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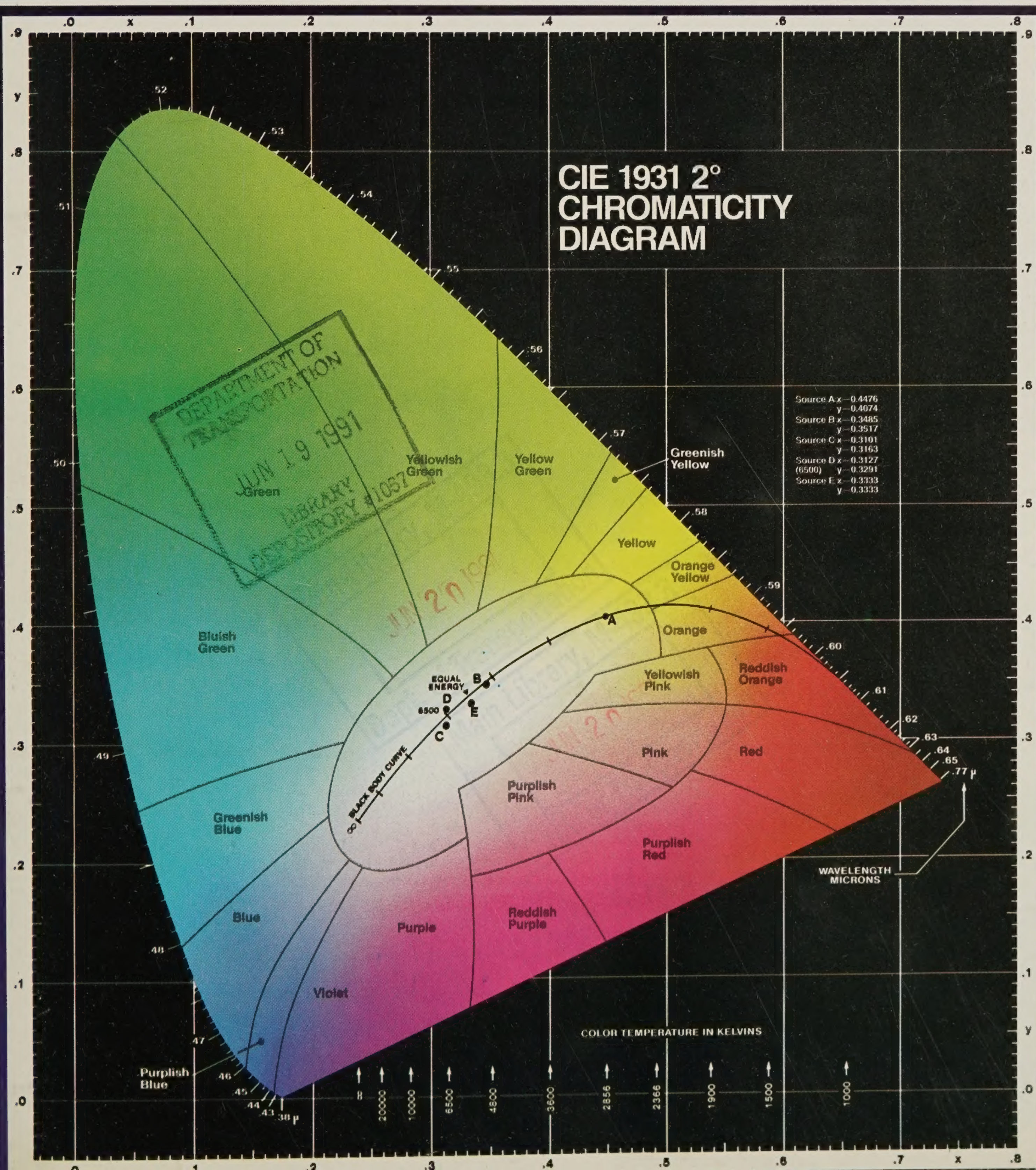

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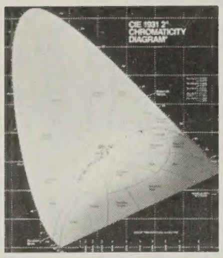

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COVER: The CIE chromatically diagram. The chromatic aspect of any light source or object can be represented by a point (x,y) which is plotted inside the horseshoe shaped area. Color specifications, including those for traffic signs (see article on page 1), are usually given in terms of such a color space.

IN THIS ISSUE

Articles

Departments

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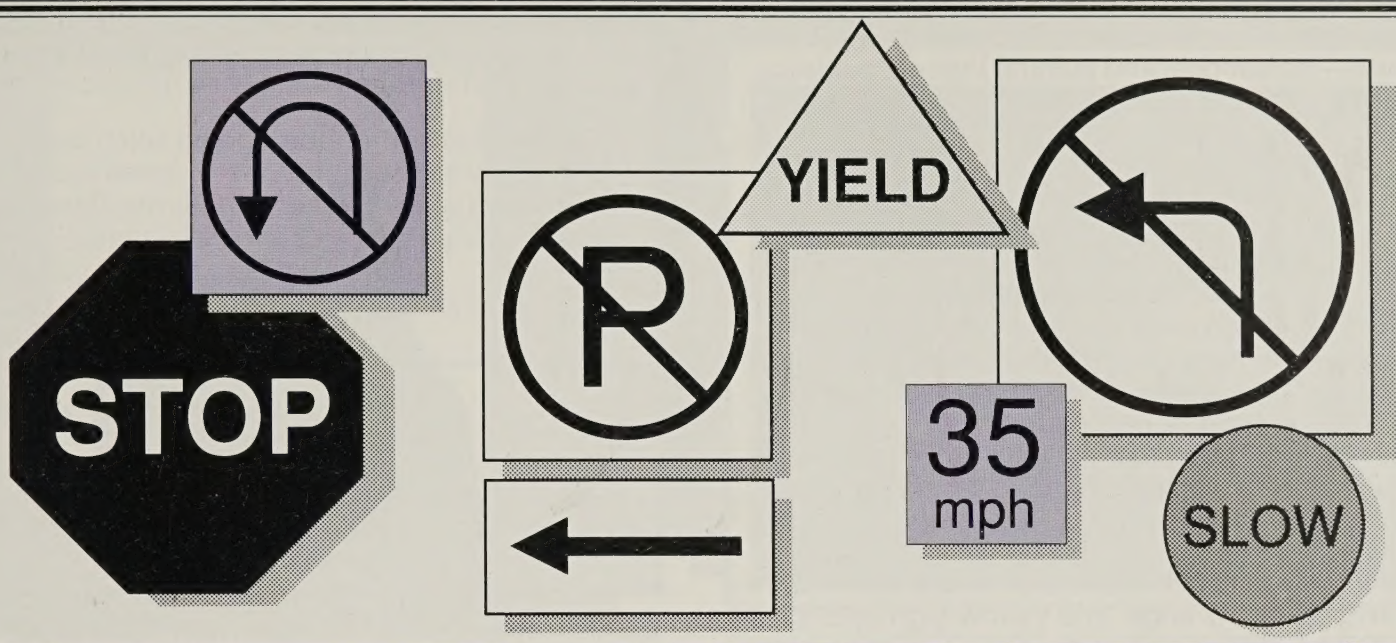

Color Recognition of Retroreflective Traffic Signs Under Various Lighting Conditions

by John B. Arens, A. Reza Saremi, and Carole J. Simmons

Introduction

Sign colors contribute substantially to correct sign recognition. While daytime color appearance is influenced somewhat by weather conditions (e.g., sun, clouds, rain, or fog) nighttime sign colors are greatly affected by the artificial lighting (headlamps, fixed sign lights, or a combination thereof) under which they are seen. For example, signs made from retroreflective materials reflect light from headlamps back to the driver very efficiently. Signs made from other than retroreflective materials (i.e., from opaque materials) are not adequately visible under headlights alone and must be illuminated by fixed lights to be visible at night. Fixed sign lights are also often used with retroreflective signs to improve the signs' conspicuity and legibility. In such cases signs are seen under a combination of fixed sign lighting and headlights. Depending on the spectral distribution of the light produced by the various types of sign lights and headlamps, the chromaticity of illuminated signs will shift markedly at night. The present research grew out of concern over possible changes in color appearance resulting from such chromaticity shifts as well as from changes in color specification. The study was conducted in 1990 at the Turner-Fairbank Highway Research Center and was sponsored by the Federal Highway Administration (FHWA) as part of the Grants for Research Fellowships program.

Background

Color Specifications for Traffic Signs

Color coding is used to aid drivers in the prompt recognition of highway signs, pavement markings, traffic signals, and other traffic control devices. The *Manual on Uniform Traffic Control Devices* (*MUTCD*) specifies meanings for eight colors:

- Red—stop or prohibition.
- Yellow—general warning.
- Orange—construction and maintenance warning.
- Blue—motorist services guidance.

- Green—indicated movements permitted, direction guidance.
- Brown—recreational and cultural interest guidance.
- Black and white—regulatory. (*1*)[1]

To standardize the appearance of the colors used in the *MUTCD*, the FHWA has issued color specifications in the form of central values and tolerance limits. Historically, these specifications were based on the colors of available materials rather than on experimental data on color recognition. For example, the acceptable region for yellow includes the rather orangish yellows produced by lead chromate, the pigment once widely used in producing yellow road markings. Progress in the manufacture of pigments and retroreflective materials may have made an improved standard highway yellow possible.

There has been concern about possible color confusion among red, orange, and yellow sign colors, especially at nighttime, since the FHWA specifications for these three colors are relatively closely spaced in the International Commission on Illumination (Commission Internationale de l'Eclairage-CIE) chromaticity diagram. Several recent studies have analyzed experimental data on the color appearance of materials viewed under diffuse sources of illumination. (*2,3,4*) These materials included ordinary (opaque) paints and pigments conforming to the American National Standards Institute's (ANSI) specifications Z-53.1 as well as retroreflective samples conforming to FHWA specifications. (*5*) One analysis recommended that the safety color specifications should be considered for adoption in highway signing applications. (*3*)

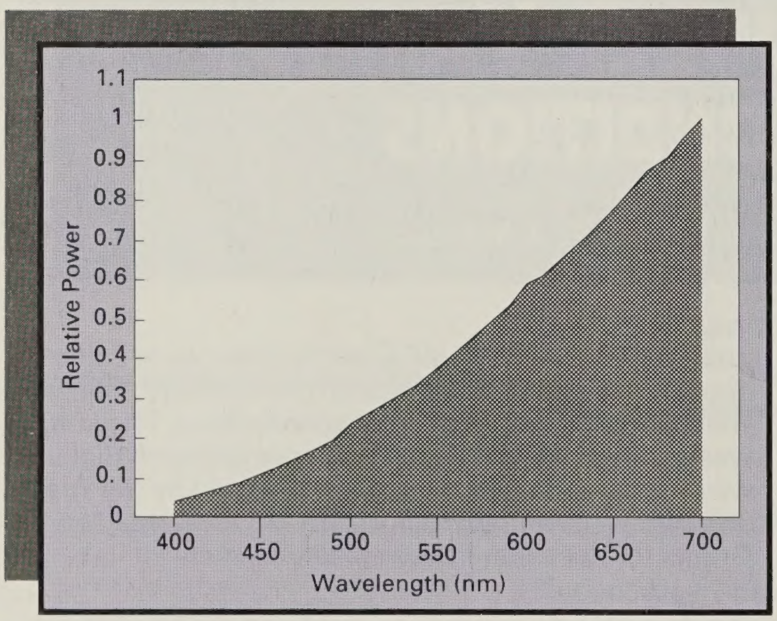

Figure 1.—Spectral power distribution for incandescent tungsten-halogen lamp used in this study.

[1]Italic numbers in parentheses identify references on page 7.

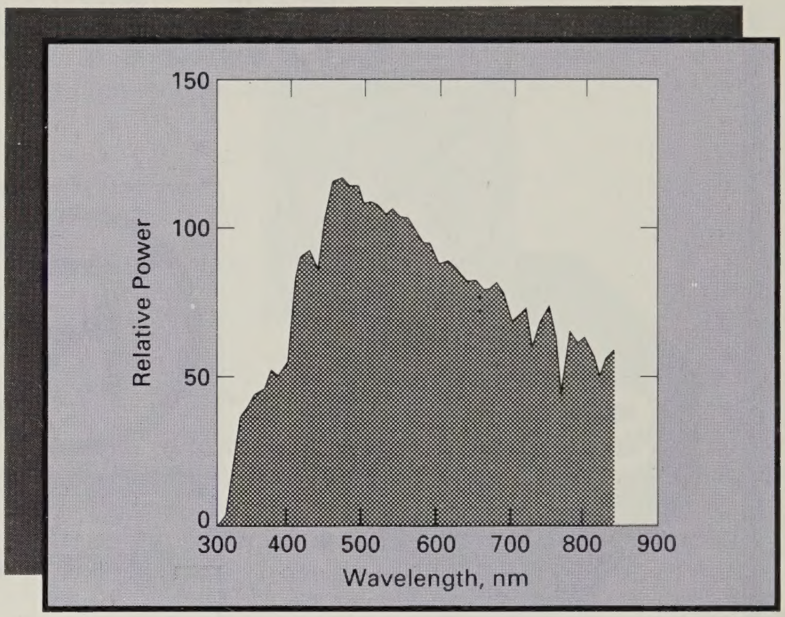

Figure 2.—Spectral power distribution for typical daylight (CIE 1971).

Headlamp Types

Currently used tungsten-halogen headlamps produce light with much energy in the red portion of the spectrum with a related color temperature of around 2,800 to 3,000 K (figure 1). Daylight, on the other hand, contains much energy in the blue portion of the spectrum—about 6,500 K for natural daylight (figure 2). Since signs (or any other object for that matter) can only reflect light available, their colors appear different under headlights than under daylight. Motorists are, however, accustomed to this much redder appearance. Within the next 2 years, cars will probably be produced with metal-halide headlamps rather than tungsten-halogen headlamps. The industry's rationale for changing from tungsten-halogen to metal-halide is the latter lamp's much higher efficiency, longer life, and smaller size (figures 3 and 4.) The metal-halide lamp produces visible energy at distinct wavelengths across the spectrum with a good amount of blue and considerably less red than the tungsten-halogen lamp; its related color temperature is expected to be about 4,200 to 4,500 K (figure 5). The effect of such a change in headlamp spectral composition on the nighttime appearance of traffic signs is not yet fully known. One computational analysis found mixed results for the sample of High-Intensity Discharge (HID) spectral power distributions studied; there were indications that the discriminability of red versus orange, yellow, and brown might actually be improved under certain HID sources as compared with tungsten halogen sources. (*6*)

Objectives

The main objective of the present study was to compare current FHWA standard retroreflective signing materials with those materials following ANSI safety color specifications. Specifically, the study:

- Compared color identification of these materials when viewed in the retroreflective mode (i.e., under headlighting) as well as under diffuse lighting.
- Compared color recognition for retroreflective materials viewed under tungsten-halogen versus metal-halide simulated headlamps, either alone or in combination with various fixed light sources commonly used for sign lighting.

Study Design

Laboratory setup

The laboratory setup was designed to simulate sign-viewing geometry for a passenger car positioned 400 ft (121.9 m) from a traffic sign, with the sign 14 ft (4.3 m) to the right from the right-hand edge of the road and 8 ft (2.4 m) above the road surface (figure 6). For that geometry, the driver sees the sign at an observation angle of about 0.2 degrees. The observation angle is comprised of a ray from the headlights to the sign and a ray from the sign back to the observers' eyes.

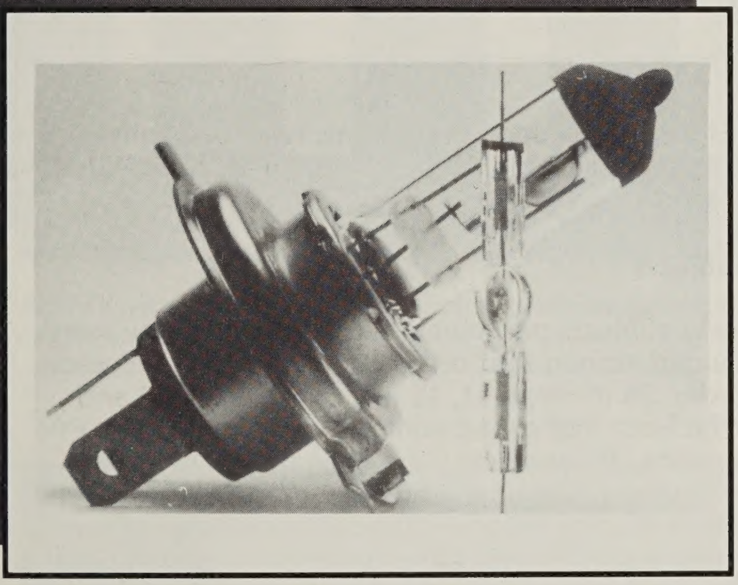

Figure 3.—Arc-tube of proposed metal-halide automotive headlamp compared with a conventional tungsten-halogen lamp.

Twelve different retroreflective sheeting materials (7 yellow, 3 red, and 2 orange) from 2 manufacturers were evaluated. Since two pilot studies had shown no problems in color recognition of blue and green samples, this study was restricted to yellow, red, and orange. (*7,8*) The FHWA and experimental ANSI samples were included for each color.

Since retroreflective sheeting is not commercially available in ANSI colors, these samples were custom made for use in this study. The red and orange sheetings were all FP-85 Type II (enclosed lens) materials; the yellow sheetings included Type III (encapsulated lens) and an experimental prismatic material (not included in the FP-85 typology), as well as Type II materials. (*9*) See table 1 for a full description of the 12 sheeting materials. Each of the 12 materials was mounted on a 1- by 2-ft (30- by 61-cm) aluminum panel. Black and white striping was used as a border along the upper and lower edges of the panels; otherwise, the panels were blank.

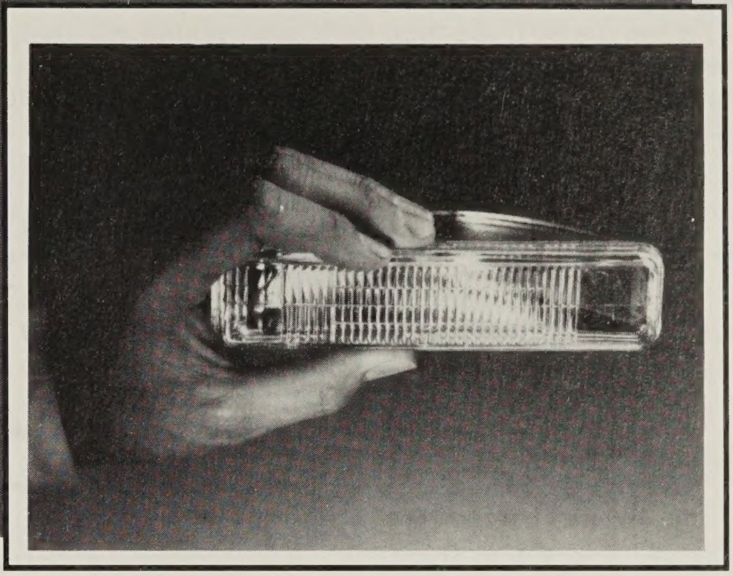

Figure 4.—Headlamp design utilizing metal-halide discharge lamp.

Three types of lighting were used: simulated daylight, headlighting only, and a combination of headlighting plus fixed sign lighting. A daylight simulator with two spectrally correct fluorescent lamps of 6,500 K was used to provide the diffuse simulated daylight condition.

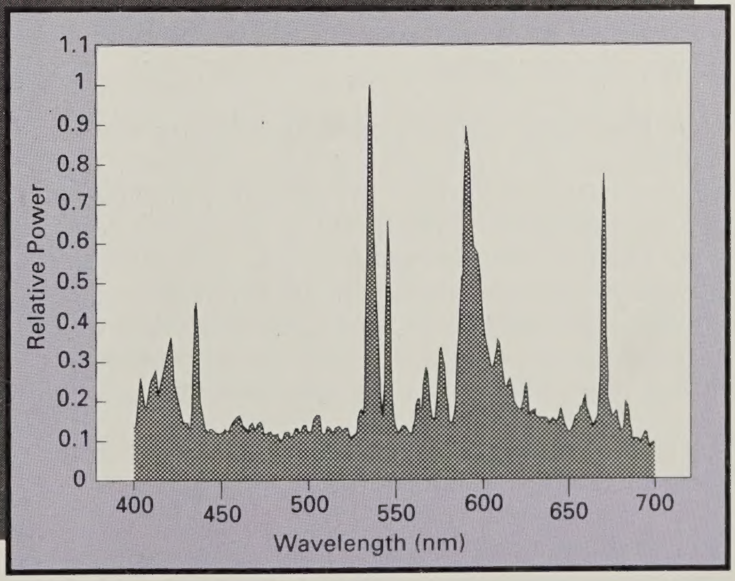

Figure 5.—Spectral power distribution for metal-halide lamp used in this study.

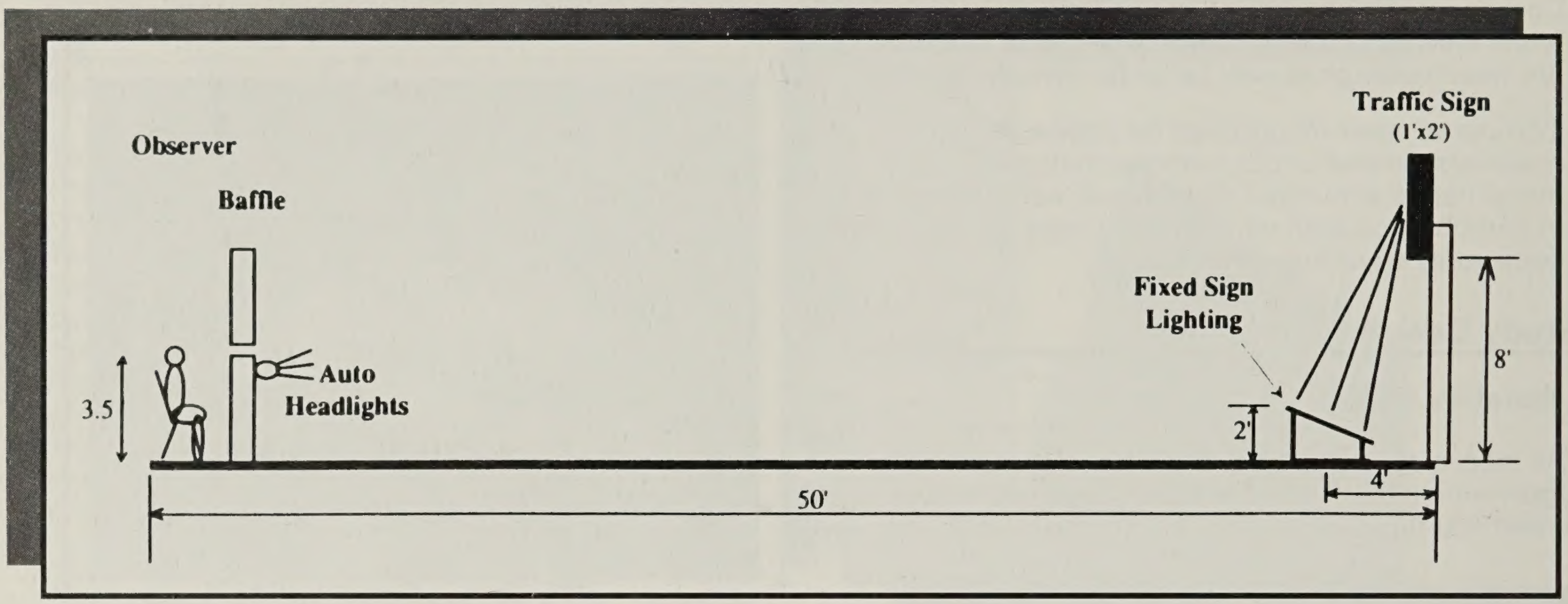

Figure 6.—Experimental design setup.

The light sources simulating either tungsten-halogen or metal-halide headlamps had to be quite small to fit into a space that allowed maintenance of the 0.2-degree observation angle within the 50-ft (15.2-m) laboratory space. This size limitation precluded the use of real headlamps.

To simulate the tungsten-halogen headlamp, a small 30-W tungsten-halogen narrow beam floodlamp was used. To simulate the metal-halide headlamp, a 70-W neutral white metal-halide lamp with a 3,800 K color temperature was used. Figure 5 shows the spectral power distribution for this lamp. The lamps were located close to the observers' eyes (one to the left, the other to the right) to ensure maintenance of the 0.2-degree observation angle. Photometric information on sealed beam headlights showed an illuminance level of 0.2 lux at the sign surface. To provide this illuminance level at the sign surface, neutral density filters were used to attenuate the luminous intensity of these lamps.

For the fixed sign lighting used in combination with headlighting, four different light sources were used: clear mercury, phosphor-coated mercury, phosphor-coated metal-halide, and high-pressure sodium. Each of these lamp types was mechanically adjusted to produce about 200 lux on the sign surface with a geometry similar to that used for bottom-mounted sign lights. This level represents the average illuminance used for overhead guide signs.

Each of the 12 signing materials was viewed under a total of 11 lighting conditions:

- One daylight condition.
- Two headlight type conditions.
- Eight combination conditions: two headlight type conditions with each of four different fixed sign lights.

Subjects

Forty subjects participated in the study. They were divided among four different age groups—25 and under, 26 through 44, 45 through 65, and 66 and over. Each age group contained five males and five females. All subjects were licensed drivers with corrected visual acuity of 20/40 or better, as tested with a Bausch & Lomb Ortho-Rater. Subjects were screened for normal color vision with the Ishihara pseudoisochromatic plate test. (*10*)

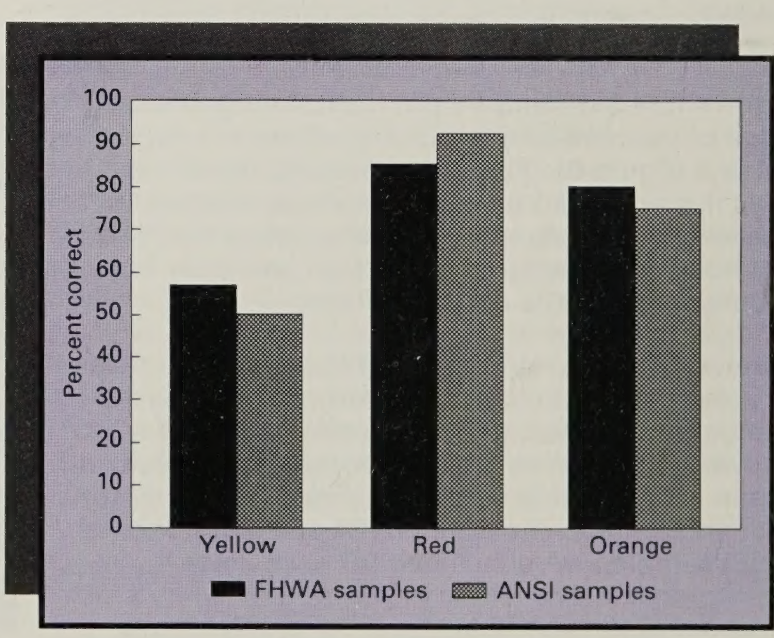

Figure 7.—Mean correct color identification across all lighting conditions.

Experimental Procedure

Subjects were seated on a chair of adjustable height and given time to adapt to the lighting conditions. Subjects were instructed to press a hand-held button as soon as they could identify sign color; they were told to use a single-word color term such as green, yellow, red, lime, or olive in making their identification. To begin each trial, a single sign panel was moved into the viewing position; the shutter was then opened. The subject's color naming response and response time were recorded. A within-subjects design was used in which each subject viewed each of the 132 stimuli (i.e., 12 panels under each of the 11 lighting conditions).

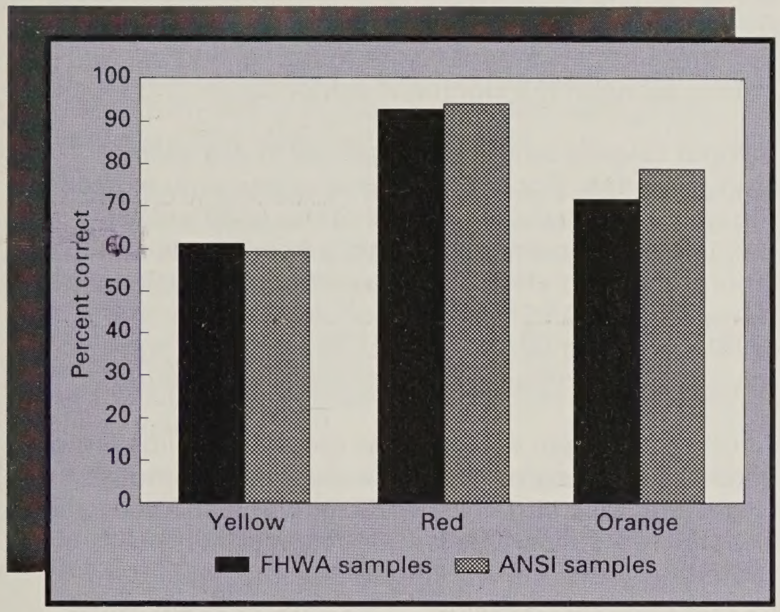

Figure 8.—Mean correct color identification under daylight and headlights only.

Data Analyses and Results

For purposes of analysis, color naming responses were coded as correct if they agreed with the nominal color of the material; any other response was considered incorrect even though there is no real right or wrong regarding a person's perceptions. Thus, if a subject identified a nominally orange sample as gold, this was coded as an incorrect response.

Table 1 presents the percentage of subjects responding correctly to each color sample under each of the 11 lighting conditions. Figures 7 through 9 are bar graphs based on these data. Figure 7 shows overall means for FHWA and ANSI samples for each color, averaged across all 11 lighting conditions. In figure 8, the means are averaged across the daylight and headlights only conditions. Figure 9 presents the means across the eight headlights with fixed lighting conditions.

Table 1.—Percent correct color identification

				Daylight	**Headlights Only		***Headlights and Fixed Lighting							
	SPEC.	*TYPE	MFR	(6500 K)	TH	MH	TH/ HPS	MH/ HPS	TH/ Cl.Hg	MH/ Cl.Hg	TH/ Ctd.Hg	MH/ Ctd.Hg	TH/ Ctd.MH	MH/ Ctd.MH
Yellow samples	FHWA	II	A	75	21	23	53	58	3	3	13	10	50	60
	FHWA	III	A	90	68	73	43	70	75	75	60	75	68	73
	FHWA	PR	A	33	78	90	63	80	58	78	60	75	63	75
	ANSI	II	A	98	30	28	53	60	0	5	5	15	35	55
	ANSI	II	B	88	3	3	70	83	3	5	3	8	20	25
	ANSI	III	A	90	73	70	60	78	23	13	53	38	73	55
	ANSI	PR	A	65	76	90	68	78	80	63	88	85	83	85
Red samples	FHWA	II	A	100	89	90	58	58	90	78	98	95	100	98
	ANSI	II	A	100	89	85	71	73	95	95	100	98	95	100
	ANSI	II	B	100	98	93	73	85	98	90	100	100	100	100
Orange samples	FHWA	II	A	98	73	48	85	93	68	65	90	90	93	85
	ANSI	II	B	98	68	73	60	90	58	60	78	75	80	93

Notes:
* Types II and III comply with specifications in FP-85.
Type PR was a prismatic material not included in FP-85.

** TH = Tungsten Halogen
MH = Metal Halide

*** HPS = High Pressure Sodium
Cl.Hg = Clear Mercury
Ctd.Hg = Phosphor Coated Mercury
Ctd.MH = Phosphor Coated Metal Halide

Two general features of the data may be noted. First, consider the three general types of lighting used. As would be expected, simulated daylight resulted in more accurate color naming than did either the headlights only or the fixed lighting with headlights conditions. Second, consider the relative accuracy of recognition for the three colors studied. The red samples were the best recognized of the three colors. (Under daylight, 100 percent of the subjects' responses for the reds were correct.) In most cases, the orange samples were also correctly identified by a large majority of the subjects. The yellow samples were, on the whole, correctly identified less frequently than the reds or oranges, regardless of the lighting condition.

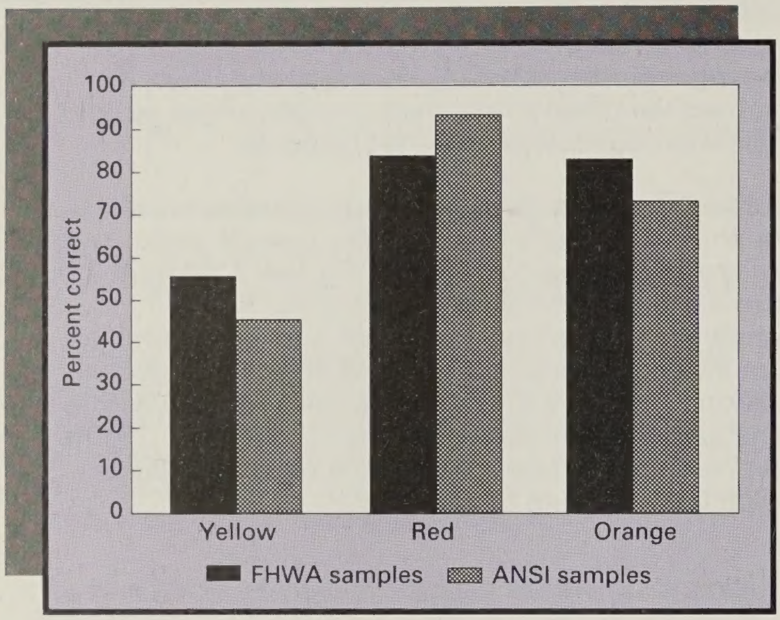

Figure 9.—Mean correct color identification under fixed lighting with headlights.

The study's most important finding was that while there was variation within the material-lighting combinations, the type of specification (FHWA or ANSI) did not result in any large or systematic difference in the level of accurate color identification. This finding held true regardless of the lighting condition considered.

The second major finding was that the accuracy of color identification was not systematically affected by the type of headlamp used. This finding can be seen by comparing the mean percentages (averaged across all 12 materials) for tungsten-halogen (63.8 percent) and metal-halide (63.8 percent), as well as by comparing the individual percentages for each material under these two lighting conditions.

Discussion and Conclusions

This study aimed to assess the possible improvement in driver recognition of traffic sign colors to be achieved by changing from the FHWA highway colors to the ANSI safety colors. To this end, sign color appearance under daylight and various nighttime viewing conditions was investigated. Although some lighting-color combinations improved correct color recognition when viewing the ANSI safety colors, these improvements were marginal and applied only to some of the signing material colors and types.

Several caveats must be recognized in discussing study findings. For example, one uncertainty exists regarding spectral correctness of the ANSI experimental samples, since these were hand-made in a laboratory shop. There are no color specifications for retroreflective ANSI safety colors at this time: the ANSI Z-53.1 standards to which the samples were made apply to opaque (nonretroreflective) paints.

Another uncertain variable was the metal-halide lamp used in the experiment. The Society of Automotive Engineers' Discharge Forward Lighting task force and CIE's Technical Committee "Headlighting with HID Lamps" are still working to develop a standard for HID headlamps that includes, among many other parameters, color specifications for the metal-halide automotive headlamp. This study used a commercially available small wattage metal-halide lamp similar in makeup to what the final headlamp design is expected to be. Although study findings thus most likely resemble what would be found using the final headlamp design, some caution should be exercised in using the results of this limited study to recommend color specification changes.

Finally, the appropriateness of the various lighting configurations used during data collection must be addressed. Red, yellow, and orange signs are predominantly seen under either daylight or headlamp illumination only: with the exception of some construction signs, signs of these colors are seldom seen under fixed sign lighting. Thus, correct identification of the red, yellow, and orange FHWA colors versus the ANSI colors is most significant under daylight or headlight only conditions. While the present nighttime study did not show any substantial benefits of the ANSI safety colors over the currently used FHWA highway colors, other studies did show significant benefits when using the ANSI colors under diffuse daylight conditions.

Therefore, additional work should be conducted once a prototype of the finalized metal-halide headlamp design and appropriate retroreflective ANSI signing material samples are available. This work should investigate not only the color recognition of these materials, but also their overall effectiveness relative to road safety.

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(*1*) *Manual on Uniform Traffic Control Devices (MUTCD).* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.

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Q&A

How to Conduct Questionnaire Surveys

by Peter A. Kopac

> *The Governments are very keen on amassing statistics—they collect them, add them, raise them to the nth power, take the cube root, and prepare wonderful diagrams. But what you must never forget is that every one of those figures comes . . . from the village watchman, who just puts down what he damn pleases.* (*1*)[1]
>
> —British economist Josiah Stamp, 1929

[1]Italic numbers in parentheses identify references on page 15.

Introduction

Designing, organizing, and conducting a questionnaire survey is like establishing and running a business. Although these activities require technical knowledge and skill, administrative ability, and specific experience or training, the general impression is that, with a little luck, anyone can do them well. Thus, many people assume that starting a business requires no special skills beyond a willingness to try. The annual failure of thousands of new small businesses demonstrates the naivety of this assumption. Similarly, the findings from thousands of questionnaire surveys that are unreliable or misleading prove that conducting a viable, reliable questionnaire survey is not as easy as it might seem.

Contrary to common assumptions, a questionnaire is more than a list of questions. Rather, it is a scientific instrument for measuring and collecting particular kinds of data. And, like all other scientific instruments, a questionnaire must be designed in accordance with particular specifications and tailored to the specific aims of the surveyor. (*2*) Only by careful "soup-to-nuts" planning, construction, and implementation can reliance be placed upon the results of the questionnaire survey.

To assist anyone planning to conduct a questionnaire survey, this article provides a comprehensive checklist of items to consider in questionnaire development (figure 1). These items take the surveyor from the initial survey planning stages through instrument design and development and on to actual survey implementation. By following the information and suggestions provided here, surveyors can use a systematic methodology to collect valid data and achieve reliable results.

Planning the Survey

1. What question or questions are to be answered by the survey?
2. How and by whom will the results be used?
3. How large an effort is needed?
4. Is the desired information already available?
5. How will information be obtained?
6. What kind of sampling is appropriate?
7. How big a sample is needed?

Constructing the Questionnaire

1. Is there a clear understanding of the topic to be addressed?
2. Are needed definitions provided?
3. How long should the questionnaire be?
4. Are the right type(s) of questions being asked?
5. Are questions properly worded?
6. Are questions in logical order?
7. Is the questionnaire attractive?

Sending the Questionnaire

1. Has the questionnaire been pretested?
2. Is the cover letter effective?
3. When should the questionnaire be sent?
4. When and how to followup?

Figure 1.—Questionnaire development checklist.

Planning the Survey

What question or questions are to be answered by the survey?

Before the survey can be undertaken, the surveyor must be able to present its objective clearly and specifically. What is the problem that the survey will address? Typically, the general nature of this problem has been determined already. However, the surveyor must further define the specific problem that is to be studied objectively and scientifically in the survey.

Next, the surveyor must determine the facts needed to answer the problem statement. What are the specific questions to be answered by the survey? What data need to be collected? Collecting information for its own sake rarely justifies the effort required to assemble and present it. Therefore, the survey should not pose questions whose answers are interesting but unessential to the main thrust of the investigation. In making these determinations, the surveyor should keep in mind the survey's end user—the agency or individuals who will use the survey findings. By keeping these potential consumers in mind, the surveyor is more likely to determine those questions that will be most meaningful and useful.

How and by whom will the results be used?

This question is related to the previous one. In developing the survey plan, the surveyor must keep in mind the characteristics and information needs of the survey's eventual consumers. While it is not possible to foresee all the misuses to which survey statistics may be put, many abuses can be prevented if the surveyor is aware of the consumers' needs.

How large an effort is needed?

Depending on the nature of the problem to be addressed and the amount of information already available on that topic, the surveyor may want to use the survey as a small preliminary or pilot study to form the basis for recommended subsequent research.

This option, however, is rarely available: more often the problem needs to be addressed in full immediately. In these cases, the surveyor should have some control or input relative to planning the survey's required funding and time. The surveyor should ensure that sufficient funds will be available not only for the collection of the necessary data but for their tabulation, analysis, and presentation. Similarly, the surveyor should ensure that sufficient time is allotted for questionnaire development, distribution, collection, followup, and for resolving any problems that may arise. If either the survey budget or schedule is underestimated, the survey is not likely to be successful.

Is the desired information already available?

No survey should be undertaken until the surveyor is satisfied that the required facts have not already been collected. Often, a careful search will show that some of the desired information is already published or on file. However, if the available facts are inconclusive, outdated, or otherwise insufficient, the surveyor can profit by avoiding the mistakes of the earlier survey or by expanding upon those aspects that the original did not emphasize. (*3*)

How will information be obtained?

Once the problem to be investigated has been defined and the decision to conduct a survey finalized, the surveyor should next decide what survey method should be used to obtain the desired information from the respondents. Three general survey procedures are available:

- Personal (face-to-face) interview.
- Telephone interview.
- Self-administered questionnaires.

The advantages and disadvantages of these procedures are shown in figure 2.

What kind of sampling is appropriate?

Although it is sometimes possible to survey an entire population, generally this technique would result in an unwieldy amount of data. To limit the population surveyed, a sample is drawn to reflect the characteristics of the total population. By using a carefully drawn sample, the surveyor is assured that potential respondents have been selected in a standard, scientific manner.

Many surveyors assume that a sample can be drawn unsystematically—e.g., by accident or self-selection—and thereby yield a random sample. This assumption is incorrect: unsystematic sampling may be biased at worst or unrepresentative at best. Because many surveyors fail to decide what population they are sampling, they have no way of knowing if they are exposing all of the population to the sampling process. A similar problem exists

Survey Procedure	Advantages	Disadvantages
Personal interview	• Yields high percentage of returns. • Information secured is more likely to be correct than with other methods. • Interviewer can control who answers questions. • Language can be adapted to suit respondent. • More of respondent's time can be taken than with telephone interviews. • Visual material can be presented to respondent. • Face-to-face interview more conducive to considered responses.	• High costs. • Interviewer bias may distort returns. • Recorded data may be inaccurate if interviewer is not properly trained. • Takes more time than telephone interview.
Telephone interview	• Quickest of the survey techniques. • Low cost. • Low refusal rate.	• Attitude scales must be used with caution. • Visuals cannot be used.
Self-administered questionnaire (usually delivered by mail)	• Low cost. • Anonymity can be ensured. • Can be answered at the respondent's convenience giving respondent time to consider each point.	• Low returns. • Questions can be misinterpreted. • Questions must be simple and self-explanatory. • Questionnaire must be brief. • Answers are likely to be brief ad superficial.

Figure 2.—Advantages and disadvantages of three popular survey procedures. (3)

when the source or list from which the sample is chosen does not represent the population. Therefore, the surveyor must first define the survey population and then select a method or methods of sampling it. Following are descriptions of the most commonly used sampling types:

- Random sampling.
- Stratified sampling.
- Purposive sampling.

By using two or more of these sampling techniques, a survey can capitalize on their combined advantages and counterbalance their disadvantages. This method is called double or mixed sampling.

Random Sampling. Random sampling assures each individual or element in the population the same chance of being chosen for inclusion in the survey. If the sample is chosen at random and is sufficiently large, it will represent all the groups in the population in approximately the correct proportions. One advantage of random sampling is no advance knowledge of the characteristics of the population is necessary. A disadvantage of the technique is that a low percentage of returns could result in an accidental sample. (*3*)

Stratified Sampling. Stratified sampling is frequently recommended as the most efficient procedure for ensuring representativeness. (*3*) The procedure calls for dividing the population into two or more strata and then drawing a random sample from each stratum. Stratified sampling may be proportional or disproportional depending on the number of samples selected within each stratum. In **proportional stratified sampling**, samples are drawn from each stratum in the same proportion as they occur in the population. Consequently, the only difference between proportional sampling and random sampling is that the former ensures that the right proportion is obtained from each stratum. (*3*) In **disproportional stratified sampling**, an equal number of samples is secured from each stratum, thereby facilitating reliable comparison of the different strata. The goal of obtaining an equal number of samples, however, is very difficult to achieve in actual practice.

Purposive Sampling. The objective of purposive sampling is to make the sample look like the population. There are several ways of doing this:

- Select the sample so its averages are the same as the population averages for known characteristics believed relevant to the phenomenon being investigated.
- Select the sample so its frequency distribution of each relevant characteristic resembles the population's frequency distribution.
- Select the sample so it will contain the same proportions as the population's at the upper and lower ends of the frequency distribution (deciles, quartiles, etc.).
- Select the sample so that its variability (e.g., standard deviation) is the same as the population variability.

One advantage of purposive sampling is it may be cheaper than other sampling techniques. A major disadvantage is that much must be known about the population before sample selection.

How big a sample is needed?

The optimum sample size ensures efficiency, representativeness, and reliability. It should provide the most useful information with the required level of reliability at the minimum cost. The sample should be large enough to yield statistically representative and significant results in all key proposed tabulations and to avoid intolerable sample error. It should not be so large, however, as to waste funds, delay the project, or achieve a needlessly high level of precision.

When trying to determine the optimum size of the sample, the surveyor should follow the guidance provided below. In general, the surveyor should note that it is sound practice to err on the side of too large a sample rather than too small. (*3*)

To determine optimum sample size, the surveyor should perform the following.

Secure preliminary information about the population. If the sample will be used to make a percentage estimate of the population, a preliminary estimate of the approximate size of this percentage is needed. On the other hand, if the purpose is to predict the average of the population, the surveyor needs an estimate of the standard deviation. Fortunately, both these estimates can be rough and still prove useful.

Determine the required precision of the prediction. This determination depends upon the error permissible in the estimate and the degree of confidence that the estimate will fall within the permissible error.

Calculate the required sample size. For estimating *percentages*, use

$$n = \frac{pqz^2}{T^2}$$

where
p = the preliminary estimate of the percentage
q = 100 - p
z = the number of standard error units (from a normal probability table)

T = the required precision or tolerance

Example: Suppose we are permitted a ±5-percent error in estimating from a population the percentage of engineers with 10 years or more of experience. Assume we will be satisfied with a 90-percent degree of confidence that the estimate will fall within the 5-percent tolerance. We have reason to believe that the percentage of engineers with 10 years or more of experience is somewhere around 75 percent. Substituting in the formula above, we have:

$n = (75)(25)(1.64)^2/(5)^2$
$n = 202$

$$n = \frac{(75)(25)(1.64)^2}{5^2}$$

Thus, we need to take a random sample large enough to assure responses from about 200 engineers if we want a 90-percent probability that the true percentage is within ±5-percent.

For estimating *averages*, use

$$n = \left(\frac{\sigma z}{T}\right)^2$$

where
σ = the estimated standard deviation
z = the number of standard error units
T = the required precision or tolerance

Example: Suppose we want to estimate the average design strength of concrete pavement mixes within 100 lb per square in (psi) (7.0 kg/cm^2). Let us assume we will be satisfied with a 95-percent degree of confidence that our estimate will fall within the 100-psi (7.0 kg/cm^2) tolerance.

If we use 300 psi (21.1 kg/cm^2) as the estimated standard deviation of concrete pavement mix design strength, we can substitute in the formula above:

$$n = \left[\frac{(3000)(1.96)}{100}\right]^2$$

$n = 35$

Thus, we need to take a random sample large enough to assure 35 responses regarding concrete pavement mix design strength if we want a 95-percent probability of estimating the average design strength within ±100 psi (7.0 kg/cm^2).

If the preliminary estimate of either the percentage or standard deviation proves to have been too large, the computed sample size also will have been larger than necessary and therefore conservative; the preliminary estimate may also come out too small, with the opposite result. To help set sample size, the surveyor should try various estimates in the formula to see what effect each has on the computed sample size.

Construction of the Questionnaire

Is there a clear understanding of the topic to be addressed?

If the questionnaire is to be meaningful to others, the surveyor needs to have a good working knowledge of the topic to be addressed. If the surveyor does not fully understand the topic, the questions may be vague or ambiguous, complex issues may be oversimplified, insufficient space may be provided for responses, etc. In such cases, respondents may show their frustration by either rushing through the questionnaire, providing only superficial answers or not responding at all.

Are needed definitions provided?

Related to understanding the survey topic is the concept of understanding the respondents. The surveyor must:

- Understand the respondents' language, and use it correctly.
- Not talk down to the respondents.
- Not assume too quickly that respondents will understand the question in the intended frame of reference.
- Ensure that the questions have the same meaning for all respondents. (*4*)

Additionally, definitions of key terms used in the questionnaire should be provided. There should not be too many definitions, nor should the definitions be lengthy or complicated. The definitions may appear together in a section above the questions themselves; if only one or two definitions are to be given, it may be more appropriate to include them in notes following the respective question. The objective is to get the respondents to read and understand each definition.

How long should the questionnaire be?

The percentage of questionnaires returned decreases as the number of pages increases from 1 to 10. (Interestingly, there does not seem to be a significant difference in the percentage of returns as pages increase from 10 to 35.) Although evidence suggests that with the proper incentives and a carefully pretested form, certain groups will respond thoroughly to a very long questionnaire. However, the best approach is to keep the form as short as possible to obtain the needed information. (*3*)

To keep the questionnaire's length down, the surveyor should evaluate each proposed question separately. Only those questions bearing directly on the problem should be included; answers to questions that can be secured from other sources may be deleted unless absolutely necessary as a check.

Are the right type(s) of questions being asked?

There is no generally accepted type of question that can be universally recommended for all questionnaires. Rather the type(s) of questions selected for use in a given questionnaire should depend primarily on the anticipated tabulation plan (i.e., how will the data be grouped in the tables?). To determine the appropriate type(s) of questions to use, the surveyor should both consider the tabulation plan and the strengths and limitations of the various types of questions as presented below.

Open-End Questions. Open-end questions give respondents free latitude in making their responses. An example of such a question is "What is the principal reason for your dislike of product A?" A drawback to their use is that open-end questions may yield such a variety of responses that the task of condensing and analyzing them is both time consuming and difficult to handle statistically. Open-end questions are often used in the exploratory phases of a study when the area covered by the question is still not well understood.

Dichotomous Questions. These questions elicit either/or responses (yes/no, true/false, good/bad, etc.) They usually also allow for a third response such as "don't know," "neither," etc. Surveyors, however have found that if the noncommittal third alternative is not given, relatively few respondents will fail to make a choice between the two options presented, thereby "forcing" some respondents to take a definite stand when actually they would not do so otherwise. The chief advantage of the dichotomous question is its simplicity. One of its limitations is that a slight misunderstanding of the question's meaning may result in a complete reversal of response. (*3*)

Multiple Choice Questions. Multiple choice questions allow respondents to choose from among several possible answers. The list of alternatives must be complete enough to cover all possible answers. Multiple choice question results can be tabulated easily and interpreted with greater precision than can answers to open-end questions. Multiple choice questions may take any of several forms; arguably the most popular of these are checklists and rating scales.

Checklists. Checklists are multiple choice questions consisting of a statement of the problem or question followed by a list of three or more possible answers. Checklists should be made up only after some preliminary survey or pretest has determined the types of replies that may be expected; this ensures that most answers will not fall in the "other" category that is usually provided with a limited list. The advantage of the checklist is that it serves to remind respondents of their various options.

Rating Scales. Rating scales allow respondents to choose among various degrees of opinion. The scale may be numerical (e.g., ranging from 1 to 5) or verbal (e.g., ranging from "poor" to "excellent"). Most dichotomous questions can be turned into rating scale questions simply by introducing degrees of opinion to the response options. After doing so, the extreme responses can be sorted out for use in comparative analyses where a high statistical significance level is desired. One problem with rating scale questions, however, is there is often a tendency for the respondent to choose a moderate rating.

Ranking of Items. In ranking of items questions, the respondent is asked to arrange a list of words, phrases, statements, pictures, etc., in some order. The ranking adds a dimension not found in checklists. However, a limitation of these questions is the fact that the size of the intervals between rankings is usually not the same: the difference between the first and second choices may be much greater than the difference between the second and third choices. Another limitation is the relatively small number of items that may be included. It has been suggested that as few as three choices give the best results; the optimum number probably varies with the subject matter. (*3*)

Are questions properly worded?

Asking questions to gain desired responses is more difficult than it may seem. The greatest danger in wording questions lies in taking too much for granted regarding language and terminology, reader comprehension and background, etc. Surveyors must develop a critical attitude toward their questions and should carefully analyze the wording of each. The critique is best done during pretest of the questionnaire. Every objection that may be raised about the phrasing should be carefully studied and answered. (*4*)

Following are some suggestions for wording questions:

- Use simple words and correct punctuation

- Use underline or boldface type for emphasis.

- Make questions concise and unambiguous.

- Formulate questions to yield exactly the information desired (e.g., specify the units for the answer) and avoid leading questions, i.e., questions worded in such a way as to suggest the answers.

- Avoid words such as "always" or "any," "about" or "near," "possible," and "should." When using "you" or "your," make it clear whether the second person singular or plural is intended.

- Cover only one point per question. If there are two or more ideas in the question, it will be confusing to determine to which thought the answer applies.

- Allow for all possible responses, i.e., multiple choice answers should be mutually exclusive and complementary and provide for "don't know" and "other" answers.

- Keep asking "What am I assuming or taking for granted by this question?"

Are questions in logical order?

To avoid confusion and misunderstanding, questions should be arranged logically. The questionnaire should, for example, open with a question that can be easily answered, preferably with a simple yes or no. If a difficult question is asked at the beginning, respondents may refuse to continue with the questionnaire.

After this important opening question, there must be an easy-to-follow logic, an established order, to the form. Order should be considered at three presentation levels:

- Topics covered by the questionnaire.

- Questions under each topic.

- Response alternatives to a single question. (*5*)

The surveyor should note that once a train of thought has been established, breaking that sequence can lead to poor results. Thus, a totally unrelated question, suddenly asked, is not desirable.

Is the questionnaire attractive?

An attractive questionnaire is a strong selling point for respondent cooperation. Attractiveness can be accomplished by the appropriate use of colors, pictorial materials, spacing, type, arrangement, etc. Research has shown that yellow paper—followed closely by pink—has the highest percentage of returns; dark-colored questionnaires usually are not effective. (*3*) The questionnaire should look easy to complete. This goal can be met by requiring very little writing of the respondent and/or arranging the various items so the questionnaire does not appear crowded.

Sending the Questionnaire

Has the questionnaire been pretested?

Regardless of how carefully the questionnaire has been worded, it should not be assumed that it will work well until it has been tested under field conditions. A pretest can be used to check the wording and sequence of questions, questionnaire length, clarity of instructions, effectiveness of cover letter, and other related items. Pretests also enable the surveyor to turn open-ended questions into multiple choice ones.

A pretest is normally done by furnishing the questionnaire to typical respondents, reviewing their responses, and interviewing them to get their reactions, suggestions, and other comments. Based on this feedback, the questionnaire is then revised as appropriate. Especially difficult questionnaires may require several revisions.

Another way to pretest the questionnaire is by developing several different drafts and simultaneously sending a different draft to each of several small samples of respondents. Such a pretest will provide comparative information on relative rates of return, data completeness and appropriateness, data suitability for tabulation, etc. (*3*)

Is the cover letter effective?

A letter of transmittal soliciting respondent cooperation should accompany the questionnaire. This letter should:

- Be on official letterhead.

- Explain the purpose of the survey and the uses to be made of the data.

- Provide instructions on how to fill out the form (if such instructions are not printed on it).

- Thank the respondent for cooperating.

Customized, personal touches to the letter can be effective in motivating potential respondents. Examples include a hand-written postscript or personal signature. (*3*) Another possible "motivator" is including self-addressed stamped or franked envelopes. Finally, promising to furnish survey results to respondents can also be effective. Of course, such a promise must be fulfilled in a timely manner.

When should the questionnaire be sent?

The surveyor must determine the most opportune time for sending out the questionnaire. This choice may be based on several factors, since the season of the year, the month, week, or time of the week during which a questionnaire should arrive in order to have the best chance of being filled out will vary with the type of respondent. (For example, a survey of construction engineers might best be done in the winter months when work is not at its peak.) The surveyor should also take into account the timing of the mailing vis-a-vis periods such as holidays, extremely hot weather, and important national events.

When and how to followup?

Followup of some kind is usually required to ensure an adequate rate of response. (*3*) The first followup might take the form of a short note or postcard reminding the recipient of the overdue questionnaire. A tactful suggestion may be included to disregard the reminder if the reply is on the way. The second reminder may include a copy of the questionnaire since the respondent may have misplaced the original. This second followup may also take the form of a telephone call.

The first followup activity should be undertaken when the daily returns have dwindled down to a trickle. Subsequent followups, if needed, should be spaced closer and closer together.

The acceptable percentage of responses depends on such variables as type of respondent, size of the questionnaire, subject matter, etc. However, it is not unrealistic to expect a 75-percent or greater rate of response for most questionnaires. (*6*)

Summary

This article is intended to provide guidance for the development of generic questionnaires. While the examples provided are engineering- or highway-related, the discussion may be equally applicable to questionnaires in other fields.

There is more to developing good questionnaires than just wording good questions. Weeks of planning and exploratory work are often needed. Thus, it is important that the surveyor schedule sufficient time. Successful questionnaire development includes identifying the specific problem, understanding the subject matter, and knowing the respondents. Appropriate survey method, sample size, type of sampling, and type of questions have to be given adequate consideration. The use of pretest is probably the greatest help in devising the actual wording of questions. The surveyor should also think well ahead to the data analysis phase. Because each survey tends to present its own problems, no amount of advice or guidance can substitute for thoughtful care, common sense, and good organization.

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Technology Transfer and Its Tools

by Burton W. Stephens

Introduction

During the past year, the Federal Highway Administration (FHWA) has greatly increased emphasis on the marketing of new technologies. As part of the October 1990 FHWA reorganization, a new office of Technology Applications was formed to increase the agency's effectiveness in implementing and deploying new and improved products. Prior to the formation of this new office, the requirement for marketing new technology and research and development (R&D) products to the highway community were developed and arrayed into a multi-phased process. (*1*)[1] To further delineate marketing principles appropriate for inclusion in public sector operating programs and to help translate these principles into specific technology transfer efforts, a seminar is now being developed for both the FHWA and other transportation agency personnel.

Technology Transfer

Technology transfer is the process by which the results of R&D are converted into practical and useful processes, products, and programs. Earlier *Public Roads* articles have dealt with various issues related to technology transfer and R&D product marketing. (*2,3,4*) This article looks at the fundamental ingredients of marketing strategies and new methods of technology transfer to rapidly deploy implemented technology.

To be useful, the products of highway-related R&D must be carefully marketed to potential users. This selling process applies both to a technology which the "customer" acknowledges is needed (e.g., a highway sign format that allows improved message recognition and comprehension by drivers) or one which solves a problem of which the customer was previously unaware. In either case, the user must be convincingly "sold" on the product—particularly if it represents a substitution for existing procedures.

In such situations, the R&D product or process under development must be assessed for its ultimate transfer to users. A technology transfer specialist must thoroughly assess the R&D effort to devise a marketing strategy to get the R&D results to the appropriate users. This marketing strategy assessment follows the basic framework outlined below and displayed in figure 1. Ideally, users should become involved with—or interested in—the research

[1]Italic numbers in parentheses identify references on page 21.

early in the process and be afforded opportunities for following its progress. This goal is easily realized when the R&D is short term and yields waited-for results, but it is seldom realized when the R&D is more fundamental and provides results only after many years or even decades.

A product must be valuable. The first essential element in any marketing strategy is to have an actual or potential product that is unique and cost beneficial to users. Researchers who are conducting fundamental or methodological studies do not—by definition—focus on the ultimate value of their work to end users. Rather, their work must be independently assessed to determine whether it may result in a product likely to be of value to end users.

Users must be targeted. Users must be specified with considerable precision. It is not enough to say that a particular product is for highway engineers, city traffic engineers, or State transportation chief executive officers. The salient characteristics of the user target group must be specified so that product format and instructional language are appropriate

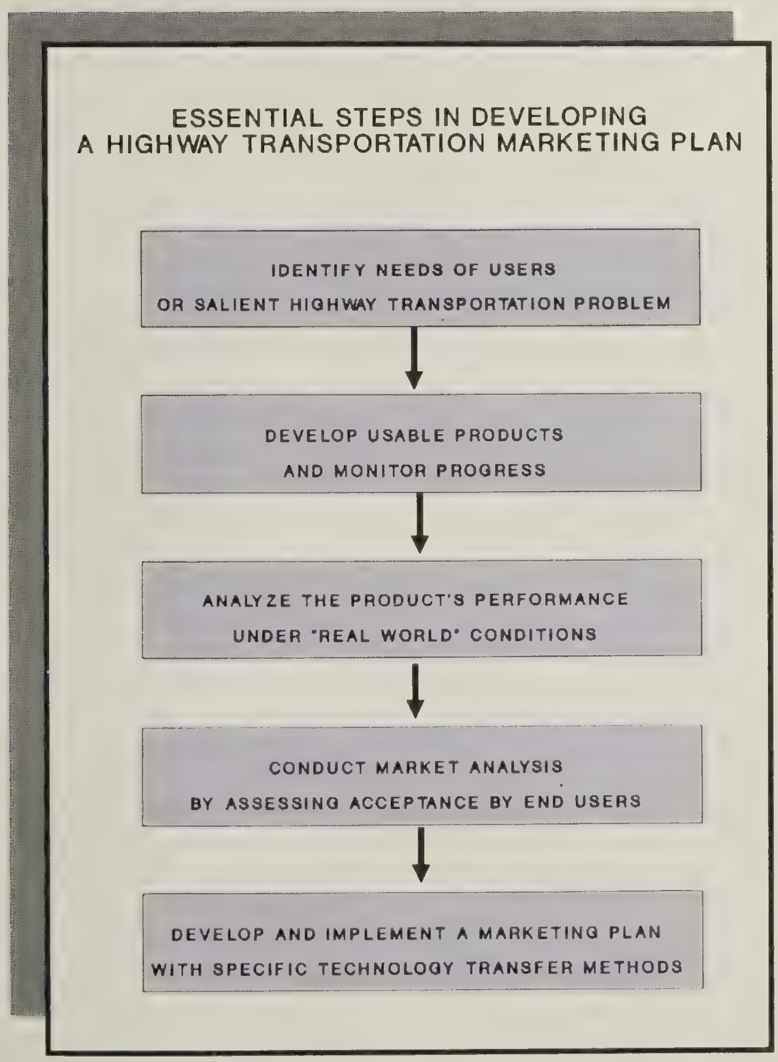

Figure 1.—Essential steps in developing a highway transportation marketing plan.

for that set of users. Costs and other issues should be presented in a framework that is relevant to and easily understood by that audience.

A product must be tested. No product originating in R&D should be actively promoted before field testing. Consequently, a third essential element of a marketing strategy is the systematic testing and evaluation of the product under operational or real-world conditions. A product developed in an R&D environment may work very reliably in such a setting. However, because researchers want their products to succeed, they may overlook simple and obvious problems that may occur when customers begin to use the new product. An example of such a flawed product was a traffic data base manager known as the Integrated Traffic Data System; although very impressive when demonstrated, it has yet to succeed in an actual operating environment. (*5*)

Appropriate technology transfer techniques must be used. The fourth element in a highway product marketing strategy is the selection of appropriate techniques for product delivery. Traditionally, the delivery of new highway products derived from R&D has been through written reports that generally aim to provide the detail and background needed to carry out specific implementations. Many other delivery techniques are available and they generally are preferable to text formats.

The appropriate marketing techniques to be used ultimately depends upon the potential user's prior information and selection of appropriate ways of demonstrating the product's use and benefits. The most common way to determine this information need is by conducting a limited marketing survey (i.e., getting systematic feedback from a sample of potential product users). Unless the product helps fulfill a brand new objective or function, the most effective technology transfer techniques are ones which permit the user to actually use a new product and allow the customer to visualize contrasts between the techniques currently being used and the new product. "Hands-on" demonstrations ideally are included in any new technology transfer technique, whether it is primarily educational, informational, or promotional. In other words, if a customer is convinced that he or she can master a new technique, the first step toward operational or day-to-day use is achieved and resistance-to-change is reduced. This critical hands-on element should be borne in mind as various innovative technology transfer techniques are examined in the next section of this article.

There must be followup with users. The final element in a marketing strategy is to followup with and get feedback from users. This step is frequently treated as nonessential and separate from the task of getting new technology into use. However, some technology transfer efforts succeed and others fail; a great deal of information can be obtained by understanding the causes of such success and failure. This information can only be derived through followup with users.

Technology Transfer Techniques

Over the years, the FHWA has been most successful in providing technology transfer through direct technical assistance and its demonstration projects. The salient characteristics of such efforts are:

- Personal and direct contact which provides a highly motivated interaction between the technology transfer agent and the customer.
- A guided tutorial with hands-on experience and feedback that offers the most effective form of learning new procedures.

The principal reasons that such techniques are not used more are simply there is insufficient time and money available to do the job. Techniques which augment or substitute for person-oriented technology transfer must create and maintain a "user-friendly" environment.

Recent technological advances have brought about sweeping changes in the ways in which technology transfer activities can be conducted. The remainder of this article details the newest and most useful technology transfer methods for application in marketing the products of highway-related R&D. For simplicity, these products and techniques are grouped by relevant area of technology transfer activity, i.e.:

- Training.
- Information dissemination.
- Promotion.

Training

The FHWA presents highway-related training mostly through short courses funded by the National Highway Institute (NHI). The NHI mechanism represents a significant training tool: during fiscal year 1990, the NHI offered 73 different courses and made presentations to more than 15,300 participants.

The drawbacks of such training are that students must schedule their time far in advance and travel to specific locations. In recognition of these drawbacks, the NHI has recently tried to develop and present more "train-the-trainer" type courses. While such courses yield an expanded network of instructors thereby increasing training opportunities, this approach does not address participants' scheduling problems. Other, relatively new, training technologies do, however. The use of *satellite, teleconferencing technology*, and *interactive videodiscs* alleviates many logistic difficulties and facilitates training of more persons—including those support and paraprofessional personnel who frequently are not included in training allocations at all.

Training using communications satellites is becoming commonplace for high-tech industries and organizations such as the National Aeronautics and Space Administration, which routinely develops and/or uses this technology. There are major differences between standard classroom training and training using space satellites to reach a larger number of students over a broad geographic area.

Only one U.S. organization is currently using satellites for highway training. Pennsylvania State University has to date presented 3 courses on highway design and hydraulics to 32 centers throughout Pennsylvania. (*6*) These courses are based on training materials already developed for classroom settings and augmented with video graphics and videotapes from construction sites. The incremental cost of satellite training over classroom training is approximately $20,000 per course. However, it is estimated that in Pennsylvania alone, the number of students reached during the same instruction periods is five to six times that possible via classroom training.

Teleconferencing allows meetings to be held without participants having to travel long distances. The first highway-related teleconference took place in 1984, during the annual Transportation Research Board meeting in Washington, D.C. In conjunction with this meeting, a teleconferencing session took place involving 1-way video and 2-way audio transmission among 20 States. (*7*) Since then, two demonstrations of teleconferencing for highway engineers have taken place: one in Pennsylvania on hazardous wastes shipments; the other on hydraulics, originating at the University of Tennessee.

Interactive video provides self-paced instruction for individuals. It uses laser-video technology and has received the most study by the FHWA as an advanced training resource. In 1982, the first FHWA interactive video project was undertaken to determine the technology's feasibility for highway engineers and technicians. The FHWA began by developing basic hardware configurations and assessing system cost effectiveness. (*8*) This effort resulted in the Individualized Self-Paced Instruction for Traffic Engineers (IN-SPITE) system. The first instructional material developed for this system was a course on traffic control in work zones, which contains modules on the proper selection of traffic control devices, sample applications, and flagging. Based on testing in Arizona and Maryland, this course was more effective than standard training. Last year, six complete IN-SPITE systems were operating on IBM-compatible computers; the system has since been distributed for further field testing.

Microcomputer tutorials are provided on disk formats. These tutorials are usually developed for specialized courses rather than for more general training purposes. Moreover, if substantial audio and complex visual materials are needed, an interactive videodisc system is used rather than a tutorial format. Tutorials are best used to simulate the actual operations of an analyst using given computer software.

The FHWA has developed one such tutorial to assist intermediate and advanced users of TRAF-NETSIM, a microscopic simulation model that provides detailed evaluation of proposed operational improvements on urban networks. A second course has been planned for the corridor flow model, CORFLO, a macroscopic computer simulation for corridors with both signalized intersections and freeways.

Information dissemination

Generally, technical information is disseminated to potential users via technology-sharing reports; demonstration projects; and oral presentations at national, regional, and local meetings. However, the most effective method of acquiring information on new technologies is through informal discussions and telephone conversations. These informal means of dissemination tend to have greater value than the formal mechanisms, mainly because when an inquiry is made, it is usually answered immediately. These critical characteristics of human communication (i.e., active involvement and timeliness) are usually not present when articles are published and speeches presented. Also, although much written information is archived so that knowledge can be actively pursued through modern library systems and computer-based information retrieval systems, highway agencies seldom use archived information to seek out new technologies for performing old tasks.

Thus, better methods for disseminating new technical information in a manner consistent with human communication needs include the use of *electronic bulletin boards (EBB's)* and *expert systems.* Both of these methods obviate the need for answering communications in a real-time, person-to-person exchange, yet provide a similar convenience.

Electronic bulletin boards provide a logical extension of personal networking by allowing questions and their answers to be posted using telephone lines. Although all established EBB's maintain data bases and utility programs and post general bulletins and announcements, their greatest benefits come from exchanges of needed information. Figure 2 illustrates how to use EBB's to get specific information. The expansion of national services such as PRODIGY is resulting in the broader acceptance of EBB's as a routine approach for exchanging information. Presently, there are about 20 active EBB's for highway-related information in the United States. These bulletin boards are operated by several of the Rural Technical Assistance Programs at their respective Technology Transfer Centers and by the Institute of Transportation Engineers. In addition, the FHWA initiated its Federal Electronic Bulletin Board System in 1988. (*9*) This board supports information on specialty conferences, such as meetings of the Traffic Software Users Group, and other specific information related to their fields of inquiry.

EBB use is restricted by the availability of personal microcomputers for technical personnel and the number of laptop and other portable computers available for use in field settings.

Expert systems are computer-based methods for simulating the reasoning and decision-making processes of human experts. They make use of domain-specific knowledge, allowing nonexperts to make viable decisions without extensive training or experience in narrow specialties. An operational expert system is a decision tool that allows both managers and technicians to orchestrate facts and judgments so as to develop solutions to particular problems that mimic those that would be reached by experts.

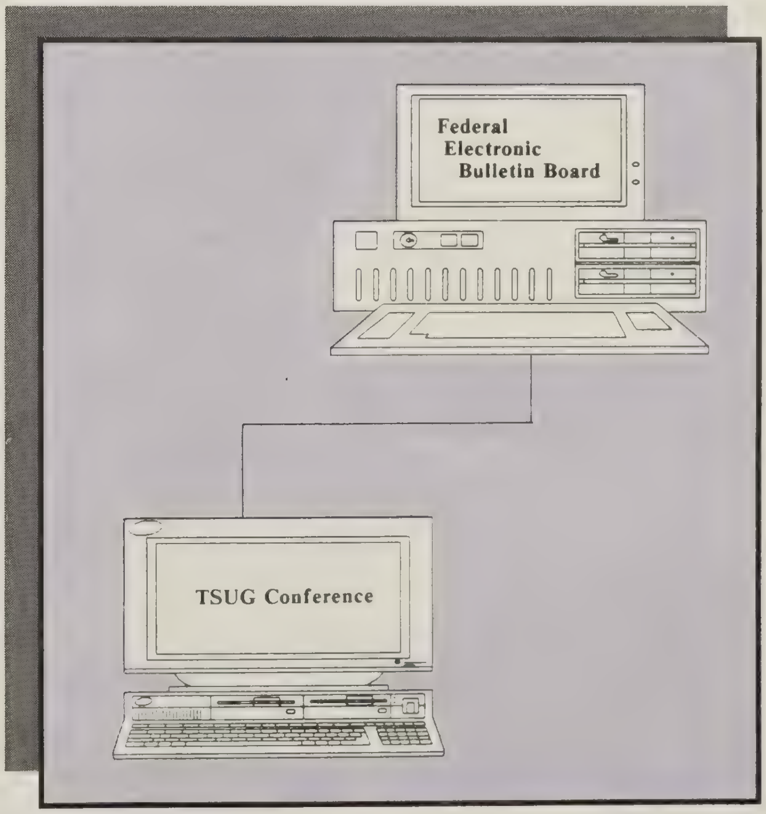

Figure 2.—The Traffic Software Users Conference.

Expert systems can be used to solve complex problems for which there are no useful algorithms for carrying out analytical or mathematical solutions. Because most decisions made by highway operational personnel are of this type, it is not surprising that the highway transportation field has begun to seriously tap the potential of expert systems technology. To date, more than 15 highway-related expert systems have been evaluated and refined for practical use by generalists.

Expert systems now available cover a selection of work zone traffic control techniques, analysis of bridge maintenance procedures, and selection of mixes for rehabilitation of flexible pavements. (*10,11,12*) Many more such specialized systems covering a wide variety of common transportation engineering topics are currently under development or have been recently released. The FHWA created guidelines for developing expert systems to assist those interested in using this technology. (*13*)

Promotion

Private industry devotes substantial funds to promotional activities. The industry recognizes that technicians and managers must have an appreciation of the potential of new products being introduced into the marketplace. Public sector organizations such as the FHWA do not have large budgets for such activities, but can nevertheless launch effective promotional campaigns with the aid of several new communication and computer-oriented technologies.

Traditionally, technology transfer specialists have used educational techniques such as slide-tape shows, exhibits, road shows, and hands-on demonstrations of new technologies. Newer promotional tools, derived from the latest generation of microprocessors, are now coming into common usage. These microprocessor-based tools permit significant reductions in labor and time to produce useful materials including *videotapes* and *demonstration disks*.

The successful promotion of new products require a means of motivating potential users. Such motivation can come through identification with actual users. Short of actual demonstrations, of hands-on simulations, videotape is currently the most readily available medium for providing a substitute for direct experience.

The computer demonstration disk is a medium which can be used to provide the experience and running an actual applications program, without having the actual program. This technique can provide hands-on experience by a simple simulation of actual operations.

As greater usage is made of the interactive tools described earlier in the section on training techniques, promotional materials will be able to provide increasing faithful simulations of the use of actual design, evaluation, and operational tools.

Videotapes have often been used to present and promote complicated concepts to an array of target audiences. Recently, however, numerous developments in videotape scripting, production, and editing have increased their use and distribution. For example, the popularity of home video camcorders has increased the availability of high-quality equipment, reduced costs, and gone far toward eliminating the need for experienced production personnel. Consequently, good quality productions now only need a few individuals, none of whom require extensive training.

The price for a videotape production has remained relatively high, despite reductions in actual production costs. A number of promising developments should result in reduced costs, however. Recently, short promotional materials have been produced by relative novices using a technique known as video desktop publishing. The video desktop publishing technique is exemplified by a series of 5- to 10-minute videos depicting new and better methods for performing routine engineering and technician jobs. This video series, titled "The Idea Store" is produced by the Pennsylvania Department of Transportation and has been used effectively to motivate audiences unfamiliar with new products and techniques available to the transportation community.

The potential increased value of videotape as a promotional tool comes from the availability of affordable, easy-to-use production techniques. It is a relatively simple matter today to blend and enhance video footage taken by novices. The inclusion of off-the-cuff presentations of new technologies in an operating environment can provide the alliance needed to help convince skeptics. Such involvement is not exactly hands-on, but it comes close.

Demonstration disks provide another means of dramatically presenting new technologies to an increasing number of potential users. The general availability of personal microcomputers facilitates this method of graphically representing new highway products using standard-sized microcomputer floppy disks.

Demonstration disks are most appropriately used to convey the benefits of microcomputer software; the technique is commonly used by the computer software industry. The first FHWA demonstration disk aimed at promoting the use of a specific software package has been developed for the microcomputer version of TRAF-NETSIM. The program's graphics quality enhances the outputs for both users of the software and managers.

Demonstration disks also can be used to promote products that have little or no relation to microcomputers. For example, one of the FHWA's demonstration disks converted a general information brochure to a computerized format. This format depicted the relationships among major federally supported traffic software packages more dynamically than was possible with a static brochure. In fact, the demonstration disk appears to have increased comprehension of potential traffic managers and software users as to the capability of various software packages.

Conclusion

Numerous new tools that make extensive use of common communication and computer technologies are available to technology transfer specialists. Used properly, these tools can facilitate the rate at which new technologies are understood by potential users and put into use. All traditional areas of technology transfer—training, information dissemination, and promotional activities—can be enhanced by these new tools. However, such technologies should not be used indiscriminately; rather, they should be applied in the context of an overall marketing strategy for transferring those new technologies that have been shown to work under real-world conditions and are cost effective.

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$$\ldots$$

$$\Sigma\ (X\ \ -X\ )^2 = 8[(3.125-3.3$$

STATISTICAL SHORTCOMINGS IN TRAFFIC STUDIES: PART II

Harry S. Lum

Part I of this article, which appeared in the last issue of Public Roads, discussed the theoretical advantages of factorial design—its efficiency, economy of experimental units, and ability to provide information on several treatment factors jointly and simultaneously—thus permitting a broader generalization of the experimental results. This article describes the practical advantages and disadvantages of factorial design.

Introduction

Factorial design is a powerful tool that can provide information not otherwise obtainable from single-factor experiments. There are, however, limitations in its use: these are due more to practical than to theoretical constraints. One such limitation is a logistical one, applying to the availability of resources (e.g., time, labor, and the pool of experimental units). A second limitation is interpretive—the complexity of the factorial design experiment often makes it difficult to interpret and explain results.

This article explores the nature of these limitations, their impacts on factorial design, and methods for alleviating these impacts.

Logistic Limitations

In a simple 2 by 2 factorial design, the number of treatment combinations is four. As more factors or levels are added to the design, the number of treatment combinations expands geometrically. Doubling the number of levels of a 2 by 2 design to 4 by 4 yields 16 treatment combinations, four times that of the original design. Similarly, an ambitious 3 by 3 by 3 by 3 experiment comprises a total of 81 treatment combinations. The logistic difficulties implicit in this large total are illustrated by the following example.

Suppose a researcher wants to investigate the driving behavior of people over 65 years of age. The researcher plans to use four replicates—a factorial experiment requires a minimum of two replications to estimate sampling variance. For a 3 by 3 by 3 by 3 experiment, four replicates will require 324 subjects. Even if it is possible to recruit this number of subjects, the researcher can expect to lose some before the experiment is over. This attrition may be due to illness, "no shows," or "aborts" (i.e., subjects chose not to continue the experiment after starting it). The greater the number of subjects involved in the study, and the lengthier the study sessions, the greater the chance of subject attrition. Moreover, even if the researcher can recruit and retain all required subjects, scheduling problems, equipment failure, errors in recording data, or the loss of completed data sheets may also result in an unequal number of observations.

Interpretation Limitations

The second limitation of high order factorial design is the difficulty in substantive interpretation of the data because of the complexity of the phenomenon under investigation. For example, in a three-factor experiment, there will be one three-factor interaction term (A by B by C) and three two-factor interaction terms (A by B, A by C, and B by C). If the experiment shows that *none* of these terms are statistically significant, the researcher can say that the three factors affect the response variable independently of each other. On the other hand, if the three-factor interaction *is* significant, then each of the two-factor interaction terms must be investigated separately at each level of the third factor. If the three-factor interaction term is *not* significant, but any or all of the two-factor interactions *are* significant, then each of the single factors must be explained or interpreted with reference to the specific level of the two factors. And as more factors are introduced into the design, data interpretation grows in complexity.

For a 4-factor factorial design, there are 11 interactions that must be assessed. Some of the interaction terms may be statistically nonsignificant; others, marginally significant; still others, statistically significant. The researcher must evaluate the results, in light of the statistical evidence, for their practical significance or theoretical implication. However, the fact that statistical analysis indicates that a given interaction term is significant does not necessarily mean that it has substantive meaning. Rather, it could be that there is no interaction but, due to sampling variation, a large enough value was obtained to be declared significant. On the other hand, a significant interaction, while real, may run contrary to present knowledge. Such an interaction should not be ignored or dismissed as spurious for one of the advantages of factorial design is to suggest other approaches or provide greater insight into a particular research problem. Consequently, there is no formulaic easy way to analyze factorial experiments and interpret the results. Each experiment is unique and subject-matter oriented.

The consequence of the logistic limitation usually results in an unequal number of observations among the cells. The impact of this limitation is that statistical analyses become complex. In the extreme case where the disparity of cell sizes is too great, the whole experiment would be useless.

Impacts of Limitations: Unequal Cell Sizes

A requirement for factorial experiments is that each cell must have an equal number of observations (n's). Statistical tests based on equal n's tend to be less sensitive to distortions when certain assumptions underlying the statistical tests are violated. Mild departure from the assumptions of normality and homogeneity of variance among the cells poses no serious problem in interpreting the outcome of an analysis of variance when the n's are equal. Furthermore, calculations are simpler with equal n's since the

Table 1.—Artificial data for a 2 by 2 factorial experiment with unequal cell sizes

cell (1,1)	cell (1,2)	
data = 2,3,3,4 total = 12 mean = 3 # of obs = 4	data = 3,3,3 total = 9 mean = 3 # of obs = 3	Total of means = 6
cell (2,1)	**cell (2,2)**	
data = 3,4,4,2 total = 13 mean = 3.25 # of obs = 4	data = 4,4,5,5 total = 18 mean = 4.50 # of obs = 4	Total of means = 7.75
Total of means = 6.25	Total of means = 7.50	Grand total = 13.75

Table 2.—Analysis of variance of data from table 1

Component	Sum of squares	Degree of freedom	Mean sum of squares	F-ratio	P-value
Row	$0.766 \times n_h = 2.828$	1	2.828	5.41	0.04
Column	$0.391 \times n_h = 1.444$	1	1.444	2.76	0.12
Interaction	$0.391 \times n_h = 1.444$	1	1.444	2.76	0.12
Error	5.750	11	0.523		
Total	11.483	14			

C (correction factor) = $(13.75)^2/4 = 47.266$

Row = $1/2[6^2 + 7.75^2] - C = 0.766$

Column = $1/2[6.25^2 + 7.50^2] - C = 0.391$

Interaction = $3^2+3^2+3.25^2+4.5^2$-row - column - C = .391

Error = 5.750 = 192 - 186.250

Total by definition = 11.733 = 192 -180.267

Harmonic mean $n_h = (2 \times 2) / [1/4 + 1/3 + 1/4 + 1/4] = 3.692$

n's can be treated as a constant. To illustrate, the variance of the mean of the ith row and the jth column is σ^2/n_{ij}. If $n_{ij} = n$ for all the cells, then the variance of the mean for any cell is σ^2/n.

In practice, even with careful planning and rigid control of a moderate-sized experiment, more often than not the researcher must work with unequal n's. Under certain conditions, however, there are quick and easy methods of analyzing data from an experiment with unequal cell frequencies. These methods are:

- *Unweighted means*—Applicable when the disparity in the n's is no greater than a ratio of 2 to 1 between the largest and the smallest n's, and most of them are in close agreement.
- *Equal numbers within rows (columns).* Applicable when the cell frequencies within any row (column) are equal.
- *Proportional subclass numbers.* Applicable when the cell frequencies are proportional, i.e., in the same proportion within any row or column.

These methods provide exact statistical tests in the absence of significant interactions. Examples of these methods are available in reference *1*.

Unweighted means

The method of unweighted means is used in many computer software packages to analyze data with unequal cell frequencies. Since this is a common practice, a numerical example is presented here to illustrate the rationale of the method together with the necessary calculations for the analysis of variance table.

The data in table 1 is contrived: the numbers are simple to facilitate computations of the analysis of variance table. There are four data points in all the cells except for cell (1,2) where there are three. Table 2 is the analysis of variance table and computations. Note that the harmonic mean (3.692) and not the arithmetic mean (3.750) is used to represent the average cell size. Also note that by definition the total sum of squares is 11.733 which in this case is not equal to the sum of the components. This discrepancy is known as nonorthogonality. When cell sizes are equal, the sum of components will be equal to the sum of squares and orthogonality is preserved. Conversely orthogonality is preserved when the cell frequencies are equal—the sum of component sums of squares equals the total sum of squares.

Multilinear Regression

When the disparity among the cell frequencies is great, then a least-square solution, as in multiple linear regression analysis, must be used. All computerized statistical packages have multiple linear regression routines. Before a multiple regression routine is selected, it is critical that the researcher understand the outputs of such a solution. Extensive literature exists on the methods commonly used in dealing with unequal cell frequencies. (*2*) A discussion of these methods is not within the limits of this article. Examples of applying linear regression techniques to a set of data involving unequal cell frequencies that yield different results are also available. (*3*) Finally, guidelines are available for selecting one of the four types of

[1]Italic numbers in parentheses identify references on page 26.

Table 3.—Analysis of variance table from example

Source of variation	Degree of freedom	Sum of squares	Mean squares	*F*-ratio
One-factor				
A	1	35.77	35.77	5.85[a]
B	3	1,484.50	494.83	80.99[a]
C	1	18.38	18.38	3.01
D	2	1.11	0.56	<1.00
E	1	1.45	1.45	<1.00
F	1	183.71	183.71	30.07
Two-factor				
A x B	3	11.47	3.82	<1.00
A x C	1	4.51	4.51	<1.00
A x D	2	6.42	3.21	<1.00
A x E	1	1.36	1.36	<1.00
A x F	1	0.28	0.28	<1.00
B x C	3	28.71	9.57	1.57
B x D	6	53.62	8.94	1.46
B x E	3	54.37	18.12	2.97[a]
B x F	3	81.36	27.12	4.44[a]
Residual error	37	226.24	6.11	
C x D	2			
C x E	1			
C x F	1			
D x E	2			
D x F	2			
E x F	1		Unreported Data from Sample Study	
All three factors	56			
All four factors	56			
All five factors	32			
All six factors	6			

[a]Statistically significant at the 5-percent level.

analysis of variance tables that are incorporated into the SAS-76 computer program. (*4,5*)

An Example

The analysis of variance shown in table 3 was taken from the open literature to serve as an example. It illustrates the inherent difficulty of large factorial design compounded by the problem of unequal cell frequency. In this table, there are six factors—A with two levels, B with four, C with two, D with three, E with two, and F with two. One complete replication would thus require 2 by 4 by 2 by 3 by 2 by 2 or 192 treatment combinations. Several treatment combinations were not observed, although it is not known which ones are missing. The omission of these unreported two-factor interactions raises questions about the validity of the analysis. Also, three of the unreported two-factor interaction terms—C by F, D by F, and E by F—involve the highly statistically significant factor F (30.07). Experience shows that when a main factor or factors are highly significant, there is a strong possibility that an interaction term involving that single factor is also statistically significant. In this example, the two-factor interactions: C by F, D by F, and E by F are not reported.

The two-factor interactions, B by E and B by F, were reported to be statistically significant at the 5-percent level. The B by E interaction may be accounted for by random variation since the *F*-ratio was marginally significant with a calculated probability level of 04.6. Notwithstanding, the highly significant B factor calls for further analysis before prematurely concluding that the B by E interaction was random variation due to sampling.

As for the B by F interaction, there are four levels of the B-factor and two levels of the F-factor yielding a total of eight B by F treatment combinations. In spite of the statistically significant B by F interaction term, the author of the report failed to conduct further analysis to determine which treatment combinations differ from the others.

The flawed and incomplete analysis described above and illustrated in table 3 raises many other questions. For example, why are there so many missing observations? How many times was the experiment replicated? How valid are the results of the analyses of variance? Why are some of the two-factor interaction terms not reported? What is the interpretation of the statistically significant two-factor interaction terms? What are the practical implications of these statistically significant terms? Could the experiment be conducted on a reduced scale with four variables instead of six? Similar questions are all too frequently raised in readers' minds at the conclusion of traffic study reports.

Summary

The analysis of variance technique was developed and designed primarily to analyze experimental data in a simple, straightforward fashion. The factorial design in the analysis of variance framework is a powerful tool for analyzing several independent variables simultaneously. There are however, several practical reasons that tend to limit the use of high order factorial experiments. For example, one of the requirements of factorial design is that each treatment combination (cell) must be replicated more than once and that the frequency of observations be equal for all cells. Another limitation is the difficulty in interpreting results of the analysis. A high order factorial design introduces more sources of variation with a greater potential for interaction with other variables. This complexity means that substantive interpretation of the results and data becomes difficult and—possibly—misleading.

The first of these limitations, logistics, is rather handily addressed. In real-life seldom—if ever—are traffic studies using the analysis of variance technique conducted without missing observations; these missing observations result in the problem of unequal cell frequencies. Providing this disparity is not too great among the cells, there are statistical methodologies to overcome this shortcoming while retaining a meaningful analysis.

The second limitation, interpretation, requires more thought to remedy. Based on the above, the factorial design may appear somewhat quixotic—a simple analytic tool of limited practical use because of the complexity involved in substantive interpretation of the data collected. The complexity is not in the technique, but in the phenomenon under investigation. In fact, it is rather simple to write the computational formula for any high order factorial design once the computational formula for a two-way design is understood.

Conclusions

The aim of any research effort is to seek reliable information to questions or problems of interest. The first step is to define and identify the problem. Next, an experiment to elicit the needed information must be designed and planned. In planning the experiment, the working hypothesis is translated into a statistical hypothesis to be evaluated from the data. The planning should also include the identification of the amount and kind of data to be collected and the methodology for analyzing the data. Following conduct of the experiment, the final phase of the research effort is to interpret the data analyses and draw conclusions about the relations under study.

Given these steps in a research effort, researchers must not only pick the right method and study design that suits the analysis, but must also complete a full discussion of the interpretations.

All too frequently, authors neglect to explain the significance of their findings, instead leaving the reader to determine the meaning of statistical significance. Such an approach is unfair to the readers, especially those who have not followed the experiment from beginning to end; unfair to the data, since it leaves them essentially uninterpreted; and unfair to the study, since it neglects to expand upon the practical implications with respect to study objectives. To ensure the utility and comprehensibility of study findings, authors must carefully and thoroughly interpret their data and not just leave the figures in their "number-crunched" state.

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Recent Publications

The following are brief descriptions of selected publications recently published by the Federal Highway Administration, Office of Research and Development (R&D). The Office of Engineering and Highway Operations R&D includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Intelligent Vehicle-Highway Systems Research Division, Design Concepts Research Division, and Information and Behavioral Systems Division. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&D Report Center.

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Present Practices of Highway Transportation of Hazardous Materials, Publication No. FHWA-RD-89-013

by IVHS Research Division

This report summarizes the state of the art of safe highway transportation of hazardous materials. The report includes a reviews of literature related to safe transportation of hazardous materials, the responsibilities and current practices of government agencies, and current methodologies for establishing safe routes. The report also includes a critique of accident, incident, and exposure data bases; recommendations for improving the current FHWA routing guidelines, and recommendations for future research related to highway transportation of hazardous materials.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-124016, price code: A12.)

Truck Characteristics for Use in Highway Design and Operation, Vol. I: Research Report, Publication No. FHWA-RD-89-226

by Design Concepts Research Division

Highway geometric design and traffic operations are based in part on consideration of vehicle characteristics. Even though truck characteristics may be more critical, many of the current highway design and operational criteria are based on the passenger car. This report reviews existing data for highway design, including truck dimensions, braking distance, driver eye height, acceleration capabilities, speed-maintenance capabilities on grades, turning radius, offtracking and suspension characteristics, and rollover threshold.

The report also includes evaluated highway design and operational criteria such as sight distances, vertical curve length, intersection design, critical length of grade, lane width, horizontal curve design, vehicle change intervals at traffic signals, sign placement, and highway capacity. An assessment and a cost analysis were made on the need to change the current highway design and operational criteria to accommodate trucks.

Volume II of the report (FHWA-RD-89-227) contains appendixes documenting the detailed data collection and analysis activities.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-100982, price code: A12.)

AC Stripping Problems and Corrective Treatment, Publication No. FHWA-RD-90-049

by Pavements Division

This study was designed to determine the most effective method of introducing lime into asphalt concrete mixtures, to improve the reliability of the laboratory test methods used to identify moisture-susceptible asphalt-aggregate combinations, and to evaluate the effectiveness of the recommended procedures using experimental construction projects.

Results indicated that both tensile strength and resilient modulus are significantly controlled by the interaction among aggregate type, presence of lime and freeze-thaw cycles. The addition of lime through wet methods resulted in higher strengths than dry methods, however, the difference was not statistically significant to support a conclusion that wet methods are better than dry methods.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-105924, price code: A09.)

Evaluation of the Supplemental Procedure of the Maximum Specific Gravity Test for Bituminous Paving Mixtures, Publication No. FHWA-RD-90-082

by Pavements Division

Performed in the Federal Highway Administration Bituminous Mixtures Laboratory located at the Turner-Fairbank Highway Research Center, McLean, Virginia, this study investigated the effects of performing the supplemental procedure of AASHTO T 209 (or ASTM D 2041). Using both thoroughly coated aggregates and partially coated aggregates, the procedure was performed to determine its effects on the percent air voids, effective specific gravity of the aggregate, and the maximum specific gravity of a bituminous paving mixture.

The supplemental procedure should correct the test data for water absorbed into the aggregate during the test. Although the supplemental procedure can be used when designing mixtures, it is most often used for determining the maximum specific gravities of moisture damaged pavement samples, or cores or specimens where sawing has exposed a significant amount of aggregate. The majority of aggregates used in this study had water absorptions below 2.5 percent and thus were not highly absorptive.

It is recommended that the supplemental procedure not be performed on laboratory mixtures or pavement cores having aggregates with water absorptions below 2.5 percent. When testing any mixture prepared in the laboratory during the mixture design process, the procedure for determining the maximum specific gravity should only be performed on well-coated mixtures so that the supplemental procedure does not have to be used. For highly absorptive aggregates, it is recommended that the test only be performed at high binder contents which provide thick coatings. Only binder contents close to optimum should be used. The maximum specific gravities for the lower binder contents can be

calculated using the effective specific gravity of the aggregate. For laboratory mixtures containing highly absorptive aggregates, the supplemental procedure may indicate whether the coating is sufficient.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-124065, price code: A03.)

Work Zone Traffic Control Delineation for Channelization, Publication No. FHWA-RD-90-089

by Information and Behavioral Systems Division

This report describes a study of the delineation requirements for work zone traffic control. The research included a comprehensive review of past studies and current practices, and an examination of current standards. It was concluded that, in spite of the increasing number of different types of channelizing devices, there appears to be no scientific basis for the spacing criteria in the taper or tangent sections of a work zone.

A laboratory-based testing procedure was used to determine the most appropriate spacing configuration. An interactive video system was used to test subject recognition distances of eight different device types spaced at the standard distance, 1.5 times, and 2.0 times the standard distance. Over 240 subjects, were tested. The results showed bigger devices were more visible than smaller ones and indicated better the nature of the delineation. The spacing of devices, however, did not have a significant effect. In lesser reflectivity areas, there should be closer spacing.

Field testing was undertaken at six actual work zones. Right and left lane closures were used to test the various device-spacing configurations, under both day and night conditions. Manual and automated methods were used to gather the field data for traffic approaching a work zone. The study area included four points equally spaced over the 2,000 ft (600 m) before the work zone and the activity at the start of the taper for the lane closure. The tests were performed under the hypothesis that the most effective treatment would minimize the percentage of traffic in the closed lane at the start of the taper.

Field data were analyzed for 2,100 4-minute observation periods. Statistical analysis of the data determined neither type of device (round barrels, oblong barrels, Type II barricades, and cones with reflectorized collars) or device spacing (55, 80, and 110 ft) [16.5, 24.7, 33.0 m] had a significant effect on driver lane changing behavior. An arrow panel was operating at all lane closure sites which seemed to override any effects of the delineation devices. Recommendations for locating work zones to maximize the sight line on the approach to the taper are presented.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-124107, price code: A06.)

Performance of Jointed Concrete Pavements,
Vol. I: Evaluation of Concrete Pavement Performance and Design Features, Publication No. FHWA-RD-89-136,
Vol. II: Evaluation and Modification of Concrete Pavement Design Analysis Models, Publication No. FHWA-RD-89-137,
Vol. III: Summary of Research Findings, Publication No. FHWA-RD-89-138,
Vol. IV: Appendix A: Project Summary Reports and Summary Tables, Publication No. FHWA-RD-89-139,
Vol. V: Appendix B: Data Collection and Analysis Procedures, Publication No. FHWA-RD-89-140,
Vol. VI: Appendix C: Synthesis of Concrete Pavement Design Methods and Analysis Models; Appendix D: Summary of Analysis Data for the Evaluation of Predictive Models, Publication No. FHWA-RD-89-141

by Pavements Division

This series of reports documents the findings of a comprehensive study of the effect of various design features on the performance of jointed concrete pavements. The effect on performance of slab thickness, base type, slab length, reinforcement, joint orientation, load transfer, dowel coating, longitudinal joint design, joint sealing, widened lanes, and subdrainage is discussed. The findings are based on data collected from 95 pavement section located around the country. Well-documented environmental and traffic analyses help to isolate the effect of these design features.

Also presented is an evaluation of 11 currently used models for concrete pavement design, analysis, and performance prediction. This evaluation was performed using data from the various pavement sections. It was found that none of the models were able to adequately model the performance of these inservice pavements.

New prediction models for present serviceability rating, joint faulting, transverse cracking, and transverse joint spalling were developed. An evaluation of the cost effectiveness of selected pavement design features was also made.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. PB-91-100511 for set of RD-

89-136 to 141. RD-89-136 PB-91-100529 A10; RD-89-137 PB-91-100537 A14; RD-89-138 PB-91-100545 A08; RD-89-139 PB-91-100552 A13; RD-89-140 PB-91-100560 A08; RD-89-141 PB-91-100578 A17.)

Structural Overlay Strategies for Jointed Concrete Pavements,

- **Vol. I** **Sawing and Sealing of joints in AC Overlays of Concrete Pavements, Publication No. RD-89-142,**
- **Vol. II** **Cracking and Seating of Concrete Slabs Prior to AC Overlay, Publication No. FHWA-RD-89-143,**
- **Vol. III** **Performance Evaluation and Analysis of Thin Bonded Concrete Overlays, Publication No. FHWA-RD-89-144,**
- **Vol. IV** **Guidelines for Selection of Rehabilitation Alternatives, Publication No. FHWA-89-145,**
- **Vol. V** **Summary of Research Findings, Publication No. FHWA-89-146,**
- **Vol. VI** **Appendix A-Users Manual for the EXPEAR Computer Program, Publication No. FHWA-RD-89-147,**

by Pavements Division

This series of reports documents an extensive field study and evaluation of three structural overlay strategies for jointed concrete pavements. The performance of these different rehabilitation strategies is documented and guidelines on their applicability are presented. Specific construction recommendations for each strategy are also discussed.

Volume IV presents practical guidelines on the selection of rehabilitation strategies for jointed concrete pavements, including selecting among structural overlay types and choosing among other restoration and rehabilitation alternatives.

Volume V is a summary of the research findings. Volume VI is a Users Manual for the advisory system EXPEAR which is used to help select the most appropriate concrete pavement rehabilitation strategy. It is an excellent training tool.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. PB-91-100586 for set of RD-89-142 to 147. RD-89-142 PB-91-100594 A07; RD-89-143 PB-91-100602 A08; RD-89-144 PB-91-100610 A09; RD-89-145 PB-91-100628 A05; RD-89-146 PB-91-100636 A05; RD-89-147 PB-91-100644 A04.)

Technology Applications

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Safety and System Applications and the Office of Research and Development (R&D), Federal Highway Administration. Some items by others are included when they are of special interest to highway agencies. All publications are available from the National Technical Information Service (NTIS). In some cases, limited copies of publications are available from the R&D Report Center.

When ordering from the NTIS, include the PB number (or the publication number) and the publication title. Address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Requests for items available from the R&D Report Center should be addressed to:

Federal Highway Administration
R&D Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Asphalt Content Determination Manual, Publication No. FHWA-IP-90-008

by Office of Technology Applications

This report examines the assessment procedures for evaluating an asphalt concrete mixture and evaluates the suitability of updating current procedures and equipment. Current test requirements call for the asphalt content and gradation to be compared with specifications to certify the level of quality in the mixture. Newer techniques include the nuclear asphalt content (NAC) gauge, the use of biodegradable solvents, and determination of gradation from cold feed testing. The evaluation of State experience and special studies, and analysis of raw data collected by various State agencies provided supporting data that show the NAC gauge can be substituted for traditional extraction tests for asphalt content determination.

Several of the new biodegradable solvents can be substituted directly for traditional ones with the same level of accuracy in asphalt content determination. When special procedures were used to account for fines removed during rinsing operations, biodegradable solvents did not produce a consistently different gradation.

It is recommended that the biodegradable solvents be used in conjunction with the NAC gauges to provide a more economical means of evaluating an asphalt concrete mixture. A number of studies examining cold feed determination indicate that the cold feed gradations are as accurate, and no more variable than the determination of gradation in place or from the delivery system. The durability of the aggregate can alter this if it degrades during production, producing a different gradation on the roadway.

This publication may only be purchased from the NTIS. (PB No. 91-125443, price code: A05.)

Highway Subdrainage Design by Microcomputer: (DAMP) Drainage Analysis and Modeling Programs 1.1, Publication No. FHWA-IP-90-012

by Office of Technology Applications

This report presents the users manual and technical guide for the software program, DAMP (Drainage Analysis and Modeling Programs), designed to perform drainage design for highways by microcomputer. This program includes a comprehensive examination of the drainage factors which affect pavement design and performance. The following modules are included: a) determination of net inflow by surface infiltration, ice lensing, and an evaluation of pavement geometry affecting outflow of water, b) determination of the AASHTO drainage coefficients using base drainage times, and climatic saturation moisture calculations, c) an edge drain analysis of pipe drains, geocomposite fin drains, and granular trenches, d) drainage layer analysis using calculated permeability and thicknesses, and e) filtration analysis using granular material gradations and filter fabric evaluation.

These calculation modules have been programmed into a user interactive program which allow the user to use any module independently of the others to perform sensitivity analyses. Context sensitive help is provided and graphical help screens are included where necessary. The program has the ability to perform batch calculations and print results directly to a disk file or a printer.

This publication may only be purchased from the NTIS. (PB No. 91-128272, price code: A06.)

Evaluation of the PAVEDEX Road Survey System in Iowa, Publication No. FHWA-TS-90-038

by Materials Division

The Iowa Department of Transportation (DOT) evaluated the PAS I Road Survey System that uses video photography to identify and quantify pavement cracking and patching distresses. Comparisons were made to procedures currently used in the State.

Interstate highways, county roads, city streets, and two shoulder sections were evaluated. Variables included travel speeds, surface type and texture, and traffic control conditions. Repeatability and distress identification were excellent on rigid pavements. Differences in distress identification and the effect of surface textures in the flexible test sections limited the repeatability and correlation of data to that of the Iowa DOT method.

Cost data indicates that PAVEDEX is capable of providing results with improved accuracy at a reasonable cost, but in excess of that experienced currently by the Iowa DOT. PAVEDEX is capable of providing network level pavement condition data at highway speeds and analysis of the data to identify 1/8-in (3.2 mm) cracks at approximately 2 to 3 lane mi (1.6 km) per hour with manual evaluation. Photologging capability is also included in the unit.

This publication may only be purchased from the NTIS. (PB No. 91-124073, Price code: A06.)

Pavement Management at the Local Government Level, Publication No. FHWA-TS-90-042

by Office of Technology Applications

Local governments are making considerable efforts to implement pavement management systems. Sponsored by the State of California Department of Transportation and the Federal Highway Administration through the Rural Technical Assistance Program (RTAP), this study surveyed and evaluated the experiences of 13 agencies that initiated the development of a pavement management system (PMS). The report summarizes the results of the study and includes a discussion of factors to be considered for a local government PMS.

As a result of the survey and initial findings, six local government agencies were provided both financial and technical assistance to implement pavement management activities within their organizations.

The results suggest that the development of a generic pavement management system would be desirable. This generic system might be developed inhouse or with the assistance of a consultant. Included in the report is a brief discussion of the form that such a system might take and the stages of its development.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-124081/AS, price code: A04.)

Workshop on Field Inspection and Rehabilitation of Traffic Control Devices, Proceedings, Publication No. FHWA-TS-90-048

by Office of Technology Applications

The Federal Highway Administration has begun a number of initiatives to improve signing on the Nation's roadways. These include workshops to obtain input from experts across the country, a review of each State's highway sign replacement and refurbishing program, and a training course. This report documents the proceedings of two workshops and details the remarks made by the panelists and the comments and concerns of the participants on each issue.

Limited copies of this publication are available from the R&D Report Center. Copies may also be purchased from the NTIS. (PB No. 91-108605/AS, price code: A11.)

Open Roads: A Look at Freeway Incident Management, Publication (videotape) No. FHWA-SA-91-011

This 20-minute video program presents—in clear, nontechnical language—the current state of the practice of freeway incident management and is intended for viewing by top-level management, elected officials, citizen groups, and other interested parties.

Through an effective mix of animation, special effects, on-camera interviews, and real-world video footage, this video program dramatically depicts the severity of the incident *problem*, then offers effective and practical *solutions*. In doing so, it touches upon a broad range of proven, successful incident management strategies—including many simple, low-cost procedures that can be readily adopted.

Loan copies may be obtained by contacting:
Mr. Keith J. Harrison
Federal Highway Administration
Office of Traffic Operations and IVHS
Traffic Operations Division (HTV-31)
400 Seventh Street, S.W.
Washington, DC 20590
(202) 366-2250

Copies will be available for *purchase* from:
Institute of Transportation Engineers
525 School Street, S.W.
Suite 410
Washington, DC 20024-2729
(202) 554-8050

GPO Subject Bibliography

To get a complete free listing of publications and periodicals on highway construction, safety, and traffic, write to the Superintendent of Documents, Mail Stop : SSOP, Washington, D.C. 20402-9328, and ask for Subject Bibliography SB-03 Highway Construction, Safety, and Traffic.

New Publications

Annual Report: Office of Research, Development, and Technology 1990, Publication No. FHWA-RD-90-107

The Office of Research, Development, and Technology (RD&T) has released its 1990 annual report. This report is a continuation of the series of annual and biennial reports published since 1974.

For fiscal year 1990—October 1989 through September 1990—the report covers exclusively the offices of research, development, and technology housed at the Turner-Fairbank Highway Research Center. Along with an overview of the research center, this report includes summaries of the various research programs managed or performed by the staff. The back section includes a list of research and development publications for 1990.

While supplies last, individual copies of the reports in the series are available without charge from the Federal Highway Administration, R&D Report Center, HRD-11, 6300 Georgetown Pike, McLean VA 22101-2296. Telephone: (703) 285-2144.

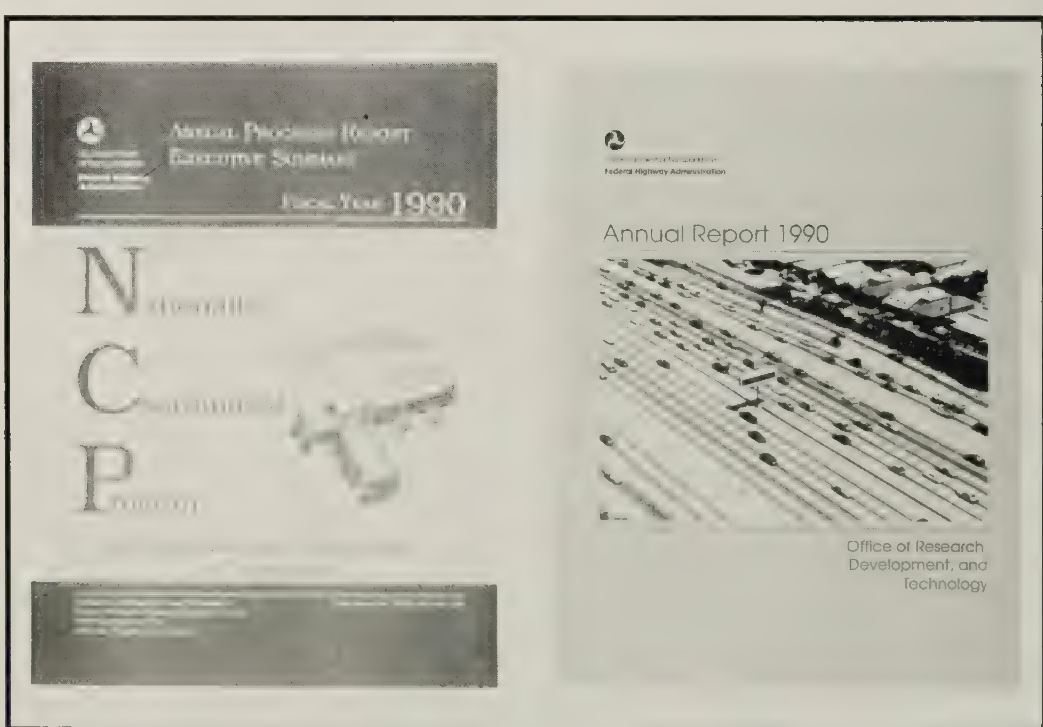
Nationally Coordinated Program of Highway Research, Development, and Technology: Annual Progress Report, Executive Summary, Fiscal Year 1990, Publication No. FHWA-RD-90-109

This executive summary gives an overview of progress being made under the Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology during the period from October 1, 1989 through September 30, 1990. The Office of RD&T uses the NCP as a management framework for highway research activities. The objectives of the NCP are to:

- Ensure resource concentration on critical problems.
- Minimize duplicated efforts among researchers.
- Identify and highlight gaps in research.

This report covers technologies for highway design, construction, and operations including the specific categories of: Highway Safety, Traffic Operations, Pavements, Structures, Materials and Operations, Policy and Planning, and Motor Carrier Transportation.

Limited copies of this Executive Summary are available from the R&D Report Center, HRD-11, 6300 Georgetown Pike, McLean VA 22101-2296. Telephone: (703) 285-2144.



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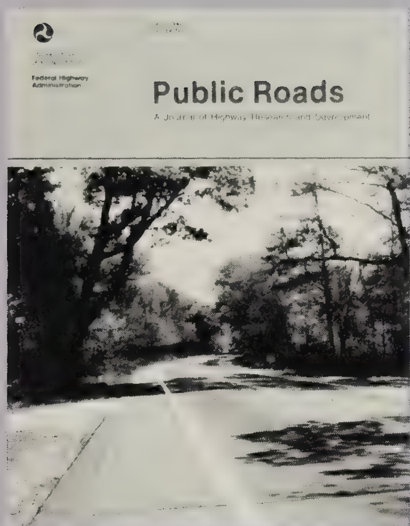

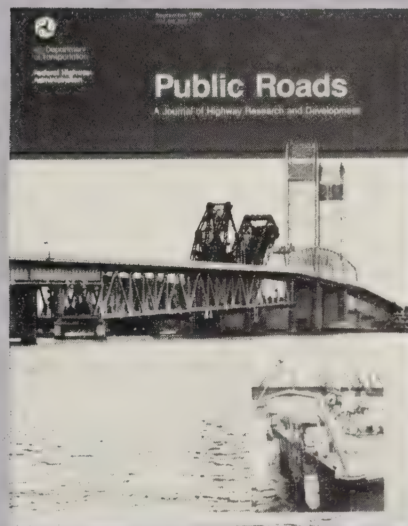

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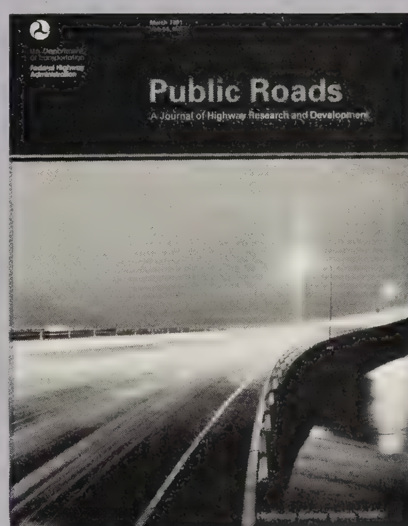

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Contents of Volume 54

List of Authors

(and volume page references)

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