The visibility of objects on the roadway at night has been studied under different conditions of fixed lighting and pavement reflectance in a 15:1-scale model of a divided urban freeway. Visibility was measured in accordance with the quantitative methods described by the International Commission on Illumination, involving psychophysical measurements of equivalent contrast and physical measurements of disability glare and luminance. Initially, three realistic targets were studied at 20-ft (6.1-m) intervals throughout the luminaire cycle down the center of each of eight lanes, under six layouts of model luminaires. Average results indicated that visibility did not increase so much with increases in illuminance as was expected. Also, when the spacing of luminaires was wide, variability in visibility was great. These results were attributed to an anticamouflage effect of roadway luminance nonuniformities. Subsequent research with identical targets of different reflectances confirmed this and indicated that the visibility potential of different pavements and lighting systems should be based on visibility measures of targets of the normal reflectances weighted in proportion to the frequency of their occurrence. The quantity of data needed for this purpose implies need for a physical correlate of target visibility. Target visibility can be predicted reasonably well from roadway luminance and the arithmetic average of the local contrasts of different parts of a target with adjacent portions of the roadway background. It now seems possible to compute indexes of visibility potential for different roadway environments. Further work is needed to assess transient adaptational effects and individual differences in visibility threshold.

NIGHT VISIBILITY UNDER DIFFERENT SYSTEMS OF FIXED ROADWAY LIGHTING: A PROGRESS REPORT

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At the Institute for Research in Vision (IRV), a 1:15 highway visibility simulator was developed (1) and used (2) to study visibility with a special meter known as the Blackwell visual task evaluator (3). Because these data are difficult to interpret in terms of practical recommendations for the design and evaluation of different systems of fixed roadway lighting, the project was continued in the hope of obtaining data of greater practical value. The report represents considerable progress in the direction of practical information.

ASSESSMENTS OF VISIBILITY AND VISUAL PERFORMANCE

The relations between visibility or visual performance and illumination were clarified by the publication of Report 19 (4) of the International Commission on Illumination (CIE). The methods outlined in that report have been used throughout this program. The central ideas are described briefly below.

Visibility of an object varies between bare detection and easy recognition, and illumination is one variable influencing visibility. What is needed is a quantitative metric for describing visibility. Visibility meters are used to reduce the contrast of an object until the object reaches its visibility threshold, the border line between visibility and invisibility. The initial degree of suprathreshold visibility is measured by the inverse of the contrast attenuation required to bring an object to visibility threshold.

Because operators of visibility meters have individual contrast sensitivities, each measurement of initial visibility is referenced to a 4-min luminous disk of variable contrast. This is the visibility reference task. Both object and reference task are pre-

sented for $\frac{1}{5}$-sec exposures once a second in a continuous pulse train. The initial visibility of the object is defined by the equivalent contrast $\tilde{C}$, which is the physical contrast of the 4-min disk having equal visibility to that of the object when both are viewed at the same level of general luminance at threshold. Thus, an object of $\tilde{C} = 1$ and a 4-min disk of physical contrast = 1 will simultaneously reach the visibility threshold if both are contrast attenuated by a visibility meter, and this equivalence will be achieved regardless of the contrast sensitivity of the meter operator.

After a value of $\tilde{C}$ is obtained, threshold contrasts obtained on a reference population of 68 normal 20 to 30 year olds are used to describe the degree to which the object exceeds threshold contrast at each value of general luminance. The procedure is shown schematically in Figure 1. The value of C_{eq} is identical to $\tilde{C}$. The value of $\tilde{C}$ (C_{eq}) is obtained with a visibility meter at a known luminance and hence is plotted in Figure 1 as a point. The solid curve is known as the visibility reference function and represents threshold contrast values for the 4-min disk obtained by the reference population at each luminance level. The measure of suprathreshold visibility is

$$VL = \tilde{C}/C_1$$

where C_1 is the threshold contrast at a given luminance for the reference population. $\tilde{C}$ does not depend on luminance, but of course VL does. VL can be computed for any luminance from the definition.

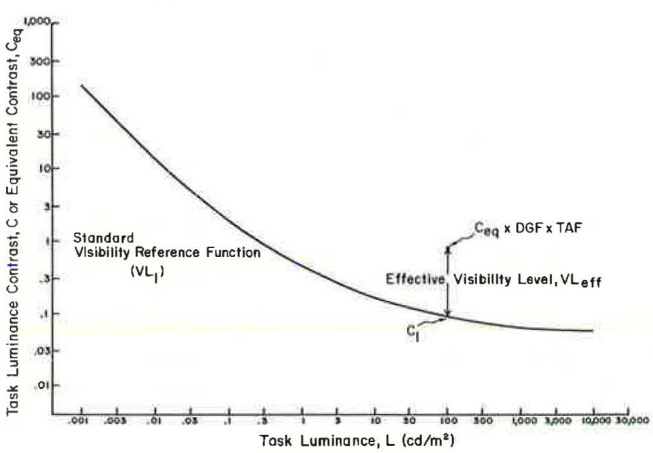
The CIE system is based on the reference lighting condition produced within a photometric sphere. For all real systems, corrections must be made for effects due to unequal luminance from point to point in the visual environment. For the steady eye, these are described by the disability glare factor (DGF). For the moving eye, they are described by DGF times the transient adaptation factor (TAF). The effective visibility level is

$$VL_{eff} = VL \times DGF \times TAF$$

$$= \tilde{C}/C_1 \times DGF \times TAF$$

VL_{eff} measures the degree of suprathreshold visibility in units equal to the threshold contrast for the reference population. VL_{eff} is a linear quality and may be measured

Figure 1. Construction from CIE Report 19 showing the definition of C_{eq} ($\tilde{C}$).



and indeed calculated with some ease and assurance.

In the CIE system, visual performance is defined as the visual work that is required under realistic conditions such as those encountered in night driving. It has been shown (4) that visual performance bears a monotonic though nonlinear relation to VL_{eff}. To date, our work has been mainly concerned with the visibility aspect of the problem and this will be described in some detail. Sets of visibility data obtained with targets of different reflectances are used to define indexes of the degree to which different roadways provide object visibility.

THE IRV HIGHWAY VISIBILITY SIMULATOR

Roadway With Luminaires

Detailed descriptions of the design and construction of the simulator may be found elsewhere (1, 2). The essential details of the simulator are summarized in the following.

The model scale was set at 1:15 so that a 600-ft (183-m) section of roadway and a 200-ft (61-m) viewing distance could be simulated within a 55-ft (16.8-m) room. The roadway is 120 ft (36.6 m) wide and has 12-ft (3.6-m) lanes on either side of a 24-ft (7.3-m) median strip. The surfaces are portland cement concrete on the right and bituminous concrete on the left, the optical properties of which simulate the properties of actual sections of new roadway surfaces constructed in accordance with Interstate standards. The pavements were laid with a crown representing a $^3/_{16}$-in. (4.8-mm) rise per foot in the middle of each four-lane section, simulating an eight-lane urban freeway. The luminance factors of the pavement samples for diffuse illuminance were approximately 0.04 for the bituminous concrete and 0.50 for the portland cement concrete. There is a 32-in.-high (0.8-m) median divider that simulates portland cement concrete dividers in common use.

Luminaires are mounted above the roadway on pendulum poles to simulate different mounting heights. There is a mechanical coupling and an electrical outlet every 20 ft (6.1 m) in each of four stringers running the entire length of the roadway. Two stringers are near the outer edges of the roadway, and two are near the edges of the median strip.

There are locations for luminaires beyond the roadway surface at each end. In all, there are 164 locations for luminaires and an equal number of electrical outlets. Each outlet is supplied with voltage-stabilized 110 Vac, controlled by individual Variacs. A voltage-switching control board makes it possible to monitor the voltage being supplied to each outlet in turn, and the value can be read on a digital meter. This arrangement makes it convenient for the operator to adjust the voltage supplied to each luminaire to a standard value.

Data from only one of the four sets of scale-model luminaires are described in this report: the type BIII medium semi-cutoff (MSC) simulated luminaires. These were mounted 35 ft (10.7 m) high with an overhang of 3 ft (0.9 m) from the edge of the pavement. In addition, data are reported for a system of four longitudinally continuous fluorescent strips mounted 60 ft (18.3 m) high, which provides approximately uniform horizontal illumination at all points over the highway. The four fluorescent strips were adjusted in width, and their positions over the highway were determined on the basis of the requirements for uniform horizontal illumination. Thus, their output was arbitrary, and they represent any system capable of producing approximately uniform horizontal illumination. Therefore output can be scaled to correspond to any realistic lighting system capable of producing approximately uniform horizontal illumination. Simulation of the type III MSC luminaire in general use, however, was an extremely time-consuming and difficult project because of the scale.

Details of design, the measurement procedure, and isoillumination contours of the prototype and the model luminaire were given in earlier reports (1, 2). In general, the isoillumination contours are a little too extended longitudinally and a little too restricted transversely. Because the simulation is not exact, we designated our model luminaire as type BIII MSC to indicate a Blackwell simulation. The simulation was good enough

to carry out a realistic study of highway visibility as long as the limitations noted above were recognized.

There are light projectors at the ends of each side of the roadway with separate voltage controls that illuminate pieces of cardboard mounted on the wall at the far end of the simulator. Each projector illuminates half the cardboard roadway extension. Projector output is adjusted so that the luminance of the adjacent roadway extension matches the average luminance of the lane under study. Interchangeable boards with different reflectances were used to cover the range of average roadway luminances obtained with different luminaire layouts. The roadway extensions were wide enough so that visibility targets were always seen against either the roadway or the roadway extension or a combination of the two.

Illumination and Luminance Photometry

The patterns of horizontal and vertical illuminance produced under test conditions were measured with a mobile illumination photometer. The sensor was a barrier-layer photocell whose angular response followed the cosine law approximately. The signal from the photocell was broadcast by an FM transmitter mounted on the photometer carriage, received at the observation station at the rear of the simulator, and used to drive the y-axis of an x-y plotter.

The photocell carriage can be moved back and forth along the roadway just above the surface either horizontally or vertically. The carriage is driven by a chain drive mounted in the median strip divider. An arm extends out from the median strip across the roadway to a protective strip at each edge of the roadway. The photocell can be mounted on this arm at any distance from very close to the median divider to near the outer edge of the roadway on either side. The photocell carriage is driven by a braked variable-speed drive so that it can be stopped at any point along the roadway with an error of less than 1 ft (0.3 m).

There is a continuous circuit board of reed switches running the entire length of the median strip. As the carriage moves along the roadway, its precise position is indicated by the circuit board assembly to within 1 ft (0.3 m). The signal from the circuit board is used both to drive the x-axis of the x-y plotter and to operate a digital meter readout device calibrated in scale feet. The illumination photometer was used to record continuous illumination profiles of both horizontal and vertical illumination in the center of each of the eight lanes. These illumination traces were made for each illumination system described (2).

Luminance photometry was accomplished with a Spectra Pritchard model 1970 photometer. A special elliptical aperture was designed to make a separate measurement of the average road luminance in each lane. Average road luminance $\bar{L}$ is measured in footlamberts (cd/m^2).

Visibility Meter and Glare Lens Measurements

There is an instrument carriage at the observation end of the simulator from which the experimenter views the roadway at the simulated angle appropriate for an automobile driver. The carriage has a precision motor-driven mounting table with two positions. In the first position, the visibility meter is pointed precisely at an object of interest. In the second position, a photometer is pointed precisely at the same object. The observer eye level of 48 in. (1.2 m) above the roadway is preserved. The visibility meter used is the special contrast-reducing model 3 Blackwell visual task evaluator (VTE). This device (3) gives the operator a telescopic view of objects on the roadway surrounded by an annulus whose luminance is set equal to the luminance surrounding the object, either by using the flicker photometer mode of the instrument or, as in this study, by setting it equal to the luminance of a physically measured background. This simultaneously sets the luminance of the light veil produced by the instrument to the same luminance. Then a contrast control gradually reduces the magnitude of focused light reach-

ing the eye of the operator from the object and its background and at the same time increases the magnitude of light veil; the total of focused light and light veil is maintained at a nearly constant value. The object is brought to visibility threshold by means of the contrast attenuation produced by exchanging light veil for focused light. The extent to which contrast attenuation is required provides a quantitative measure of the initial visibility of the object. In this study, the object whose visibility is being measured is presented to the observer's eye in a continuous train of $\frac{1}{5}$-sec exposures in accordance with the standard CIE system of measuring visibility (4). In all the measurements, the contrast of the target was set to the value at which the observer could just barely detect that there was something there to be avoided. This information criterion amounts to a detection criterion of visibility. Each visibility measurement was made five times by an experienced observer. Thus, each value of $\tilde{C}$ reported here represents the average of five independent measurements.

The Spectra Pritchard photometer was mounted in the second position of the observer carriage. By a switch control this is positioned to point at exactly the same object as the VTE and at the correct observer eye position. The target was then removed, and two measurements were made to enable computation of DGF. With a 2-deg aperture in the photometer, we measured the luminance of the area of the roadway or roadway plus extension. Then an optical analog device, the Fry-Pritchard-Blackwell disability glare lens (5), was attached to the front of the photometer, and a second measurement was made. This device integrates all the components of disability glare in the environment, simulating the behavior of the normal 20- to 30-year-old human eye in this regard. Thus a separate DGF was computed for each position of a target under each lighting system. No measurement or calculation of the TAF has been attempted as yet, for no standardized procedure currently exists. Nor have we considered individual differences in sensitivity (6).

RESULTS OF VISIBILITY STUDIES

Studies With Three Realistic Targets

The first study was visibility of three realistic targets under six lighting systems. These consisted of six layouts of the previously described luminaires: 240-ft (73.2-m) opposite, 120-ft (36.6-m) staggered, 120-ft opposite, 60-ft (18.3-m) staggered, 60-ft opposite, and four continuous fluorescent strips providing approximately uniform horizontal illumination. For each layout, the following measurements were made:

1. Vertical and horizontal illumination traces the length of the highway at the center of each of the eight lanes,
2. Average roadway luminance for each lane separately,
3. Five visibility measurements of each of three targets every 20 ft (6.1 m) throughout the luminaire cycle down the center of each of the eight lanes, and
4. Disability glare measurements at each of these positions.

For the uniform illumination, all of these measurements were made for three positions in the center of each lane. The simulated viewing distance was kept at 200 ft (61 m) throughout.

The three realistic targets were agreed on by the various sponsors of the research. One target was a manikin made from wooden circular and cylindrical components to simulate the body proportions of a 6-ft (1.8-m) male. The body had a reflectance of 26 percent, and the body parts were constructed from calculations of proper scale areas. Another target was the rear of a model automobile simulating a clean, newly waxed, dark green sedan with the usual chrome. The third target was a white line marker made to scale by mounting retroreflective tape on supportive strips that were put together to form a continuous line marker along the inside edge of the two inside highway lanes, i.e., those next to the median.

The measurement procedures and tabular data for the type BIII MSC luminaires are reported elsewhere (2), but the data on the continuous strips are reported here.

Data are given in Tables 1 and 2. In Table 1 are given the arithmetic averages of all values obtained with the three targets in all longitudinal locations, in each of the four lanes, with each of the two pavement types. When two luminaire spacings were used with the same number of luminaires per mile, such as 240 opposite and 120 staggered, the two sets of values are shown separately and then averaged. All pertinent quantities are shown; VL_{eff} is computed by assuming TAF = 1. For the continuous-strip lighting, it was assumed that approximately uniform horizontal illumination could be produced by mounting luminaires at 30-ft (9.15-m) opposite spacing. Thus, in computing $\bar{L}$ and VL, we assumed levels of illumination appropriate to a spacing of 30 ft opposite.

VL_{eff} should show a systematic increase as spacing is reduced, for each reduction in spacing doubles the number of luminaires and approximately doubles all values of illumination and luminance. Table 1 shows that, for portland cement concrete pavement, VL_{eff} increased from 17.0 to 20.1 to 31.8 to 53.6 as the number of luminaires was increased by two, four, and eight. These values of VL_{eff} should be compared, however, with values of 17.0, 22.2, 28.3, and 35.2 to be expected from the increases in $\bar{L}$ alone (the value at the widest spacing is used as a base). When the value of VL_{eff} is greater or less than expected, the values of $\tilde{C}$ are either greater or smaller than the

Table 1. Arithmetic averages and average deviations for three realistic targets in four lanes.

Pavement	Spacing (ft)	Arithmetic Average $\tilde{C}$	$\bar{L}$ (ft-L)	VL	DGF	VL_{eff}	VL_{eff} Expected[a]	Average Deviation $\tilde{C}$	VL_{eff}
Portland cement concrete	240 opposite	4.72	0.794	17.6	0.968	17.0		1.04	3.97
	120 staggered	4.64	0.820	17.6	0.970	17.0		1.18	4.54
	Average	4.68	0.807	17.6	0.969	17.0	17.0		
	120 opposite	3.87	1.46	18.9	0.973	18.4		0.651	3.14
	60 staggered	4.55	1.52	22.4	0.966	21.8		1.06	5.48
	Average	4.21	1.49	20.6	0.970	20.1	22.2		
	60 opposite	5.28	2.88	33.0	0.965	31.8	28.3	0.831	5.06
	30 opposite[b]	6.75	5.76	52.9	1.010	53.6	35.2	0.738	5.71
Bituminous concrete	240 opposite	7.52	0.482	22.4	0.945	21.3		2.76	8.58
	120 staggered	9.55	0.522	29.5	0.942	27.9		3.21	9.97
	Average	8.54	0.502	25.9	0.944	24.6	24.6		
	120 opposite	3.84	0.970	15.6	0.942	14.8		0.684	2.78
	60 staggered	7.45	1.09	28.8	0.937	27.1		1.82	6.80
	Average	5.64	1.03	22.2	0.940	21.0	33.1		
	60 opposite	5.28	1.53	26.6	0.928	25.0	39.1	1.43	7.76
	30 opposite[b]	16.2	3.06	107.0	0.988	104.0	51.3	2.55	16.8

Note: 1 ft = 0.3 m, 1 ft-L = 3.4 cd/m².
[a]Due to $\bar{L}$ alone. [b]Continuous strips.

Table 2. Arithmetic averages and average deviations for three manikin targets.

Pavement	Manikin ρ	Arithmetic Average $\tilde{C}$	$\bar{L}$ (ft-L)	VL	DGF	VL_{eff}	Average Deviation $\tilde{C}$	VL_{eff}
Portland cement concrete	0.434	2.92	1.05	12.2	0.970	11.9	0.445	1.82
	0.260	3.86	1.05	16.1	0.970	15.7	0.570	2.18
	0.074	4.51	1.05	18.8	0.970	18.3	0.864	3.32
	Average	3.76	1.05	15.7	0.970	15.3	0.626	2.44
Bituminous concrete	0.434	3.29	0.932	13.1	0.961	12.7	0.886	3.46
	0.260	3.44	0.932	13.5	0.961	13.0	0.913	3.64
	0.074	4.92	0.932	19.7	0.961	18.9	0.634	2.43
	Average	3.88	0.932	15.4	0.961	14.9	0.811	3.18

Note: 1 ft-L = 3.4 cd/m²

value obtained with the widest spacing. The data for the portland cement pavement show that $\tilde{C}$ decreased as the number of luminaires was doubled from those used at 240 opposite and 120 staggered, then increased as the number of luminaires was doubled and doubled again. $\tilde{C}$ has a minimum value for the 120 opposite and 60 staggered spacings, being higher for either wider or closer spacings.

The data for bituminous concrete show a similar pattern with respect to $\tilde{C}$ except that the differences are much greater, and the values of VL_{eff} show essentially no improvement as spacing is reduced except for the closest spacing (30 opposite). Values of VL_{eff} fall far below expectations based on the increases in illumination and luminance except for the 30 opposite (continuous strip) layout.

There is one further result of interest. With neither pavement is there an entirely consistent trend for greater values of VL_{eff}, but in three of the four cases VL_{eff} is greater with bituminous than with portland cement pavement.

These effects suggest the existence of what we have called an anticamouflage effect (2). That is, to at least some extent, luminance nonuniformity can be a boon in that it provides such a variety of values of roadway luminance that some part of an object is sure to be seen because an appreciable local contrast exists. Of course, roadway nonuniformity can also conceal objects that resemble luminance nonuniformities, and these two effects can work together to produce good and less good patterns of roadway luminance so far as static visibility goes. This could explain the observed results. Because the bituminous pavement is more specular than portland cement pavement, the effects produced by luminance nonuniformity would be expected to be greater, which was the case.

Table 1 also gives measures of the variability among values of $\tilde{C}$ and VL_{eff} that make up each average. Variability is, of course, due to both errors in measuring $\tilde{C}$ and real differences in $\tilde{C}$ from location to location on the roadway. The data for portland cement concrete pavement under continuous-strip lighting should show little variability due to the second factor and hence give us a measure of the variability due to errors in measuring $\tilde{C}$. We see that the average deviation in this case is 0.738 for a mean of 6.75, representing 10.9 percent. This implies that measurement errors in $\tilde{C}$ are somewhat less than ±10 percent in sets of five measurements, which seems reasonable. Other average deviations are much larger, no doubt because of real differences in visibility among different locations. In general, average deviation values represent larger percentages of the averages the wider the luminaires are spaced. Values of average deviation are consistently larger for the bituminous pavement than for the portland cement pavement because of the greater luminance nonuniformities in the former resulting from its greater specularity.

The apparent significance of the anticamouflage effect made us wonder to what extent the data obtained in this study were influenced by the reflectances of the targets selected. Accordingly, a special study was conducted to investigate sample lighting conditions from among those included in the first study. The three targets were identical except for reflectance.

Studies With Manikins of Three Reflectances

Targets with different reflectances were studied under one lighting condition, 240-ft opposite spacing, which showed the bituminous concrete pavement to be superior to the portland cement pavement. Three identical manikins were painted to have diffuse reflectance, ρ, of 0.434, 0.260, and 0.074. Measurements were made following the same procedures as in the first study except that only the outermost lane (the one under the luminaires) was studied for each pavement.

The results, averaged for all three manikins, are given in Table 2. VL_{eff} is essentially equal for the two pavements: 15.3 for portland cement and 14.9 for bituminous. This differs significantly from results given in Table 1 in which VL_{eff} was higher for bituminous in three cases out of four. It thus appears that the initial data were influenced by target reflectances, inadvertently favoring the bituminous pavement. Table 2 also gives the measures of data variability, confirming that the differences between

the two pavements are not statistically significant.

The most rational approach is to study targets of normal reflectances in proportion to their frequency of occurrence in assessing the visibility potential offered by any given roadway. This of course greatly complicates the task of making measurements. For this reason, we decided to investigate use of simplified targets of varying reflectance to determine a physical correlate of $\tilde{C}$ so that we could make physical measurements and calculations of visibility data.

Studies of Two-Dimensional Rectangular Targets of Four Reflectances

We constructed four two-dimensional targets of uniform reflectance, each measuring 12 in. (0.3 m) wide by 32 in. (0.8 m) high. This size was selected so that the targets could be seen entirely against the roadway itself and not against the roadway extension. The diffuse reflectance values ρ for these targets were 0.726, 0.508, 0.317, and 0.0442. Luminance and visibility measurements were made exactly as in the other studies for each of these targets at each target position, except that only the two outermost lanes were studied.

Average results are given in Table 3. As shown in the table, the narrowest spacing (30 opposite) yields higher values of VL_{eff} than the wider spacings for each pavement. Values of VL_{eff} at all spacings are quite similar for the two pavements; portland cement pavement shows a slight advantage as in the previous study. However, values of $\tilde{C}$ are also slightly higher on the average with the portland cement pavement, the reverse of what is shown in Table 2. Apparently, when a variety of target reflectances are used, the two pavements yield about equal average values of VL_{eff} and factors such as luminance nonuniformity show up only for some target reflectances.

A glance at individual values for the different reflectance targets shows that average values of VL_{eff} are somewhat misleading. For example, with each pavement, there is one target that is badly seen under continuous-strip lighting. Inasmuch as this lighting produces uniform roadway luminance, there is indeed a case of fairly good camouflage occurring for each pavement. Camouflage does not occur with the wide luminaire spacing because of the large luminance nonuniformities which are produced. These data suggest the importance of assessing roadway lighting in terms of both average VL_{eff} and a measure of variability in VL_{eff} among different targets, with as large a number included in the data set as possible. Table 3 gives measures of data variability, which show that, the closer the spacing of the luminaires is, the smaller is the percentage of variability in individual values of VL_{eff}. Overall, the percentage of variability is approximately the same for the two pavement surfaces.

It may be useful to consider the smallest value of VL_{eff} occurring with each layout and each pavement for any of the four targets. Using average deviation steps from each average value of VL_{eff}, we find values of 1.6, 5.6, 6.8, and 0.9 as the worst values of VL_{eff} to be expected from the 240 opposite, 120 opposite, 60 opposite, and continuous-strip lighting systems respectively. This index of merit favors first the 60 opposite system and second the 120 opposite system quite strongly. Two of the worst cases appear with portland cement and two with bituminous, suggesting as before that the pavement surfaces are roughly equivalent. We need to extend this analysis to the other six lanes of pavement to provide the complete story of all targets and all locations. This implies the need for a physical calculation system to augment the data we have collected with the visibility meter approach.

PHYSICAL CORRELATES OF $\tilde{C}$

The psychophysical data on simplified targets of varying reflectance presented have been used in a study of different physical correlates of $\tilde{C}$. Additional luminance measurements were made of minute areas of each target and the immediate roadway background. A 2-min photometric aperture was used. Five readings of target luminance

Table 3. Arithmetic averages and average deviations for four rectangular targets.

Pavement	Target ρ	Spacing (ft)	Arithmetic Average $\bar{C}$	$\bar{L}$ (ft-L)	VL	DGF	VL_{eff}	Average Deviation $\bar{C}$	VL_{eff}
Portland cement concrete	0.726	240 opposite	3.76	1.28	17.0	0.970	16.5	1.70	7.46
		120 opposite	2.28	2.30	13.2	0.965	12.8	0.404	2.24
		60 opposite	1.50	3.85	10.4	0.965	10.0	0.240	1.60
		30 opposite[a]	1.04	9.14	7.92	1.010	8.00	0.181	0.977
	0.508	240 opposite	4.84	1.28	22.0	0.970	21.3	1.60	6 93
		120 opposite	3.29	2.30	19.0	0.965	18.3	0.686	3.78
		60 opposite	2.46	3.85	17.1	0.965	16.5	0.612	4.08
		30 opposite[a]	3.31	9.14	29.0	1.010	29.3	0.190	1.63
	0.317	240 opposite	6.06	1.28	27.6	0.970	26.9	1.11	5.06
		120 opposite	4.17	2.30	24.1	0.965	23.3	0.684	3.76
		60 opposite	3.26	3.85	22.6	0.965	21.9	0.362	2.42
		30 opposite[a]	5.57	9.14	49.0	1.010	49.5	0.617	5.50
	0.0442	240 opposite	7.53	1.28	34.1	0.970	33.1	0.921	4.15
		120 opposite	6.46	2.30	37.4	0.965	36.0	1.04	5.77
		60 opposite	4.34	3.85	30.2	0.965	29.1	0.735	4.90
		30 opposite[a]	7.96	9.14	69.7	1.010	70.4	0.390	3.46
	Average	240 opposite	5.55	1.28	25.2	0.970	24.4	1.33	5.90
		120 opposite	4.05	2.30	23.4	0.965	22.6	0.704	3.89
		60 opposite	2.89	3.85	20.1	0.965	19.4	0.487	3.25
		30 opposite[a]	4.47	9.14	38.9	1.010	39.3	0.344	2.89
Bituminous concrete	0.726	240 opposite	4.79	1.20	21.1	0.961	20.3	0.805	3.52
		120 opposite	2.43	2.19	13.8	0.964	13.3	0.710	3.86
		60 opposite	1.50	3.32	9.93	0.957	9.49	0.170	1.01
		30 opposite[a]	3.84	7.31	32.0	0.994	31.8	0.977	8.11
	0.508	240 opposite	5.06	1.20	22.4	0.961	21.5	1.10	4.83
		120 opposite	2.98	2.19	17.0	0.964	16.3	0.788	4.31
		60 opposite	2.50	3.32	16.6	0.957	15.8	0.292	1.95
		30 opposite[a]	0.873	7.31	7.23	0.994	7.18	0.378	3.13
	0.317	240 opposite	5.43	1.20	24.0	0.961	23.0	1.23	5.33
		120 opposite	4.03	2.19	22.9	0.964	22.1	0.927	5.11
		60 opposite	3.32	3.32	22.0	0.957	21.1	0.368	2.32
		30 opposite[a]	3.65	7.31	30.3	0.994	30.1	0.163	1.41
	0.0442	240 opposite	7.22	1.20	31.8	0.961	30.5	0.844	3.73
		120 opposite	5.30	2.19	30.1	0.964	29.0	0.967	5.38
		60 opposite	4.58	3.32	30.4	0.957	29.1	0.895	5.82
		30 opposite[a]	8.12	7.31	67.4	0.994	67.0	0.950	7.89
	Average	240 opposite	5.62	1.20	24.9	0.961	23.8	0.995	4.35
		120 opposite	3.68	2.19	21.0	0.964	20.2	0.848	4.66
		60 opposite	2.98	3.32	19.7	0.957	18.9	0.431	2.78
		30 opposite[a]	4.19	7.31	34.3	0.994	34.1	0.617	5.13

Note: 1 ft = 0.3 m, 1 ft-L = 3.4 cd/m^2.
[a]Continuous strips.

were made in a row down the center of each target. These readings were averaged inasmuch as each target had essentially uniform luminance from top to bottom. The average target luminance was used in all calculations of contrast. Five readings of roadway luminance were also taken along each of the three boundaries each target made with the road, that is, along the left, bottom, and right sides of each target. These 20 luminances were measured for each target in each location under each of the four lighting systems studied. Then, separate formulas were used to compute different measures of target contrast and the correlation between values of $\tilde{C}$ and each measure of contrast was evaluated.

There was a special problem involving the shadow cast by the target on the roadway at its bottom edge. We investigated the effect of including or excluding these values from each definition of contrast.

Three definitions of contrast were used: contrast based on average luminances of target and background; maximum contrast, i.e., the highest contrast of any part of the target with an adjacent portion of the background; and average contrast, i.e., the arithmetic average of the local contrasts of different parts of the targets and adjacent por-

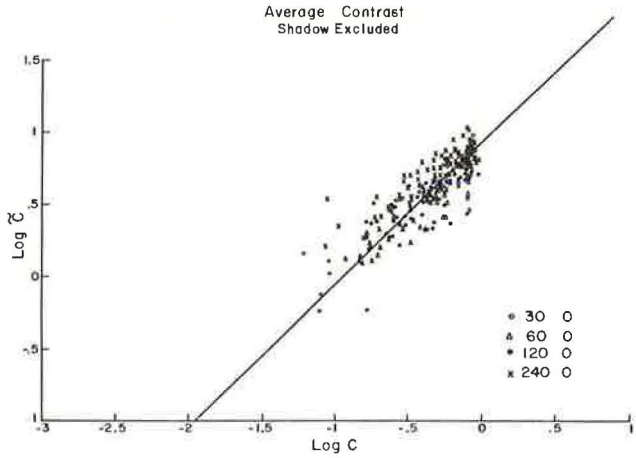


Figure 2. Scatter diagram of individual values of $\tilde{C}$ plotted as a function of average contrast.

tions of the background. In each case, individual values of $\tilde{C}$ obtained were plotted as a function of paired values of each computed contrast. The scales were logarithmic, and a line of unit slope was drawn corresponding to perfect correlation. The lines of unit slope were moved along the abscissa for best fit in each case. Degree of correlation was given by the spread of the points about the line.

It seemed clear that the target shadows should be excluded from any calculation of target contrast, inasmuch as the correlation obtained by excluding these values was significantly better. Of the three measures, contrast based on average luminances shows clearly the least correlation, and average contrast shows somewhat higher correlation than maximum contrast. Figure 2 shows the best of the six sets, using average contrast excluding shadow contrasts. The degree of correlation looks distinctly promising of practical usefulness.

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Transient adaptation refers to the rapid fluctuations in the sensitivity of the eye that result from sudden changes in luminance level. The research reported here examines the effects of transient adaptation and resultant losses in visibility by using luminance levels comparable to nighttime highway lighting conditions. At low luminance levels, sudden increases produce losses in visibility equivalent to those previously found at higher levels. However, at low luminance levels, decreases produce smaller losses than those observed at higher luminance levels. The results also suggest that there is a preadapting level or range of levels below which there is little or no difference between visibility losses for 10- and 100-fold decreases and above which there is a difference. The transition appears to be a gradual one and is complete at about 8 ft-L. The findings of these investigations suggest that visibility loss depends more on the ratio of steady-state thresholds, particularly at low luminance levels, than on the ratio of luminance change as previously supposed. Research has been initiated on the problem of nonuniformities in roadway luminances in the motorist's visual environment. Results indicate that the size of a nonuniformity may have little effect on transient adaptation. However, experiments to examine multiple nonuniformities and the effect of nonuniformities at various distances from the line of sight on transient adaptation are planned.

VISIBILITY LOSSES CAUSED BY TRANSIENT ADAPTATION AT LOW LUMINANCE LEVELS

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Visual adaptation is the process wherein the sensitivity of the eye adjusts to variations in luminance level over time. Some of these changes in sensivity are accomplished in a few hundred milliseconds, but others take several minutes to an hour. The research on transient adaptation is concerned with the faster changes, which are thought to be primarily neural in nature. Adaptation that takes place over a longer period of time, which appears to be more closely related to the concentration of photopigment in the receptors of the eye (1), is not covered here.

When the eye is presented with a sudden increase or decrease in the prevailing level of illumination, a transient burst of neural activity occurs in the retina that is relayed along visual pathways, signaling the change (2, 3). If the individual is asked to perform a visual task at this time, such as the recognition of a test letter, he or she will need greater contrast between the letter and the background if recognition is to take place. This is because the visual system is busy handling information related to the change in luminance level. Thus, the activity produced by the change masks the letter, i.e., makes it less visible. The greater the change in luminance level is, the greater is the additional contrast necessary to recognize the test letter. Eventually, the activity due to the sudden change subsides and reaches a steady state of complete adaptation.

The momentary loss in visibility associated with transient adaptation occurs whenever an individual changes his or her point of regard to surfaces having different luminances, when he or she views a variegated surface, or when natural illumination changes occur in the visual environment. Because variation in the visual field is necessary for vision to exist, the research on transient adaptation has addressed the question of how much variation in luminance should be permitted in the field of view and still allow adequate visibility to be maintained.

A number of experiments have been conducted by Boynton and associates at the University of Rochester (3, 4, 5, 6, 7). These have dealt with luminance levels similar to those encountered in interior lighting conditions. The research presented here was undertaken to provide a similar description of transient adaptational effects at