREAT, STATE, DAMAGE*LIGHT, DAMAGE*TREAT, LIGHT*TREAT, STATE*DAMAGE, STATE*LIGHT, STATE*TREAT, STATE*DAMAGE*LIGHT, STATE*LIGHT*TREAT, and DAMAGE*LIGHT*TREAT

N of Observations: 10,406

Weighting Factor: N (Number of Combination Trucks)

Source	DF	Chi-Square	Prob.
DAMAGE	1	204.03	0.0000
LIGHT	1	671.67	0.0000
DAMAGE*LIGHT	1	0.40	0.5268
TREAT	1	1227.75	0.0000
DAMAGE*TREAT	1	1.35	0.2444
LIGHT* TREAT	1	7.46	0.0063
STATE	1	75.61	0.0000
STATE*DAMAGE	1	45.55	0.0000
STATE*LIGHT	1	78.37	0.0000
STATE*TREAT	1	145.80	0.0000
STATE*DAMAGE*LIGHT	1	4.99	0.0254
STATE*LIGHT*TREAT	1	8.08	0.0045
DAMAGE*LIGHT*TREAT	1	13.66	0.0002
Likelihood Ratio	2	3.67	0.1598

Table 3-11 shows the predicted values for Florida and Pennsylvania from our "best" model in dark conditions. The tape is 28.4 percent effective when the predicted values in Florida or the predicted values in Pennsylvania are used to calculated effectiveness. This is our "best" estimate of tape effectiveness in dark conditions. The three-variable interaction DAMAGE*LIGHT*TREAT is significant, so the effectiveness estimate is significantly greater than zero.

The "best" models for dark-not-lighted and for dark-lighted, dawn, and dusk conditions can be found by repeating the three steps outlined for dark conditions: fitting the full model, excluding non-significant interactions to find the "best" model, and calculating the effectiveness using the predicted values from the "best" model.

The best model for dark-not-lighted conditions is all main effects, all two-variable interactions, and only the DAMAGE*LIGHT*TREAT three-variable interaction. The other three-variable interactions and the four-variable interaction were non-significant. Our "best" effectiveness estimate for dark-not-lighted conditions is 40.1 percent based on the predicted values. This is significant. (The $\div^2$ for DAMAGE*LIGHT*TREAT is 26.42.)

TABLE 3-11 Predicted Values from the "Best" Model				
	Florida		Pennsylvania	
Treated	Side & Rear	SV & Front	Side & Rear	SV & Front
Dark	512.921726	645.078273	525.078273	963.921725
Daylight	1023.612350	1231.387650	873.387649	1,270.612350
Untreated				
Dark	298.078274	300.921726	200.921735	296.078275
Daylight	648.387651	874.612349	281.612349	459.387650
Effectiveness		28.4%		28.4%

The best model for dark-lighted, dawn, and dusk is all main effects, all two-variable interactions, and the STATE*LIGHT*TREAT and the DAMAGE*LIGHT*TREAT three-variable interactions. Our "best" effectiveness estimate is -0.9 percent. The DAMAGE*LIGHT*TREAT interaction was kept in the model although this interaction was not significant. Therefore, we conclude that the tape does not significantly reduce the side and rear crashes of combination trucks under these conditions.

Table 3-12 shows that the estimates obtained by simply pooling the data are nearly the same as by the CATMOD procedure. Essentially, these techniques are interchangeable on the current data set. Since the confidence bounds and statistical significance are much easier to calculate on the pooled data and the techniques are interchangeable, the pooled effectiveness estimate will be presented throughout the remainder of the report.

TABLE 3-12 Tape Effectiveness by Two Alternative Procedures Florida Plus Pennsylvania		
	Simple Pooled	CATMOD Procedure
Dark	29%	28.4%
Dark-Not-Lighted	41%	40.1%
Dark-Lighted, Dawn, & Dusk	-3%	-0.9%

The confidence bounds for dark conditions is $29 \pm (1.645)*0.064 = 29 \pm 10$ percent using the pooled data and the standard deviation equation in Section 3.3. The lower bound is 19 percent and the upper bound is 39 percent. For dark-not-lighted conditions, the standard deviation is 0.060 and the confidence bounds are 41 ± 10 percent using the pooled data. So the lower and upper bounds are 31 and 51 percent, respectively.

CHAPTER 4

TAPE EFFECTIVENESS IN SPECIFIC SITUATIONS

The objective of this chapter is to see if the tape is more effective in some types of crashes than others. For example, does it work better when the weather is clear or rainy? Most of the analyses in this chapter are performed much the same way as in Chapter 3. Tractor/trailer combination involvements in crashes are tabulated by trailer treatment (treated; untreated) and damage area (side/rear; SV/frontal) and light conditions (dark; light). But here, additionally, they are classified by another variable. In our example, they are tabulated by the weather conditions, either clear or rainy. Then, separate effectiveness analyses are performed for each condition.

The most noteworthy finding is that the tape is less effective when the driver of the "other" vehicle is over 50 years old than when the driver is 15-50 years old (Section 4.4).

Twelve comparative analyses of effectiveness were performed:

Effectiveness by collision types

- Rear vs. side impacts
- Various side impact collision types

Effectiveness by environmental/roadway conditions

- Clear weather conditions vs. bad weather conditions
- High speed limit roads vs. low speed limit roads
- Urban vs. rural

Effectiveness by tractor/trailer characteristics

- Van vs. flatbed
- Clean vs. dirty tape

Effectiveness by characteristics of the other driver/vehicle

- Younger vs. older driver
- Male vs. female driver
- Passenger car vs. pickup truck, van, or sport utility vehicle (SUV)

Effectiveness by crash-level injury severity

- Fatal vs. nonfatal-injury vs. property-damage-only crashes
- Fatal or nonfatal-injury vs. property-damage-only crashes

Most of the additional variables used to classify crashes by specific situations were on the conspicuity data base created especially for this evaluation (see Section 2.2). The variables used to classify the various side impact collision types in Pennsylvania and the urban/rural variable were only available on the state data files. These analyses used the merged conspicuity and state data file.

The conspicuity cases and the state cases were merged using the Crash Report Number assigned to each crash on the PAR in Florida. The Florida merged data set had 4,592 cases (4,592/5,535 = 83 percent of the conspicuity cases) after excluding the cases with unknown trailer treatment, light condition, or damage area.

The merge was not as easy or as successful for the Pennsylvania data. The Incident Number assigned to each crash on the paper-copy PAR in Pennsylvania is available on the conspicuity data base, but it is not contained on the State data base. The State assigned a different number to each case when they created the State data base. So, in Pennsylvania the following variables were used to match cases: accident date, county, number of vehicles, vehicle number, model year, and driver age. Here, the merged data set had 3,837 cases (3,837/4,871 = 79 percent of the conspicuity cases) after excluding the cases with unknown trailer treatment, light condition, or damage area.

The merged data set is slightly smaller than the conspicuity data set because some of the cases on the conspicuity data set did not match to a corresponding case on the state data set. For this reason, the merged data set was only used when the variables needed were not available on the conspicuity data set. Most of these unmatched cases are minor crashes with little damage to the vehicles and no reported driver injuries. These cases probably do not meet the minimum criteria for state reported crashes and are therefore not contained on the state data set. Errors in the variable(s) used to match cases can also account for some of the unmatched cases. This probably happens more in Pennsylvania than Florida because an error in any one of the six variables used to match cases in Pennsylvania will result in an unmatched case.

4.1 EFFECTIVENESS BY COLLISION TYPES

Is the tape more effective on the rear of the trailer than on the side of the trailer? NHTSA's regulatory evaluation projected that it would be (see Section 1.1). To answer this question, two separate analyses were performed: one to estimate the effectiveness of the tape in rear impacts and one to estimate the effectiveness of the tape in side impacts. The basic contingency table here tabulated crashes by trailer treatment, damage area, and light conditions, similar to the basic contingency table in Chapter 3. But to estimate the tape effectiveness in rear impacts, only rear impacts were compared to SV/frontal impacts and to estimate the tape effectiveness in side impacts, only side impacts were compared to SV/frontal impacts.

Table 4-1 shows the effectiveness of the tape in rear and side impacts. The results for both states combined show a higher effect in rear impacts, however the state results are not entirely consistent. The Florida estimates suggest that the tape is more effective in rear impacts than side impacts, but the Pennsylvania estimates suggest there is little difference between side and rear impacts. The tape may be more effective in preventing rear impacts than side impacts, but with the different results from only two states we cannot be sure.

TABLE 4-1
Tape Effectiveness by Impact Point

	FL & PA		Florida		Pennsylvania	
Rear Impacts						
Dark	**43%**	**S**	47%	S	34%	S
Dark-Not-Lighted	**51%**	**S**	55%	S	43%	S
Side Impacts						
Dark	**17%**	**S***	-1%	NS	41%	S
Dark-Not-Lighted	**32%**	**S**	25%	S*	43%	S

S - Statistically Significant at .01 level.
S* - Statistically Significant at .05 level.
NS - Not Statistically Significant.

As was discussed in Chapter 1, the tape is expected to be more effective in side impact collisions where a vehicle strikes a combination truck at an angle than in collisions where a vehicle sideswipes a combination truck. To see if this is true, we classified certain two-vehicle crashes into subgroups based on the "first harmful event" as defined on the state files. The limited information on the collision configuration and the different classification methods of the two states precluded a more detailed subgrouping. The "first harmful events" we considered are:

- Angle collision
- Sideswipe
- Turning (Florida only) - i.e. at least one vehicle was making a turn prior to the crash

Other "first harmful events" (head-on, rear-end) are excluded because they are generally not front-to-side or side-to-side impacts. The analysis comprised all the vehicles involved in these crashes, including those with frontal damage and those with side damage.

Table 4-2 shows the effectiveness of the tape by "first harmful event." The sample sizes in the various cells are too small, and the results too inconsistent between Florida and Pennsylvania to draw strong inferences, although effectiveness does appear to be consistently higher in angle collisions than in sideswipes.

TABLE 4-2 Tape Effectiveness by First Harmful Event (Side Impact Collisions)						
	FL & PA		Florida		Pennsylvania	
Angle						
Dark	**46%**	**S**	30%	NS	83%	S
Dark-Not-Lighted	**58%**	**S**	40%	NS	94%	S
Sideswipe						
Dark	**8%**	**NS**	-21%	NS	42%	NS
Dark-Not-Lighted	**28%**	**NS**	33%	NS	24%	NS
Turning						
Dark	**-55%**	**NS**	-55%	NS		
Dark-Not-Lighted	**8%**	**NS**	8%	NS		

4.2 EFFECTIVENESS BY ENVIRONMENTAL/ROADWAY CONDITIONS

Three separate effectiveness analyses were performed to see if the tape is effective in the dark under three different weather conditions: clear; rainy or foggy; snowy or sleeting. Table 4-3 shows the results.

The combined data show about equal effectiveness in clear and in rainy/foggy conditions. Under clear conditions, the combined point estimates and three of the four state estimates show a substantial reduction in crashes. In rain or fog, the point estimates are positive and similar to those for clear weather, but there is only enough data for significance in the combined data set. Florida did not have any crashes occurring in snow or sleet and even Pennsylvania did not have enough for statistically meaningful findings.

TABLE 4-3 Tape Effectiveness by Weather Conditions						
	FL & PA		Florida		Pennsylvania	
Clear						
Dark	**28%**	**S**	12%	NS	43%	S
Dark-Not-Lighted	**43%**	**S**	35%	S	50%	S
Rain and Fog						
Dark	**31%**	**S***	34%	NS	31%	NS
Dark-Not-Lighted	**39%**	**S***	44%	S*	39%	NS
Snow and Sleet						
Dark	**-12%**	**NS**			-12	NS
Dark-Not-Lighted	**-17%**	**NS**			-17	NS

Table 4-4 compares the effectiveness of the tape on roads with high and low speed limits. The combined data show about the same effectiveness on both types of roads. The tape is clearly effective on roads with high speed limits. On roads with speed limits of 50 mph or above, the tape is effective for the combined data and individual state data. On low speed roads the results are less conclusive. The combined estimates show the tape is effective on low speed roads, but the state results are inconsistent. The tape is highly effective in Pennsylvania, but it may not be in Florida.

TABLE 4-4
Tape Effectiveness by Speed Limit

	FL & PA		Florida		Pennsylvania	
Speed Limit is Less than 50 MPH						
Dark	**26%**	**S***	-4%	NS	54%	S
Dark-Not-Lighted	**46%**	**S**	16%	NS	68%	S
Speed Limit is 50 MPH and Above						
Dark	**29%**	**S**	25%	S	30%	S
Dark-Not-Lighted	**39%**	**S**	41%	S	34%	S

Table 4-5 shows the effectiveness of the tape is likely to be about the same in urban and rural areas. The tape is clearly effective in rural areas. The combined estimates are significant as are the individual state estimates under both lighting conditions. The tape is probably effective in urban areas. The combined point estimates are positive and significant. The state point estimates suggest a substantial reduction in crashes, more than 30 percent, but only one is significantly greater than zero. Statistical significance is hard to attain here, because very few cases are in urban areas (18 percent in Florida and 27 percent in Pennsylvania).

TABLE 4-5
Tape Effectiveness by Urban vs. Rural Location

	FL & PA		Florida		Pennsylvania	
Urban						
Dark	**35%**	**S***	30%	NS	31%	NS
Dark-Not-Lighted	**57%**	**S**	78%	S	41%	NS
Rural						
Dark	**32%**	**S**	23%	S*	40%	S
Dark-Not-Lighted	**39%**	**S**	32%	S	45%	S

When the data is divided into four groups (rural vs. urban, side vs. rear impacts), there are not enough cases in any group for strong conclusions. However, the point estimates suggest that the tape may be more effective in urban side impacts than in rural side impacts. If so, that would be consistent with the idea that urban side impacts are more likely to be angle rather than sideswipe collisions, where the tape might be more effective.

4.3 EFFECTIVENESS BY TRACTOR/TRAILER CHARACTERISTICS

Five different trailer types were identified on the conspicuity data base. The effectiveness of the tape on the two most common types is shown in Table 4-6. The tape is probably effective on vans in dark-not-lighted conditions. The combined estimate is significant. The state point estimates are positive and close to the combined point estimate. In "dark" conditions, the results for vans are mixed.

The tape is clearly effective on flatbeds. The estimates are fairly large and significant for the combined data and the individual state data. It also appears the tape is more effective on flatbeds than vans. All point estimates for flatbeds are higher than their counterparts for vans. The CATMOD procedure to test the effectiveness estimates by trailer type showed that the effectiveness estimates for flatbeds are significantly different than the effectiveness estimates from vans. Flatbeds even when loaded are probably less visible than van trailers in the dark because of their low profile. This makes the tape very effective on flatbeds.

TABLE 4-6
Tape Effectiveness by Trailer Type

	FL & PA		Florida		Pennsylvania	
Van						
Dark	**11%**	**NS**	-9%	NS	26%	S*
Dark-Not-Lighted	**25%**	**S**	21%	NS	28%	S*
Flatbed						
Dark	**55%**	**S**	41%	S*	65%	S
Dark-Not-Lighted	**63%**	**S**	50%	S*	70%	S

The effectiveness of clean and dirty tape was compared to see if dirt and grime diminish the effectiveness of the tape. The condition of the tape was indicated on both the side and the rear of the trailer, so we considered the effects of dirt on the side and the rear of the trailer, separately. The basic analysis tabulated tractor/trailer combination involvements by trailer treatment (treated; untreated) and damage area (side/rear; SV/frontal) and light conditions (dark; light). But here, additionally, they will be classified by tape condition: clean vs. dirty on the side and clean vs. dirty on the rear.

First, let us consider the analysis for the tape condition on the side of the trailer. Here, instead of comparing side/rear impacts to SV/frontal impacts, we compared only side impacts to SV/frontal impacts. We also compared clean, treated vehicles to untreated vehicles for the effectiveness of clean tape and dirty, treated vehicles to untreated vehicles for the effectiveness of dirty tape. Untreated trailers were not classified as clean or dirty. Therefore, we could not compare clean, treated vehicles to clean, untreated vehicles and dirty, treated vehicles to dirty, untreated vehicles. "Some dirt" and "very dirty" were combined into one category and analyzed together because there were too few "very dirty" trailers to analyze separately. The only difference in the analysis of the tape condition on the rear of the trailer is that rear impacts were compared to SV/frontal impacts.

Table 4-7**S** shows the effectiveness in **side** impacts for clean and dirty tape on the side of trailers. There appears to be no difference in the effectiveness of clean and dirty tape on the trailer side. The combined point estimates are all around 30 percent except for clean tape, dark conditions. Although the individual state point estimates are not consistent, there is little difference between the point estimates for clean and dirty tape within each state.

TABLE 4-7S
Tape Effectiveness in Side Impacts by Tape Condition on the Side of Trailers

Side Impact Analysis	**FL & PA**		Florida		Pennsylvania	
Trailer Side - Clean						
Dark	**13%**	**NS**	1%	NS	37%	S
Dark-Not-Lighted	**33%**	**S**	32%	S	43%	S
Trailer Side - Dirty						
Dark	**27%**	**S**	-2%	NS	46%	S
Dark-Not-Lighted	**30%**	**S**	7%	NS	37%	S*

Table 4-7**R** shows the effectiveness in **rear** impacts for clean and dirty tape on the rear of trailers. This table not only shows that clean tape is highly effective on the rear of trailers, but also that dirty tape appears to be effective on the rear of trailers. The combined and state point estimates are consistent and the combined point estimates have enough data for statistical significance. Since the point estimates for clean tape are consistently larger than the point estimates for dirty tape, the CATMOD procedure was used to test if the effectiveness varied by tape condition. The CATMOD procedure showed that the effectiveness estimates for clean tape are significantly different than the estimates for dirty tape. In other words, clean tape is more effective than dirty tape on the rear of the trailers.

It is not obvious why clean tape should make more of a difference in rear impacts than in side impacts. The ambiguous results for clean vs. dirty tape in side impacts are consistent with the inconclusive overall results for side impacts. In Table 4-1, Pennsylvania showed a strong effect for the tape in side impacts, but Florida showed no effect in dark conditions and a weak effect in dark-not-lighted conditions.

TABLE 4-7R Tape Effectiveness in Rear Impacts by Tape Condition on the Rear of Trailers						
Rear Impact Analysis	**FL & PA**		Florida		Pennsylvania	
Trailer Rear - Clean						
Dark	**53%**	**S**	55%	S	55%	S
Dark-Not-Lighted	**62%**	**S**	65%	S	54%	S
Trailer Rear - Dirty						
Dark	**27%**	**S**	26%	NS	19%	NS
Dark-Not-Lighted	**33%**	**S**	30%	NS	26%	NS

4.4 EFFECTIVENESS BY OTHER DRIVER/VEHICLE CHARACTERISTICS

The next three analyses focus on the other vehicle involved in a two-vehicle crash with a combination truck. The "other" vehicle is not necessarily the striking or impacting vehicle, because in some crashes it is the truck that strikes the other vehicle. The "other driver" is the driver of the other vehicle. Two-vehicle crashes where both vehicles are combination trucks were excluded from the analysis. Single-vehicle crashes by definition were also excluded, thus side/rear impacts were only compared to frontal impacts. In Florida, 63 percent of the other vehicles are passenger cars and 23 percent are pickup trucks, vans, and sport utility vehicles (SUVs) (and 14 percent are heavy trucks, other or unknown vehicle types). In Pennsylvania, 58 and 21 percent of the other vehicles are passenger cars and light trucks, respectively (and 21 percent are heavy trucks, other or unknown vehicle types).

Table 4-8 shows the effectiveness of the tape by the other driver's age. Younger drivers of other vehicles benefit more from the tape than older drivers. The effectiveness estimates for 15-50 year old drivers are quite large and significant. The combined point estimates for drivers older than 50 are small and not significant. Although the state point estimates for older drivers are not consistent, most of them are not significant just like the combined results. The point estimates for younger drivers are almost always much larger than the corresponding point estimates for older drivers. The CATMOD procedure comparing the younger and older driver point estimates showed that there is no significant difference under dark conditions, but that there is a significant difference under dark-not-lighted conditions. This suggests that at least in "dark-not-lighted" conditions younger drivers of other vehicles benefit more from the tape than older drivers. It is possible that older drivers' eyesight is so poor at night (and/or reaction time so slow) that the tape might not become visible soon enough to prevent collisions with combination trucks. If this is so, it might be appropriate to explore more intense conspicuity treatments that would give the older drivers benefits comparable to those of young drivers. However, an alternative, less troubling interpretation of these results is that older drivers keep a greater distance from combination trucks and have less need for the tape. Another caveat is that the contrast in the results is seen mainly in Florida, whereas the tape is still quite effective for older drivers of the other vehicles in Pennsylvania.

TABLE 4-8 Tape Effectiveness by Other Driver's Age						
	FL & PA		Florida		Pennsylvania	
15-50 years old						
Dark	**44%**	**S**	31%	S	54%	S
Dark-Not-Lighted	**58%**	**S**	53%	S	60%	S
More than 50 years old						
Dark	**20%**	**NS**	-8%	NS	53%	S*
Dark-Not-Lighted	**10%**	**NS**	-7%	NS	34%	NS

Most of the other drivers are male (66 and 69 percent in Florida and Pennsylvania, respectively). Table 4-9 shows the effectiveness of the tape is about the same when the other driver is male and when the other driver is female. The result is consistent with intuition: there is no obvious reason why the tape should be more effective for drivers of one gender, except perhaps that some male drivers are more aggressive.

TABLE 4-9 Tape Effectiveness by Other Driver's Gender						
	FL & PA		Florida		Pennsylvania	
Male						
Dark	**41%**	**S**	30%	S*	49%	S
Dark-Not-Lighted	**53%**	**S**	50%	S	51%	S
Female						
Dark	**36%**	**S**	11%	NS	67%	S
Dark-Not-Lighted	**44%**	**S**	25%	NS	67%	S

Table 4-10 shows similar effectiveness of the tape regardless of whether the other vehicle is a passenger car or a light truck. This, too, is intuitively reasonable: it is unlikely that the higher seating height in light trucks make the tape significantly more or less visible than to the car driver.

TABLE 4-10 Tape Effectiveness by Other Vehicle Type						
	FL & PA		Florida		Pennsylvania	
Passenger Cars						
Dark	**35%**	**S**	11%	NS	60%	S
Dark-Not-Lighted	**54%**	**S**	41%	S	67%	S
Light Truck, Vans, and SUVs						
Dark	**49%**	**S**	40%	NS	53%	S*
Dark-Not-Lighted	**44%**	**S**	30%	NS	51%	NS

4.5 EFFECTIVENESS BY CRASH-LEVEL INJURY SEVERITY

Driver injury severity is coded on the conspicuity data base as follows:

K Killed
A A injury - incapacitating injury
B B injury - non-incapacitating injury
C C injury - possible injury
O Not injured

A new variable, crash-level injury severity, was created to classify the most severe driver injury in each crash. Separate effectiveness analyses were performed on four [overlapping] crash-level injury severity groups: not injured; A, B and C injuries; fatal; and the combined injury group of fatal, A, B, and C injuries.

Table 4-11 shows the effectiveness estimates by crash-level injury severity. The tape may not reduce very minor crashes. When none of the drivers in the crash are injured, the tape effectiveness is not significantly different from zero. The tape clearly reduces injury crashes.

The tape significantly reduces crashes where at least one of the drivers was killed. The pooled data effectiveness estimates are large and achieve statistical significance. But while these data support a conclusion that the tape saves lives as well as reducing nonfatal crashes, the point estimates themselves should not be relied upon, since they are based on a small sample of fatal injury crashes. There are about 300 fatal injury cases in the pooled data for dark conditions compared to about 4,900 fatal, A, B, and C injury cases. There are even fewer cases for the dark-not-lighted conditions. Therefore in Chapter 5, a range of lives saves will be estimated using the 29 percent (all crashes) and 44 percent (fatal, A, B, and C injury crashes) reduction.

TABLE 4-11
Tape Effectiveness by Crash-Level Injury Severity

	FL & PA		Florida		Pennsylvania	
Not Injured						
Dark	**6%**	**NS**	-38%	S*	36%	S
Dark-Not-Lighted	**14%**	**NS**	-33%	NS	41%	S
A, B, & C Injured						
Dark Conditions	**41%**	**S**	41%	S	37%	S
Dark-Not-Lighted	**54%**	**S**	61%	S	41%	S
Fatal						
Dark	**68%**	**S**	66%	S*	74%	NS
Dark-Not-Lighted	**71%**	**S**	56%	NS	90%	S
Fatal, A, B, & C Injured						
Dark	**44%**	**S**	45%	S	40%	S
Dark-Not-Lighted	**55%**	**S**	60%	S	45%	S

The CATMOD procedure comparing injured (K, A, B, or C) and not injured (O) shows that the effectiveness estimates for injured are significantly different than the effectiveness estimates for not injured. Thus, the tape is more effective at reducing injury crashes than non-injury crashes.

4.6 TAPE EFFECTIVENESS DURING THE DAYLIGHT

The fleet study[11] discussed in Section 1.1 concluded that the tape is effective not only in dark conditions but also during daylight. Other research suggests that the tape might be more effective on the side than the rear of the trailer during daylight. To the limited extent that our data can be used to address this issue, they do not support either premise.

Only a two-variable analysis method was available to estimate the effectiveness of the tape during daylight. The analysis tabulates tractor/trailer vehicle involvements in crashes by trailer treatment (treated; untreated) and damage area (side and rear impacts; single-vehicle and frontal impacts). The analysis compares the involvement rates of treated and untreated tractor/trailer combination trucks at only daylight conditions. We did not have exposure data or a control group for additional adjustments of these rates. Table 4-12 shows the two-variable contingency table and the effectiveness estimates by state. Neither estimate is significant; therefore there is no evidence here of a reduction of crashes involving treated trailers during daylight.

[11]Burger, W. J., et al, *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task III – Field Test Evaluation of Vehicle Reflectorization Effectiveness,* NHTSA Report No. DOT HS 806 923, Washington, DC, 1985.

Table 4-12
Number of Crash Involvements and Effectiveness During the Daylight

	Florida		Pennsylvania	
	Side & Rear	SV & Frontal	Side & Rear	SV & Frontal
Treated	1,024	1,231	873	1,271
Untreated	648	875	282	459
"Effectiveness"		-12%		-12%

When you only compare side to single-vehicle and frontal impacts, the tape is -7 and -27 percent effective during daylight in Florida and Pennsylvania, respectively. For rear impacts, the tape is -27 and 1 percent effective in Florida and Pennsylvania, respectively. The tape does not appear to reduce either side or rear impacts during daylight.

We believe that the two-variable method used here is intrinsically flawed and these results may be inaccurate. But without a good control for daylight crashes such as mileage or other exposure data, this is the only method available to estimate the effectiveness of the tape during daylight.

CHAPTER 5

BENEFITS OF CONSPICUITY TAPE

The addition of conspicuity tape on the side and rear of heavy trailers has reduced crashes involving combination trucks and injuries sustained in these crashes. In the pooled data described in Chapter 3, we found a 29 percent reduction of side and rear impacts into combination trucks, in the dark. In Chapter 4, we found a 44 percent reduction in all injury levels sustained in these crashes. When all heavy trailers have conspicuity tape, the tape will prevent approximately 7,800 crashes per year, prevent approximately 3,100 to 5,000 injuries per year, and save an estimated 191 to 350 lives per year.

5.1 CRASHES AVOIDED PER YEAR

During the baseline year 1999, NHTSA's General Estimate System (GES) reported that there were 20,883 actual side and rear impacts into combination trucks in dark conditions (referred to below as the N0 group). Some of these tractor-trailer combinations had trailers treated with conspicuity tape and others had trailers not treated with tape. We are going to estimate the number of crash-involved combination trucks during the dark in side and rear impacts that would have occurred if:

- All the trailers had not been treated with tape (N1). N1 > N0.
- All the trailers had been treated with conspicuity tape (N2). N1 > N0 > N2.
- The crashes avoided by adding tape to trailers: N1 - N2.

To calculate crashes avoided, we must first calculate the percentage of trailers that have tape and the percentage of trailers that do not have tape in the baseline year. In 1999, 71 percent of the crash-involved trailers in the dark with side or rear damage had tape in Florida and 72 percent of the crash-involved trailers in the dark with side or rear damage had tape in Pennsylvania. We believe the Pennsylvania percentage of trailers with tape is more representative of the full year than the Florida percentage because the Pennsylvania data is from the first 11 months of the year and the Florida data is only from the first five months of the year.

Since there are 20,883 crash involved trailers damaged in the side and rear in the dark in 1999, then 72 % * 20,883 = 15,036 of these trailers had tape and 5,847 of these trailers did not have tape. Given that conspicuity tape reduces involvements by 29 percent (Table 3-12), then the number of involvements that would have occurred if the treated trailers had not been treated with tape is 15,036 / (1-.29) = 21,177. Thus, there would have been N1 = 21,177 + 5,847 = 27,024 involvements if all trailers had not been treated with tape.

If all trailers had been treated with tape, then there would have been N2 = 27,024 * (1-.29) = 19,187 crash involved combination trucks with side or rear damage in the dark. That is a reduction of N1 - N2 = 27,024 - 19,187 = 7,837, which is rounded to 7,800 crashes per year.

5.2 NONFATAL INJURIES AVOIDED PER YEAR

To calculate the injuries prevented by adding conspicuity tape to trailers, we used the same method as for crashes. As above, 72 percent of the trailers actually had tape in 1999 and 28 percent did not have tape. Table 4-11 showed that the tape is 41 percent effective in preventing nonfatal injuries (pooled data - dark conditions). So injuries avoided per year will be calculated using that estimate and the more conservative estimate (29 percent effectiveness in all crashes) to give a range.

The GES reported that there were 8,159 A, B, and C injuries in combination truck crashes during 1999 where the combination truck was damaged in the side or rear in the dark. There must have been approximately 8,159 * 72% = 5,874 injuries occurring in crashes where the trailer involved had tape and 2,285 injuries occurring in crashes where the trailer involved did not have tape.

Given that nonfatal injuries are reduced by 41 percent, if the trailers that were treated with tape did not have tape, there would have been 5,874/(1-.41) = 9,956 injuries in these crashes. Thus, there would have been N1 = 9,956 + 2,285 = 12,241 injuries occurring in crashes involving a combination truck if the trailer did not have tape. If all the trailers in all of these crashes had tape, then there would only be N2 = 12,241 * (1-.41) = 7,222 injuries. That is a reduction of N1 - N2 = 12,241 - 7,222 = 5,019 injuries, which is rounded to 5,000 injuries.

Based on the more conservative 29 percent reduction, if the trailers that were treated with tape did not have tape, there would have been 5,874/(1-.29) = 8,273 injuries in these crashes. Thus, there would have been N1 = 8,273 + 2,285 = 10,558 injuries occurring in crashes involving a combination truck if the trailer did not have tape. If all trailers had tape, then there would be N2 = 10,558 * (1-.29) = 7,496 injuries. This is a reduction of N1 - N2 = 10,558 - 7,496 = 3,062 injuries, which is rounded to 3,100 injuries. Therefore, when all trailers have tape, the tape will reduce 3,100 to 5,000 injuries per year relative to a trailer fleet without tape.

5.3 LIVES SAVED PER YEAR

The same method applies to lives saved. Two estimates of fatality reduction will be used to calculate lives saved: 29 percent - the effectiveness of tape found in all crashes; 44 percent - the effectiveness of tape found in fatal, A, B, and C injury crashes.

In the 1999 FARS data, there were 508 fatalities occurring in crashes where a combination truck had side or rear damage, and the crash took place in the dark. Seventy-two percent or 508 * 72%

= 366 fatalities occurred in crashes where the trailer involved had tape and 142 fatalities occurred in crashes where the trailer involved did not have tape.

Based on the more conservative 29 percent reduction, if the trailers that were treated with tape did not have it, then there would have been 366 /(1-.29) = 515 fatalities in these crashes. There would have been N1 = 515 + 142 = 657 fatalities if none of the trailers had tape. The number of fatalities that would have occurred if all of the trailers had tape is N2 = 657 * (1-.29) = 466. Here, the difference is N1 - N2 = 657 - 466 = 191 lives saved annually by adding conspicuity tape to trailers.

If the tape is 44 percent effective in preventing fatalities and if the trailers that were treated with tape had not had it, then there would have been 366 /(1-.44) = 654 fatalities in these crashes. There would have been N1 = 654 + 142 = 796 fatalities if none of the trailers had tape. The number of fatalities that would have occurred if all of the trailers had tape is N2 = 796 * (1-.44) = 446. Therefore, the difference is N1 - N2 = 796 - 446 = 350 lives saved annually by adding conspicuity tape to trailers. Therefore, when all trailers have tape, the tape will reduce 191 to 350 lives per year relative to a trailer fleet without tape.

REFERENCES

Burger, W. J., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task I – Accident Analysis and Functional Requirements*, NHTSA Report No. DOT HS 806 100, Washington, DC, 1981.

Burger, W. J., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task III – Field Test Evaluation of Vehicle Reflectorization Effectiveness*, NHTSA Report No. DOT HS 806 923, Washington, DC, 1985.

Green, P., et al., *Accidents and the Nighttime Conspicuity of Trucks,* University of Michigan Highway Safety Research Institute, Report No. UM-HSRI-79-92, Ann Arbor, MI 1979.

Hansen, Morris H., Hurwitz, William N., and Madow, William G., *Sample Survey Methods and Theory, Volume I*, John Wiley & Sons, New York, 1953, pp. 512-514.

Minahan, D. J. and O'Day, J., *Car-Truck Fatal Accidents in Michigan and Texas*, University of Michigan Highway Safety Research Institute, Report No. UM-HSRI-77-49, Ann Arbor, MI, 1977.

Olsen, P. L., et al., *Performance Requirements for Large Truck Conspicuity Enhancements,* NHTSA Report No. DOT HS 807 815, Washington, DC, 1992

Preliminary Regulatory Evaluation - Proposed Amendment to FMVSS No. 108 to Require Retroreflective Material on the Side and Rears of Heavy Trailers, NHTSA, Washington, DC, 1991.

SAS/STAT Users's Guide: Volume1, ACECLUS-FREQ, Version 6, Fourth Edition, SAS Institute Inc., Cary, NC, 1990.

Ziedman, K., et al., *Improved Commercial Vehicle Conspicuity and Signalling Systems, Task II – Analyses, Experiments and Design Recommendations*, NHTSA Report No. DOT HS 806 098, Washington, DC, 1981.