Operation. The contents reflect our views and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation.

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Visual Complexity and Sign Brightness in Detection and Recognition of Traffic Signs

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The effects of sign luminance on the detection and recognition of traffic-control devices are mediated through contrast with the immediate surround. In addition, complex visual scenes are known to degrade visual performance with targets well above the visual threshold. A laboratory study was conducted to determine ways of measuring visual complexity and to assess the capability of changes in sign luminance to offset decrements in performance that result from added complexity. Positive results were found for warning, construction, and stop signs but not for the black-on-white regulatory sign. Regression equations that use complexity factors, contrast, and target variables suggested that, in complex scenes, complexity is a more significant determinant of sign detection than brightness or contrast. A field study was also conducted to determine if these findings could be observed in terms of real-world driver performance. The effects of visual complexity were observed in the field, and increasing sign brightness improved sign detection and recognition under specific conditions.

The role of sign brightness and the visual complexity of the nighttime highway environment in the detection and recognition of traffic signs was studied in both laboratory and field situations. The laboratory study permitted control over a large number of highway scenes that varied in the amount of visual clutter. The field study was undertaken to determine whether sign brightness and visual complexity had an observable effect on driver behavior.

LABORATORY STUDY

The primary objective of the laboratory study was the development of a metric for visual complexity based on target-independent characteristics of the visual field. In this regard, the study addressed the question of whether a sign location that causes sign-recognition problems can be identified from measurements or observations of the location itself. A secondary objective of the laboratory study was to determine whether increases in sign brightness offset decrements in visual performance that result from the visual complexity of the location.

The detection of a visual target, such as a traffic sign, is influenced by the characteristics of the target and by the contrast of these target characteristics with similar dimensions of the surround. For example, the attention-getting value of a target increases as

1. The target's brightness increases (1,2),
2. The brightness contrast between the target and its surround increases (2-7),
3. The brightness contrast between different parts of the target increases (e.g., sign legend to background) (2,5),
4. The target's size increases relative to other stimuli in the visual field (2,8,9),
5. The shape of the target contrasts with noise items (10), and
6. The target's hue contrasts with noise (5,11).

In addition to the effects of target characteristics, the characteristics of a target's surround also influence the likelihood of target detection. Specifically, several basic studies suggest that target conspicuity increases as

1. The number of noise elements in the visual field decreases (12-18),
2. The overall density of noise items in the visual field decreases (19-21),
3. The density of noise items immediately adjacent to the target decreases (22),
4. The distance between the target and noise increases (15-17,23),
5. The target is located further from the center of the visual field than the noise (versus when the target is located closer to the center of the visual field than the noise) (23-27),
6. The number of irrelevant classes of stimuli in the visual field decreases (i.e., as the visual field becomes more homogenous) (28), and
7. The variability within each irrelevant class of stimuli decreases (21).

Because the majority of the studies listed above reflect basic research efforts that often use abstract targets located within relatively sterile visual matrices, operational definitions that facilitate measurement of these dimensions in complex highway scenes have not been established. One applied study (29) that did use photographs of actual road scenes as stimuli found that background complexity had a substantial negative effect on detection. The components of background complexity, however, were not evaluated.

The experimental methodology of the laboratory study attempted to simulate real-world variation in visual complexity via photographic stimuli. In order to simulate a driver's search for signing in-

Table 1. Overview of variables analyzed.

Item	Visual	Photometric
Scene	Twenty-two variables that measure uniformity and brightness of scene; number, size, and location of light sources; presence of recognizable detail and distracting things; general descriptions; e.g., number of point sources of light, number of traffic signs, wet or dry pavement, and land use	Scene illuminance measured at observer's eye
Surround	Thirteen variables that measure uniformity and brightness of surround, presence of other signs, and number and size of light sources, e.g., number of bright point sources, number of large bright sources of light, uniformity of surround, and brightness of surround	Minimum surround luminance, maximum surround luminance, and average surround luminance
Contrast	Three variables that measure the brightness of the sign relative to the area immediately adjacent to it, e.g., proportion of perimeter darker than sign, proportion of perimeter lighter than sign, and proportion of perimeter equal to sign brightness	Minimum external contrast, maximum external contrast, and average external contrast
Sign	Three independent variables: device type, sign brightness, and distance	Luminance of sign legend, luminance of sign background, and integrated target luminance

Figure 1. Factorial arrangement of distance by brightness by device.

	Brightness							
	Dim				Bright			
	Sign Type				Sign Type			
Distance (feet)	STOP	SPED	CROS	DTOR	STOP	SPED	CROS	DTOR
250								
400								
600								
800								

formation, uncertainty about what sign would appear was created by using four distinctly different signs, and uncertainty about where to look for a sign was maintained by varying scenes and the placement of signs within scenes.

Variables

The independent variables and their respective values are listed below:

1. Type of device: (a) DETOUR (DTOR)--black on orange; (b) SPEED ZONE AHEAD (SPED)--black on white; (c) STOP--white on red; and (d) PEDESTRIAN CROSSING (CROS)--black on yellow;
2. Sign brightness: low and high; and
3. Distance from observer: 250, 400, 600, and 800 ft.

(Note, for sign brightness for each sign type at a single distance, the luminance of target signs was controlled such that bright signs were typically twice as bright as dim signs and the standard deviation for a given brightness was kept below 25 percent of the mean.) Device type was varied to explore the effect of visual complexity on those traffic signs with colors and shapes that are used most frequently or in the most critical situations. Sign brightness was manipulated in order to identify the conditions under which increased brightness is likely to improve sign recognition. Distance was included to create the uncertainty necessary in a study of conspicuity and to assess the effects of distance or size.

Because the role of visual complexity in detection and recognition is not well understood, target and contrast variables were also included in the design so that the relative importance of each and their interactions could be evaluated. Four categories of variables were measured in each visual stimulus: target, contrast, surround, and scene. Because it was not known what size area should be referred to as surround, the target's surround was defined in two ways. Specifically, the surround was defined as a circular spatial area that surrounds the center of the target sign, which subtends a radius of 1° and 2° of visual angle, respectively. Measurements in all categories were made both visually and photometrically to provide a most comprehensive assessment. The pool of variables available for analysis can be subdivided as shown in Table 1.

Experimental Design

The design of this study was complicated by the need to assess both the effects of the independent variables, which were controlled, and the variables that describe visual complexity, which were largely uncontrolled. The first of these objectives was amenable to analysis of variance, while the second was suited primarily to methods of correlation and regression.

Figure 1 shows the factorial arrangement of the three independent variables. The contents of each of these cells were observations of either scenes or subjects, depending on the analysis to be performed. When the unit of observation was subjects, scores were the proportion of correct responses over 20 scenes. When the units of observations were scenes, scores were the proportion of correct responses over 40 subjects.

The complete factorial of brightness (2) by devices (4) by distance (4) resulted in 32 cells. Eighty scenes were grouped into four sets of 20, and each set of scenes was crossed with only 8 of the 32 cells. This resulted in a total of 640 stimuli. An image of each scene without a target sign was also included, bringing the total stimuli to 720. In short, then, each roadway scene was presented nine times: eight times with a target sign and one time without a sign. Of the eight instances of the scene with signs, there were two signs at both levels of brightness at two distances.

Procedure

Subjects attended three experimental sessions, scheduled on different days, during which they were individually tested. During each session, which

Table 2. Multiple correlations of visually and photometrically determined scene, surround, contrast, and target brightness measures with criterion of sign recognition.

	STOP		DTOR		CROS		SPED	
Measure	Visual	Photometric	Visual	Photometric	Visual	Photometric	Visual	Photometric
Scene	0.70	0.06[a]	0.53	−0.32[a]	0.66	−0.31[a]	0.72	−0.26[a]
Surround	0.48	0.12	0.60	0.26	0.44	0.10	0.61	0.19
Contrast	0.28	0.24	0.38	0.39	0.27	0.12	0.52	0.42
Target brightness	0.27	0.59	0.26	0.52	0.15	0.49	0.31	0.54
Distance[b]	−0.61	-	−0.54	-	−0.52	-	−0.45	-

[a]Zero-order correlation of scene illuminance with criterion.
[b]Zero-order correlation.

lasted about 90 min with two 5-min rest periods, a subject responded to 240 projected stimuli so that data were collected for all 720 different stimuli after three sessions. Each session was preceded by both training and practice with the actual task. The task required the subject to view nighttime road scenes and to report, by using specific labels, their recognition of any of nine targets summarized in the table below:

Category	Target	Label
Road	Road curvature	Curve
	Solid center and/or edgeline	Solid
	Dashed lane line	Dashed
Traffic	Traffic moving in same direction	Same
	Traffic moving in opposite direction	Opposite
Signs	STOP sign	Stop
	PEDESTRIAN CROSSING	Cross
	DETOUR	Detour
	SPEED ZONE AHEAD	Speed zone

Subjects were shown stimuli for 3-s durations with a 15-s interstimulus interval during which blank images were projected to maintain constant dark adaptation. A quiet buzzer alerted subjects to the onset of the next trial. Subjects reported targets in different orders, which may have reflected personal search strategies or degrees of certainty.

Apparatus and Stimuli

The stimuli were composite 2.4x2.8-in color transparencies made from separate original transparencies of the scene and the sign. The procedure developed permitted any sign to be inserted into any location of any scene.

A 5x6.7-ft glass-beaded screen was located on one wall of the room while the projection equipment was isolated to limit the sound and light contamination of the experimental situation. The subject was seated 11.9 ft from the screen and the projected image constituted a 30°x24° visual field.

Subjects

A total of 40 volunteer subjects participated in the study and were reimbursed for completion of all three sessions. They were solicited from a larger sample of subjects who had been vision tested within the previous year. All subjects were required to have a driver's license and to wear corrective lenses if their license required it. The sample was fairly evenly divided as to sex but stratified on age based on the nighttime driving patterns obtained from data provided by the Federal Highway Administration (FHWA).

Results and Discussion

An analysis of variance revealed that all main effects and interactions (except sign by brightness) were significant. Obviously, bright signs were easiest to recognize, as were signs located at the nearer distances that subtended larger visual angles. Of more interest was the fact that the PEDESTRIAN CROSSING sign was easiest to recognize ($P = 0.89$) and the SPEED ZONE sign most difficult ($P = 0.57$). If response bias, which favored the SPEED ZONE sign, had been factored out, the difference between these proportions would have been even greater. The distance-by-brightness interaction showed that brightness had the greatest effect at the far distances, namely, 600 and 800 ft. The sign-type-by-distance interaction showed that the PEDESTRIAN CROSSING sign was affected least by distance and the DETOUR sign was affected most.

Regression equations were computed to evaluate the relative effectiveness of different determinants of sign recognition for each of four groups of variables measured visually and photometrically. The multiple R's (based on all variables in each group to a limit of 20, which produced asymptotic values) obtained for scene, surround, contrast, and target brightness and the zero-order R's for distance and photometrically determined scene illuminance are given in Table 2.

It should be remembered that the visual and photometric measurements within a category were not designed to measure the same thing, only the same concept or domain. Higher correlations do not imply that one method of measurement is more reliable. The differences are more likely to be attributable to differences in validity, since the underlying variables were generally different in substance as well as different in the method of measurement. For example, where visual assessments resulted in a higher correlation than photometric measurements, the difference is probably attributable to visual assessments that capitalize on the ingenuity and flexibility of the subjective process involved. Obviously, the 22 different visual measures of scenes are measuring more variance in the scene than a single measure of scene illuminance.

Inspection of Table 2 suggests that visually determined measures of the scene and surround were better predictors of detection than were photometrically determined measures. There was not much difference in visual and photometric measurements of contrast, while photometrically determined measures of target brightness were superior to visually determined brightness.

In general, the determinants of detection in order of importance were scene, surround, target brightness, and external contrast. Although surround factors were more important than target brightness (measured photometrically) for DETOUR and SPEED ZONE signs, the reverse was true for the STOP and PEDESTRIAN CROSSING signs. In any case, however, these differences were not large. Scene effects were most important for all but the DETOUR sign, where the difference between the effects of scene and surround factors was small (R = 0.53 versus 0.60).

The zero-order correlation of illuminance with the criterion revealed that brighter scenes resulted in poorer performance for all but the STOP sign, where the correlation was not significant. This may be attributable to the fact that the STOP sign was the darkest target used, and therefore the direction of contrast in bright scenes was not unfavorable to its recognition.

The zero-order correlations with distance (which also measured target size) are in Table 2 for reference. In general, this variable accounted for less variance than scene variables but more variance than the surround. In absolute terms, distance or size accounted for between 20 (SPEED ZONE) and 36 percent (STOP) of the variance in detection. (The variance accounted for is given by the correlation or multiple R^2.)

Because the determinants of detection (i.e., scene, surround, contrast, and brightness) are not independent of each other, multiple regressions were computed to evaluate the increments in predicted variance of using surround, contrast, and target variables in addition to scene variables. The R^2 for these equations is given in Table 3.

The predicted variance for scene variables ranged from 28 (DETOUR) to 52 percent (SPEED ZONE). About half of the difference in the predicted variance between these two signs was eliminated by the inclusion of surround variables in the regression equation. It is the R^2 for scene and surround that shows the proportion of variance in detection probability associated with scene complexity. For all signs, visual complexity (scene plus surround variables) accounted for more than 50 percent of the variance in the detection criterion.

The inclusion of contrast variables added little to the overall predictive validity; the greatest effect was a 4 percent increase (from 53 to 57 percent) for the DETOUR sign. The effect of adding target brightness was greater, ranging from a 4 percent increment for the PEDESTRIAN CROSSING sign to 10 percent for the STOP and SPEED ZONE signs. Brightness probably would have had even more importance if it had been put into the equation before contrast. The inclusion of distance had a modest effect of 7 percent on the DETOUR sign and 6 percent for the STOP and PEDESTRIAN CROSSING signs, but it had no effect for the SPEED ZONE sign.

Although these data provide strong support for the relative importance of scene complexity as a determinent of detection, one might still question whether or not the combined predictive validity of target brightness and external contrast might not be as great. Table 4 compares the predictive validity of visual complexity with that of sign brightness and external contrast at 400 and 600 ft. Data for 800 ft were excluded because photometric measurements were generally not possible with such small targets. The 200-ft data were eliminated to maintain balance in the analysis with respect to scenes. Photometric measures were used for brightness and visual measures for contrast, since (as indicated in Table 2) these had the highest validities.

The predictive validity (R^2) of visual complexity (scene and surround) appears to be consistently higher at the farthest distance. These validities also appear stable across sign types, ranging from 0.52 to 0.68 at 400 ft and 0.62 to 0.72 at 600 ft. The validities for brightness and contrast showed greater variability between signs. In all but one instance (SPEED ZONE at 400 ft), visual complexity had a greater validity than brightness and contrast. In general, the differences in validities were greatest at 600 ft, since (with the exception of the DETOUR sign) the validity of visual complexity increased with distance, while the validity of brightness and contrast decreased or remained the same.

Although the magnitude of these R's would suggest that visual complexity is of overwhelming importance to sign recognition, the issues of reliability and generalizability must be considered. Because of the empirical approach taken in this research, the reliability of the regression equations cannot be estimated. Even more important is the fact that complex scenes were overrepresented, which almost certainly accounts for the fact that visual complexity predicted performance better than target brightness and contrast. Additional research seems to be called for to determine the interaction of visual complexity and sign brightness within a sample that includes the full range of visual complexity.

The simple correlations of individual scene and surround variables are potentially useful to understanding the dynamics of visual complexity. Variables whose zero-order correlations with the criterion were significant for at least three of the four target types were as follows:

1. Parked vehicles on right,
2. Type of area (e.g., commercial versus rural),
3. Total area of large bright sources of light in area left of target,
4. Number of traffic signs,
5. Number of bright point sources of light,
6. Number of different (contrasting) surfaces touching target sign,
7. Proportion of perimeter darker than sign, and

Table 3. R^2 for each of four target types by using 20 variables from five groups of measurement categories.

Measurement Category	DTOR	CROS	STOP	SPED
Scene	0.28	0.44	0.49	0.52
Scene + surround (visual complexity)	0.53	0.61	0.57	0.66
Scene + surround + contrast	0.57	0.62	0.60	0.66
Scene + surround + contrast + brightness[a]	0.63	0.66	0.70	0.76
Scene + surround + contrast + brightness[a] + distance	0.70	0.72	0.76	0.76

[a] Brightness was represented by the four photometric measurements of target brightness.

Table 4. R^2 for equations of visual complexity versus brightness (photometric) and contrast (visually measured) at two distances for all signs.

	R^2 for Following Signs and Distances							
	SPED		STOP		CROS		DTOR	
Type of Sign	400 ft	600 ft	400 ft	600 ft	400 ft	600 ft	400 ft	600 ft
Bright + contrast	0.76	0.69	0.43	0.33	0.22	0.23	0.43	0.58
Visual complexity (7 variables)	0.68	0.72	0.52	0.62	0.58	0.69	0.63	0.64

8. Proportion of perimeter equal to sign brightness.

The relation of most of these variables with the criterion was consistent with normal expectations. Two exceptions were total area of large bright objects and number of different surfaces touching target. The number of large bright objects to the left aided detection. This may have occurred because eye fixations were diverted away from the large bright lights and toward the area where the sign was located. Likewise, the number of surfaces touching the target was positively correlated with performance. This finding may be an artifact of the correlation of this variable with distance or it may be a result of the fact that, with more surfaces, there are more chances of high brightness contrast over some part of the sign's perimeter. Further study is necessary to answer these questions.

FIELD STUDY

Both the laboratory and field research efforts of this project were designed to assess traffic sign recognition as a function of both device luminance and visual complexity. The field study represented an attempt to measure the effect of luminance on sign detection in visually different roadway settings under real-world conditions. Two specific hypotheses were tested by the field study. The first of these was that the probability of a driver detecting a traffic sign increases as the luminance of the device increases. The second hypothesis tested was that the probability of a driver detecting a traffic sign increases as the visual complexity of the roadway environment decreases.

In order to draw conclusions about luminance effects on detection in the real world, an attempt was made to collect the field data under conditions that were as naturalistic as possible. Inconspicuous techniques were used to measure traffic performance in response to a controlled treatment condition. The field data-collection procedure involved the unobtrusive measurement of changes in the speed of subject vehicles in response to a diamond-shaped yellow warning sign with the legend SPEED TRAP. To the extent that this procedure minimized experiment-induced sensitivity to the target sign among the subject drivers, the field data should be representative of the behavior of real-world drivers under natural conditions.

Although this approach may have maximized the external validity of the field study results, vehicle speed profiles had to be used as a surrogate measure of sign recognition. Vehicle behavior can be used as an index of recognition only if the recognition of a particular sign consistently stimulates an uninterrupted sequence of driver recognition, decision, and reaction. The SPEED TRAP sign was chosen for use in the field study on the basis of the assumption that drivers who exceed the speed limit are sufficiently motivated to recognize such messages and then decrease vehicle speed.

In spite of its face validity, it was considered necessary to test this assumption by actually demonstrating that speeding drivers do, in fact, slow down after recognizing the SPEED TRAP sign. A pilot study was conducted at two highway sites to determine whether the sign elicited an observable response. The results of the pilot provided three observations. First, speeding drivers did decelerate when the SPEED TRAP sign was deployed. Second, the frequency of decelerations was greater when an array of tape switches (used to record vehicle speeds) was deployed together with an unmarked, shoulder-parked passenger car; and, third, drivers did not respond to the tape switches and car when the sign was not present. These findings were interpreted as indicating that the presence of the car lends credibility to the message of the sign, thereby sufficiently motivating drivers to respond to the device. On the basis of this pilot study, it was concluded that the SPEED TRAP sign could justifiably be used in a methodology that purported to measure vehicle speed profiles as an indication of target sign detection.

Site Selection

The only practical method available to vary visual complexity was by site selection. An attempt was made to select three different highway sites that were as closely matched as possible in terms of both roadway geometrics and the operational traffic situation but systematically different in terms of level of complexity. The effort to match the sites, however, was limited to some extent by requirements imposed by both the instrumentation used for data collection [e.g., traffic evaluator system (TES)] and the experimental methodology itself.

The limitations imposed by the experimental methodology and the requirements of TES deployment reduced the number of candidate sites so that visual complexity played a less-than-optimal role in the selection of sites. The overall strategy employed in the site selection process was to weigh individual site characteristics in terms of apparent relevance to the hypotheses being tested and then to select the three sites that were best matched on the relevant variables.

Apparatus

The apparatus used in the field study consisted of the SPEED TRAP sign, the TES used to record vehicle trajectory data, and the shoulder-parked passenger car that was deployed to lend credibility to the message of the target sign. TES was used to record vehicle speeds at each site. TES (30) is a hardwire system that records momentary closures in electronic circuits that are actuated by wheel-hits on a series of tape switches deployed on the surface of the road throughout the site.

The target sign was a standard 36-in yellow diamond warning sign with a black, nonstandard legend: SPEED TRAP. The sign was displayed on a portable sign mount that was designed to be sturdy, inconspicuous, and similar to the typical standards for shoulder-mounted signs.

At each site, the target sign was positioned in the middle of a 1200-ft course that was instrumented via the TES. TES was used to develop a speed profile that consisted of eight speed measurements, each of which represented the vehicle's average velocity over the 150-ft interval between adjacent TES traps. The first of these traps was located 600 ft upstream of the target sign, and the ninth trap was 600 ft downstream of the target sign. A trap consisted of a parallel pair of tape switches affixed to the road surface perpendicular to traffic flow and spaced precisely 4 ft apart. The basic data that are recorded with this system are the arrival times of an axle over a particular switch. With this output, existing computer programs were used to generate vehicle speed profiles over the measured course and to identify vehicle types on the basis of number of axles and length of the wheelbase. Headways and spot speeds at each trap were also calculated.

Data-Collection Procedure

Data were collected on consecutive weekday nights at each of the three sites. The first night of data collection at each site was used to gather control data, which were used to identify the typical speed pattern through each site--uninfluenced by the SPEED TRAP sign. The only difference between the control and treatment conditions was the absence of the target sign on the control nights. The time of night during which data were collected varied minimally from one night to the next; these times ranged from 6:00 p.m. at the earliest to 2:30 a.m. at the latest. Data collection was limited, however, to hours of full dark; that is, data were never gathered during the twilight conditions of dusk. Finally, each night's data were recorded under clear, dry conditions.

Subjects

The subject sample for the field study was restricted to motorists exceeding the posted speed limit because only these drivers could be expected to have been sufficiently motivated to detect, recognize, and respond to the message of the SPEED TRAP sign. The posted speed limit was 45 mph at the low-complexity site and 40 mph at the other sites. In the State of Pennsylvania, it is a fairly common belief among motorists that speeding citations are almost certainly given to those drivers that are in violation of the posted limit by 6 mph or more. Because of the widespread nature of this belief, the sample was restricted to vehicles whose measured speed over the first 150 ft of the course was more than 6 mph above the limit. Because the subject sample consisted of nighttime motorists that were speeding, young males were probably overrepresented in comparison with the driving population as a whole.

Because decreases in speed that were due to influences other than the SPEED TRAP sign constituted a source of error variance, the subject sample was further limited to vehicles that appeared to be uninfluenced by other vehicles on the road. Specifically, each subject vehicle was required to maintain at least an 8-s clear headway throughout the 1200-ft measured course. A vehicle traveling 55 mph, for example, had to have a headway distance of at least 645 ft. Another extraneous source of speed reductions among stream vehicles may have been activity on either the shoulder or the road itself. Examples of such activity included vehicles poised to merge into the mainstream, pedestrians walking near the edge of the road, and marked police cars passing through the site. These kinds of events were coded manually by members of the field crew during the hours of data collection, and subject vehicles that may have been influenced by such activities were subsequently deleted from the sample.

Because of the greater observation angles and slower performance characteristics associated with larger trucks, the sample was limited to passenger cars, vans, and pick-ups, with no distinctions made among these subgroups. Further, to eliminate those vehicles whose speed-related behaviors may have been influenced by lane-change maneuvers, only those vehicles that did not change lanes within the study site were included.

Independent Variables

The study objectives dictated that both sign luminance and visual complexity be systematically varied as independent variables. Three levels of sign luminance were presented at each of three data-collection sites that differed in terms of visual complexity.

Sign luminance was varied by using three target signs. The high-luminance condition employed a sign made from new type III sheeting (181 cd/footcandle/ft^2). The medium-luminance sign was made from new type II sheeting. The low-luminance sign featured new type II sheeting that was artificially degraded by stretching standard hardware cloth (16 squares/in) across the face of the sign (33 cd/footcandle/ft^2).

Because legibility as well as detection varies as a function of specific luminance, it was considered necessary to estimate the legibility distances associated with each of the luminance conditions (31). Because the legibility distance associated with the high-luminance sign was estimated to be only 21 ft or 7 percent greater than that for the low-luminance device, and because this 21-ft difference in predicted legibility distance comprised only 14 percent of the 150-ft interval separating adjacent TES traps, it was not likely that differences in legibility distance across devices would produce any measured differences in the initial locations of vehicle speed reductions.

The other independent variable--visual complexity--was varied by selecting three matched data-collection sites that differed primarily in terms of the visual environment adjacent to the roadway. The visual complexity of each site was determined by first rating the site on each of the visual dimensions of complexity defined in the laboratory study and then using these coded variable values as input to one of the regression equations.

In general, the procedure used to rate the visual dimensions of complexity was the same as that used in the laboratory study. Specifically, a 35-mm color slide of each site, taken from a location 400 ft upstream of the medium-luminance target sign, was projected onto a 5-ft x 6-ft 8-in glass-beaded screen and evaluated along each complexity dimension by two trained independent evaluators. Notes taken at the site were used to assist this rating procedure. Disagreements in initial ratings were resolved by a discussion of the rationales used by each of the evaluators in arriving at their respective ratings.

After the complexity variables were rated, the level-of-complexity characteristic of each site was determined by using the coded variable values as input to the regression equation developed for the yellow diamond PEDESTRIAN CROSSING sign via the laboratory study.

Experimental Design

The field study was designed to provide information relevant to specific hypotheses that stated that both the probability and distance of sign detection increase as sign luminance increases and as visual complexity decreases. In addition, this design also allowed for an exploration of the potential interactive affects of luminance and complexity on both the probability and location of sign recognition. These hypotheses were examined by recording data that indicated the incidence and location of vehicle speed reductions elicited by the SPEED TRAP sign. The percentage and location of these vehicle decelerations were assumed to be indicative of the probability and location of target sign recognitions, respectively.

The level of visual complexity was controlled by selecting three highway sites that were matched to the extent possible except with regard to the nature of the adjacent visual environment, which differed systematically to provide low-, medium-, and high-complexity conditions. As such, visual complexity was a between-site variable with only one site representing each of three levels of complexity. Because this design used only one instance of each

Table 5. Sign effects within complexity levels for lane 1.

Complexity	Sign Present?	Speed Reduction? Yes	No	Yes (%)	Chi-Square
Low	Yes	136	230	37.2	
	No	55	142	27.9	
	Total	191	372		4.88[a]
Medium	Yes	181	204	47.7	
	No	81	128	38.8	
	Total	262	332		4.40[a]
High	Yes	118	58	67.0	
	No	96	38	71.6	
	Total	214	96		0.75[b]

[a]Significant. [b]Not significant.

Table 6. Brightness effects within complexity levels.

Lane	Complexity	Percentage Speed Reduction at Following Brightness Levels: Low	Medium	High	Chi-Square (low versus high)
1	Low	37.2	35.6	38.3	0.03[a]
	Medium	42.2	45.0	54.5	3.88[b]
	High	73.1	68.8	64.0	0.74[a]
2	Low	15.9	13.9	18.2	0.27[a]
	Medium	40.8	40.7	47.0	1.38[a]
	High	63.5	64.6	57.6	0.81[a]

[a]Not significant. [b]Significant.

complexity level to assess the effect of complexity, any other between-site differences may have confounded the influence of complexity. For this reason, any conclusions about this independent variable should be interpreted cautiously.

The level of sign luminance, however, was a within-site variable. Each of three luminance conditions--low, medium, and high--was presented at each site. The target sign was deployed on two nights per site, and the three luminance conditions were balanced across nights to preclude confounding with day of the week. Data were collected for approximately 6 h each night, and an attempt was made to divide this period into two or more equal blocks of time. Each of the three luminance conditions was presented for equal intervals of time within each of these blocks, and the order of presentation of the three levels of luminance was counterbalanced across blocks to avoid confounding luminance effects with time of night.

Findings

The dependent variable--incidence of speed reductions--was derived by evaluating the speed profile of each subject vehicle as it traversed the 1200-ft measured course. Eight interval speeds, obtained from nine TES traps, comprised the raw data that were used for the dependent measure.

The major area of inquiry was the effect of the SPEED TRAP sign on the incidence of speed reductions. For this purpose, a number of ways of measuring speed change was considered. The selected measure was the exit speed (the average speed between traps eight and nine) minus the entry speed (the average speed between traps one and two). This measure had the advantages of simplicity and ease of interpretation. In addition, it was preferred over shorter-term measures because it tended to avoid unimportant speed fluctuations and concentrate on those speed changes that were more likely to reflect driver intentions.

An initial analysis was done simply to determine if the presence of the SPEED TRAP sign was conducive to speed reductions. In this analysis, scene complexity and sign brightness were ignored; that is, the data were collapsed (i.e., summed) over the levels of complexity and brightness. In this analysis, treatment data (data collected with the sign present) were compared with control data (those collected with the sign removed) so that the focus was on the effect of the sign itself.

The results of this analysis failed to show statistically significant sign effects for either lane. That is, while the proportion of vehicles that reduced speed was higher when the SPEED TRAP sign was in place, the magnitude of the increase was not sufficiently large to preclude the results being due to chance alone.

However, a second analysis (summarized in Table 5), in which the sign effect was examined within data-collection sites (i.e., within levels of complexity), shows that for lane 1 the sign had an observable effect at the low- and medium-complexity sites. In both instances, the sign had the effect of increasing the relative frequency of speed reductions by 9 percent. The likelihood of a speed reduction was increased by 33 percent at the low-complexity site and by 23 percent at the medium-complexity site.

None of the results for lane 2 traffic showed statistically significant findings. Any explanations of this are speculative at best. It may have been due to the greater viewing angle or a difference in the nature or motivations of the drivers who chose to travel in lane 2.

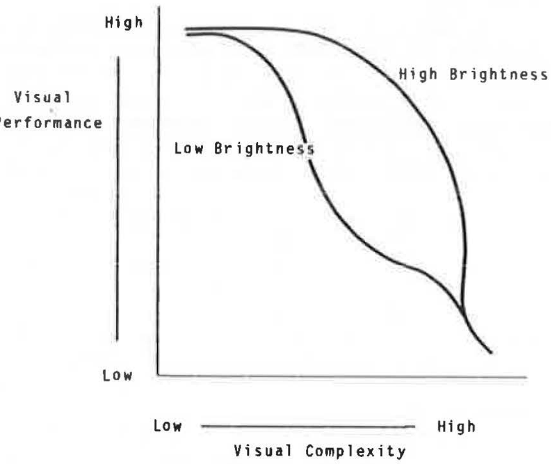
The findings for lane 1, however, suggest that there may have been an effect of visual complexity; that is, that the sign became less effective as scene complexity increased. This is indicated by the greater likelihood of speed reductions associated with the presence of the sign at the low-complexity site and the absence of such an effect at the high-complexity site.

The final analysis was to determine if sign brightness influenced the likelihood of speed reductions. Specifically, Did brighter signs elicit more frequent speed reductions? The results are given in Table 6, where the effect of sign brightness is examined within each complexity level.

As noted earlier, there were no significant effects for the lane 2 data. For lane 1, only the medium-complexity data reflected a statistically significant sign brightness effect. (The test statistics resulted from a comparison of the high- versus the low-brightness sign; while this procedure failed to use all the available information, it allowed the testing of one-sided hypotheses, thereby reflecting the ordinal nature of the levels of sign brightness.)

Once again, plausible, but speculative, explanations for the lane 1 findings are offered in the following. First, at the low-complexity site, the low-brightness sign may have been sufficiently detectable that increased brightness was superfluous; hence, increased brightness would not be expected to yield beneficial effects. The medium-complexity site may have fallen in a range of reduced sign conspicuity where sign detection was sensitive to sign brightness in the expected way. Finally, the high-complexity site differed from the other two in a unique way. On-site observations by the experimenters revealed that the sign was markedly darker than its surround. As a result, increasing sign brightness resulted in a reduction of sign-surround contrast. This, in turn, could well have led to the

Figure 2. Theoretical relations suggested by field study.



observed, though statistically insignificant, reduction in driver responsiveness to increases in sign brightness, as shown in Table 6.

In summary, lane 2 showed no sign, complexity, or brightness effects. For lane 1, a sign effect was found at the low- and medium-complexity sites but not at the high-complexity site; this, in turn, suggested the existence of a complexity effect. Sign brightness was found to influence driver responsiveness only at the medium-complexity site. This was consistent with reasonable expectations based on level of complexity and sign-surround contrast considerations.

SUMMARY

The two studies reported build a strong case for the usefulness of visual complexity as a predictor of sign detection and recognition. The results indicate that, at locations within complex visual scenes, measures of the scene and the sign's surround predict visual performance better than sign contrast and brightness. The laboratory study indicated that target brightness could offset the detrimental effects of visual complexity. Although the field study supported this finding, it also suggested that brightness might not have an effect at the extremes of visual complexity. The results of the field study suggested the theoretical relations shown in Figure 2. When visual complexity is low, performance is asymptotic and any reasonably reflective sign will be recognized. When visual complexity is extremely high, performance is likely to be equally poor with all retroreflective signs, and sign redundancy or internal illumination may be needed.

The measures of visual complexity, sign brightness, and contrast should provide a useful contribution to future research. Methods for measuring contrast, surround, and other variables have not previously been well defined for complex stimuli. The photometric methods for measuring internal contrast should also be of benefit. The fact that visual measures can have significant validity and be reliably coded suggests the potential for a practical method whereby field personnel can judge the visual complexity of a location and its effect on driver recognition of traffic signs.

The absence of cross validation and the inclusion of only three sites in the field study places obvious reservations on the reliability of the findings. Nevertheless, the consistency and pattern of results suggests that continuation of this research seems warranted. Given the abstract nature of most previous research, this report represents an important step toward developing practical and usable results. Additional work is now needed to refine the measures of visual complexity, formulate and test hypotheses about their interrelations, and develop a scale and procedure that makes visual complexity easier to measure.

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Assessing the Built Environment for Pedestrians Through Behavior Circuits

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Planners are generally concerned with those social and physical attributes that are distributed in time and space. These attributes typically occur in independent clusters or behavioral settings that vary in scale from an apartment complex to a large urbanized region. Within these settings, attributes can normally be analyzed in terms of identifiable and recurrent elements, patterns, and sequences. If one divides human behaviors by their scale and generality, it will be noticed that the things people do at the widest compass can be called behavior streams or activities. These, in turn, can be further separated into behavior circuits, which are differentiated by specific purpose. A systems view of the behavioral science/transportation framework is first described. The paper then examines the use of behavior settings and behavior circuits in pedestrian planning, designing, and the development of performance standards. Relative to a set of needs and purposes, certain aspects of environmental form typically support or constrain desired human action and communicate meaning and value.

Assessing the built environment from the standpoint of safety is an interdisciplinary inquiry that embraces the applied social and behavioral sciences. This assessment depends on the development of fundamental knowledge of the interaction of man-made physical environment variables with other environmental variables in influencing behavior.

This paper examines the use of behavior settings and behavior circuits in assessing the built environment, particularly the infrastructure built for the transportation of people. The outcome of this investigation can be used productively in assessing either the existing built environment or for planning future facilities. Although this paper focuses on assessing pedestrian planning and safety vis-a-vis the built environment, the techniques described here can be extended to other modes of transportation.

BACKGROUND

With the introduction of the transportation system management (TSM) element (1) in urban transportation planning, there is widespread interest among engineers and planners to improve existing pedestrian facilities and to plan new ones. In this and former efforts there has been a persistent tendency to imitate the classic planning and designing procedures adopted by planners for highway facilities. This has been unfortunate. The current predicament is in part the consequence of a gross underestimation of the complexities of human perception and mental need. All of the planning tools and procedures may be impeccable, but if the physical consequences--the actual objects in space--do not add up to a satisfying, vigorous, and safe environment, the total effort is of little consequence.

In recent years, many designers and planners have formulated new microtheories of the environment in an attempt to plan cities. Lynch (2), in his Image of the City, takes a cognitive approach to the environment in his attempt to get to the visual quality