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REFLECTIVE LICENSE PLATE MATERIAL

Final Report

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16. Abstract The literature on nighttime conspicuity (visibility) and legibility of non-reflectorized and reflectorized license plates and their accident reduction potential, safety and other benefits was reviewed. A nighttime field study using 20 young subjects using an experimental car and an opposing glare car (both H6054 lowbeams) was conducted to assess the nighttime conspicuity performance (550 ft, 2 license plate display locations, 2 seconds exposure time) and the nighttime legibility performance (81.2 ft legibility distance, 2 seconds exposure time) of new and used reflective sheeting license plates (Texas plates, 3 Numbers and 3 letters) and of new and used beads on paint license plates (Arizona plates, white characters, 3 Numbers and 3 Letters). The results of this nighttime field study indicate that under fairly close to real world conditions, the reflective sheeting license plates provide better and statistically significant conspicuity and legibility performance than the beads on paint license plates. A cost analysis considering all costs (including the metal plate, packaging, distribution, etc.) indicates that for a life cycle time of 5 years, the yearly costs of the reflective sheeting license plates is about $1.10 while that of the beads on paint license plates is about $1.08. However, calculations indicate that if the reflective sheeting plates are used one year longer than the beads on paint plates (very small conspicuity and legibility performance decrease between Texas new and Texas used would appear to make this life extension feasible) then the reflective sheeting plates would actually have a slight cost advantage over the beads on paint plates for any life cycle time period.

17. Key Words	18. Distribution Statement
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Foreword

This is the first of several small studies dealing with the evaluation of Arizona's Current License Plate. Therefore the conclusions of this report should not be considered as the controlling factor in decisions concerning the manufacture distribution or format of license plates likely to be available to Arizona motorists in future years.

Several aspects of the license plate evaluation need further study and shall be the topic for further research within the Arizona Department of Transportation. These can basically be classified under the following broad headings:

1. License plate format (letter and number size, combinations and spacing and types of special plates).

2. A thorough economic analysis of format options, material options and manufacturing options.

3. An analysis of Legislative Conformity and/or Statutory Amendments necessary for the various options.

4. The preparation of specifications and preparation of bid documents.

This entire sequence leading to some final decision on a future license plate for Arizona is expected to be complete in eighteen months.

Table of Contents

List of Figures

List of Tables

REVIEW OF LITERATURE

Reflectorized licence plates have been in use for many years as a means of aiding the driver in the initial detection, recognition, and identification of stationary or moving vehicles on or off the roadway especially at night. Fricker [1] specified many functions of the license plates and he considered the plates as static visual displays. Some of the functions as stated by Fricker are that the license plate is an indication that the vehicle was properly registered at the time the plate was issued; it is the most specific means of identifying vehicles involved in accidents for law enforcement agencies and witnesses; and the reflectorized plate is an important item for nighttime traffic safety officials. Larimer [2] pointed out that in the common motoring situations in which reflective license plates have been shown to operate effectively are the delineation of parked cars prevalent in residential areas; warning of damaged, stalled, or parked and unlighted cars and trucks on the road as well as on the shoulders of rural roads; supplementary warning for motorists approaching from the rear at higher relative speed; effective protection in case of taillight failure unknown to the motorist; and positive delineation of approaching "one - eyed" vehicles by indicating the relative position of the vehicle on the road. A number of studies have been conducted to establish the visibility and legibility distances of reflectorized and non reflectorized license plates made of different materials. Larimer [2] studied the visibility of reflectorized license plates at night under conditions of rain, mist, snow and glare. He concluded that vehicles equipped with reflectorized license plates are visible up to a distance of 1000 ft and that an increase in the reflective brilliance of the plates increases the visibility distance. In the case of opposing headlights (glare), he concluded that plates capable of reflecting 5 cp per incident foot-candle, on the average provide the minimum brilliance for a requisite warning at 50 mph. The new reflective plates typically reflect 20 cp per incident foot-candle and the new beads on paint plates typically reflect 2 cp per incident foot-candle.

Improvements in plate visibility due to reflectorization were shown by many other studies. Wortman [3] evaluated the reflectorized annual license plate materials using legibility and visibility distances as the criteria among others. He concluded that there are no significant differences between the legibility distances of plates made of different materials and stated that it is doubtful that an improvement in the reflective materials would increase the legibility distances. In the case of visibility he concluded that plates with light colored backgrounds yielded the best visibility distances all of which provide adequate stopping distance and that reflectorization of the legend only, does not provide for safe stopping distances at speeds associated with modern highways. However, in general Wortman's data show that plates with reflective sheeting can be detected at greater distances than plates with beaded legends. In another study Israelsen et al. [4] evaluated the legibility of reflectorized license plates in a rainfall simulator under dry and varying degrees of rainfall conditions. They compared legibility distances of plates (new and used) made of beads on paint material, reflective sheeting and new paint and concluded that reflective sheeting plates were read farther than the corresponding beads on paint plates under all conditions with the margin increasing under rainfall conditions. They also concluded that the legibility of used beads on paint plates fell substantially below that of painted plates under wet conditions whereas reflective sheeting plates maintained a significant advantage under all the conditions tested. Stoke et al. [5] compared the legibility and visibility of enamel and reflectorized license plates and concluded that the reflectorized license plate makes a vehicle more readily seen and recognized than an automobile with conventional enamel license plates. Olson et al. [6] conducted a field study on the nighttime legibility of license plates to investigate the effect of factors such as background reflectivity, legend contrast, approach direction and vehicle lights. They concluded that fully reflectorized license plates provide superior legibility compared with only legend reflectorized plates (these results are in agreement with the findings of Israelsen et al.[4]). Furthermore, for the range of the materials tested they concluded that the higher the luminance of the plate, the better the legibility provided. In summary, they suggested that fully reflectorized plates provide improved legibility under both new and worn conditions.

One of the most comprehensive studies on license plates was conducted by Baerwald et al. [7] in which they evaluated the legibility of reflectorized license plates made of 5 different materials under various conditions of reflectorization, color combinations and width and spacing of numerals. The conclusions provided by the authors were that there appears to be no appreciable difference in legibility of the various types of materials used to reflectorize the plates and that on the average reflectorized plates increased the legibility by 28% when compared with non reflectorized plates. They also concluded that based on a visibility point of view reflectorized license plates may have contributed to a slight reduction in the total number of nighttime accidents. Post et al. [8] in a study of reflectorized materials for license plates concluded that (i) a background of reflectorized sheeting can provide about an 11-fold increase in reflectivity when compared with light beaded legends on a dark background and (ii) plates with light beaded legends and dark paint backgrounds provide about a 14-fold increase in reflectivity compared to plates using dark painted legends and light backgrounds. Zwahlen [9], based upon the results of a field study, indicated that in roadway situations such as in horizontal curves where reflective targets could become visible for the first time in the periphery of a driver's visual field, appropriate increases in the reflectivity of a target must be made in order to assure timely detection.

The general conclusion, then, is that reflectorization of any kind improves plate legibility and visibility. However, the other question is whether reflectorization of license plates helps in the reduction of nighttime accidents. Several studies have addressed the relationship between reflectorized plates and nighttime traffic crashes. Vanstrum et al. [10] studied the effect of reflectorized license plates from an accident reduction point of view in the State of Tennessee and upon careful analysis concluded that there was a significant accident reduction which can be attributed to the introduction of reflective sheeting license plates. Campbell et al. [11] conducted a study to assess the effect of reflectorized license plates on rear end collisions at night. For this purpose, they made a comparison of reflectorized and non reflectorized vehicles during a six week transition period (transition from enamel to reflectorized plates) in 1966 and concluded that reflectorized plates are effective in reducing night rear end collisions. In contrast with all the studies which considered accident reduction, Stoke [12] concluded that there was no statistically significant difference between the number of night rear - end collisions and crashes of vehicles equipped with reflectorized license plates (473 accidents) and those with control non-reflective license plates (497 accidents). Stoke's study, however, was critically discussed by Sacks (see 12), Vanstrum (see 12), Kleinknecht et al. [13] and Hulbert et al. [14] and many questions were raised regarding the experimental design and the interpretation of results by Stoke. Henderson et al.[15] reviewed, summarized and integrated the available body of data concerning vehicle conspicuity including engineering analyses and other analytical studies, as well as experimental data from laboratory, simulation and field studies. In all the authors reviewed five studies and quoted that "all the five studies are subject to methodological problems and present interpretation difficulties". They also quoted that "a statistically significant but not an overwhelming safety benefit can be associated with the reflectorized plates".

Some of the above mentioned legibility studies agree with each other in the aspect that there is no significant improvement in the legibility distance of dry, clean license plates due to the use of different reflective materials such as beads on paint, reflective sheeting etc.. However, as stated earlier, Israelsen et al.'s study showed a significant improvement in the legibility distances for the plates made of reflective sheeting materials under all the conditions (dry and varying degrees of rainfall) when compared to the beads on paint plates or new paint plates. Zwahlen [16] pointed out that most of the visibility studies indicate a reduction in the accident rate because of reflectorization (one study by Stoke [12] indicated that the reduction observed was not significant) and argued that, if the reflectivity of the license plates used in those studies had been higher, the results would have been more positive. Zwahlen [16] concluded that reflective license plates with higher specific intensity levels consistently increase the conspicuity of a car parked along a highway at night in a statistically and practically significant manner.

The above mentioned studies on legibility and visibility represent quite diverse approaches to the same problem and provide legibility distances which appear to be higher than one could expect under realistic driving conditions. This could be due to factors such as the lack of a windshield and therefore the lack of the effect of windshield transmittance (which has a slight distance reducing influence) in studies where no experimental cars were not used, the use of numerals only (no letters) license plates, the probable use of larger height, width, spacings and other legibility enhancing characteristics of the characters, the probable use of meaningful combinations of numbers (i.e. 234 789 etc), the use of highly trained and fairly efficient subjects such as highway patrol personnel and policemen, the differences in visual capabilities of the subjects used, the differences in background/legend color combinations, the differences in the position of the observer, larger (unlimited) exposure times, more scope for learning and so on. Moreover, the studies involve both field and laboratory measurements, and range in complexity from elaborately controlled studies to fairly superficial efforts. None of these studies by itself can be considered to be complete and definitive and each one can be faulted in one way or another as to its methodology. Despite this, taken collectively, these studies provide a convincing and consistent picture of the clear superiority of reflectorized plates over conventional painted only plates from the standpoint of both legibility and visibility. Therefore, any study dealing with the comparison of conventional painted only plates to reflectorized plates would be most likely a waste of time and effort. However, a carefully controlled and realistic (close to real world conditions) nighttime license plate study investigating visibility and legibility performance would be beneficial to establish any superiority that might exist among the reflective materials (beads on paint vs retroreflective sheeting) currently being used in the U.S. Therefore, it is the objective of this study to determine the nighttime legibility and conspicuity performance (under opposing glare) of embossed new and used license plates made of retroreflective sheeting and reflective beads on paint (white characters reflectorized only).

METHOD

Subjects

A total of 20 young and healthy undergraduate students (10 males and 10 females, avg. age 20.5 years) participated in the tests. All the subjects had a valid driver license with an average driving experience of 3.5 years. None of the subjects had any past accident history although a few of them had moving traffic violations. All the subjects were given a standard vision test using a Baush and Lomb vision tester and their visual acuities ranged form 20/17 to 20/25 (corrected vision if applicable). A contrast sensitivity test using the Vistech contrast sensitivity charts provided normal results for all the subjects used in the study.

Experimental Site and Apparatus

The experiments were conducted in an old unused airport runway (75 feet wide and 1500 feet long) which is located at the outskirts of the city of Athens, Ohio. A two-lane state highway with moderate traffic is located parallel (about 200 feet away) to the runway. A number of luminares, a few illuminated advertising signs and other light sources were within the field of view. A 1981 Volkswagen Rabbit with properly aimed H6054 beams was used as the experimental car for both the nighttime legibility and the conspicuity experiments and a 1983 Nissan Stanza with properly aimed H6054 beams was used as the opposing glare car for the nighttime conspicuity experiment. Figures 1 and 2 show the experimental site and setup for the legibility experiment and for the conspicuity experiment respectively.

A set of three portable stands (to rotate the plates into an exposure position and to rotate back into a not visible position) were designed and fabricated to mount the license plates. Each stand consists of an adjustable base, a 4 ft long vertical iron tube (diameter = 1.25 in.) which can be screwed to the base and a sliding collar which can be slid on to the vertical tube and tightened at any height by means of a wing screw. A DC motor is fixed to one side of the sliding collar and the shaft of the motor is extended to fit an aluminium plate holding bracket on the other side which is again adjustable to hold new plates or plates that are slightly worn or bent. Figure 3 shows the typical set up for one stand. An electronic circuit was built to control the motors via a computer. A computer program was written in C language for a Zenith laptop 8088 PC (10 MHz clock speed) to turn the motors ON or OFF and to rotate them in the desired direction. An adjustable mechanical stop was also provided to stop the license plate fixed in the holder (which is turned by the motor) at any desired angle to the horizontal plane so as to expose it to the subject sitting in the experimental car. The computer and the control circuit were powered by a portable generator. Twelve license plates of each type, Texas new, Texas used, Arizona new and Arizona used were tested in the experiments which accounted for a total of 48 plates. Four 5 watt walkie - talkies were used as communication devices between the experimenters sitting in the car with the subject and experimenters operating the computer and changing the plates.

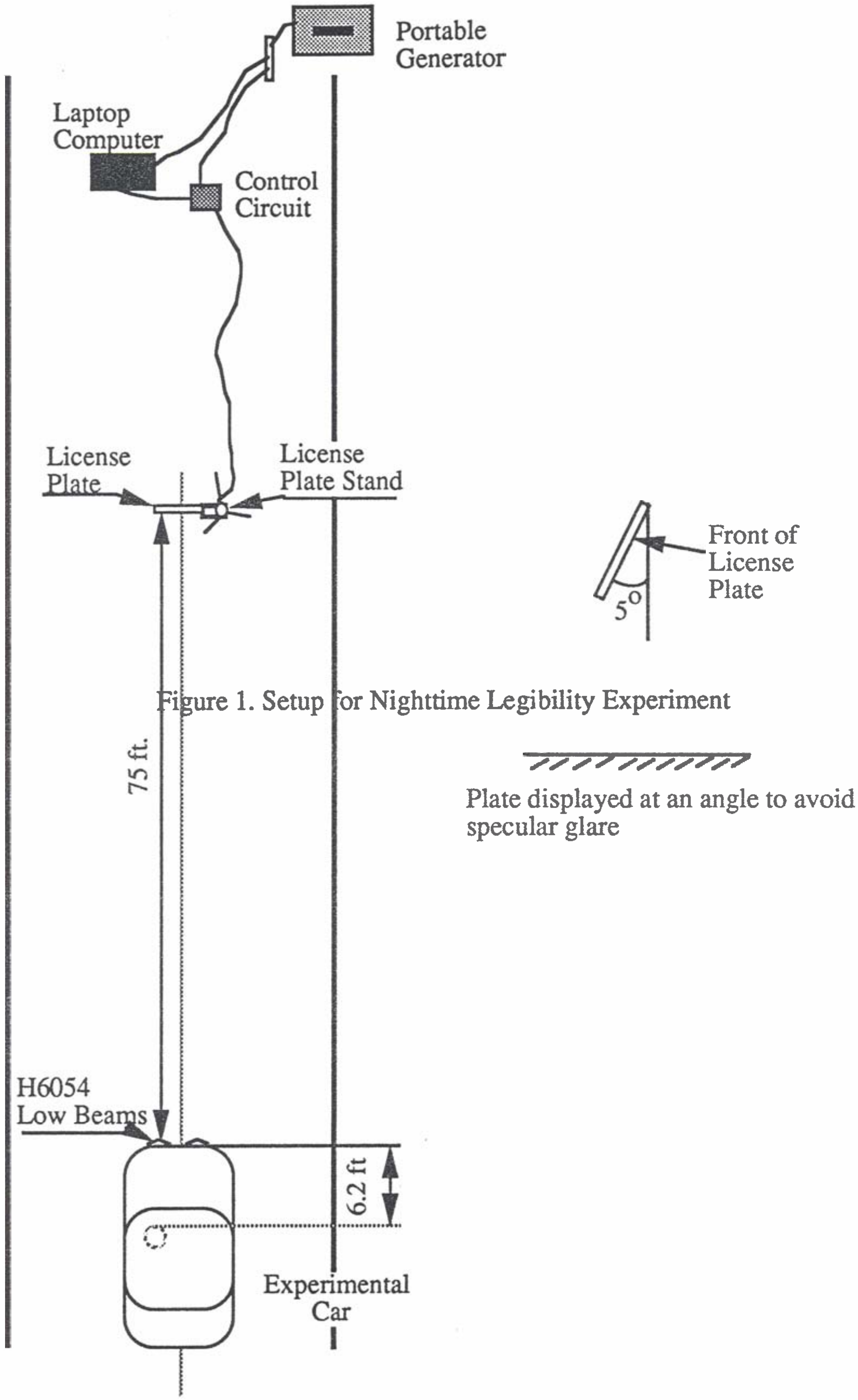

Figure 1. Setup for Nighttime Legibility Experiment

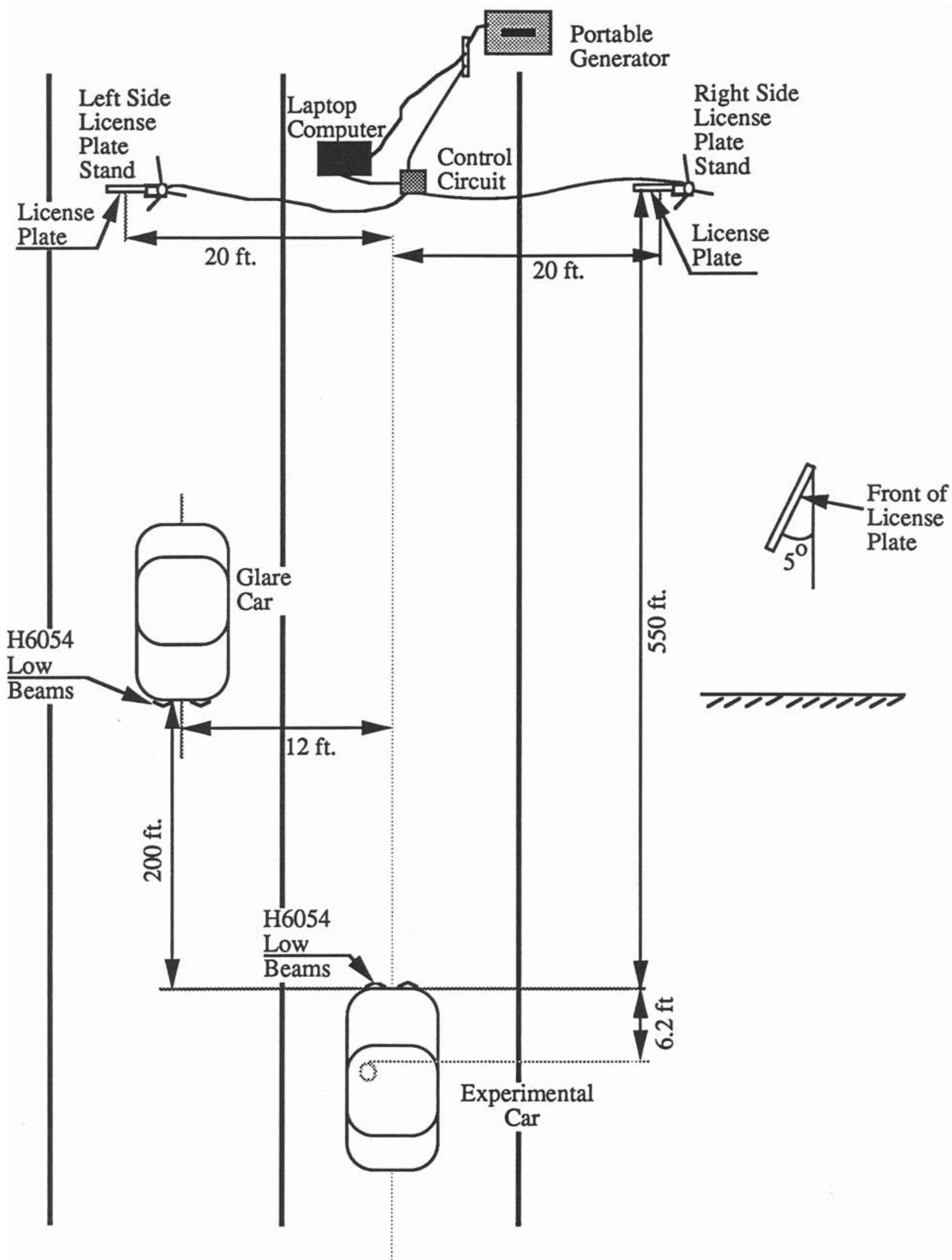

Figure 2. Setup for Nighttime Conspicuity Experiment

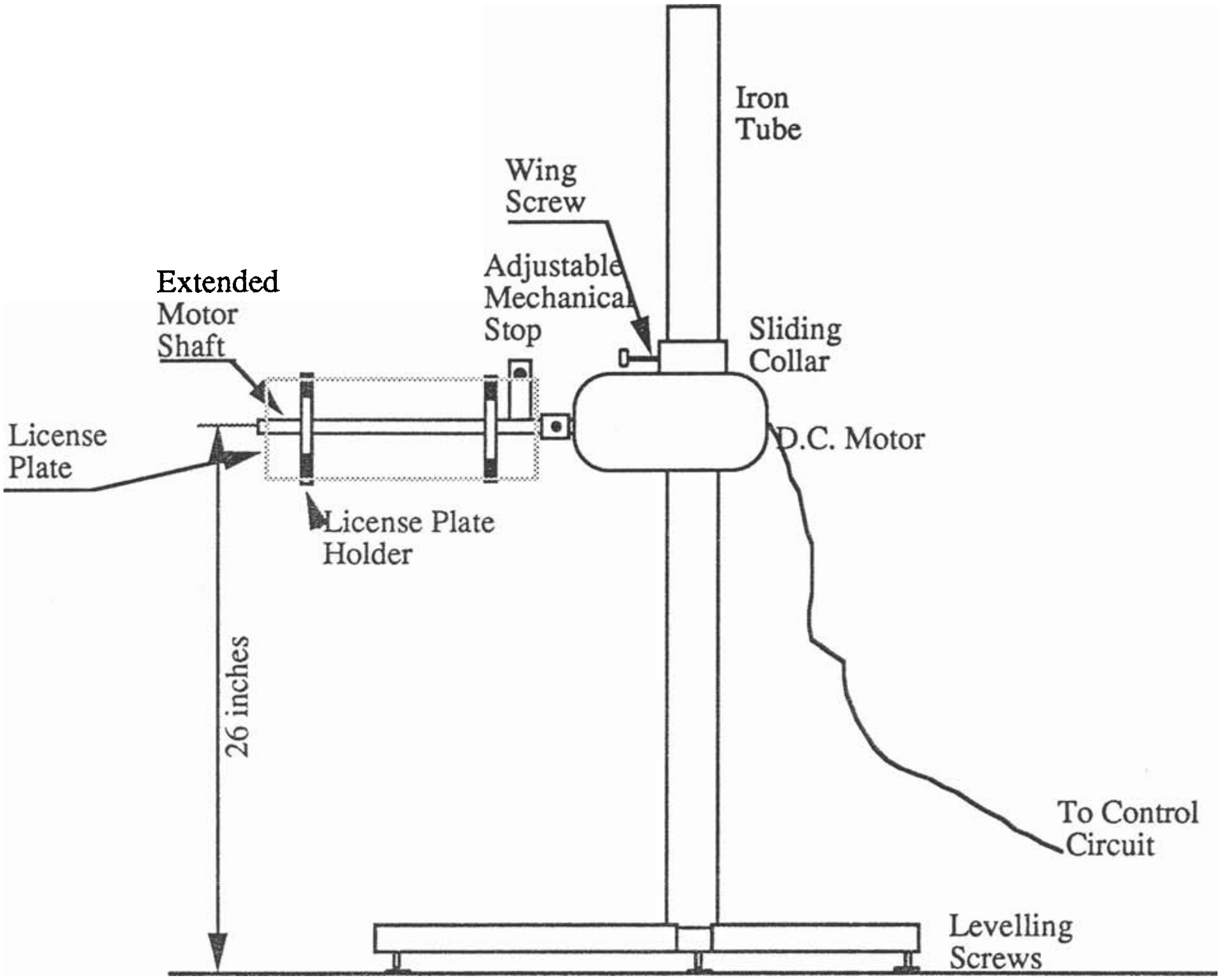

Figure 3. License Plate Stand

Specimen Plates

Both the nighttime legibility and the conspicuity experiments used the same clean and dry 12 specimens each of 4 the types of license plates: Texas New (TN), Texas Old (TO), Arizona New (AN) and Arizona Old (AO). All specimen plates used in the study were provided by the Arizona Department of Transportation (ADOT) and had 3 numbers and 3 letters, the group of 3 letters appearing first in all the cases except for the TO plates which had the group of 3 numbers appearing first. The Texas plates were made of reflective sheeting (blue characters on a white background) and the Arizona plates (white characters on a dark red painted background) were made of beads on paint. The data obtained from the experiments conducted by Neu [17] and Kuntz [18] were used in a random computer generation of registration numbers with an average level of difficulty for the letters and the numbers. Some letters as well as numbers have not been considered in the random generation since they are either very easy or too hard to read. From the randomly generated registration numbers, all the meaningful combinations (eg: NAM 567) have been eliminated and the new plates were manufactured from the remaining combinations. The used Texas and Arizona plates have been selected from a set of 40 and 34 used plates respectively. These used plates had issue dates from 1981 to 1989 (dates provided by ADOT), but only plates issued from 1985 to 1989 were used (60 month life time requirement by ADOT) such that they confirmed as best as possible to the selection criteria mentioned above for the new plates. Figures 4, 5, 6 and 7 show the specimen license plates with the letters and numbers used on the TN, TO, AN and AO license plates respectively. One plate of each type was selected at random from the group of 12 each and photometric measurements were made with the CapCalc computer controlled photometric measurement system for both the nighttime legibility and the conspicuity experimental arrangements. Table 1 lists the character luminance, the background luminance and the average luminance of the license plates.

Experimental Design

A randomized block experimental design was used for both the nighttime legibility and conspicuity experiments. The dependent variable in the nighttime conspicuity experiment was the detection or the missing of the displayed license plate (randomly presented either on the left side or on the right side). The dependent variables in the nighttime legibility experiment were the correct reading of each number (3 in a group) and each letter (3 in a group) on the license plate. For the nighttime legibility experiments, the main independent variables were the plate material (2 levels; beads on paint and reflective sheeting) and the age or condition of the plate (2 levels; new and old). For each subject the

Figure 4. Specimen Texas New Plates Used in the Conspicuity and Legibility Experiments.

Figure 5. Specimen Texas Old Plates Used in the Conspicuity and Legibility Experiments.

Figure 6. Specimen Arizona New Plates Used in the Conspicuity and Legibility Experiments.

Figure 7. Specimen Arizona Old Plates Used in the Conspicuity and Legibility Experiments.

Table 1. Approximate Luminance Values for the Specimen License Plates Used in the Nighttime Experiments

Plate Type	Experiment	Luminance (cd/sq. m)		
		Character	Background	Average
TN	Legibility	120	300	210
TO	Legibility	50	230	160
AN	Legibility	60	5	25
AO	Legibility	50	2	20
TNL	Conspicuity	------	------	4
TOL	Conspicuity	------	------	2
ANL	Conspicuity	------	------	<0.5
AOL	Conspicuity	------	------	<0.5
TNR	Conspicuity	------	------	30
TOR	Conspicuity	------	------	10
ANR	Conspicuity	------	------	3
AOR	Conspicuity	------	------	3

TN - Texas New, TO - Texas Old,
AN - Arizona New, AO - Arizona Old
L (left side of driver) and R (right side of driver) denote the position of display location,
Lowbeams, H6054

plate material and age were balanced in such a way that each of the resulting combinations of material and age (4 combinations) were displayed exactly once in a random order for every 4 exposures thus giving a total of 24 replications for each combination accounting for a total of 96 responses from each subject. For the nighttime conspicuity experiments the main independent variables were the plate material (2 levels, beads on paint and reflective sheeting), the display position (2 levels, left or right) and age or condition of the plate (2 levels; new and old). The resulting combinations of material, position and age (8 combinations) were displayed exactly once in a random order for every 8 exposures (4 similar combinations at each display position) thus giving a total of 12 replications for each combination accounting for a total of 96 responses from each subject. The experiments were also balanced in such a way that one half of the subjects started with the nighttime legibility experiment and one half of the subjects started with the nighttime conspicuity experiment and an equal number of males and females participated in the study.

Experimental Procedure

The nighttime legibility experiments were conducted with the license plates being displayed at a distance of 75 feet from the front of the experimental car (81.2 ft legibility distance). The State of Arizona requires that the license plates must be legible at 100 ft during daytime (Statute 28-308), but no requirement for nighttime legibility was found. The license plate stand was positioned in a manner that the horizontal center of the license plate was exactly along the longitudinal center of the car with the lowbeams and the plate holder was fixed in such a way that the vertical center of the license plate was at a height of 26 inches above the ground. This height was the average vertical center height of 30 rear license plates (the State of Arizona uses license plates only in the rear) measured for 30 vehicles chosen at random in a parking lot. For both the nighttime legibility and conspicuity experiments the plates were presented in a random order mentioned in the experimental design section for a duration of exactly 2 seconds which was also computer controlled. The following is an explanation for choosing the 2 sec exposure time. Road and traffic information is obtained by motorists by making a continuous string of eye fixations, each one lasting from about 0.3 sec to 2 sec. On the modern high speed highways, drivers do not have unlimited time to look out for targets while driving. The maximum eye fixation duration of 2 sec will then be a fairly conservative choice for the exposure time.

The subjects were given two to three trial runs after giving them proper and detailed instructions which also allowed them to be somewhat dark adapted and familiar with the experimental procedure. Two experimenters sat in the back seat of the car, one noting down the responses of the subject and the other in constant communication with the experimenters at the license plate stand via the walkie - talkies. Six experimenters were used to conduct the nighttime conspicuity and legibility experiments and each subject took about one to one and half hours to go through the entire experiment. Vision testing and filling out subject questionnaires took another 30 to 45 minutes. The subjects were instructed to read out the characters on the plates and say 'blank' if they could not discern any particular character and press the horn as soon as they were ready for the next plate to be presented. For the nighttime conspicuity experiment, the car was moved to a distance of 550 ft. away from the two stands. ADOT's *Special Terms and Conditions* for bids states that all the license plates must meet the minimum required nighttime performance to provide a visible reflectivity at a minimum distance of 550 ft when using standard lowbeam headlights. The 550 ft distance, incidentally is equivalent to the *stopping sight distance* for a design speed of 55 mph on wet pavements [19]. The time between the nighttime legibility and the conspicuity experiments, or viceversa, gave the subjects a rest period of about 5 to 10 min. An opposing glare car (lowbeams) was positioned to the left of the experimental car such that the front to front distance between the cars was 200 ft and the longitudinal center to center distance was 12 ft (typical two - lane rural highway dimensions). There are many occasions on a two-lane highway driving situation where a motorist approaches an opposing glare car and must also be able to detect a retroreflective target ahead of his/her car in due time. The distance of 200 ft for the opposing car was selected arbitrarily. The two stands were positioned at a distance of 20 ft to the left and 20 ft to the right from the longitudinal center of the experimental car. The subjects were instructed to respond by saying 'left' or 'right' indicating the position at which they could see the plates being displayed at random as mentioned in the experimental design section. The experimenter operating the computer (the left or right position at which the plate would be displayed was computer controlled) would count 1, 2, 3, ... in the walkie - talkie after the first, second, third,... plates were displayed, so that the experimenters sitting in the car with the subject would know that a plate was displayed in the case the subject missed to see it.

After the legibility and the conspicuity experiments were finished, an exit interview was conducted with each subject to find out if there were any difficulties during the experiments which could have probably affected their performance in any way. Very few subjects were excluded since they were not wearing the right contact lenses or had experienced problems with their contact lenses during the experiment. Two sets of data collection forms were prepared for each subject, one for the experimenter noting down the responses of the subject in the car and the other one for the experimenters changing the plates at the stand. The mechanical stop was adjusted in such a way that the plates were leaning forward at an angle of about 5 degrees to avoid specular glare.

RESULTS AND DISCUSSION

A two - tailed paired t-test (subjects served as their own control) was conducted for the percent of correct characters read by the subjects in the legibility experiment for all possible pairwise combinations of the four types of plates- TN, TO, AN and AO (6 combinations, TN vs AN, TO vs AO, TN vs AO, TO vs AN, TN vs TO and AN vs AO). Table 2 summarizes the results of the paired t-tests for legibility. The results indicate that the TN plates provides a slightly better legibility performance and that there is no indication of any significant differences in legibility performance between the TN plates and the TO plates. However, the AN plates have a statistically significant better legibility performance when compared to the AO plates. Figures 8 and 9 show bar graphs for the percentage of correct letter responses and correct number responses respectively as a function of plate type (TN, TO, AN and AO). It can be seen from Figure 8 that the TN plates have the highest (93%) correct letter responses and that the AN plates (87% correct letter responses) have better correct letter responses than the TO plates (83% correct letter responses). The reason for this is that the group of numbers occur first on the TO plates while for all the other 3 types the group of letters appear first on the left side of the license plate. It appears that the first three characters on these plates are better recognized than the last three characters. This fact is further supported when looking at Figure 9 which shows that the TO plates have the best performance in terms of percent of correct number responses. It can also be seen that there is no large difference in the percentages of correctly recognized characters between reading numbers and letters and thus the number and the letter data were combined to get the overall performance (percentage of correct character responses) for the plate types which indicate that the Texas plates (both new and old) are slightly better than the Arizona plates (see Figure 10).

A one-tailed paired t-test was conducted on the correct detection responses for the number of license plates detected on each side (left and right) by the subjects in the night time conspicuity experiment on all possible pairwise combinations of the four types of plates in two positions (8 comb.). Table 3 summarizes the results of the paired t - tests for the nighttime conspicuity performance. The results indicate that TN plates have a better performance for both the left and the right positions. Figures 11 and 12 show bar graphs for the percentage of correct detection responses for the left and for the right positions respectively as a function of plate type (TN, TO, AN and AO). Again, the figures show that the TN plates provide slightly better nighttime conspicuity performance than the other

Table 2. Summary of the two-tailed paired t- tests for the nighttime legibility experiments

Pairs of plates	Two-tailed probability	Comment
TN, AN	0.0006	Significant
TO, AO	0.0320	Significant
TN, AO	0.0043	Significant
TO, AN	0.2387	Not Significant
TN, TO	0.0631	Not Significant
AN, AO	0.0043	Significant

TN - Texas New, AN - Arizona New,
TO - Texas Old, AO - Arizona Old

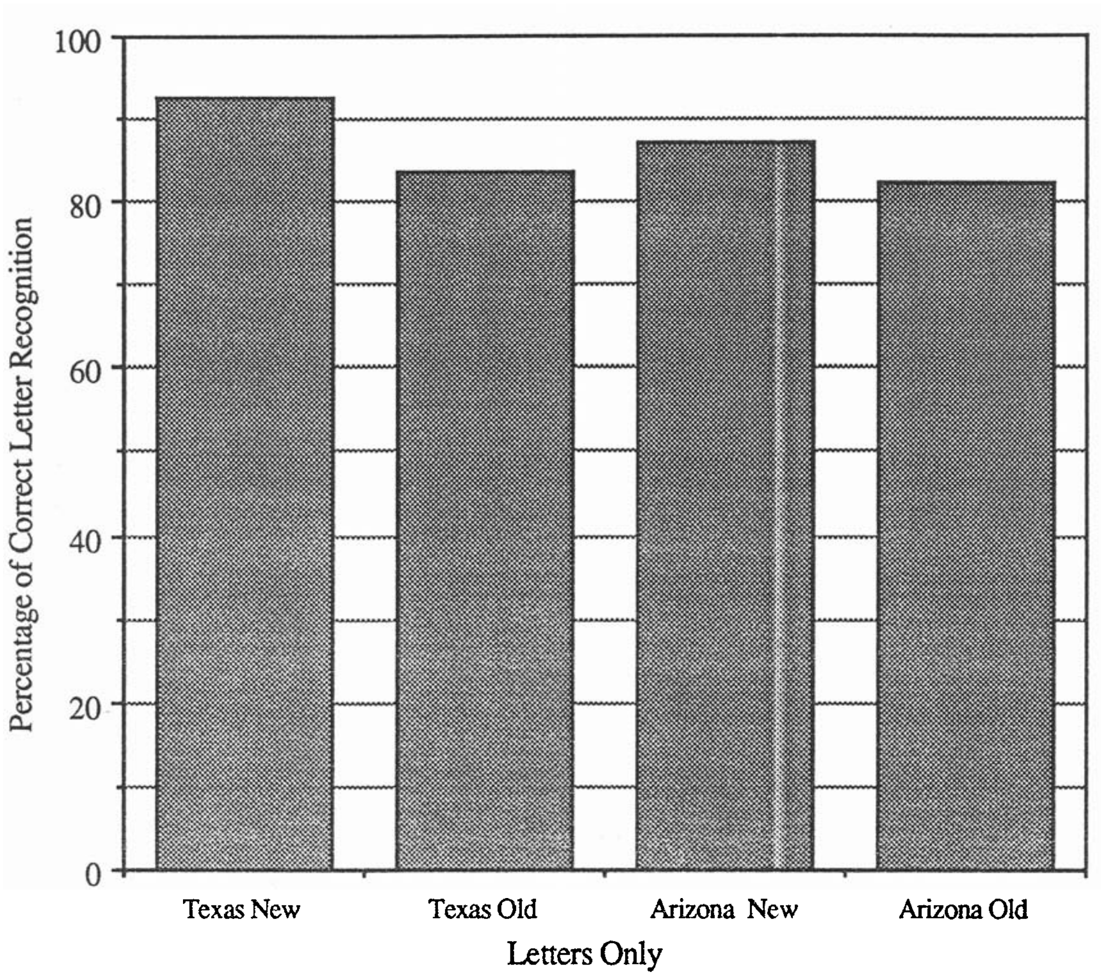

Figure 8. Responses of 20 Subjects for Nighttime Legibility Experiment; 81.2 feet Legibility Distance; Three Letters Per Letter Group; Dark Blue Letters on White Retro-reflective Background for Texas Plates; White Retro-reflective Letters on Dark Red Paint Background for Arizona Plates; Two Seconds Exposure Time; Letter Height of 2.74" for Texas Plates, 2.86" for Arizona Plates; Letter Width of 1.22" for Texas Plates, 1.23" for Arizona Plates; Stroke Width of 0.33" for Texas Plates, 0.35" for Arizona Plates; Letter Spacing of 0.39" for both Texas & Arizona Plates; Center of License Plate held at a distance of 26" above ground; Halogen H6054 HeadLamps at a height of 24"above ground; Low Beams; Total of 1440 Letter Presentations for Each License Plate Type

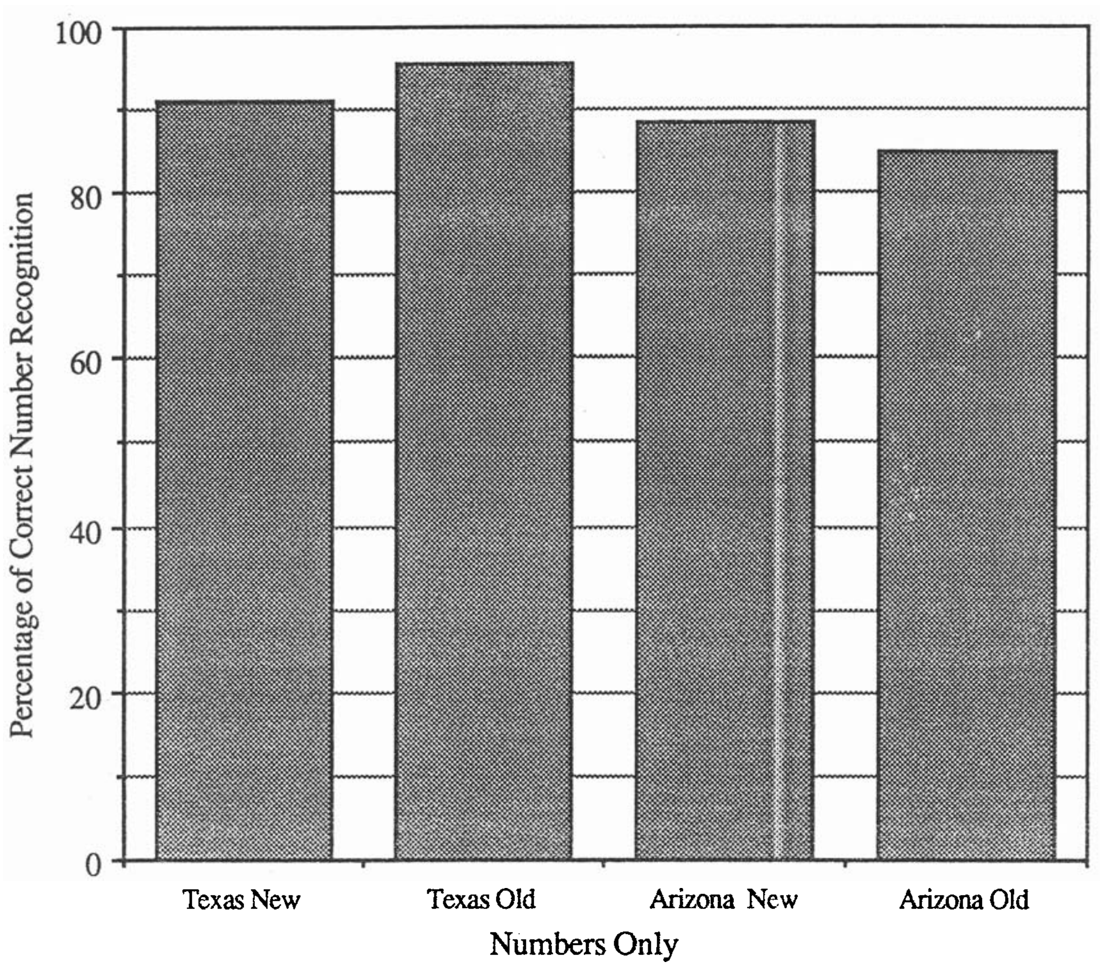

Figure 9. Responses of 20 Subjects for Nighttime Legibility Experiment; 81.2 feet Legibility Distance; Three Numbers Per Number Group; Dark Blue Numbers on White Retro-reflective Background for Texas Plates; White Retro-reflective Numbers on Dark Red Paint Background for Arizona Plates; Two Seconds Exposure Time; Number Height of 2.74" for Texas Plates, 2.86" for Arizona Plates; Number Width of 1.22" for Texas Plates, 1.23" for Arizona Plates; Stroke Width of 0.33" for Texas Plates, 0.35" for Arizona Plates; Number Spacing of 0.39" for both Texas & Arizona Plates; Center of License Plate held at a distance of 26" above ground; Halogen H6054 HeadLamps at a height of 24"above ground; Low Beams; Total of 1440 Number Presentations for Each License Plate Type

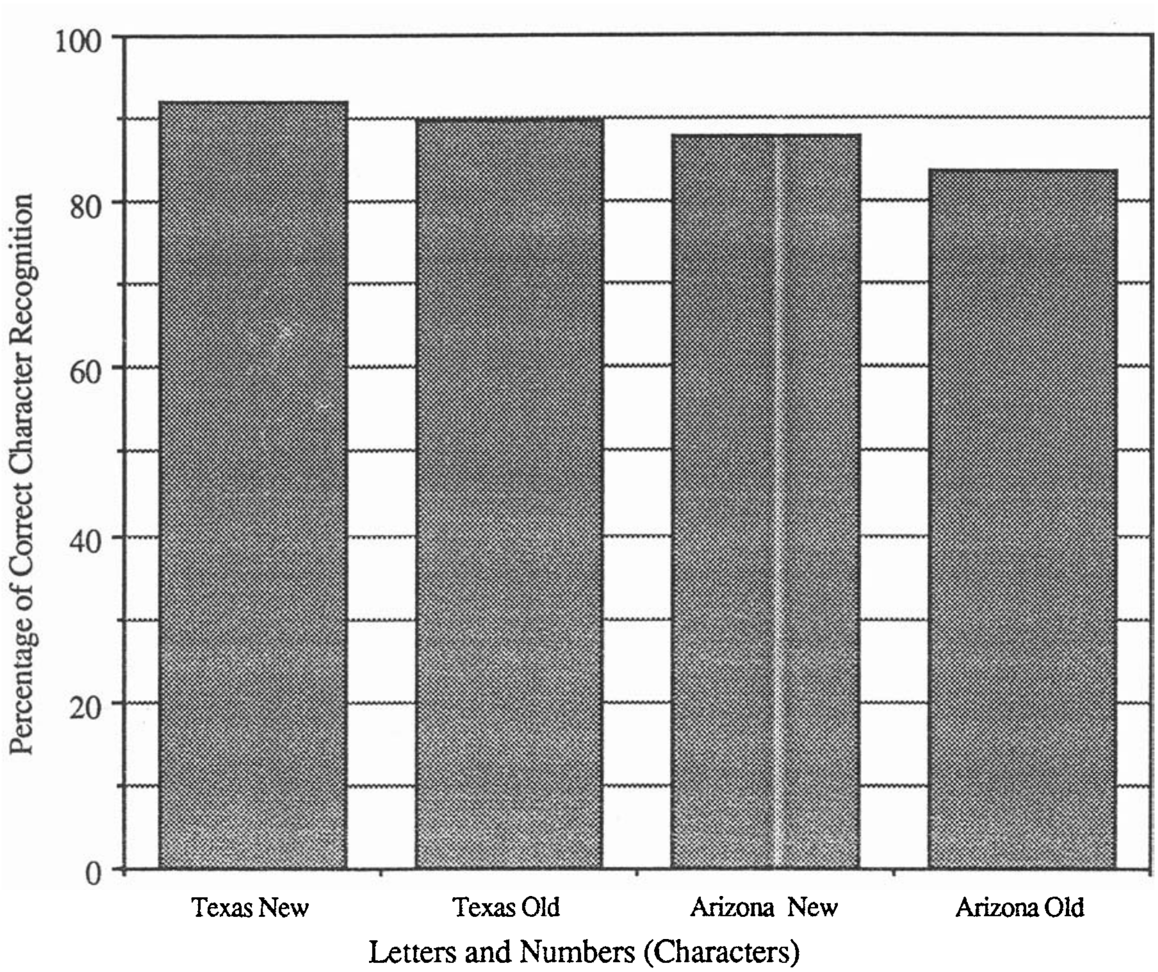

Figure 10. Responses of 20 Subjects for Nighttime Legibility Experiment; 81.2 feet Legibility Distance; Three Letters and Three Numbers; Dark Blue Characters on White Retro-reflective Background for Texas Plates; White Retro-reflective Characters on Dark Red Paint Background for Arizona Plates; Two Seconds Exposure Time; Character Height of 2.74" for Texas Plates, 2.86" for Arizona Plates; Character Width of 1.22" for Texas Plates, 1.23" for Arizona Plates; Stroke Width of 0.33" for Texas Plates, 0.35" for Arizona Plates; Character Spacing of 0.39" for both Texas & Arizona Plates; Center of License Plate held at a distance of 26" above ground; Halogen H6054 HeadLamps at a height of 24"above ground; Low Beams; Total of 2880 Character Presentations for Each License Plate Type.

Table 3. Summary of the one-tailed paired t- tests for the nighttime conspicuity experiments

Pairs of plates	One-tailed probability	Comment
TNL, ANL	0.0001	Significant
TOL, AOL	0.0000	Significant
TNR, ANR	0.0018	Significant
TOR, AOR	0.0046	Significant
TNL, TOL	0.2126	Not Significant
ANL, AOL	0.0897	Not Significant
TNR, TOR	0.5000	Not Significant
ANR, AOR	0.5000	Not Significant
TOL, ANL	0.0001	Significant
TOR, ANR	0.0018	Significant

TN - Texas New, AN - Arizona New,
TO - Texas Old, AO - Arizona Old
L (left side of driver) and R (right side of driver) denote the position of display location

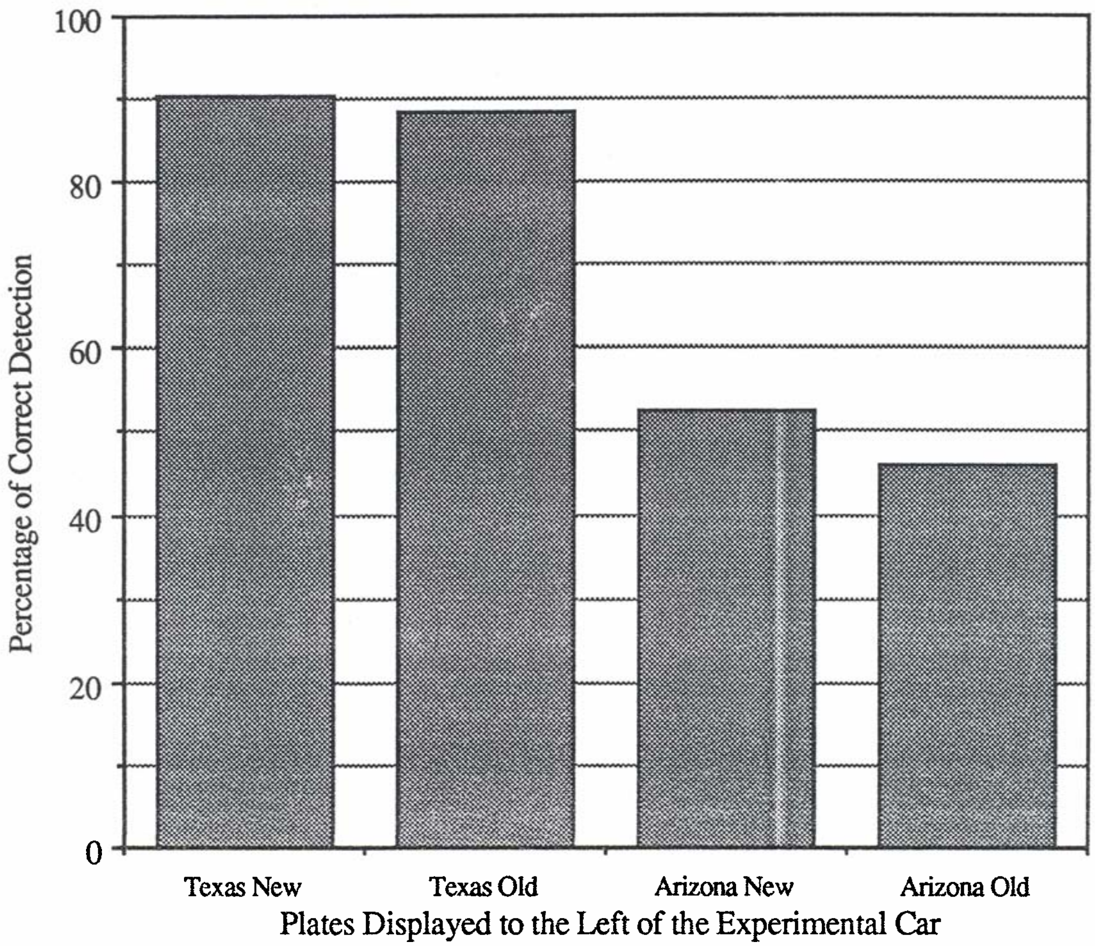

Figure 11. Responses of 20 Subjects for Nighttime Conspicuity Experiment; Dark Blue Letters on White Retro-reflective background for Texas Plates; White Retro-reflective Letters on Dark Red Paint Background for Arizona Plates; Two Seconds Exposure Time; License Plates displayed at 20 feet to the Left of the Center Line of the Experimental Car at a distance of 550 feet in front of the Car; H6054 Lowbeams for Both the Experimental and the Opposing Glare cars; Opposing Glare Car positioned at a distance 200 ft. from the front of the Experimental car, with a Lateral Offset of 12 feet to the Left of the Center Line of the Experimental Car; Total of 240 Presentations for each Plate Type.

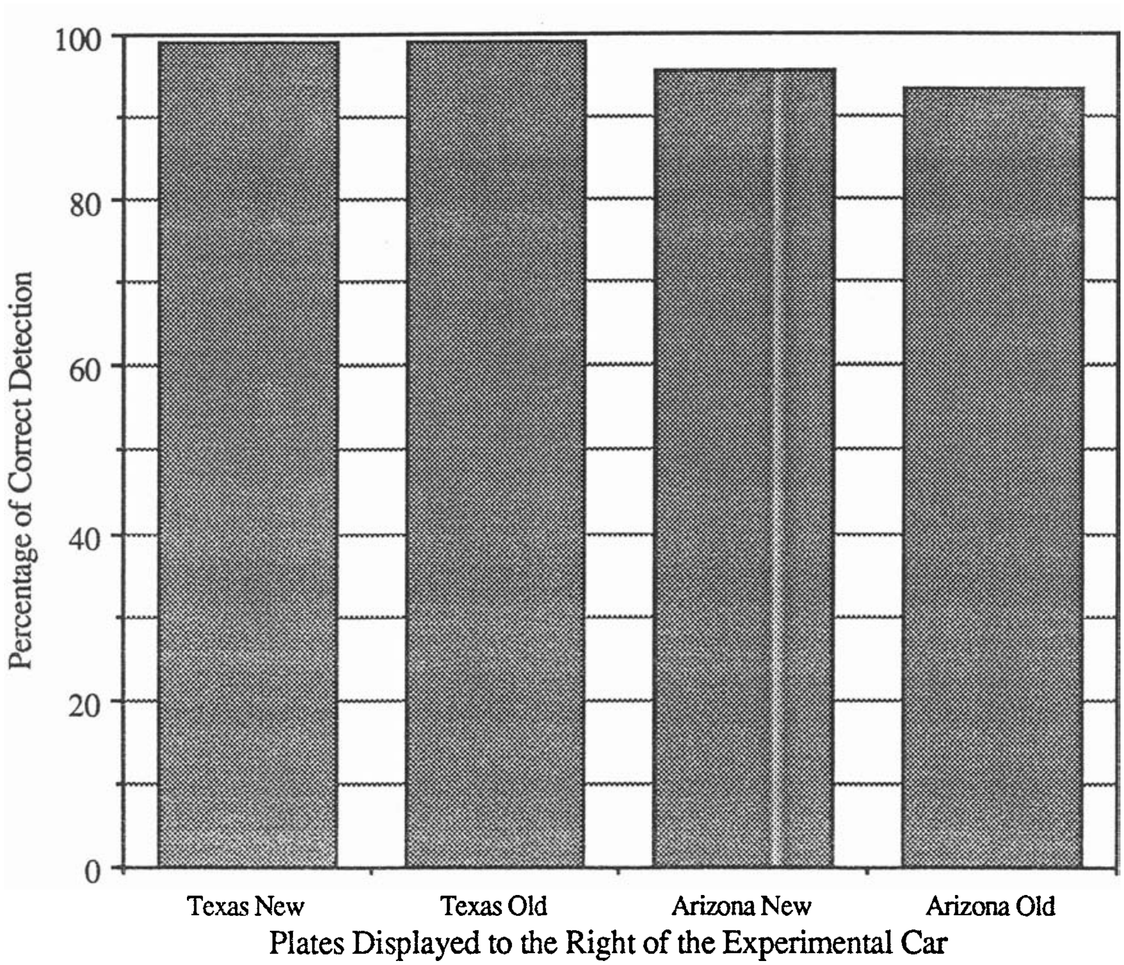

Figure 12. Responses of 20 Subjects for Nighttime Conspicuity Experiment; Dark Blue Letters on White Retro-reflective background for Texas Plates; White Retro-reflective Letters on Dark Red Paint Background for Arizona Plates; Two Seconds Exposure Time; License Plates displayed at 20 feet to the Right of the Center Line of the Experimental Car at a distance of 550 feet in front of the Car; H6054 Lowbeams for Both the Experimental and the Opposing Glare cars; Opposing Glare Car positioned at a distance 200 ft. from the front of the Experimental car, with a Lateral Offset of 12 feet to the Left of the Center Line of the Experimental Car; Total of 240 Presentations for each Plate Type.

plate types for both positions. Figure 11 shows that the Arizona plates have a rather low number of correct detections for the left side indicating that opposing car glare in a close proximity to where the license plate is located has a more severe and degrading effect on the detection of these plates than on the detection of Texas plates. As shown in Figure 12 for the right side, the Texas plates performed slightly better than the Arizona plates in terms of the number of correct detections.

Measurements of the height, width and spacing between the characters of the license plates used in the experiments were made and for the legibility experiment, the visual angles for the height of the characters for Texas and Arizona plates were calculated. It was observed that the Arizona plates on the average have a larger character height (2.86", should be slightly easier to read than the Texas characters) when compared to the Texas plates (2.74"). This indicates that the Arizona plates subtend a larger visual angle (10.0 min of arc with an increase of about 4.25%) when compared to the Texas plates (9.7 min of arc). Observation and entrance angles for the left and the right beams of the experimental car were calculated for both the nighttime legibility and conspicuity experiments using an available interactive computer program and the values are listed in Table 4.

The fixed or administrative costs of issuing a license plate as obtained from the Arizona Motor Vehicle Division is about $ 5.00 (metal plate, packaging, distribution, etc.). Table 5 summarizes the analysis of the costs of producing the two types of plates. The analysis indicates that if the beads on paint plate lasted 5 years before reissue and the reflective sheeting plate lasted 6 years before reissue, the costs would be $1.02 per year and $0.92 per year respectively, giving a cost advantage of $0.10 per year for the reflective sheeting plates. Moreover, since the results indicate a very minimal decrease in legibility and conspicuity performance between the new and used Texas reflective sheeting plates, there is a high feasibility to obtain a satisfactory 72 month life cycle instead of a 60 month life cycle. If both types of plates lasted 5 years, then the advantage would be for the beads on paint plates at $0.08 per year. The difference in costs if the reflective sheeting plates lasted one more year than the beads on paint plates are also shown in the last column of Table 5.

CONCLUSIONS

The available literature on conspicuity and legibility has been reviewed. Some of the studies concluded that there is no appreciable difference in daytime or nighttime legibility performance while some showed that there is in fact a significant difference in the legibility performance between the various types of materials used to reflectorize the license

Table 4. Observation and Entrance Angles of the License Plates Used in the Nighttime Legibility and Conspicuity Experiments

Experiment	Light Source	Lateral Distance (ft)	Longitudinal Distance (ft)	Observation Angle (degrees)	Entrance Angle (degrees)
Legibility	Left beam	0	75 (81.2)	1.25	5.04
Legibility	Right beam	0	75 (81.2)	2.33	5.04
Conspicuity	Left beam	-20*	550 (556.2)	0.17	5.34
Conspicuity	Left beam	20	550 (556.2)	0.19	5.47
Conspicuity	Right beam	-20*	550 (556.2)	0.35	5.47
Conspicuity	Right beam	20	550 (556.2)	0.31	5.34

Reference axis of license plate is directed 5 degrees downward
* The negative sign indicates that the position of the license plate is to the left ahead of the driver.
Height of the center of license plate from the ground = 2.17 ft (26")
Height of light sources (left and right beams) from the ground = 2 ft (24")
Distance between the centers of the two light sources = 3.33 ft (40")
Longitudinal horizontal distance from a driver's eye position to the light sources = 6.2 ft (74.4")
Lateral horizontal distance from a driver's eye position to the center of the car = 1.075 ft (12.9")
Height of a driver's eyes from the ground = 3.6 ft (43.3")

Table 5. Cost Analysis of the License Plates.

Fixed Costs (metal plate, packaging, distribution etc.) = $5.00

	Reflective Sheeting Plate	Beads on Paint Plate
Reflectorization Cost	$0.50	$0.11
Transaction or Fixed Cost	5.00	5.00
Total cost / Plate	$5.50	$5.11

Cost/Year	Reflective Sheeting Plate (RS)	Beads on Paint Plate (BOP)	Actual Difference in Costs	Difference in Costs if Reflective Sheeting plates last 1 more year
1 year	$5.50	$5.11	$0.39	-$2.36
2 years	2.75	2.56	0.19	- 0.73
3 years	1.83	1.70	0.13	- 0.32
4 years	1.38	1.28	0.10	- 0.18
5 years	1.10	1.02	0.08	- 0.10
6 years	0.92	0.85	0.07	- 0.06
7 years	0.79	0.73	0.06	- 0.04
8 years	0.69	0.64	0.05	- 0.03

Fixed Costs Estimates of Plates Furnished by Arizona Motor Vehicles Division

Costs for the 2nd, 3rd,... years have been obtained by dividing the 1st year costs by 2, 3,... respectively

Negative difference in costs (last column) indicates cost advantage for the reflective sheeting plates

Calculations for 1st year: $5.50 - $5.11 = $0.39 (actual difference)

$5.50/2 - $5.11 = -$2.36 (difference in costs if reflective sheeting lasts one more year)

Calculations for 2nd year: $2.75 - $2.56 = $0.19 (actual difference)

$1.83 - $2.56 = -$0.73 (difference in costs if reflective sheeting lasts one more year)

(3rd year cost of RS) (2nd year cost of BOP) plates. With regard to visibility or conspicuity, the literature review indicates that compared with conventional (painted only) plates, reflectorized plates improve the vehicle detection distances anywhere from two (legend only reflectorized) to seven (both legend and background reflectorized) times. Most of the studies that have attempted to study the direct safety benefits of fully reflectorized plates in terms of accident reduction have shown a reduction in night accidents and/or night rear-end collisions that may be associated with full reflectorization using reflective sheeting material. However, one of the studies (Stoke) indicates that this reduction in accidents is not statistically significant. All of these studies may be criticized on methodological grounds and in some studies there have been differences as to the interpretation of the results, but it is important to note that with the present accident reporting system (not sufficient in depth information) the benefits of reflectorization are very difficult to quantify in terms of accident reductions and an increase in safety.

Experiments and testing conditions have been designed to test the conspicuity and the legibility of Texas and Arizona plates under somewhat close to real world conditions. For both legibility and conspicuity, the retroreflective sheeting material of the Texas plates shows better performance than the beads on paint design of the Arizona plates and these differences are statistically significant at a significance level of 0.05. It would have been more reasonable to conduct the conspicuity experiment at a distance between 750 ft to 1025 ft instead of 550 ft since the larger range is the *decision sight distance* (for a design speed of 50 mph [19]). Any distance greater than 550 ft would not have been in accordance with the present visibility requirements used by the State of Arizona. However, looking at the results of this study it can be argued that at these longer decision sight distances, the Texas reflective sheeting plates would most likely show an even better conspicuity than the Arizona beads on paint plates.

It can be expected that there exists a rather close relationship between plate age and ultraviolet exposure and possible losses in reflectivity due to UV exposure. If there is in fact a large effect (decrease in reflectivity) due to UV exposure, the used Arizona and the used Texas plates (in use from 1 to 5 years) would be expected to show a fairly large decrement in both legibility and conspicuity performances. However, looking at the results of this study there appears to be very little loss in terms of conspicuity and legibility performance between new and used Texas plates, while there exists a somewhat larger but still relatively small decrement between the new and used Arizona plates. This would indicate that the beads on paint design might be slightly more susceptible to ultraviolet exposure and age than the reflective sheeting design. The effect of road contamination (dirt and road grime) could not be explicitly evaluated since there exist no standards or fixed procedures that can accurately quantify the level of contamination and moreover, such an additional investigation was beyond the scope and financial resources of this study. It is, however, expected that dirt and road grime would affect both of these license plate types in a similar manner and therefore one could expect that dirty reflective sheeting plates would always provide a slight to moderate superior conspicuity and legibility performance when compared with equally dirty beads on paint plates.

The cost analysis shows a slightly increased total cost per plate for the reflective sheeting plates when equal life cycle times are considered. However, this increased initial cost is rather modest and might not be a factor at all if reflective sheeting plates can be used over a longer life cycle time than the beads on paint plates. Moreover, as indicated above the new vs old license plate results indicate that the life expectancy and conspicuity and legibility performance of the reflective sheeting material with increasing age is slightly higher than that of the beads on paint material. In addition, reflective sheeting plates do provide a statistically significant, small to moderate performance increase with regard to nighttime conspicuity and legibility. In summary, it can be concluded from the results of this study that the reflective sheeting design shows a consistently slightly better performance (statistically significant) for both conspicuity and legibility than the beads on paint design under fairly realistic conditions. It should also be noted that the results obtained in this study and the conclusions drawn are based upon the performance of young and healthy and in many ways ideal subjects. It can be expected that the performance differences between reflective sheeting and beads on paint plates will be most likely greater and even more significant if impaired or elderly drivers are considered.

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