Effectiveness of Holland Tunnel Transitional Lighting During the Winter Months

ALAN T. GONSETH, Research Technician, The Port of New York Authority

The Port of New York Authority has previously conducted experiments in conjunction with the installation of mercury-vapor transitional lights in the Holland Tunnel.

The experiments were run during periods of maximum annoyance due to sun glare, which exists for about one hour per day at most, when the sun is between 5 degrees north to 5 degrees south of due east. The tunnel approach ramp is in a due east direction.

Sun position data show that the sun is above the horizon in that position only during the period of March 21 to September 21. Allowing for rainy and cloudy days during that period, it is estimated that this occurs only about 120 days per year.

The study reported in this paper was conducted to determine if the flow of traffic is affected during the winter months when the tunnel entrance ramp is shaded by local industrial buildings. If not, possibly a decorative facade constructed over the portal could shade the entrance in summer as well as in winter and thereby reduce, if not eliminate, the need for extensive transitional lighting all year long.

Once the vehicle operator passes under a tunnel portal the decided reduction in light intensity causes a speed reduction until his eyes have adjusted to the change. Transitional lighting, of course, has improved this operational feature considerably. New facilities are being equipped with flared portals and variable transitional light sources controlled by photoelectric cells. However, on existing tunnels and underpasses it would be almost impossible in many cases to flare the portals, and costly indeed to revise the facility lighting system to adapt an automatically controlled variable light source. With this in mind it was thought that it might prove easier and more economical to reduce the light intensity outside rather than increase it inside the tunnel.

●AN EARLY morning driver approaching the Holland Tunnel on Twelfth Street in Jersey City, New Jersey in the interim from early spring to mid-fall is confronted with a low-lying, but brilliant sun which is directly within his line of sight and his line of travel. The pupils of the driver's eyes automatically adjust to this extreme light condition. However, when the vehicle eventually reaches the tunnel and passes under the portal, the driver is met by a decided reduction in light intensity. Once again the pupil of the driver's eye must adjust to this reversed drastic change. The fulfillment of this eye adjustment requires a certain time increment during which the driver's ability to see is reduced. (It has been proven medically, but most everyone realizes from personal experience, that it takes the pupil of the eye slightly longer to adjust when subjected to a change from light to dark as opposed to a change from dark to light (1). Throughout this period of adjustment it has been noted, and it only stands to reason, that the driver would immediately decelerate his vehicle until his vision returned to a reasonably trustworthy degree.

Temporary blindness of this type not only creates conditions for accidents, but could also reduce the capacity of the tunnel lanes because of slower entering speeds and irregular flow. However, it has been indicated by the Illuminating Engineering Society that:

1. A change in brightness having a maximum ratio of 15 to 1 would not be difficult for the driver's eye to adjust to for speeds greater than 30 mph and would not cause temporary loss of vision(1).

2. The normal eye is able to adapt to this brightness change within the space of 2 to 3 sec.

3. Subsequent studies and research may justify modifying this advised 15 to 1 (outside to inside) ratio to, say, 20 or 30 to 1; especially in instances of slower entering speeds (1).

4. A normal eye doubles size in approximately 10 sec when required to suddenly adapt from extremely high to low brightness levels.

However, certain recent findings point to the possibility of adopting somewhat shorter eye adjustment times in the neighborhood of 2 sec for greater intensity differentials than 15 to 1(2).

EXISTING TUNNEL LIGHTING

The basic Holland Tunnel lighting is done by continuous-burning 150-watt filament lamps in flush-type luminaires on 20-ft linear and opposite spacing, as they were installed at the junction of the side wall and ceiling in 1927. The light intensity on the roadway ranges from 1.5 to 2.0 foot-candles and cannot be varied. Several methods of transitional lighting were investigated and tried in an attempt to create a smooth transition of lighting intensity between daylight and the basic tunnel lighting.

At one time supplementary daytime entrance lighting only utilized 200-watt incandescent lamps spaced on 10-ft centers for approximately the first 300 ft and on 15-ft centers for the next 200 ft after which regular 20-ft spacing applied for the next 1,000 ft. Sometime thereafter in order to increase the transitional light intensity, floodlights were provided in the ceiling, for a distance of approximately 150 ft, spaced at 15-ft intervals. A total of 44 floodlights were installed, of which 12 were 1,000 watts, 8 were 750 watts, 16 were 500 watts, and 8 were 300 watts. Still later, Simes fluorescent fixtures were installed along the left wall for a distance of approximately 220 ft, replacing the 200-watt incandescent lamp. Finally, in the latter part of 1957, a series of 400-watt reflector-type mercury-vapor lamps were installed, on 10-ft centers for approximately 110 ft and are now used in place of the floodlights and fluorescent fixtures. They provide uniform wall coverage at a 45-ft-candle level.

STATEMENT OF PROBLEM

During the mornings of the winter months, the sun does not affect the driver as much as it does in the summer months. The sun remains low, but swings to the south enroute to setting in the west instead of following a direct east-west line as is the case in the summer (Fig. 1). The people travelling east on Twelfth Street in Jersey City are still faced with the sun, but when they have proceeded beyond the Holland Tunnel toll booths, the roadway is shaded by local industrial buildings (Fig. 2).

The 1,000 ft or so of shaded roadway allows the driver's eyes to adjust, somewhat like a stage in transitional lighting, and in turn, reduces the ratio of outside to inside brightness considerably. It was thought that because the shaded roadway leading to the tunnel portal had reduced the light differential between the outside and inside that perhaps it reduced it to such a degree that if the mercury-vapor lamps were not used, then possibly the ratio would not increase beyond the 15 to 1 maximum ratio suggested by the Illuminating Engineering Society. If this is true, then there should be no significant difference in the speeds of vehicles in the transitional zone immediately within the tunnel portal with the transitional lights on or with them off.

APPROACH TO THE SOLUTION

The purpose of this report was to determine if the mercury-vapor transitional lights had any significant effect on traffic entering the eastbound tube of the Holland Tunnel during the winter months. To do this required the collection of speeds and headways just outside the tunnel portal and just inside the tunnel portal during heavy, free-flowing

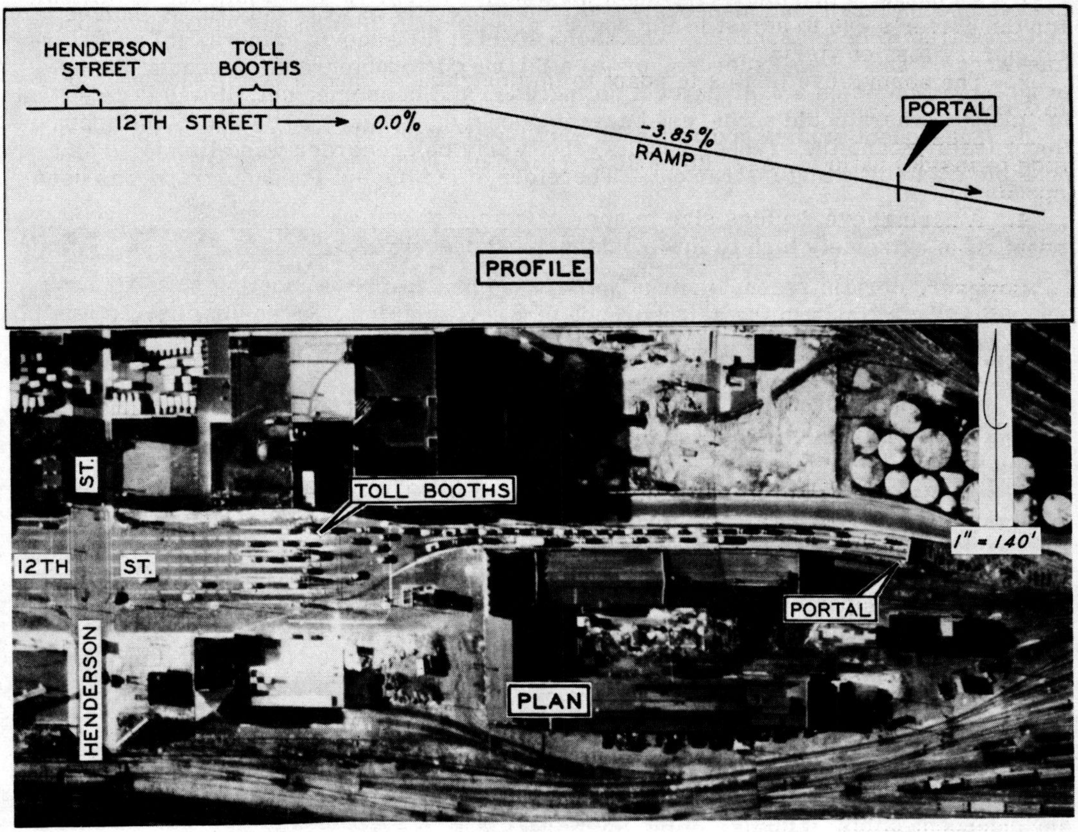


Figure 1. Plan and profile of tunnel approach.

volumes and during lower, free-flowing volumes. Good weather conditions were needed to fulfill the necessary requirements. A before-and-after study could quickly be assimilated by turning the transitional lights, which are on a separate circuit, on and off at will. In addition, no lane changing by vehicles is permitted on the approach or within the tunnel which is advantageous for this study. Following is a description of the use of the equipment that was decided on to be used and how the data was analyzed and interpreted to logically draw conclusions and recommendations.

METHOD OF STUDY

Site Description

The Holland Tunnel south tube is 8,371 ft long and carries two lanes of eastbound traffic from Jersey City, New Jersey to New York City on a 20-ft dark asphaltic concrete pavement. The bare concrete ceiling is 13 ft over the roadway and allows 12 ½ ft for operating headroom. The walls of the tube are covered with white tiles which are highly reflective and delineate the tunnel outline. For all intents and purposes, the roadway on either side of the portal of the south tube in the study area is a tangent section on a 3.85 percent downgrade. This one tube carries approximately 27,000 to 30,000 vehicles daily and has a composition of traffic having up to 50 percent commercial vehicles which are kept primarily in the right-hand or "slow" lane.

Instrumentation

Several methods could be used to collect speed and headway data, ranging from a movie camera to a count done manually at key stations. However, it was necessary to have speeds taken instantaneously and, therefore, there were only three choices that appeared to be reasonable. The choices were: (a) a movie camera, (b) an Esterline-Angus Twenty Pen Recorder, or (c) a Simplex Productograph. Because the approach roadway is on a 3.85 percent downgrade, and in an open cut, it was decided that the movie camera could not be used advantageously. Because of the bulk, the operational features and the graphed results, the twenty pen recorder was eliminated as a possible data collecting instrument. Therefore, the Simplex Productograph was used.

Figure 2. Shadowed entrance ramp.

This device is essentially a time clock which prints time to a tenth of a second plus a six letter code on standard adding machine tape. Hours, minutes and seconds are printed in figures, and tenths of a second are printed by a vernier scale. The productograph can be activated by either a road tube or a manual switch. Because of the problem caused by the laying of road tubes, and also their unknown psychological effect on drivers, it was deemed best to use micro-switches to activate the Simplex Productograph Recorder. A Macbeth Illuminometer had been previously used to determine the light intensity on the walls inside the tunnel with the transitional lights on and with them off. The Illuminometer was to be used on the day of the study to determine the light intensity outside the tunnel.

Basic Assumptions

Brief speed checks taken in the left-hand or "fast" lane at random indicated an approximate 25-mph vehicle entering speed. It was decided that only one lane of traffic could be checked adequately and inasmuch as the left lane has higher speeds it was felt that the transitional lighting would affect its traffic more, therefore, it was chosen as the

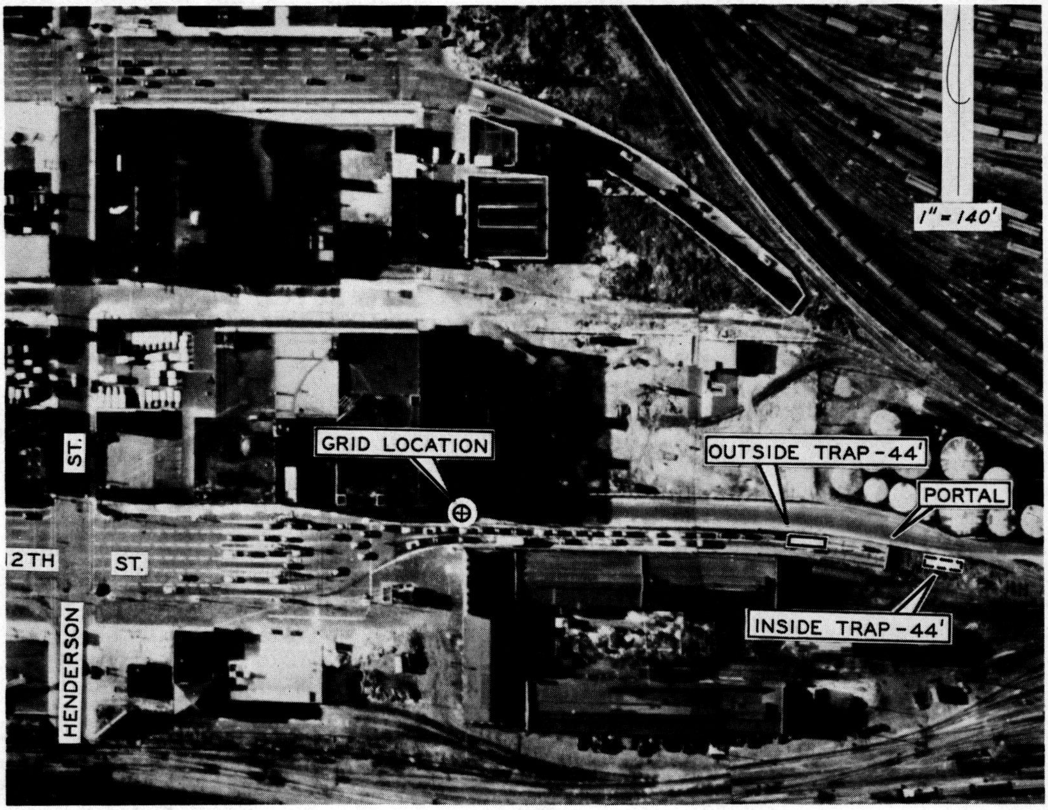


Figure 3. Speed measuring zone and grid locations.

study lane. It was assumed that a PIEV (Perception-Intellection-Emotion-Volition) time (3) of 1 sec for the driver to react to the light differential from the time when he passed beneath the portal until he applied the brakes was included in the average eye adjustment value of 2.5 sec. This would indicate that the average motorist would begin deceleration when he is 1 sec beyond the portal and start accelerating again 2.5 sec beyond the tunnel portal. Converting these times to distances by using the average 25-mph entering speed shows that deceleration could be anticipated to start about 37 ft inside the tunnel with acceleration beginning at about 82 ft beyond the portal (assuming the driver's deceleration slowed him to an average of 20 mph during the last 1.5-sec adjustment period). Therefore it was decided that a 44-ft speed measuring zone would be placed in a position starting 40 ft inside the tunnel. The position of the other speed measuring zone was completely arbitrary, but for convenience sake, it was placed in a position starting 124 ft outside the tunnel (Fig. 3).

Inclement weather caused several postponements of the study date. Finally, the data was taken on the morning of December 31, 1958. Investigation of New Years Eve traffic data of past years taken at the Holland Tunnel indicated that the A.M. peak-hour traffic was normal for a weekday and only the P.M. peak hour was affected by the occasion of New Years Eve. The transitional lights were turned off for 15 min and then on for 15 min throughout the morning study period.

Conventions

Throughout the remainder of this report, the following definitions and conventions will be used:

Speed Measuring Zone. — A 44-ft section of pavement where a time was recorded for each entering and exiting vehicle.

Outside Speed Measuring Zone. — The zone that is set up outside the tunnel portal (Zone 1).

Inside Speed Measuring Zone. — The zone that is set up within the tunnel (Zone 2).

Headway. — The time differential between the front bumper of a vehicle entering a speed measuring zone and the front bumper of the preceding vehicle.

High Volume Study. — The comparable study done between 9:30 A.M. and 10:07 A.M.

Low Volume Study. — The comparable study done between 11:00 A.M. and 11:30 A.M.

Lights On. — 400-watt mercury-vapor transitional lights are on.

Lights Off. — 400-watt mercury-vapor transitional lights are off.

ANALYSIS OF DATA

Comparable Studies

During the collection of the data, the recording tape was marked when the flow of vehicles was restricted by breakdowns within the tunnel, or by shock waves (4) (accordian effect) as caused by bottleneck conditions. Therefore, the only data that was accepted was that of free-flowing vehicles.

Each vehicle's speed was recorded and classified along with its headway for both the inside and the outside speed measuring zone. Because the data was taken for a 15-min period with the lights being on and then a 15-min period with the lights being off, it was assumed that the vehicles had exactly the same stream characteristics except for the effect of the transitional lights. The only usable data during the high-volume study period with the transitional lights on was from 9:31 A.M. to 9:39 A.M., when 166 vehicles were recorded. A comparable volume was recorded when the transitional lights were out from 9:56 A.M. to 10:07 A.M. The comparable periods of lighter volume with the transitional lights on and off were 11:00 A.M. to 11:17 ½ A.M. and 11:17½ to 11:30 A.M., respectively.

Statistical Analyses

Velocities. — The mean ($\bar{X}$) velocities for both the "lights on" and "lights off" phases of both the high-volume and low-volume studies were calculated. Next the standard deviation (a measure of scatter) for the speed was calculated by the use of the formula:

$$s = \sqrt{\frac{(X-\bar{X})^2}{N-1}} \tag{1}$$

in which

s = standard deviation
X = individual measured value
$\bar{X}$ = mean value
N = sample size

These calculated values are given in Table 1.

Before starting the analysis a check was made to see if the sample sizes were large enough to be dependable, by the use of the formula:

$$N = \left[Z_{(1-\frac{1}{2})} \frac{s}{d} \right]^2 \tag{2}$$

in which

s = standard deviation
d = tolerance
$1-\frac{1}{2}$ = % confidence
N = sample size needed
Z = confidence limits

TABLE 1

SPEED DATA

Time A.M.	Transitional Lights	No. of Veh.	Outside Speed Measuring Zone Mean Speed (mph)	Outside Speed Measuring Zone Std. Dev. (mph)	Inside Speed Measuring Zone Mean Speed (mph)	Inside Speed Measuring Zone Std. Dev. (mph)
9:31-9:39	On	166	21.9	4.8	25.0	5.0
9:56-10:07	Off	176	22.4	5.3	24.3	4.5
11:00-11:17½	On	232	23.4	3.7	29.0	4.6
11:17½-11:30	Off	174	23.6	4.2	29.4	4.8

For example, if the outside speed measuring zone, during the high-volume period, when the lights were on, it was desirable to be 99 percent sure that the population mean was within -0.5 mph of the estimated mean, a required sample size would be:

$$N = \left[2.576 \frac{(4.8)}{1.0} \right]^2 = (12.36)^2 = 153$$

This is less than the 163 recorded, therefore, the sample size is adequate. The remaining sample sizes were checked and the results are given in Table 2.

TABLE 2

SAMPLE SIZE

Time A.M.	Outside Speed Measuring Zone Recorded Sample	Outside Speed Measuring Zone Required Sample	Inside Speed Measuring Zone Recorded Sample	Inside Speed Measuring Zone Required Sample
9:31 to 9:39	166	153	166	165
9:56 to 10:07	176	175	176	134
11:00 to 11:17½	232	91	232	151
11:17½ to 11:30	174	117	174	153

Because the standard deviation is the square root of the variance, it is possible to obtain the variance for the different conditions. The variance can be used in testing statistically whether two estimates of variability are significantly different (5). One such procedure is the statistic F given by the formula:

$$F = \frac{s_1^2}{s_2^2} \tag{3}$$

which has a sampling distribution called the F distribution. There are two sample variances involved and two sets of degrees of freedom. This test is to determine if the variances of two comparable variables are significantly different. Assuming a 95 percent confidence limit, the F ratio limit of acceptability is 1.35. If the ratio is between 1.00 and 1.35, it indicates that it cannot be proved that the two variables are significantly different. For instance, the F ratio for the variance of the inside speed measuring zone was calculated for the high-volume comparison as follows:

S_1 = variance of the speeds in the inside speed measuring zone with the lights on.
S_2 = variance of the speeds in the inside speed measuring zone with the lights off.

$$F = \frac{S_1}{S_2} = \frac{(5.0)^2}{(4.5)^2} = 1.23$$

$$1.23 < 1.35$$

Therefore, with 95 percent confidence it can be said that the two estimates of variances cannot be proved significantly different.

The same procedure was used to compare the "lights on — lights off" velocity variances of the three other conditions. In all cases the ratios were less than 1.35 and, therefore, there was no significant differences with the results given in Table 3.

Because there was no significant difference in the velocity variances, they can safely be assumed as equal in each case.

Now that the variances are considered to be equal, it is possible to test to see if the means are equal. This can be done by setting up the hypothesis that the means are equal, knowing that the variances are equal. The procedure for this is outlined and explained by Dixon and Massey (5, p. 121) and is as follows:

Step (1) Hypothesize that the means are equal:

$$\mu 1 = \mu 2$$

Step (2) Assume an α, or rejection limit. Say 0.05 (for 95 percent confidence)
Step (3) Select the statistic t, which is given by the formula:

$$t = \frac{\overline{X}_1 \quad \overline{X}_2}{Sp\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} \tag{4}$$

in which

S_p = pooled variance
$\overline{X}_1$ = larger mean speed
$\overline{X}_2$ = lower mean speed
N_1 = sample size
N_2 = sample size

Step (4) The rejection limits set up with the selection of $\alpha = 0.05$ and statistic t are:

$$1.658 > \text{ or } < -1.658$$

Step (5) Solve: All the variables in equation 4 are known except the pooled variance (S_p) which can be obtained by the following formula for which all the appropriate values are known:

$$S_p^{\,2} = \frac{(N-1)S_1^2+(N-1)S_2^2}{N_1 + N_2 - 2}$$

For example, if the speeds in the inside speed measuring zone during the high-volume comparable period are put through this process, it is found:

$$S_p = \frac{(166-1)\ (5.0)^2 + (176-1)\ (4.5)^2}{166 + 176 - 2}$$

$$S_p^2 = \frac{4125 + 3544}{340}$$

$$S_p^2 = 22.56$$

$$\therefore S_p = 4.75$$

Now substituting in the "t" formula it is found that:

$$t = \frac{25.0 - 24.3}{4.75\sqrt{\frac{1}{166} + \frac{1}{176}}}$$

$$t = 0.43$$

Inasmuch as $0.43 < 1.658$ and $0.43 > -1.658$ it cannot be proved that the two mean speeds are significantly different.

The same process was used on the other comparisons and the results are given in Table 3.

TABLE 3

ACCEPTANCE TABLE

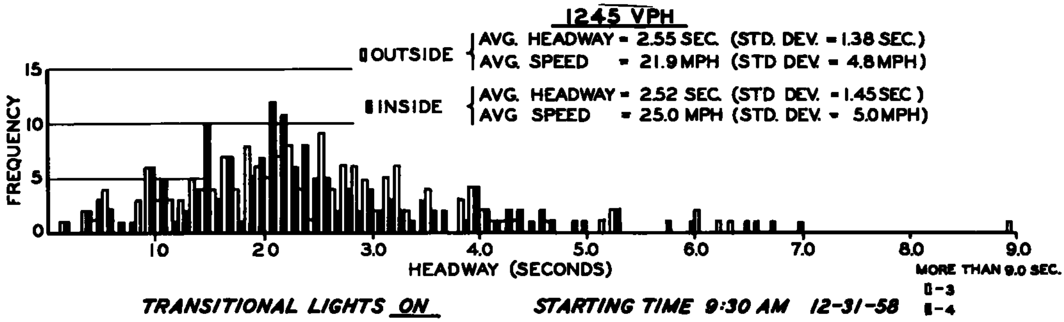
	Acceptable Range	High Volume Comparison Outside Zone	High Volume Comparison Inside Zone	High Volume Comparison Outside Zone	High Volume Comparison Inside Zone
F ratio	1.00 to 1.35	1.22	1.23	1.29	1.09
S_p	-	5.04	4.75	3.92	4.69
t value	-1.66 to 1.66	0.289	0.430	0.161	0.270

Headways. — The headway data cannot be analyzed in a similar manner because they form a skewed distribution and not a normal distribution. The frequency of headways under the various conditions (Figs. 4 and 5) show the skew of the distribution. If headways of 9.0 sec or more are disregarded it can be seen by averaging the remaining values that the differences between the inside and outside speed measuring zone during any one counting period are negligible. It would appear that if the lights had any effect, the headways would be smaller in the inside speed measuring zone when the lights were out. Of course, the headways of vehicles do vary with the volume (Fig. 7). A close inspection indicates that the means of the various groups of headway comparisons decrease as the volume increases (Table 4). Figures 6 and 7 show that the headways follow normal patterns when plotted against speed and volume, respectively.

Brightness

In order to determine the brightness outside the tunnel, readings were taken with a window-frame type of grid containing twelve openings, each 8 in. by 8 in. This grid was located 5 ft away from the observer at the height of an automobile front window. Readings were taken through each opening by means of a Macbeth Illuminometer. (Fig.

8). The grid was placed on the sidewalk of the open cut ramp leading to the tunnel and was positioned perpendicular to the roadway (Fig. 3). Readings were taken through the center of each square of the grid. Certain readings were taken into the open sky with the remainder of the readings being taken on the surrounding features (Fig. 8). The brightness of the sky averaged to about 2,000 foot-lamberts (ft-L) whereas the brightness of the shadowed wall area in front of the tunnel mouth was recorded in the vicinity of 220 ft-L. Taking the 220 ft-L and dividing by a converted 45 foot-candle (ft-C) wall coverage when the lights were out will yield an outside to inside brightness ratio. In this case the 45 ft-C can be considered 33.3 ft-L because at the angle of observation, the reflection factor of the tile wall was 74 percent. Hence, (.74) (45) =



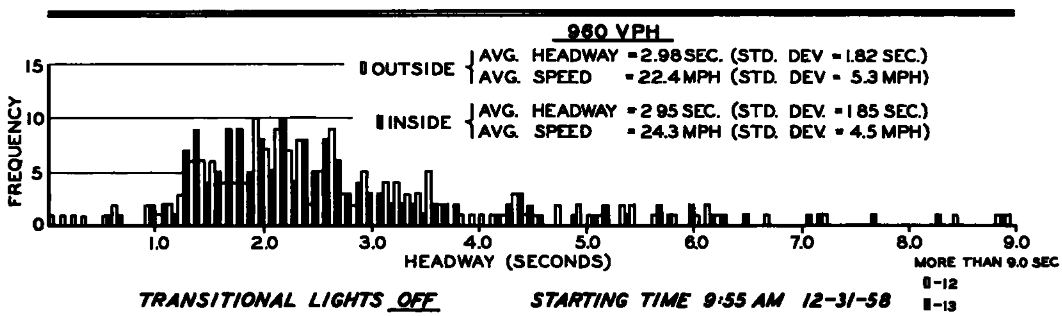


Figure 4. Headway frequency (high volume).

33.3 ft-L. Therefore, the outside to inside brightness ratio is:

$$\frac{220}{33.3} = 6.6:1$$

This is considerably less than 15 to 1.

The wall coverage when the transitional lights are on has an average of about 60 candlepower (c.p.) or 44.4 ft-L. Therefore, its ratio of outside to inside brightness is:

$$\frac{220}{44.4} = 5:1$$

This is also considerably less than 15 to 1 as suggested by the Illuminating Engineering Society.

This more than likely has a strong influence on why the speeds could not be proved significantly different when the lights were on from when they were off.

Limitations

A more comprehensive study of this nature would probably give more convincing re-

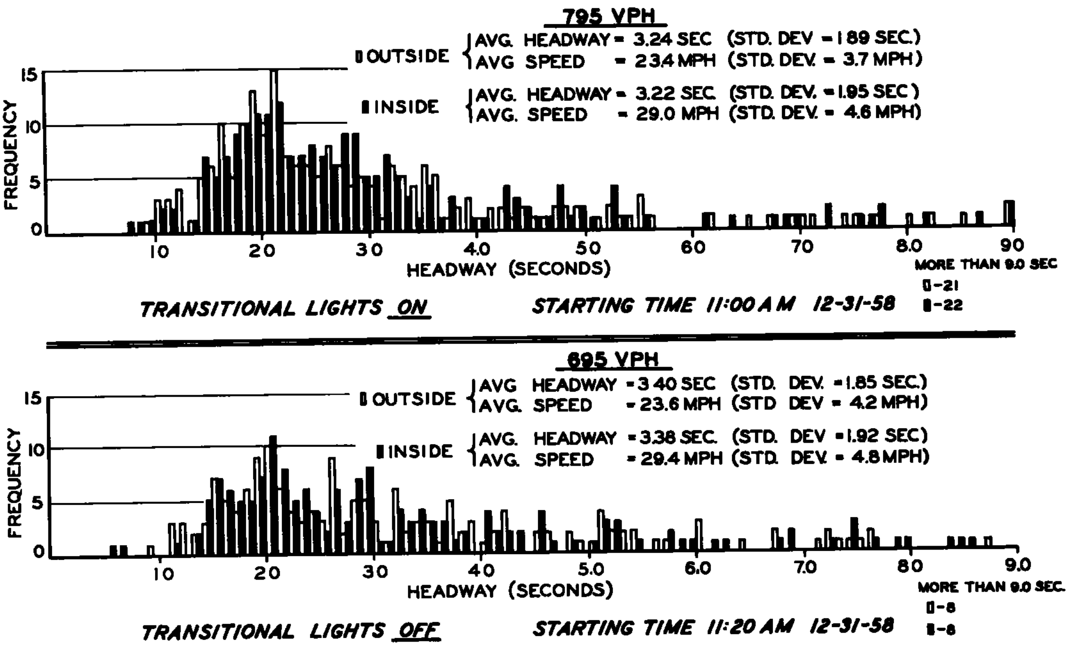


Figure 5. Headway frequency (low volume).

TABLE 4

HEADWAY DATA

Time A.M.	Lights	No. of Veh.	Outside Speed Measuring Zone: Mean Headway	Outside Speed Measuring Zone: Std. Dev.	Inside Speed Measuring Zone: Mean Headway	Inside Speed Measuring Zone: Std. Dev.
9:31-9:39	On	163	2.55	1.38	2.52	1.45
9:56-10:07	Off	167	2.98	1.82	2.95	1.85
11:00-11:17½	On	215	3.24	1.89	3.32	1.95
11:17½-11:30	Off	168	3.40	1.85	3.38	1.92

sults. If four or more speed measuring zones could be used with three of them within the tunnel, then it would be possible to determine if the lack of transitional lighting had its effect beyond the point where the one inside speed measuring zone in this study was located. The location of the one inside zone in this study was determined by the selection of a PIEV time and an eye adjustment time. As was previously discussed, there are differences in opinion among authorities in the field as to the absolute values of these time factors, but the one thought to most closely parallel this particular problem was chosen and used.

The manual activation of the micro-switches in connection with the productograph were adequate for the purposes of this study. However, if a more exact study is required as far as speeds and headways are concerned, it is suggested that a concealed ultrasonic detector or photoelectric cell be used.

CONCLUSIONS

Because the ramp leading to the mouth of the Holland Tunnel is in shadow even on the brightest days during the morning peak hours of the winter months, it is found that there is no uncomfortable glare in the driver's eyes. In addition, it was found that the shadows on this open cut ramp create an outside to inside brightness ratio of less than 15:1 whether the transitional lights are on or off. These factors indicate that the transitional lights should have no great degree of influence on the drivers' reaction to entering the tunnel due to a change in light intensity. The conclusion that is of most importance, and which is in full agreement with the foregoing indications, is that the speeds and headways could not be statistically proved as significantly different whether the vehicles entered the tunnel with the transitional lights on or with them off. Therefore, it can be said that the limited work of this study shows that in the winter months, when the ramp leading to the portal of the South Tube of the Holland Tunnel is in shadow on a relatively bright day, the 400-watt mercury-vapor transitional lights have no effect on the entering traffic.

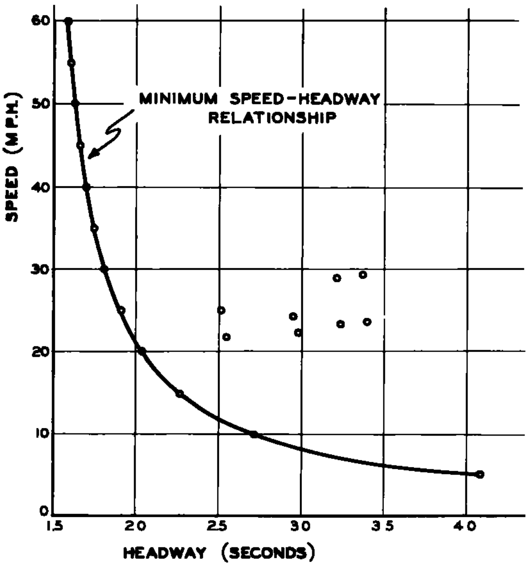


Figure 6. Speed vs headway.

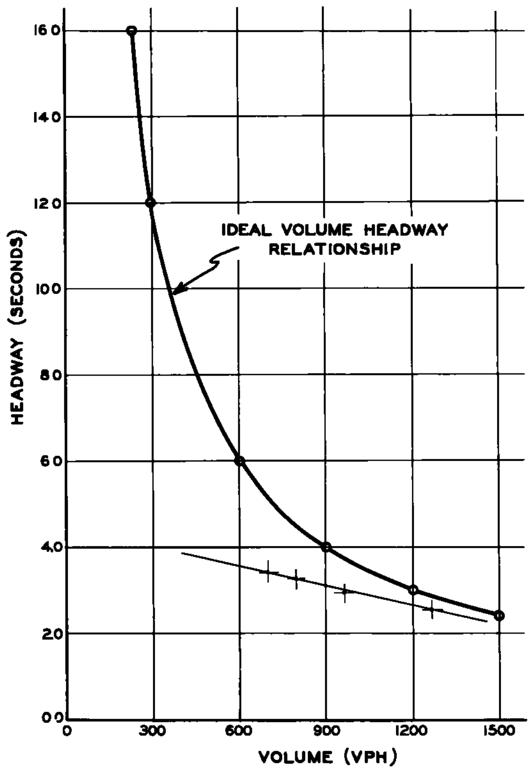
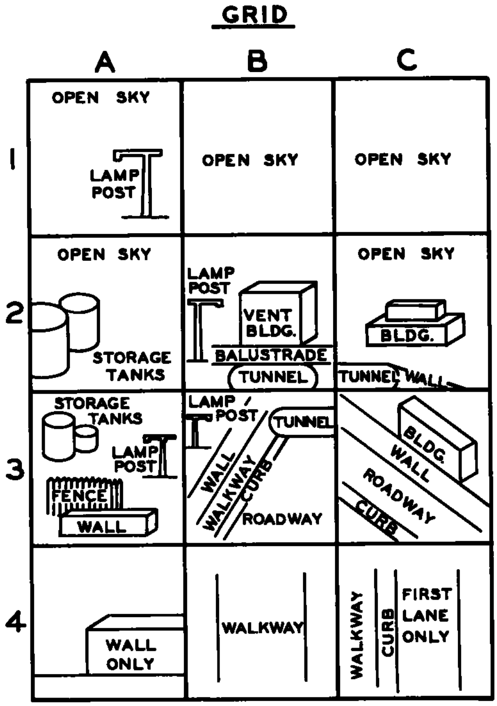


Figure 7. Volume vs headway.

RECOMMENDATIONS

The seriousness of the safety of tunnel users requires that the foregoing conclusions should be considered only as a guide toward a more comprehensive and inclusive research project to determine beyond all doubt that transitional lights have no effect under the stated conditions. If necessary, the outside to inside brightness ratio can be reduced by increased transitional lighting or possibly by shading the approach ramp to the tunnel or underpass. Economics, aesthetics and adaptability to the local surroundings would become the determining factors.



BRIGHTNESS CHART

POSITION ON GRID	BRIGHTNESS (FT. LAM.)
A1	3000
A2	2550
A3	1100
A4	160
B1	3200
B2	206
B3	217
B4	160
C1	3000
C2	121
C3	196
C4	186

Figure 8. Illuminometer grid.

REFERENCES

1. "Lighting Traffic Tunnels and Underpasses." Illum. Eng. Soc., New York, N.Y. (1957).
2. Brass, J.R., et al.,"A New Approach to Highway Tunnel Lighting." Reprint 25, p.3, Illum. Eng. Soc., New York (1956).
3. Matson, T.M., et al.,"Traffic Engineering." P. 21, McGraw-Hill (1955).
4. Lighthill, M.J., and Whitham, G.B., "On Kinematic Waves, II. A Theory of Traffic Flow on Long Crowded Roads." Proc. Royal Soc. (London), Series A, 229:1178, 317-345 (May 10, 1955).
5. Dixon, W.J., Massey, F.J., "Introduction to Statistical Analysis." Pp. 102-105 McGraw-Hill (1957).
6. Forbes, T.W., "Speed, Headway and Volume Relationships on a Freeway." Proc. Institute of Traffic Engineers, p. 103 (1951).