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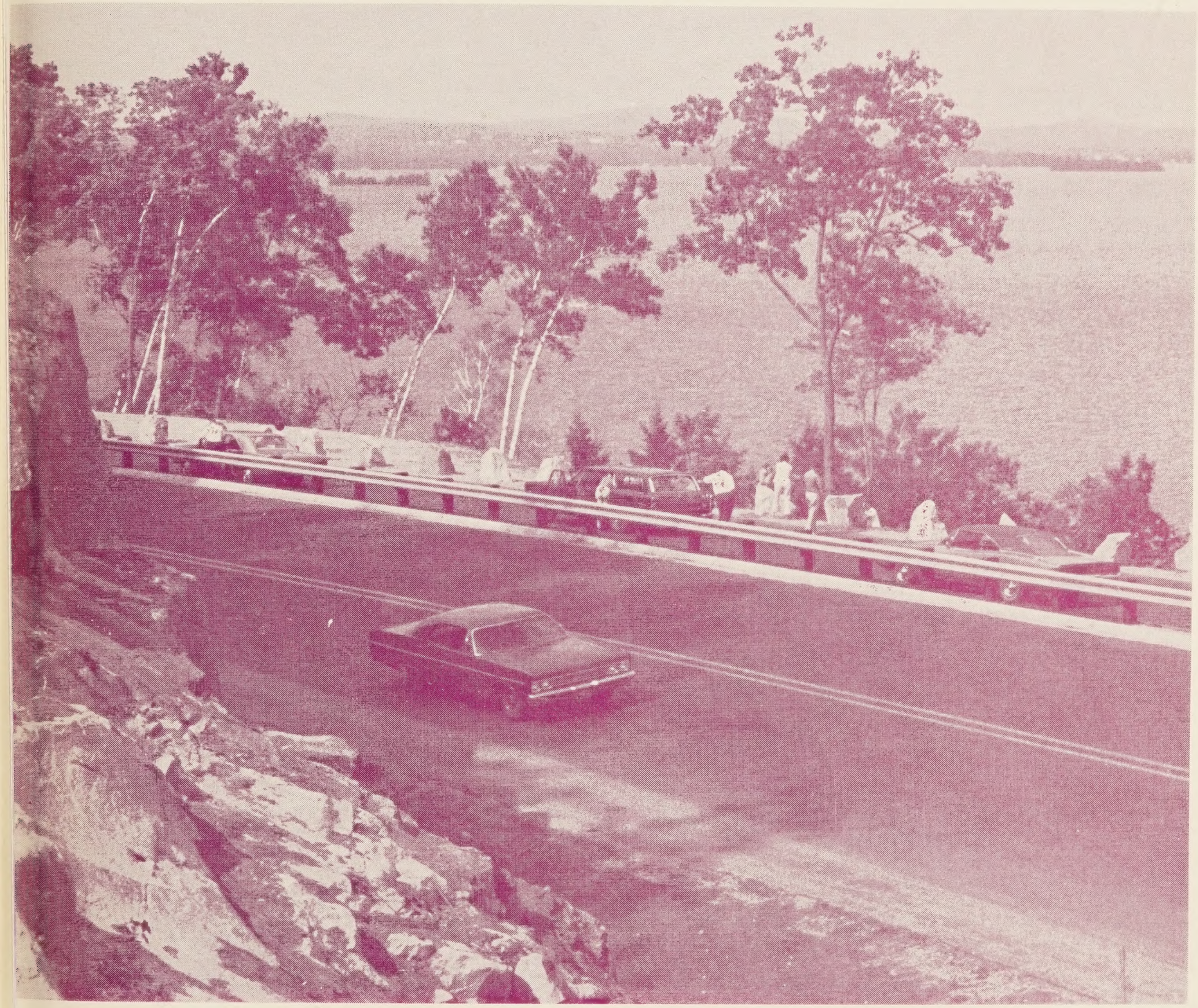
Public Roads

A JOURNAL OF HIGHWAY RESEARCH



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

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U.S. DEPARTMENT OF TRANSPORTATION
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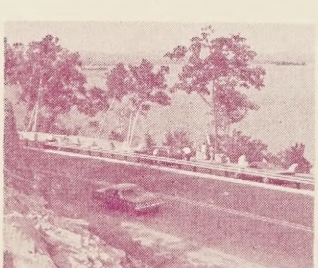
CONTENTS

Articles

Departments

What would you like to read about in PUBLIC ROADS?

See page 157



COVER

Natural roadside viewing area along N.H. Route 11 near Alton Township, Belknap County, N.H. (Photo courtesy of New Hampshire Department of Public Works and Highways).

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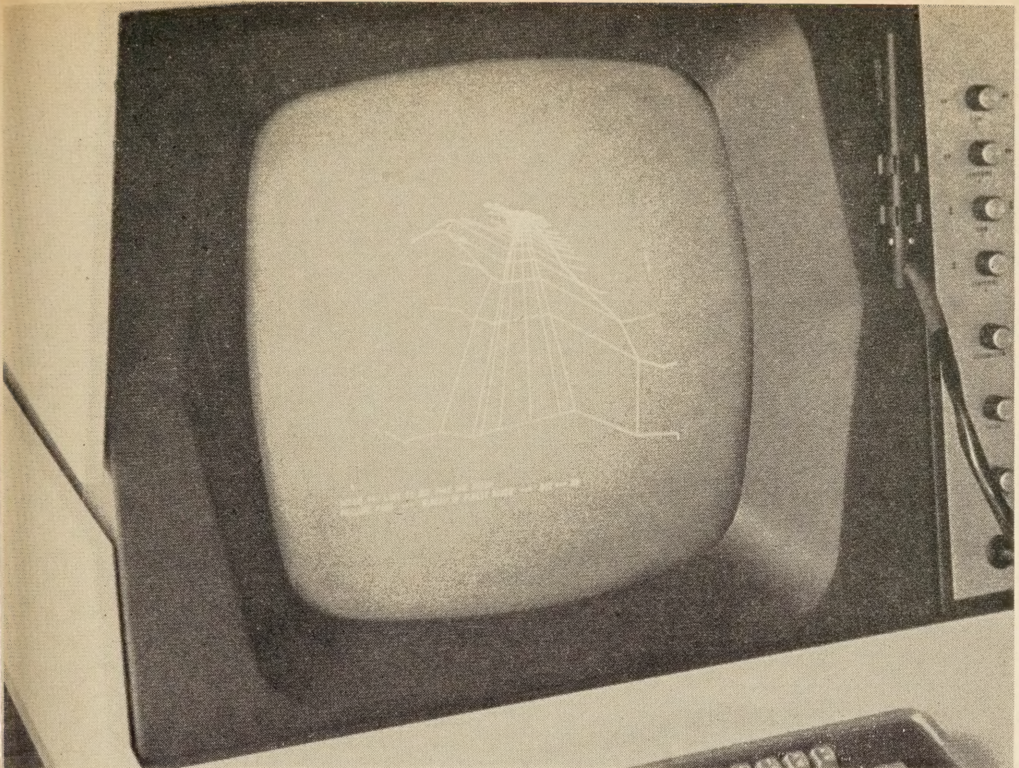

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Simulating the Driver's View of New Highway Design Before Construction

Reported by [1] LARRY J. FEESER, Associate Professor, and JOHN D. MEYER, Graduate Student, Department of Civil Engineering, University of Colorado, and JOHN D. CUTRELL, Chief, Automatic Data Processing Branch, Region 9, Federal Highway Administration

An animated movie that simulates the driver's view in a drive over a newly designed highway, not yet constructed, is now possible through the implementable software package developed in the research project described here. Using data already developed during the design process, the package generates perspective views of the proposed highway and displays them either serially to produce animation or singly to permit evaluation of roadway sections.

Perspective views based on highway design data can be used not only by highway engineers to eliminate unsafe features and other undesirable characteristics from the final design, but also by landscape architects and others concerned with the highway and its environment to visualize the final view that will be seen by the driver.

Introduction

MUCH WORK has been done to build and operate driver simulators, but it has been oncerned, primarily, with drivers' reactions ɔ external situations such as headlight glare, ignalization, and the maneuvering of other ehicles. Most driver simulators use a highly tylized representation of the roadway enironment, which is projected on a screen to ive the subject the feel of driving on a high-ay. More recently, closed circuit television as provided the visual image for the simulaɔr as a television camera is driven along a cale model of a highway or street by a comuter responding to the drivers' simulator ɔntrols, and the television image is projected ı a screen in front of the subject.

Little use is made of available simulation techniques to evaluate the designs of new highways before actual construction begins. Highway facilities are very costly to construct, and more thought should be given to the interrelation of design parameters during the design stage, particularly, as regards drivers' reactions to different design features.

At present, highway design is evaluated almost exclusively from horizontal plan and vertical profile drawings of the facility (fig. 1). It takes a highly experienced highway engineer to visualize the static relationship between vertical and horizontal alinement and the effect of alinement on the surrounding topography. In the past, highway engineers

[1] Based on a paper presented at the Summer Computer mulation Conference, Denver, Colo., June 10–12, 1970.

gained this experience by performing the many laborious computational tasks by hand. Many young designers lack this exposure to the voluminous data involved in highway design because present day design computations have been automated to make use of high speed computers. Present work in the industry is concerned with computer-generated static perspective views to provide the important visualization needed to evaluate proposed highway designs, (*1, 2, 3*).[2]

Dynamic simulation of the highway situation by computer-drawn perspective views had been attempted, but was successful only to a limited degree. At a Highway Research Board meeting in Washington, D.C. (*4*), French engineers presented an animated perspective highway film produced by photographing successive retouched computer-plotted views. This technique, although effective, had the disadvantage of requiring artwork on the plots to create realism. Moreover, the technique was proprietary and could not be made generally available to U.S. State highway departments, except at prohibitive cost. In addition to the cost, the time needed to produce such a film obviates its general use.

It would be most advantageous if designers could evaluate dynamically proposed design features before the highways are built. To drive over a simulated highway at the design stage would allow the designer not only to eliminate blind spots, dangerous hilltop curves, and confusing intersections and exit ramps, but also to provide better signing. Highway engineers, safety experts, and behavioral scientists, could collaborate to adjust horizontal and vertical alinement to enhance safety, just as alinement at present is adjusted to permit less expensive earthwork and to achieve desirable side slopes.

The research project reported here was conducted in response to this need for a method of simulating proposed highway designs. The project was a part of the U.S. Federal Highway Administration's program of highway engineering research for a Total Integrated Engineering System (TIES). TIES is a major software development effort intended to provide an integrated approach to highway-related computer science (*5, 6*). It covers application areas such as route location, soils investigation, road geometry, bridge design, and construction engineering and administration. This program of research and implementation is administered by the Federal Highway Administration's Office of Development. Analysis and programing are contracted to State highway agencies, universities, and commercial software developers.

As a result of the methodology developed in the research project, an animation movie simulating a driver's experience on an actual design project was made by photographing the Cathode Ray Tube (CRT) of the interactive graphics terminal at the University of Colorado. For this technique, animation is achieved by moving the observer down the proposed road in small increments and taking a photograph of the computer-drawn view at each position. Since each new observer position constitutes a new perspective plot, the amount of computation required to generate a movie is economically critical. Moreover, the use of animation to compare designs creates the need for plots of several alternate alinement configurations; therefore, one of the primary aims of the research was to find a low-cost method of making perspective plots.

To meet these criteria, the resultant software had to be highly efficient and data-structure oriented rather than general in concept. The method was kept economically feasible by using pre-existent data bases, by developing efficient algorithms for coordinate transformation and for visibility of lines, by photographing directly the CRT display device, and by using a computationally efficient computer.

Data Base

Design data for the project was supplied by the Federal Highway Administration (FHWA). None of the data was especially contrived for graphics use; it was real data typical of that from federally sponsored highway projects. Most modern highway departments have the necessary data for perspective plotting as a natural byproduct of their current design processes, and these data are in a form that is easily adapted to the graphics system under discussion. A system of engineering highways is reviewed briefly in the following paragraphs to help illustrate the availability of the data base for perspective highway plots:

- The first step in the highway design process is to obtain contour maps of the area through which the road is to pass. Contour maps are plotted from aerial photographs—a common practice for all of today's mapmakers. Aerial photography is always accompanied b[y] an accurate field survey to establish horizont[al] and vertical control points.
- Working on the contour map, highw[ay] engineers then select a centerline for the roa[d]way to be designed. A computerized horizont[al] alinement program refines the selected li[ne], and the computer provides an output of co[n]trol points, which are precise x-y coordinat[es] delineating the traverse of the centerline. T[he] computer also establishes, mathematical[ly], terrain stations—usually at 50-foot inc[re]ments—and other selected points at whi[ch] cross sections occur. Computer programs [for] resolving the roadway horizontal alinem[ent] problems are standard and commonly us[ed] items in most highway departments.
- After terrain stations and the cro[ss]-section lines are physically plotted on t[he] contour map, a stereo plotter is used to m[ea]sure the elevations and distances of numero[us] terrain points along the cross-section lin[e]. In this operation, the stereo plotter is link[ed] to a digitizer, which is in turn linked to a ca[rd] punch machine. From this setup, the elevati[on] and the distance from centerline for each t[er]rain point is punched on a data card simp[ly] and rapidly by manipulation of the ste[reo] plotter. Experienced operators record, in [?] seconds or less, distances and elevations of [?] terrain points along a typical cross-section li[ne], which might be 200 feet long.
- Next, vertical alinement is establish[ed]. The highway engineer again selects a line, t[his] time a proposed gradeline, which he delinea[tes] in the vertical plane. A typical vertical ali[ne]ment computer program refines the select[ed] gradeline and provides as outputs elevations [at] all control stations.
- Finally, the roadbed is designed. In t[his] step, the engineer decides on roadway widt[hs], side slope ratios, ditch depths, and sup[er]elevations. These decisions are then express[ed] mathematically and submitted along with [the] terrain-point information to a roadw[ay]

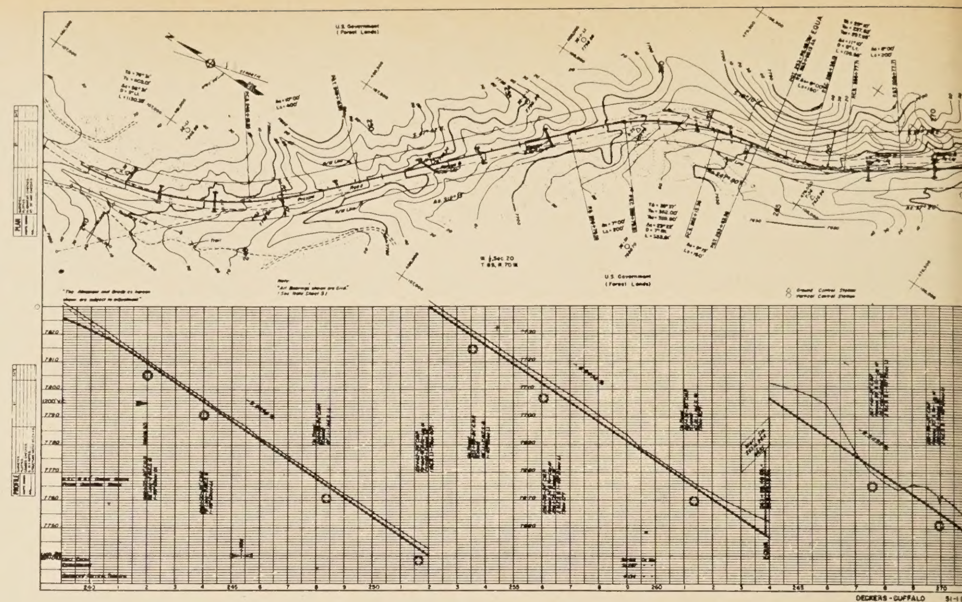

Figure 1.—Typical plan and profile sheet.

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[2] Italic numbers in parentheses refer to the bibliography listed on page 147.

template design computer program. This program in turn performs the roadbed design computations for the engineer. The engineer has the ability to adjust, throughout this computer aided engineering process, such things as horizontal alinement, vertical alinement, and detailed side roadbed design parameters. With a roadbed design at each cross section, the quantity of earthwork is automatically computed by a succeeding computer program which in most design agencies is referred to as an earthwork program.

From this design process, all necessary information for perspective plotting is available. The roadbed template at each cross section is fundamental to all earthwork programs and contains all distances and elevations necessary to draw the roadway. Outside of the templates lie the actual terrain points, which are well described on the terrain-point cards by the digitizing process. Terrain-point cards are fundamental to designing each cross section. Thus the roadway and the adjacent terrain are described automatically by the design process. A program to assemble this information into a compact form for graphics use has been written by the FHWA.

The advantages of highway data are that all cross sections occur serially and, with the exception of switchbacks, that each cross section is farther from the observer than the preceding one. These advantages facilitate the rapid, low-cost generation of perspective plots.

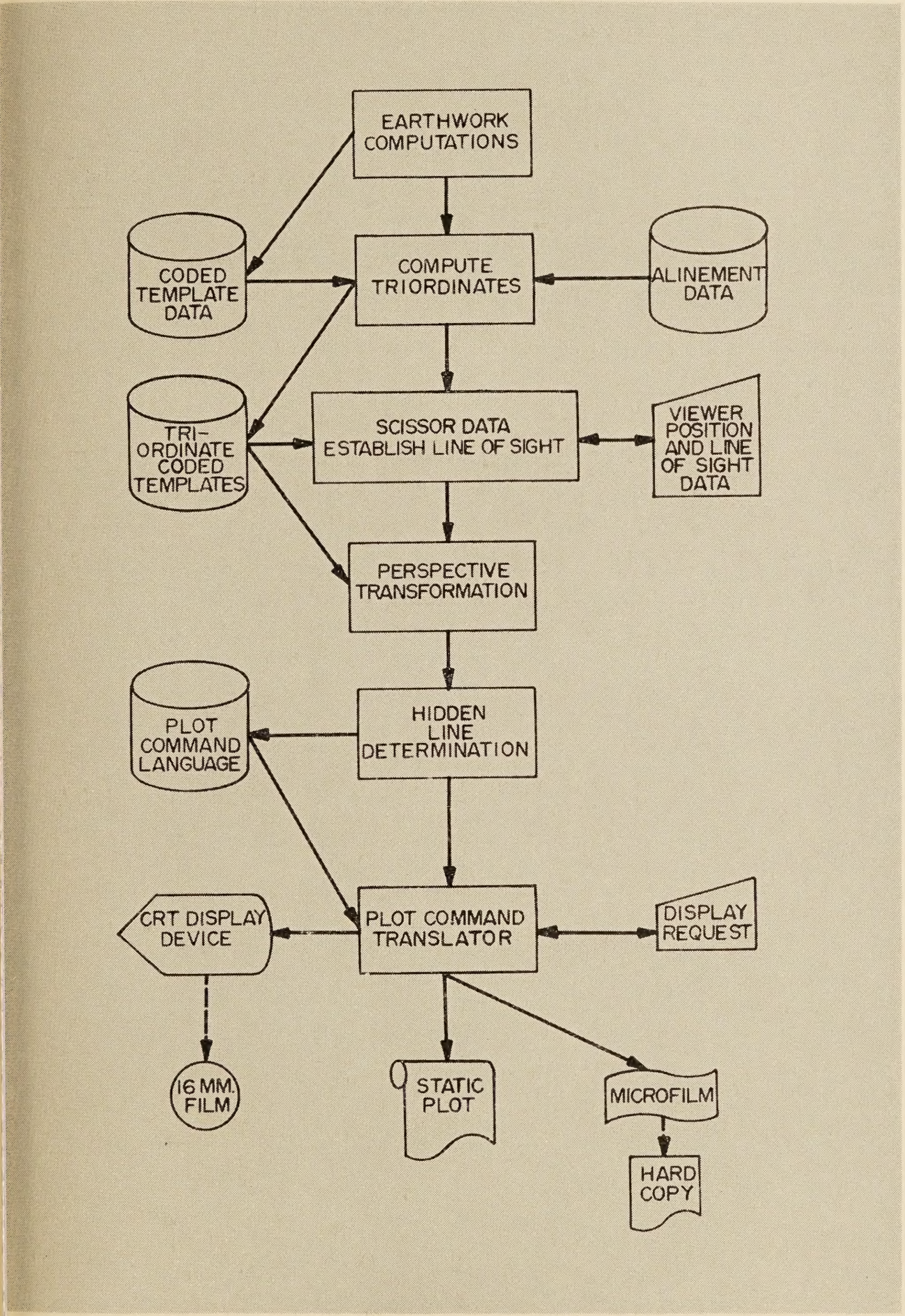

Figure 2.—Process macro diagram—highway design perspective view plot.

Methodology

Work done by others to provide visual information by computer graphics, (*4*, *7*, *8*, *9*, *10*), has been very specialized and used only in limited situations. However, the work reported here can be adapted and applied by all highway departments equipped to provide the aforementioned data base from location and earthwork automation, which is used as an input file for the developed program.

Basically, the methodology, which follows the process macro shown in figure 2, consists of the following steps:

- Data input—Data on location and on direction of observer's eye sight.
- Set up and positioning of window plane on which perspective view is projected.
- Identification and retrieval of basic cross-section data from location and earthwork programs.
- Perspective-coordinate transformation for all points of a cross section.
- Removal of hidden lines.
- Output of final completed view to intermediate data base—pilot command language (PCL).
- Display of perspective views—on CRT, by 35 mm. microfilm on hard copy from the microfilm, or by 16 mm. motion pictures filmed from the CRT.

The program allows certain flexibilities in the input information. The terrain station, distance left or right of the design centerline, and the elevation above or below the roadway surface is provided to position the observer. The observer's line of sight is designated by providing information to calculate the x, y, and z coordinates of the point being looked at or by indicating that the line of sight should be tangent to the design alinement. After observer location and line of sight is established, the program generates a window plane on which the perspective view is projected. Other input data at this stage controls scissoring by limiting the size of the window to exclude coordinate data outside the desired field view.

The basic cross-section data from the combined location and earthwork programs are identified and retrieved to yield x, y, and z coordinates. This information is the primary data that will be transformed into perspective views that the human eye can recognize as shapes of terrain and highway features. The coordinate points are tagged with a position code to provide longitudinal connecting lines between points of the cross sections.

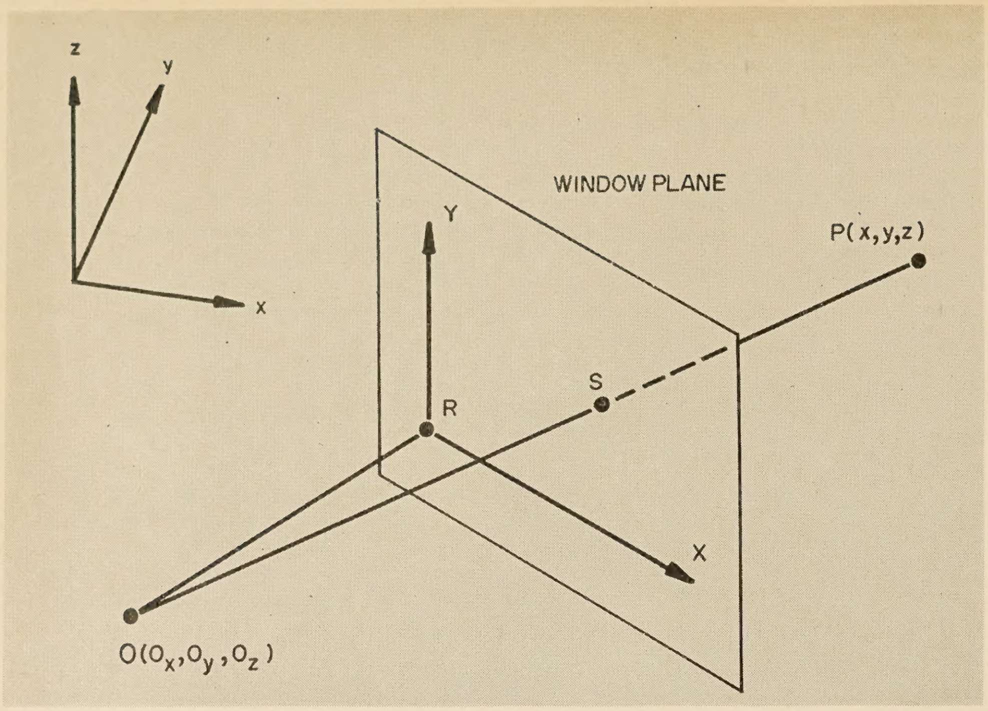

Figure 3.—Coordinate system for perspective transformation.

Perspective transformation

The technique used to transform the coordinate data into perspective data is basically the one described by Kubert, Szabo, and Giulieri (*11*). The transformation can be illustrated by points in three-space (fig. 3) in which certain information with respect to a rectangular coordinate system x, y, and z is known—the coordinate locations of both the observer and the point to be represented in perspective coordinates, and the direction of the observer's line of sight.

The observer is located at point O (O_x, O_y, and O_z) and the line OR is the line of sight. A window plane is constructed perpendicular to the line of sight. It is the projected coordinates of point P as they intersect the window plane on a line connecting P and O that are the perspective coordinates of point P. This projected point is designated $S(X, Y) = S(\xi, \eta, \zeta)$ where X and Y are the perspective coordinates and ξ, η and ζ are the x, y and z coordinates of the point.

Points O and P are described in terms of the overall coordinate system x, y, z. The line of sight, OR, makes angles α, β and γ with the x, y, and z axes respectively. The control parameter of the perspective projection is the distance OR, which will be called d.

If the X-axis is situated parallel to the x–y plane, then the transformation equations given by Kubert, Szabo, and Giulieri (*11*) are:

$$X = [(\xi - r_x)\cos\beta - (\eta - r_y)\cos\alpha]/\sin\gamma$$
$$Y = (\zeta - r_z)/\sin\gamma$$

Where,

$$\xi = O_x + K(x - O_x)$$
$$\eta = O_y + K(y - O_y)$$
$$\zeta = O_z + K(z - O_z)$$

and,

$$K = d/[(x - O_x)\cos\alpha + (y - O_y)\cos\beta + (z - O_z)\cos\gamma]$$
$$r_x = O_x + d\cos\alpha$$
$$r_y = O_y + d\cos\beta$$
$$r_z = O_z + d\cos\gamma$$

These transformations are general except when the line of sight is vertical ($\sin\gamma = O$), in which case, an alternate definition of the X-axis can be used to avoid the problem. In the developed program, there was no need to look vertically; therefore, the possibility was omitted.

The perspective transformation package of the program takes the input information concerning location of the observer and the line of sight, and sets up the window plane b making use of the input distance, d. By readin cross-sectional information serially, the pe spective coordinates of each point are ca culated and saved for plotting later.

Removing hidden lines

To develop a plausible perspective imag the parts of the image that the real eye woul not see must be excluded. For example, pr jections that would appear beyond curv and hills in the highway and behind roadsid bluffs and other protrusions cannot be visib in the image. Thus, the lines representin these hidden areas must be removed.

Although a rather general hidden-lin algorithm exists (*11*), it requires that data o all points plotted be available for checkin during the entire procedure. Such a procedu seemed unsatisfactory because of the larg amount of data that must be handled to pl perspective views, and the constraints on t availability of core storage in most desig agencies. Instead, an efficient hidden-lin algorithm not requiring a large data-ba resident in core was used. This techniqu which has been used by the Pennsylvani State Highway Department (*12, 13*) makes u of the data structuring to cut down on t amount of data that needs to be retained fro one cross section to the next.

Data available from highway design proce is highly structured. Cross-section informatio occurs serially; each successive cross sectio is farther from the observer than the previo one, provided that the roadway alineme does not have switchbacks within the sig distance being plotted.

In dealing with the first cross sectio perspective coordinates of all points of t cross section are developed, and then plotti information is generated. Any successive poi with perspective coordinates that fall belo the curve described by the first cross secti is invisible, and the curve can be used f checking visibility. The curve used for chec ing visibility, called the blackout array (fig. 4 is a collection of X and Y coordinates of poin on the curve.

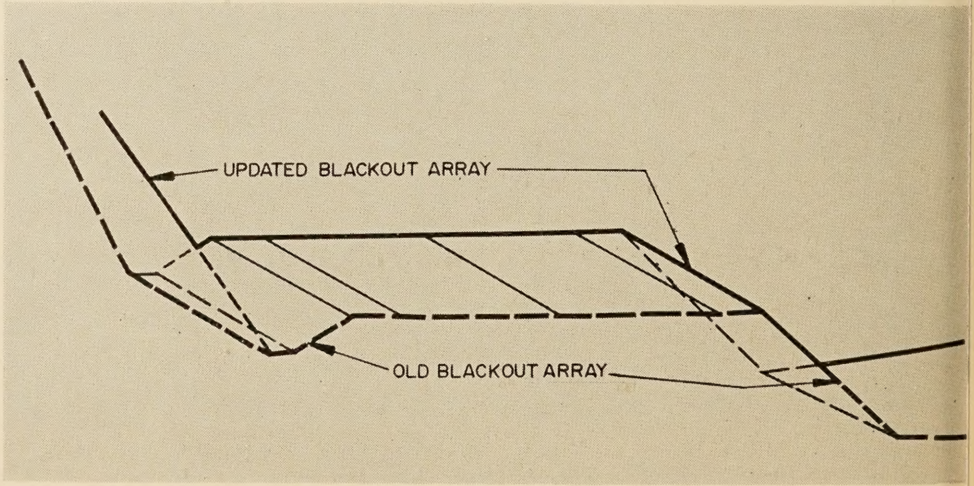

Figure 4.—Blackout array concept.

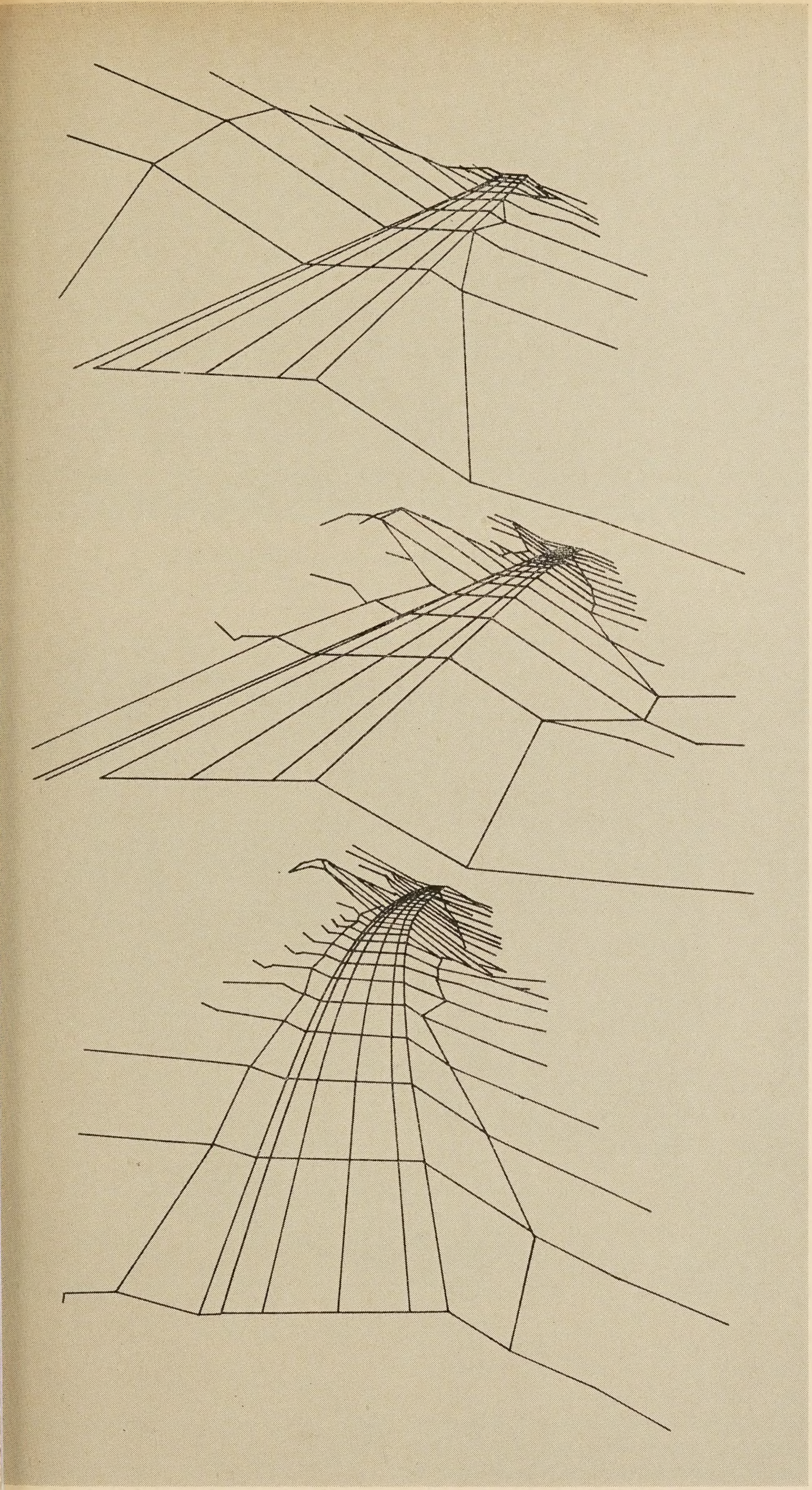

Figure 5.—Typical perspective view—McClure Pass, Colo.

As additional cross sections are looked at, the points are checked for visibility. If the points are visible, the blackout array is updated to include the new visible points so that the visibility of the next section is checked against all previous data. This technique has proved very effective. For each cross section the previous data that has to be stored is the information in the blackout array. Consequently, considerable storage space is saved, and checking for visibility is simplified and shortened. Interpolation capability, to handle visibility problems of line segments, and longitudinal line generation and plotting are additional features of the hidden-line routine.

Plot command data base

An intermediate data base, called plot command language (PCL), permits the information on a perspective view to be used by a variety of output hardware and devices. PCL, which has the ability to annotate, rotate, and scale information, supplies translator programs for the particular hardware and plotting device to be used. The main part of the data base that deals with the point and line plots has been kept as simple as possible. Each point of the plot is represented by three items of information: A draw or no-draw command, an X coordinate to which the drawing device should move, and a Y coordinate that corresponds to the X coordinate.

Animation

Animation—also used in other engineering disciplines during the last few years (*14, 15, 16, 17*)—requires a sequence of views correctly timed for the viewer to perceive motion. For smooth animation, the sequence must be spaced closely enough to complement the visual acuity of the human eye. The rate at which the sequence is viewed determines the rate of motion achieved; consequently, the more views that are generated, the smoother the animation. Animation that simulates driving on the highway requires a very large number of views—60 miles per hour of travel requires 520 views per minute for smooth animation.

After the views are generated by the program, they must be plotted and filmed. The available methods of plotting, all of which were evaluated for ease of filming, are pen and ink plotting, such as the incremental drum plotter; plotting directly on microfilm; and photographing directly a large CRT.

The first method is too slow and costly for the application reported here. The second is very good, possibly the best, especially if a 16-mm. microfilm camera is used. The views shown in figure 5 were plotted on microfilm.

The microfilm plotter available for use in the project was a 35 mm. plotter. The cost of producing a 35-mm. film was 5 cents per frame, which makes animation very costly. Because of this cost, and because a 35-mm. motion picture projector is difficult to obtain, it was decided to photograph the perspective views directly from a CRT. The motion picture camera used to photograph the CRT was equipped with a 10-mm. lens, electric drive mechanism, single frame device, and a remote release device. Because this camera is a reflex type, it was a simple matter to properly aline the camera position. For the project, the camera was mounted on a tripod directly in front of the CRT display. However, it is planned to develop a camera mount that attaches to the CRT and includes a light shroud to eliminate external light.

Movies for most nonsound projection equipment are filmed at the rate of 16 frames per second. For sound films, this rate is usually increased to 24 frames per second. As the film produced in the project had no sound, the 16-frame-per-second rate was used. The demonstration film contained three duplicate images of each view in the sequence, and the distance between each viewer position is 10 feet. This information is fed to the plot program along with information that positions the viewer relative to the center of the highway. This viewpoint used for the animation was 4 feet to the right of the roadway centerline and 4 feet above it.

The animation was taken from actual data for a project in the mountains of Colorado. The highway was designed by Region 9 of the U.S. Federal Highway Administration. An oblique photograph of a roadway typical of that in the animation is shown in figure 6. Viewing of the demonstration film never fails to spark a great deal of enthusiasm for the technique.

Figure 6.—Oblique photograph of typical roadway.

Figure 7.—Interactive graphics terminal.

Implementation

As previously stated, a computationally efficient computer can make the production of animation an economical operation. Most State highway departments use computers that are not computationally oriented because of the nontechnical processing involved in the administration of a highway department. This constraint should not be considered a deterrent, however, as perspectives can also be produced economically on these machines.

An even bigger constraint is the lack of proper graphic display devices. Some 35 of the 50 States have digital plotters, but none has CRT graphic display equipment with vector capabilities. This situation undoubtedly will change as the usefulness of these devices is increased through application development. Certainly highway design methodology is a fertile area for interactive graphics techniques. The potential of automation-aided design undoubtedly will be realized as research and development funds are made available for this purpose.

The highway design perspective plotting technique was developed on two computer hardware configurations simultaneously. One of these, the IBM 360 model 40 with 128k bytes of core memory, did not have an interactive-graphics capability, but a Calcomp 663/770 incremental drum plotter was available at the installation. This configuration was used to test the basic system architecture. Resultant PCL output was plotted on the incremental drum plotter for quick verification.

The other configuration was a Control Data Corporation 6400 with 64k words of fast-core memory and 125k words of extended-core storage. The CDC 6400 is located at the University of Colorado. The graphics hardware at this installation include the CDC 280 Microfilm Plotter with a 35-mm. camera, a Calcomp 763/770 Incremental Drum Plotter, and a CDC 282 Interactive Graphics Terminal. The latter, shown in figure 7, serves two purposes: (1) It gives the highway engineer a quick way of viewing a design plot, and (2) it is the image source from which to film animation [illegible] 16-mm. motion pictures.

Conclusions

The merits of a dynamic method to sim[illegible]late driving on a design facility prior to actu[illegible] construction are self-evident. The importan[illegible] of well-engineered highways in the enviro[illegible] ment has increased sharply during the last decade. More attention is now paid to the adequacy of highways to transport persons safely, comfortably, and swiftly. Highway design warrants the combined consideration of the different disciplines to achieve these community values. Highway design animation provides a needed focal point for interdisciplinary consideration and evaluation.

New criteria for highway location and design, based on visual and kinesthetic sensation, are being developed (*18*, *19*). Highway-design animation offers an effective tool to evaluate data related to these aspects also. It seems apparent that the technique presented here is a mere beginning to the application of animation graphics and computer driven display devices to highway design.

ACKNOWLEDGMENTS

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New Publications

The Federal Highway Administration has recently published three documents. These publications may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, prepaid. The following paragraphs give a brief description of each publication and its purchase price.

Highway Statistics, 1969

Highway Statistics, 1969 ($1.75 a copy), a 212-page bulletin, is the 25th in the annual series presenting statistical and analytical tables of general interest on motor fuel, motor vehicles, highway-user taxation, State and local highway financing, road and street mileage, and Federal aid for highways.

The *Highway Statistics* series has been published annually beginning with the year 1945, but most of the earlier editions, except 1966, 1967, and 1968, are now out of print. However, much of the information presented in earlier editions is summarized in *Highway Statistics, Summary to 1965*, which may be purchased from the Superintendent of Documents for $1.25.

Interstate System Accident Research Study-1

Interstate System Accident Research Study-1, 1970 ($1.00 a copy), reports the results of an investigation of the safety record of the Interstate Highway System as compared to conventional existing highways. The study was a joint effort between 40 State highway departments and the Federal Highway Administration. It consists of three volumes:

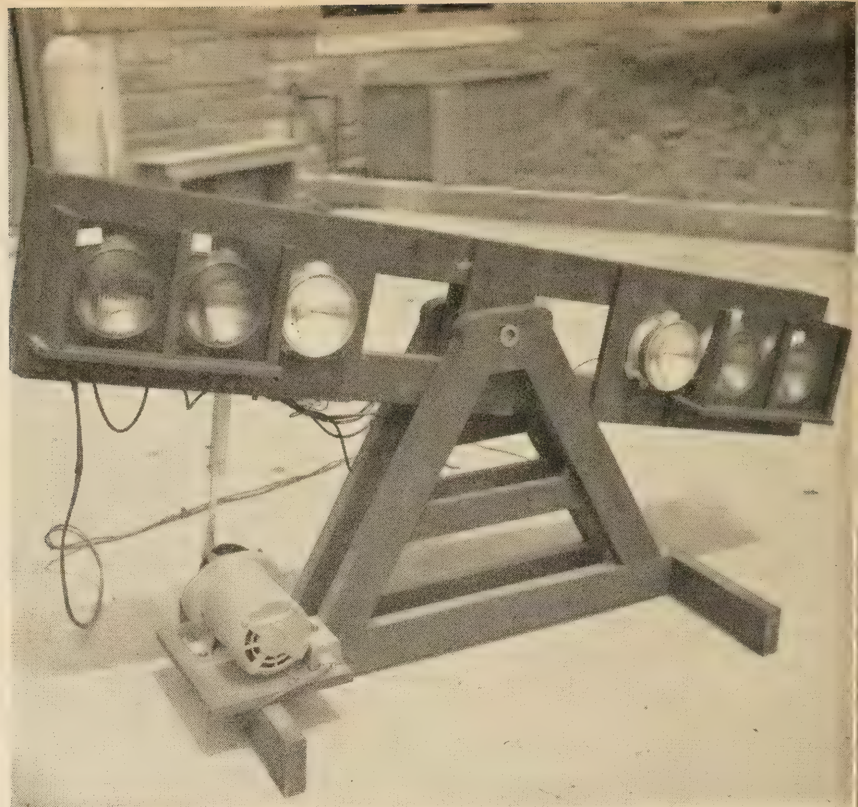
Vol. I—Comparison of Accident Experience on Interstate and Non-Interstate Highways—The Influence of Highway, Traffic, and Environmental Characteristics.

Vol. II—Property Damage Cost Analysis and Accident Reduction Benefits.

Vol. III—Analysis of Accident Expansion Factors.

Highway Transportation

Highway Transportation, November 1970 (65¢ a copy), a 40-page booklet, describes the programs of the Federal Highway Administration (FHWA) and related operations. To be issued on an irregular basis, this issue features highways in relation to public transportation, environmental factors, and safety, as well as reports of the Bureau of Motor Carrier Safety and other FHWA programs.



Mechanical headlights stand used in reported experiment to simulate vehicul roll at night.

Effect of Vehicular Roll on Polarized Headlighting

Report by[1] **WALTER S. ADAMS**
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The results of an experimental research study to explore the effect of vehicular roll on polarized headlighting performance and its effect on driver comfort are reported in this article.

Operation of a polarized headlighting system relies on the phenomenon that two polarizers with their planes of polarization mutually perpendicular permit only a negligible amount of light to pass through to an observer. However, if the polarizers are rotated, an increasing amount of light leakage occurs as the planes of polarization rotate away from their perpendicular relation. This leakage in polarized headlighting systems, caused by vehicular roll, was shown to have an insignificant effect on the ability of drivers to detect pavement markings at night, adding further support to the logic of using polarized headlighting systems. Neither high intensity polarized headlighting nor conventional high beam headlighting was significantly affected by vehicular roll.

Data obtained in the study showed that polarized headlighting improved target detection distances by 32 percent over high beam headlighting. Moreover, these same data, also used to analyze the relation between detection distances and lateral pavement-marking positions (centerline or shoulder), support the use of pavement-edge markings—an additional benefit obtained from the study.

Introduction

HIGH intensity polarized (HIP) headlighting for vehicles often has been proposed to improve the night-driving environment by reducing glare from the headlamps of approaching vehicles (*1, 2, 3*).[2]

The HIP headlighting system consists of dichroic filters placed in front of high intensity headlamps (100 watts or more) and an analyzing filter placed in front of the driver's eye. The planes of polarization of both the dichroic filters and the analyzer are 45 degrees from horizontal and parallel to each other. The planes of vibration of the light emerging from the headlamps are also 45 degrees from horizontal. A vehicle equipped in exactly the

[1] Work on the reported project was performed while Mr. Adams was on a temporary assignment with the Office of Research.

[2] Italic numbers in parentheses identify the references listed on page 157.

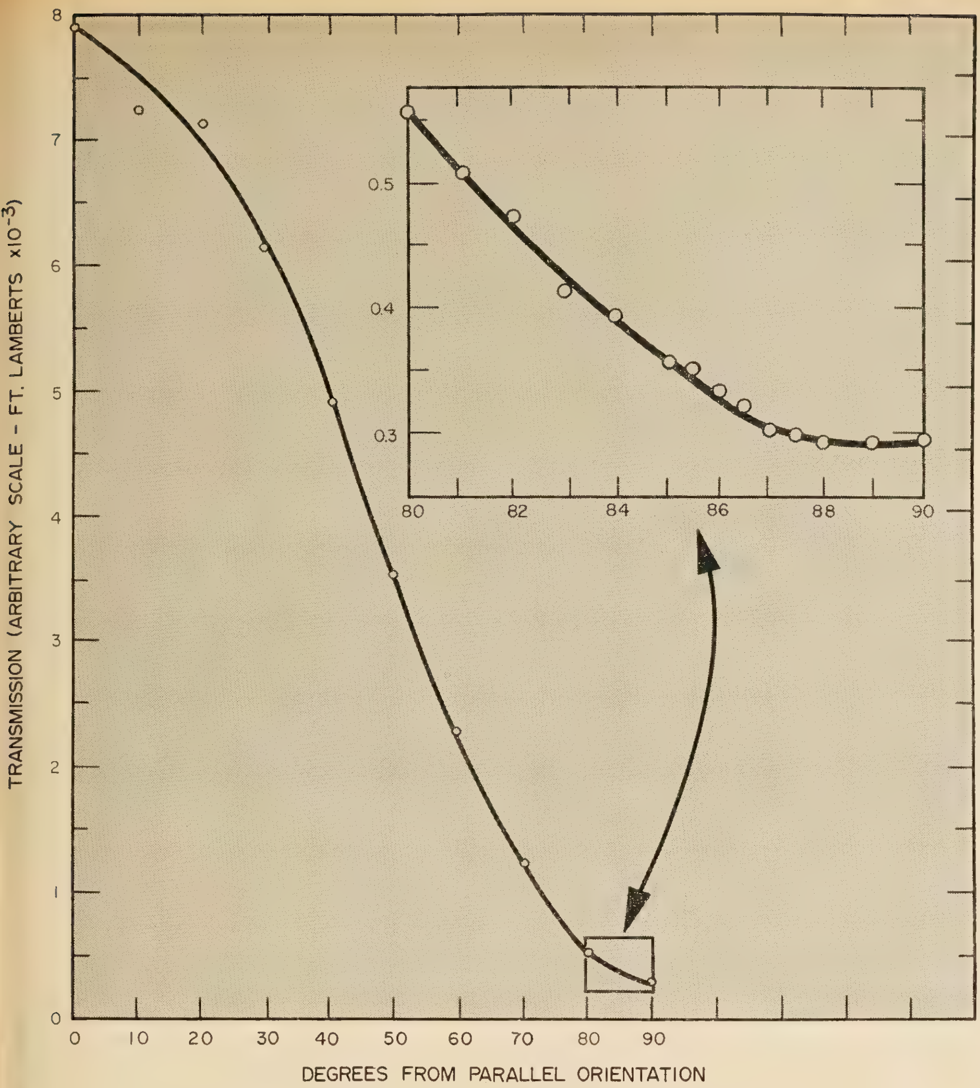

Figure 1.—Transmissivity of a typical polarizer or analyzer.

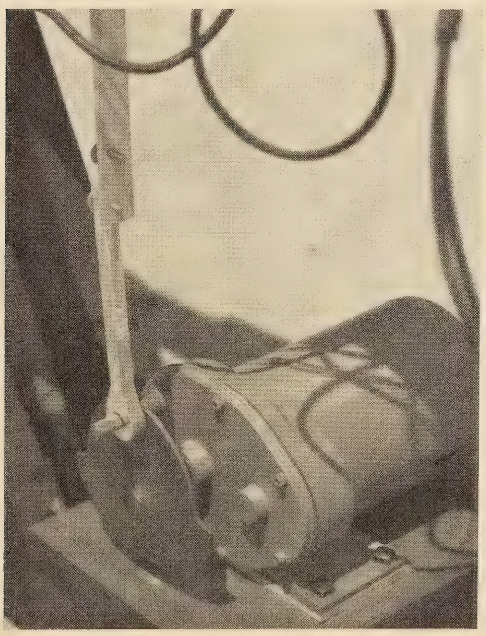

Figure 2.—Motor drive unit on headlight stand.

same manner, but approaching from the opposite direction, emits light with planes of vibration that are perpendicular to those of the original vehicle. Theoretically, with perfect polarizers, an opposing car viewed through an analyzer should appear to have no headlights and, consequently, no nighttime glare. Actually, the filters are not perfect, and perpendicularity seldom occurs, but the imperfect polarization has proved beneficial rather than detrimental. The small amount of light leakage allowed by imperfect filters aids in identifying approaching vehicles by producing a negligible amount of glare.

In the HIP system when the planes of opposing headlamp filters are not perpendicular to the planes of a viewer's analyzing filter, additional light leakage occurs. The amount of light leakage depends on the degree of misalinement between the two filters (see fig. 1). In previous studies of the polarized lighting system this misalinement has been kept to a minimum. Tests were usually conducted on airport runways or other surfaces where vertical geometric characteristics (crown and superelevation) bumps, holes, etc., are either marginal or nonexistent. Experimentally producing this misalinement or *roll* and measuring its effect on a group of test drivers was the prime objective of the study reported here.

The effectiveness of a vehicular lighting system can be measured by the distance at which a driver can detect a target illuminated by the system. This method of measurement has been used extensively in the evaluation of the polarized headlighting system (*4*). Its value lies in the fact that the need to see objects at a distance is most important to a driver. If his sight distance is increased, his time to react to a situation is lengthened, and the driving task is made easier. Detection distances was therefore one of the measurements used in this experiment to determine whether vehicular roll has an effect on the HIP system.

Dynamic studies of vehicular roll have shown that a practical maximum of 7° of roll occurs in moving vehicles on a highway,[3] which represents an occasional occurrence. Observation of an average roadway in the United States would substantiate the presence of vehicular roll, an inherent characteristic caused by the vehicle's instability and the road's geometric characteristics. When a vehicle passes from a superelevated section (horizontal curve) to a crown section (tangent) of highway, the transitioned pavement causes the vehicle to roll. Typically, rural highways have a maximum superelevation of 0.08 ft. per ft. of pavement width, corresponding to a roll angle of almost 6° if the normal crown of 0.02 ft. per ft. of pavement width in the opposite direction is also considered. Moreover, roadway bumps, potholes, vehicle suspension, and other factors contribute to vehicular roll. Therefore, two roll angles were used in this experiment: 7° as a practical maximum, and 15° as the theoretical maximum

[3] Personal communication with Dr. P. Robert Knaff, Chief, Driver Performance Division, National Highway Traffic Safety Administration, and based on data obtained by Dr. Leonard Segal, Highway Safety Research Institute, University of Michigan.

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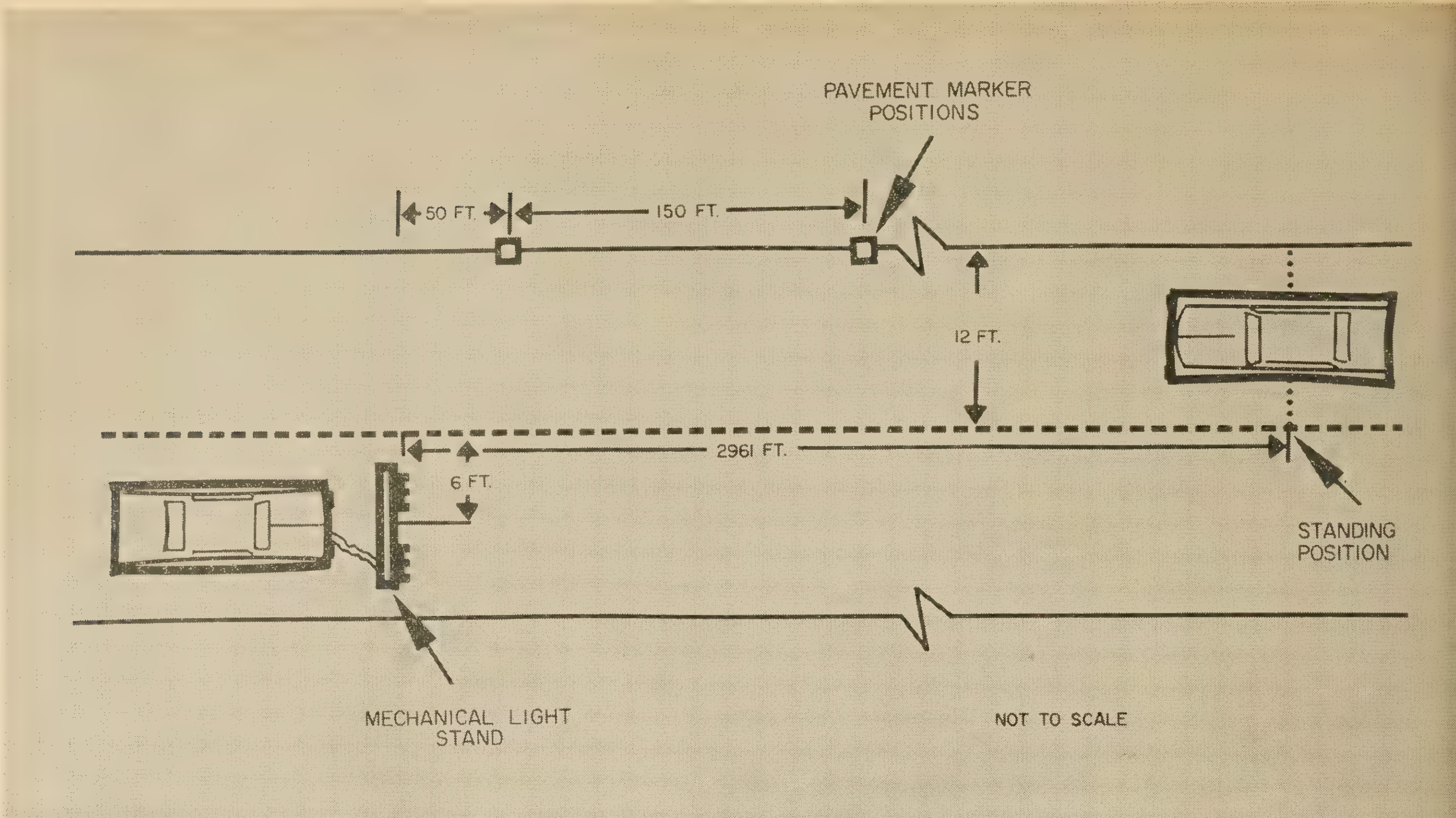

Figure 3.—Test track.

that might occur for short durations where two curves with maximum superelevations meet at full cloverleaf interchanges or where roll caused by vehicle suspension and superelevation are additive. An additional no-roll condition was used as a control.

In an effort to generalize the data from this study, the conventional high beam (HB) lighting configuration was included in the test runs as a control system. Thus the data obtained could be used to study the overall benefits of the HIP system. The control system was also used to determine whether the simulated roll produced in the study had any side effects on a conventional lighting system. The results could then be used in the final analysis of the effect of vehicular roll on the HIP system to correct any effects attributed to simulation. It was possible that the simulated roll would distract the subject driver more than real world roll and could significantly affect his detection ability.

To vary the detection task, four target positions were chosen. A fixed glare source was used with four separate target positions to produce four different glare conditions for each lighting system and roll angle. Also, test runs were randomized to prevent the drivers from becoming keyed to detecting any one target. For each of the eight drivers, 24 different combinations of the three variables were used (2 lighting systems × 3 roll angles × 4 target positions = 24 combinations). Each condition was repeated and eight control runs were added for a total of 56 runs. The eight control runs were divided between four no-opposing glare situations to obtain base data and four no-target situations to inhibit the drivers from guessing, and to determine whether in fact they were guessing. Design of the experiment involved the following four variables:

- Vehicular lighting systems—HB and HIP.
- Roll angle—0°, 7°, 15°.
- Target position (four)—centerline 50 feet, 200 feet; shoulderline 50 feet, 200 feet.
- Subjects—eight different drivers.

The data were then subjected to analyses of variance procedures to determine the statistical significance of results obtained. This procedure was used to determine whether the difference among variables occurred by chance alone.

Test Procedure

Field work for this experiment was done at the airport in the Agricultural Research Station in Beltsville, Md. A simulated stretch of tangent highway approximately three-quarters of a mile long was used as a test track. The bituminous surfaced test track was marked to provide two 12-foot lanes with 4-inch nonreflecting white solid-edge markings and dashed centerline. Although the simulated roadway lacked roadway crown and some environmental features—nearby trees, fences, mail boxes, etc.—th test track closely resembled a dark rur highway situation. There was no lighti interference from nearby facility buildin because they were not in active use duri the night testing hours.

Each series of test runs was preceded by short instruction period for the driver w was told that he was taking part in a highw research study but that, to assure an unbias performance, the basic reason for and t intent of the study wouldn't be discuss until the experiment was completed. On details related to his actual performan during the test were provided. At this ti and at the end of the series of test runs, t driver's reaction times were determine Average reaction times were used during t data reduction process to correct the drive detection distances.

Vehicular roll was simulated by mounti two sets of headlamps, HIP and HB, on mechanical stand (see illustration at beginni of article). The roll angle was controlled a motor-driven eccentric cam (see fig. 2) a had a frequency of 1 cycle per second, whi gave the driver sufficient repeated exposu to the full-roll condition to experience the r effect during the critical period of targ detection. As no crown existed on the te track, the three angles produced by the ca 0°, 7°, and 15°, were also the misalinem angles between the analyzer of the drive car and the headlights on the mechani stand. The headlight stand was placed in t

Table 1.—Detection distances for the two driver groups

Driver Groups		Detection Distance			
		HIP		*HB*	
Number	*Age*	*Average*	*Range*	*Average*	*Range*
		(feet)	*(feet)*	*(feet)*	*(feet)*
9	>30	263.2	184—346	168.8	89—294
11	<30	254.4	175—343	135.5	59—173

Table 2.—Five-way analysis of variance

Source of variation [1] [2]	Degree of freedom	Sum of squares	Mean square	*F* ratio	Significance level [3]
A	1	25,410,126	25,410,126	2,206.61	0.01
B	1	32,083	32,083	2.79	NS
AB	1	34,163	34,163	2.97	NS
C	2	4,609	2,304	.20	NS
AC	2	19,183	9,591	.83	NS
BC	2	29,304	14,652	1.27	NS
ABC	2	23,486	11,743	1.02	NS
D	1	7,986,834	7,986,834	693.42	.01
AD	1	7,455	7,455	.65	NS
BD	1	645	645	.06	NS
ABD	1	13,324	13,324	1.16	NS
CD	2	22,879	11,439	.99	NS
ACD	2	75,545	37,772	3.28	.05
BCD	2	73,408	36,704	3.19	.05
ABCD	2	69,017	34,508	3.00	NS
E	7	18,491,949	2,641,707	229.35	.01
AE	7	1,779,094	254,156	22.07	.01
BE	7	593,679	84,811	7.36	.01
ABE	7	240,403	34,343	2.98	.01
CE	14	186,587	13,327	1.16	NS
ACE	14	164,227	11,730	1.02	NS
BCE	14	111,728	7,980	.70	NS
ABCE	14	347,159	24,797	2.15	.05
DE	7	1,865,890	266,555	23.14	.01
ADE	7	291,468	41,638	3.62	.01
BDE	7	83,539	11,934	1.04	NS
ABDE	7	185,152	26,450	2.30	.05
CDE	14	229,511	16,393	1.42	NS
ACDE	14	81,145	5,796	.50	NS
BCDE	14	457,789	32,699	2.84	.01
ABCDE	14	109,567	7,826	.68	NS
Within SS	192	2,211,445	11,517	------------	------------
Total SS	------------	480,737,224	------------	------------	------------

[1] A=Lateral position (centerline, shoulder).
B=Longitudinal position (50 feet, 200 feet).
C=Roll angle (0°, 7°, 15°).
D=Lighting system (HIP, HB).
E=Subjects (8).

[2] SS=Sum of squares.

[3] NS=Not significant.

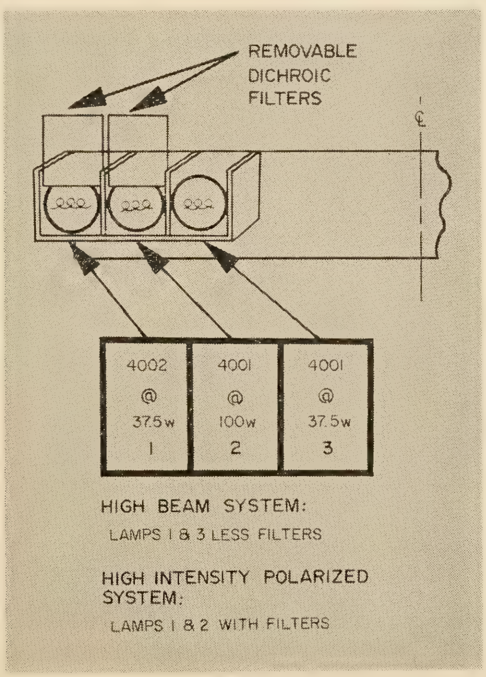

Figure 4.—Lighting systems.

center of the opposite lane and simulated an opposing passenger car as shown in figure 3. The headlamps on the stand were powered through a direct connection to the electrical system of an auxiliary vehicle with its engine idling at a constant speed. The input voltage to each headlamp was therefore maintained at approximately 12.5 volts.

The detection target used in the tests was a commercially available 4- by 4-inch two-faced, retroreflective, raised corner-cube pavement marker button. The reflective surfaces were shaped like an isosceles trapezoid with 3⅛- by 3⅝-inch bases and a 1¹⁄₁₆-inch altitude. The larger base was placed on the pavement and the smaller base was elevated ½ inch above the pavement. The marker was located at any of four positions: two of the marker positions were on the shoulder edgeline and two on the centerline as shown in figure 3. The driver approached the target at a constant speed of approximately 40 m.p.h. after accelerating from a fixed starting position. Upon detection of the target, the driver was asked to activate the test vehicle's horn. This action stopped a digital measuring device that recorded distance traversed to the nearest 0.0002 miles or approximately 1 foot. With the distance traversed and reaction-time corrections available, a corrected detection distance could be determined for each run. The driver was allowed one practice run to become familiar with the appearance of the target.

After completing each test run, the driver was asked to evaluate subjectively the discomfort he experienced from the opposing glare source. The evaluation was reported to an observer in the back seat of the test vehicle. The driver then returned to the starting position while appropriate adjustments were made to the lighting stand, target positions, and measuring device.

Both the test vehicle and the mechanical stand were equipped with three pairs of headlamps (fig. 4). The HB system comprised pairs of standard type 4001 and 4002 sealed-beam lamps, or four 37.5-watt filaments operated conventionally. The HIP system comprised a pair of type 4001 sealed-beam lamps with special 100-watt filaments, plus a pair of 4002 lamps using the standard 37.5-watt filaments. Dichroic filters placed in front of the HIP light sources produced the high intensity polarized light. The analyzer, which completes the HIP system, consisted of special polarizing glasses similar to polarized sunglasses, except for orientation of the polarizing material. The observer in the test vehicle referred to the glasses as *sunglasses* and, to avoid influencing the drivers' subjective evaluations of the two types of lighting systems, informed the driver when to wear or remove them. These analyzers, or *sunglasses*, were used only during the HIP test runs.

A copy of the pre-arranged random order of runs was available to the observer, who changed the lenses and lamps of the vehicle and recorded, for each run, both the distance measurement and the subject's discomfort glare evaluation. The observer otherwise played a passive role in the rear seat of the vehicle, restricting communication with the test driver to the minimum.

During the pre-test instruction period, each driver was advised that some of the many runs to be made would omit the target or opposing headlights. These were control runs that were included to encourage drivers to be alert at all times. It was theorized that an awareness of the possibility that any run might be a control run would deter a subject's inclination to act from sheer habit as the study progressed.

Experimental Drivers

Eight University of Maryland students, 18 to 23 years old, were chosen to be subject drivers in the experiment. Their driving experience is shown in the following tabulation:

Age	*Years of driving experience*	*Miles of driving per year*
18	1½	6, 000
18	2	20, 000
20	4	10, 000
21	3½	15, 000
21	4	10, 000
22	3½	17, 000
22	6	20, 000
23	6	6, 000

It was considered unnecessary to employ a heterogeneous group of drivers or to obtain the visual acuity of each driver, as the object of the experiment was to determine differences in an individual's detection distances for several pertinent variables rather than differences among the subjects. The homogeneous group used was further justified by data collected by Hemion (*4*), who provided an additional subdivision of his line-target data by age groups under 30 and over 30. Detection distances for the two groups were about equal for the HIP system, the principal lighting system of interest in the present study. The older group had only slightly longer detection distances for the HB system. These results are shown in table 1.

Results

The statistical procedure known as *analysis of variance* was used to determine whether differences in detection distances were real or caused by experimental error. A general discussion of the results is presented first and followed by a more detailed discussion of some of the principal variables of interest.

Results of a five-way analysis of variance, which contains the following independent variables, are shown in table 2:

A. Lateral position of pavement-marker target—centerline or shoulder.

B. Longitudinal position of pavement-marker target—50 or 200 feet from the glare source.

C. Roll angle—0°, 7°, 15°.

D. Lighting system—HIP or HB.

E. Subject drivers—eight.

Table 3.—Four-way analysis of variance, high intensity polarized (HIP) system

Source of variation [1] [2]	Degree of freedom	Sum of squares	Mean square	*F* ratio	Significance level [3]
A	1	13, 144, 040	13, 144, 040	839. 75	0. 01
B	1	11, 812	11, 812	. 75	NS
AB	1	2, 408	2, 408	. 15	NS
C	2	4, 280	2, 140	. 13	NS
AC	2	42, 523	21, 261	1. 34	NS
BC	2	90, 381	45, 190	2. 85	NS
ABC	2	84, 836	42, 418	2. 68	NS
D	7	15, 149, 990	2, 164, 284	136. 63	. 01
AD	7	993, 492	141, 927	8. 96	. 01
BD	7	383, 910	54, 844	3. 46	. 01
ABD	7	219, 272	31, 324	1. 98	NS
CD	14	251, 193	17, 942	1. 13	NS
ACD	14	115, 939	8, 281	. 52	NS
BCD	14	341, 615	24, 401	1. 54	NS
ABCD	14	310, 012	22, 143	1. 40	NS
Within SS	96	1, 520, 698	15, 840	----------	----------
Total SS	----------	304, 295, 870	----------	----------	----------

[1] A = Lateral position (centerline, shoulder).
B = Longitudinal position (50 feet, 200 feet).
C = Roll angle (0°, 7°, 15°).
D = Subjects (8).
[2] SS = Sum of squares.
[3] NS = Not significant.

Table 4.—Four-way analysis of variance, high beam (HB) system

Source of variation [1] [2]	Degree of freedom	Sum of squares	Mean square	*F* ratio	Significance level [3]
A	1	12, 273, 541	12, 273, 541	1, 705. 84	0. 01
B	1	20, 916	20, 916	2. 91	NS
AB	1	45, 080	45, 080	6. 27	. 05
C	2	23, 209	11, 604	1. 61	NS
AC	2	52, 204	26, 102	3. 63	. 05
BC	2	12, 331	6, 165	0. 86	NS
ABC	2	7, 667	3, 833	0. 53	NS
D	7	5, 207, 850	743, 978	103. 40	. 01
AD	7	1, 077, 070	153, 867	21. 39	. 01
BD	7	293, 307	41, 901	5. 82	. 01
ABD	7	206, 283	29, 469	4. 10	. 01
CD	14	164, 905	11, 778	1. 64	NS
ACD	14	129, 432	9, 245	1. 28	NS
BCD	14	227, 903	16, 278	2. 26	NS
ABCD	14	146, 714	10, 479	1. 46	NS
Within SS	96	690, 747	7, 195	----------	----------
Total SS	----------	176, 441, 354	----------	----------	----------

[1] A = Lateral position (centerline, shoulder).
B = Longitudinal position (50 feet, 200 feet).
C = Roll angle (0°, 7°, 15°).
D = Subjects (8).
[2] SS = Sum of squares.
[3] NS = Not significant.

Table 5.—Mean values of detection distances for opposed-glare conditions

	High intensity polarized (HIP)	High beam (HB)	△ HIP—HB	
			Feet	Percent
Vehicular roll:	*Feet*	*Feet*		
0 degrees	1, 181	916	265	29
7 do	1, 198	895	303	34
15 do	1, 189	892	297	33
Target position:				
50 c/l [1] feet	928	654	274	42
200 c/l do	933	643	290	45
50 Sh [1] do	1, 438	1, 128	310	27
200 Sh do	1, 458	1, 180	278	24
All data	1, 189	901	288	32

[1] c/l = centerline, Sh = shoulderline.

The variable of principal interest roll angle, C, was not significant (see table 2), and its first-order interactions were also not significant. Two second-order roll interactions, ACD and BCD, were significant at the 0.05 level of confidence. To further analyze these and other interactions, the analysis was reduced to two four-way analyses of variance, considering the data for each lighting system HB and HIP separately (see tables 3 and 4). The second-order ACD and BCD interactions of the five-way analysis of variance were then reduced to two first-order interactions AC's and BC's. The AC interaction was not significant for the HIP system and significant only at the 0.05 level of confidence for the HB system. The BC interactions were not significant for either lighting system. In summary, the results of these analyses indicate that roll angle has no effect on the HIP system and only a minor effect on the conventional high beam lighting when roll angle and lateral position interact.

The lateral position of the pavement-marker target, A; lighting systems, D; and subjects, E; were significant main variables of the five-way analysis of variance at the 0.01 level of confidence (table 2). The only significant first-order interactions of these variables were those that interacted with subjects, E. This expected result probably was due to differences in visual acuity and glare sensitivity among subjects. The remaining variable, longitudinal position, B, of the pavement-marker target, did not have a significant effect on detection distances. This finding was consistent with earlier work by Hemion (4).

Vehicular roll

As stated previously, three simulated roll conditions were considered in the study. The maximum simulated roll of 15° was well above the maximum roll angle likely to be encountered in highway driving, Therefore, since

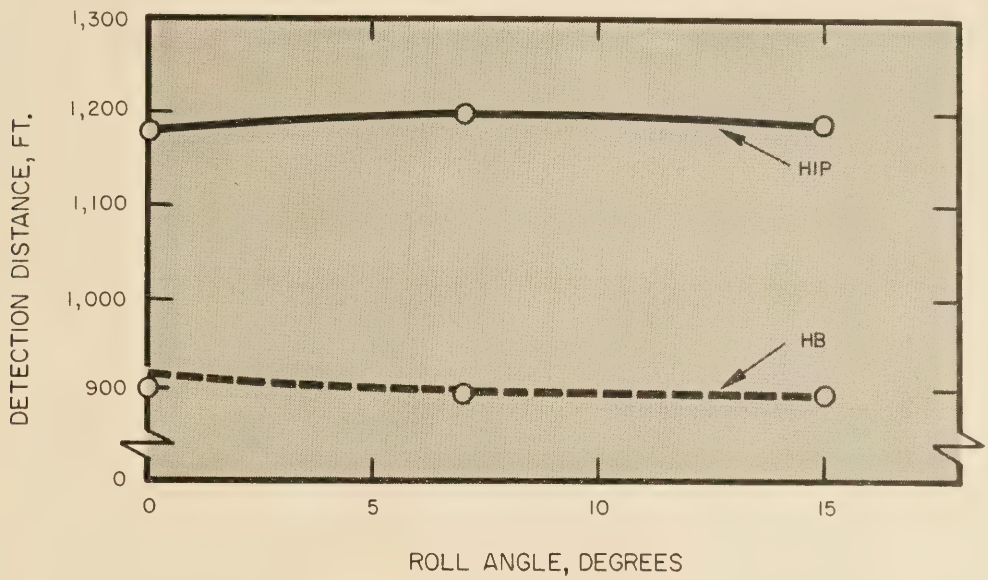

Figure 5.—Effect of roll angle on detection distances.

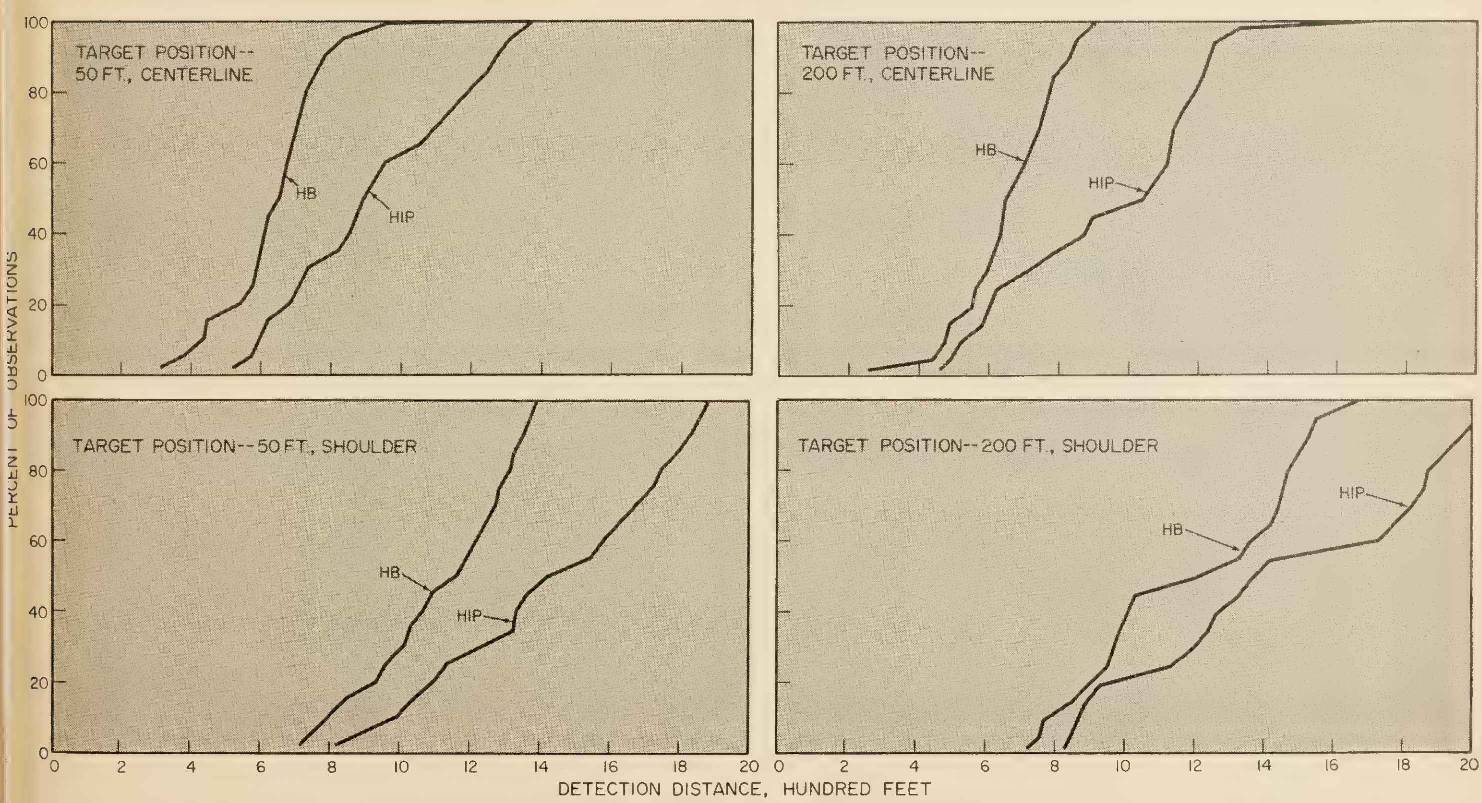

Figure 6.—Cumulative distributions for each of four target positions.

it was determined that detection distances were not affected by roll angles as large as 15°, the overall effect of roll on the HIP system can be considered negligible. As noted earlier, the four-way analysis of variance on the HIP data shown in table 3 indicated no significant differences in detection distances among the three roll angles. These data are summarized as mean values in table 5 and figure 5. The analysis of variance of the HB data also showed no significant difference in detection distances at the three-roll angles. Mean values for the HB system are also summarized in table 5 and figure 5.

Target position

Although target position was included as a variable primarily to prevent drivers from guessing, it also contributed useful information to the study. Laterally, the target was located on either the centerline or shoulderline. With the target on the shoulderline, average detection distances were 500 feet longer than with the target on the centerline. Cumulative distributions for each target position are shown in figure 6. The mean values for detection distance–target position are shown in figure 7. This magnitude of improved detectability was present regardless of which lighting system was used. Statistically, the 500-foot improvement of shoulder-edge markings compared to centerline markings was significant at the 0.01 confidence level for each lighting system tested. These results support the use of pavement-edge markings in highway delineation.

Four no-target runs per subject were included to discourage the experimental drivers from guessing. All 32 runs were recognized as such and no false responses were recorded. Therefore, it was assumed that the drivers had followed instructions and indicated detection only when they were sure that a target was present.

Discomfort glare evaluations

Discomfort glare was evaluated subjec tively and recorded immediately following eac run. Any discomfort glare that the drive had encountered during any part of tha run was rated according to the following 0 t 6 scale:

Rating	*Discomfort glare*
0	No problem.
1	
2	Bothersome.
3	
4	Quite uncomfortable.
5	
6	Practically blinding.

The HIP system's mean value of discon fort glare was approximately two points le bothersome than the HB system on the point scale. These values compared w with studies done by Hemion (4).

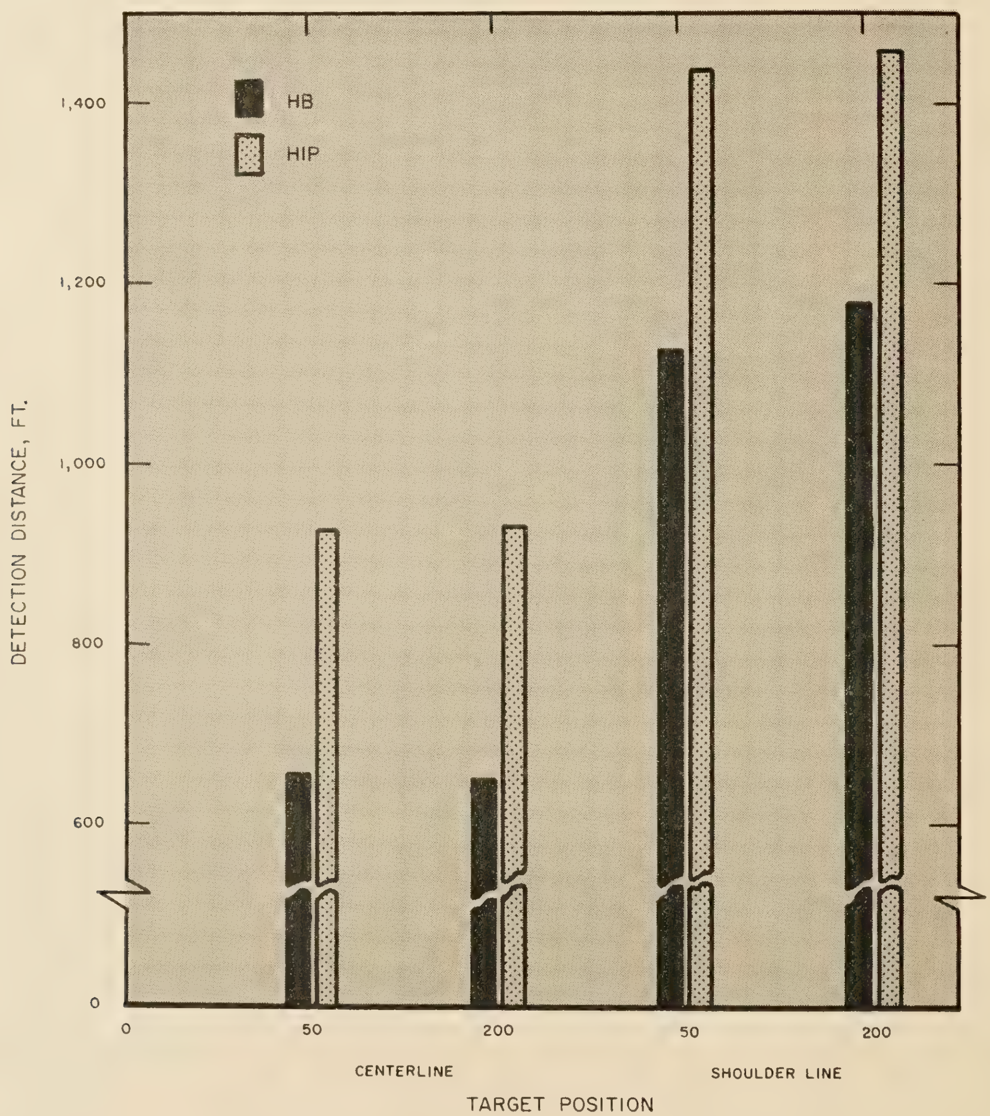

Figure 7.—Effect of target position on detection distance.

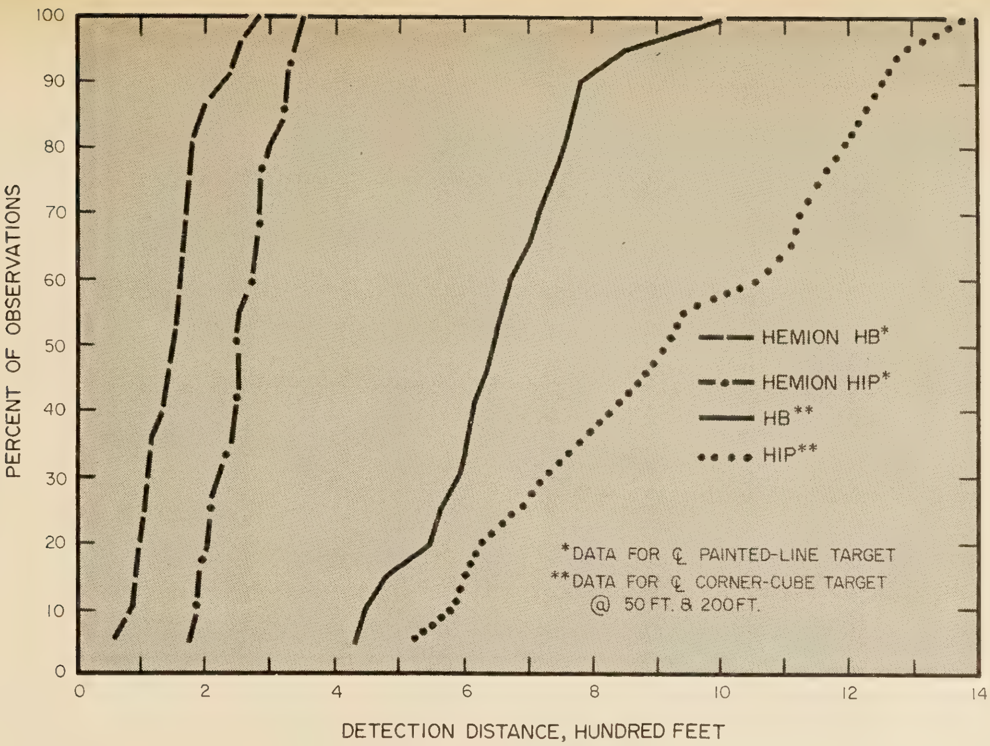

Figure 8.—Comparison of detection distances for beaded-paint and corner-cube centerline targets.

Mean values of discomfort glare evaluations or the eight drivers are as follows:

oll angle	HIP	HB	Difference
°	1. 44	3. 69	2. 25
°	1. 55	3. 58	2. 03
5°	1. 81	3. 75	1. 94
ll	1. 60	3. 68	2. 08

For either the HIP or the HB lighting ystem, the differences in discomfort glare valuations among the three roll conditions vere less than 0.4 point compared with the -point difference noted between the HIP nd HB systems. These results clearly indicate hat vehicular roll has only a minimal effect n the discomfort glare evaluations of either he HIP or the HB lighting system.

ighting mode

Although this experiment was not designed o determine differences between the HIP nd HB lighting systems, such a comparison ıvolving vehicular roll—a variable not explored in earlier studies—is possible. As shown ı table 5, detection distance was improved 2 percent by using the HIP system rather ıan the HB system during the meeting tuation. These data were statistically significant at the 0.01 level of confidence. With ıe HIP system, the average detection disınce for the eight drivers was 1,189 feet, or 38 feet (32 percent) more than the 901 feet veraged with the HB system. Averages were omputed from each driver's 48 opposed-glare runs of which 24 were HB and 24 were HIP runs.

The foregoing comparison of the two lighting modes agrees with similar studies by Hemion, which showed a 54 percent improvement in detection distances with the HIP system in the opposed-glare condition. The 54 percent–32 percent differences between the two studies can be attributed to the use of different targets, target positions, and test subjects. Sign, pedestrian, and no-passing beaded-paint-strip targets were used in the Hemion studies, whereas highly reflective corner-cube marker targets were used in the study reported here.

Data from the two studies were analyzed to compare detection distances for beaded paint and corner-cube markers. Data for centerline pavement markings in the opposed glare condition from both studies are plotted in figure 8. Data for shoulder markings are not shown, as shoulder targets were not used in the Hemion study. The 50th percentile detection distance, shown in figure 8 for the HIP system, was 223 percent greater with the corner-cube reflective marker than with beaded paint. The comparable value for the HB system was 265 percent. Accordingly, a more widespread use of corner-cube reflectors on centerline markings seems desirable where they are not likely to be removed by snowplow blades. The comparison in figure 8 also makes possible a more direct comparison of the two lighting systems. With the HIP system, target detection distances were 42 percent longer (50th percentile) than with the HB system, according to the experiment's centerline data. The corresponding figure for Hemion's centerline beaded-paint pavement-marking data was 64 percent.

No-glare condition

Analysis of data for the no-glare condition was not originally considered in the experiment, and only a few no-glare test runs were made, resulting in an unbalanced set of data. For some conditions no data existed, yet for others, one, two, or three, data points were available. Although the data as collected could not provide a statistically sound analysis of the no-glare condition, it appeared that the two lighting systems, HIP and HB, each produced distances of the same relative magnitude—±10 percent. Detection distances for no-glare runs were 42 and 106 percent longer for the HIP and HB systems, respectively, than for comparable opposed-glare runs. The distraction effect of the oscillating opposing-glare source might have accounted for these differences.

A comparison plot of opposed-glare and no-glare conditions are shown in figure 9. To obtain a more meaningful comparison of the two glare conditions, the no-glare values plotted are not the averages of the available detection distances for any particular condition. All drivers were not exposed to each condition, and an average derived from only a part of them may have resulted in nonrepresentative points owing to different visual acuities among the drivers. To help offset this imbalance, the no-glare values plotted are the mean of the differences in detection distance among the available subject's no-glare and

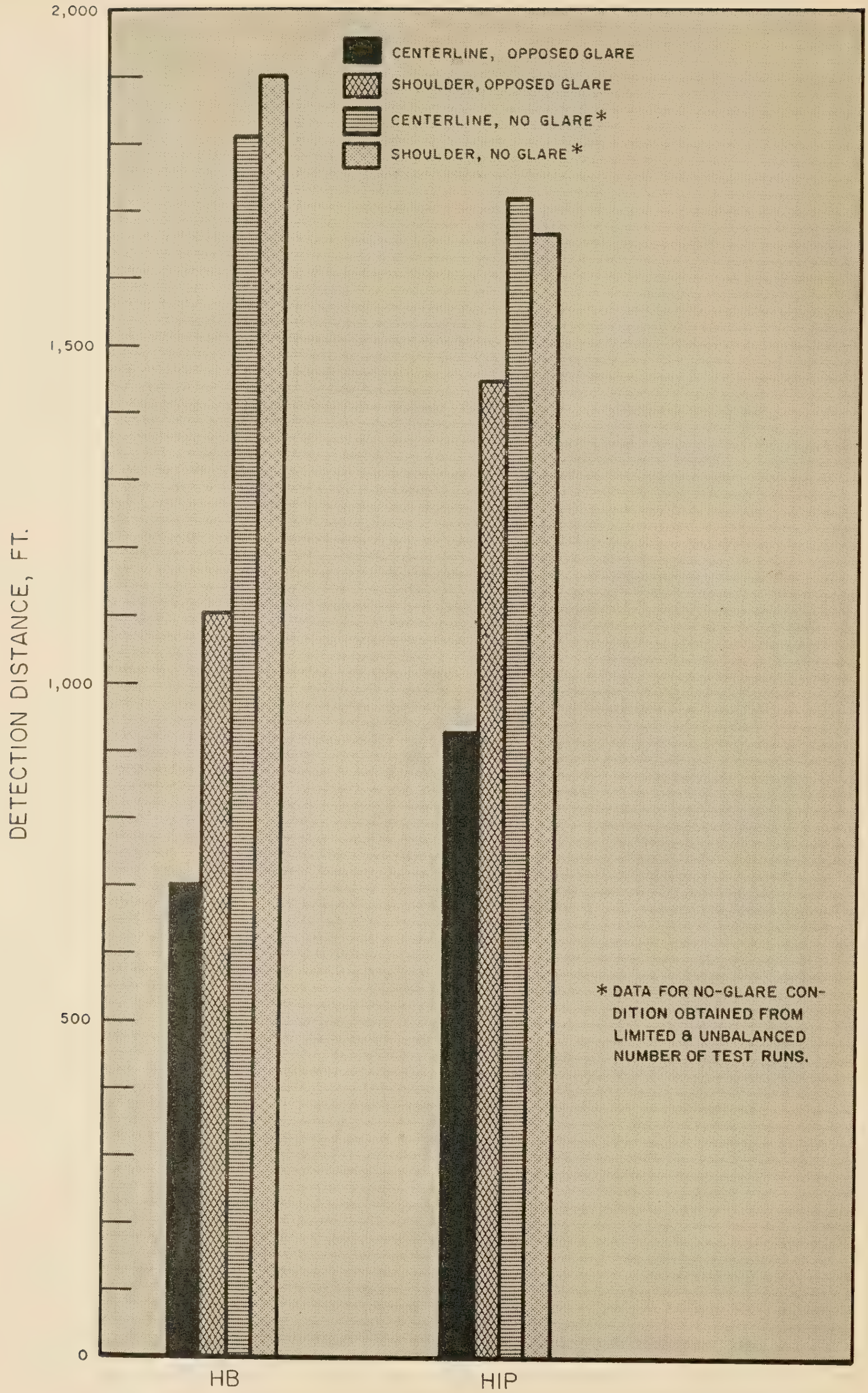

Figure 9.—Comparison of detection distances for centerline and shoulder targets, opposing-glare and no-glare conditions.

opposed-glare runs for a particular condition added to the eight subject's mean value for the comparable opposed-glare condition.

Summary

Within the bounds of this experiment, vehicular roll has no detectable effect on the performance of high intensity polarized headlighting systems. The amount of light leakage resulting from vehicular roll or imperfect lenses that the system can tolerate without causing significant glare problems to the driver is a question that remains unanswered. Further studies of the system should consider the maximum leakage that the system can tolerate and how this leakage could be beneficial. It is evident that a perfect system is not necessary and, in fact, may prove undesirable. Small amounts of light leakage aid in vehicle detection and could possibly be employed to improve illumination. Additional illumination could be made available by altering the polaroid lenses to admit directionally-controlled-unfiltered light rays. These unfiltered rays could be those illuminating the area to the right of the vehicle. Driver appreciation research by Jehu (*5*) would appear to support this position.

The HIP system proved superior to conventional high beams by improving detection distances by 32 percent during meeting situations and by reducing glare from opposing vehicles. Refinements, one of which is discussed in the preceding paragraph, possibly could make the system even more beneficial and acceptable to the motoring public.

Subjective glare evaluations were the only measurements related to comfort and fatigue. The effect that vehicular roll, or light leakage, has on comfort and fatigue is considered as important as the significant improvement in detection distances. The Federal Highway Administration is now exploring more meaningful ways to assess the dollar value a driver assigns to nighttime visual comfort.

Target-position data, although unrelated to lighting modes and vehicular roll, are related to highway delineation. The recent widespread use of pavement-edge markings to delinate roadways in the United States has been considered desirable, but only limited proof of its accident-prevention benefits exists (*6, 7*). Moreover, in this regard, traffic operation studies have been inconclusive. The target-position data of the experiment reported here substantiate the belief that shoulderline markings, at least during opposed-glare conditions, are beneficial. The mean detection distance was more than 500 feet longer for shoulderline targets than for centerline targets. Considering that a driver's need for roadway delineation is greatest when opposing headlights set up a glare situation, shoulderline marking with its additional detection-distance characteristics (see fig. 7) fulfills drivers' needs during these critical periods.

Conclusions

The following conclusions are based on drivers' abilities to detect a raised corner-cube pavement marker when two vehicles, both of which are equipped with high intensity polarized headlights or alternatively with conventional high beam headlights, meet at night on a two-lane rural highway.

- Vehicular roll has an insignificant effect on detection distances and a minimal effect on subjective glare evaluations.
- The high intensity polarized system improves detection distances by 32 percent and reduces discomfort glare over the conventional high beam headlighting system.
- The lateral position of the pavement-marker target has a significant effect on detection distances. Targets located on shoulderline provided 500 feet of additional detection distance over the same target, under the same conditions, that were located on centerline. These results support the use of pavement-edge markings in roadway delineation.

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(*3*) *The Polarized Headlight System*, by Edwin H. Land, HRB Bulletin No. 11, 1948, pp. 1–20.

(*4*) *The Effect of Headlight Glare on Vehicle Control and Detection of Highway Vision Targets*, by Roger H. Hemion, Southwest Research Institute, Report No. AR–640, May 1968, NTIS Report No. PB 179441.

(*5*) *Some Polarized Headlight Systems*, by V. J. Jehu, Illuminating Engineering Society Transactions (London), vol. 21, No. 7, 1956, pp. 160–167.

(*6*) *Effect of Pavement Edge Markings on Traffic Accidents in Kansas*, by A. J. Basile, HRB Bulletin No. 308, 1962, pp. 80–86.

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Digest of Recent Research and Development Results

Reported by the Implementation Division, Office of Development

The items reported here have been condensed from highway research and development reports, predominantly of Federally aided studies. Not necessarily endorsed or approved by the Federal Highway Administration, the items have been selected both for their relevancy to highway problems and for their potential for early and effective application.

Each item is followed by source or reference information. Reports with an "NTIS" reference number are available in microfiche (microfilm) at 95 cents each or in paper facsimile at $3 each from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

EVALUATION OF SHRINKAGE—COMPENSATED CEMENT CONCRETE

Extremely low resistance to sulfate attack is indicated for concrete beams made with shrinkage-compensated cement, based on accelerated weathering tests simulated by alternate drying and wetting in sodium sulfate solution. Comparable beams made with type II cement proved to have considerably more resistance. With respect to cracking, a reinforced concrete box girder bridge deck using shrinkage-compensated cement exhibited about the same amount of cracking at 15 months as a similar deck made with type II cement.

Evaluate Performance Characteristics of Expanding Cement Concrete, 1968, California Division of Highways Report No. D-3-24. NTIS No. PB-18075.

DYNAFLECT EVALUATION

Extensive evaluation of the Lane-Wells *Dynaflect* system (a towed pavement surface testing and recording device) indicates satisfactory and reliable performance in measuring deflections on either (1) Subgrade during construction, or (2) pavement systems needing remedial or preventive maintenance. The system is economical, fast, and highly mobile. Versatility of the Dynaflect appears to open up the feasibility of other potential areas of research.

Evaluation of the Lane-Wells Dynaflect, 1968, California Division of Highways, Report No. D-4-64.

CONCRETE SURFACE WEAR TESTS

Wear tests in the laboratory on concrete made with three different aggregates and several different cement contents yield the following findings:

- Compressive strength is not a good indicator of wear resistance.
- Harder coarse aggregate did not always provide the greater resistance to wear.
- Concrete wear resistance improved with increased cement content up to six sacks.
- Concrete using light-weight coarse aggregates always had less wear resistance than did concrete of normal-weight coarse aggregate.
- Admixtures reduced wear resistance in some cases.

A correlation between rates of wear on the roadway versus the laboratory is desirable.

Concrete Wear Study, 1968, Louisiana Department of Highways, Report No. 63-8c. NTIS No. PB-183410.

BITUMINOUS ROLLING WITH SOLID-RUBBER TIRES

In a roller performance comparison study of solid-rubber tired versus high-contact-pressure pneumatic rollers, it was found that both types required the same number of passes for optimum compaction of freshly paved hot-mixed asphaltic concrete, with no significant difference in either performance or compaction results. Best initial rolling temperatures on the binder course were 200° F., using a pneumatic roller contact pressure of 85 p.s.i., and 180° F., for the solid-rubber-tired roller.

Solid Rubber Tired Roller Study, 1968, Louisiana Department of Highways, Report No. 63-4B. NTIS No. PB-180533.

PAVEMENT QUALITY CONTROL

In a recent study, control tests during construction of portland cement concrete pavement and bituminous paving mixtures were taken in a form suitable for statistical evaluation. The results demonstrated a practical acceptance plan able to reflect realistically the level and variability of quality achieved. The plan also provides a realistic tool for price penalties when quality does not measure up. For concrete pavements on most projects the coefficient of variation was generally satisfactory, but testing errors were somewhat high. For bituminous paving mixtures, tests indicated excessive variation in bitumen content. A newly developed pycometer method of measuring bitumen content appears promising. Nuclear density measurements of bituminous pavement provided quick and satisfactory information. The study illustrates how better job control can be realistically attained.

Determination of Statistical Parameters for Highway Construction, 1968, West Virginia Department of Highways, Report No. 18. NTIS No. PB-182328.

BIAS INTRODUCED BY WIDELY USED STANDARD SAMPLING TECHNIQUES

The widely used standard sampling techniques currently employed in highway construction for quality control introduce a significant bias favor of acceptance. This is indicated by comparisons with research data obtained through statistical random sampling. Examination of specific items on 18 projects clearly indicated, in each instance, less than 100 percent compliance with specification limits. The report by the California Division of Highways concluded that statistical specifications providing better control can be devised without a significant cost increase. Other selected conclusions were:

- Moving-average control charts can positively control gradation of aggregate.
- The Kelly Ball can effectively measure consistency of concrete.
- Nuclear devices can adequately control density of embankments.
- A statistical acceptance plan can substantially reduce acceptance testing of Spelter coating on C.M.P.

Study of Statistical Methods of Quality Control, California Division of Highways, Report No. F–1–1.

PILE DRIVING ANALYSIS—STATE OF THE ART

The rational approach of the wave equation for solving pile-driving problems has long been recognized as more precise than the many empirical formula methods. Computers have now made it practical to utilize the complicated computations of the wave equation for evaluation and correlation of pile-driving solutions obtained with commonly used empirical formulas. Seven years of intensive investigation and correlation analysis have clearly shown the degree and consistency of variations in formula-calculated load capacity within a typical range of pile parameters as predicted by commonly used empirical formulas. The correlation results have contributed significantly to improvements in the formulas commonly applied in field calculations. A condensed summary of these investigations is expected to be available in the near future.

A Comparison of Dynamic Pile Driving Formulas With the Wave Equation, April 1968, Texas Highway Department, Report No. 2–5–62–33.

WELDED JOINT GUIDE SPECIFICATIONS FOR LARGE, HIGH-STRENGTH STEEL REINFORCING BARS

Welding test evaluations have produced a complete set of recommended guide specifications for welded joints in large-size, high-strength reinforcing steel. Joints prepared and welded in accordance with proposed specifications should preserve at least 85 percent of the tensile strength and 50 percent of the ductility available in the unwelded bar. However, results also indicated that welded tensile strength equal to 90 percent of that of the unwelded bar is the most that can be expected from butt-welded joints. Test welds on ASTM A–408, A–431, and A–432 steels showed that electrodes of 308 stainless steel are not suitable for welding butt joints.

Mechanical Properties and Specifications for Welded Joints on Large High-Strength Steel Reinforcing Bars, September 1968, California Division of Highways, Study No. D–4–28. NTIS No. PB–180722.

CONCRETE BOX BEAM DESIGN

Test results demonstrate that omitting end blocks and interior diaphragms does not significantly affect torsional rigidity of prestressed concrete box beams, indicating an opportunity for savings both in material and workmanship costs. Pure bending and a combination of bending and torsional stresses were applied to four prestressed concrete box beams by static loading in the laboratory. The four beam depths were 36, 36, 27, and 17 inches respectively. One of the 36-inch beams had end blocks and interior diaphragms; the other three had none. The final phase of the study will involve tests of a large full-scale model of a box beam bridge.

Through-Voided and Conventional Box Beams Subjected to Combined Bending and Torsion, January 1969, Pennsylvania Department of Transportation, Report No. 100.

IMPROVED ACCURACY IN DESIGN OF CONCRETE BOX GIRDER BRIDGES

New design equations for multicelled, straight, nonskewed box girder bridges are believed to yield improved structural economy and design accuracy. The greater accuracy in calculating wheel load distribution results from allowing for effects of span length, total bridge width, number of lanes, number of cells, cell width, and fixity at the supports. The new method owes its practical feasibility to high speed digital computers. About 120 separate computer analyses of different loadings were utilized in developing the new design equations.

Wheel Load Distribution in Concrete Box Girder Bridges, January 1969, California Division of Highways, Report No. D–4–53. NTIS No. PB–183923.

DESIGN REFINEMENTS FOR LARGE METAL PIPE CULVERTS

Recent study results confirm the validity of the *imperfect trench* method for placing large diameter metal pipe culverts in high rock fills. However, it is of interest to designers that the measured horizontal load on the pipe was found to be higher than expected. The various instrumental measurements correlated well. The results can be used to refine fill height and gage tables for pipe culverts as well as culvert design procedures. The study should encourage increased acceptance of the *imperfect trench* method for culvert installation.

Behavior of the Rebuilt Wolf Creek Culvert, 1968, Montana State Highway Commission, Study Item No. R–11. NTIS No. PB–179884.

EPOXY CONCRETE HEADERS ARE SUPERIOR

Epoxy concrete *post-cast* header construction for bituminous concrete pavements at bridge expansion joints is superior in durability, according to comparison tests with 12 other types of headers, eight of portland cement concrete and four of the steel angle type. Concrete variables involved type of cement, reinforcing steel, and type cure. Thickness of metal (1/4 inch and 1/2 inch) was the only variable in the steel angle headers. The comparison rating of superior for the epoxy concrete headers took into consideration initial cost and placement restrictions, as well as durability. The test results suggest possible solutions to some of the problems encountered in post-cast header construction.

Post-cast Headers for Bituminous Concrete at Bridge Expansion Joints, January 1969, California Division of Highways, Study Item D–4–18. NTIS No. PB–183252.

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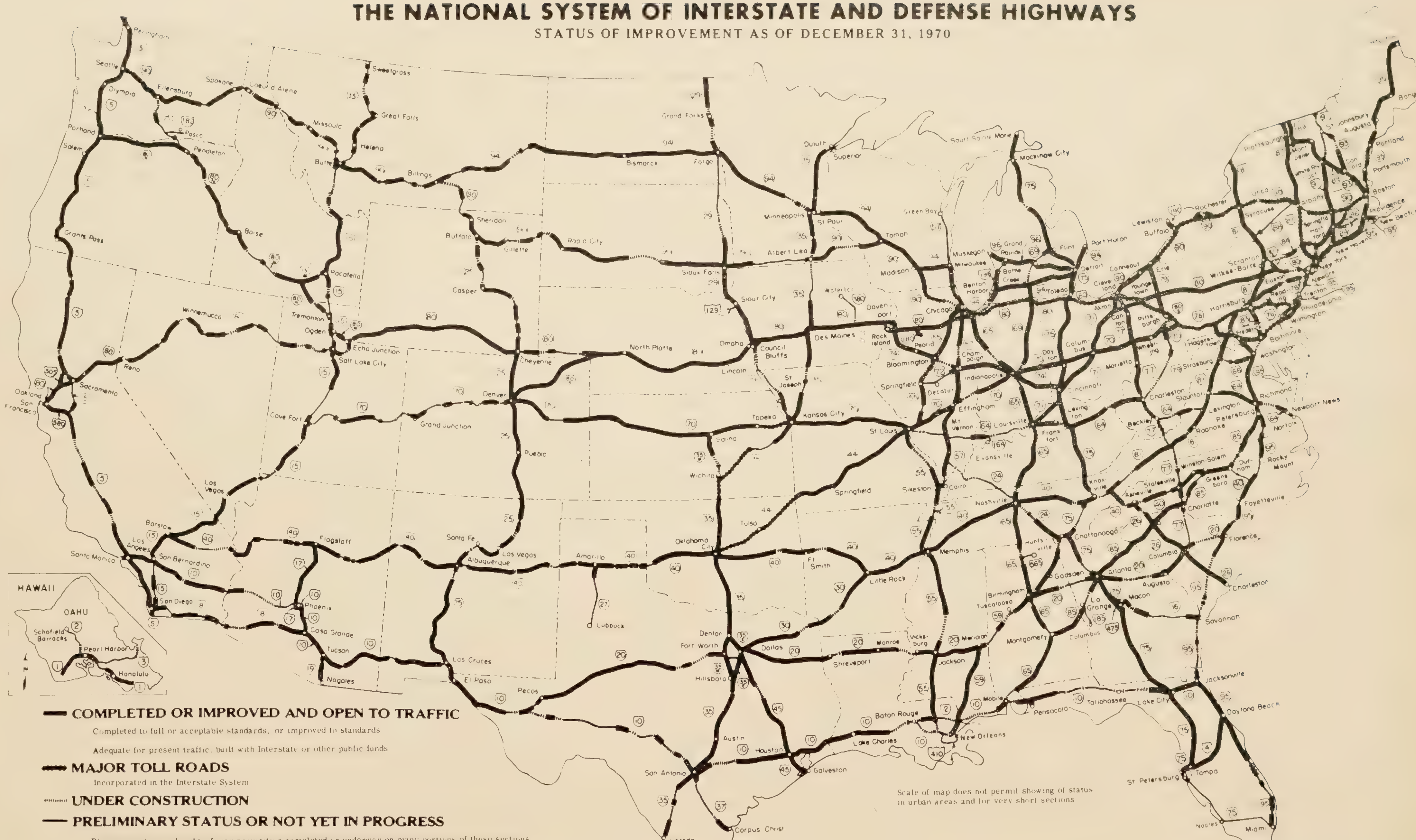
STATUS OF IMPROVEMENT AS OF DECEMBER 31, 1970



COMPLETED OR IMPROVED AND OPEN TO TRAFFIC

Completed to full or acceptable standards, or improved to standards

Adequate for present traffic, built with Interstate or other public funds

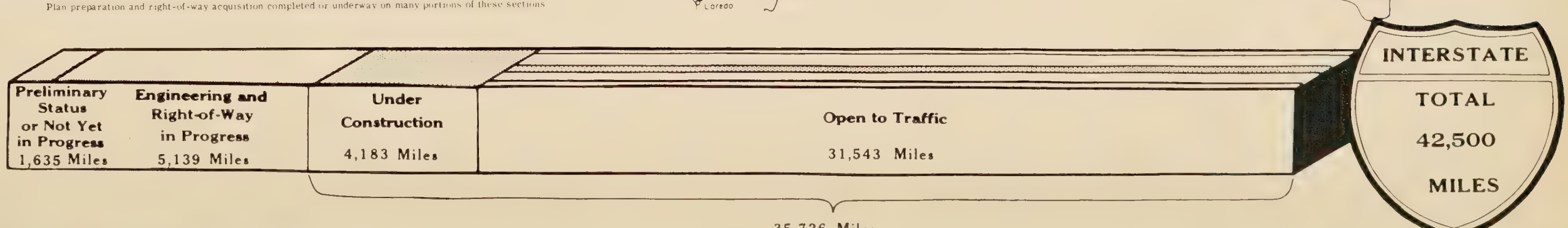
MAJOR TOLL ROADS

Incorporated in the Interstate System

UNDER CONSTRUCTION

PRELIMINARY STATUS OR NOT YET IN PROGRESS

Plan preparation and right-of-way acquisition completed or underway on many portions of these sections



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Analysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.
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Calibrating & Testing a Gravity Model for Any Size Urban Area (1968). $1.00.
Capacity Analysis Techniques for Design of Signalized Intersections (Reprint of August and October 1967 issues of PUBLIC ROADS, a Journal of Highway Research). 45 cents.
Construction Safety Requirements, Federal Highway Projects (1967). 50 cents.
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Federal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.
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Handbook on Highway Safety Design and Operating Practices (1968). 40 cents.
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  Supplement No. 2 (Nov. 1969). 40 cents.
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  Vol. 1—A Survey and Critique. 70 cents.
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