HIGHWAY SMOKE STUDIES[1]

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SYNOPSIS

In this report some of the problems of smoke evaluation are analysed. The subject may be divided into three phases: (1) establishing evaluation criteria, (2) devising instrumentation, and (3) formulating measurement techniques and standards. The possible evaluation criteria have been reviewed and the smoke criterion selected was the reduction in visibility rather than the annoyance, discomfort, or nuisance aspects. Visibility is shown to be related to brightness ratios and contrasts. An instrument for measuring brightness ratios and contrasts has been designed and a working model has been constructed and calibrated. Preliminary field data are shown for several sets of smoke conditions. The plan for a complete study is outlined together with suggestions for techniques for field measurements and standard definitions.

Smoke emitted by motor vehicles on the highway has long been recognized as a hazard to safe operation. It is also one of the principal sources of annoyance and discomfort to vehicle operators, pedestrians and other persons in congested areas. The nuisance aspect and the effects of smoke on public health are receiving widespread attention. Many municipal, county and other local area smoke abatement programs have been re-activated since the end of the war. The smoke reduction program in the Los Angeles area is noteworthy in this respect (*1*).[2] The activities of this city and county group have covered smoke emitted by highway vehicles as well as other transportation and industrial smoke sources. The combination of smoke and fog in the atmosphere results in an unusually disagreeable situation commonly termed "smog." In some localities and under certain atmospheric conditions smoke from vehicles contributes a great deal to the overall "smog" problem.

Since 1939, the California Vehicle Code has contained Section 673.5 Exhaust Products, which states, "No motor vehicle shall be operated in a manner resulting in the escape of excessive smoke, gas, oil, or fuel residue." This statement covers the general desires of the legislators and public but requires considerable interpretation by enforcement agencies relative to the definition of "excessive."

The methods of smoke evaluation that have been used to regulate industrial smoke, railroad engine smoke and marine engine smoke have been carefully reviewed in order to determine whether or not these techniques could be applied to motor vehicle conditions. These studies resulted in the conclusion that up to this date there are no smoke evaluation schemes that are entirely satisfactory for an enforcement agency to use on the highways.

As a stop-gap measure, a modification of the Ringelmann Chart (*2*) technique has been adopted by the California Highway Patrol. This method uses a visual comparison between the vehicle smoke density and a standard density plate to measure the degree of smoking. Five steps are provided and any smoke of density corresponding to step No. 2 or higher is defined as excessive. Details of the technique are given in Appendix A. Obviously there are serious limitations to the use of this method. The present study has been conducted in order to explore the possibilities of developing a more satisfactory method to measure and define motor vehicle smoke.

In order to evaluate the smoke emitted by vehicles it is necessary to first decide upon the criteria to be used for measuring the smoke; second, to devise equipment with which to make the measurements; and third, to establish standards for densities of smoke. It has been the object of this study to consider these three phases of the problem. To date the

[1] Sponsored by The Institute for Transportation and Traffic Engineering, University of California, Berkeley, California and The California Highway Patrol.

[2] Italicized figures in parentheses refer to list of references at the end of the paper.

available criteria for measurements have been reviewed and a technique has been selected. A measuring instrument has been designed, constructed and preliminary calibration and field data have been taken.

DISCUSSION OF SMOKE EVALUATION

Consideration of the problem as a whole indicates that there are two fundamental aspects that need to be differentiated:

1. The reduction in visibility of objects caused by smoke.
2. The annoyance, discomfort, and damage caused by the solid or liquid smoke particles.

The reduction in the visibility of objects caused by smoke particles in the path between the observer and the object is of paramount importance in the safe operation of motor vehicles. The visual sense is responsible for approximately 85 percent of the brain stimulation relating to body reaction, muscular coordination, and reflex actions that are used in driving. When perception distances are reduced, contrasts changed, and visual acuity lessened by the scattering and absorption of light by smoke particles the driving task is made very much more difficult.

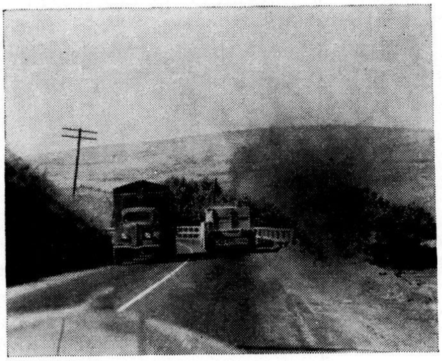


Figure 1. Truck smoke reduces visibility. A Subway sign is almost obscured by the smoke from the truck.

Figure 1 shows a situation where the smoke from a vehicle has reduced the visibility of a roadside sign to practically zero. In this case, the information on the sign indicating the approach to a subway is important to the safe operation of the vehicle.

These visual difficulties lead to an immediate and unfavorable reaction of the driver to the smoke. A nuisance value of varying degree is automatically assigned to the particular situation. If the smoking conditions are prolonged as they are at times when following a badly smoking vehicle or when in a badly congested area that does not have good natural air circulation, a distinct discomfort may result. Such discomfort may result from breathing the solid or liquid smoke particles or may be due to the other toxic gases that result from the burning of motor vehicle fuel. Motor vehicle exhaust products contain varying amounts of the following substances: H_2O, CO, CO_2, N, C, O, SO_2, acrylic aldehyde, unburned hydrocarbons, and others.

Of these, only the carbon, liquid water and unburned hydrocarbons cause smoke. The CO, SO_2, and acrylic aldehydes are the only toxic gases present, but under highway conditions these are not ordinarily present in sufficiently large concentrations to be physiologically harmful. Special conditions can develop, however, where these gases can cause trouble, but these cases will not be discussed here. The CO gas is odorless and cannot be detected except with very sensitive instruments. This leaves the SO_2 and the acrylic aldehydes as the principal gases that "smell up" the highway. These gases certainly do constitute a public nuisance and no doubt cause discomfort and eye smarting under "smog" conditions, but ordinarily on the highway they are not harmful.

The smoke particles may be annoying in other ways and may do damage that is harmful and has commercial significance. Deposits of unburned oil and "smudge" can collect on following vehicles and roadside structures. This can cause immediate local trouble or long term damage to vehicles and structures. These aspects will not be analyzed in this paper. The references contain discussions of these problems.

Either the reduction in visibility or the annoyance aspect of the problem may be considered to be most important, depending upon one's viewpoint and the interest of the person will influence to a large extent, the method that is selected to evaluate the smoke. For instance, in orchard heating a large amount of "smudge" is generated. The principle complaints have to do with the carbon deposits on buildings, clothes hanging on lines to dry, etc. So, the method of evaluation usually consists of a collection of the soot on a white filter

paper. The change in reflection is used as a measure of the smoke. This scheme is obviously not suitable to highway studies, but the question is: What measurable quantity should be used?

Before it is possible to proceed further, it is necessary to define the limits of the problem. This was partially accomplished by listing a set of ground rules as follows:

1. The method of evaluation is to be suitable for field use. Laboratory type of equipment and trained personnel should not be required.

2. The measurements should yield immediate data on the smoke density. It should not be necessary to make a measurement and then have to wait for the completion of a secondary process or extra task before getting the final answer.

3. It is not desirable to have a system that requires the test vehicle to stop.

4. A fixed installation on the highway should be avoided if possible in order to have a more flexible system and to eliminate the possibility of forewarning the vehicle operator.

5. Calibration should be simple and readily accomplished in the field.

6. Visual comparison methods should be avoided if possible.

7. The technique should employ a suitable instrument that can be used in a car following or approaching another vehicle that is emitting smoke.

These ground rules and the consideration of the operating hazards involved in motor vehicle operation seemed to point to the visibility aspect of the problem as the one to examine critically for possible evaluation techniques. This was done and the following possible schemes of evaluating visibility conditions were considered:

1. Photographic methods—A number of photographs have been taken from following and approaching cars. Movies and still pictures have been made. This technique is very useful for exploratory work and research, but is not practical for enforcement use because of the time delay in processing the film, the skill required of the operators, the possibilities of "doctoring" the film, and the cost.

2. Light transmission measurements—This method is very satisfactory for stationary engines or for fixed installations along a highway. Attachment devices can be designed for use on moving vehicles, but would require that the vehicles be stopped and made the subject of a test with the operator aware of the check-up. This method has been fairly well developed by Professor Schweitzer (*3*)(*5*) and others (*4*), but it is not considered to be a practical enforcement method.

3. Direct sampling of the exhaust to obtain the size and quantity of smoke particles. This method could employ the principle of (a) collection by filtering or (b) the use of electrostatic precipitation. These principles are useful as laboratory or fixed installation techniques, but are not suitable for the purpose in mind.

4. Brightness Ratio measurements—Measurements of the brightness of objects, clouds, sky and other portions of the visual field, can be made from a moving vehicle without in any way interfering with the object vehicle. Visibility and brightness ratios can be correlated on a scientific basis. This principle would satisfy the ground rules B, C, D and G, but it remained to be investigated whether or not the remaining conditions could be satisfied.

An instrument capable of measuring brightness and, therefore, brightness ratios, is available in the form of a visual comparison device. This commercial instrument (The Luckiesh-Taylor Brightness Meter) requires a stationary mount and a trained operator in order to get consistent results. Serious troubles are encountered in color mis-matches and the rapid changes that occur in the smoke patch. It is *not*, therefore, suitable for general use.

DESIGN OF THE INSTRUMENT

Since there were no suitable instruments available, the second phase of the study has been to design and construct an instrument capable of evaluating the desired brightness quantities.

Analysis of the problem shows that the reduction in visibility can be correlated to the change in brightness of an object after the smoke is introduced in the visual path.

The quantities that are necessary are the initial brightness of the object, B_o, the brightness of the same object with intermediate smoke, B_s, the background brightness of the object without smoke, B_{bo}, the background brightness of the object with smoke, B_{bs}, and the adaptation brightness of the eye, B_A.

These quantities permit the brightness ratio and contrast to be calculated as:

$$\text{Brightness Ratio} = \frac{B_s}{B_o} \text{ and}$$

the brightness contrast to be calculated as:

$$C_o = \frac{B_o - B_{bo}}{B_A} \text{ without smoke—}$$

$$\text{or } C_s = \frac{B_s - B_{bs}}{B_A} \text{ with smoke}$$

The brightness ratios and contrasts of objects with and without smoke can then be correlated in terms of threshold seeing or in

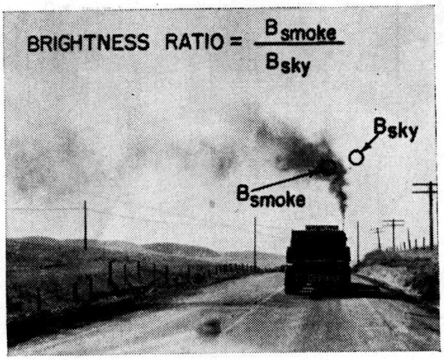


Figure 2. Smoke Seen Against a Uniform Background. This is a suitable location for measurements.

terms of acceptable values established by statistical means in order to fix defining values for tolerable, objectionable and excessive amounts of smoke.

After a field survey, it was observed that conditions could almost always be found along a highway where the smoke could be observed against a uniform or nearly uniform background. Thus, in Figure 2, the same truck observed in Figure 1 is seen a few hundred yards farther down the road with the smoke silhouetted against a uniform sky background. Measurements of the sky brightness on each side of the smoke patch and the smoke brightness will give the desired brightness ratio. This can then be used to evaluate the reduction in brightness of other objects that are obscured by the same smoke.

The brightness ratio measurements of the smoke against a uniform background yield the same data that would be obtained by transmission measurements for $\frac{B_{\text{smoke}}}{B_{\text{sky}}} = 1 -$ transmission factor. Thus these data can be correlated with usual density specifications such as 20, 40, 60 percent smoke, etc. The principle advantage of this method is that a secondary light source is not required and the defining smoke densities can be adjusted to take the background brightness into account.

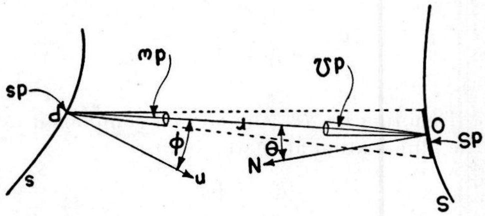


Figure 3

The basis for the design of a physical brightness meter for this study is outlined as follows:

Brightness of a luminous surface *S* (Fig. 3) at a point *O* on the source in the direction *OP* is defined as follows:

$$B = \frac{dI}{d\sigma} \quad (1)$$

$d\sigma = dS \cos \theta$
B = brightness in luminous flux/steradian × area
I = intensity in luminous flux/steradian
S = area
σ = projected area in the direction OP

θ denotes the angle between the direction OP and the normal N of the luminous element dS and $d\sigma$ the area of the projection of the element dS upon a plane normal to OP.

If the medium were absorbing, the relative visibility of *S* would vary with the position of the observer's eye along *OP* in a fixed direction. The brightness contrast between *S* and its immediate background measured at the source, *S*, then would not describe properly the variations of relative visibility.

We shall show how brightness measurements can still account for relative visibility when the concept is extended to a point in the field along the line *OP*.

From Figure 3 the flux d^2F emitted by dS

and contained in the solid angle, $d\Omega$ may be expressed as:

$$d^2F = \frac{B(dS\cos\theta)(ds\cos\phi)}{r^2}$$ where: r = distance between O and P

But·

$$d\omega = \frac{dS\cos\theta}{r^2}$$

Thus:

$$\frac{dF}{ds} = dE_P = B\cos\phi\, d\omega$$

Denoting by dE_n the normal component of the illumination at P we obtain:

$$dE_n = Bd\omega$$

and:

$$B = \frac{dE_n}{d\omega} \qquad (2)$$

If the medium is non-absorbing, that is if no flux is "lost" on its way from S to s, we may conclude from (2) that the brightness of a luminous source, S, can be defined as the normal component of illumination at the point, P, produced by source, S, per unit solid angle at P.

Equation (1) has meaning only if S is a light-emitting surface and fails for volume distributed light-sources as sky, clouds, etc. Equation (2) has meaning for any light source and defines the actual conditions at the observer's eye.

Method of Measurement—We would like to measure the average brightness over a solid angle at a point P where the observer's eye is assumed to be located. The average Brightness, B, over ω is defined as:

$$B_\omega = \frac{1}{\omega}\int_\omega B\, d\omega \qquad (3)$$

But:

$$B = \frac{dE_n}{d\omega}$$

and substituting in (3) we get:

$$B_\omega = \frac{1}{\omega}\int_\omega dE_n \qquad (4)$$

Formula (4) can be interpreted as follows:

Take a point P and an infinitesimal surface ds thru P whose normal n is contained within a solid angle ω about P, (Fig. 4).

Measure the normal illumination dE_n on this surface by allowing only a small cone of flux $d\omega$, whose axis is perpendicular to ds, to strike it; dE_n will be equal to that flux divided by ds. Repeat the process by rotating ds about P for all possible directions of its normal within ω; the sum of all the corresponding dE_n measurements is equal to the average brightness at P times the solid angle, ω.

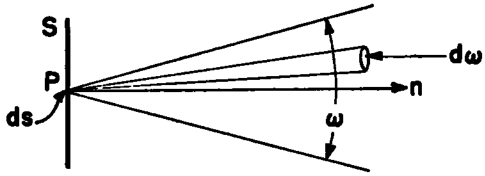


Figure 4

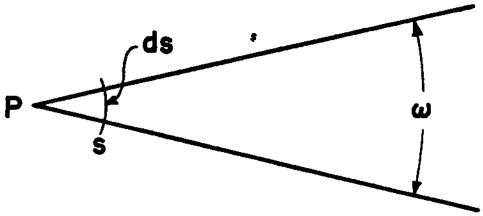


Figure 5

Since a point is well approximated by a spherical surface of infinitesimal radius, formula (4) suggests the following scheme (Fig. 5):

If the internal surface of the cone of apex at P is perfectly absorbing (that is black), all the rays but the radial ones will be absorbed and the illumination at P will approximately be:

$$E_p = \int_\omega dE_n$$

In order to register the amount of light incident at P, the surface s can be made of a sensitive cell provided with a corrective filter. Obviously the surface of the cell should have the shape of a spherical casket. Since such a form is not generally available, it can be substituted by a plane surface provided it is small enough to reduce the loss in accuracy due to the deviations caused by the cosine law.

An instrument using the above design considerations will give the average brightness for the solid angle of the acceptance cone. In order to obtain data for use in computing brightness ratios and contrasts it is necessary to have the acceptance cone as small as possible. In the tentative design a cone apex plane angle of one degree has been selected. It may be desirable to reduce this angle still further to an ultimate limit that as yet has not been determined. A cone angle of one degree will include a circular area approximately 1.7 ft. in diameter 100 ft. ahead of the observer. This would seem to be a practical size for smoke studies. Furthermore an angle of this size corresponds to the approximate size of the foveal region of the eye so that it should be possible to correlate instrument readings with visibility data.

The very small angular opening imposes instrument design problems because of the small amount of light flux that can be received by the cell. Three designs have been investigated that involve (1) a phototube and d.c. amplifier, (2) an electron multiplier tube and optical system and (3) an electron multiplier tube and shielding cone. At the present time type (3) seems to have the most promise because of its simplicity and high sensitivity without the necessity of conventional amplifiers. The experimental instruments based upon these design principles are shown in the accompanying photographs (See Figure 6). Photograph A shows the device that utilizes a phototube and d.c. amplifier. Photograph B shows the instrument that uses the electron multiplier tube. The latter instrument can be used with an optical collecting lens or with a set of baffles to shield the instrument to a 1 deg. field.

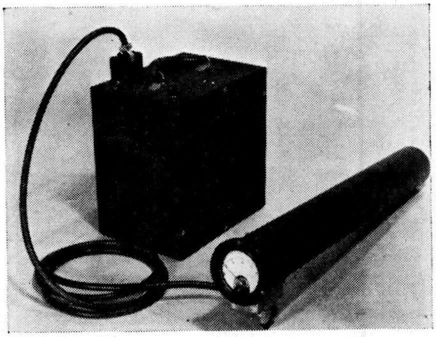
The circuit for the device shown in Photograph B is given in Figure 7.

The circuit consists of 10 identical stages with 5000-Ω, 2-watt rheostats each, which allows the voltage per stage to vary from 90 v. to 135 v.

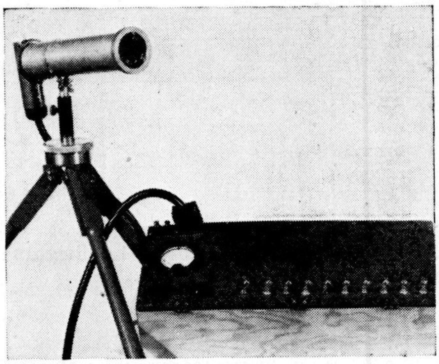
A 50μa microammeter, M1, in series with a 5-megohm resistor is used as a voltmeter and allows the voltage to be measured across each stage whether the tube is operating or not.

A microammeter, M2, of same range as the preceding one is connected between the anode and dynode No. 9 and gives an indication of the amount of light incident on the cathode (No. 11).

Description of the Double Switch: The two rotating wheels A and A′ are connected by a central axis thru O and O′, which causes them to rotate together. The conducting rims r and r′ are continuously in contact with the fixed poles b and b′. Contact poles c and c′ are fixed to r and r′ and consequently make corresponding contact with 11 and 1, 1 and 2,



A. Vacuum Phototube and DC Amplifier



B. Photomultiplier Tube and Shielding Cylinder

Figure 6. Physical Brightness Meters

etc. In this way, the current flowing through "M1" multiplied by 5×10^6 gives the voltage across any two successive terminals, i.e.; No. 11 and No. 1 or No. 1 and No. 2 and so on.

Calibration—Figure 8, illustrates the design features and the arrangement of the apparatus during calibration.

The intensity of the point-source was maintained constant at 150 candlepower and decreased to a lower value by shielding it from the cell with a neutral filter having a transmission factor of 0.0418.

Since the source has approximately the di-

mensions of a point, the illumination of the cell is equivalent to $\int_\omega dE_n$ of formula (4). Hence:

$$E = \frac{I}{r^2} = \int_\omega dE_n$$

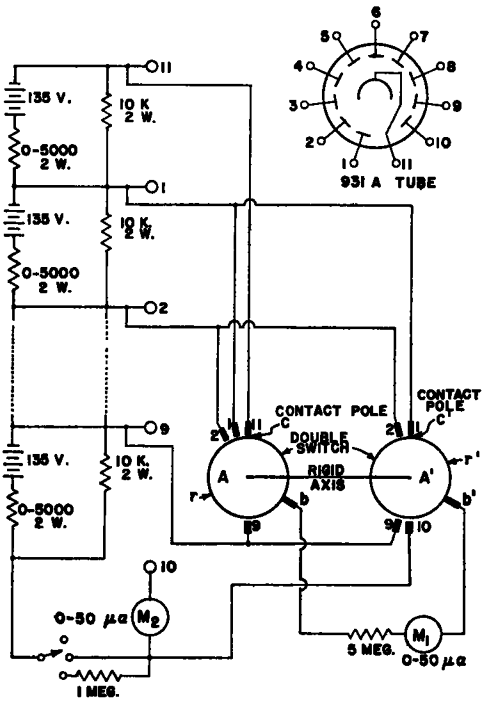


Figure 7. Circuit Diagram—931 A Brightness Meter.

show the initial calibration. The value of sensitivity obtained from the slope of the graph:

σ = 0.18 × 10^{-3} lumens per sq. ft. per μa is rather large since no correction filter was used on the phototube. Moreover with the 931 A the sensitivity curve is almost linear. This is a very satisfactory result.

DISCUSSION AND USE OF THE BRIGHTNESS METER

The design considerations outlined in the preceding sections have been built into the meter shown schematically in Figure 8. This instrument has been used for a limited number of field evaluations. The actual field tests that have been made, reveal that the present design gives the measurements that are wanted but it is not as portable and flexible as is desired. There are a few features such as range changing filters and better sights that are necessary. The design is now being refined to incorporate the minor changes that have been found desirable.

Trial runs were made with the instruments using trucking equipment furnished by one of our local transportation companies. The set-up of equipment was as shown in Figure 10. The physical brightness meter and a visual brightness meter were used for comparative purposes. Observers also made a visual appraisal of the smoke conditions using the Ringelmann Chart method and personal evaluations. Brightness measurements were made

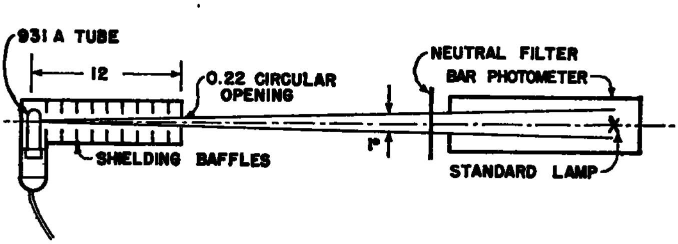


Figure 8

and

$$B = \frac{1}{\omega} \times \frac{I}{r^2} = \frac{E}{\omega}$$

Since E differs from B only by a constant factor, the current of the tube can be plotted against E for the sake of simplicity. The plotted data on the enclosed graph, Figure 9,

of the sky background and the smoke patch, using both instruments. These data are shown in Table 1.

The truck equipment used for these tests was in very good condition and it was difficult to cause the engines to smoke. The measurements indicated that the instrument had adequate sensitivity and gave results that are in

approximate agreement with visual appraisals. The visual appraisals are very hard to make. The density is very hard to judge with the Ringelmann Chart and the brightness fields are different in color in the visual brightness meter. The physical brightness meter readings are taken from the dial of a meter and are readily obtained.

The device was then taken on the road for actual field use. The first series of readings

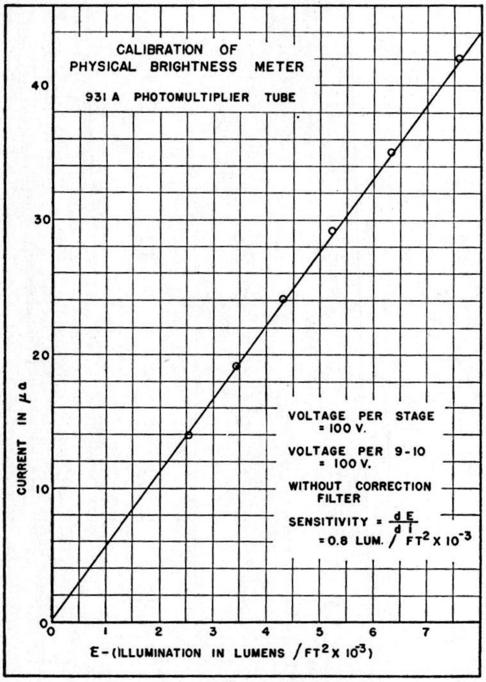


Figure 9

were made on random truck traffic along U. S. Highway 50 between Oakland and Stockton, California. Readings were first made from a stationary car parked along the road near the bottom of Pergola Hill. Typical readings are shown in Table 2.

The measurements made from a stationary car cover several densities of smoke measured against a clear blue sky. The readings clearly differentiate between very light, light and heavy smoking.

The observer car was next operated in a normal manner along the highway. Smoke measurements were made on following and approaching vehicles as these vehicles were encountered. A list of typical results are shown in Table 3.

Table 3 gives data on moving vehicles operating under actual roadway conditions. Readings could not be taken with the visual brightness meter (Luckiesh-Taylor) because of the movement of the observer vehicle. Readings were readily made with the physical brightness meter for both sky background and uniform hillside backgrounds. It may be noted that the brightness ratios are the same whether a high level (sky) background or a low level (hillside) background is used. The only condition imposed is that the background shall be approximately uniform.

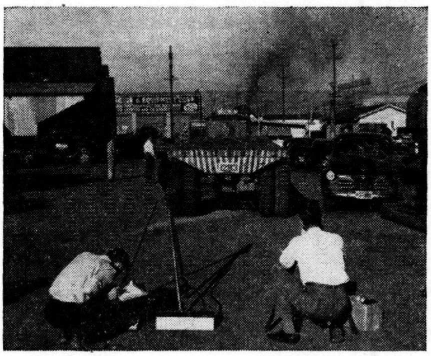


Figure 10. Trial Run Using Physical Brightness Meter and Visual Brightness Meter to Measure Smoke.

These results indicate that brightness measurements can be readily made using any one of a number of observation methods. The brightness measurements can be correlated with visibility conditions by making a comprehensive survey of actual brightness values of highway smoking conditions together with visual appraisals of each situation. A set defining of brightness ratios can then be established for several ranges of background brightness. Such definitions can cover smoke densities that may be described as (1) tolerable, (2) objectionable, and (3) excessive. More steps may be established if they are considered necessary.

The data that are available at present are not sufficiently complete to permit the defining conditions to be established but these data are being accumulated and should be available in the near future. As soon as sufficient information is on hand, it is proposed that tentative

TABLE 1
STATIONARY TESTS—CONTROLLED SMOKING

Conditions	Ringelmann Chart Readings	Visual Brightness Meter			Physical Brightness Meter		
		B_s	B_{sky}	Br. Ratio	Smoke Br. Meter Read.	Sky Br. Meter Read.	Br. Ratio
		C/in²	*C/in²*				
Vehicle Idling (very light smoke)	Approx. 1 (20% density)	2.8	3.2	.87 (13% den.)	18	21	.86 (14% den.)
Approx. ½ load (brakes set) (light black smoke)	Approx 2 (40%)				12	16	.75 (25% den.)
(light black smoke)	Approx 2 (40%)	2.6	3.2	.75 (25% den.)	6	9	.67 (33% den)

TABLE 2
STATIONARY CAR—RANDOM MOVING TRUCKS

Condition	Ringelmann Chart Readings	Visual Brightness Meter (Luckiesh-Taylor)			Physical Brightness Meter		
		Smoke Br. (C/in²)	Sky Br. (C/in²)	Br. Ratio	Smoke Br.	Sky Br.	Br. Ratio
1. Observer car facing east at Pergola—very light smoke—truck and trailer loaded—about 150 ft away.	less than 1 (20%)	1.9?	2.9	.66 (34%)	40	48	.83 (17%)
2. Same as 1 but about 300 ft. away.	less than 1 (20%)				38	44	.86 (14%)
3 Facing west—at Dublin—heavy smoke—tank truck	about 3 (60%)				9	27	.37 (63%)
4. Same as 3—light smoke	about 2 (40%)				25	37	.67 (33%)
5 Facing east—at Pergola—heavy smoke—large van (tractor, semi-trailer and trailer)	about 3 (60%)	.9	2.5	.36 (64%)	10	23	.43 (57%)
6. Same as 5—truck farther away	about 3 (60%)				11	20	.55 (45%)

TABLE 3
MOVING OBSERVER CAR—RANDOM MOVING TRUCKS

Condition	Ringelmann Chart	Physical Brightness Meter			
		Smoke Br.	Background Br.	Br. Ratio	Smoke Density
					%
1. Light smoke Sky background	1-2 (20%-40%)	25	35	.72	28
2 Brown hill background	(20%-40%)	12	18	.67	33
3 Brown hill background	(20%-40%)	8	12	.67	33
4. Brown hill background	(20%-40%)	9	13	.69	31
5. Sky background	(20%-40%)	30	44	.68	32
6. Sky background	(20%-40%)	38	50	.76	24
7. Sky background	(20%-40%)	20	35	.57	43
8. Moderately heavy smoke Sky background	2-3 (40%-60%)	25	45	.55	45
9 Sky background	(40%-60%)	20	40	.50	50
10. Hill background	(40%-60%)	12	25	.48	52
11. Hill background	(40%-60%)	15	32	.47	53
12. Hill background	(40%-60%)	13	30	.43	57
13. Heavy smoke Sky background	3-4 (60%-80%)	7	20	.20	80
14. Sky background	(60%-80%)	12	25	.48	52
15. Hill background	(60%-80%)	5	10	.50	50

defining values for highway smoke will be established on the basis of the measurable brightness ratios.

TABLE 4

Background Brightness[a]	Brightness Ratio	Smoke Density	Smoke Definition
c. per sq. in.		*percent*	
2.0 to 3.5	1.0 to 0.75	25 or less	tolerable
	0.74 to 0.60	26–40	objectionable
	0.59 to 0.0	41 or more	excessive

[a] The limits at other background brightnesses will have to be evaluated also.

The defining conditions could be presented as in Table 4.

An enforcement agency could adopt such a standard set of defining conditions or it could change the limits to suit its particular situation. The method is available, the instrument details have been worked out and the basis for defining smoke density is outlined. It is hoped that this preliminary study may be helpful in smoke evaluation and control.

REFERENCES

(1) "The Operator's Viewpoint of Exhaust Smoke"—S.A.E. paper at Annual meeting, Detroit, Michigan, January 12–16, 1948.

(2) U. S. Department of Interior, Bureau of Mines, Inf. Cir. 6888, Chart 0-442814.

(3) Schweitzer, P. H., "Smokemeter of Simple Design Tests Diesel Combustion," *Automotive Industries*, Aug. 20, 1938, p. 238.

(4) Brown, Kenneth M., "Requirements of a Smokemeter," *S.A.E. Journal*, May, 1941, p. 188.

(5) "Must Diesel Engines Smoke"—*S.A.E. Quarterly Trans.*, Vol. 1, No. 3, p. 476–487, July 1947.

APPENDIX A

CALIFORNIA HIGHWAY PATROL HEADQUARTERS GENERAL ORDER NO. *518A*

TO: ALL MEMBERS OF THE CALIFORNIA HIGHWAY PATROL

**RE: SMOKE ENFORCEMENT—REFERENCE SECTION 673.5

Supplementing Headquarters General Order #518

The Ringelmann type smoke chart has been adopted by the United States Bureau of Mines, and numerous cities, counties and political subdivisions within the United States and abroad. There are numerous court cases on record to establish the validity of the method and to provide precedents for court decisions.

1. Effective immediately the Ringelmann Chart with five standardized density steps shall be used in evaluating the conditions of excessive smoke, gas, oil or fuel residue to determine when excessive smoking of motor vehicles occurs.

2. A motor vehicle shall be considered to be emitting "excessive" smoke, gas, oil or fuel residue if on visual comparison for a reasonable period the exhaust products have a density that is equal to or greater than No. 2 (40%) on the Ringelmann chart.

3. A supply of Ringelmann charts for the Patrol Officers is being forwarded. The instructions for the use of these charts are printed thereon, and in addition thereto the following items should also be considered.

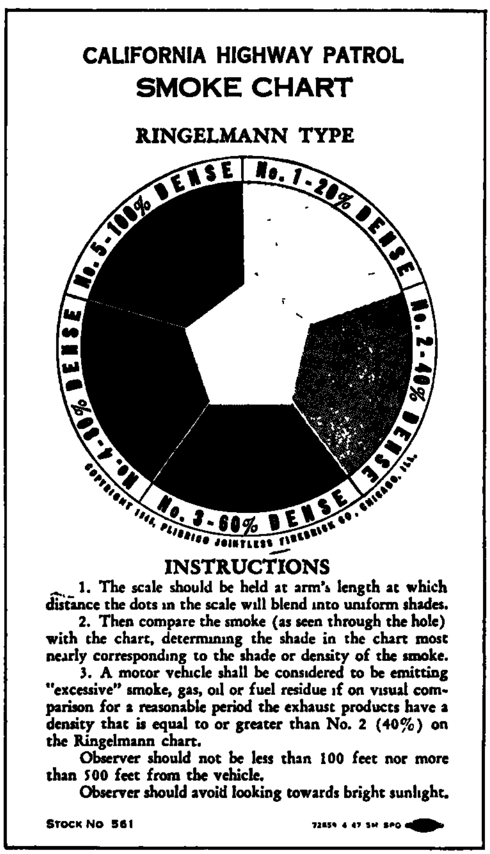


Figure 11

a. Do not use in a moving vehicle unless two men are in the car; it is not practical or safe to attempt to drive and use the chart simultaneously.
b. Care should be exercised in noting the distance that the observation is made and other variables which may affect the accuracy of the reading.
c. The readings should only be taken in daylight hours, and during periods of good visibility.
d. Concentrate upon the serious violators first. As experience is gained and as conditions on the road improve the less serious cases can be investigated.
e. On any notice of arrest or warning issued note under "violation" the density number appearing on the Ringelmann Chart. Example: Excessive Smoke—Reading No. 3 on Ringelmann Chart.

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APPROVED:
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WEAVING TRAFFIC

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SYNOPSIS

Cross weaving may occur on any type of highway or its connections and is a result of the convergence and relatively nearby divergence of traffic streams.

The section of the roadway in which cross weaving takes place is commonly known as a weaving area.

A weaving area can be constructed for but a fraction of the cost of an equivalent grade separated facility.

For successful operation of a weaving area, the speeds of the several traffic streams must be nearly equal. Uniformity of operating speeds can be achieved only when the three main elements of a weaving section are properly proportioned for the volume of traffic to be handled. A change in any one of these elements would alter the speed of the traffic streams, reduce the capacity, and affect the overall operation.

The three main elements of a weaving section are: (1) the angle of approach, (2) the width, and (3) the length.

The angle of approach affects the speed of the entering traffic, the angle of weaving, and the place of weaving.

The width of the weaving section must be sufficient to allow the traffic that is to weave to spread out laterally, thus creating the necessary gaps between vehicles and allowing weaving to take place throughout the length and width of the weaving section. This width must also be sufficient to carry the through traffic at each side without interference to the weaving vehicles.

More data are needed before determination can be made for the proper combination of length, width, and angle of approach for various volumes and speeds of traffic. The data available seem to indicate that if the maximum length is more than 900 ft. traffic streams tend to travel side by side, resulting in a forced weaving near the end of the weaving section.

Weaving has been defined as "The act performed by a vehicle in moving obliquely from one lane to an adjacent lane, thus crossing the path of other vehicles moving in the same direction."

Cross weaving is the converging at an oblique angle of separate traffic streams moving in the same general direction so that the streams cross each other in the weaving area and then diverge in separate traffic streams.

Cross weaving occurs whenever traffic streams come together and then separate. This may occur on all types of highways. For example, as shown in Figure 1, a divided highway may have an outer connection at one interchange and an inner connection at the