

Moving Vehicle Method of Estimating Traffic Volumes and Speeds¹

WILLIAM J. MORTIMER, Superintendent of Highways
Cook County, Illinois

The two most commonly used methods for obtaining traffic volumes are the machine count and the manual count at fixed locations or stations, and for a number of hours duration. These methods are expensive and time-consuming.

Many attempts have been made in the past to develop sampling techniques whereby the total volume of traffic could be estimated by sampling only a relatively small portion of the total traffic flow. One such technique was recently developed in England by Wardrop and Charlesworth and reported under "A Method of Estimating Speed and Flow of Traffic from a Moving Vehicle." The Cook County Highway Department investigated this technique to test its usefulness in this country, considering only the estimation of the flow of traffic.

If a large number of sections are to be sampled, with the idea of estimating the total combined volume of all sections, the method appears to be very useful, for while in any single section there may be a sizeable error, these errors appear to cancel out when sections are combined. If a fixed degree of precision is required on all sections, the sampling time will vary inversely with the volume in question.

It appears, at present, that for estimating total traffic volume flow or total vehicle miles driven, this method is the fastest and may well be the most economical. Studies are underway to compare the cost of this method with other known and accepted methods.

● **TECHNIQUES** in traffic engineering are constantly being improved. Each such improvement adds to the collection of tools for establishing sound highway programs. No new technique is of real value unless it features significant advantages over the old.

Traffic volumes for use in highway planning are obviously important. To realize such information quickly and economically is of equal importance.

The moving car method is offered as a means for estimating traffic volumes and speeds quickly, economically and accurately.

DESCRIPTION OF METHOD

The main objective of this study is to test the feasibility of a method of estimating traffic volumes on urban streets by use of extremely short counts taken from a moving vehicle. This study is an extension of work first done by John Wardrop and George Charlesworth and presented before the Institution of Civil Engineers, London, England.

The moving car method under study here, requires the use of a car, a driver, and one or more observers. The number of observers is dependent upon the details sought. In this study it was found that one observer was sufficient, as no breakdown of vehicular types was attempted. Figure 1 illustrates the method.

In this method, as the moving car unit "U" travels a sector of highway under study, the observer records the stop watch time required to drive the section, the vehicles "M" moving in the opposite direction and met by the moving car unit, the vehicles "O" overtaking the moving car unit, and the vehicles "P" passed by this moving car unit.

These observations are the basis for the estimates of traffic volumes and velocities of the highway section traversed.

FIELD TECHNIQUES

Included in this study were ten road sections described in the table entitled, "Description of Sections."

¹ Reproduced by permission from a copyrighted report of the Cook County (Ill.) Highway Department.

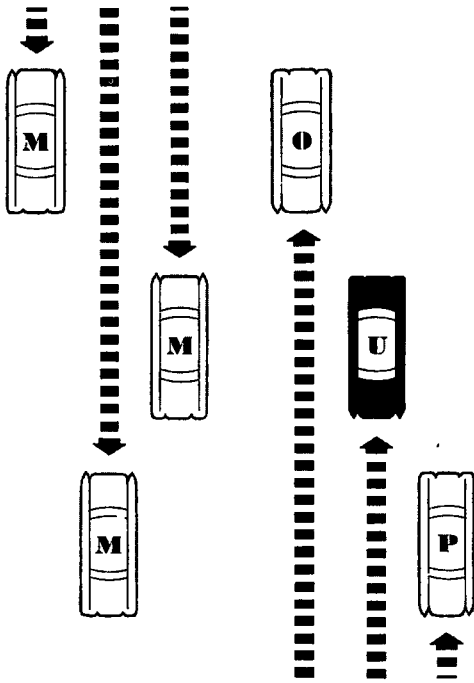


Figure 1.

The spatial relationships of the sections to one another are illustrated in Figure 2.

In selecting this network of sections, an attempt was made to include a variety of road types containing a significant difference in traffic volumes and land use.

Figure 2 shows all of the field elements required to conduct this study, namely study travel path, the relative paths of the two

DESCRIPTION OF SECTIONS						
	Length in Miles	Average Driving Time in Minutes	Average 5 Hour Volume	Land Use	Highway Type	Through Street (T) Not Through (N T)
①	33	12	2622	Residential	4 Lane Divided	T
②	30	11	3381	Residential	4 Lane Divided	T
③	50	12	3730	Residential	4 Lane Divided	T
④	85	19	6491	Business	4 Lane	T
⑤	50	14	261	Residential	2 Lane	N T
⑥	30	14	292	Residential	2 Lane	N T
⑦	50	14	2329	Residential & Business	2 Lane	T
⑧	50	12	2272	Residential & Business	4 Lane	T
⑨	50	12	2372	Residential & Business	4 Lane	T
⑩	33	14	297	Residential	2 Lane	N T

STUDY AREA DIAGRAM

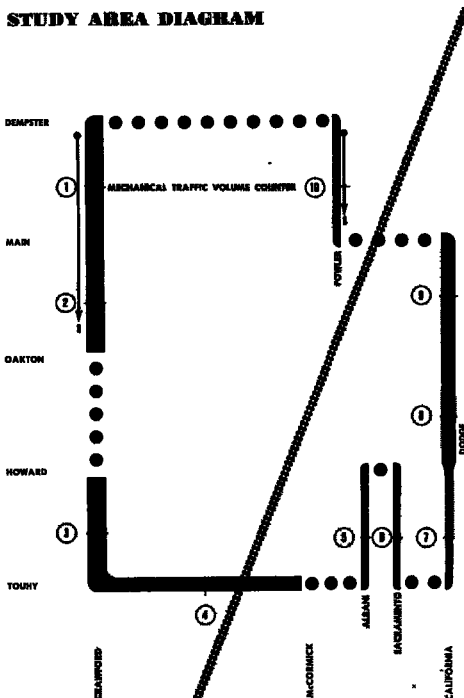


Figure 2.

COUNTY OF COOK

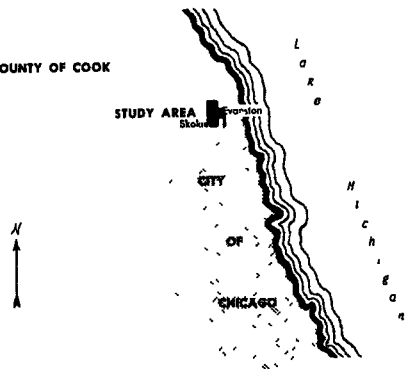


Figure 3. Area location map

vehicles used, and the location of the mechanical traffic volume counters. Speed meter locations used for this study are not shown in Figure 2. The paths of the two vehicles shown in Figure 2 were designed to reduce the errors which could arise from sampling uni-directional travel

Each car contained a driver and one recorder.² As the car entered a section, the recorder actuated the stop watch and began the count of: (1) the oncoming vehicles, (2) the vehicles overtaking the test car, and (3) the vehicles passed by the test car.

No special instructions were given the driver other than to observe traffic rules and regulations. At the end of the designated road section the observer ceases to count and records the totals on the data sheet as illustrated in Figure 4.

To avoid loss in vehicles counted, the counting was done from the center of the intersecting streets at each end of the section.

One of the sections, No. 4, contained a railroad crossing at grade. The recorders were instructed to keep the stop watch running while awaiting the crossing of trains and then to count the accumulated vehicles. Failure to keep time running would heavily bias the estimated volume if the accumulated cars were then counted.

During the test period, the mechanical traffic counting machines were maintained to an accuracy ± 3 percent by regularly scheduled fifteen minute manual counts. For each five hour test period there was a minimum of four such fifteen minute manual checks for each machine.

Each car starting at an opposite end of the test grid traveled through each of the ten sections nine times during each of the five test days. This resulted in 90 vehicle runs per section, or a total of 900 runs for the ten sections. These runs were made between the hours of 10:00 A. M. and 3:00 P. M. This period was selected on the hypothesis that traffic flow on urban streets during these off peak hours is uniform and distributed in time as the Poisson distribution.

The data obtained from the above described technique is sufficient for estimating both traffic volume and speed for the section.

USE OF POISSON DISTRIBUTION IN FUNCTIONAL TRAFFIC RELATIONSHIPS

The five hour period from 10:00 A. M. to 3:00 P. M. was chosen for this study, as previously stated, because the traffic flow in that period is generally quantitatively uniform. There is a direct relationship between these five hour traffic volumes and the total 24 hour volumes. In the study area these five off peak hour volumes were found to be approximately one fourth of the 24 hour totals. Expansion to 24 hour volumes on the basis of this relationship introduces additional random errors, so that for this study only the five hour estimates were used.

It seemed likely that the flow of traffic in this period was Poisson distributed so that the volume in any given sized time interval would have a mean and variance equal to $n t$

where

n = average volume per minute, and
 t = minutes of time interval.

This conformity to the Poisson distribution was tested for fifteen minute intervals by the use of Chi square: for each section the five hours were divided into twenty 15 minute periods, with mean equal to $\frac{5 \text{ hour volume}}{20}$; for each mean fifteen minute volume a Poisson series was determined; the observed frequencies were then paired with the expected Poisson frequencies and the value of Chi square determined. The results indicated quite conclusively that the hypothesis of Poisson distribution could reasonably be accepted.

It is desired to estimate the five hour volume from a sample of t minutes with n vehicles per minute. Under the Poisson assumption, the mean of the estimate will be $\frac{300}{t} (n t)$

² Two recorders were used in preliminary tests. One was found sufficient for the particular details desired.

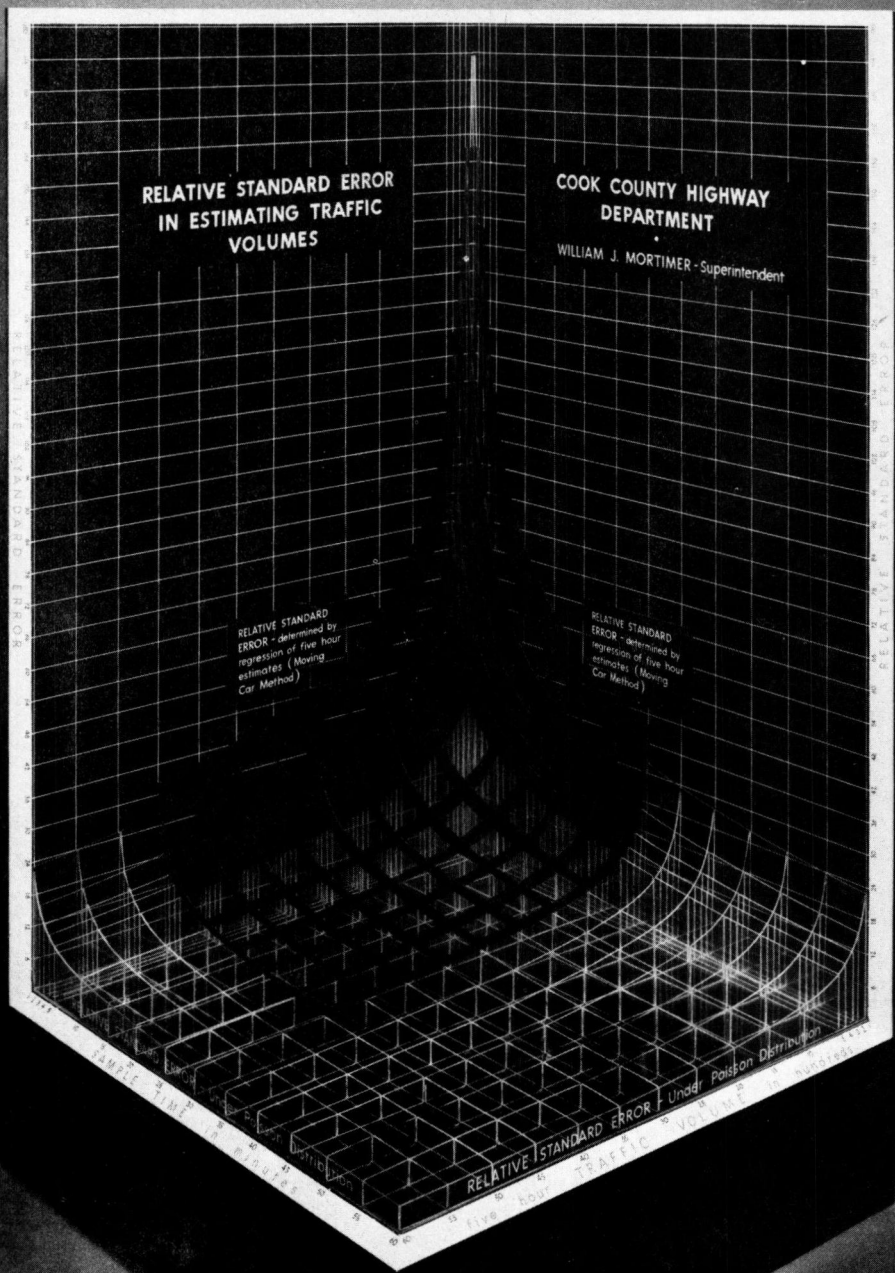


Figure 4.

and the variance $\frac{300^2}{t^2} (n t)$ or the standard error equal to $\frac{300}{t} \sqrt{n t}$, which reduces to $300 \sqrt{\frac{n}{t}}$. If it is necessary to study the ratio of the standard error to the 5 hour volume the standard error is divided by 300 n and the result is:

$$k = \frac{1}{\sqrt{n t}}$$

where $k = \frac{\text{standard error of the 5 hour estimate}}{\text{5 hour actual volume}}$

This k will be referred to as the relative standard error.

Since it is so often desirable to refer to the relative error, the above formula has been transposed in several ways so as to study:

1. Relative standard error as a function of volume and sample time, $k = \frac{1}{\sqrt{n t}}$
2. Volume necessary to achieve a given relative standard error in a given time, $n = \frac{1}{k^2 t}$ and,
3. Time required to achieve a relative standard error with a given volume, $t = \frac{1}{k^2 n}$.

Numerical Examples

1) If $n = 50$ or $300 n = 15,000$

and $t = 2$

$$\text{then } k = \frac{1}{\sqrt{50 \times 2}} = \frac{1}{10} = 10$$

2) If $k = 05$

and $t = 10$

$$\text{then } n = \frac{1}{0025 (10)} = \frac{1}{025} = 40$$

or $300 n = 12,000$

3) If $k = 075$

and $n = 15$ or $300 n = 4,500$

$$\text{then } t = \frac{1}{(005625) (15)} = \frac{1}{084375} = 11.85 \text{ minutes}$$

The family of curves titled "Poisson relationship of traffic volume and relative standard error to required sample time in estimating 5 hour volume" can be used to find the theoretical sampling time required when the 5 hour volume and relative standard error are specified.

These curves were used in the study of the moving car method and comparisons are made with this family of curves and those curves actually found in the study. These comparisons are discussed in the following section on analysis of field data.

It should be pointed out that these Poisson curves are not limited to use with the moving car method, but can be used with any sampling technique for this five hour period, or can easily be adjusted for use within any time period where traffic flow conforms to the Poisson distribution.

ANALYSIS AND INTERPRETATION OF FIELD DATA

Volumes

The field data were gathered over a five day period between the hours of 10:00 A. M. and 3:00 P. M. for each of 10 road sections. This gave a total of 18 runs per day for each of the ten sections, nine for each day for each direction. The estimates of five

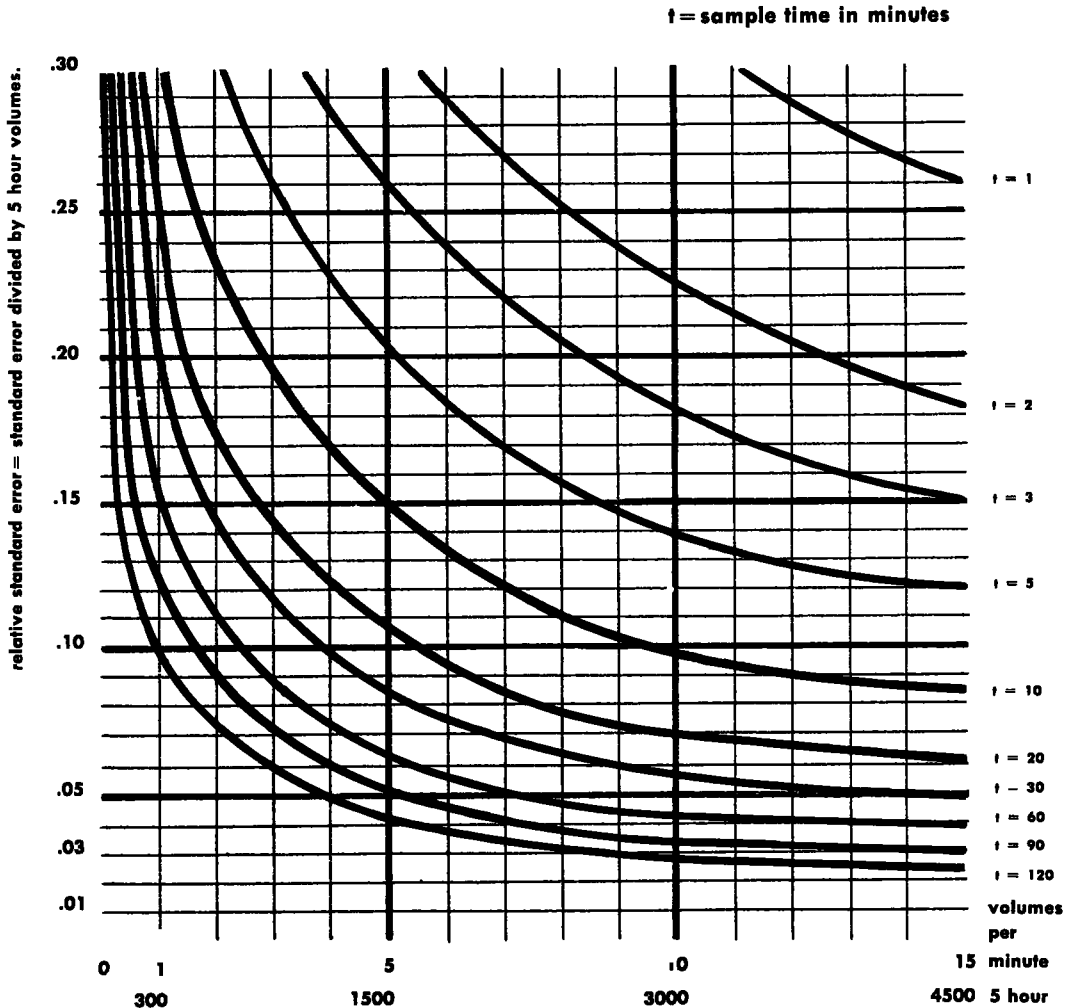


Figure 5. Poisson relationship of traffic volume and relative standard error to required sample time in estimating 5 hour volumes. (Sampling is done between 10.00 A.M. and 3.00 P.M.)

hour two directional volumes were obtained from the formula

$$V = 300 \frac{M + (O - P)}{t}$$

Where V = 5 hour estimated volume
 M = vehicles met from opposite direction
 O = vehicles overtaking the test car
 P = vehicles passed by the test car
 t = time of the run

If the directional flows for any given section are equal, then as little as one run in either direction can be used for estimating the desired volume. In the ten sections under study for the five off peak hours, the directional flows were found not to be significantly different. Application of the above formula to the data from one run in either direction was found to give an unbiased estimate of the five hour two directional volume. This obviously would not be true when the directional flows differed and if total two way volume were desired in such a case an equal number of runs would have to be made in each direction and the estimate made from the combined total. One directional flow can

DATA SHEET

RECORDER *Charles Kloppe*

DAY AND DATE *Monday 6/6/55*

SECTION *Crawford Ave., Rocky Hill, to Howard St.*

LENGTH *.50*

DIRECTION *North*

Time of Day	Time (Minutes & Seconds)	Vehicles Met from Opposite Direction	Vehicles Overtaking Test Car	Vehicles Passed by Test Car
10:21	0'59"	17	0	2
10:49	0'53"	12	0	0
11:18	0'58"	18	0	1
11:40	1'09"	10	0	0
12:45	0'57"	11	0	1
1:20	1'14"	10	1	1
1:47	1'00"	12	0	1
2:18	0'57"	10	0	0
2:42	0'57"	22	0	1

Figure 6. Three dimensional model portraying the functional relationship between relative standard error, sampling time, and five hour traffic volume.

also be studied, but this involves a slightly different formula (1).

Since it was found possible to obtain unbiased estimates from all volume classes under study, the bulk of the analysis centered around a study of the efficiency of the method under varying volumes and sample times. For each of the ten sections, random combinations were made of the eighteen daily observations, and for each such combination the five hour estimate was computed.

For each day's data the following combinations were used: (1) 18—1 run observations, (2) 9—2 run observations, (3) 6—3 run observations, (4) 3—6 run observations, (5) 2—9 run observations, and (6) 1—18 run observation.

For all such groupings, the means and standard errors were computed. From these, a study was made of the functional relationship between volume, sample time, and standard error. In no section were the means found to differ significantly between groupings.

The following set of graphs illustrates for each of the six time groups the limits of two standard errors around the line "estimated volume equals actual volume." The points plotted around the line show the relation of estimated volume to actual volume. Under an assumption of normality, the indicated limits can be taken as those between which about 95 percent of all estimates will fall.

This assumption is not strictly fulfilled when the number of samples is small, but the two indicated limits give the reader a rough idea of the range of the estimates under varying sample times.

The inner limits are the two standard error limits of the Poisson estimates and the outer limits (indicated by the shaded band) are the two standard error limits of the actual estimates. The discrepancies between the two sets of limits can most likely be explained in terms of random sampling errors.

These limits can be seen to decrease sharply as sample time is increased from 1.3 minutes in the first graph to 23.9 minutes in the sixth graph. For time equal 1.3 minutes the low volume sections (about 300 vehicles per 5 hour period) show standard errors upward of 100 percent while the larger volume sections (3,000 to 5,000 vehicles per 5 hour period) show standard errors of 50 to 60 percent. For time equal 23.9 minutes the low volume sections still show standard errors of 35 to 55 percent while the higher volume sections show standard errors of only 10 to 20 percent.

For the ten combined sections with a total volume of about 22,000 vehicles, the following table indicates for each of the given number of runs per section, the standard error of the sum of the estimated volumes and the proportion of the standard error to the actual total volume. This estimate of total volume would be of use mainly in determining total vehicle miles traveled.

Number of runs (R) per section and average total time (t) in minutes.

Total volume equals 22,000 vehicles.

R	1	2	3	6	9	18
t	13 4	26 4	39 7	79 8	119 4	239 1
Standard error of the sum of estimates	2813	1994	1661	1025	987	871
Relative standard error	128	091	075	047	045	040

It can be seen from studying this table that as the number of runs is increased from 6 to 18, the relative standard error diminishes very slowly. There is clearly some point beyond which the further reduction in error is not worth the added cost and time spent. This point would have to be determined in each case and would depend primarily upon the use to be made of the data.

Another set of graphs follows which shows relative standard error as a function of volume. The Poisson determined curve is also plotted so as to provide a direct comparison of actual relative standard error to expected Poisson relative standard error. The bounds of the Poisson determined expectancies are indicated by the single black line curve, and the bounds of the observations are shown by the extent of the shaded section.

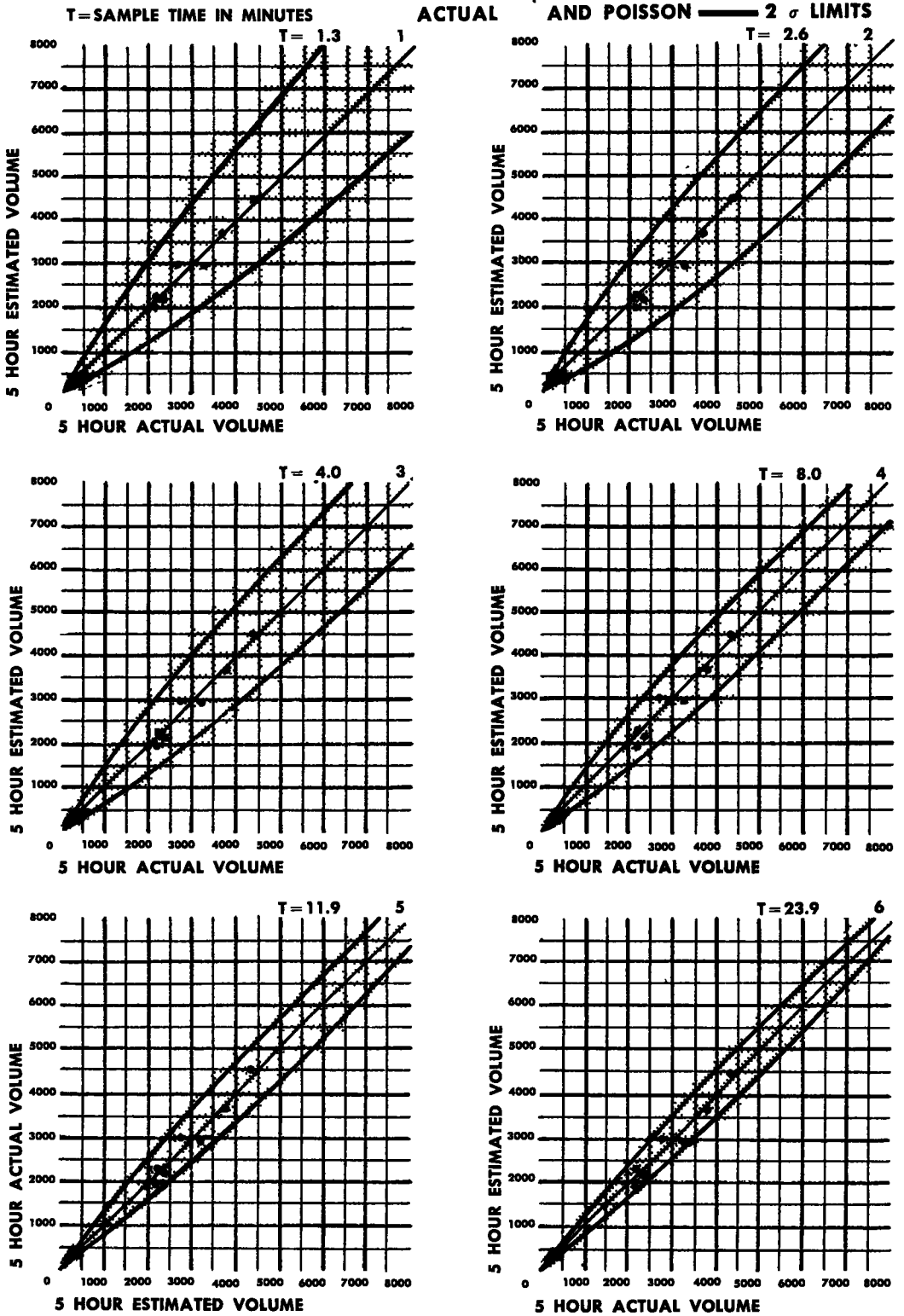


Figure 7.

ACTUAL RELATIVE σ

AND POISSON RELATIVE σ

AS A

FUNCTION OF 5 HOUR VOLUME

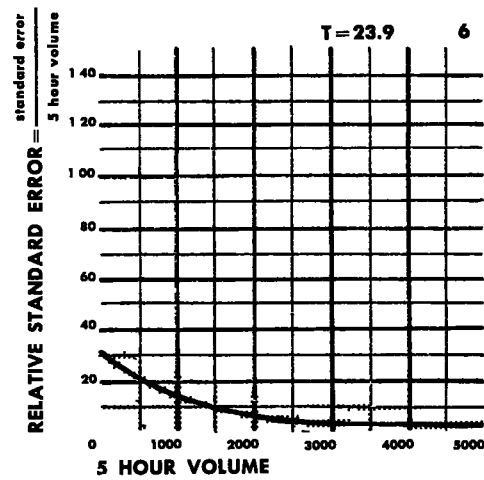
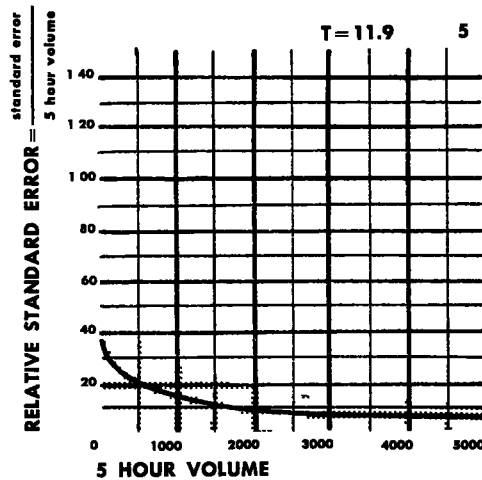
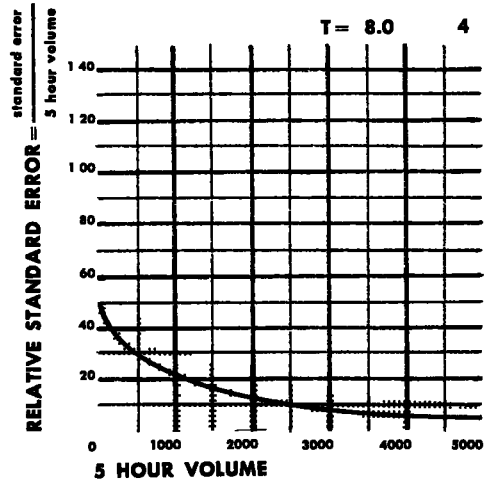
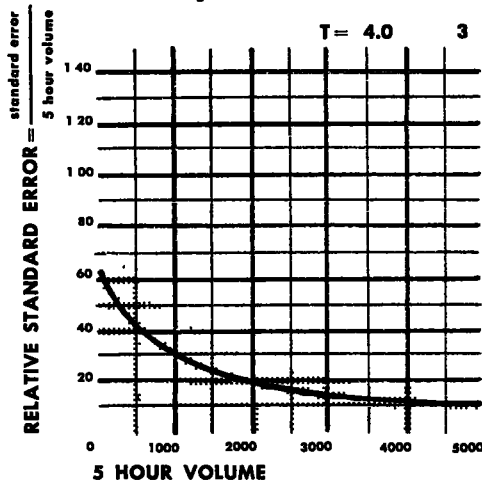
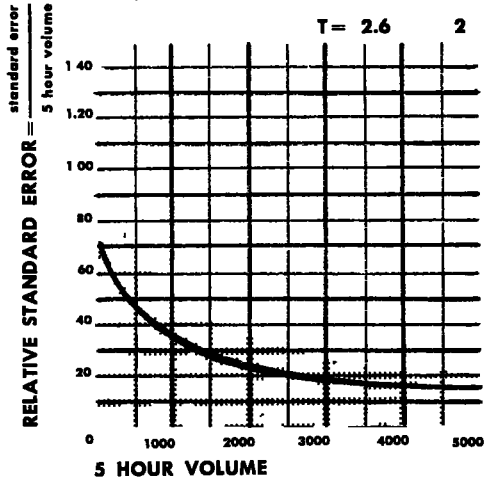
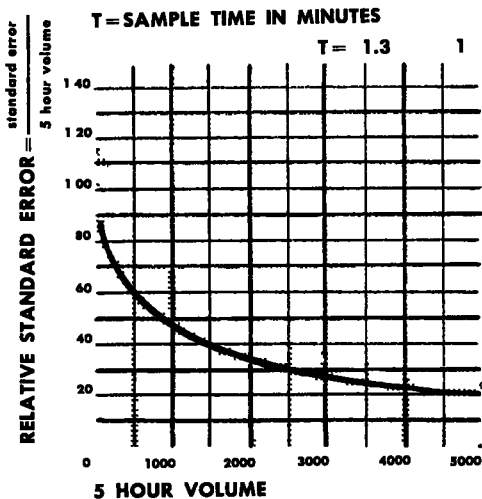


Figure 8.

A multiple regression study was done to predict standard error as a function of volume and sample time. The resulting formula is:

$$Y = 297.4 - 19.3 X_1 + 143 X_2$$

where Y = estimated standard error
 X_1 = sample time in minutes
 X_2 = 5 hour volume of section

The regression itself has a standard error of 186.2. The value of R^2 is 0.661 indicating that the regression accounts for about 66 percent of the total variation in standard error. Both regression coefficients were highly significant. Within a limited range this regression is a fair predictor.

A second regression study was done to predict standard error as a function of the Poisson determined standard error, $300 \sqrt{\frac{n}{t}}$.

The resulting equation was:

$$Y = 1.245 X - 4$$

where Y = estimated standard error
 X = Poisson determined standard error, $300 \sqrt{\frac{n}{t}}$

R^2 was found to be 0.912 indicating that about 91 percent of the variation in standard error can be accounted for by the regression. The standard error of estimate for the regression was 94.7 a significant reduction of the value found in the preceding regression.

The regression coefficient was found to be highly significant, but the constant, -4 , was found not to differ significantly from zero. The regression is a highly efficient predictor of standard error, which further substantiates the assumption of Poisson distribution.

Speeds

Suppose it is required to estimate the average speed of traffic for both directions on a given section of road. The average time required to drive through the section in each direction must first be computed. This is found to be:

$$t_T = t_1 + t_2 - \frac{(O_1 + O_2 - P_1 - P_2)}{V}$$

where t_T = driving time for a round trip
 t_1 = driving time for one direction
 t_2 = driving time for other direction
 O_1 & O_2 = vehicles overtaking test car while traveling in directions 1 and 2 respectively
 P_1 & P_2 = vehicles passed by test car while traveling in directions 1 and 2 respectively
 V = two directional estimate of traffic flow per minute

It is a simple matter to convert the driving time to speed. One directional speed can also be studied by use of this method (1), but for this study the uni-directional speeds were assumed equal. This assumption was tested over the ten sections under study and found acceptable.

The average speed of traffic for use as control was found by two methods: (1) the radar tested speed across a given point, and (2) the time required for a vehicle to travel the entire section as measured by standing observers at each end of the section, using synchronized stop watches. A 20 percent sample was taken and vehicle identification was accomplished by the license plate method.

The radar tested speed, as might be suspected, tended to be higher than the speed computed by the other method. Since the travel time for the section included stopping at the end of the section, the second method was used as the control.

The average actual speed for the ten sections was 27.4 mph and the average estimated speed 24.5 mph. The average error of estimate was -2.9 mph with standard deviation

equal to 1.8 mph. On the basis of these figures alone, the hypothesis of zero average error could not reasonably be rejected. However, in all ten sections, the estimated speed was found to be an underestimate of the control speed. A sign test would be highly significant and lead to the rejection of the hypothesis that the estimate was as likely to be above as below the control speed. For the ten sections under study, the latter test seems more indicative of the technique.

Referring to the formula for average time required to drive a round trip on the section,

$$t_r = t_1 + t_2 - \frac{(O_1 + O_2 - P_1 - P_2)}{V}$$

it is seen that if the test car drives the run at the average speed of all cars driving the run, then the only factor influencing the estimate of speed is the number of overtaking and passed vehicles. These are assumed to balance in the long run. However, in this study, there was a marked tendency for the number of vehicles passed by the test car to be greater than the number overtaking it. The explanation for this seems to lie in the nature of the road sections studied. In a residential, suburban, or business area, there is a tendency for vehicles to slow down to turn, park, etc. This tendency would increase the probability of the test car passing a vehicle and hence upset the balance assumed to exist between vehicles overtaking and vehicles passed by the test car. Where the number of passed vehicles is small relative to the estimated flow the effect of this imbalance may be negligible, but where it is large (especially noticeable on low volume sections) the effect is significant, and will produce an underestimate of speed as measured by the standing observers at each end of the section. It must be pointed out that only the through traffic passes both observers within a useful comparative time period so that the observer method almost certainly produces an overestimate of the true average speed of all traffic on the section. In any event, on high volume sections or on sections where turning and stopping are minimized, the moving car technique should give an unbiased estimate of speed.

APPLICATION

Volume counts on a street system are now secured by machine or manual counts. These existing methods require machines and manpower in various proportions. Any extensive counting program might require the use of a substantial number of men and machines not readily available.

The techniques presented in this paper will provide a method of volume counting which will require a bare minimum of manpower and equipment. It offers a means of securing economically and quickly a blanket volume count of all streets in a given area.

Such information as vehicle miles of travel on a road network, volumes over this road network, vehicle classifications and vehicular speeds may be realized from this technique.

Comparative operating time and cost of this method over current methods will vary with specific problems, but appears to be substantially lower in many cases.

For example, a one hundred mile network of roads could be covered once by this method in less than five hours with one car and two men.

For varying total volumes of a given network, the following table indicates the standard error expected in estimating the sum of the volumes of the individual sections. This is on the basis of one covering of the network:

Sum of the volumes of the individual $\frac{1}{2}$ mile sections	Expected Standard error	Relative Standard error
50,000	4,157	0.083
100,000	5,896	0.059
200,000	8,327	0.042
300,000	10,203	0.034
500,000	13,170	0.026
1,000,000	18,630	0.019

This table emphasizes the potential of the moving car method for blanketing road systems quickly, economically and accurately.

Three methods for obtaining total vehicle miles traveled were suggested in a previous paper (3). Each method is listed below along with the time required to obtain volume estimates for computing total vehicle miles traveled on a 100 mile network of roads (2 miles square with 25 x 25 grid of streets).

1. A six minute manual traffic count eight times a day in each block. Totaling 1,650 man hours.
2. A one hour manual count at every other intersection. Travel time plus 312 man hours.
3. Mechanical non-recording counts at approximately every five blocks. One hundred man hours plus 6,000 machine hours.

Assume that the individual sections have 5 hour volumes of 250 vehicles or a combined total of 50,000 vehicles for 200 one-half mile sections. Then the moving car method would require 11 runs or about 96 man hours to insure against errors exceeding ± 5 percent, but for errors ± 10 percent only three runs would be necessary, or a total of 26 man hours.

If the individual sections have as much as 2,500 vehicles per five hour interval, then one run or less than 9 man hours would insure against errors exceeding 5.2 percent.

SUMMARY

For the five off peak hours the hypothesis of Poisson distribution of traffic flow was found acceptable.

The moving car method was found to produce an unbiased estimate of the five hour bi-directional traffic volumes.

By regression analysis it was found that the standard error of the five hour estimated volume could be reasonably determined by the relationship

$$S. E. = 1.245 \text{ Poisson's } S. E. -4,$$

$$\text{where Poisson } S. E. = 300 \sqrt{\frac{n}{t}}$$

The standard error in estimating the five hour volume is sufficiently small in certain applications to consider the use of this method in preference to other existing methods.

Although it appears that an unbiased estimate of speed can be obtained from this method, the fact that the control speed tended to overestimate true speed points to the need for further study.

REFERENCES

1. A Method of Estimating Speed and Flow of Traffic from a Moving Vehicle, by J.G. Wardrop and G. Charlesworth, Institution of Civil Engineers, London, England.
2. Sampling Theory of Surveys with Applications, by Pandurang V. Sukhatme.
3. Highway Research Board Proceedings, 1950, p. 320.