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FINAL REPORT

ASSESSMENT OF TRAFFIC CONTROL PRACTICES WITH RESPECT TO OLDER DRIVERS

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16 **Abstract**

When signage on a rural highway in Kansas was upgraded, the State received some comments that begged the question of whether modern highly reflective sign sheeting materials could, in some circumstances, actually decrease the legibility of signage, particularly for older drivers. Older drivers tend to have poorer visual acuity, requiring larger signs to provide the same legibility as found in a younger population. However, older drivers also tend to be more sensitive to glare and slower to recover from glare blindness. This study was conducted to determine if highly reflective sheeting could cause a reduction in sign legibility due to veiling glare, especially in older drivers. The test was conducted using 60 drivers in an actual automobile and full scale signs and distances. The data collection was conducted in a test facility where external factors could be eliminated, isolating the variables of greatest interest. Older drivers as a whole were found to exhibit poorer performance in terms of visual acuity and response time, but no detrimental effects attributable to glare were observed.

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ASSESSMENT OF TRAFFIC CONTROL PRACTICES WITH RESPECT TO OLDER DRIVERS

Final Report

Prepared by

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THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

July 2007

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ABSTRACT

When signage on a rural highway in Kansas was upgraded, the State received some comments that begged the question of whether modern highly reflective sign sheeting materials could, in some circumstances, actually decrease the legibility of signage, particularly for older drivers. Older drivers tend to have poorer visual acuity, requiring larger signs to provide the same legibility as found in a younger population. However, older drivers also tend to be more sensitive to glare and slower to recover from glare blindness. This study was conducted to determine if highly reflective sheeting could cause a reduction in sign legibility due to veiling glare, especially in older drivers. The test was conducted using 60 drivers in an actual automobile and full scale signs and distances. The data collection was conducted in a test facility where external factors could be eliminated, isolating the variables of greatest interest. Older drivers as a whole were found to exhibit poorer performance in terms of visual acuity and response time, but no detrimental effects attributable to glare were observed.

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CHAPTER ONE - INTRODUCTION

The population nationally is aging. The population in Kansas over 65 is increasing faster than the national average for that age group. Over the next 25 years, the population of Kansas is expected to increase by 21% while the 65-and-over population is expected to increase by 73%, triple the overall rate. Meanwhile, the percentage of the driving age population who are 65 or older will increase from the current 17.5% to nearly 25%.

Older drivers tend to have certain characteristics that merit special consideration with respect to traffic control. Older drivers, as a group, have decreased visual acuity, narrowed peripheral vision, lower sensitivity to contrast, longer glare recovery times, and decreased cognitive abilities. These disadvantages are compensated at least in part by the tendency for older drivers to limit their driving to daytime, off-peak hours. They also drive larger cars, carry fewer passengers, and drive at lower speeds than younger drivers. However, despite these compensatory behaviors, older drivers are still over-represented in many crash statistics, most notably crashes at intersections. It should also be noted that there is a wide range of abilities among drivers, and particularly among older drivers.

The growing proportion of drivers who are 65 or older and the special needs of many older drivers combine to make traffic safety among older drivers an increasingly pressing issue. Research has been conducted that addresses many different facets of traffic control as it relates to the older driver. However, much of the research results are ambiguous with respect to their practical application. Two specific concerns that have arisen from efforts to improve highway safety relate to the brightness of signs and the lateral placement of signs when a highway's shoulders are widened.

Many developments in recent years have improved the reflectivity of signing materials, resulting in greater conspicuity, generally associated with increased safety. However, some drivers suggest that signs are sometimes *too* bright. A brighter sign can be seen from a greater distance, increasing the time available for driver response. However, if there is a point at which glare becomes a significant factor, especially for older drivers, increasing the sign's reflectivity may actually decrease the sign's legibility. Although conventional wisdom asserts that brighter, more highly reflective signs *always* improve safety, complaints received by the Kansas Department of Transportation suggest that perhaps there are situations in which signs can be *too* bright. This is especially true for older adults because as drivers age, their visual acuity tends to decrease and their sensitivity to glare and glare recovery times tend to increase.

The second concern stems from the state's increasing amount of two-lane highways being improved by widening the shoulders to 10-12 ft, to accommodate the increasing volumes more safely. The wider shoulders require that signs be moved farther from the traveled lane. For some drivers, the signs may be easy to miss or difficult to read. It is reasonable to suspect that a change in the lateral placement of a sign might necessitate some manner of compensation. For example, increasing the reflectivity of the sign might make the sign more conspicuous, and a larger sign would increase the legibility distance. However, little data is currently available to verify the problem and to support any specific remedial action.

Following the reconstruction of portions of US-400, KDOT received several complaints related to the signage on the section. Two themes could be identified among the complaints. One was that some of the new signs were so bright that they hurt the eyes. The second was that guide signs were easily missed. These two themes relate to different aspects of static traffic control, and are at least partially at opposition. A sign so bright as to cause glare would, because of that same brightness, stand out at night. Nonetheless, both issues were considered in this work.

1.1 Veiling Glare

Research funded by the FHWA has suggested that the reflectivity of a sign can be so great as to decrease legibility, presumably by means of veiling glare, one of two principle types of glare. *Specular glare* occurs when a reflected image obscures the content of a sign, as when the sun reflects off a sign in the early morning or late evening hours. *Veiling glare* occurs when the brightness of a sign is so high as to significantly decrease the contrast between the legend and the background sheeting. Because older drivers tend to have a decreased sensitivity to contrast and require longer glare recovery times, either type of glare is of greater concern when considering the needs of older drivers.

Significant research has been conduct by the FHWA and others regarding minimum recommended values for various parameters related to sign illumination. Most research has addressed both conspicuity and legibility. Other research has addressed the needs of older drivers with respect to glare recovery times, primarily (almost exclusively) as a result of glare from the headlights of oncoming traffic. Very little research exists that examines the relationship between veiling glare and legibility.

This project will examine this issue, verifying whether or not legibility can be adversely impacted by the use of higher type of signing materials, and identifying recommended practice for roadside signing.

1.2 Lateral Placement

Two difficulties may exist with respect to the legibility of street signs used on highways where the shoulder has been widened. First, moving the sign farther from the traveled lane laterally decreases the sign's conspicuity by moving it farther into the periphery of the driver's primary focus of vision. Second, the lateral shift increases both the incident angle of illumination from the vehicle's headlights and the net legibility distance required to permit the same amount of time for driver response. This project will investigate the degree to which the widening of the shoulders of a two-lane highway affects both aspects of signage and whether or not the effects suggest any remedial actions.

Assessing the effect of glare on the legibility of traffic signs is somewhat problematic. Several different techniques have been used to study legibility, each with certain advantages and disadvantages. Field tests in which subjects drive an automobile and legibility distances are measured are perhaps the best representation of the actual driving environment. [1,2,3,4] Isolating the parameters under study can be extremely difficult, though, as well as unsafe, particularly when studying factors that may impair driving performance. Moreover, the added demand of having to drive an unfamiliar vehicle can bias the data. Laboratory tests can effectively isolate a single contributing factor. [5,6,7] For some purposes, such tests are ideal. However, in other cases they are an oversimplification, missing the effects of the complexity of the driving task on the driver's performance. Laboratory studies of the minimal requirements of luminance contrast and letter size for signs fail to capture the increased attentional demands drivers incur during on-road performance. This can be problematic (especially for investigations involving older drivers [8]) since it has been well established that as attention is spread among multiple tasks, the ability to perform even simple perceptual tasks declines. [e.g., 9]

A third category, referred to here as *controlled field tests* (i.e., controlled environment and use of a 1:1 scale for sign size and placement), offers a compromise between field tests and laboratory tests. [10] A controlled field test would generally utilize a stationary vehicle in a controlled environment. Legibility distances would be actual, rather than scaled, especially for nighttime tests. However, if participants are only required to identify signs, the data may be biased by oversimplification of the driving task as with laboratory tests. This paper introduces a methodology for studying sign legibility that capitalizes on the strengths of simulators, field experiments, and laboratory studies by approximating the attentional and perceptual demands of a highway environment in a controlled setting. Thus the driver is responsible for more than just a single task, such as identifying a sign, and yet the factors under study can be effectively isolated while avoiding the threatening environment of an unfamiliar driving situation that could potentially distort the results.

CHAPTER TWO - LITERATURE REVIEW

Many studies have been conducted using many different techniques to explore the factors contributing to the legibility of signs. Olson conducted a field study in which subjects drove on public roads, identifying signs as they were able.[1] Helmut and Schnell used a similar technique, though the effect of age was not examined.[2]

Mercier et al. (1993) performed a study on behalf of FHWA with two primary goals (a) to define minimum nighttime visibility requirement for traffic control devices, and (b) to develop measurement devices and computer management tools necessary to effectively implement these requirements.[5] Two separate studies were performed to accomplish the first goal. The first study developed a computer model designed to define minimum retroreflective values and performed an evaluation of the proposed values. The second study measured luminance thresholds for traffic signs (warning, regulatory and guide signs). The experiment was conducted in the Photometric and Visibility Laboratory at the Turner-Fairbank Highway Research Center. All interior surfaces (walls, ceiling, and floor) were black to minimize light reflection and allow better control of light level. Subjects in a darkened laboratory viewed a series of scaled traffic signs. Simulated viewing distances were measured. Sign luminance was increased in steps until the subject was able to correctly identify the sign.

Dewar et al. (1994) examined comprehension levels of all of the symbols in the MUTCD as a function of age.[6] A Kodak carousal slide projector was used to project slides of the traffic signs. Subjects provided information about their driving backgrounds and wrote their responses to each of the signs in a test booklet. Subjects sat at distances from the screen of 3 to 12 m. The test facilities ranged from a small classroom that could accommodate 20 observers to an auditorium that seated 90. All facilities had chairs and tables and adjustable lighting. Drivers were tested in groups ranging from 8 to 60 participants each. The subjects viewed the signs for 30 to 40 sec each, wrote the sign's meaning in the answer booklet and immediately indicated their familiarity with the sign using a five point rating scale. Approximately equal numbers of young, middle-aged, and elderly drivers were tested in each of six previously determined random orders of sign presentation. Half way through the presentation of the slides subjects were given a 15-min break.

Graham et al. (1997) conducted a research to establish a minimum level of highway sign luminance or existence of retro-reflectivity.[3] They focused on sign luminance requirements of forty-two subjects 65 years of age or more and nineteen subjects 25 years of age or less. The experiment was carried out in a parking lot on the campus of the University of North Carolina at Charlotte. The parking lot was closed to traffic and the overhead lighting was turned off during testing. The test vehicle and signs were placed on the 180 by 20 m asphalt-surfaced test area to simulate a two-way, two-lane rural highway.

Mace et al. (1994) published a report of their research on relative visibility of increased legend size vs. brighter materials for traffic signs.[10] The objective of the research was to determine, for older and younger drivers, the relative conspicuity and legibility of signs with different retroreflective materials containing legends using different stroke widths and other stylistic variations. The study on retroreflectivity and stroke width on sign legibility used a static letter legibility methodology. Subjects were seated in the front seat of a stationary car with low-beam highlights on and they viewed signs at a number of fixed distances. Each sign was exposed for 10 seconds. Unlike testing one sign at a time, numerous trials were completed with variety of signs at one location before moving the sign. Two subjects were tested at a time by having subjects make their responses in private using a cloth partition.

Kuhn (1999) conducted a study to assess the performance of four nighttime illumination technologies commonly used by on-premise sign advertisers.[4] These technologies were field tested at night and during the day with four different combinations of text and background color. Ninety-two subjects were recruited for research participation. The two measures of effectiveness (MOEs) were the threshold distance for recognition of the target word and the legibility distance threshold for the distracter words. The independent, or controlled, variables were font type, text and background color, and nighttime illumination technology (i.e., externally illuminated, internally illuminated [translucent and opaque background], and neon). The test site was PTI's Bus Research and Testing Facility. The 5042-ft long 15-ft wide oval track was equipped with seven overhead luminaires. The signs were placed along the two long tangent sections of the test track allowing for at least 1,200 ft of sight distance for each sign. The overhead luminaires were illuminated during nighttime testing to simulate real-world viewing conditions. The observation vehicle, a 1994 Ford Crown Victoria, was equipped with a distance-measuring instrument (DMI) to record observation distances. The DMI was interfaced with a laptop computer and a button box containing three buttons for use in recording distance data for analysis. From the initial start point, the experimenter drove around the one-mile track in a clockwise direction. When the first sign became visible, the subject was instructed to find the target word and identify its location on the sign. At the end of a correct reading, the experimenter pressed the button on the button box connected to the DMI, which correspond with the location of the target word. The experimenter then asked the subject to select and read one of the distracter words located on the sign. At the end of a correct reading, the experimenter pressed the button on the button box connected to the DMI, which correspond with the location of the distracter word the subject read. The experimenter pressed the first button on the button box when the vehicle was parallel with the sign. The distance between the first and third button pushed provided a threshold recognition distance measurement for the trial. The difference between the second and third button pushed provided a threshold legibility distance measurement for that test trial.

Helmut and Schnell (1998) conducted a daytime and nighttime sign recognition and legibility field driving experiment that involved 11 new reflectorized right-shoulder-mounted traffic signs and 10 young, healthy subjects.[2] The distinguishing feature of this research was that in previous studies the subjects had been encouraged to guess the symbols or legends. But in this experiment, the subjects were instructed to say aloud the information on the traffic signs at the point during the approach when they could clearly identify all visual details of the message or the symbol. It was found that legibility distances measured were considerably shorter than those obtained in studies when guessing was allowed. It was also found that average daytime distances were 1.8 times longer than the average nighttime legibility and recognition distances. The experiment was performed on a runway of the Ohio University airport, which was about 23 m wide and 500 m long. A repeated measurement design was used in this exploratory field experiment. No sign randomization technique was applied. Rather, the locations of the signs were determined based on their estimated legibility. During the actual experiment the vehicle was driven at about 8 to 16 km/h in the (simulated) rightmost lane.

Douglas and Pollack (1983) conducted a laboratory study to determine ways of measuring visual complexity and to assess the capability of added complexity.[7] A field study was also conducted to determine if the findings could be observed in real-world driver performance. The effect of visual complexity was observed in the field, and increasing sign brightness improved sign detection and recognition under specific conditions. The design of the study was complicated by the need to assess both the effects of the independent variables, which were controlled, and the variables that describe visual complexity, which were largely uncontrolled. Subjects attended three experimental sessions, scheduled on different days, during which they were individually tested. During each session, which lasted about 90 min with two 5-min rest periods, a subject responded to 240 projected stimuli. The task required the subject to view nighttime road scenes and to report, by using specific labels, their recognition of any of nine targets. Subjects were shown stimuli for 3-sec duration with a 15-sec interstimulus interval during which blank images were projected to maintain constant dark adaptation. A quiet buzzer alerted subjects to the onset of the next trial. Subjects reported targets in different orders, which may have reflected personal search strategies or degrees of certainty. The stimuli were composite color transparencies (2.4X2.8 inch) made from separate original transparencies of the scene and the sign. A 5 ft x 6.7 ft glass-beaded screen was located on one wall of the room while the projection equipment was isolated to limit the sound and light contamination of the experimental environment. The subject was seated 11.9 ft from the screen. A total of 40 volunteer subjects participated in the study and were compensated for completion of all three sessions.

CHAPTER THREE - METHODOLOGY

In this study, two tests were used to examine the effects with respect to older drivers of increasing the lateral placement of a sign and of increasing the brightness of a sign by using a more reflective sheeting. The same participants were used for both tests so that any relationship between the two could be examined. The first test used a PC-based change detection technique to study the effect of lateral placement on sign conspicuity. The second test examined sign legibility with respect to both sheeting type and lateral placement. Because glare is very difficult to replicate in the laboratory and liability issues preclude on-road field tests in this instance, a large facility was obtained to allow the use 1:1 scale signs and distances and the use of a stationary passenger car without the liability risk inherent in a field test.

3.1 Participants

Sixty participants were tested, all active drivers currently licensed to drive in their state of residence. Participants were divided into three equal groups based upon chronological age, with age ranges of 18 to 25, 45 to 55, and 65 to 85 years of age, respectively. There are two points of significance regarding the sample chosen. First, the sample size (twenty observers per age range) was chosen because it should provide sufficient power (with multiple observations per observer to enhance data stability), based upon a power analysis, to detect moderate sized effects [11]. A larger sample size would be necessary to detect small effects that may be of theoretical interest, but for the purposes of traffic safety, small effects are not likely to produce a meaningful impact on real-world driver performance. Second, though chronological age is, itself, a poor predictor of declines in performance (i.e. some 85 year-olds have better ocular health than some 65 year-olds), the addition of a moderate aged sample allows for modeling of general age-related declines which may be nonlinear with respect to time.

3.2 Pre-testing

Participants were tested for visual ability prior to the experiment. Except in cases of gross visual loss, participants were not excluded based on visual characteristics, allowing for a range of visual abilities within the sample to reflect the range of abilities in the driving population. The pre-tests included three measures of low-level vision: static acuity (near and far Snellen acuity), contrast sensitivity (VCTS 6500), and color vision (Ishihara Color plates).

3.3 Experiment 1

In Experiment 1, subjects were asked to view pairs of images on a PC. The images in each pair were nearly identical, differing in only a single element. For example, an image of a highway scene might be digitally edited to remove a particular sign or vehicle. Subjects were then asked to identify the element that changes from one image to the other. The time required for the subject to detect the change was recorded, and these times served as the measure of comparison between image sets, subjects, and subject groups. A series of image pairs were observed and changes identified by each subject. A portion of the image pairs focused on the study issue, while the changes in other pairs were unrelated to the study issue so that subjects would not begin to anticipate the nature or location of the change.

Custom software was employed to display two alternating images to the observer using a typical PC display. The images were identical except for a single element. In some cases a guide sign was overlaid on the image using digital imaging techniques (e.g., appearing in one image but not the other). To prevent the user from anticipating the location of the change in the image, other elements were changed in other images, such as the addition of a maintenance truck or a pedestrian, or the illumination of the brake lights of a vehicle ahead of the observer.

Two images were shown during each observation, alternating between the two. Between each image, a gray screen was displayed to prevent the observer's attention from being attracted to sudden changes in local luminance. The observer was instructed to press the left mouse button to stop the timer when they had identified the element of the images that was changing. An experimenter recorded the accuracy of the observations.

3.3.1 Data Analysis

The detection time data was biased by the age of the observer. Older adults are generally slower across a range of tasks than younger adults (i.e., Cerella, 1985 [12]). However, there are analytic techniques available to remove the effect of generalized slowing to examine differences in reaction time due only to the task. In the present work, the reaction time data was analyzed using the technique of Faust et al (1999) [13], which removes the influence of general slowing. An analysis of variance (ANOVA) was conducted to determine how changes in the various aspects of the signs influenced reaction time performance, as well as how these changes interacted with age.

3.4 Experiment 2

The second experiment was designed to examine three variables: sign material (engineering grade; Diamond Grade™ VIP, categorized by KDOT as high intensity; and

Diamond Grade™ LDP), lateral sign placement (16 ft, 30 ft, and 50 ft from the edgeline), and sign distance (70 ft, 135 ft, 200 ft). The influence of these variables on both sign legibility and secondary task performance was measured. Sign legibility was measured using a target detection task in which the participant verbally indicated if a particular target was present on a sign, or not. The target used was a typical guide sign (green background with white legend; Clearview font). The dimensions of the sign included a 10-2/3 in (27 cm) legend with 6 in (15 cm) border. The only exception to the specifications of a standard guide sign was that for the center character ("C") of the middle line, the Clearview font "C" was replaced with a Landolt C. Prior to each test run, a sign assembly of the appropriate reflectivity was placed on the apparatus. The target and non-target (i.e., forward and backward Landolt C) were on opposite sides of the sign assembly, so changes in target type simply required rotating the assembly 180 degrees. On each trial, the participant identified the orientation of the target C by indicating whether they observed a forward C (gap to the right) or a backward C (gap to the left). The sign showing a backward C is depicted in Figure 3.1. There were ten trials per condition (five gap left and five gap right), which was considered to be a minimum number needed to provide stable data in each cell after averaging. The experiment was blocked by sign material and distance. The orders of both the lateral placements at each distance and the signing materials at each location were randomly generated by the computer. Presentation order of the blocks was counterbalanced across observers.

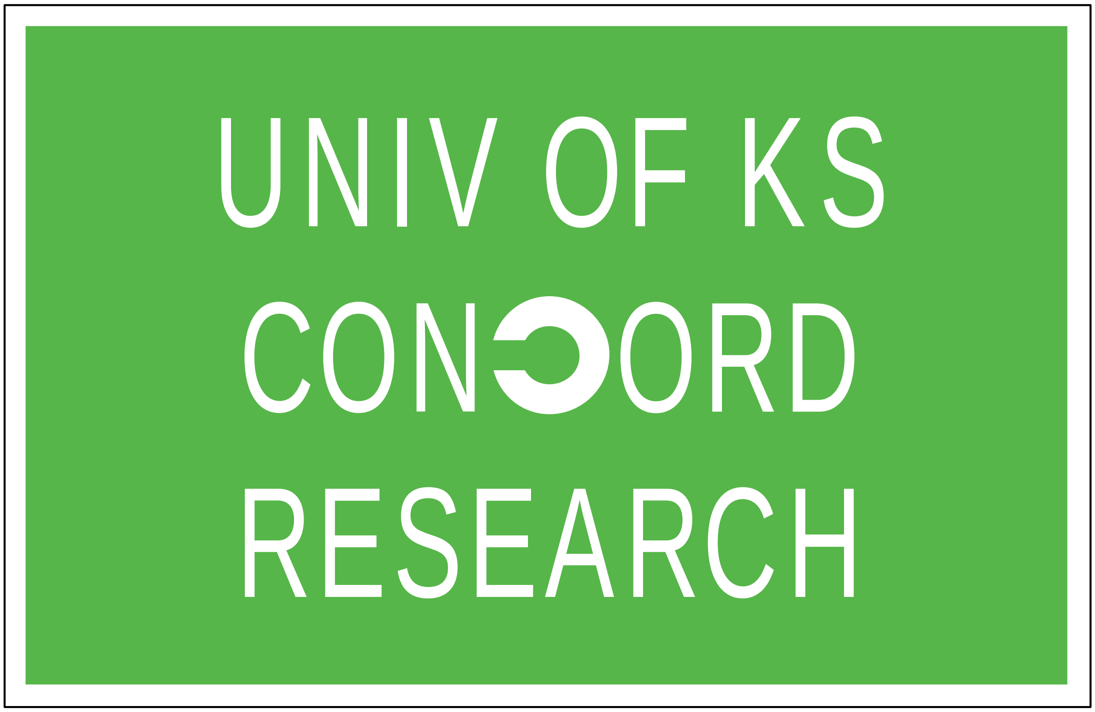

Figure 3.1: Test sign with backward C.

Secondary task performance was measured by obtaining an estimate of the influence of sign characteristics on reaction time (RT) to a traffic event. In this case, the event was the activation of brake lights on a “car” in front of the observer. The time required for the observer to react to this event by depressing their brake pedal was measured. In addition to providing a measure of the effects of glare upon performance for a task other than reading the sign itself, this task served to increase the attentional load upon the participant, to more accurately reflect the attentional demands of an actual driving task. The observers were required to monitor the brake lights during the entire experimental session, effectively creating a dual-task environment reminiscent of on-road demands, which reduced the ability of observers to anticipate the appearance of the sign stimuli. The experiment included approximately six baseline trials (brake light occurred when no sign was present) per condition and 108 secondary task trials (four per condition) in which the brake light occurred while the sign was illuminated.

Between trials, the observer sat in the car in the darkened environment monitoring the taillights in front of them for change. To start a trial, at a random point, the headlights were illuminated for two seconds, revealing the sign. The observer responded verbally to indicate whether they perceived the target to be present or absent. On secondary task trials, the taillights also increased in luminance, requiring a braking response in addition to the sign judgement.

3.4.1 Apparatus

Figure 3.2 provides a schematic of the experiment layout. Observers were seated in a stationary car (B) located at one end of a light-sealed warehouse. The facility measured 240 ft (73.2 m) long by 125 ft (38.1 m) wide, with the test car facing in line with the longer dimension. Taillights were mounted on wooden posts and positioned 50 ft (15.2 m) in front of the driver, simulating a preceding car (D). These lights were connected via photo-optic relay to the computer’s parallel port, allowing them to be turned on and off by the computer (C). The brake light circuit was also connected to the computer so that the status of the brakes could be monitored. Illumination was provided by the vehicle headlights (A), also controlled by the computer. Two light emitting diodes (LEDs) were magnetically mounted to the roof of the test car and used by the computer to indicate to the researchers operating the signs which of the two targets were to be displayed next. A large cart was constructed to hold the signs (E), allowing them to be easily moved from one location to the next. For each sheeting type, the two target signs (one forward C and one backward C) were mounted back to back. For each condition, the sign assembly of the required sheeting type was placed onto a stand designed to rotate, allowing the sign assembly to be easily rotated to show the correct target, as indicated by the computer using the LED indicator lights (F). When the sign assembly was rotated to display the next target, a wireless remote connection to the computer was used to signal the PC that the signs were ready for the next observation.

The active devices in the experimental setup are shown in Figure 3.3. The shaded areas each contain a subsystem that was either monitored or controlled by the PC. Both were accomplished using the computer's parallel port. The subsystems shown shaded in Figure 3.3 are described briefly in Table 3.1. The following sections provide additional details about particular elements of the setup configuration.

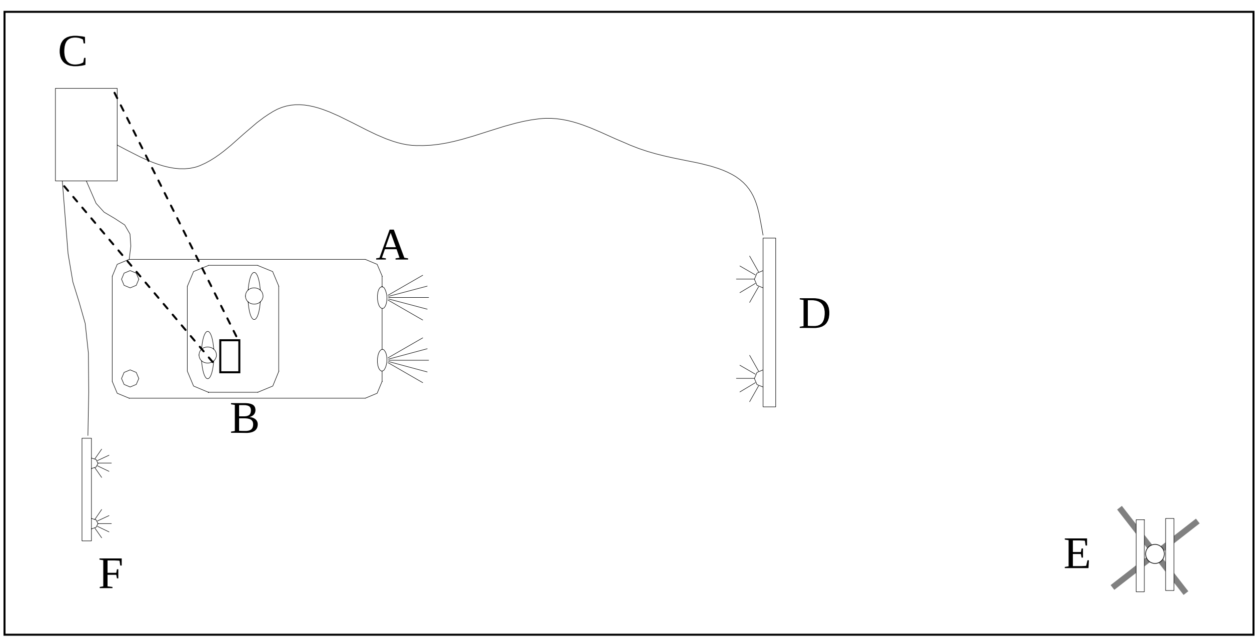

Figure 3.2: Study schematic.

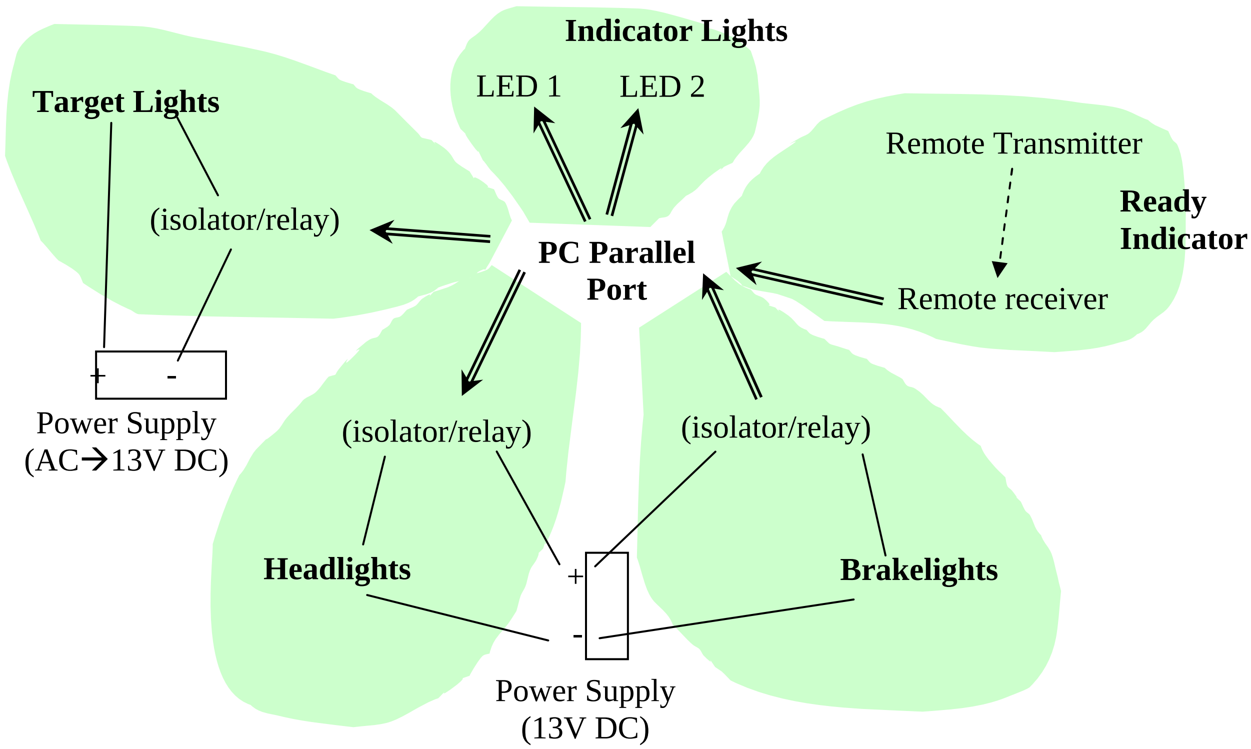

Figure 3.3: Subsystems and Device Connections

3.4.1.1 Target Lights

The target lights were used to provide a secondary stimulus for the driver. Comprised of a power supply, a control circuit connected to the PC, and break lights intended for mounting on a trailer, the target lights were intended to emulate a vehicle in front of the test vehicle. The tail lights were in continuous on as they would be during nighttime conditions. When the break lights were activated (i.e., the brightness increased), the participant was to press the break pedal in the test vehicle with their foot, much as they would while actually driving when the vehicle ahead applied their breaks.

Table 3.1: Electronic Subsystems

Subsystem	Power Source	Description
Sign Indicator	PC (5 mV)	LED's placed on the roof of the vehicle (out of sight of the participants) indicated the orientation of the next sign during a run. Workers placed the appropriate sign.
Ready Indicator	AA Batteries	A pair of walkie-talkies was used for the workers manning the sign station to signal the PC in the vehicle that the correct sign was in position. One unit was wired to the parallel port. When the sign was in position, the workers pushed the call button on the other unit. Upon receiving the signal, the PC automatically initiated the next trial, following a pause of random length. The process was not detectable by the participants.
Brake Lights	Vehicle Power (13 V DC)	Custom wiring installed in the test vehicle tapped into the test vehicle's electrical system. A lead from the brake light circuit was connected to the PC's parallel port through an optical isolator.[1] The PC monitored the brake light status to time the participant's response.
Headlights	Vehicle Power (13 V DC)	A lead from the headlights circuit ran through an optical isolator[1] to the PC, allowing the PC to turn the headlights on and off at designated times.
Target Lights	13V DC via AC to DC Power Converter	Through an optical isolator[1], the PC turns the target lights on and off, providing the stimulus for the participant's secondary task.

Figure 3.4 shows the target lights from the passenger side of the test vehicle with the facility illuminated. Figure 3.5 shows the assembly in the darkened facility with the test vehicle headlights on. Without the headlights, all that can be seen are two near red lights (i.e., the target lights) and two distant red lights (i.e., exit signs above doors on the opposite end of the building, one of which can be seen in the left of the image).

[1] An optical isolator transfers a boolean signal (i.e., on or off) from a circuit of one voltage to a circuit of another. In this setup, isolators were used to allow the PC's parallel port, which uses a voltage of 5 mV, to control and monitor circuits associated with the test vehicle, which use a voltage of 13 V.

Figure 3.4: Target Light Assembly with Test Facility Illuminated

Figure 3.5: Target Light Assembly with Headlights On In Darkened Facility

3.4.1.2 Sign Indicator Lights

The sign indicator lights, shown in Figure 3.6 were dual brightness LEDs housed in a black box with a magnetic mount. The lights were affixed to the roof of the test vehicle well rearward of the front windshield, and were operated on low luminance. In this configuration, the participant was not able to detect the operation of either or both lights. The lights were used to notify the staff in charge of placing signs which sign should be showing for the next trial. The computer generated a pseudo-random order for the signs, and for each trial illuminated one or both indicator lights to communicate the next in order (e.g., one LED = forward C, two LEDs = backward C). Figure 3.7 shows the location of the indicator lights on the vehicle.

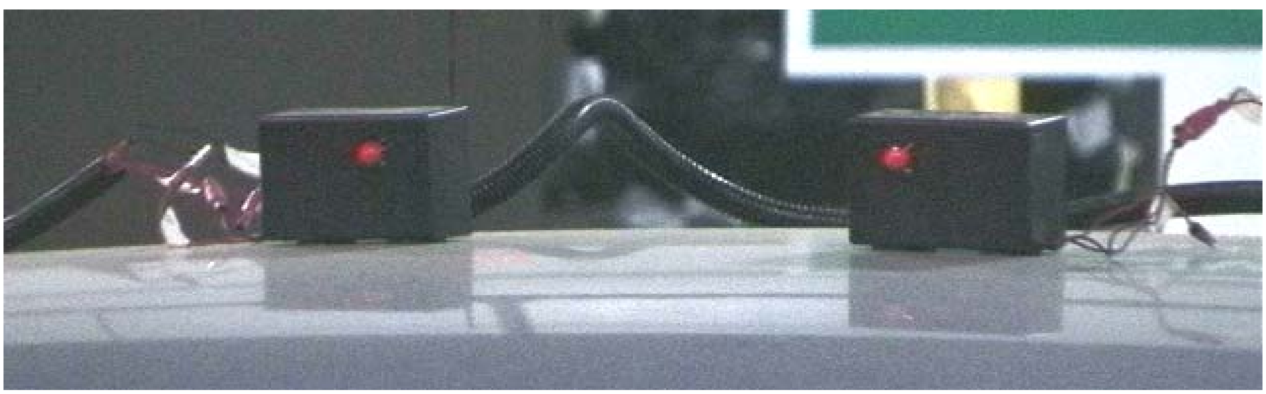

Figure 3.6: Sign Indicator Lights

Figure 3.7: Location of Sign Indicator Lights

3.4.1.3 Sign Assembly

The signs had to be positioned 5 ft above the level of the “pavement” to be consistent with federal guidelines for rural signage. During each test, the signs had to be switched as quickly as possible, changing from the forward C to the reversed C (or vice versa) as appropriate. Between tests, the signing material had to be changed and/or the sign moved to a different location. A cart was designed and assembled to help facilitate the functions of the experiment. Large-wheeled casters were used to facilitate moving the cart across the dirt floor of the facility. For each signing material, two signs (one showing a forward “C” and the other showing a reversed “C”) were mounted back to back using two pieces of 2x4 lumber as spacers, one horizontal across the top and one vertical along one side. The bottom and opposite side were left open to facilitate easy mounting of the sign on the stand and the storage racks. The display stand comprised a pole with a crossbar on the top affixed to the cart such that the sign mounted on the pole would be at the appropriate height. The pole was segmented such that a rotating joint could be placed between the pieces. A pare of signs was lifted onto the cross bar, and then rotated as appropriate during each test. Between tests, the sign pair was removed from the cross bar and placed on a storage rack, the cart was moved (if appropriate), and the appropriate sign pair mounted on the cross bar. With the facility darkened, staff were able to distinguish the signs at close range, but the test participants could not even see the sign assembly until the test vehicle headlights were illuminated. Figure 3.8 shows the sign assembly with one of the forward “C” signs mounted. One of the reverse “C” signs is shown in the inset to the right of the assembly.

Figure 3.8: Sign Assembly and Reverse “C” Sign

Figure 3.9: PC Control Center set up in rear seat of test vehicle.

3.4.1.4 PC Control Center

The computer to control and monitor the active subsystems was a laptop Intel-based computer, connected to all subsystems via the parallel port. During the tests, the PC was located in the back seat of the test vehicle, resting on a bed-tray as shown in Figure 3.9.

All participant responses were recorded either automatically (pressing of the brake pedal) or by research staff (verbal response of primary task) on the computer using custom software developed for the test. A clipboard was used to hold a procedural check list and record any anomalies observed during the test. The software, shown in Figure 3.10, was used to control and monitor the various electrical systems that were operating during the tests. All triggers needed during the tests were silent (e.g., field notification that the signs were ready or triggering the start of a series of trials), using a mouse over technique rather than mouse clicks to trigger buttons and other controls. This precluded any noises that would give the participants any clues as to when test events would occur or what sign would be shown next. Additionally, most events had pseudo-random latencies so that no recognizable patterns developed as research staff conducted multiple tests. Each electrical system was connected to the computer through the parallel (i.e., printer) port, using either a send or receive contact, depending on whether the particular system needed to be controlled by the software (headlights, target lights, and sign indicator LEDs) or monitored by the software (sign ready indicator and brake lights).

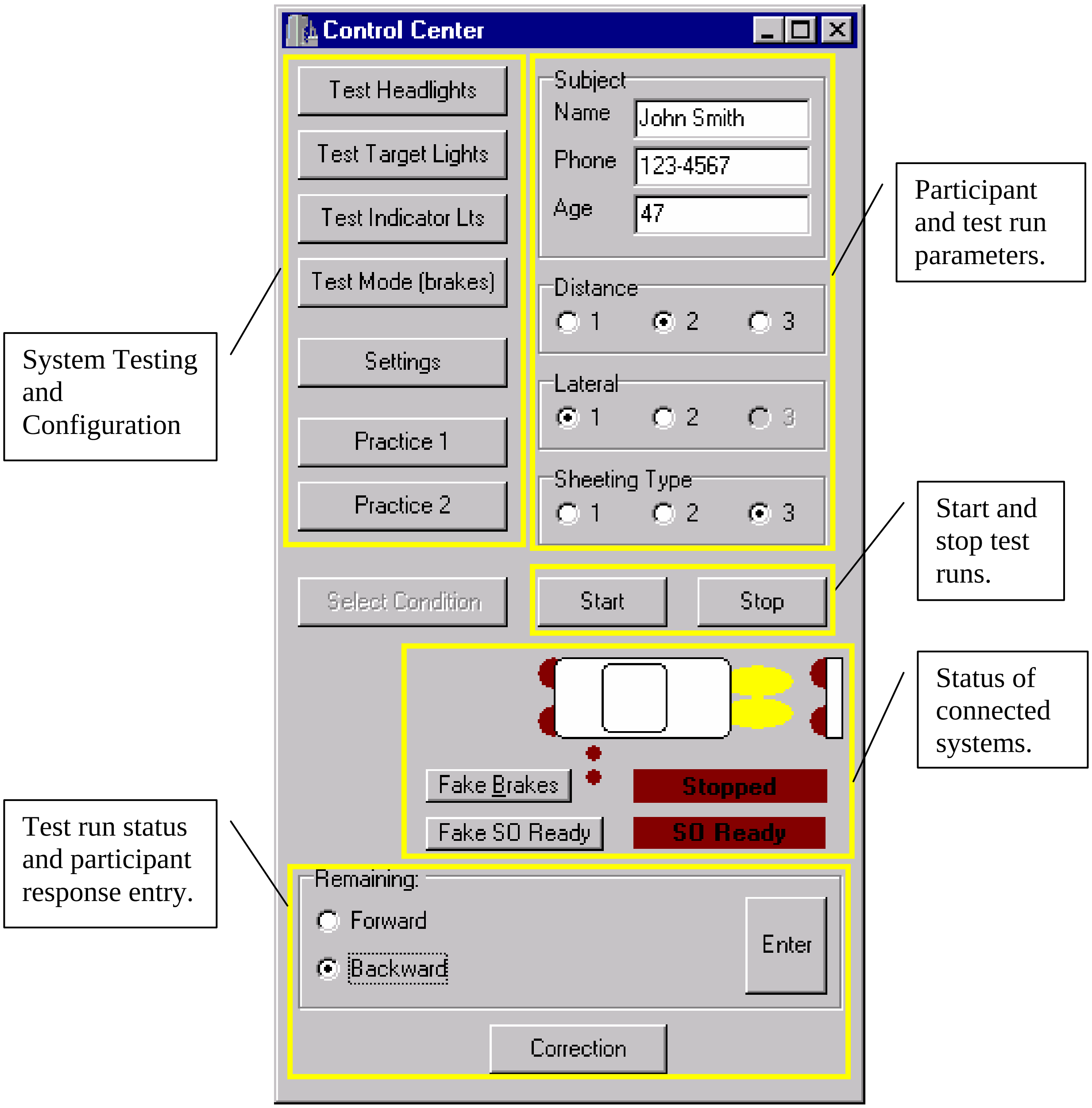

Figure 3.10: Custom Control Center Software

The computer was running the Windows NT 4.5 operating system (OS). Because this OS is not a preemptive multitasking OS[2], when an event occurred, the control center software had to wait it's turn for CPU time to perform all detection of changes in the status of any of the test systems or to get a time from the system clock to log when a test event or participant response occurred. Thus when a time is obtained, the application does not know the exact time of the event, but only that the event occurred between the time obtained and the last time at which the application had access to the CPU. To verify that this time gap was not so large as to skew the data analysis, the software continually tracked the most recent time at which it was given CPU time. In so doing, when an event or response occurred, the software could ascertain hard boundaries on the exact time of the event, which had to have occurred between the last CPU time before the event was detected and the first CPU time after the event was detected. The difference between the two times represented uncertainty in the time logged. These times were nearly always 0.1 seconds or less, and any event with larger uncertainty was thrown out.

3.4.1.5 Test Vehicle

In order to simulate actual driving conditions as closely as possible, an actual automobile was used. The test vehicle was a 1995 Chevy Lumina. Participants sat in the driver's seat, held the steering wheel with their hands (although the vehicle did not move during the tests), and pressed the brake pedal with their foot. The engine remained running throughout the tests to power several of the electrical systems used in

[2] In a preemptive multitasking environment, the OS controls allocation of CPU time among applications, guaranteeing each application a pre-specified slice of CPU time during a given time interval. In a non-preemptive, or cooperative, multitasking environment, applications have full use of the CPU until they voluntarily release it to other applications. Consequently, one application can potentially cause significant delays in other applications.

the test and to make the air conditioner available to keep the participants comfortable (the test was conducted during summer months and the test facility was not air conditioned). Fans were placed near the exhaust of the vehicle to ensure continual circulation of the air, and a carbon monoxide meter was in operation inside the vehicle when participants were present and outside the vehicle on the trunk at other times. At no time during the tests did the carbon monoxide meter ever show questionable levels.

Opaque black material was used to cover the sideview and rearview mirrors to prevent distractions. The tail lights were covered to prevent their illumination from revealing what sign would be displayed next.

Custom wiring was installed in the vehicle to allow the PC to control the vehicle's headlights and monitor the brake lights. The headlights circuits were wired such that the vehicle headlights would operate normally apart from the PC, but when connected the PC could bypass the switch, turning the headlights on and off while the vehicle controls were set to *off*. The brake light circuit was tapped into with a lead running to the computer and then to ground. The PC simply monitored whether the circuit voltage was low (brake lights off) or high (brake lights on), and logged the difference between when the target lights were illuminated and the time at which the brake was pressed, as indicated by the brake lights turning on.

3.4.2 Facility Preparations

The setup for the experiment comprised two fundamental parts. One was setting up all of the equipment described above and shown in Figure 3.3, including placing all items in the correct location, connecting all the electrical devices appropriately, testing each electrical connection and the control and response of the PC, and performing a dry run (i.e., without an actual participant) to ensure nothing had been overlooked. The second part of the setup was to prepare the facility to emulate nighttime conditions. The facility preparations involved eliminating all light sources that might invalidate the test by allowing participants to see the signs even when the vehicle headlights were off. The facility had five garage doors, two pedestrian doors that had windows, and two exhaust fans. Each of these was sealed using opaque plastic sheeting. Plastic sheeting was also used to isolate the illumination in the ready room and to cover the illuminated front face of the soft drink vending machine. There was an exhaust vent in the center of the roof that occasionally opened and let in a small amount of light, but there was no means to access it. The light entering through the vent proved to be insufficient to reveal which sign was showing nor the motion of the staff in charge of changing the signs, and so had no effect on the test results. A diagram of the facility is shown in Figure 3.11.

The dashboard of the vehicle and the tail lights were covered with opaque plastic to avoid any interference with the experiment. All the lights in the testing area of the facility were kept off throughout the experiments. In the restrooms and in the ready room, very dim illumination was supplied so that the participants eyes could adjust and remain adjusted to nighttime conditions. The dim lighting throughout the facility also had an unanticipated secondary benefit. The facility was commonly used as a horse arena, and so was home to a great number of flies. In dim lighting, flies become motionless, as if sleeping, and remain so indefinitely so long as the lighting remains low. The lighting conditions greatly enhanced the comfort of the participants and staff alike by keeping the flies asleep and out of sight.

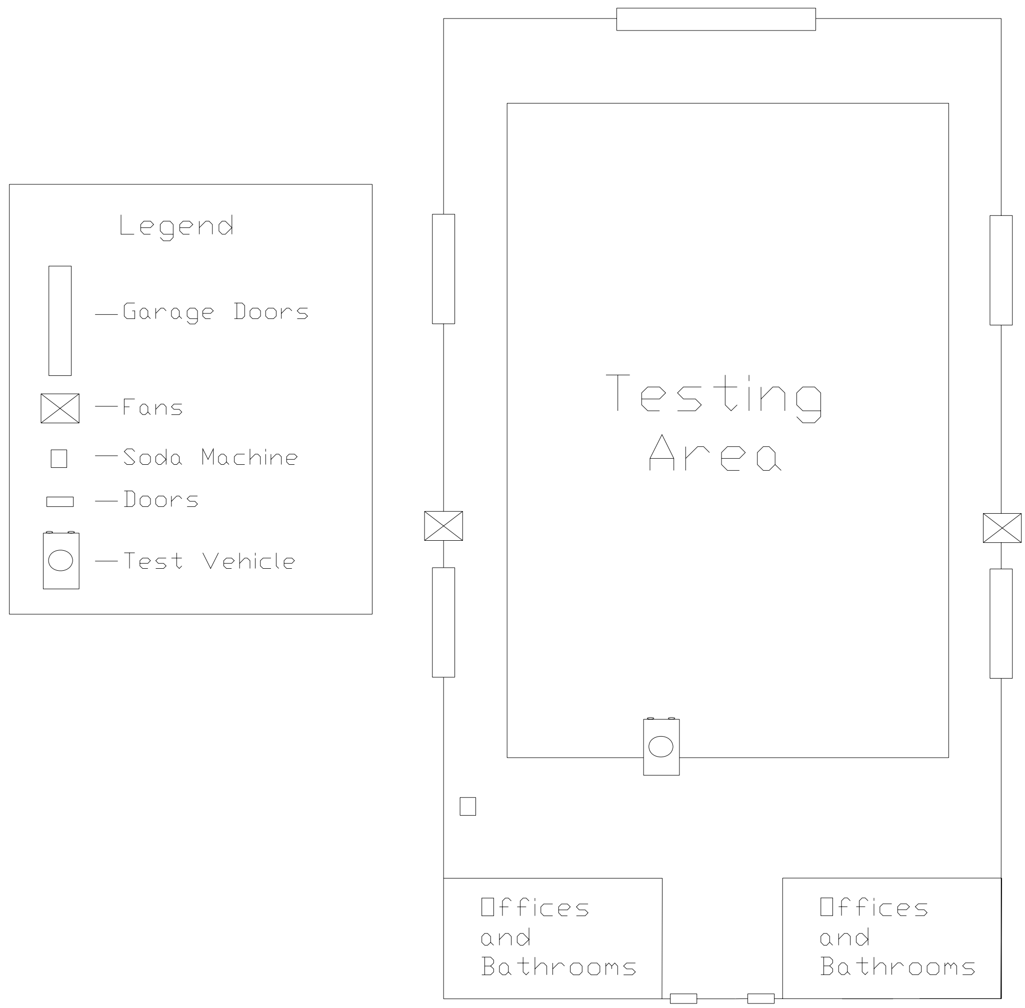

Figure 3.11: Sketch of Testing Area

3.4.3 Sign Locations

One of the objectives of this study was to assess the effect of lateral placement on nighttime sign legibility, particularly for older drivers. Three lateral placements were used. The nearest was 16 ft from the centerline of the vehicle, representing half the width of a 12-ft lane plus a 10-ft shoulder. The farthest lateral placement was 50 ft, stipulated by KDOT as the farthest lateral placement of interest. The middle placement, 33 ft, was simply the midpoint between the two other values.

The longitudinal distances were 70 ft, 135 ft, and 200 ft from the driver's seat of the test vehicle. The largest of the values was constrained by the size and design of the facility. The nearest distance, 70 ft, was based on several factors, including a maximum desired eccentricity of about 15 degrees and positioning the sign far enough behind the target lights that the target lights did not illuminate the activity of those overseeing sign placement. After the first few participants, it became clear that the desired number of participants could not be tested with the full array of sign locations and sheeting types in the time during which the facility would be available. It was decided to omit the three sign locations that had an eccentricity greater than 15 degrees. The sign locations relative to the test vehicle and the locations omitted from the study are shown in Figure 3.12:12.

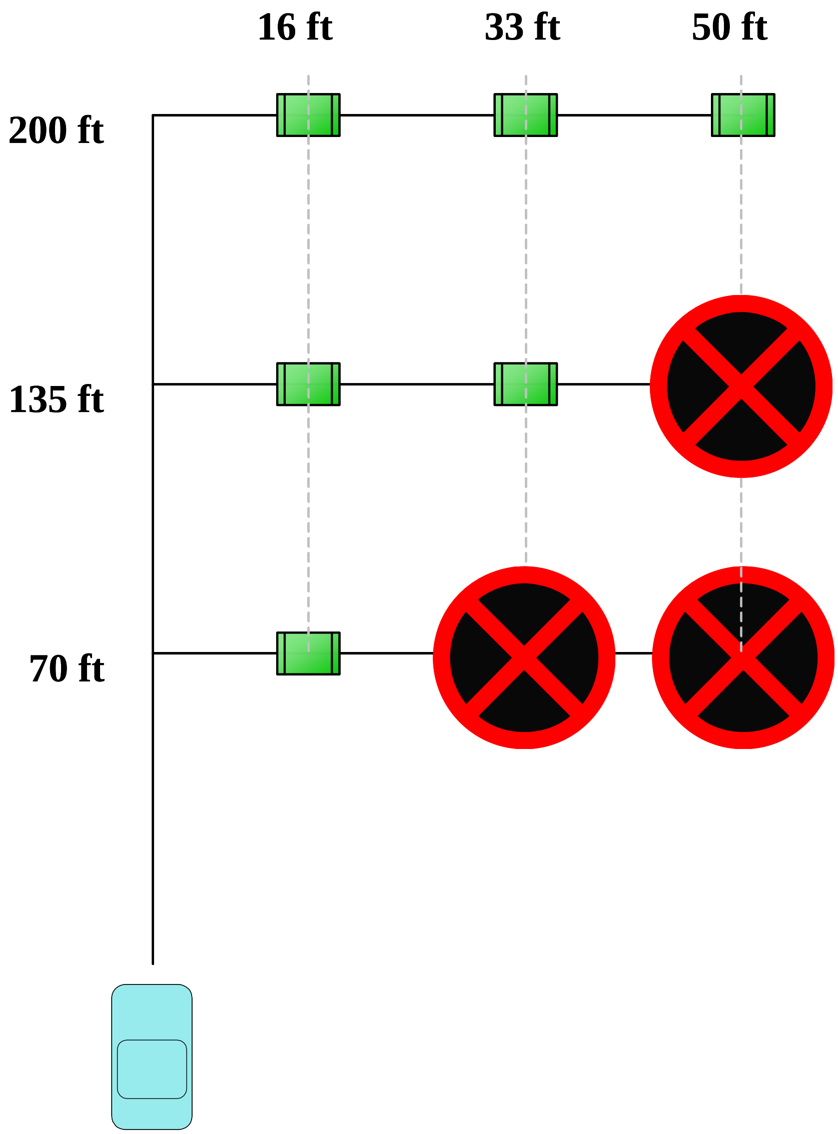

Figure 3.12: Sign Locations With Omitted Locations Indicated

3.5 Data analysis techniques

In addition to the primary measure of glare on sign legibility, this design provides RT data for a secondary event, which can used to assess the effect of glare on braking performance. The inclusion of “on-road” effects of glare is an important consideration that is often overlooked in sign design. However, RT data is biased by the age of the observer. Older adults are generally slower across a range of tasks than younger adults. [12] However, there are analytic techniques available to remove the effect of generalized slowing to examine differences in RT due only to the task and remove the effects of generalized slowing with age [13]. Baseline RTs were not substantially different in the present data, and thus this transformation was not required.

CHAPTER FOUR - RESULTS

4.1 Experiment 1

The results of Experiment 1 did not provide any evidence that lateral placement of signs significantly affects their conspicuity, given that signing rules are properly followed (i.e., eccentricities of 10° or less and size appropriate for design viewing distance). This does *not* mean that lateral placement is of no importance, but only that the lateral placement *alone* does not significantly affect conspicuity. For example, moving a sign laterally may change the background complexity as viewed by drivers, and consequently change the conspicuity of the sign. The lateral placement was only indirectly responsible for the change in conspicuity. The immediate cause was the change in background complexity.

In this experiment, only lateral placement could be considered. The factors affecting conspicuity are many and the relationships between the factors are complex and not thoroughly understood. Isolating the various factors (e.g., background complexity, contrast between sign and background, importance of sign relative to other scene elements, and proximity of sign to other important elements) is an extremely difficult task and is beyond the scope of this work.

It is possible that large increases in lateral placement of a sign could be associated with changes in conspicuity, but when the lateral placement of a sign is significantly increased, the viewing distance must increase to maintain acceptable eccentricity, requiring a corresponding increase in the size of the sign. The increase in size most likely offsets any effects of lateral placement with respect to conspicuity. Changes in lateral placement that are not large enough to require an increase in sign size likely are insufficient to adversely affect conspicuity to any practically significant degree.

4.2 Experiment 2

The effects of sheeting type (engineering grade, high intensity grade, or diamond grade) and age group (younger, middle-aged, or older) across varying vertical placement distances (70, 135, or 200 feet) and lateral placement distances (16, 33, or 50 feet) on sign-reading accuracy and response time to probe events were examined with a series of Mixed Group (Split-Plot) Analyses of Variance (ANOVA) with age group as a between groups factor and sheeting type as a within-subject factor. Because of time constraints related to the use of the facility, the design could not be fully crossed, and thus the effects of sheeting and age group were examined separately for each presented combination of vertical and lateral placement distance. All effects are reported as significant if $p<.05$, and effect sizes are provided to augment the significance tests. The Greenhouse-Geisser correction for violations of the sphericity assumption (unequal variances between conditions) was employed as necessary. Accuracy means below 0.5 were changed to 0.5 under the assumption that 0.5 represents chance performance, the lowest possible score. The distribution of response times was examined separately for each condition, and data points three or more standard deviations from the condition mean were removed (approximately 2.2% of the data were removed in this manner). The results for accuracy will be presented first, followed by the response time data.

4.2.1 Accuracy

Univariate statistics for all accuracy data are reported in Table 4.1:. The effects of age group and sheeting type on accuracy at the closest vertical (70 feet) and lateral distances (16 feet) were examined first. There was no significant main effect of age group. However, there was a significant main effect of sheeting type, Greenhouse-Geisser $F(1.3, 66.2) = 5.9$, $MSE = .006$, $p = .004$, $eta^2 = .100$. Accuracy rates were lower using the diamond grade sheeting than under the engineering grade or high-intensity grade, which were not different from each other. There was no significant interaction between age group and sheeting type. The effects of age group and sheeting type on accuracy at the second vertical (125 feet) and first lateral distances (16 feet) were then examined. No significant effects were detected. The same effects were examined at the second vertical (125 feet) and second lateral distances (33 feet). There was a significant main effect of age, $F(2,56) = 3.7$, $MSE = .04$, $p = .032$, $eta^2 = .116$, such that older adults were significantly less accurate than younger adults. Middle-aged adults were not significantly different from each group. There was no significant main effect of sheeting nor a significant interaction with age group.

Table 4.1: Mean (Standard Deviation) Percent Correct Per Experimental Condition

		Distance (Vertical-Horizontal, in ft)					
Age Group	**Sheeting Type**	**70-16**	**135-16**	**135-33**	**200-16**	**200-33**	**200-50**
Younger Adults		***N=19***	***N=20***	***N=20***	***N=20***	***N=21***	***N=17***
	Engineering Grade	0.99	0.99	0.98	0.97	0.94	0.94
		(0.02)	*(0.03)*	*(0.04)*	*(0.08)*	*(0.13)*	*(0.12)*
	Diamond Grade (VIP)	0.99	0.99	0.98	0.95	0.96	0.94
		(0.03)	*(0.05)*	*(0.04)*	*(0.11)*	*(0.12)*	*(0.13)*
	Diamond Grade (LDP)	0.98	0.99	0.99	0.98	0.97	0.96
		(0.04)	*(0.04)*	*(0.03)*	*(0.04)*	*(0.11)*	*(0.09)*
Middle-Aged Adults		***N=18***	***N=19***	***N=19***	***N=19***	***N=18***	***N=17***
	Engineering Grade	1.00	0.98	0.92	0.95	0.93	0.85
		(0.00)	*(0.07)*	*(0.12)*	*(0.08)*	*(0.12)*	*(0.18)*
	Diamond Grade (VIP)	0.99	0.98	0.96	0.96	0.93	0.91
		(0.03)	*(0.04)*	*(0.07)*	*(0.07)*	*(0.13)*	*(0.13)*
	Diamond Grade (LDP)	0.96	0.97	0.96	0.97	0.94	0.95
		(0.08)	*(0.09)*	*(0.10)*	*(0.07)*	*(0.10)*	*(0.11)*
Older Adults		***N=19***	***N=20***	***N=20***	***N=20***	***N=21***	***N=16***
	Engineering Grade	0.96	0.97	0.89	0.90	0.84	0.75
		(0.10)	*(0.06)*	*(0.18)*	*(0.11)*	*(0.21)*	*(0.13)*
	Diamond Grade (VIP)	0.97	0.96	0.88	0.94	0.80	0.78
		(0.09)	*(0.07)*	*(0.19)*	*(0.13)*	*(0.19)*	*(0.20)*
	Diamond Grade (LDP)	0.92	0.96	0.88	0.97	0.86	0.85
		(0.16)	*(0.09)*	*(0.20)*	*(0.07)*	*(0.16)*	*(0.19)*

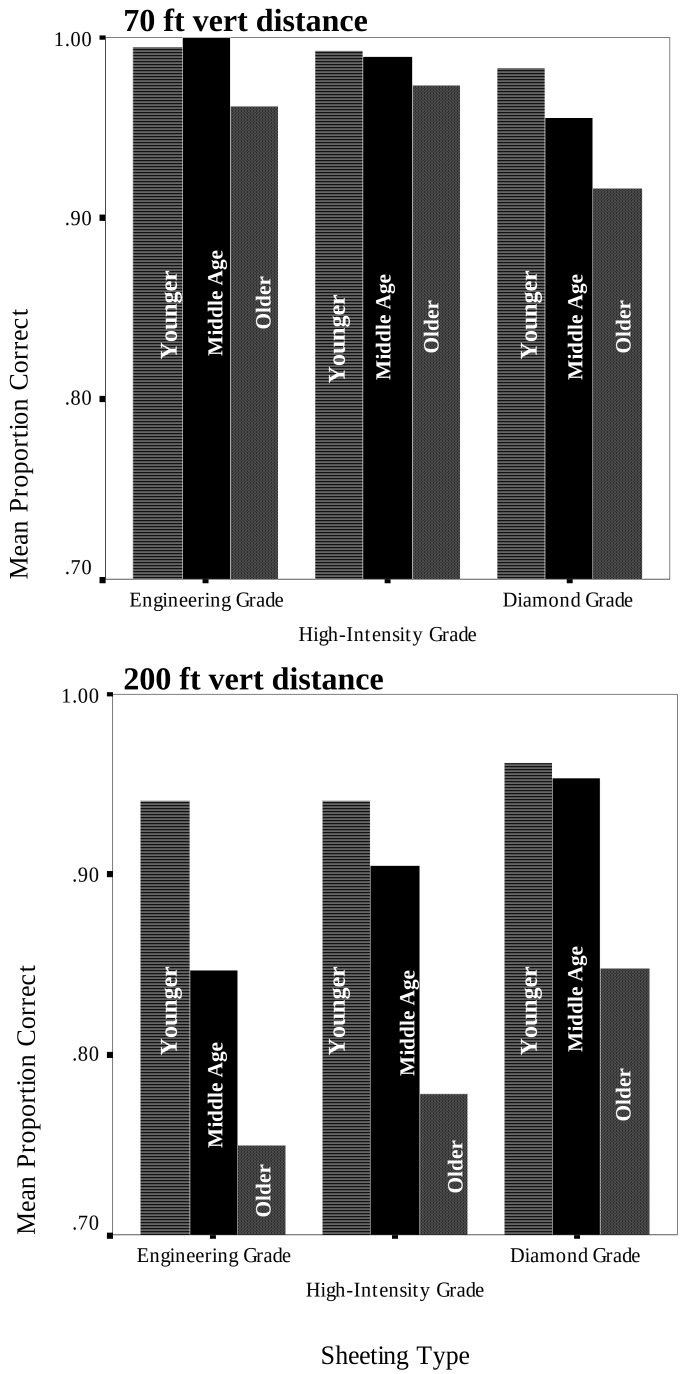

Figure 4.1: Mean Proportion Correct by Age Group and Sheeting Type

The effects of age group and sheeting type on accuracy at the third vertical (200 feet) and first lateral distances (16 feet) were then examined. No effects were significant. The same effects were examined at the third vertical (200 feet) and second lateral distances (33 feet). There was a significant main effect of age, F(2,57) = 5.1, MSE = .05, p = .009, eta2 = .152, such that older adults were significantly less accurate than younger or middle-aged adults, who were not different from each other. There was no significant main effect of sheeting nor a significant interaction with age group. Finally, the effects of age group and sheeting type on accuracy were examined at the third vertical (200 feet) and third lateral distances (50 feet). There was a significant main effect of age, F(2,47) = 3.7, MSE = .04, p = .001, eta2 = .244, again such that older adults were significantly less accurate than younger or middle-aged adults, who were not different from each other. There was also a significant main effect of sheeting type, F(2,94) = 6.3, MSE = .01, p = .003, eta2 = .119, such that accuracy rates were higher for the diamond-grade sheeting than for engineering grade. The high-intensity grade was not different from either type. There was no significant interaction between sheeting type and age group.

To summarize, the results indicate that while the diamond grade sheeting appears to be related to higher levels of accuracy for the farthest conditions, it also is related to lower levels of accuracy for the nearest conditions. This pattern of results is depicted in Figure 4.1.

4.2.2 Probe Event Response

Next, the effects of age group and sheeting type on 1-second probe response time for the closest vertical (70 feet) and lateral distances (16 feet) were examined. There was a significant main effect of age, $F(2,47) = 6.3$, $MSE = 310560.4$, $p = .004$, $eta^2 = .211$, such that older adults were slower to respond to the probe than younger or middle-aged adults, who were not different from each other. There was no main effect of sheeting nor an interaction with age group. The same effects were examined at the second vertical (135 feet) and first lateral distances (16 feet). There was a significant main effect of age, $F(2,45) = 9.1$, $MSE = 150120.2$, $p < .001$, $eta^2 = .287$, again such that older adults were slower to respond to the probe than younger or middle-aged adults, who were not different from each other. There was again no main effect of sheeting nor an interaction with age group. The same pattern of results was observed at the second vertical (135 feet) and second lateral distances (33 feet), significant main effect of age, $F(2,50) = 11.5$, $MSE = 359532.0$, $p < .001$, $eta^2 = .315$.

The effects of age group and sheeting type on 1-second probe response time for the third vertical (200 feet) and first lateral distances (16 feet) were then examined. There was a significant main effect of age, $F(2,50) = 8.6$, $MSE = 203511.6$, $p = .001$, $eta^2 = .255$, except in this case, the younger adults responded to the probe more quickly than both the middle-aged and older adults, who were not different from each other. No main effect of sheeting or interaction with age group was observed. The same pattern was observed at the third vertical (200 feet) and second lateral distances (33 feet) significant main effect of age, $F(2,50) = 10.9$, $MSE = 228536.7$, $p < .001$, $eta^2 = .305$. Finally, the effect of age group and sheeting type on response times to 1-second probes was examined at the third vertical (200 feet) and third lateral distances (50 feet). As before, there was a significant main effect of age, $F(2,49) = 10.0$, $MSE = 439397.7$, $p < .001$, $eta^2 = .290$, such that older adults responded more slowly than younger and middle-aged adults, who were not different from each other. However, there was also a significant main effect of sheeting, *Greenhouse-Geisser* $F(1.3,65.5) = 6.2$, $MSE =$

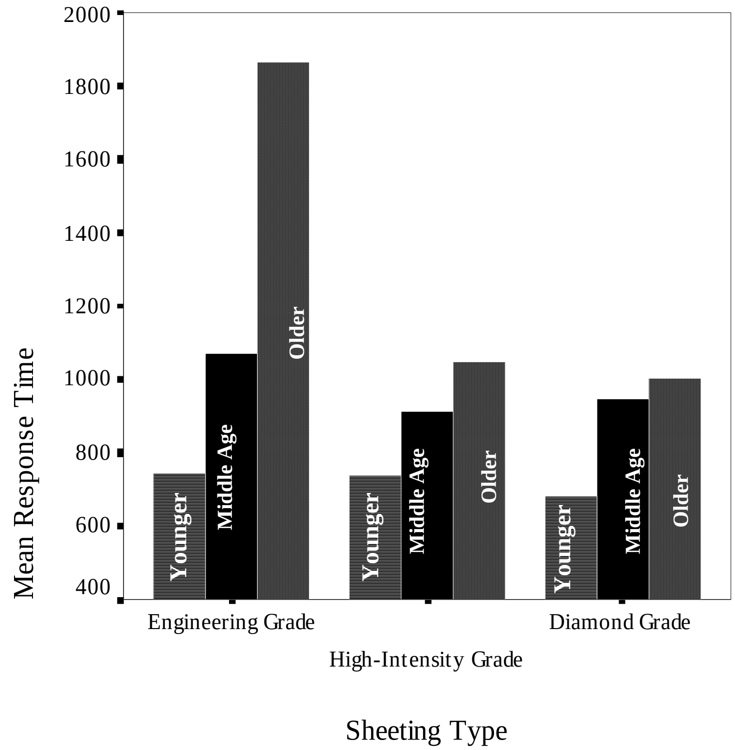

Figure 4.2: Mean Response Time to 1-Second Probes by Age Group and Sheeting Type

480864.4, p = .009, eta2 = .112, such that responses to the engineering grade were slower than responses to the high-intensity grade and diamond grade, which were not different. These main effects were qualified by a two-way interaction, however, Greenhouse-Geisser F(2.7,65.5) = 3.5, p = .026, eta2 = .124, such that the effect of sheeting appears to only be true for older adults. This interaction is depicted in , and univariate statistics for the 1-second probe response times per condition are given in Table 4.2.

Table 4.2: Mean (Standard Deviation) for 1.0-Second Probe Events Per Experimental Condition (in ms)

	Distance (Vertical-Horizontal, in ft)					
Age Group **Sheeting Type**	**70-16**	**135-16**	**135-33**	**200-16**	**200-33**	**200-50**
Younger Adults	***N=19***	***N=19***	***N=20***	***N=20***	***N=21***	***N=17***
Engineering Grade	852.9	699.7	691.5	686.1	787.0	740.9
	(585.8)	*(231.7)*	*(155.9)*	*(287.3)*	*(399.1)*	*(200.2)*
Diamond Grade (VIP)	788.7	670.7	759.9	643.8	662.6	739.6
	(452.8)	*(249.3)*	*(251.6)*	*(188.1)*	*(188.9)*	*(284.5)*
Diamond Grade (LDP)	659.8	585.7	736.3	714.7	625.3	680.1
	(204.8)	*(114.4)*	*(302.3)*	*(394.1)*	*(125.5)*	*(150.2)*
Middle-Aged Adults	***N=16***	***N=17***	***N=18***	***N=18***	***N=16***	***N=18***
Engineering Grade	863.5	731.8	929.2	912.4	897.4	1071.3
	(523.7)	*(205.0)*	*(418.2)*	*(476.8)*	*(500.2)*	*(839.6)*
Diamond Grade (VIP)	807.2	773.8	959.3	993.1	919.0	912.6
	(262.9)	*(178.1)*	*(455.8)*	*(512.8)*	*(527.7)*	*(381.9)*
Diamond Grade (LDP)	808.0	847.1	879.1	803.0	1054.3	947.4
	(302.3)	*(431.6)*	*(414.1)*	*(237.7)*	*(548.6)*	*(488.0)*
Older Adults	***N=15***	***N=12***	***N=15***	***N=15***	***N=16***	***N=17***
Engineering Grade	1000.7	1034.0	1243.1	887.2	1144.3	1865.9
	(460.7)	*(352.2)*	*(438.4)*	*(147.5)*	*(390.2)*	*(1266.1)*
Diamond Grade (VIP)	1179.1	923.8	1295.0	1228.9	1119.2	1045.8
	(653.6)	*(197.2)*	*(568.2)*	*(512.3)*	*(557.6)*	*(316.5)*
Diamond Grade (LDP)	1247.5	1052.5	1341.4	1077.7	1066.1	1004.4
	(623.0)	*(462.4)*	*(799.6)*	*(413.9)*	*(471.7)*	*(556.6)*

The effects of age group and sheeting type on response times to the 2.5-second probes were examined first for the closest vertical (70 feet) and closest lateral distances (16 feet). There was a significant main effect of age group, $F(2,48) = 9.6$, $MSE = 83769.4$, $p < .001$, $eta^2 = .287$, such that older adults responded slower to 2.5-second probes than did younger or middle-aged adults, who were not different from each other. No other effects were significant. At the second vertical (135 feet) and closest lateral distances (16 feet), there was again a main effect of age, $F(2,51) = 3.7$, $MSE = 81425.6$, $p = .032$, $eta^2 = .126$, with the same pattern just described. No other effects were significant. No effects were significant at the second vertical (135 feet) and second lateral distances (33 feet) as well as the third vertical (200 feet) and closest lateral distances (16 feet). At the third vertical (200 feet) and second lateral distances (33 feet), there was again a significant main effect of age, $F(2,52) = 5.8$, $MSE = 64721.1$, $p = .006$, $eta^2 = .181$, such that older adults responded more slowly to the probe than younger or middle-aged adults, who did not differ. There was also a significant main effect of sheeting type, $F(2,104) = 3.4$, $MSE = 18548.2$, $p = .036$, $eta^2 = .062$, such that responses were significantly faster to the diamond grade sheeting than the high-intensity sheeting. The engineering grade did not differ significantly from either type. No significant interaction was observed. Finally, at the farthest vertical (200 feet) and lateral distances (50 feet), there was only a significant effect of age group, $F(2,39) = 4.4$, $MSE = 128929.0$, $p = .019$, $eta^2 = .185$, such that older adults responded more slowly to the probe than younger or middle-aged adults, who did not differ. Univariate statistics for the response times to 2.5-second probes per condition are given in Table

Table 4.3: Mean (Standard Deviation) for 2.5-Second Probe Events Per Experimental Condition (in ms)

		Distance (Vertical-Horizontal, in ft)					
Age Group	**Sheeting Type**	**70-16**	**135-16**	**135-33**	**200-16**	**200-33**	**200-50**
Younger Adults		***N=18***	***N=19***	***N=20***	***N=20***	***N=21***	***N=16***
	Engineering Grade	655.6	622.5	591.6	645.9	659.5	657.7
		(184.5)	*(131.5)*	*(114.9)*	*(185.5)*	*(226.8)*	*(135.0)*
	Diamond Grade (VIP)	651.7	668.6	621.1	675.4	631.8	678.8
		(155.0)	*(192.4)*	*(149.4)*	*(228.9)*	*(207.3)*	*(166.1)*
	Diamond Grade (LDP)	610.3	629.2	677.9	663.2	621.3	642.4
		(117.5)	*(181.5)*	*(283.5)*	*(184.5)*	*(136.3)*	*(188.9)*
Middle-Aged Adults		***N=17***	***N=18***	***N=18***	***N=18***	***N=17***	***N=15***
	Engineering Grade	604.8	654.3	624.3	621.3	628.0	665.4
		(94.4)	*(208.3)*	*(135.3)*	*(110.0)*	*(127.5)*	*(130.5)*
	Diamond Grade (VIP)	623.7	607.2	640.2	728.5	664.1	678.8
		(131.3)	*(85.2)*	*(119.8)*	*(426.2)*	*(141.2)*	*(166.1)*
	Diamond Grade (LDP)	630.6	644.8	753.1	638.3	610.3	609.7
		(122.7)	*(134.3)*	*(409.9)*	*(167.6)*	*(148.1)*	*(88.8)*
Older Adults		***N=16***	***N=17***	***N=16***	***N=15***	***N=17***	***N=11***
	Engineering Grade	474.1	735.2	838.1	730.3	785.5	868.0
		(205.7)	*(222.8)*	*(411.5)*	*(151.1)*	*(230.8)*	*(398.2)*
	Diamond Grade (VIP)	995.2	791.1	691.2	718.1	848.2	988.5
		(570.2)	*(358.5)*	*(158.2)*	*(186.6)*	*(229.5)*	*(548.9)*
	Diamond Grade (LDP)	809.0	761.5	748.5	721.8	710.5	796.7
		(273.0)	*(211.4)*	*(234.1)*	*(140.3)*	*(160.0)*	*(250.2)*

For all conditions but two, older drivers exhibited longer response times to the 2.5-second probe events. In only one condition (the farthest distance and closest lateral placement) was there a significant effect of sign sheeting type.

4.2.3 Summary

There were three types of measurements taken (accuracy, RT to 1.0s probe, RT to 2.5s probe) at each of six locations. The effects of age and sheeting type were examined for each of the 18 conditions (3 measurements x 6 locations). In one case, the older and middle aged groups both underperformed the younger group. Of the remaining 17 cases, the older group underperformed the other two groups except in the following cases, where there was no significant effect of age.

1. 70x16, accuracy
2. 135x16, accuracy
3. 135x33, 2.5s probe
4. 200x16, accuracy
5. 200x16, 2.5s probe

There were four cases where a significant effect of sheeting type was observed. These locations and effects are described in Table .

Table 4.4: Significant Effects of Sheeting Type

Vertical Distance	Lateral Distance	Measurement Type	Description
70 ft	16 ft	Accuracy	Diamond Grade (LDP) was associated with lower scores than the other sheeting types
200 ft	50 ft	Accuracy	Diamond Grade (LDP) was associated with higher scores than the other sheeting types
200 ft	33 ft	2.5s probe	Diamond Grade (LDP) sheeting was associated with faster RTs than the other sheeting types
200 ft	50 ft	1.0s probe	Engineering Grade sheeting was associated with slower RTs than the other sheeting types for the older participant group. No difference was observed for the other age groups.

All of the significant differences identified in the experiment are noted in Figure 4.3 on a sketch of the staging area.

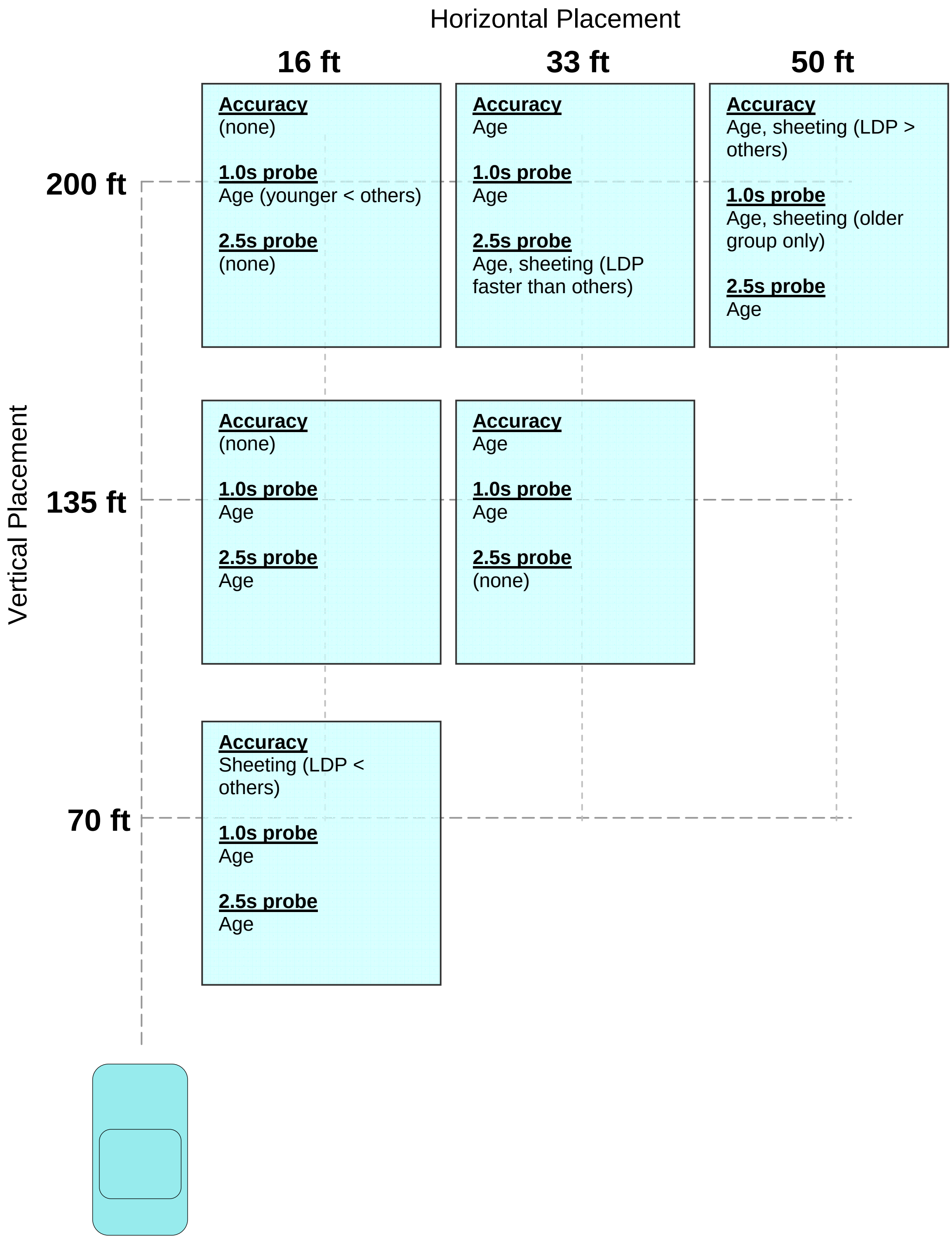

Figure 4.3: Summary of Significant Differences Identified in Experiment 2

4.3 Luminance

To help interpret the results of the tests, luminance measurements were taken of the signs under each of the test conditions. The results suggest that the significant differences found in the accuracy analysis are not attributable to glare. If glare were occurring, the effect would be greatest where the luminance is greatest, and greater luminance would correspond to lower accuracies. In fact, however, the greater accuracies corresponded to greater luminance, suggesting that inaccuracies were due to poor illumination, rather than excessive illumination (i.e., glare). Figure 4.4**Error! Reference source not found.** shows a plot of the luminance values at the first horizontal distance for the three sheeting types and the three vertical distances. The measurements were taken from the driver's perspective (i.e., from inside the test vehicle) with the low beam headlights on.

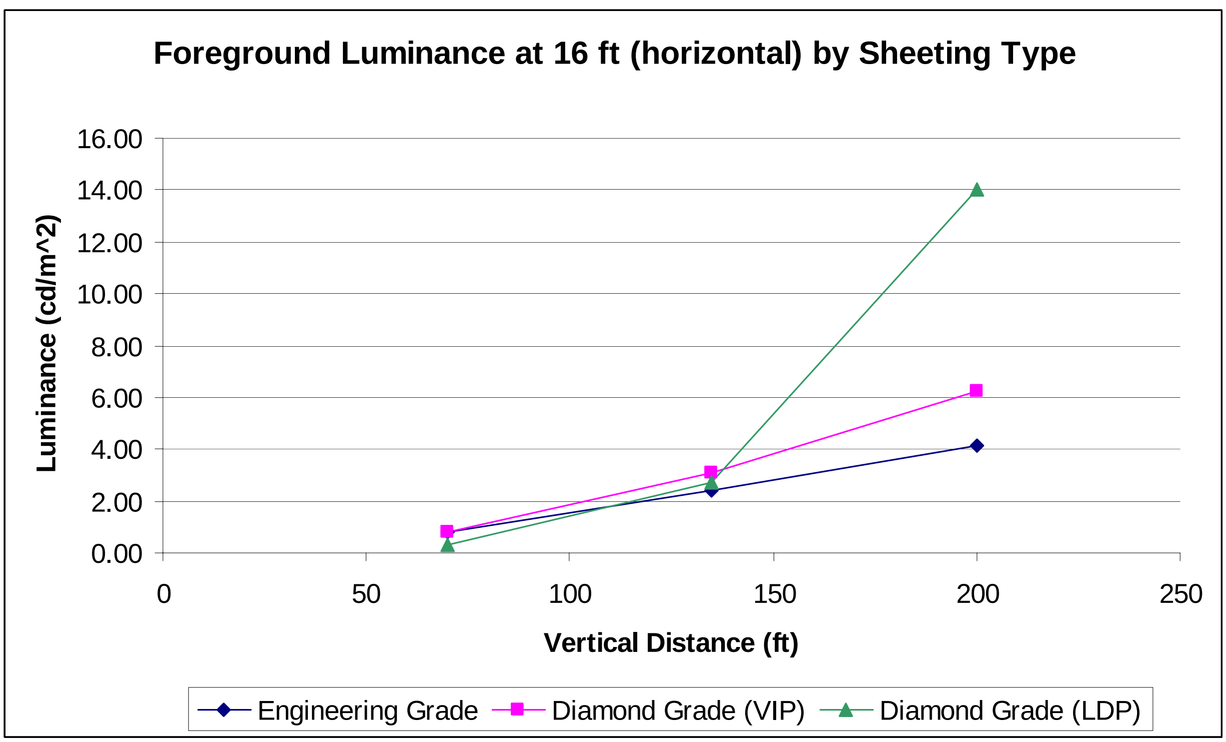

Figure 4.4: Foreground Luminance at 16 ft by Sheeting Type

CHAPTER FIVE - CONCLUSIONS AND RECOMMENDATIONS

5.1 Methodology

There are four considerations for the measurement of glare in highway signs in older adults that are addressed by the controlled field test methodology and which should be considered in similar studies.

5.1.1 The Test Bed

1) The test itself should reflect the attentional demands of driving, without increasing those demands to the point that observers are in danger. Actual on-road studies have the potential to be dangerous if glare blindness occurs. An in-car study with secondary tasks is one way to duplicate real-world attentional demands.
2) Real signs viewed at real distances and which are illuminated by vehicular light sources should be used where possible. Scaling may not properly model actual on-road conditions.

5.1.2 Participants

1) Obtaining a sample size to detect small effects is rarely realistic. However, it is possible to increase power by enhancing data stability with multiple observations per condition per observer.
2) Many age-related changes are nonlinear with respect to time. Thus, the inclusion of a middle-aged group allows researchers to model nonlinear trends in the data.

5.1.3 Measurements

1) The task should measure how glare influences sign legibility. The data collected should be bias-free and preferably include a measure of bias when older adults are tested. At the very least, forced-choice procedures should be used to avoid problems associated with differences in criteria between the participants.
2) The task should include a measure of how glare influences the ability of the driver to detect crucial on-road events. Sign legibility is probably a secondary consideration if prolonged glare blindness prevents drivers from noting changes in their environment such as the braking of leading cars. Response to braking events is a good task because of its obvious importance and because the task generates RT data, which may be more sensitive to changes in glare than sign readability data.
3) Perceptual and attentional measures should be included in pretesting when assessing the performance of older adults. Chronological age itself is often a poor predictor when age-related changes to these factors are accounted for.

5.1.4 Data Analysis

1) Legibility data should be collected in such a way that they can be analyzed using techniques that allow for consideration of covarying factors, such as age, vision, and attention. These techniques include analysis of covariance and multiple regression approaches. Researchers should avoid making age-specific recommendations when other factors that covary with age may account for most of the variability in the age data.

2) The use of RT data is suited for measuring secondary task performance. However, with older observers, these data may need to be scaled using appropriate statistical procedures to account for generalized slowing with age.

5.1.5 Veiling Glare

The data collected do not show evidence of veiling glare or glare blindness. Higher accuracies were related to higher levels of luminance, which is the opposite of what would be expected were glare a significant factor. Longer response times were observed among older drivers in some cases, but these too were related to lower levels of luminance, not higher. Researchers observed that at the farthest distances, older drivers frequently took longer to read the sign than did their younger counterparts, although this quantity was not measured during the experiment. The patterns found among the response times are inconsistent with the hypothesis that glare blindness results from signs.

One characteristic of the experiment that should be noted is that it emulated conditions on a flat and level highway segment. Glare may occur on crest vertical curves because the curvature of the road can result in a vehicles headlights being oriented directly at a sign, rather than the usual orientation (focused slightly downward). However, it is not feasible to test all possible orientations and curvatures, nor is it feasible to refrain from placing signs on crest vertical curves. Moreover, in such cases, it is likely that all sheeting types would present a similar problem. Consequently, only the most common circumstance was considered in this study in order to isolate any effect of sheeting type that might exist.

The results of this study show no evidence that glare is a significant component of sign legibility, nor that glare blindness results from headlights reflecting off highway signs. Based on these results, no changes are recommended to KDOT policies and practices with respect to signing.

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APPENDIX A: CONSENT FORM

Consent Form—Detecting traffic information—Subject Copy

This study is designed to investigate how we detect information while driving. The experiment consists of two phases. In the first phase, you will be asked to view signs in a simulated driving environment and make a judgement about the sign. The second phase requires you to view a series of displays on the computer screen and to respond on the keyboard. During the second phase you will also be given some simple eye-tests. **All information collected is confidential. No information will be released which will affect your driving privileges.**

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary, and I am free to decline to participate or withdraw at any time. If I chose to decline, I will not be penalized in any way. Further, I understand that all information obtained in this study is confidential. With my signature I acknowledge that I am 18 years of age or older and that I have received a copy of this consent form to keep.

____________________________________ ________________

Signature of the Participant Date

General information:

Dr. Eric Meyer: 785 864 3963

Dr. Paul Atchley 785 864 9803

Questions regarding scheduling:

Lesa Hoffman 785 832 2207

APPENDIX B: PARTICIPANT INSTRUCTIONS

Participant Instructions

1. Have participant fill out informed consent form. Give he or she a copy to keep.

2. While in the orientation room, explain to the participant what he or she will be doing.

As you already know, this is a study about highway signs. This is a joint project between the Civil Engineering and Psychology Departments at KU, and is sponsored by the State of Kansas Department of Transportation. On behalf of all these people, we thank you for coming.

Today you will be performing a simulated driving task. While you will be seated in an actual car, you will not actually be driving. You will have 2 tasks to perform. The first task concerns a pair of taillights that will be in front of you. These lights will brighten frequently, so as to simulate brake lights. Your task is to press the brake pedal whenever these lights come on. They will come on at random intervals so it is important that you keep your eyes on the taillights to respond as quickly as possible. When you hit the brakes, these lights will go off and you will only see the taillights. If you do not hit the breaks, the lights will go off by themselves after a short interval.

(Check to make sure he or she understands up to this point.)

While you are performing the task of pressing the brakes when the brake lights ahead of you come on, you will be asked to do another task. Periodically, the headlights of the car you are in will come on and illuminate a sign either directly in front of you or off to your right. The distance of the sign from you will vary. The sign will always say "CONCORD." However, half of the time, the middle C in "CONCORD" will be backwards. Whenever the headlights come on and you see the sign, tell the experimenter in the back seat whether the middle C was facing forwards or backwards. He will then record your answer on the computer. You will not need to see the experimenter, just say your response aloud.

(Check again to see that he or she understands this task.)

APPENDIX C: SETUP PROCEDURES

Separate itemized setup procedures were developed for the test vehicle, the computer and connected systems wiring, the sign location, and light elimination. Numbers in parentheses refer to an equipment list not included in this document.

Test Vehicle Setup

1. Level car using wooden blocks under the front tires. (Check level using laser and/or bubble level)
2. Place Black Covers 1 & 2 (34-35) on the side mirrors.
3. Place Black Cover (36) on rearview mirror.
4. Put Power Strip (28) in back seat of car.
5. Place Carbon Monoxide Meter (29) in back seat of car.
    a. plug into power strip
6. Place Lab Table (27) on top of pillow in the back seat of the car.
7. Plug Computer (37) and Carbon Monoxide Meter (29) into Power Strip (28).
8. Plug Power Strip (28) into Extension Cord #2 (26).
9. Plug Extension Cord (26) into electrical outlet located to left of the test vehicle.
10. Cover tail lights with plastic (use masking tape, NOT duct tape)
11. Cover “Cyclops” brake light with plastic (use masking tape, NOT duct tape)

Computer and Connected Systems Wiring Setup

1. Put Parallel Port Cord (02) into computer's parallel port.
2. Indicator Light #1 (06) and Indicator Light #2 (07) to Indicator Lights Main Cord (01). (Connect Positives to the non-labeled ends on the Indicator Lights. These produce a lower intensity illumination.)
3. Indicator Lights Main Cord (01) to Parallel Port Cord (02).
4. Brake Light Relay (03) to break light wires connected to the white tube in the testing car.
5. Brake Light Relay (03) to Parallel Port Cord (02). Place plastic cover on relay.
6. Headlight Relay (04) to headlight wires connected to the white tube in the testing car.
7. Headlight Relay (04) to Parallel Port Cord (02). Put plastic cover on relay.
8. Parallel Port Cord (02) to the Connection Wire to Brake and Target Light (09).
9. Taillight Relay (05) to the Connection Wire to the Brake and Target Light (09).
10. Taillight Relay (05) to the Connection Wire to the Target Light (08).
11. Target light wires to the brake light fixtures (10).
12. Power source wires to the (+) and (-) outlets of the Power Supply Box (11).
13. Extension Cord #1 (15) to Power Supply (11).
14. Extension Cord #1 (15) to electrical outlet located on the pillar to the left of the test vehicle.

Sign Location Setup

1. Place Small Red Tap Light (32) on trunk using the trunk keyhole to align.
2. Place Small White Tap Light (33) on the front roof of the car, using car's logo and the rear tap light to align.
3. Place large, easy to see object at location of driver.
4. Shoot distances with ProLaser (41).
    a. Measure out first distance (70ft) moving in a straight line from front of car.
    b. Place Flag (40) approximately 1' from this location (toward the test vehicle) so that sign will rest on the location itself when lined up behind the flag.
    c. Move to 90 degree angle (counterclockwise) from straight line to car.
    d. Shoot first lateral distance & shoot distance to car from this point.
    e. Check this distance with computed hypotenuse and make necessary changes.
    f. Place Flag (40) approximately 1' from this location (toward the test vehicle) so that sign will rest on the location itself when lined up behind the flag.
    g. Shoot second lateral distance & then shoot the distance to the car.
    h. Check distance with calculated hypotenuse and make necessary changes.
    i. Place Flag (40) approximately 1' from this location (toward the test vehicle) so that sign will rest on the location itself when lined up behind the flag.
    j. Repeat same procedures for 2^{nd} distance (135ft) and 3^{rd} distance (200ft).

Light Elimination Setup

1. Turn off all lights in offices and bathrooms.
2. Use black plastic sheeting (42-47) to cover areas where light enters building.
    a. For garage doors, place plastic sheets (48) in cracks at bottom and at the top of doors. (Use the Ladder (40) for the tops.)
    b. For fans, use duct tape (41) to cover entire area with plastic (47&49).
    c. For front doors, cover the windows with the plastic (45&46) and tape (41)
    d. For pop machine, cover the entire front side of the machine with the plastic (44) and tape (41).

K - TRAN

**KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM**

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY