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NHTSA Light Vehicle Antilock Brake System Research Program Task 7.1:

Examination of ABS-Related Driver Behavioral Adaptation – License Plate Study

DISCLAIMER

NOTE

REGARDING COMPLIANCE WITH

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16. Abstract

Numerous crash data statistical analyses conducted over the past few years suggest that, for automobiles, the introduction of four-wheel antilock brake systems (ABS) has produced net safety benefits much lower than originally expected. The studies indicate the apparent increase in single-vehicle crashes involving passenger cars equipped with four-wheel ABS almost completely offsets the safety advantage such vehicles have over their conventionally-braked counterparts. Other studies have suggested that this may be occurring because people drive faster in ABS-equipped vehicles, such as due to behavioral adaptation. As part of its Light Vehicle ABS Research Program, NHTSA conducted an observational experiment to investigate the possibility of behavioral adaptation resulting from ABS.

An experiment was conducted to unobtrusively determine whether drivers of vehicles equipped with ABS have a tendency to drive faster than drivers of conventionally braked vehicles. Several locations on public roadways around Ohio were selected as data collection sites. At these sites, the speed and license plate information of passing vehicles were unobtrusively measured and recorded using a laser speed gun, video camera, and laptop computer. Data were collected at each site for specified periods during daylight hours (balanced for AM/PM) in both wet and dry road conditions. Using the license plate number, the VIN number was obtained and then decoded to determine whether each vehicle had ABS. Average speed data for specified conditions and locations were compared for vehicles with ABS versus those without.

The results of this study showed that type of brake system (ABS or conventional) had no significant effect on driving speed under the conditions examined. This finding of no significant speed effects was true for all sites, pavement conditions, and model years of vehicles observed. A consistent, but insignificant, trend was seen in mean speed by brake system for each site where higher speeds were observed for drivers of ABS-equipped vehicles. Significant results that were found included higher speeds for drivers of newer model cars, higher speeds for dry pavement, and that speed as a function of location (site). Overall, based on observed vehicle speed results, evidence of passenger car ABS-related driver behavioral adaptation was not observed using the methods employed in this study. Based on these and other related results from NHTSA's Light Vehicle ABS Research Program, the authors believe that behavioral adaptation due to ABS is not occurring during "real world" driving. Thus, the results of this study suggest that the apparent increase in single-vehicle crashes involving ABS-equipped vehicles cannot be attributed to behavioral adaptation.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

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An experiment was conducted to determine whether the existence of behavioral adaptation could be inferred from differences in observed operating speeds between ABS and non-ABS-equipped vehicles under real-world conditions. Testing was conducted to unobtrusively determine whether drivers of vehicles equipped with ABS have a tendency to drive faster than drivers of conventionally braked vehicles. Several locations on public roadways around Ohio were selected as data collection sites. At these sites, the speed and license plate information of passing vehicles were unobtrusively measured and recorded using a laser speed gun, video camera, and laptop computer. Data were collected at each site for specified periods during daylight hours (balanced for AM/PM) in both wet and dry road conditions. Using the license plate number, the VIN number was obtained and then decoded to determine whether each vehicle had ABS. Average speed data for specified conditions and locations were compared for vehicles with ABS versus those without.

The results of this study showed that type of brake system (ABS or conventional) had no significant effect on driving speed under the conditions examined. This finding of no significant speed effects was true for all sites, pavement conditions, and model years of vehicles observed. A consistent, but insignificant, trend was seen in mean speed by brake system for each site where higher speeds were observed for drivers of ABS-equipped vehicles. Significant results that were found included higher speeds for drivers of newer model cars, higher speeds for dry pavement, and that speed as a function of location (site). Overall, based on observed vehicle speed results, evidence of passenger car ABS-related driver behavioral adaptation was not observed using the

methods employed in this study. Based on these and other related results from NHTSA's Light Vehicle ABS Research Program, the authors believe that behavioral adaptation due to ABS is not occurring during "real world" driving. Thus, the results of this study suggest that the apparent increase in single-vehicle crashes involving ABS-equipped vehicles cannot be attributed to behavioral adaptation.

1.0 INTRODUCTION

1.1. Effects of ABS on Crash Rates

Antilock brake systems (ABS) have been introduced on many passenger car and light truck make/models in recent years. In general, ABS appear to be very promising safety devices when evaluated on a test track. Under many pavement conditions antilock brake systems allow the driver to stop a vehicle more rapidly while maintaining steering control even during situations of extreme, panic braking. Brake experts anticipated that the introduction of ABS on passenger vehicles would reduce both the number and severity of crashes. However, a number of crash data analyses have been performed in recent years by NHTSA, automotive manufacturers, and others that indicate that the introduction of ABS has not reduced the number of crashes where they were expected to be effective. Results of these analyses suggest that, for automobiles, the introduction of ABS has produced net safety benefits much lower than originally expected for ABS-equipped light vehicles [2,3,4,5]. Safety benefits due to ABS were seen in light truck (rear wheel ABS only) crash data studies.

Kahane [1] found that, with the introduction of ABS, involvements in fatal multi-vehicle crashes on wet roads were significantly reduced by 24 percent, and nonfatal crashes by 14 percent. However, these reductions were offset by a statistically significant increase in the frequency of fatal single-vehicle, run-off-road crashes, as compared to cars without ABS. Fatal run-off-road crashes were up by 28 percent and nonfatal crashes by 19 percent.

A later, 1998 study by Hertz, Hilton, and Johnson [2, 3] was similar to an earlier study by the same authors [4] except that it was based on more recent (1995 - 96) crash data. The effects found by the 1998 study were generally similar to the findings of the earlier study except that ABS now appears to be decreasing one particular subtype of single-vehicle road departure crashes, frontal impacts with fixed objects, rather than increasing their numbers.

The most recent NHTSA study of ABS-related crash data was published in 2000 by Hertz et al [5]. This analysis differed from the earlier work by Hertz in that it included vehicles whose owners had selected ABS as an option. The inclusion of the vehicles with optional ABS did not seem to make very much difference in the estimation of the effect of all-wheel ABS in crashes of all severities. Results showed that ABS still seemed to have a beneficial effect in preventing each crash type except for side impacts, where it appeared to be associated with a higher response rate, especially for passenger cars. It still appeared to be beneficial in preventing pedestrian crashes, rollovers, run-off-road crashes and frontal crashes with another moving vehicle. The previous Hertz study indicated several instances where ABS was not beneficial in fatal crashes. The only statistically significant one remaining in the 2000 study was rollovers of LTVs. However, this increase was still large enough to negate most of the benefits of ABS.

1.2. NHTSA's Light Vehicle ABS Research Program

In an effort to investigate possible causes of the crash rate phenomena identified, NHTSA developed its Light Vehicle ABS Research Program, as outlined in [6]. This program contained nine separate tasks which address potential theories as to the cause of the lack of net crash benefits such as driver behavior in a crash-imminent situation, driver response to ABS activation, ABS hardware performance, and environmental factors. To date, NHTSA research has found no systematic hardware deficiencies in its examination of ABS hardware performance (as documented in [7]). It is unknown, however, to what extent the increase in run-off-road crashes may be due to drivers' incorrect usage of ABS, incorrect response to ABS activation, incorrect instinctive driver response (e.g., oversteering), changes in driver behavior (i.e., behavioral adaptation) as a result of ABS use, and/or some other factor.

Task 1 of NHTSA's Light Vehicle ABS Research Program, performed by Hertz in 2000 [5] as mentioned in the previous section, involved performing a new crash data study of the effect on safety of adding four-wheel ABS to automobiles. This study differed from those previously conducted [1, 2, 3, 4] in that it focused on newer vehicles and antilock brake systems and included some methodological improvements. This study endeavored to address whether whatever problem may have caused the apparent increase in single-vehicle crashes for ABS-equipped automobiles still existed following the introduction of newer generation ABS hardware.

Task 2 of this program involved conducting a national telephone survey to determine drivers' knowledge and expectations about ABS. This information will be used to determine whether the apparent increase in single-vehicle crashes for automobiles was due to drivers' misunderstanding of ABS functionality. Results of the survey showed that, although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicle was so equipped. Certain types of brake pedal feedback from an activated ABS were often misinterpreted, making driver reaction sub-optimal and in some cases potentially dangerous. Drivers who owned ABS-equipped vehicles had similar misunderstandings as well. There was also some evidence these drivers placed more confidence in ABS and what it could do for them than the non-ABS owners did, in many of the possible conditions contained in the survey. Lastly, this survey also found that information imparted at the time of purchase was the means by which the majority of drivers find out about the brakes on their vehicle. Approval ratings for lengthy or mandatory information sessions were not well received, though some methods held promise.

Task 3 involved the examination of selected single-vehicle crash reports collected by the National Automotive Sampling System (NASS). The goal of this work was to determine what differences could be identified in the characteristics of single-vehicle crashes incurred by ABS-equipped versus non-ABS-equipped automobiles using NASS Crashworthiness Data System (CDS) cases. Results of this examination of crash cases did not provide conclusive evidence that ABS had a significant effect on crash rates for the time period covered.

Task 4 [7] measured the braking performance of a group of current production ABS-equipped vehicles over a broad range of surfaces and maneuvers. While ABS stopping performance has been measured by many groups over many years, there is a possibility that poor performance on some unusual surface or during some maneuver may have been overlooked. If such could be found, this might explain the apparent increase in single-vehicle crashes of ABS-equipped automobiles. Results of this study showed that for most maneuvers, on most surfaces, ABS-assisted stops yielded distances shorter than those made with the ABS disabled. The one exception was on loose gravel where stopping distances increased by an average of 27.2 percent overall. Additionally, the vehicular stability observed during testing was almost always superior with ABS. For the cases in which instability was observed, ABS was not deemed responsible for its occurrence.

Task 5 examined the hypothesis that the apparent increase in single-vehicle crashes with ABS-equipped vehicles is due to driver "oversteering" in crash-imminent situations. In a crash imminent situation, a driver's first action is expected to be a very hard push on the brake pedal. Oversteering occurs when the driver, possibly believing that the hard braking input is insufficient to avoid the upcoming obstacle (such as another vehicle), rapidly turns the steering wheel by a large amount. For conventionally braked or rear-wheel ABS only vehicles, this oversteering has little effect, since the initial driver brake pedal activation is likely to lock the vehicle's front wheels. However, for a vehicle equipped with four-wheel ABS (where the ABS minimizes front wheel lockup and allows the driver to maintain steering capability), the oversteering may result in the vehicle missing the upcoming obstacle, going off of the roadway, and being involved in a single-vehicle crash.

Task 5 was divided into multiple subtasks to examine driver crash avoidance behavior with and without ABS. This task sought to assess the prevalence of driver oversteering and examined the effects of training on successfully avoiding a crash. Task 5.1 used a driving simulator to address this issue. Task 5.2 examined driver crash avoidance behavior in a test track environment on a dry, high coefficient of friction road surface. Task 5.3 also studied driver crash avoidance behavior in a test track environment but on a wet, low coefficient of friction road surface.

Results of the test track studies, Tasks 5.2 and 5.3 [8], showed that drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering can occur. However, a significant number of road departures did not result from this behavior for dry or wet pavement. ABS was found to significantly reduce crashes on wet pavement as compared to conventional brakes. Results of the simulator study (Task 5.1) [9] also showed that excessive steering can occur during realistic crash avoidance situations. However, this steering was not found to result in a significant number of road departures.

Task 6 investigated the effects of ABS during road recovery maneuvers (i.e., when a driver attempts to maneuver an automobile back onto the roadway after a departure). Many road departures occur when the driver maneuvers the vehicle in an essentially straight line that leaves the road. This action may be due to driver inattention, sleepiness, or intoxication. None of these causes are related to the presence or absence of ABS. However, the presence of ABS may or may not influence the ability of the driver to safely return the vehicle to the roadway. Task 6 was still underway at the time of publication of this report.

Task 7 looked at the issue of ABS and risk compensation. Several studies have found that people drive faster or more aggressively on test tracks in ABS-equipped vehicles than with conventionally-braked vehicles. The goal of this task was to try to determine if these trends occur during typical driving on actual public roads.

Task 7 was divided into multiple subtasks. Task 7.1, the subject of this report, involved remote, unobtrusive observation methods to collect data about the behavior (e.g., speed) of drivers. Task 7.2 collected more detailed data about the driving behavior of subjects using instrumented vehicles in a naturalistic research setting. Task 7.2 was still underway at the time of publication of this report.

Task 8 involved the integration of data from all of the preceding tasks in an attempt to infer why the crash data studies did not find the anticipated increase in safety for ABS-equipped automobiles.

Task 9 involved the dissemination of task results. NHTSA has shared knowledge gained through the program's research efforts by reporting its findings with interested parties within NHTSA and the public at large. Summaries of current research efforts and results-to-date have been presented for discussion.

NHTSA's Light Vehicle ABS Research Program has only been a first step in assessing the anticipated safety benefits from ABS. This program deals solely with trying to learn why the crash data studies did not find the anticipated increase in safety for ABS-equipped automobiles. The development of countermeasures to resolve any problems discovered is left to future research.

2.0 BACKGROUND AND OBJECTIVES

2.1. Behavioral Adaptation and ABS

One theory that has developed to explain the lack of apparent ABS crash benefits is that of behavioral adaptation. Behavioral adaptation, in this case, implies that as additional safety features are added to vehicles, drivers will alter their behavior in such a way that results in decreased safety, such as by becoming less cautious or driving more aggressively. This change in behavior may be attributable to drivers' knowledge and beliefs that the added safety features will prevent them from having a crash or being injured. Changes may also be due to the driver's experience with the ABS-equipped vehicle (regardless of knowledge) and how it "feels" and performs. A report by Fambro, Koppa, Picha, and Fitzpatrick [10] stated, "Drivers take advantage of these systems if they are aware of their existence and are experienced in their use; however, if drivers are not aware or experienced, their braking performance tends to approach that of non-ABS braking systems."

Thus, the apparent increase in single-vehicle crashes involving ABS-equipped vehicles may be due to changes in driver behavior (i.e., behavioral adaptation) due to the presence of or their perceptions of the benefits provided by ABS, or both.

2.1.1. Related Research

Studies have been conducted in recent years that show that people may modify their driving behavior in response to the addition of ABS to their vehicle. For example, drivers of ABS-equipped vehicles may operate their vehicles at higher speeds due to the perception that ABS increases the vehicle's handling and braking performance [11]. This increased vehicle speed could result in more run-off-road, single-vehicle crashes, particularly on curved roads.

Smiley and Rochford [12] performed an experiment involving drivers operating test vehicles with and without ABS on a closed course. One set of 20 subjects driving in the ABS active condition received an explanation of the benefits of ABS followed by 30 minutes of practice in an ABS-equipped vehicle performing "emergency" braking maneuvers. The other group of 20 subjects in the ABS condition received the explanation of ABS benefits, but no braking practice. The remaining 40 subjects drove with the vehicle's standard brakes with half of the subjects receiving braking practice and the other half receiving no practice. Results showed that "adaptation was evident on both wet and dry roads" and the adaptation was "in the form of higher speeds for subjects with ABS who had received practice with hard braking." Those who drove with ABS but did not receive practice with hard braking did not show significantly higher speeds compared to those driving without ABS. Greater brake pedal forces were observed for the ABS groups. Behavioral changes were stated to have been associated more with drivers' knowledge that they were using an antilock brake system, rather than as a result of practice with that system. Related results reported by Grant and Smiley [13] stated that "…those who were shown the increased control available with ABS drove faster in a curved following task, accelerated faster, and used higher brake pedal forces than others who had not been shown the benefits of ABS."

Fambro, et al [10] found that, compared with conventional braking systems, "ABS result in shorter braking distances by as much as 30 m at 90 km/h." They further stated "differences were most noticeable on wet pavements where ABS resulted in better control and shorter braking distances."

NHTSA was interested in determining whether portions of the noted test track study results could be replicated in an experiment conducted under real-world conditions. As a result, plans were developed for an observational study of driver speed as a function of brake system (the subject of this report) and an on-the-road naturalistic study of driver behavior with and without ABS (Task 7.2).

2.1.2. National Telephone Survey of Driver Experiences and Expectations Regarding Conventional Brakes versus ABS

As part of its Light Vehicle ABS Research Program, NHTSA conducted a national telephone survey to assess drivers' knowledge and expectations about ABS (Task 2). This information was desired, in part, for use in determining whether the apparent increase in single-vehicle crashes for automobiles was due to drivers' misunderstanding of ABS functionality.

That study found that although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicle was so equipped. Certain types of brake pedal feedback from an activated ABS were often misinterpreted, making driver reaction sub-optimal and in some cases potentially dangerous (e.g. taking their foot off the pedal). Drivers who owned ABS-equipped vehicles had similar misunderstandings and there was evidence that some of these drivers were overconfident in what ABS could do for them (e.g. allowed them to follow other vehicles more closely). Additionally, a small segment of the respondents expressed a willingness to change their driving habits if they had ABS. However, this was based on drivers knowing their vehicle was equipped with ABS.

This survey study can be distinguished from the Smiley and Rochford study in several ways. First it was subjective and not empirical. Second, 65% of the drivers of ABS-equipped vehicles did not receive any instruction on the benefits of ABS prior to using the vehicle, whereas all of the ABS drivers had in the earlier study. Lastly, 18% of all drivers responding to the survey didn't even know if their vehicle was equipped with ABS. Even though the results of the survey did not negate the theory of behavioral adaptation, it raised the question of how could drivers be adapting to something many knew very little about.

2.1.3. Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario

To determine whether some aspect of driver behavior in a crash-imminent situation was counteracting the potential benefits of ABS, NHTSA embarked on a series of human factors studies, which composed Task 5 of the research program. These studies focused on the examination of driver crash avoidance behavior as a function of brake system and various other factors. While these studies were not designed to disprove the theory of behavioral adaptation, a comparison of the results [8] produced evidence that was at odds with an element of the Smiley and Rochford report.

In order to obtain authentic driver behavior in an unsuspected crash-imminent situation, experimenters placed subjects into naturalistic settings, informed them they were being examined to collect data on normal driving behavior, and instructed them to maintain the distance separating them from a lead car throughout their drive. After 15 minutes of driving, experimenters suddenly moved a Styrofoam car into their path, eliciting realistic crash-avoidance behavior from this incursion. Results of this study showed, in part, that there was no statistical difference in applied brake pedal force between drivers of ABS vehicles and those with conventional brakes under these realistic circumstances. In addition, 69% of all subjects participating in the "dry pavement" portion of the test failed to apply sufficient brake pedal force to activate ABS or lock up the vehicle's wheels.

Comparison of the two studies ([8] and [12]) showed three important similarities. In both experiments, drivers of ABS-equipped vehicles knew the car they were driving had ABS. Moreover, drivers of ABS-equipped vehicles received instruction on how best to operate a vehicle so equipped, while drivers of conventionally braked vehicles did not receive ABS instructions. Lastly, subjects in both studies were given the opportunity to practice braking with the brake system they were to drive with (ABS or conventional brakes) prior to beginning their test drive.

2.1.4. Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario

To determine whether some aspect of driver behavior in a crash-imminent situation was counteracting the potential benefits of ABS, NHTSA embarked on a series of human factors studies, which composed Task 5 of the research program. These studies focused on the examination of driver crash avoidance behavior as a function of brake system and various other factors. While these studies were not designed to disprove the theory of behavioral adaptation, a comparison of the results [8] produced evidence that was at odds with an element of the Smiley and Rochford report.

2.2. License Plate Study Objectives

As part of its Light Vehicle ABS Research Program, NHTSA sought to determine whether behavioral adaptation might have contributed to the perceived lack of benefits of ABS-equipped vehicles in terms of observed crash reductions. As such, Task 7 of NHTSA's Light Vehicle ABS Program investigated whether the concept of passenger car ABS-related driver behavioral adaptation was an existent and observable phenomenon. Task 7.1 endeavored to unobtrusively determine whether drivers of vehicles equipped with ABS had a tendency to drive faster than drivers of conventionally braked vehicles. If increased speeds could be identified in association with ABS-equipped vehicles, this speed difference might then be attributable to ABS-related behavioral adaptation.

This report outlines the method and results for Task 7.1 of NHTSA's Light Vehicle ABS Research Program, called the "License Plate Study".

3.0 METHOD

An experiment was conducted to unobtrusively determine whether drivers of vehicles equipped with ABS had a tendency to driver faster than drivers of conventionally braked vehicles. Several locations on public roadways around Ohio were selected as data collection sites. At these sites, the speed and license plate information of passing vehicles were unobtrusively gathered from behind as vehicles drove away from an overpass (not on approach). Data were measured and recorded using a laser speed gun, video camera, and laptop computer. Data were collected at each site for specified periods during daylight hours (balanced for AM/PM) in both wet and dry road conditions. Using the license plate number, the VIN number was obtained and then decoded to determine whether each vehicle had ABS. Average speed data for specified conditions and locations were compared for vehicles with ABS versus those without.

3.1. DATA COLLECTION

3.1.1. Road Type

The type of roadway chosen for data collection was divided highways with two lanes in each direction. Data were collected for both lanes traveling in a particular direction at each site chosen.

There was some interest in collecting data on rural two-lane roads, however this was not done due to safety related issues. It was determined that the lack of berms and overpasses on this type of road (which could be used to park the data collection vehicle out of harm's way) might compromise the safety of employees and passing drivers.

3.1.2. Site Selection

Four locations on public roadways around Ohio were selected as data collection sites. The speed limit for all sites was 65 mph, and each was a four-lane divided highway. The selected sites allowed the person facilitating the unobtrusive data collection to be safely away from traffic. To facilitate unobtrusive data collection, sites were selected where an overpass was present on which the experimenter could be stationed along with data collection equipment. Overpasses were chosen that had raised concrete "sidewalks" (as can be seen in Figure 1) on which data collection equipment could be placed such that it was not blocking any part of a travel lane. An attempt was also made to select sites where entrance and exit ramps were not present to prevent merging traffic from affecting travel speeds. Sites were also selected such that speed could be measured as the vehicle was moving away from the data collection equipment to prevent passing motorists from realizing that their speed was being measured prior to the actual data collection. (Note that drivers with laser detectors may have been notified by these systems that their speed was being measured, however, the notification would have been delivered after their data had been recorded.)

Unobtrusive measurement of vehicle speed was accomplished by observation of vehicles from atop a highway overpass as the vehicles passed underneath on the roadway below, traveling away from the collection site. The list of Ohio roadways on which a site for data collection was selected can be seen in Table 3.1 below. Figures 1 through 3 show views of the data collection sites for I-70, I-75, and S.R. 33. Photographs of the data collection site for I-71 were not obtained. Data collection equipment shown in these photos is described in detail in Section 3.2.

Local state highway patrol offices and other law enforcements personnel were notified of the plan to collect data at a specified site prior to data collection.

Table 3.1: Location of Data Collection Sites Used in "License Plate Study"

Highway	Location
I - 71 S	Berkshire Rd overpass 2 miles North of St. Rt. 36, near Delaware*
I - 75 N	Meranda Rd. overpass near 119 Anna/Minster exit, South of Anna
I - 70 W	Sylvan Shores Dr. overpass, 1 bridge east of St. Rt. 54, I-70 interchange, 10 miles East of Springfield
S.R. 33 E	S.R. 4/36 overpass looking down onto S.R. 33 Eastbound, West of Marysville

* Note: The site on Interstate 71 (just north of St. Rt. 36 near Delaware) has since been widened to 6 lanes.

Figure 1. I-70 Data Collection Site.

Figure 2. I-75 Data Collection Site.

Figure 3. State Route 33 Data Collection Site.

3.1.3. Pavement conditions

Data collection was conducted under both dry and wet pavement conditions. Some research [8] has shown that drivers of ABS-equipped vehicles do tend to drive faster on dry roads than those in vehicles equipped with conventional brakes. However, drivers of ABS-equipped vehicles may be more likely to adjust their driving style on wet pavement or otherwise less favorable road conditions than on dry roads. Drivers may think that they can drive faster with ABS under certain conditions (e.g., on a wet or snow-covered road) but perhaps not others (e.g., ice).

Pavement was characterized as “dry” or “wet” but no specification quantification of these conditions was possible. Data were typically not collected during periods of active precipitation due to degradation of the visibility of license plate features.

3.1.4. Data Collection Periods

Data collection was conducted on weekdays that were not holidays. Data were collected during daylight hours to ensure that sufficient light was present to permit capture of video images with distinguishable license plate features.

The initial goal for both dry and wet pavement conditions was to collect data for two four-hour periods: one AM (e.g., 8:00 am until 12:00 pm) and one PM (e.g., 12:30 pm to 4:30 pm). This would result in eight hours of dry pavement data and eight hours of wet pavement data for each site. However, difficulties were encountered in trying to achieve four hour periods during which pavement was wet, but precipitation was minimal (this was important since precipitation hindered successful data collection).. In addition, precipitation was infrequent during the testing period. Thus, the data collection goal for wet pavement was lowered to two hours per site. The goal for dry pavement data collection time remained eight hours. Details regarding actual data collection durations are provided in the Results section.

When possible, slightly more time was spent collecting data than was required in order to ensure that enough data were collected to permit analysis. In some cases, it was determined during data reduction that weather conditions or equipment problems caused portions of the data to be unusable. All usable data collected was included in the analysis.

3.2. INSTRUMENTATION

3.2.1. Video Recording of License Plate Information

Two Panasonic WV-CL352 video cameras, each with a Vivitar 70-210 mm lens and a 2x filter, were used to record a visual image of the rear of each passing vehicle. Maximum magnification was calculated to be 80x. The recorded visual image provided a record of each passing vehicle’s license plate number. The video images were transmitted via an RF-Link Technology, Inc. Wavecom T24-01 RF transmitter to the base vehicle and recorded on two VCRs in SVHS format. License plate information was later extracted manually from the recorded video media.

3.2.2. Speed Measurement

Vehicle speed and range were measured using Kustom Signals, Inc. Pro Laser II and III laser speed guns. Activation of the speed gun was controlled through software. To facilitate data analysis, the output of the laser speed gun, speed and range, as well as the time of day were transmitted to the base vehicle via a Proxim, Inc. PL2 radio modem and written to an ASCII file, as well as to the video frame using a video titler.

3.2.3. Equipment Configuration

Each laser speed gun and video camera combination was arranged side by side inside of a plastic toolbox, and then mounted on a tripod for stabilization as shown in Figure 4. Both assemblies had their own separate 12-volt car battery for power. These laser speed gun and video camera assemblies were aligned so that the center of the video image (at 80x zoom) was the point in space that the laser was measuring (calibrated at 600 feet). This equipment was positioned not more than 1200 feet from the base vehicle, with data and instructions transmitted via RF transmitter and radio modem. The laptop computer was situated inside the base vehicle, shown in Figure 5. Inside the vehicle, a Test Technician monitored data collection and ensured that the equipment was working properly. Additional equipment configuration and connection information is provided in Figure 6 and Figure 7.

Due to the angle at which the equipment was directed toward the travel lanes, it was possible that data for some vehicles could not be obtained because a following vehicle (with short inter-vehicle distance) prevented clear view of their rear license plate.

Figure 4. Data Collection Apparatuses.

Figure 5. Typical Configuration of Data Collection Apparatuses and Data Collection Vehicle.

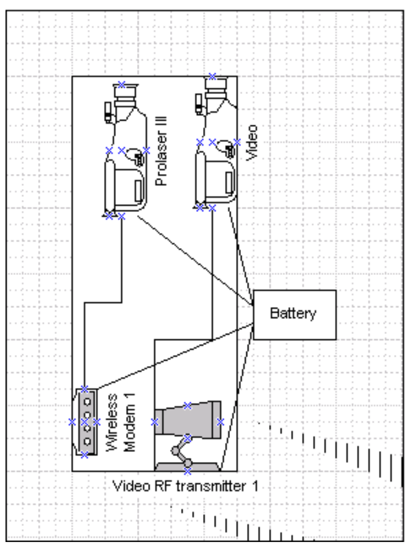

Figure 6. Configuration of Data Gathering Components.

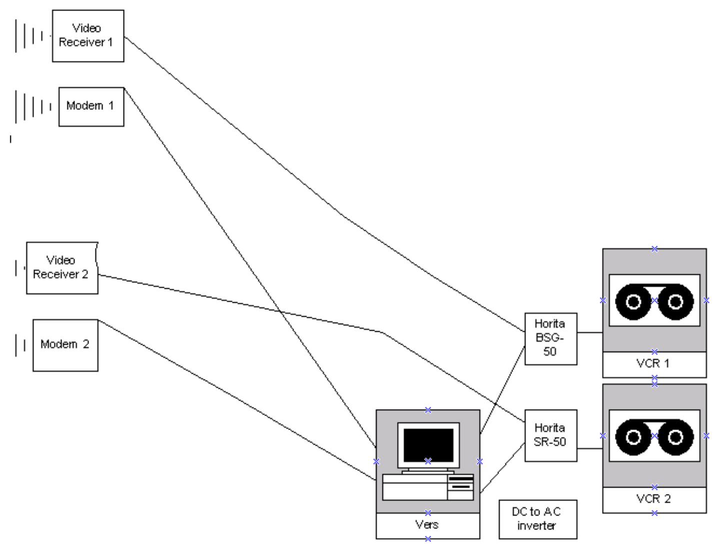

Figure 7. Data Collection Apparatus

3.2.4. Data Collection Automation

A laptop computer was used to control the data collection. Collected parameters included time of day, vehicle speed, and vehicle range (for use as a consistency check). These parameters were written automatically to an ASCII file. This ASCII file was later converted to a spreadsheet file format for analysis.

3.2.5. Protection of Equipment from Environmental Factors

To eliminate potential damage to equipment due to inclement weather, all data collection equipment was either secured inside protective plastic toolboxes (as shown in Figure 4) or inside the data collection vehicle. The video camera and laser speed gun assemblies had added support via monopods on windier days. The 12-volt power supplies were also covered to protect from moisture.

3.3. DATA REDUCTION

3.3.1. Extraction of License Plate Information from Video

License plate numbers were manually extracted (through visual observation) from the video recordings and entered into the spreadsheet file. License plate numbers that were not fully decipherable due to heavy rainfall, high winds or the target vehicle not being centered in the lane were removed from the dataset. The remaining data were entered into a spreadsheet containing the time of day and vehicle speed data for analysis.

3.3.2. Determination of Vehicle Identification Numbers

Using the spreadsheet file, a list of license plate numbers for each site was prepared in an electronic text file format. These text files were submitted to the Ohio Bureau of Motor Vehicles (BMV) for determination of the Vehicle Identification Numbers (VIN) associated with each license plate number. VIN numbers corresponding to all valid license plate numbers were obtained. Any plates that could not be identified were removed from the data set (1272 of 9968, or 12.76%). The VIN numbers that were properly identified were then added into the spreadsheet containing the data fields of speed, distance, and time of day.

3.3.3. Determination of Vehicle Brake System

For each vehicle data record for which there was a valid license plate number and valid VIN, determination of the brake system that vehicle was originally equipped with was necessary. Initial determination of vehicle brake systems was performed using PCVINA for Windows (an R. L. Polk & Co. product). This software was used to identify whether for each vehicle ABS was standard equipment, optional equipment, or not available. Whether the ABS was a two-wheel or four-wheel system could also be determined.

For VIN numbers associated with make/models that PCVINA showed as having ABS as optional equipment, the assistance of vehicle manufacturers was needed to determine whether the vehicle had been equipped with ABS. Electronic text files containing VIN information were then sent to manufacturers for final determination of brake system. Vehicle makes that were poorly represented in the data set were not sent to decoding and were removed from the data set. Information regarding the presence of ABS on vehicles for which the system was optional was received and incorporated in the data spreadsheet for use in the analysis.

3.3.4. Characteristics of Vehicles Focused On

Although the data collection equipment was configured to record information on each vehicle that passed by in both lanes, characterization of vehicle age and type was performed in order to create a vehicle set. Vehicles of interest for the data analysis portion of this study included all model year 1985 to 2000 passenger cars, light trucks, and non-commercial vehicles. Removing vehicles of model year 1984 and earlier eliminated mainly vehicles for which ABS was not available and also created a data set of contemporary vehicles that could reasonably be compared. These measures were intended to reduce the potential for biased data.

4.0 RESULTS

Data were analyzed using SAS v6.12. Since behavioral adaptation associated with the presence of ABS on a vehicle was of primary interest, speed data were compared with vehicle brake system (ABS versus conventional brakes). Pavement condition (dry/wet), site location, and model year of vehicle were also included in the analysis to look for significant interactions between brake system and these other factors. Model year of the vehicle was grouped into 3 categories: 1985-1989; 1990-1994; and, 1995-2000.

Since the data set had unequal cell sizes, the SAS analysis program used "proc glm" with a full model of all effects (n=7464). For all analyses, the Type I error was controlled at a 0.05 level of significance. For significant main effects, Tukey's (HSD) multiple-comparisons test was used, with a family confidence level set at 0.05. "Proc means" was used to follow up on significant interactions.

4.1. <u>Data Collected</u>

During data collection, 7,464 valid data points were obtained. Data were collected by a single person visiting each of the sites on different days and in no particular order. Data were recorded for both travel lanes in a single direction for each four-lane divided roadway site (data from both lanes have been combined). As stated previously, an attempt was made to collect 8 hours of data on dry pavement and 2 hours of data for wet pavement conditions for each site. Difficulties that were primarily weather-related resulted in some variation in the total length of data collection per site as well as the time of day during which data collection took place. Dry data for each site contained a morning and an afternoon session, except for the I-71 site for which all three data collection sessions took place during the morning hours. All wet data collection sessions were conducted in the afternoon except for I-71 for which data was collected in the morning. A summary of the data collection periods and resulting total length of data collection for each condition are provided in Table 4.1.

Table 4.1: Summary of Data Collection Details

Site	Pavement Condition	Date	Time Period	Hours	Total Hours (HH:MM)	Total Data Points (n)
St.Rt. 33 E	Dry	11-22-99	11:44 AM – 3: 50 PM	4:06	8:11	961
		11-23-99	8:17 AM – 12:22 PM	4:05		
	Wet	2-10-00	2:53 PM – 4:07 PM	1:14	1:14	341
I - 70 W	Dry	10-7-99	7:51 AM – 11:48 AM	3:57	7:43	1118
		10-19-99	12:15 PM – 4:01 PM	3:46		
	Wet	12-15-99	12:54 PM – 2:38 PM	1:44	2:47	361
		3-20-00	11:43 AM – 12:46 PM	1:03		
I - 71 S	Dry	9-1-99	7:33 AM – 11:37 AM	4:04	8:27	2781
		9-9-99	7:37 AM - 11:44 AM	4:07		
		10-4-99	11:43 AM – 11:59 AM	0:16		
	Wet	12-20-99	8:25 AM – 11:30 AM	3:05	3:05	374
I - 75 N	Dry	9-20-99	8:18 AM – 11:29 AM	3:11	6:41	1163
		9-30-99	12:30 PM – 4:00 PM	3:30		
	Wet	12-14-99	11:54 AM – 1:57 PM	2:03	2:03	365

4.2. Overall Results

The overall results summarizing data collected at all four sites including mean values of the main effects are listed in Table 4.1. The data represent all passenger vehicles with Ohio license plates for which speed and license plate information were obtainable. Data for some vehicles traveling through each data collection site were not obtainable or usable due to various reasons such as masked or absent license plates or damaged plates that were unreadable.

Table 4.2: Overall Results, Significant Means (*) for Main Effects

Main Effect	Levels	Mean (mph)	S.D. (mph)	n
Brake System	Conventional (Non-ABS)	69.50	5.01	2934
	ABS	69.89	4.94	4530
Pavement Condition *	Dry	70.00	4.99	6023
	Wet	68.62	4.71	1441
Site *	St.Rt. 33 E	67.64	4.55	1302
	I - 70 W	69.88	5.05	1479
	I - 71 S	71.31	4.56	3155
	I - 75 N	68.14	4.91	1528
Model Year of Vehicle *	1995-2000	70.10	4.89	4633
	1990-1994	69.13	5.00	1895
	1985-1989	69.16	5.12	936

The four-factor analysis of variance revealed that drivers in ABS-equipped vehicles did not drive significantly faster than individuals driving vehicles equipped with conventional brake systems ($F(1, 7416) = 0.03$, $p \leq 0.8642$). The main effects for model year ($F(2, 7416) = 9.22$) and site location (F(3, 7416) = 15.75) were both highly significant at $p \leq 0.0001$. The main effect of pavement condition (F(1, 7416) = 6.25) was significant at $p \leq 0.0124$.

The interaction between site location and pavement condition was also significant (F(3, 7416) = 11.07, $p \leq 0.0001$). Two-way interactions between brake system and the other main effects were not significant. Although the results were not significant, Table 4.3 presents a breakdown of brake system results for dry and wet pavement, respectively (i.e., the Brake System by Pavement Condition Interaction).

Table 4.3: Overall Speed Results for Pavement Condition by Brake System

Pavement Condition *	Brake System	Mean (mph)	SD	n
Dry	Conventional (Non-ABS)	69.79	5.02	2341
	ABS	70.14	4.98	3682
Wet	Conventional (Non-ABS)	68.38	4.85	593
	ABS	68.79	4.60	848

The three-way interaction between model year, site location and brake system was marginally significant ($p \leq 0.0122$) but a post hoc examination of factor level means revealed that the source of the variation could not be attributed to the type of brake the car was equipped with.

4.3. Results by Site

Tables 4.4 though 4.7 contain the descriptive statistics for each data collection site separately. Analyzing the data by site was not judged to be of interest, since the purpose of using a number of sites was to achieve a representative sample of roadway situations. These data are provided for informational purposes.

Table 4.4: Descriptive Statistics for St. Rt. 33 Site

Main Effect	Levels	Mean (mph)	S.D. (mph)	High	Low	n
Brake System	Non-ABS	67.48	4.71	79	47	554
	ABS	67.76	4.44	85	51	748
Pavement Condition	Dry	67.52	4.74	87	51	961
	Wet	68.01	3.97	78	47	341
Model Year of Vehicle	1995-2000	67.87	4.32	79	47	734
	1990-1994	67.52	4.64	85	51	393
	1985-1989	67.01	5.23	82	54	175

Table 4.5: Descriptive Statistics for I-70 Site

Main Effect	Levels	Mean (mph)	S.D. (mph)	High	Low	n
Brake System	Non-ABS	69.74	5.30	86	48	538
	ABS	69.96	4.90	87	50	941
Pavement Condition	Dry	70.09	4.90	87	48	1118
	Wet	69.20	5.43	86	53	361
Model Year of Vehicle	1995-2000	70.17	4.91	86	48	947
	1990-1994	69.40	5.20	86	53	356
	1985-1989	69.25	5.34	87	50	176

Table 4.6: Descriptive Statistics for I-71 Site

Main Effect	Levels	Mean (mph)	S.D. (mph)	High	Low	n
Brake System	Non-ABS	70.94	4.54	86	54	1280
	ABS	71.56	4.55	90	54	1875
Pavement Condition	Dry	71.63	4.44	90	54	2781
	Wet	68.91	4.70	83	54	374
Model Year of Vehicle	1995-2000	71.62	4.54	85	57	2014
	1990-1994	70.71	4.58	85	57	759
	1985-1989	70.89	4.45	90	54	382

Table 4.7: Descriptive Statistics for I-75 Site

Main Effect	Levels	Mean (mph)	S.D. (mph)	High	Low	n
Brake System	Non-ABS	67.99	4.96	87	53	562
	ABS	68.22	4.89	84	47	966
Pavement Condition	Dry	68.07	5.03	87	47	1163
	Wet	68.34	4.51	80	53	365
Model Year of Vehicle	1995-2000	68.52	4.88	81	56	938
	1990-1994	67.44	4.94	80	47	387
	1985-1989	67.67	4.89	87	53	203

Lower mean speeds found for the State Route 33 site may be due to the fact that the site involved a curved portion of roadway, whereas the other three sites contained only straight roadway portions. In addition, an entrance ramp was present shortly upstream from the point of data collection.

4.3.1. Speeds Observed

Although a fairly large percentage of drivers were found to be exceeding the 65 mph speed limit at the sites examined, no significant effects of speed were found as a function of brake type. Table 4.8 shows a breakdown of the percent of drivers that were found to be exceeding the speed limit. For each speed value observed, an analysis was run for the population going that speed or over to determine whether any effects of brake type could be observed for that subset of the population. No significant effects of brake type on speed were observed for any subset of speed categories as can be seen by the P values listed in Table 4.8.

Table 4.8: Overall Speed Results for

Speed	n	Percent of Observations	P for Main Effect of Brake System	P for Main Effect of Pavement Condition	P for Interaction of Brake System and Pavement Condition
66	6101	81.74	0.0032	0.2486	0.6808
67	5682	76.13	0.0012	0.1571	0.3262
68	5192	69.56	0.0025	0.2452	0.3227
69	4637	62.12	0.0113	0.225	0.3151
70	4001	53.60	0.1392	0.6508	0.8707
71	3362	45.04	0.0985	0.8044	0.6925
72	2726	36.52	0.1622	0.988	0.8808
73	2117	28.36	0.6078	0.711	0.7148
74	1586	21.25	0.327	0.8329	0.4963
75	1134	15.19	0.4799	0.6808	0.927
76	786	10.53	0.2375	0.5648	0.5693
77	544	7.29	0.7156	0.6638	0.6564
78	385	5.16	0.3465	0.591	0.6202
79	270	3.62	0.6617	0.2176	0.9949
80	175	2.34	0.0551	0.7583	0.6905
81	115	1.54	0.0733	0.5529	0.7318
82	72	0.96	0.1011	0.8631	0.8563
83	45	0.60	0.628	0.5925	*
84	29	0.39	0.568	0.2956	*
85-90	20	0.27	1	0.5113	*

5.0 DISCUSSION

5.1. Limitations of Data Collection

It should be noted that the range of driving situations in which differences in driver behavior may be observed are not fully represented in the this study (e.g., other types of roadways, other speeds, limited visibility conditions, such as night driving). Data were collected under conditions that were amenable to recording data using the methods available (i.e., laser speed measurements and video recorded images of license plate information). In summary, this study restricted conditions to the following:

a. Divided highways with two lanes in each direction. Relatively straight stretches of roadway except for one site which featured curve in roadway. (No data collected on rural two-lane roads for experimenter-related safety reasons.)
b. Speed limits of 65 mph.
c. Two four-hour periods (one AM, one PM) during daylight hours. (Data only collected in daylight for experimental protocol-related reasons, specifically successful video recording capture of license plate information.
d. Pavement was characterized as "dry" or "wet" but no specific quantification of these conditions was possible. Data were typically not collected during periods of active precipitation due to degradation of the visibility of license plate features.
e. The sole use of speed as an indication of behavioral adaptation does not acknowledge that other driver behaviors (e.g., headways, lane change behavior, etc.) may also be influenced by availability/knowledge of ABS.

5.2. Driver Characteristics and the Potential for Behavioral Adaptation

This study did not focus on any particular type of driver. Data for all drivers passing through the observation sites were collected (barring or equipment related problems). Only data for vehicles with Ohio license plates were included in the analysis since these were the only ones for which VIN information could be easily obtained. Data are assumed to be representative of "average drivers" from Ohio since no data were excluded based on characteristics of the drivers. However, it is possible that only a portion of drivers could be exhibiting behavioral adaptation related to ABS, as opposed to all "average drivers". For example, it is possible that only drivers that are more apt to take risks (e.g., driving at high speeds) or drivers that are under the influence of alcohol could be exhibiting ABS-related behavioral adaptation. This study, however, cannot address these special populations.

5.3. Driving Speed Results

The results of this study show no significant effect of brake system (ABS versus conventional brakes) on driving speed under the conditions examined. This finding of no significant speed effects was true for all sites, pavement conditions, and model years of vehicles observed. However, a consistent trend was seen in mean speed by brake system for each site where higher speeds were observed for drivers of ABS-equipped vehicles. Specifically, subjects in ABS-equipped vehicles drove an average of 0.4 mph faster than those in vehicles with conventional brake systems. However, despite the large sample size this speed difference was not statistically significant.

6.0 CONCLUSIONS

The results of this study showed no significant effect of brake system (ABS or conventional) on driving speed under the conditions examined. This finding of no significant speed effects was true for all sites, pavement conditions, and model years of vehicles observed. A consistent, but insignificant, trend of higher speeds for drivers of ABS-equipped vehicles was seen across sites. Significant results that were found included higher speeds for drivers of newer model cars, higher speeds for dry pavement, and that speed varied as a function of location (site). Overall, based on observed vehicle speed results, evidence of passenger car ABS-related driver behavioral adaptation was not observed using the methods employed in this study.

Based on these results involving "real world" driving and other related results from NHTSA's Light Vehicle ABS Research Program, evidence of behavioral adaptation due to ABS has not been obtained. Thus, the results of this study suggest that the apparent increase in single-vehicle crashes involving ABS-equipped vehicles cannot be attributed to average drivers exhibiting ABS-related behavioral adaptation under the conditions examined in this study.

The results of this study, as well as the results of other research conducted under NHTSA's Light Vehicle ABS Research Program, have revealed no evidence of changes in driver behavior that can be attributed to ABS. For adaptation to occur drivers presumably must be aware of whether or not their vehicle is equipped with ABS or be able to sense some noticeable difference in performance. NHTSA's recent national telephone survey to assess drivers' knowledge of ABS functionality and expectations of ABS performance showed that, although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicles were equipped with ABS. NHTSA's test track examination of drivers' crash avoidance behavior in an intersection incursion scenario showed that even when drivers are given a vehicle to drive and told that it is equipped with ABS, there were no differences in brake pedal forces between drivers in ABS and non-ABS equipped vehicles, and that these observed brake pedal force values were usually not sufficient to activate ABS anyway.

In summary, the results of this observational study and other on-road NHTSA research have produced no evidence of the occurrence of average drivers exhibiting ABS-related behavioral adaptation under real world conditions.

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