Proposal No. 01-5926-1
September 6, 1968

A proposal for

ROADWAY DELINEATION SYSTEMS EMPLOYING SURFACE MOUNTED LIGHTS

to

Research and Development Committee
Texas State Highway Department
Austin, Texas 78701

Attn: Mr. R. L. Lewis, Chairman

Prepared by: John M. Dale

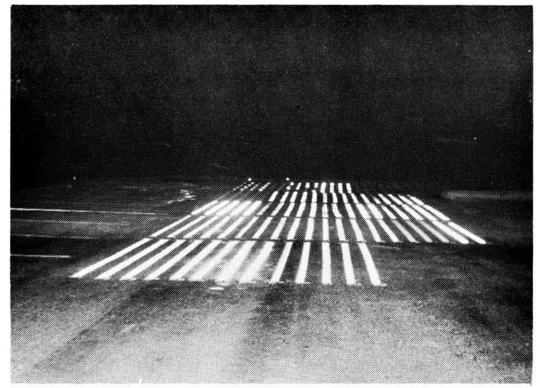
Approved:

John T. Goodwin

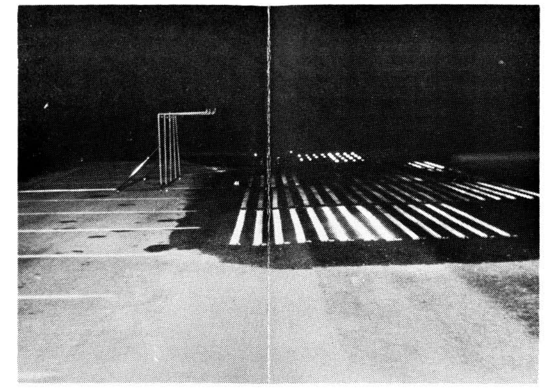
John T. Goodwin, Director
Department of Chemistry and
Chemical Engineering

SOUTHWEST RESEARCH INSTITUTE ACTIVITIES in ROADWAY DELINEATION

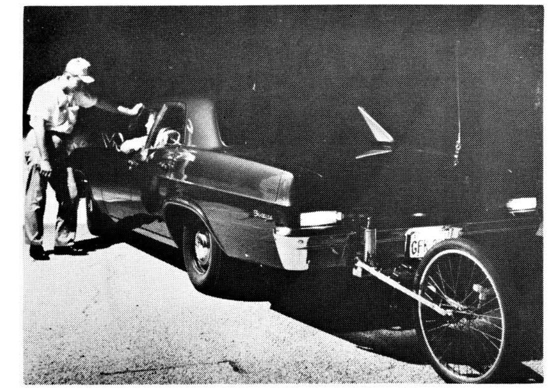
Paints



Reflectorized Markings–Dry

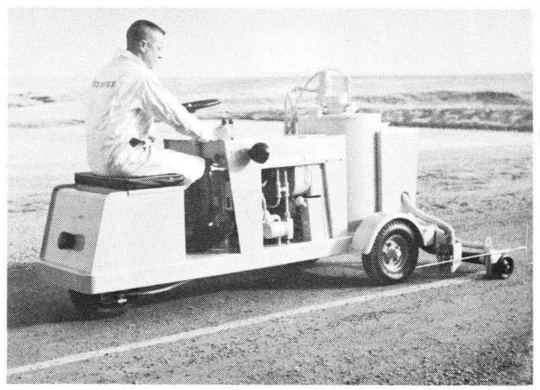


Reflectorized Markings–Wet

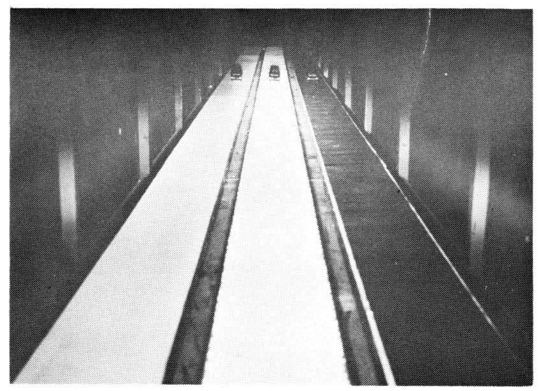


Test Car

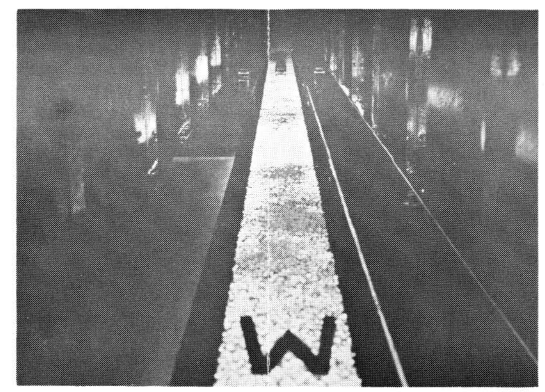
Instrumentation



Thermoplastics



Concrete, Seal Coat, Asphalt–Dry

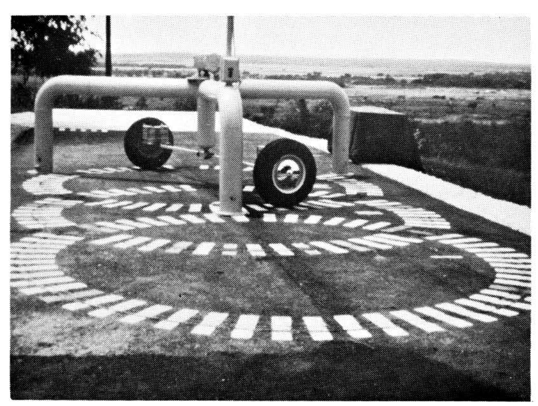


Concrete, Seal Coat, Asphalt–Wet

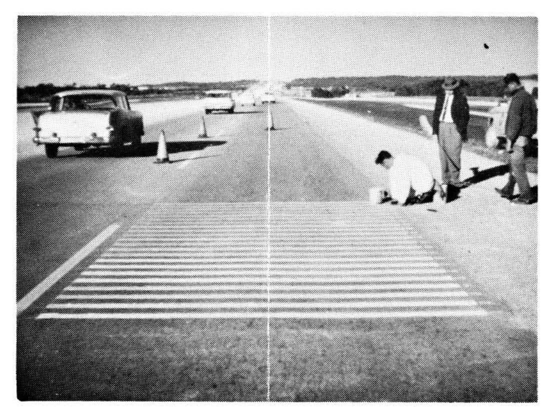
Data Collection

Headlight Glare

Epoxies & Chemical Sets

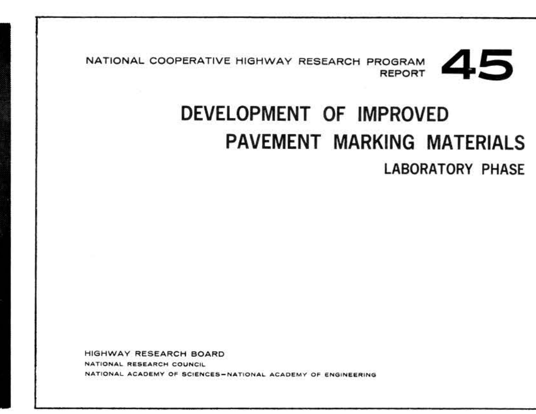


Wheel Track Facility



Road Tests

Dynamic Evaluation



NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 45

DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS

LABORATORY PHASE

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Publication of Results

EQUIPMENT DEVELOPMENT

MATERIALS EVALUATION

DYNAMIC TESTING

FOREWORD

Examination of trends in the use of highway pavement delineation systems indicates a movement to those systems which offer greater performance characteristics. A system which has outstanding pavement delineation characteristics under all conditions is that of using surface-mounted lights. The use of this system has thus far been concentrated in delineating the runways of the primary airports in the United States, with only cursory examination having been given to its use in delineation of highway pavements. Since approximately 35 percent of all motor vehicle fatalities and approximately 65 percent of all freeway fatalities involve running-off-the-road type accidents, strong justification exists for close examination of this system which has acknowledged performance characteristics but has, heretofore, been thought to be too expensive for highway application.

It is believed that surface-mounted pavement lighting systems will find increasing acceptance in highway applications and will be of great benefit to the motoring public. If allowed to follow its natural course, acceptance of this system is envisioned as taking place slowly, with a considerable duplication of effort and an inordinate expenditure of funds. To avoid this and facilitate the system's use, Southwest Research Institute proposes a subject research and development program which has as its objectives the optimization of roadway delineation systems which employ surface-mounted lights for highway applications and the development of a guide on their installation and usage. The importance of providing a guide at this time is paramount, in that the installation of wiring systems is best accomplished physically at the least cost and while roads are under construction, even though several years may elapse before traffic densities may justify installation of the lighting fixtures.

Requests for further technical information are welcome and may be directed to:

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AC 512, OV4-2000, Ext 447

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I. INTRODUCTION

In this period of mechanization, we find that man is subjected to stress exposures which tax, and not infrequently overtax, his neurosensory and motor capabilities to the fullest extent. These circumstances are fully evident and commonplace in the man-machine complex on our highways. It has long been apparent that the sensory inputs, decision processing, and motor responses required in high speed highway driving can be overwhelming; that the task must be simplified; and that a good starting point is to reduce the visual burden--the visual channel being the principal means of conveying information to the driver. The delineation system should keep the driver in his lane of the road, keep him moving, inform him of an impending choice point and provide him with information pertaining to choice. The visual cues must be simple, timely presented, standardized, and positive under all environmental conditions.

Technological developments by many organizations over the past 40 years in the area of roadway delineation have produced some exceedingly useful and significant visual cues and guide forms, particularly in the field of retroreflection, by using glass beads, prismatic reflectors, and other lens types. The adoption of uniform marking practices for use across the country, as well as the use of edgelines, is typical of advances in the utilization of markings. However, a cursory examination of present practices shows pavement delineation to be an incomplete technology.

Today, highways' pavement delineations are visible at night, solely through the mechanism of retroreflected light which, because of the law of inverse squares, interferences from environmental conditions and losses in reflection, refractive and absorption, often results in the intensities of delineations being totally inadequate. For example, Figure 1 shows freshly

FIGURE 1. GORE AREA - DAYTIME - DRY

painted and beaded lane lines and a gore area on a San Antonio expressway in the daylight that conforms almost to the letter with the recommendation contained within the Report of the Special AASHO Traffic Safety Committee, entitled Highway Design and Operational Practices Related to Highway Safety, February 1967. The gore area employs the recommended rumble markers in advance of the gore, 12-in.-wide beaded channelizing lines, and conspicuous, raised herringbone stripes between channelizing lines. In Figure 2, the same site is reviewed 2 nights later, after a light drizzle. The proximity of the power system for the overhead lighting begs its application for pavement delineation purposes.

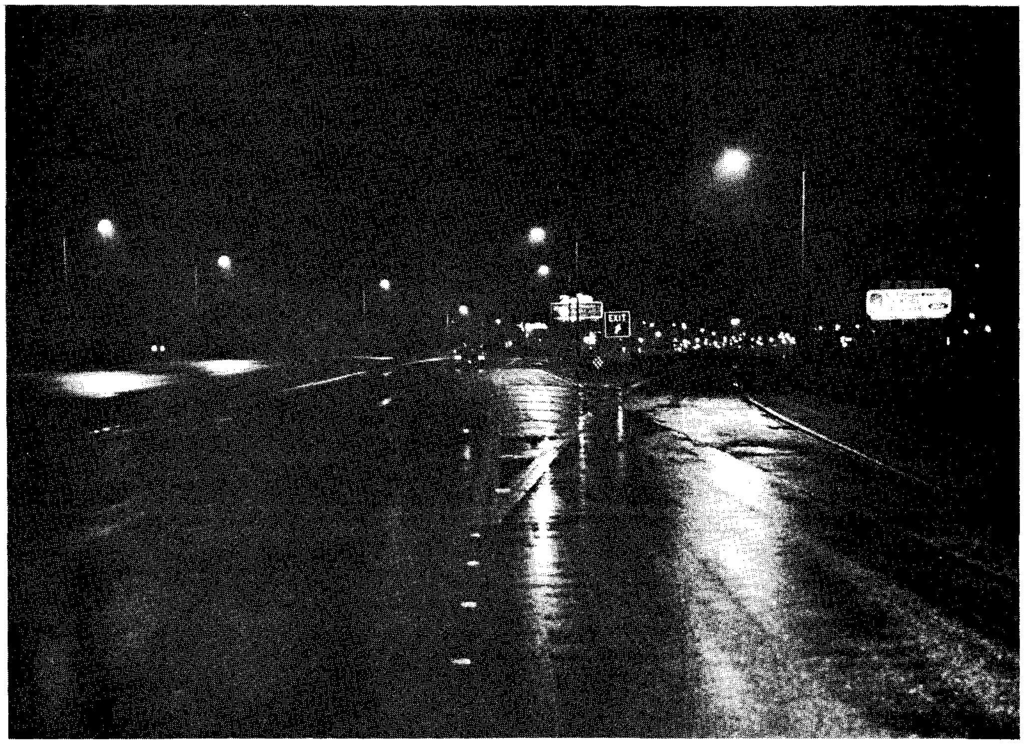

FIGURE 2. GORE AREA - NIGHTTIME - WET

Many delineation treatments are selected on the basis of a minimum first cost, when optimum designs often cost little more, particularly in relation to the cost of the roads themselves. The cost of the labor to install and replace delineation treatments often equals or exceeds the cost of the materials installed. The advance of technology and the demands for highway safety have forced a compression of the time scale as well as consideration of more expensive yet better performing designs and materials. This is quite evident in the most recent statistics on the use of pavement delineation materials shown in "1965 Usage of Pavement Marking Materials by Government Agencies in the United States," Highway Research Board Circular No. 79, April 1968, which indicates the following:

(1) Paint Usage:

	States	Cities & Counties	Total
White - gallons	8, 000, 000	5, 700, 000	13, 700, 000
Yellow - gallons	4, 000, 000	3, 800, 000	7, 800, 000
Beads - pounds	66, 000, 000	41, 000, 000	107, 000, 000

(2) Hot-Applied Thermo-Plastic Markings

White - feet	4, 288, 797
Yellow - feet	445, 427

(3) Preformed Markings

White - feet	73, 123
Yellow - feet	138, 640

(4) Button Markers

White	100, 434
Yellow	5, 000

As compared to 1950 statistics, the paint usage shown above reflects an average annual increase of 11 percent, compounded yearly. The other three types of markings do not appear in the 1950 statistics and represent trends toward the use of more costly but more effective materials. In 1968, single orders for button markers have exceeded the total number of those used in 1965. Thus, there is a definite trend to usage of more versatile and expensive marking materials, yet none of these materials or systems offer the performance characteristics of surface-mounted lighting systems. No one has ascertained how they compare on a cost-effectiveness basis.

The purpose of the proposed program is to assess the current status of surface-mounted lighting systems as they apply to highway applications, conduct research leading to improvements of this system, and provide a guide for others to follow in the design and layout of these systems, as well as provide sufficient information from which cost-effectiveness studies can be pursued. Current investment in the perfection of this system is seen as a method by which this system can be introduced properly, and thereby avoid having to overcome, at a later time, poorly conceived and operated systems that become and set standards simply by being the first systems to be installed. This is a unique opportunity in that the subject systems are nonexistent on highways at this time, except for a few experimental installations.

Southwest Research Institute's interest in this program stems not only from a long history of research in this area but more specifically from two current Institute programs which are in their final phases and constitute the foundation programs from which the study proposed here logically follows.

One of these programs is NCHRP Project 5-5, "Nighttime Use of Pavement Delineation Materials," and the other is the Bureau of Public Roads Contract CPR 11-4126, "The Effect of Headlight Glare on Vehicle Control and Detection of Highway Vision Targets."

II. TECHNICAL DISCUSSION OF THE PROBLEM

A. General

The system of delineating pavements using markings which are located on or within the traveled surface has the advantage of conveying a steady stream of uninterrupted visual information or warnings to the driver, without diverting his attention from the roadway. In the modern automobile, the headlights, which may be only 26 in. above the road surface, provide the source of illumination. If the headlights are dirty with road film, illumination may easily be reduced by 50 percent or more. The intensity of the illumination leaving the headlights diminishes inversely as the square of the distance from the source, so that maximum safe operating speeds, with headlights on low and high beam, are considered to be approximately 30 and 55 mph, respectively, with perception distances for unmarked dark objects considered to be on the order of approximately 100 and 350 ft, respectively, such that drivers often outdrive their headlights. Fog and other particulate matter in the atmosphere can scatter the light and create a glare condition separate from that of on-coming vehicles.

Assuming that the pavement is level, a ray of light from a typical automobile headlight strikes the pavement at an angle of 1 deg 14 min, with the horizontal 100 ft in advance of the vehicle. This angle becomes progressively smaller and finally narrows to 0 deg 21 min at a distance of 350 ft. The light striking the surface of the road ahead of the vehicle is largely reflected forward or absorbed by the road surface itself. If the light striking a pavement marking is to be directed back to the driver's eyes and present a clearly visible image, an optical focusing device is required. Most commonly used are small glass beads or spheres embedded in the pavement marking material or prismatic reflectors which focus and return the light to the vicinity of its source with varying degrees of efficiency depending upon a number of variables relating to the design and materials of construction of the retroreflectors, as well as the number and size of scratches and the amount of dirt or road film on the face of the retroreflector. Some of the light striking a given retroreflector will be reflected off its surface. That light which penetrates the retroreflector and is refracted, focused, and redirected back to the driver suffers losses from absorption and scatter. Depending upon the road contour and during ideal dry weather conditions, pavement marking materials with glass beads properly applied or containing other retroreflective elements can be very easily distinguished at night, at times when there is no opposing traffic. The glare from the headlights of approaching vehicles, the presence of overhead lights and other light sources often raise the illumination level to the point where the intensity of light from the retroreflecting elements is insufficient to provide the driver with visual guidance beyond a very short distance (50 ft) ahead of his vehicle.

During periods of adverse weather, the small glass beads often become submerged under a covering layer of water. Light from the car's headlights is largely reflected off the water surface and lost, and the small amount of light that penetrates the water suffers further losses to reflection, refraction, absorption, and scatter in its passage in and out through these various media. Thus, the guidance capabilities of currently used highway markings employing retroreflective elements are generally adequate during good weather and when using high-beam headlights. During periods of adverse weather, or when using low-beam headlights, which are the really critical periods where the driver's need for visual assistance is the greatest, the conventional delineations are either not functioning at all or are functioning at a marginal efficiency.

B. Design Methodology

The development of a delineation system employing a new concept must take into consideration a variety of considerations. It must include determination of the driver information requirement and engineering design criteria, the qualifications and designs of the system components, the evaluation of the components in the field, an operational analysis, and finally relate all of these considerations back to the driver information requirement. These four functional elements of design methodology are depicted in Figure 3.

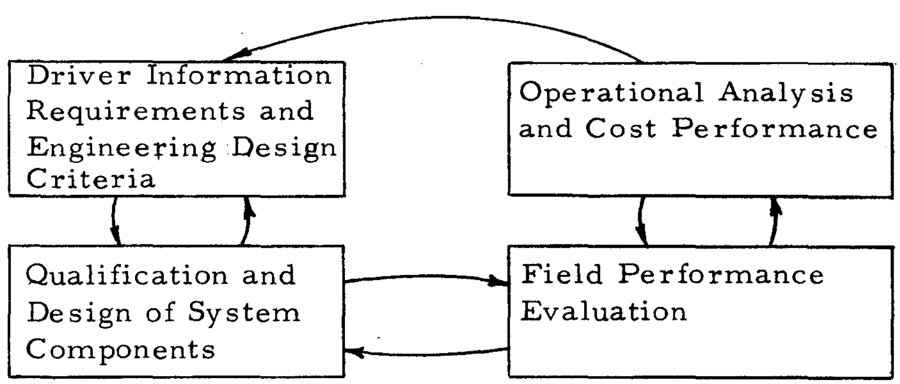

FIGURE 3. ELEMENTS IN SELECTION OF SURFACE MOUNTED LIGHTING SYSTEM

Each of the elements of the problem can be divided into functional components as shown in Figure 4. Each of these components can be subdivided into operational and physical factors as shown in Figures 5, 6, 7, and 8. The investigator needs a comprehensive knowledge of each of these factors, their interrelationships, and their combined effect on the basic elements of the design. An important task in the design methodology for this project will be the continual referral back to the driver information requirement.

C. Summary

This program must be directed to adopt the concept of delineation systems employing surface-mounted lights to highway applications. It should provide information that will qualify the unit effectiveness of this system in comparison with other systems and indicate under what conditions this system should be employed, and finally, it should serve as a guide for the installation of auxiliary components such as the wiring or conduit in roads now under construction. Thus, several years from now, when these systems are requested, the basic elements will be in place and the great expense of their postconstruction installation can be avoided.

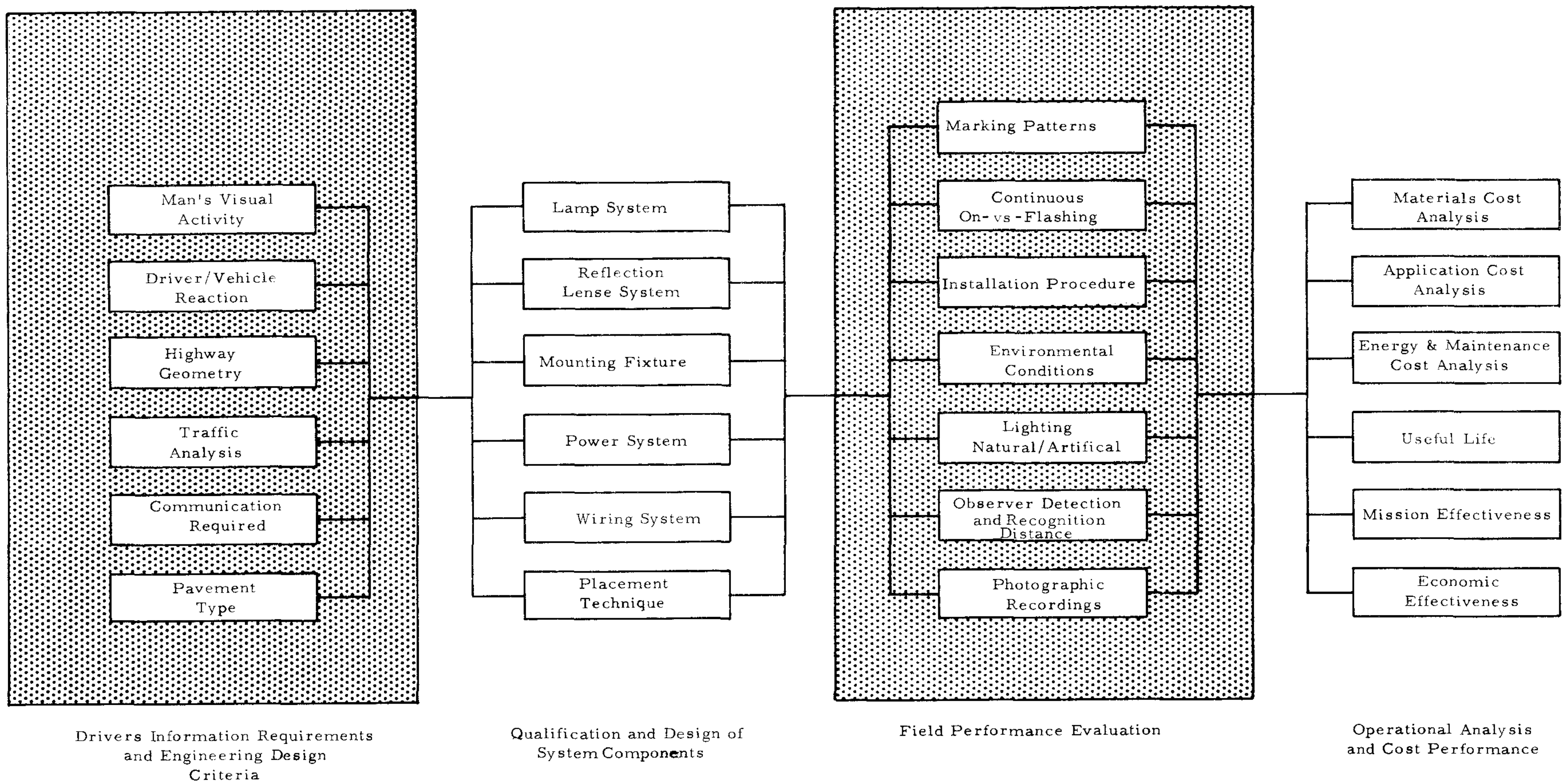

FIGURE 4. COMPONENTS IN SELECTION OF SURFACE MOUNTED LIGHTING SYSTEMS

- **Man's Visual Acuity**
  - Daylight
  - Dusk
  - Dark
- **Driver/Vehicle Reaction**
  - Response
  - Stopping Distance
  - Speed
- **Highway Geometry**
  - Grades
  - Curves
  - Lanes
  - Intersections
  - Entrances
  - Exits
  - Transitions
  - Crosswalks
  - Objects
- **Traffic Analysis**
  - Density
  - Speed
  - Urban/Rural
  - System
  - Type
- **Communication Required**
  - Center Lines
  - Lane Lines
  - No Passing
  - Edge Lines
  - Channelizing
  - Lane Drops
  - Obstructions
  - Transverse
  - Stop
  - Crosswalk
  - Word and Symbol
  - Curb
  - Object
- **Pavement Type**
  - PC - Concrete
  - B - Concrete
  - Seal Coat

FIGURE 5. FACTORS IN DRIVER INFORMATION REQUIREMENTS AND ENGINEERING DESIGN CRITERIA

Lamp Section

- Filament Type
- Voltage
- Wattage
- Size
- Constant or Flashing

Reflector and Lens System

- Aperture Angle
- Reflector Material
- Reflector Shape
- Lens Material
- Lens Shape

Mounting Fixture

- Size
- Shape
- Material of Construction

Power System

- Self-Contained
- Line System
- Photo-Cell Control

Wiring System

- Type
- Size
- Insulation
- Connectors

Placement Technique

- Adhesive
- Bolted
- Ram Set
- Embedded

FIGURE 6. DESIGN AND QUALIFICATION OF SYSTEM COMPONENTS

Continuous On vs Flashing

- Cycles
- Dwell Times

Lighting - Natural/Artificial

- Daylight
- Dusk
- Moonlight
- Dark

- Headlights--Forward HB & LB
- Headlights--Opposing HB & LB
- Overhead
- Miscellaneous Signs, etc.

Marking Patterns

- Module
- Frequency
- Color
- Layouts

Observer Detection and Recognition Distance

- Detection Distance--Static and Dynamic
- Recognition Distance--Static and Dynamic
- Appearance
- Contrast

Installation Procedure

- Sequence of Operations
- Critical Steps
- Check-Out
- Proof Test

Photographic Recordings

- Black and White/Still
- Color/Still
- Densitometer Analysis
- Contrast Analysis

Environmental Conditions

- Dry
- Wet
- Rain
- Fog
- Snow and Ice
- Blowing Snow
- Dust

FIGURE 7. FACTORS IN FIELD PERFORMANCE EVALUATION

Materials Cost Analysis

- Use Frequency
- Cost per Unit
- Cost per Mile

Application Cost Analysis

- Use Frequency
- Cost per Unit
- Cost per Mile

Energy and Maintenance Cost Analysis

- Use Frequency
- Cost per Unit
- Cost per Mile

Useful Life

- Appearance
- Durability
- Maintenance
- Replacement Frequency

Economic Effectiveness

- Cost (Equipment, Materials, Application) per Mile per Day of Useful Life

Mission Effectiveness

- Unit Effectiveness per Unit Cost

FIGURE 8. FACTORS IN OPERATIONAL ANALYSIS AND COST PERFORMANCE

III. TECHNICAL PROGRAM

For clarity and definition, the proposed program has been divided into phases and tasks. The tasks are the individual activities within each phase.

A. Phase I. Review of Past and Current Research Pertaining to Roadway Delineation

The program will be initiated by preparing accession codes which will then be submitted to the Highway Research Information Service along with a request for computer retrieval runs on publication abstracts and research-in-progress reports. The publication abstracts will be reviewed, and the appropriate reports will be ordered by the Institute's Library. The research-in-progress abstracts will be reviewed, and these will be successively screened by letter, telephone call, and selected personal visits for discussions with the principal investigators and field inspections of facilities and installations. It is felt that this procedure will provide a comprehensive assessment of existing domestic technology.

It is also felt that a specific effort beyond a review of the domestic technology is warranted, and, in particular, a review of western European technology should be included. The writer has made two recent trips to Europe and has received numerous European visitors at the Institute whose interests were roadway delineation technology. As a consequence, it must be recognized that this subject is being pursued in Europe.

The review will also be used as a vehicle to establish that the evaluation techniques employed are the best and most advanced available. Furthermore, the review will gather information on the visual acuity of drivers, under different lighting conditions, and reaction times of driver-vehicle combinations from the instant of visual detection. A recent Bureau of Public Roads pilot study of headlight beam usage by drivers showed an unexpectedly high proportion of vehicles using low-beam headlighting in driving situations which allowed and called for high-beam usage. This willingness of drivers to reduce "seeing ability" by 25 to 50 percent to avoid the switching task, glare, or for other reasons, is highly significant in relation to the delineation system. The Institute is now collecting data on the phenomena at twenty different locations across the United States, and the results of this work will be available by the time this program is initiated. Finally, the review will provide cognizance of what are considered to be the outstanding delineation treatments employed today. This information will then form a basis around which surface-mounted lighting systems will be designed.

Certain types of surface-mounted lights have designs that project above the road surface and are readily removed or destroyed by steel snow-plow blades. The Institute has been field testing the use of a recently marketed rubber snowplow blade over conventional raised marker delineators, as shown in Figure 9. The results of this work suggest that the rubber blade

FIGURE 9. PLOWING CONVENTIONAL RAISED MARKER DELINEATORS WITH INSTITUTE GRADER FITTED WITH A RUBBER SNOWPLOW BLADE

constitutes a potential solution to the problem inherent in the use of raised surface-mounted lights in the snow belt area of the country. It will be necessary to supplement the review with a letter questionnaire to all State Highway Departments to determine not only their experience with the use of rubber snowplow blades but also their basic objections to their use. This information should provide a fairly reasonable basis for determining if the surface-mounted lighting systems must be flush mounted or if they can protrude above the surface.

The information gathered on past and current research from the United States, Europe, and elsewhere, will be critically reviewed, and the significant information will be extracted and summarized in a "state-of-the-art" review.

B. Phase II. Driver Information Requirements and Engineering Design

A driver's basic delineation requirement is that he be able to see all substantive information sufficiently well and sufficiently in advance so that he, along with his vehicle, can react accordingly without placing himself or anyone else in peril. Thus, it is necessary to formulate or to establish the design criteria, that is, to develop the magnitude of those primary parameters or conditions present which contribute to or influence the basic delineation requirement. As shown in Figure 5, there are six distinct functions that provide inputs to the design criteria. Man's visual acuity in daylight, dusk, and dark determines what he sees, and this must be related to visibility distance, considering the point of detection as well as the point of recognition. The driver/vehicle reaction time is a sum of the response times of both constituents, individually and as a unit. The highway geometry and traffic requirements determine the delineation communication required. The pavement type and the shoulder treatment establish the contrasting background against which the delineation communication will be viewed. This input information must then be analyzed from the standpoint of:

(1) What are the driver/vehicle capabilities?

(2) What guidance intelligence must be provided the driver and at what recognition distance?

These data will be combined with those of the "state-of-the-art" summary and will be submitted to the Sponsor as the substantive Interim Report No. 1.

C. Phase III. Design and Qualification

1. System Components

a. Fixture Design

The fixture design includes consideration of the bulb, the reflector, the lens, and the mounting. Each of these units has to be investigated independently, with consideration given to a variety of possible ideas. In airport lighting systems, bulbs of 3 to 5 watts have been employed, but proper wattage for highway application must be determined, as well as the lamp type, i.e., incandescent, mercury, or fluorescent. Special investigation needs to be directed to the bulb design and selection to eliminate bulb damage incurred by thermal imbalances, impact, and vibration. The full benefits to be gained by reflective backup and dispersion of light with reflectors have not been investigated and therefore are worthy of study. The use of reflectors also offers an opportunity to increase the visible area of the marker to something greater than a single point source which is the size of the lamp filament. The lens that is selected for this application can also function as a means of distributing the light or directing it to a given area, and particular attention must be devoted to materials of construction and design such that the lens will be self-cleaning. Consideration needs to be given to determine if the unit should provide unidirectional, bidirectional, or multidirectional viewing, as well as a vertical aperture angle. How the unit will be affected by snow removal equipment and fixture design will also be included, along with an investigation of the various methods of mounting the units. Techniques to be investigated include the use of adhesives, steel drive nails, and embedding in the pavement.

b. Power Supply and Service Distribution

There are two basic potential systems that need to be investigated. The first of these is a battery operated, self-contained system with and without photocell control that operates either continuously or intermittently as flasher units during the periods of darkness. Investigation of self-contained battery systems, low wattage lamps, and the potential life and maintenance problems associated with self-contained systems will be carried out. The second type of service will be that involving the use of conventional power supplies with step-down transformers. This will require the evaluation and selection of the wiring layouts, the wire size, type, insulation, terminals, and the type of connectors.

c. Installation Practice

For new construction, consideration will be given to practices which will be followed in laying lines in pavement surfaces which are under construction. Of particular importance will be the treatment of the service lines as they pass from one slab to another, and the modifications that will have to be made to accommodate sawed joint construction. For existing installations, selection of the optimum technique will be made for placement of the electrical distribution lines within the pavement. Grooving techniques, cutting techniques, backfilling, and other associated treatments will be investigated. A possibility exists of employing the sawed joints in the pavement as channels for wiring installation. Another consideration in the installation practice will be spacing requirements. Because of the improved visibility of the lighted delineation systems and their greater viewing distance, it may not be necessary to use them as frequently as conventional retroreflecting markers are used. It may be desirable to use them in conjunction with reflectorized markers. It will be necessary to consider how lighted delineation systems can best be integrated into existing delineation systems in such a manner that their acceptance problems are minimized and the transition period is reduced.

2. System Analysis

After examining each of the independent system components and variables, a system design analysis will be conducted to select those component design features that appear to offer the most desirable features from the standpoint of laboratory performance.

D. Phase IV. Field Performance

Those systems which show an indication of providing the desired characteristics in the systems analysis will be taken into the field for evaluations. Actual test setups will be evaluated either on the Institute's San Antonio test track or on its Hondo test track, depending upon the degree of dynamic testing desired. The majority of the dynamic testing is done at the Hondo test track. Once test installations are prepared, it will be possible to consider, view, and evaluate new concepts such as flashing on-off systems for pavement delineation. Flashing colored lights are used as warning devices; however, flashing white lights need to be investigated for use in pavement delineation to indicate the feasibility of their use on ramp transitions, gore areas, or other types of hazardous areas. They also present a possibility as centerlines wherein, by following the flashing or sequential flashing lights' centerline, one would stay on the main thoroughfare and those nonflashing, surface-mounted pavement delineations would indicate road edges and ramps, or vice versa. Flash duration, rate, and intensity will be considered. The field performance work will provide the opportunity to examine various installation procedures from the standpoint of those factors shown in Figure 7, such as the sequence of installations, the critical steps, the check-out, and the proof testing. The installed system will be examined from the standpoint of its effectiveness under various environmental conditions such as dry, wet, and periods of precipitation. In a like manner, they will be examined under a variety of natural and artificial lighting conditions, such as headlights--forward on high and low beams, headlights--opposing on high and low beams, overhead lighting, and other miscellaneous lighting from signs.

E. Phase V. Operational Analysis and Cost Performance

It can be speculated that several lighted delineation systems will evolve from the proposed research effort that will satisfy the basic delineation requirements. These systems will very likely differ in appearance, materials of construction, costs (equipment materials, application, and maintenance), and serviceability. In order to provide for an objective and meaningful delineation treatment selection, an operational analysis will be performed to evaluate and compare candidate systems on the basis of dollar figures, as well as on performance characteristics. At this point, we will want to compare the evolved systems with the best systems employed today to determine if the evolved systems, though functionally better, are actually more or less costly from the unit effectiveness standpoint. Each of the systems will be analyzed for cost (materials plus application) and useful life. This analysis will then be converted into an economic effectiveness measure or cost per mile per day of useful life, which is exactly what most highway departments do today. At this point, however, the Institute will be able to accomplish something that few, if any, highway departments have ever been able to even attempt, i.e., to relate cost to the unit effectiveness of the system as it relates to the driver's information requirement. This should be very revealing and, as much as anything else, a measure of what is accomplished in this program.

IV. PROJECT MANAGEMENT PLAN, PROGRAM SCHEDULE, AND EXPERIENCE

A. Management Plan

For this program, the primary project team will consist of three individuals: Mr. John M. Dale, Mr. Herman F. Barsun, and Mr. William W. Bradshaw, all of Southwest Research Institute.

Coordination of the technical and administrative responsibilities of this program will be handled by Mr. John M. Dale, Manager of Process and Product Development at Southwest Research Institute. Mr. Dale is a registered professional engineer and a specialist in process and product development, particularly in the area of pavement marking materials and reflective systems. During the course of his career, he has conducted field trials of pavement marking materials at some thirty-five separate locations in the United States, Canada, and Europe, and he has authored numerous journal articles, technical papers, and patents relating to this work. Mr. Dale is Principal Investigator of the National Corporative Highway Research Program Project 5-5, "Nighttime Use of Highway Pavement Delineation Materials," wherein particular attention has been directed to the performance of pavement marking materials during periods of precipitation. Thus, Mr. Dale brings to the proposed program a comprehensive background regarding functions of pavement delineation devices, their design, performance requirements, plus extensive experience in managing and directing projects of this type.

Mr. Barsun is a registered professional engineer and a Senior Research Engineer at Southwest Research Institute. He is considered as a power equipment specialist with over 30 year's experience in design engineering and supervisor of electrical components and equipment design and development. He has had extensive experience in solving operational difficulties experienced in transformers, transformer components, and distribution systems. Mr. Barsun has conducted numerous seminars and courses of instruction on equipment maintenance, preventive maintenance techniques, and operational problem solutions. Thus, Mr. Barsun brings to the proposed program a comprehensive background regarding the function and requirements of the power systems which are an integral part of the proposed system.

Mr. Bradshaw is a Senior Research Physicist at Southwest Research Institute and a specialist in the design and development of optical devices. He has done extensive development work in the measurement of light, ranging from photoelectric detection to the very high thermal flux in Southwest Research Institute's solar and arc-imaging furnaces. Thus, Mr. Bradshaw brings to the program the talents of optical design, as well as the measurement and physics of light.

The background and experience of these individuals listed above who will direct and lead the proposed research effort is considered to be unique, as well as outstanding. The diverse background of these personnel assures a well-balanced approach to the problem. Personal data sheets of these individuals are included in the Appendix.

B. Program Schedule

The Program Scheduling Chart presented in Figure 10 provides an outline of the conduct of the proposed study over its 16-month duration. This outline conforms with the work efforts described in Section III, Technical Program, and is utilized to determine personnel requirements, manpower allocations, and projected program costs. Project progress will be indicated on this chart and reported on an interim basis as the program develops. Scheduling changes or adjustment in efforts will also be indicated as these become necessary. In summary, this chart provides a means for effective accomplishment of project management and control, as well as a means to assess and report project progress.

A forecast of manpower allocation according to technical task and professional category is presented in Table I. These data were utilized in developing the cost estimates presented in Volume II.

C. Experience

Southwest Research Institute is a nonprofit research corporation serving individuals, industry, and the government. Founded in 1947, the Institute now engages approximately 1100 employees in a wide variety of technical fields. Approximately one-third of these are professional scientists and engineers involved directly in technical work. The Institute's

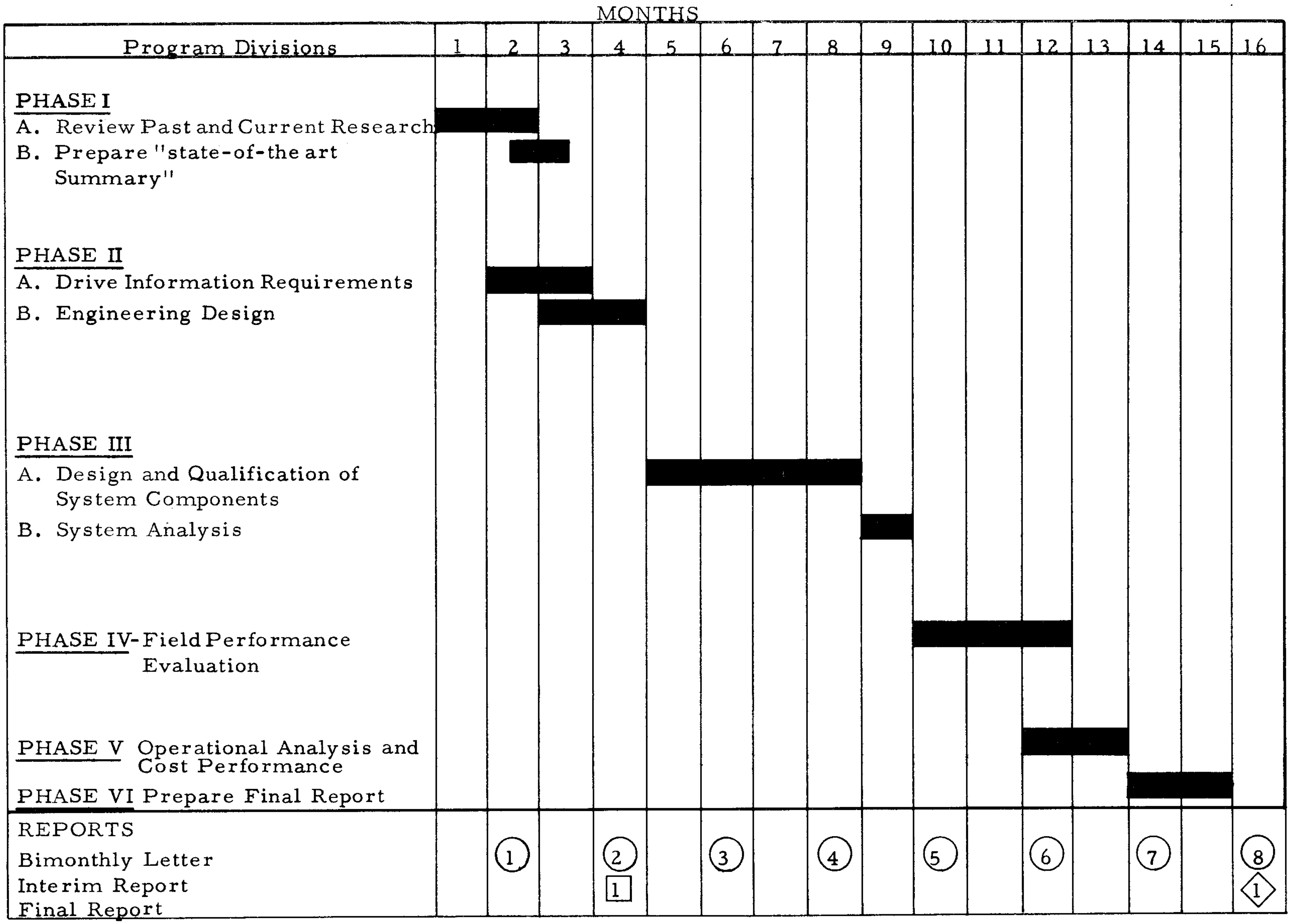

FIGURE 10. PROGRAM SCHEDULING CHART

TABLE I. PROJECT PERSONNEL

Name	Degree	Title	Professional Experience (years)	Primary Technical Contributions	Availability* (percent)
J. M. Dale	BS	Manager	18	Project Coordination, Mounting Design, Placement Design, and Field Testing	70
H. F. Barsun	BS	Sen. Res. Engr.	30	Power and Lighting Equipment, Design and Selection	50
W. W. Bradshaw	BS MA	Sen. Res. Physicist	21	Optical Device Design, and Light Measurement	50

*Based on work loads during the anticipated project period.

current annual research budget of approximately thirteen and one-half million dollars is derived from over 350 research and development projects. Some fourteen working departments comprise the organization and include the following:

- Aerospace Propulsion Research
- Applied Economics
- Applied Electromagnetics
- Applied Physics
- Automotive Research
- Chemistry and Chemical Engineering
- Electronic Systems
- Engines, Fuels, and Lubricants
- Instrumentation Research
- Materials Engineering
- Mechanical Sciences
- Ordnance, Fuels and Lubricants Research
- Physical and Biological Sciences
- Structural Research

The Institute does not engage in product manufacturing; however, it is particularly well qualified to perform development work and provide one of a kind, or prototype quantities, of various type devices, instruments, and systems. Because of its inherent lack of dependence on production-type contracts, the Institute is able to provide totally unbiased services with respect to the analysis, evaluation, selection, and recommendations of various techniques and equipment.

Southwest Research Institute has been conducting vehicle evaluations for the past 20 years. During this period, Southwest Research Institute personnel have supervised the operation of automotive fleets in all parts of Texas and at numerous out-of-state locations. The total mileage accumulated is in the hundreds of millions of miles. These programs have been sponsored by the leading vehicle and component manufacturers. The evaluations are normally conducted on a 24-hr-day basis, over all road types and under various weather conditions.

The Institute has long recognized the deficiencies in roadway delineation systems and has encouraged industrial concerns to support research in this area. The frontispiece of this proposal contains a series of pictures selected from files of past projects showing examples of the Institute's work in equipment development, materials evaluation, and dynamic testing of pavement delineation systems. Typical of these programs was one for The Sulphur Institute, a world-wide trade organization of the sulphur industry, wherein the physical properties of elemental sulphur were modified to allow it to perform as a pavement marking material. This was then field tested at twenty-three different sites in the United States and Europe, and it is now being commercialized. Patents issued on this development in Mr. Dale's name have been assigned from the Institute to the Sponsor.

A list of recent and current Southwest Research Institute projects that relate to the proposed program is presented here:

SwRI Project No.	Sponsor	Description
00-1896	USAF School of Aerospace Medicine	Factors involved in aerospace flight operations

SwRI Project No.	Sponsor	Description
01-1092	The Sulphur Institute	Development of sulphur-based pavement marking materials
01-1666	Highway Research Board	Nighttime use of highway pavement delineation materials--laboratory phase
01-2086	Martin Marietta Corporation	Visual characteristics of "Synopal"
01-2180	Highway Research Board	Nighttime use of highway pavement delineation materials--field phase
01-2295	Whittaker Corporation	Encapsulation of catalysts for epoxy resins
01-2325	Union Contracting and Engineering	Development of a pavement marking composition
03-1832	Highway Research Board	Development of waterproof roadway joints for bridges
03-1835	Highway Research Board	A study of thermal characteristics of highway bridges
03-2176	Highway Research Board	Cable systems to eliminate massive structures
07-1650	Texas State Highway Dept. and Bureau of Public Roads	Highway signing research
07-1955	Texas State Highway Department	Performance specifications for reflectorized highway sign-facing materials
07-2209	U. S. Steel Corporation	A study of roadway lighting

SwRI Project No.	Sponsor	Description
08-2126	Various	Cooperative automotive road test programs
08-2144	National Bureau of Standards	The physical condition of passenger vehicle tires in highway use
11-1908	Bureau of Public Roads	A study of automobile headlamp glare and methods of control
11-2161	U. S. Dept. of Transportation	Maximum design top speed
11-2328	U. S. Dept. of Transportation	Statistical summary of school bus accident data

V. AVAILABILITY OF FACILITIES REQUIRED TO UNDERTAKE THE SPECIFIC RESEARCH AND DEVELOPMENT PROGRAM

A. General Facilities

Southwest Research Institute's general offices and laboratory facilities are located on a 1500-acre tract west of the City of San Antonio. An aerial view of the main laboratory facilities is shown in Figure 17. The size and diverse nature of the terrain, coupled with a mild climate, are favorable to outdoor test operations. In addition to an extensive private road system on the Institute's grounds, all portions of which can be employed for test work, the Institute is bounded on its west by Interstate 410, which is a limited access, four-lane, median-separated expressway. Through arrangements with the Texas State Highway Department, District 15 Headquarters only 3 miles distant, this site has been used to conduct pavement delineation material field tests and evaluations. This section of expressway is both straight and level, and it is ideally suited for certain types of evaluations. Bordering the south property line of the Institute is Commerce Street which is under the jurisdiction of the City of San Antonio and is in an ideal remote location because it has a low traffic density, no street lights, and is virtually devoid of commercial and residential activities. The eastern and northern boundaries of the Institute are former county roads that recently have been acquired by the City of San Antonio and have also been used by the Institute for pavement delineation studies.

The Institute's general services' facilities include road building equipment, a large machine shop facility, an instrument shop, and the many other facilities that are necessary to complement and support large research programs.

B. Special Facilities

1. Equipment

Southwest Research Institute is unusually well equipped to conduct evaluations of delineation materials and devices. Over the years, while working on the various delineation studies, the Institute has acquired a unique assortment of equipment and experience in formulating and applying the various types of delineation materials such as paint, beads, thermoplastics, chemical adhesives, such as epoxies, and various other types of delineators. The Institute owns several striping machines, the most versatile of which is a Kelly-Creswell B-3-P model, self-propelled highway marking machine which was designed and modified specifically for laying highway test stripes, both transversely and longitudinally. This unit is constructed with two different bead applicators; one can be used with gravity or forced feed, and the other is a proportioning unit with a direct-drive gear mechanism to the wheels for very precise control of the amount of beads applied. Southwest Research Institute is well versed in the ASTM tests for evaluating pavement markings and has field experience in laying all of the different representative types of marking materials.

2. San Antonio Test Track

Southwest Research Institute operates an off-highway test track which is located at a remote site on the Institute grounds. This track is a straight and level hard surface roadway 1500 feet long and is used for a variety of purposes, one of which is crash impact studies. It is located away from any buildings or other distracting light sources and therefore is ideal for conduction of visibility studies and evaluation of delineation systems.

3. Hondo Test Track

Southwest Research Institute operates an off-highway test track at the deactivated Hondo Air Force Base near San Antonio. At this site, test cars are run to evaluate engines, transmission, fuels, lubricants, and highway safety studies. This track is ideally set up and instrumented for the subject program. The instrumentation was developed specifically for use in the headlight glare evaluation program.

The instrumentation system provides telemetered, digitized, printed readout every 2/10 sec of:

(1) The distances between the subject observer's car and a glare car, and between the subject car and a target or a delineation treatment

(2) The lateral displacement of the subject car from the desired straight-line path

(3) The detection and recognition region

(4) Light intensity at the observer's eyes.

The system uses a combination of mechanical and electronic techniques to obtain an optimum combination of the following characteristics:

(1) Accuracy

(2) Ease of data reduction

(3) Minimum track preparation, initially and prior to each series of tests

(4) Reliability and repeatability.

VI. COST PROPOSAL

		Estimated Man-Hours	Amount
Direct Labor Cost			
Senior Scientific Personnel		750	$ 6,750
Scientific Personnel		1500	10,950
Technician		1800	5,400
Draftsman		300	960
Total Salaries and Wages			$24,060
Provision for Vacation, Holiday and Sickness--12% (applicable only to Government pricing)			$ 2,886
Total Direct Labor Costs			$26,946
Overhead or Surcharge-- 102% (See Contractual Information, next page)			27,484
Materials and Supplies			3,000
Other Direct Costs			
Photography	$450		
Report Reproduction	150		
Telephone Tolls and Telegraph	120		720
Total Estimated Cost			$58,150
Estimated Fee and Contingencies			4,075
Total Quotation			$62,225

SOUTHWEST RESEARCH INSTITUTE
CONTRACTUAL INFORMATION
COST-PLUS-FIXED-FEE PROPOSAL

SwRI Proposal No. **01-5926-1**
Purchase Request No. ____________________

Southwest Research Institute is a not-for-profit corporation organized in the public interest and existing under the laws of the State of Texas, with its general offices at 8500 Culebra Road, San Antonio, Texas 78228. Laboratories are maintained at San Antonio, 3600 Yoakum Boulevard, Houston, Texas 77006, and 1901 N. Shoreline Drive East, Corpus Christi, Texas 78403. The Institute is tax exempt under Section 501(C)(3) of the Internal Revenue Code. The Institute presently employs approximately 1000 full-time scientists, engineers, technicians, and service personnel.

The Defense Supply Agency, Defense Contract Administration Services Office, 7071B San Pedro, San Antonio, Texas 78216 has been assigned responsibility for administration of Department of Defense contracts. The agency having cost cognizance on all Government contracts awarded this Contractor is the Defense Contract Audit Agency, San Antonio, 7077 San Pedro, San Antonio, Texas 78216.

Contractor's current financial statements are filed quarterly with the Defense Supply Agency, the audit agency, and the Directorate of Procurement, Headquarters, Air Force Systems Command, Andrews Air Force Base, Washington, D. C. 20331, who has been assigned cognizance under the program for the coordinated negotiation of overhead rates.

The accounting policies and procedures of the Institute and employee salary rates and ranges are reviewed and approved on a current basis as acceptable for Government cost-type contracts.

It is desired that a cost-plus-fixed-fee contract be provided with costs determined in accordance with the ~~Armed Services~~ Federal Procurement Regulations, ~~Section XV, Part 2~~. In accordance with current approved procedures, direct labor cost includes provision for vacation, holiday, and sickness costs at 12% of the cost of direct salaries and wages. A final negotiated overhead rate of 101.34% of regular staff direct labor cost has been established for fiscal year ended October 1, 1966 on the basis of actual cost by the cognizant audit agency. The overhead rate for fiscal year ended September 30, 1967 has not been established. The approved provisional overhead rate based on audit of current year cost incurred is 102% of direct labor cost. However, cost projections are made by the Institute on a periodic basis, and any expected variation from the approved provisional rate is refected in the cost estimate.

The approved policy of the Institute with regard to reimbursement for transportation and other travel expenses is limited to the actual cost incurred. Subsistence expenses are limited generally to $20.00 per calendar day per employee in travel status, and written justification of the traveler is required as a condition to reimbursement for any excess. Transportation by personal and/or Institute-owned automobiles is reimbursed at $.10 per mile as representing the actual cost of such transportation..

Government financing to the extent of current payments on account of allowable costs as provided in the clause entitled "Allowable Cost, Fee and Payment" in accordance with Paragraph 203.4 of Section VII of the Armed Services Procurement Regulations is requested.

The fixed fee, in the case of the Institute is paid not only for the "know-how", which it is in a position to furnish, but for the growth and expansion of the organization which has been set up primarily for the public good through scientific progress and as a specific service to the Government, industry and the public generally. The Institute, a not-for-profit organization, does not have the capital structure to provide for expansion outside of the fee received for work performed, and nominal contributions from interested individuals and organizations. Experience has proven that funds must be available to expand facilities, and also procure new and replace obsolete equipment, in order for the Institute to keep abreast with the latest in scientific development. The fixed fee proposed in this instance has been determined with due consideration given to factors set forth in ASPR, Section III, Par. 808.

This proposal shall remain in effect not longer than 90 days from date of presentation. This proposal constitutes an offer and, if accepted by a Notice of Award placed in the mail addressed to Southwest Research Institute, will form a binding contract on the terms covered by this proposal. It is agreed that any such Notice of Award will be replaced at a later date by a definitive contract bearing the same date as the Notice of Award and containing the details of the agreement between the parties.

Personnel to be contacted for any negotiations required on this procurement:

Contractual: **Mr. R. E. Chatten, Contract Admin., AC 512, CV 4-2000, Ext. 737 or**
Mr. D. D. Belto, Assistant Treasurer, Area Code 512, OV 4-2000, Ext. 231
Mr. A. C. Hulen, Treasurer, Area Code 512, OV 4-2000, Ext. 233

Technical: **Dr. J. T. Goodwin, Director, Department of Chemistry and Chemical Engineering, AC 512, CV 4-2000, Ext. 524**
Mr. J. M. Dale, Manager, Process & Product Development Section Area Code 512, CV 4-2000, Ext. 447

Contractual Information - continued

Contingent Fee Statement

Bidder represents: (a) That he has not employed or retained any company or person (other than a full-time bona fide employee working solely for the bidder) to solicit or secure this contract, and (b) that he has not paid or agreed to pay to any company or person (other than a full-time bona fide employee working solely for the bidder) any fee, commission, percentage or brokerage fee, contingent upon or resulting from the award of this contract, and agrees to furnish information relating to (a) and (b) above as requested by the Contracting Officer. (For interpretation of the representation, including the term "bona fide employee," see Code of Federal Regulations, Title 41, subpart 1-1.5 (April 1966)(August 1967)

SOUTHWEST RESEARCH INSTITUTE

By ______________________

Paul A. Braymen

Title **Assistant Treasurer**

Date: **August 12, 1968**

APPENDIX

PROFESSIONAL DATA SHEETS

JOHN M. DALE

Manager, Process and Product Development
Department of Chemistry and Chemical Engineering

Naval Air Corps - Muhlenberg College, Allentown, Pa., 1944
B.S. in Chemical Engineering, Louisiana State University, 1950
Graduate Work in Business Administration, LSU, 1950-1

A registered professional engineer, Mr. Dale is a specialist in process and product development. In his work, he has carried out a large number of projects through the various phases of development, including market research, economic analysis, laboratory investigation followed by pilot plant design, operation and field testing. Mr. Dale has conducted an extensive amount of research in the area of highway pavement delineation materials, highway night visibility, and, in particular, highway night visibility during periods of precipitation. During the course of this work, he has conducted field trials of pavement marking materials at some 23 separate locations in the United States, Canada, and Europe. Mr. Dale is the author of numerous journal articles, technical symposia papers, and holds a number of patents.

PROFESSIONAL CHRONOLOGY: Amerada Petroleum Corporation, 1950; Phillips Terminal Company, materials handling engineer, 1951-2; Phillips Chemical Company, process engineer, 1952-3; process economist, 1953-6; Southwest Research Institute, 1956-(process economist, department of industrial economics, 1956-8; senior research engineer, department of mechanical sciences, 1958-65; senior research engineer, department of chemistry and chemical engineering, 1965-6; manager, process and product development, department of chemistry and chemical engineering, 1966-).

Memberships: American Institute of Chemical Engineers, American Chemical Society (Division of Marketing and Economics), Scientific Research Society of America, American Economic Association, Kappa Sigma.

HERMAN F. BARSUN
Senior Research Engineer
Department of Instrumentation Research

B.S. in Electrical Engineering, University of Texas, 1932
M. S. in Electrical Engineering, University of Texas, 1934
Graduate Work in Electrical Engineering and Business Management,
University of Pittsburgh

Mr. Barsun, a registered professional engineer in Pennsylvania and Texas, is a power equipment specialist with over thirty years' experience in utility and industry engineering as a design engineer and supervisor of electrical component and equipment design and development. He has successfully solved operational difficulties experienced in transformers, transformer equipments, components, and distribution systems, incorporating new design techniques in such components and equipment to eliminate future difficulties. Holder of a patent in his field, he has directed numerous developments and has written many design requirements, power equipment maintenance manuals, and technical articles. His current research and development work is in the field of power equipment and systems. Mr. Barsun has conducted many seminars and courses of instruction in equipment maintenance, preventive maintenance techniques, and operational problem solution.

PROFESSIONAL CHRONOLOGY: San Antonio Public Service Company and City Public Service Board, 1934-43 (voltage correction and distribution design engineer, 1934-8; substation engineer, 1938-43); Westinghouse Corporation (Sharon, Pennsylvania), 1943-61 (design and development engineer, 1943-9; subsection group leader and supervising engineer, 1949-53; section manager, regulator and tapchanger section, power transformer engineering department, 1953-61); Southwest Research Institute, 1961-(senior research engineer, department of electronics and electrical engineering, 1961-5; department of instrumentation research, 1965-).

Memberships: National Society of Professional Engineers, Texas Society of Professional Engineers, Institute of Electrical and Electronics Engineers, Society for Nondestructive Testing, Tau Beta Pi, Eta Kappa Nu.

Rev Nov/66

WILLIAM W. BRADSHAW
Senior Research Engineer
Department of Instrumentation Research

B.S. in Physics, University of Texas, 1946
M.A. in Physics, University of Texas, 1951

A specialist in instrumentation research and instrumental analysis, Mr. Bradshaw has had extensive experience in the design and development of optical-electronic, photographic, and spectrographic devices and in the applications of infrared, ultraviolet, emission, X-ray, and magnetic resonance spectroscopy. He has engaged in improving the applications of various instruments and techniques to basic studies of radiation-induced free radicals in organic and biological materials, and in the development of radiation dosimetry based on free-radical measurement. His developmental work in the measurement of light ranges from the limits of photoelectric detection to the observation of surface reactions under conditions of very high thermal flux in SwRI's solar and arc-imaging furnaces.

PROFESSIONAL CHRONOLOGY: Teaching fellow, department of physics, University of Texas, 1946-7; research physicist, Defense Research Laboratory, University of Texas, 1947-8; research physicist, Spectrographic Research Laboratory, University of Texas, 1948-51; Southwest Research Institute, 1951-(research physicist, electromechanical section, physics department, 1951-8; senior research physicist, chemical physics section, physics research department, 1958-64; department of physical and biological sciences, 1964-6; industrial systems section, department of instrumentation research, 1966-).

Memberships: American Physical Society, Phi Eta Sigma, Sigma Pi Sigma, Society of Sigma Xi.

Rev Apr/67