Estimating Traffic Volumes by Systematic Sampling

THOMAS MURÁNYI, Chief Engineer, Institute of Traffic Engineering, Technical University, Stuttgart, West Germany

●THIS PAPER gives an account of the methods of statistical analysis from which conclusions of satisfactory accuracy relating to the annual average of daily traffic (ADT), and the duration and peak values of "critical hours," can be drawn.

The pattern of traffic fluctuations forms the basis of this method, the fluctuations being determined by means of the probability theory using the latest methods of mathematical statistics.

For a thorough knowledge of the traffic flow to be investigated it is necessary to describe the application of the traffic counting method. From data derived from surveys carried on throughout 5 years in Switzerland, and from the analyses of the results, the method of how to apply sampling to counts over the entire highway system of a country, could be established. In analysis of the results of these counts it was possible to establish the fact that the daily, weekly and monthly fluctuations in traffic flow are in accordance with mathematically determinable laws.

With the knowledge—itself obtained by sampling methods—of the factors by which the periodical fluctuations in the traffic flow are determined (κ- or ρ-curves) the ADT can be estimated economically and with sufficient accuracy from a "short count."

Not only can one obtain the ADT by means of the individual factors but, conversely, derive the amount of traffic of a random daily period on a random day of the year by means of the ADT with the aid of factors a, b, c. Furthermore, the frequency of heavy traffic hours during the year can be derived from the δ factors (Fig. 11 and 12), which indicate together with daily and monthly factors, the ratio of heavy traffic periods in daily traffic. It is these values then which make possible the stipulation of critical traffic. This is to say that the traffic volume of the thirtieth to fiftieth highest hour during the year, for which highway capacity should be designed, can also be estimated very well on various types of routes, by systematic counts requiring only a few hours, provided these are taken at the appropriate times.

NOMENCLATURE AND SYMBOLS

The symbols used throughout this paper are defined here for convenience of the reader as follows:

$n^{(x)}$ = number of traffic counts (sample counts) taken by systematic sampling for the duration of x hours; for example, $n^{(4)} = 2$ means that on the stretch of road in question two counts, each lasting four hours, were taken;

t_x = number of vehicles passing a control point during x hours; for example, $t_{14}^{(7-21)}$ means the number of vehicles proceeding in either direction which were included in the count between 7 a.m. and 9 p.m.;

t_{24} = full days traffic;

T_a = ADT, the annual average of the daily traffic volume on the section of road under investigation;

f = frequency (number of identical occurrences, identical traffic count values, etc.);

σ_D = standard deviation in the distribution of differences between means;

$s_{\bar{x}}$ = standard error of the arithmetic mean; $\pm ts_{\bar{x}}$ gives the two values (confidence limits) between which the true sample arithmetic mean will fall;

v = coefficient of variation (relation of standard error to the arithmetic mean expressed as a percentage);
P = probability factor of the error of estimation;
ϵ = margins of error of the sample, calculated by applying the theory of probability (a priori error);
e = empirically determined deviations of the sample averages from the results of actual counts (a posteriori error);
a_x = hourly factor; for example, $a_8^{(7-15)}$ means the quotient of the volume of traffic in both directions in 24 hours and the volume of traffic in both directions in the eight hours between 7 a.m. and 3 p.m.;
b_i = daily factor (where i=1, b_1=factor for Monday; where i=6, b_6= factor for Saturday); that is, the relation of daily traffic on a random weekday, i, and the average daily traffic relating to the week, T_w;
b_w = the arithmetic mean of the daily factor for the five working days, Monday through Friday;
T_w = average daily traffic relating to a week;
d_i = weekly factor; that is, the relation of average daily traffic based on one week, T_w, to the ADT, T_a;
r_i = relation between the separate values of the weekly factors for the first, second, third and fourth weeks and the corresponding monthly factor $r_i = \frac{d_i}{c_i}$ (where i = 1, the first week of the month is indicated; where i=4, the fourth week of the month is indicated);
c_i = monthly factor; that is, the relation of average daily traffic based on a month, to the ADT;
δ_p = the proportion of peak-hour traffic during the 24-hr span of daily traffic;
κ_x = kappa factor; that is, the relation between an x-hourly traffic amount on a random working day, and the ADT;
z_i = periodic factor (where i=1, the applicable period of the year, one month; i=3, 3-month period); the periodic factor shows the relation between the periodical and annual averages;
ρ_i = rho factor; that is, the relation between daily traffic amounts of a certain number of days within a definite counting period, to the ADT;
ω = a factor expressing the peak hourly traffic volume as a percentage of the ADT;
R = relation between peak hourly flows and ADT;
t_{max} = daily peak traffic, in vehicles per hour;
i_w = index, the peak traffic for work days expressed in percentage of ADT;
i_6 = index, the peak traffic for Saturdays expressed in percentage of ADT; and
i_7 = index, for calculation of Sunday traffic.

DETERMINATION OF THE ADT OF A RURAL HIGHWAY SYSTEM

By using the following typical characteristics of traffic fluctuations, an accurate figure for the annual average can be deduced.

Traffic Fluctuations During the 24 Hours of a Day

Practical execution of country-wide traffic surveys does not permit, however, a comprehensive study of the question as to what extent counts of varying duration permit of inferences regarding the volume of traffic during the 24 hours, and what margins of error must be reckoned with in making such inferences; or, in other words, to what extent the partial traffic covered during the period of the count may be regarded as a constant (stable) phase of daily traffic. The following data (indices of traffic fluctuations) are based on numerous traffic analyses and may therefore be regarded as characteristic for the variances of the different factors.

Table 1 gives the variance of the hourly factors. The figures in the first line give the volume of traffic counted during varying periods of time as percentages of the daily total. In the second line, the arithmetic means and the maximum extreme values of the hourly factors to be expected are given. The figures in the third line indicate the maximum systematic error of the factors expressed as a percentage of the factor in question. The regular pattern of relations between the daily total and the aforementioned stable strata in the daily flow of traffic enabled determination (within margin of error of 3 percent) of the volume of traffic during the 24 hours.

TABLE 1

VALUES OF THE HOURLY FACTORS AND THE MAXIMUM VARIANCES TO BE EXPECTED[1] (PROBABILITY LEVEL 5%)

Row	Length Time	Sample Counts			
		14 Hours	8 Hours	4 Hours	
		7 a.m. - 9 p.m.	7 a.m. - 3 p.m.	7 - 11 a.m.	2 - 6 p.m.
(1)	(2)	(3)	(4)	(5)	(6)
1	$100 \frac{t_x}{t_{24}}$	87.2%[2]	45.0%[2]	23.8%[2]	28.4%[2]
2[3]	$\bar{a}_x \pm 2 s_{\bar{x}}$	1.15 ± 0.02	2.22 ± 0.06	4.20 ± 0.24	3.52 ± 0.19
3	ϵ_{max}	± 1.7%	± 3.0%	± 5.7%	± 5.4%
4	e_{max}	± 3.0%	± 5.0%	± 12.0%	± 10.0%

[1]Swiss rural highways, 1953-1957.
[2]Percent of 24-hr volume.
[3]a_x = reciprocal of row 1.

The maximum error to be expected—empirically calculated for Swiss main highways—amounts to ± 5 percent in the case of 8-hr counts, and in the case of 4- to 8-hr counts it amounts to ± 12 percent (the figures in the last line).

A thorough analysis of the flow of traffic in time shows that the variable values of the hourly factors at different times of the years, are similar but not identical. Mathematically expressed, this means, that traffic and its various occurrences constitute a time-conditioned function. One result of the investigations of this function is shown in Figure 1.

From the marked characteristic of traffic as a "time-function," it follows that the annual average values of the various factors cannot be used for exact statistical estimates of traffic. On the contrary, traffic occurrences must always be regarded as time functions for the purpose of the determination and practical application of individual factors. From curve 1 in Figure 1 it can be seen that during the peak traffic of the summer months, night traffic also exceeds the annual average. The relations between the volumes of traffic during 8 or 4 and the 24 hours of the day disclose a similar pattern of behavior. The factor for the volume of traffic occuring during 8 hours of the day varies from month to month and also from day to day (curves 2 and 3).

Traffic Fluctuations During the 7 Days of a Week

The volume of traffic is by no means evenly distributed over the days of the week. It is mainly the needs of traffic on an average working day that is of importance in the solution of problems in urban areas. Yet many main rural routes are in considerably heavier use on Sundays during the 6 summer months than they are on working days. This phenomenon is demonstrated in Figure 2. On the other hand, counts for the determination of ADT are suitable only on working days. For this reason, it is desirable to know the distribution of traffic as to individual weekdays.

The daily fluctuation of traffic exhibits a high degree of regularity. Not only does the same proportion of weekly traffic occur regularly on the individual working days (Monday to Friday) on the same sections of the road network inside a closed area, but the "synchronous" pulsation is also recognizable in the weekend traffic.

The curves in Figure 3 show the changes in the so-called daily factor in the course

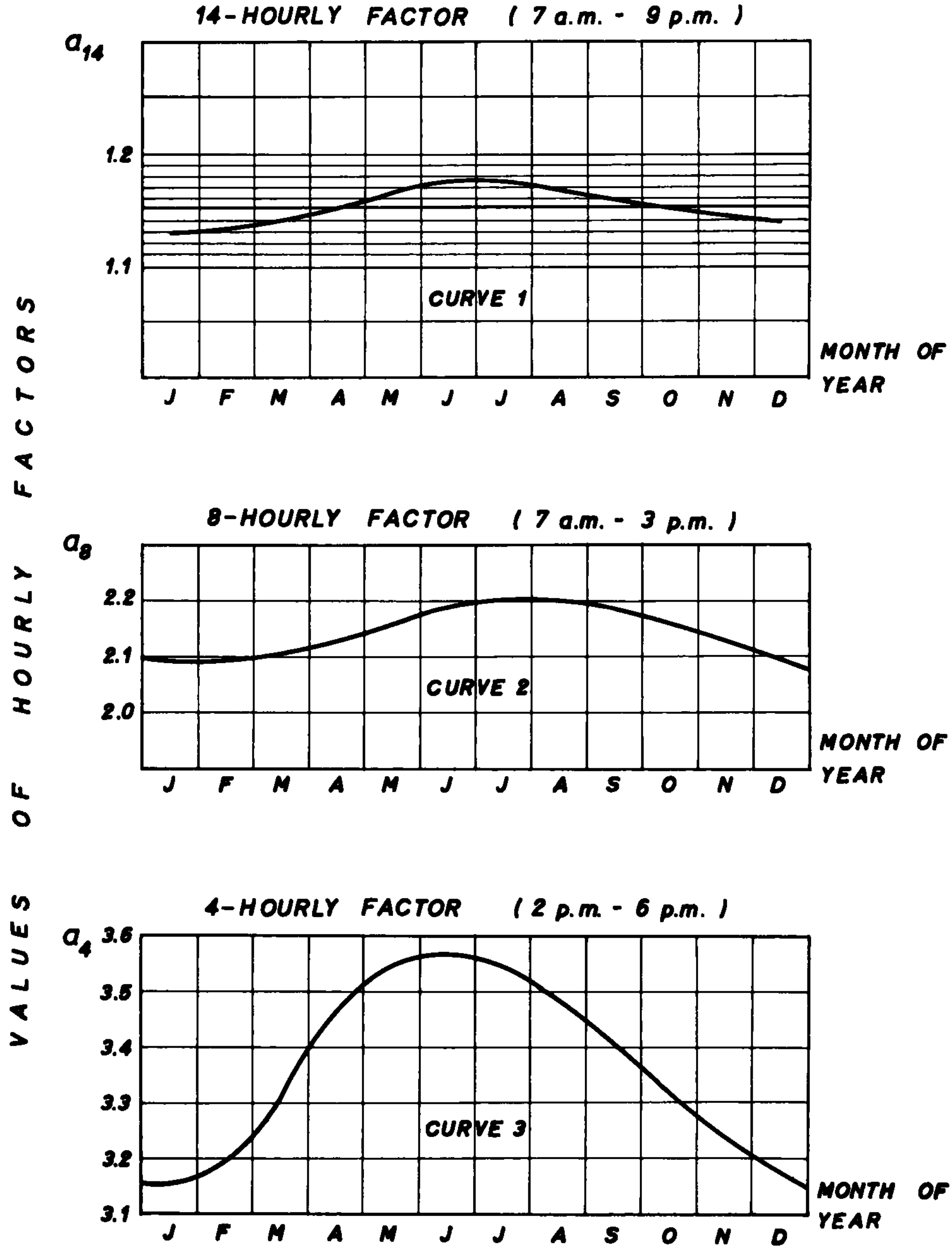


Figure 1. Seasonal fluctuations of hourly factors (Swiss rural highways, 1953-1955).

of the year. The graphs represent the smoothed curves of the factors. The flow of traffic does not exhibit the same degree of evenness on the different days of the week. Fluctuations are least marked in the middle of the week. The most favorable months of the year for traffic counts are indicated by the calculated margins of error for the daily factors.

A thorough analysis of the flow of traffic on the highway system in extensive areas (Switzerland and the Federal Republic of Germany) shows that the values of the daily factors are very stable; that is, that the validity (scope) of these factors, which reflect

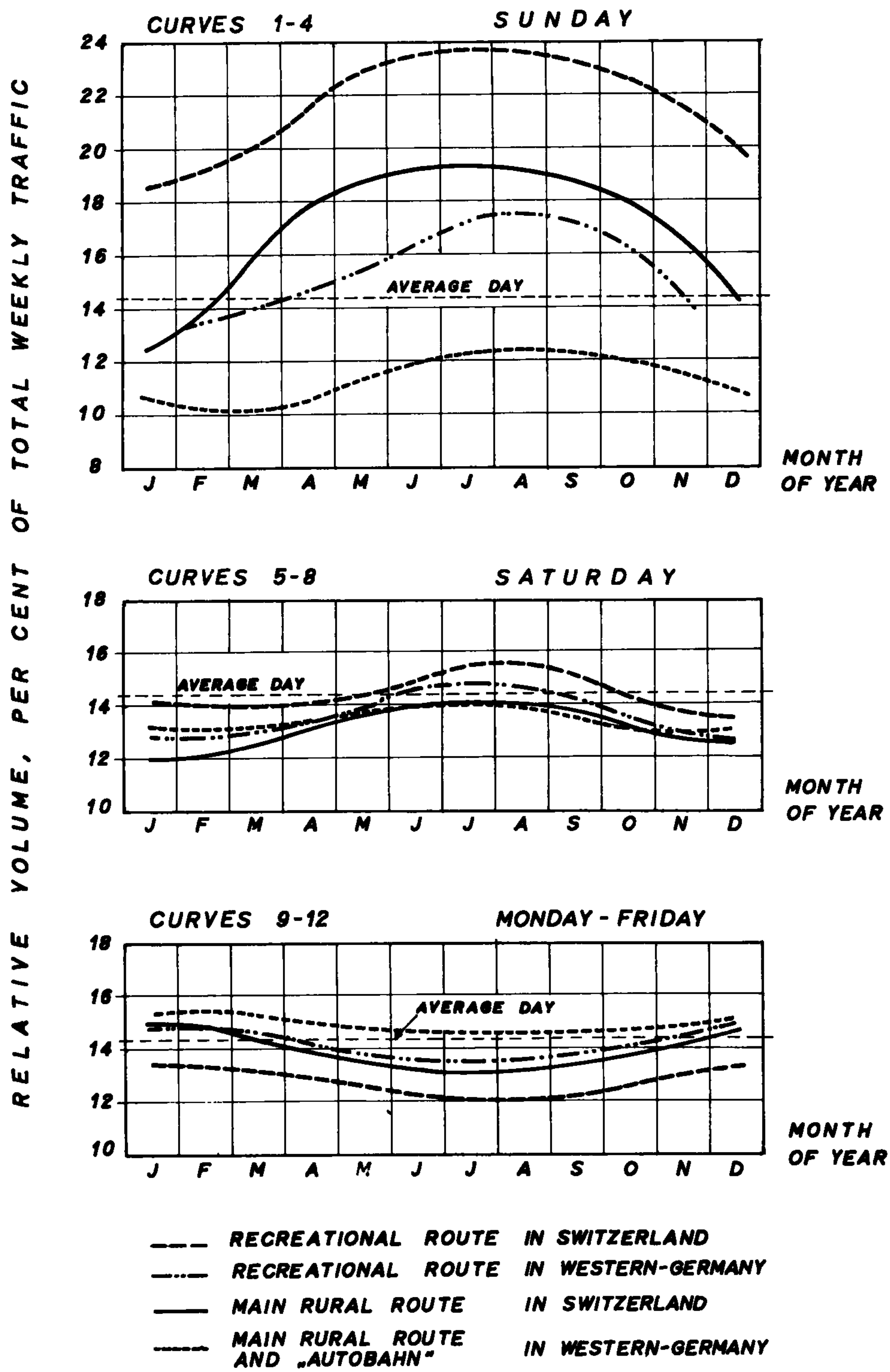


Figure 2. Weekly time patterns of traffic flow (Swiss rural highway system 1955 and rural highways in the Federal Republic of Germany, 1955-1958).

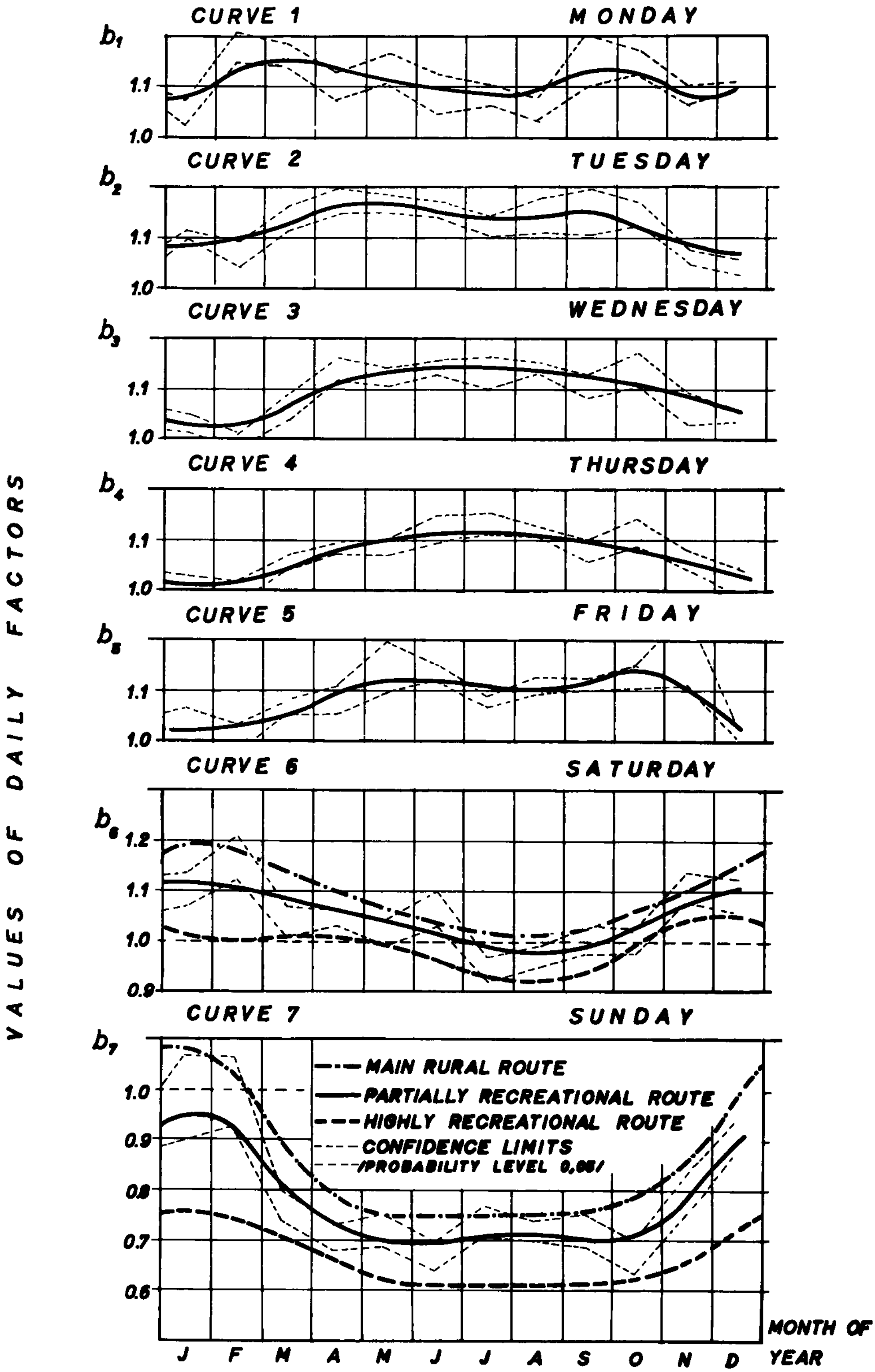


Figure 3. Seasonal fluctuation of daily factors (Swiss rural highways), 1955.

the fluctuations in road traffic, is characteristic for large areas of the country.

For the summer half of the year, the average standard error of the daily factor for the middle of the week is ± 3 percent. This means that on any Tuesday, Wednesday or Thursday during the months of May to October, all the Swiss main roads carry the same proportion of their weekly volume of traffic.

The daily factors of the five working days, Monday through Friday, are in themselves so similar that the application of the arithmetic mean of the 5 daily factors (b_w) is sufficiently accurate for an estimate of the ADT during the week (T_w). On the other hand, the factors of different road types deviate from one another. This is the result of relatively heavy Sunday traffic on a recreational route. This phenomenon is explained in the curves of Figure 2 where the characteristic weekly time patterns of traffic flow on the Swiss main highways and on the federal arterial highways of Western Germany (Bundesautobahnen) are represented.

Provided the weekly average is accurately ascertained, these curves may easily be applied. By means of the curves (Figures 1 and 3) the appropriate weekly average can be calculated from the results of the counts during x hours of the day, as follows:

$$T_w = a_x b_i t_x \text{ (veh/24 hours)} \tag{1}$$

in which

a_x = the hourly factor;
b_i = the daily factor; and
t_x = the observed number of vehicles on the counting day.

Traffic Fluctuations During the 52 Weeks of the Year

The weekly fluctuations in traffic were, as a third point of reference, offering the most appropriate basis for the calculation of the ADT. A careful traffic analysis showed that the weekly fluctuations in road traffic are also strictly in accordance with ascertainable patterns of behavior.

The indices of these fluctuations, the so-called weekly factors, d, show the relations between the weekly, T_w, and annual average, T_a, (see curve 5, Fig. 4). The relations between the montly and annual averages of daily traffic are given for each week of the months. Curves 1 - 4 in Figure 4 show that the volume of traffic varies from week to week within the month. During the months of October to June particularly, the fluctuations from week to week are so great that during this period they are out of proportion to their arithmetic mean, or, in other words, to the so-called monthly factor (curve 6, Fig. 4). Because, however, the monthly factors represent the average fluctuations of traffic from month to month, the ADT worked out from random counts during this period contains substantial errors.

A better estimate of the flow of traffic can be obtained by calculating the relation, r_i, between the separate values of the curves for the first, second, third and fourth weeks (see curves 1 - 4, Fig. 4) and the corresponding monthly factors, c_i. For the six summer months, for example, the average standard error of the weekly factors ($d_i = r_i c_i$) is ± 2.6 percent.

Practical Application of the Sampling Method

From the foregoing description it can be seen that the following correlations must be taken into account in calculating the annual averages for all sections in a given region:

$$T_a = a_x b_i r_i c_i t_x \tag{2}$$

By means of a_x the 24-hr value for the daily volume of traffic from the results of counting during x hours of the day is obtained. The weekly average is calculated from the daily factor, b_i. The corresponding monthly traffic volume can be obtained from factor, r_i, from which, by applying the monthly factor, c_i, the annual average, T_a, can be computed.

The seasonal fluctuations in traffic are sensitive to local conditions. Examples in Switzerland and in the Federal Republic of Germany prove that differences in traffic

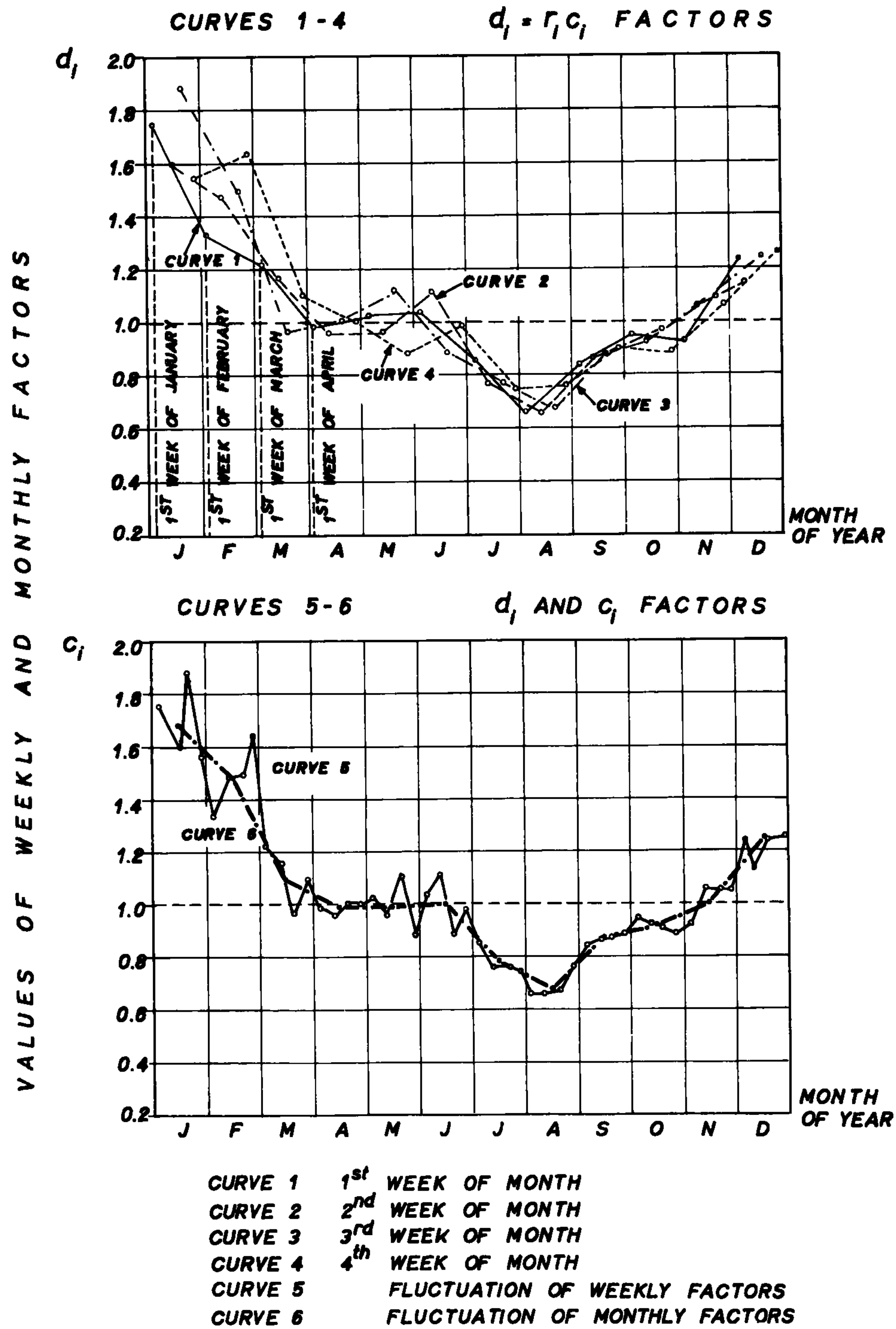


Figure 4. Seasonal fluctuations of weekly and monthly factors (roads in the Midlands and Jura Mountains, Switzerland, 1955).

flow are primarily conditioned by the variable characteristics of rural highways. To make possible an a priori definition of deviational road sections, the ADT values derived from Eq. 2 and sorted out according to sections were examined and carefully analyzed, while the individual months of count were treated separately. This analysis of distribution of error shows that in Europe, for instance, the peak traffic of summer recreational activities does not spread itself proportionately over the entire road network; that is, the laws of traffic flow are disturbed during these months (July-September). Time, relative size and duration of summer recreational traffic is highly dependent on locale.

Figure 5 shows two typical kinds of Swiss recreational routes. The roads of the Engadin have a relatively short (mid-June to mid-September) but very distinct traffic peak, while the roads along the Lake of Geneva carry over 150 percent of the traffic load during the Sundays from mid-March to mid-November. The curves of Figure 5 show the distinct time patterns of traffic flow as to Sundays and typical working days.

To be able to establish the influences of time and place in summer peak traffic, the laws of traffic flow on secondary rural routes were examined separately and the variable fluctuations in recreational and business traffic were found as well. In this way there developed generally four types of rural roads: (a) highly recreational route, (b) partially recreational route, (c) main rural route, and (d) secondary rural route. (These terms are used in accordance with T. M. Matson, W. S. Smith, F. W. Hurd: Traffic Engineering 1955, in the interest of more universal understanding.)

In dealing with European road conditions, it became necessary, additionally, to establish for some of the aforementioned road types, distinct laws as to two- and three-lane highways and multi-lane arterial highways with full control of access. As a result of the special topographical and settlement conditions of Switzerland, the entire highway network of a closed area is made up of one of the aforementioned types. Correspondingly, the three types of main roads represent—in Switzerland—three traffic regions:

1. Highly recreational routes = approaches to the Alps;
2. Partially recreational routes = roads along the Lake of Geneva; and
3. Main rural routes = roads in the Midlands and Jura-Mountains.

As the Alpine Massif of Southern Switzerland is completely shut off from the north during some months of the year, traffic conditions of this region, roads in the Tessin and the road network in the Engadin, deviate from the road type: highly recreational route.

Within these regions all the factors, including the monthly factor necessary for calculating the annual average, are constant.

In Eq. 2 some of the factors—a_x, r_i and c_i—are constant within the calendar week. The changes within the week are indicated by the daily factor, b_i. If the products of the foregoing factors are designated by k, and $b_i k = \kappa_i$, the equation for determining the annual daily average takes the following form:

$$T_a = \kappa_i \, t_x \text{ (veh/24 hours)} \tag{3}$$

in which

$$i = 1, \; kb_1 = \kappa_1 \text{ for Mondays; and}$$
$$i = 5, \; kb_5 = \kappa_5 \text{ for Fridays.}$$

In practice, the κ_1 - κ_5-curves for 5 different days (Monday to Friday) are worked out and expressed in the form of graphs. As the values of daily factors b_1 - b_5 do not differ much, an application of the average value of the daily factor of working days, b_w, may be made in most cases.

Figure 6 shows the average values of three κ-curves for working days. The graphs correspond to the area north of the Alps. By means of these κ-curves, the ADT on any section of this main highway system can be calculated directly from the count taken on any particular working day. Curve 3 gives the corrections for the 14-hr counts between the hours of 7 a.m. - 9 p.m., while curves 1 and 2 give the κ-factors for 8-hr counts (7 a.m. - 3 p. m.) and for 4-hr counts (2 - 6 p.m.). Appendix A shows the method of these calculations.

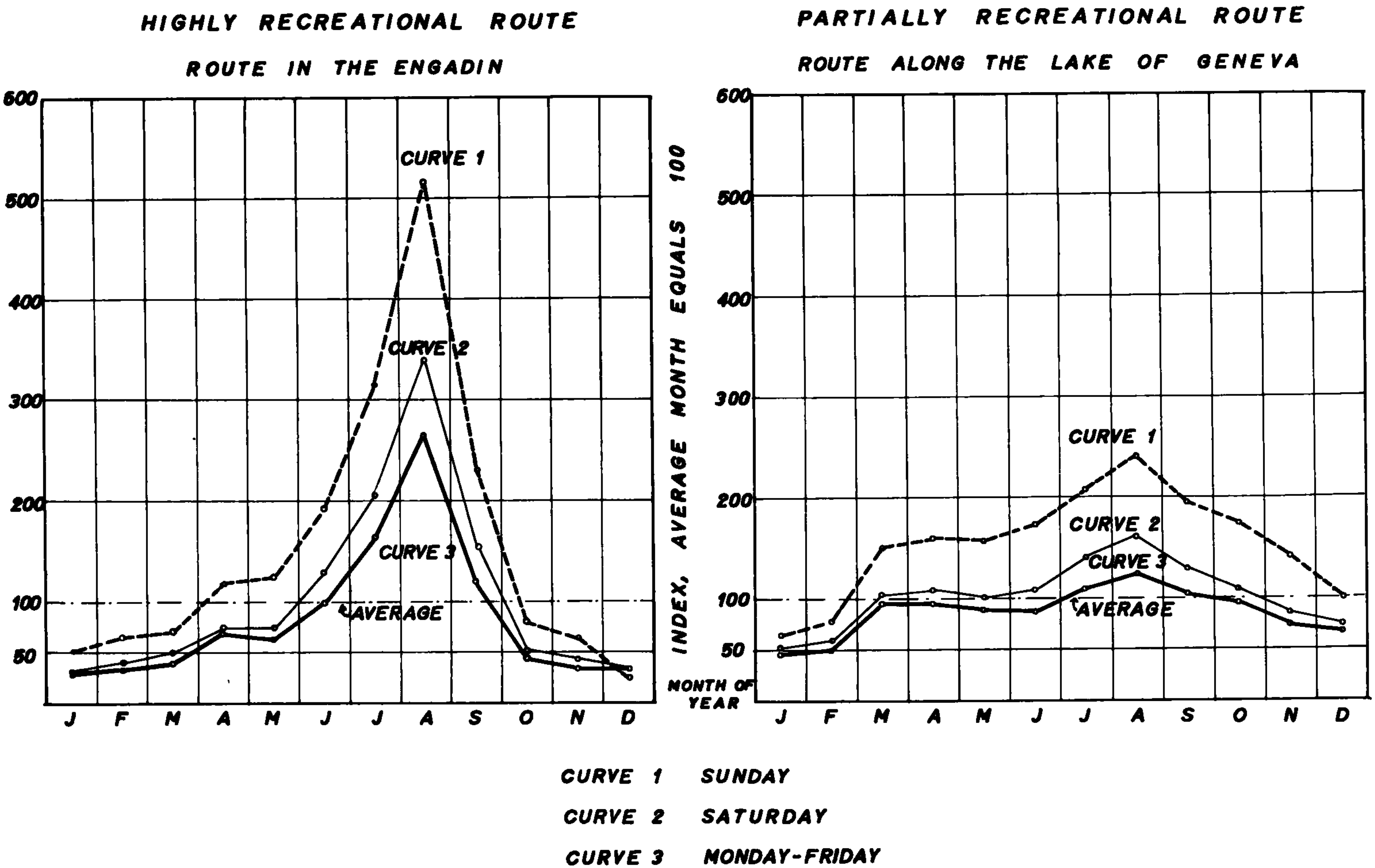


Figure 5. Monthly time patterns of traffic flow (Swiss rural highways, 1955).

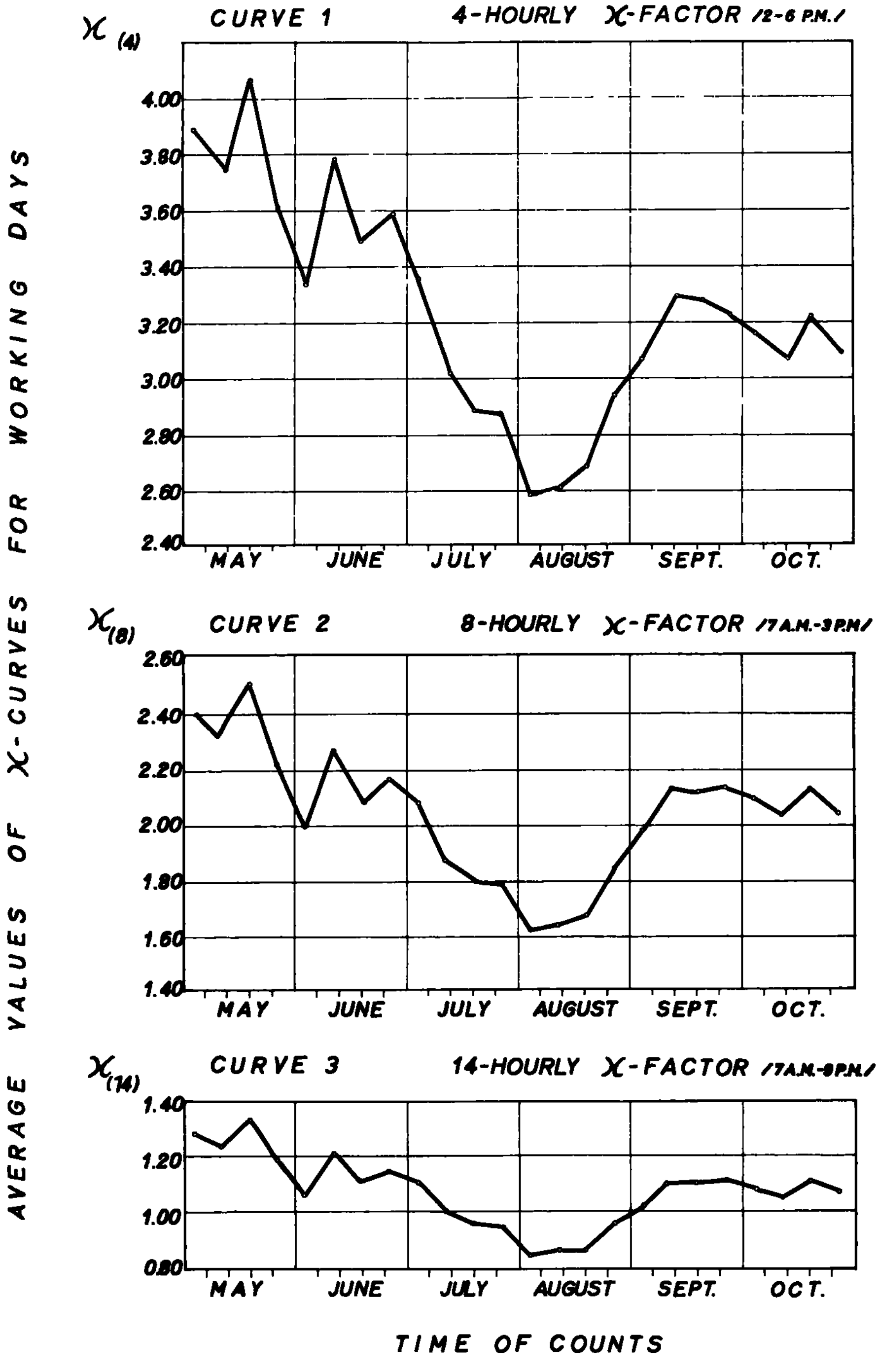


Figure 6. κ_x-curves (roads in the Midlands and Jura Mountains, Switzerland, 1955).

The Constant-Periods Method (the ρ-curves)

As has been explained, it is necessary for a thorough knowledge of the phenomenon of traffic to establish a number of κ-curves within the census year. However, even in highly developed countries those adequate traffic analyses of rural highway traffic are generally lacking which are essential to a determination of κ-factors. The method to be explained eliminates these deficiencies through a statement of relationships which enable a definition of ADT by means of universally valid factors.

The traffic analysis shows that in all the countries there exist one or more "neutral periods," which must be established during the period when the network presents the same relative traffic load of the yearly volume. The time and duration of these periods and also the magnitude of the factors for these periods are primarily dependent on the movements of the population in connection with their daily work and other occasions, and only to a lesser degree on the size and other local characteristics of an area. So long as these conditions do not change, all the characteristics of the "neutral periods" also remain constant. The marked regional and other differences in traffic fluctuation are evened out. During the neutral periods, mountain roads, roads running along valleys, roads with heavy commercial traffic, roads with local traffic and roads with highly recreational traffic carry the same relative proportion of the ADT.

The Three-Month Period.—During this period the proportion of traffic is constant, not being subject to the familiar periodic fluctuations. Consequently, the ρ_3 factor of this period is valid for every section of the highway network, and therefore an accurate determination of the daily average traffic volume by means of samples during this period could be very simple.

In Switzerland and in the Federal Republic of Germany as well, the three-month period lasts from May to July. During these three months approximately 30 percent of the total annual volume of traffic occurrences is observable throughout the rural highway system (see Col. 1, Table 2). This ratio of yearly traffic is the same in different years (1953-1957).

Table 2 gives the results of the permanent counts which were made by means of automatic machines during the 5 years, 1953-1957, in the neighborhood of Geneva, Lausanne, Berne, Basle, Zurich and St. Moritz, and which served to determine the factor governing these periodic fluctuations.

Col. 1 of Table 2 gives the values of T_i; that is, the volume of traffic occurring during the months of May to July, inclusive, expressed as a percentage of the annual total. Col. 2 gives 100/12; that is, the monthly values of the periodic factors. Col. 3 gives the frequencies for the class intervals at the 29 control stations and Col. 4 requires no further explanation. From this result the periodic factor can be calculated to be

$$z_3 = \frac{8.050}{29} = 0.278 \qquad (4)$$

Further simplification is possible if the values of 3-month factors lie approximately in a straight line. If the average value of the monthly factor for May is $\bar{c}_5$, for June

TABLE 2

ANALYSIS OF THE z_3-PERIODIC FACTOR[1]

T_i(%)	$z_3 = \frac{100}{12} \frac{1}{T_i}$	f	(z_3) f
(1)	(2)	(3)	(4)
33.3	0.250	2	0.500
32.0	0.260	6	1.560
30.8	0.270	4	1.080
29.7	0.280	8	2.240
28.8	0.290	3	0.870
27.8	0.300	6	1.800
30.0	$n_0 = (f) =$	29	8.050

[1]Swiss rural highways, 1953-1957.

is $\bar{c}_6$, and for July is $\bar{c}_7$,

$$z_3 = \frac{1}{\frac{1}{c_5} + \frac{1}{c_6} + \frac{1}{c_7}} \tag{5}$$

For Western Germany the values of these monthly factors are as follows:

(a) for partially recreational routes: $\bar{c}_5$=1.02; $\bar{c}_6$=0.84; and $\bar{c}_7$=0.81, resulting in

$$z_3' = \frac{1}{0.98+1.19+1.24} = \frac{1}{3.41} = 0.294 \tag{6}$$

(b) for rural main roads: $\bar{c}_5$=1.04; $\bar{c}_6$=0.85 and $\bar{c}_7$=0.89, and the periodic factor

$$z_3'' = \frac{1}{0.96+1.18+1.12} = 0.306 \tag{7}$$

Factors of Eqs. 6 and 7 show only a $\pm$ 2 percent deviation, which confirms the universal validity of the factor

$$\bar{z}_3 = 0.300 \tag{8}$$

When this method is used, a counting day must be selected in every month of the period. The results of these three counts must then be corrected by means of the appropriate aforementioned daily factor (see Fig. 3). The final form of the periodic factor is indicated by

$$\rho_3 = \bar{z}_3 b_i \tag{9}$$

If the material available for determining the annual average consists of the results of counts taken for only x hours of the day, the factor must be calculated by

$$\rho_3^{(x)} = a_x\ \rho_3 = a_x b_i \bar{z}_3 \tag{10}$$

The different ρ_3 values according to Eqs. 9 and 10 must be worked out beforehand as appropriate for individual counting days.

Figure 7 shows the average values of the ρ_3-curves for working days, Monday to Friday. Curve 1 gives the corrections for the 24-hr counts (ρ_3-curves), whereas curve 2 gives the factors for 14-hr counts (ρ_3-curves), etc.

The method of calculating the annual average is illustrated by means of a numerical example from Table 3.

TABLE 3

COMPUTATION OF AVERAGE ANNUAL DAILY TRAFFIC OBTAINED BY MEANS OF ρ_3-CURVES

Day of Count	t_{24}	$\rho_3^{(24)}$	$t_{24}\rho_3^{(24)}$
(1)	(2)	(3)	(4)
Tuesday, May 10	1,585 veh/24 hr	0.345	547
Tuesday, June 7	1,515 veh/24 hr	0.335	507
Thursday, July 14	1,973 veh/24 hr	0.325	641
	(ADT) $T_a = \Sigma t_{24}\rho_3$ =		1,695 veh/24 hr

Note: Permanent counting station: Carrouge, Route No. 1, Berne-Lausanne Counts made by the Union Suisse des Professionnels de la Route, 1955.

In Table 3, Col. 1 shows the exact dates of the individual counting day; Col. 2 gives the results of the counts; Col. 3 gives the $\rho_3^{(24)}$-values taken from Figure 7; and the values in Col. 4 represents the product of Columns 2 and 3.

The ρ_3-values for the network of the Federal Republic of Germany were arrived at

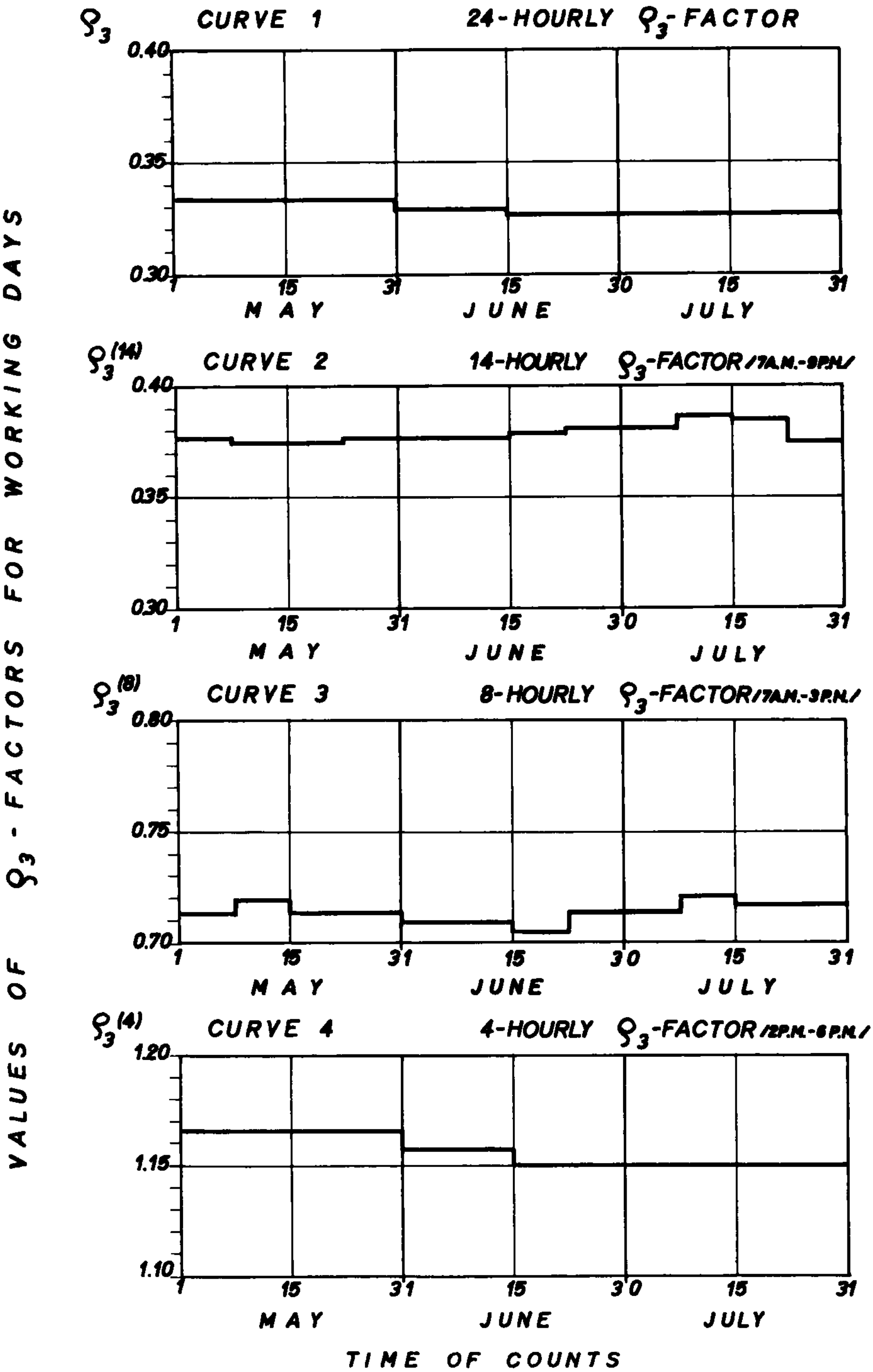


Figure 7. ρ_3-curves (Swiss rural highways, 1955).

according to Eq. 5. In this process, only the average of daily factors of the working days, b_W, were applied instead of b_i. As can be gathered from curves 9-12 of Figure 2, the value of b_W during the 3 months (May-July) remains constant. The average value of ρ_3, arrived at from Eq. 6 for partially recreational routes, represents

$$\bar{\rho}_3' = 0.304$$

and for rural main roads

$$\bar{\rho}_3'' = 0.295$$

In the calculations for the entire road sections of the Federal Republic of Germany only a single factor $\bar{\rho}_3 = 0.3$ was applied, with the computation of the ADT following the simplified Eq. 11

$$T_a = \rho_3 (q_5 + q_6 + q_7) = 0.3 (q_5 + q_6 + q_7) \tag{11}$$

in which

q_5 = traffic volume of a working day in May (v/24 h),
q_6 = traffic volume of a working day in June (v/24 h), and
q_7 = traffic volume of a working day in July (v/24 h)

The reliability of the average, obtained by ρ-curves, was checked empirically. The results obtained during the United Nations Traffic Census in 1955, were used as a basis for testing the validity of the method.

Figure 8 shows the tested road sections of the Federal Republic of Germany. ADT values of 462 different control periods were computed. Average deviation of these calculated values from the census value, T_O, amounted to $\pm$ 6.2 percent. As is seen from the chart, the error did not exceed the value of $\pm$ 10 percent in 90 percent of the control points. Results of research in Switzerland were still better where b_i daily factors were considered with regard to day of count instead of using the average b_W values.

For a counting time of 3 x 14 = 42 hours, the average error was $\pm$ 4.9 percent (see curve 1, Fig. 9). Some of the results of this empirical test are given in Appendix B. The results of a 3 x 8 = 24-hr count displayed an average error of not more than $\pm$ 5.9 percent (see curve 2, Fig. 9) and by use of $\rho_3^{(4)}$-curves (3 x 4 = 12-hr count) the value of the error does not exceed $\pm$ 15 percent (curve 3).

The "Neutral" Month.—This procedure is based on a shorter period of the year containing a constant proportion of the total annual traffic flow. This "synchronous" pulsation is particularly noticeable during June. During this one month, it is observable throughout the rural highway system of Switzerland and in Western Germany that approximately the same percentage of the total annual volume of traffic occurs.

TABLE 4

VALUES OF THE WEEKLY FACTORS IN JUNE AND THE MAXIMUM VARIANCES TO BE EXPECTED[1]

Row	Time of Counts	Weekly Factors: Mean, $\bar{d}_{(i)}$	Weekly Factors: Limits, $\bar{d}_{(i)} \pm 2s_{\bar{x}}$	Standard Deviation, ρ_D
(1)	(2)	(3)	(4)	(5)
1	1st week of June	0.842	0.81 - 0.87	0.055
2	2nd week of June	0.974	0.95 - 1.00	0.045
3	3rd week of June	0.906	0.88 - 0.93	0.045
4	4th week of June	0.879	0.86 - 0.90	0.032
5	The monthly factor $\bar{c}_6$ =	0.882	-	-

[1]Level of significance 0.05. Swiss Rural Highways, 1955.

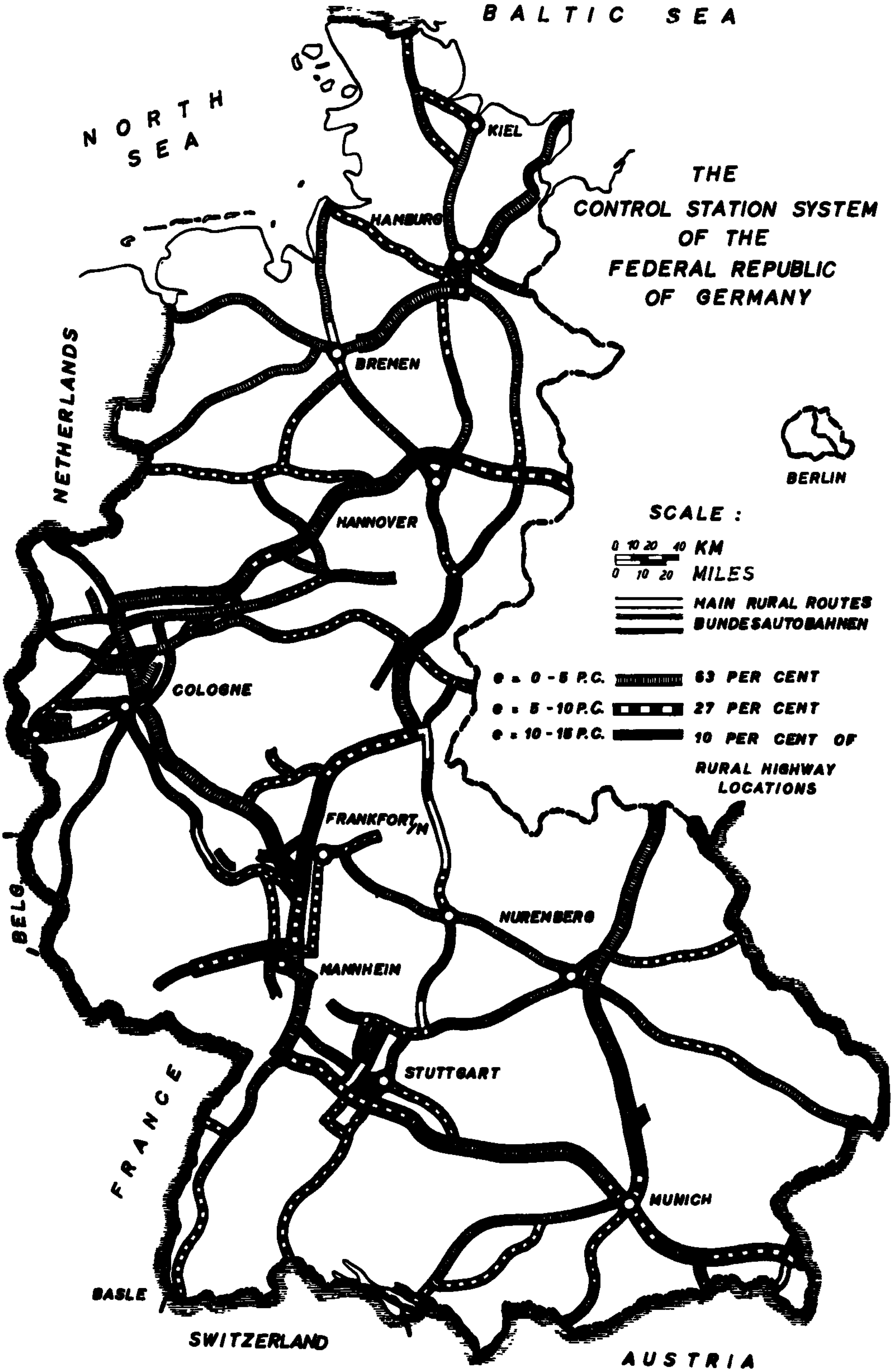
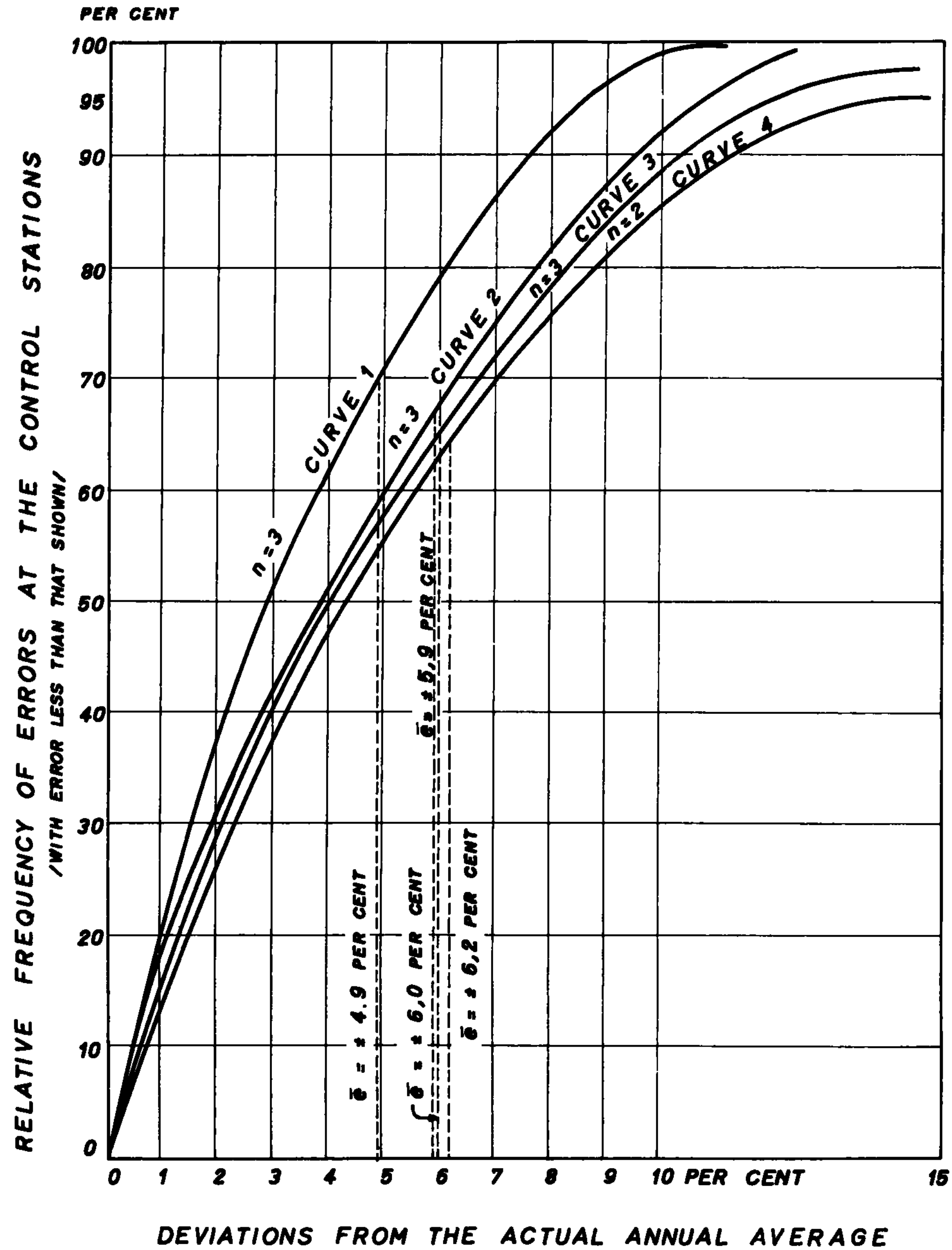


Figure 8. Empirical checking of errors in the ADT obtained by means of ρ_3- curves (main European international arteries in the Federal Republic of Germany, 1955-1958).



DURATION OF COUNT:

CURVE 1 $3 \times 14 = 42$ HOURS ($\rho_3^{(14)}$ - CURVES)

CURVE 2 $3 \times 8 = 24$ HOURS ($\rho_3^{(8)}$ - CURVES)

CURVE 3 $3 \times 4 = 12$ HOURS ($\rho_3^{(4)}$ - CURVES)

CURVE 4 $2 \times 4 = 8$ HOURS ($\rho_1^{(4)}$ - CURVES)

n = NUMBER OF TRAFFIC COUNTS

Figure 9. Empirical checking of errors in the ADT obtained by means of ρ-curves (Swiss rural highway system, counts made by Union Suisse des Professionnels de la Route, 1955).

Table 4 provides an example of the method used to examine the distribution pattern of this traffic phenomenon. In Table 4 the numerical values in Cols. 1, 2 and 5 require no explanation; Col. 3 gives the factors showing the relations between the weekly (for the first, second, third and fourth weeks) and annual averages. Col. 4 gives the maximum margins of error of the individual factors, as calculated from the results obtained from 15 continuous-count stations, indicating the degree of accuracy of the arithmetic means. The maximum error of these factors, calculated for Swiss rural highways, and expressed as a percentage of the $\bar{d}_i$ factor (with a probability of P = 95 percent), amounts to only $\pm$ 2.6 percent. These margins of error mean that the variances of these $\bar{d}_i$ weekly factors exceed the maximum deviation of $\pm$ 2.6 percent in only 5 out of every 100 repeated counts.

In dealing with the daily factor, it was also discovered that samples taken during the middle of the week provide the most reliable data for statistical estimates. When such data are used, the process of statistical induction is attended by the smallest margin of error. The average value of the daily factor in the month of June, for counting days Tuesday-Thursday, calculated for Swiss rural highways, is

$$\bar{b}_W = 1.137 = \text{constant} \tag{12}$$

The final factor indicated by the Greek letter ρ_1, must be calculated according to

$$\rho_1^{(x)} = 1.137\ d_i \tag{13}$$

The method of calculating the annual daily average is similar, as in the case of the κ-curves (Eq. 2). Substituting the value of ρ_1, derived from Eq. 13 into Eq. 2:

$$T_a \text{ (veh/24 h)} = a_x\ \rho_1^{(x)} t_x \text{ (veh/x hours)} \tag{14}$$

The different ρ_1-curves were worked out in the years from 1953 to 1957. From these data it was also possible to determine the average value of the curves. In Switzerland the values of the various ρ_1-curves remained practically unchanged between 1953 and 1957.

Figure 10 shows the values of these $\rho_1^{(x)}$-curves for counting days Tuesday to Thursday in the month of June. Curve 4 relates to 24-hr counts and their annual averages. Provided the duration of the count, x, and the number of counting days, n, are judiciously selected, very advantageous margins of error can also be achieved for "short counts" (see curves 1-3). Even though a reduction of the duration of the individual counts results in an increase in the systematic error of the ρ_1-curves, the decisive random errors can be reduced by making a greater number of counts (n = 3), so that in the final analysis the relative margins of error turn out to be very favorable.

For a counting time of 2 x 4 = 8 hours ($\rho_1^{(4)}$-curves), the average error was $\pm$6.2 percent, the maximum error of the results was $\pm$15 percent. Curve 4 in Figure 9 shows the distribution of error of the annual averages of daily traffic as calculated from 4-hr counts (n = 2).

By means of the data (see figures in the last line of Appendix C) it is possible to determine the number of counts which are required in order to remain within the margins of error prescribed for such surveys.

The applicability of the ρ_1 method was tested for the main European international arteries in the Federal Republic of Germany as well. The average value of the monthly factor amounts to $\bar{c}_6$ = 0.84 (average value of the years 1955-1958); here a strong similarity to Swiss conditions is found. In Switzerland $\bar{c}_6$ = 0.88 (see col. 3, Table 4). The expected error amounted to $\pm$7.6 percent. The distribution of error in the road network of Figure 8 is as follows when applying a single ρ_1 factor: 47 percent of the control points tested show an error of $e<5$ percent; 33 percent of the control points tested show an error of e = 5-10 percent; 13 percent of the control points tested show an error of e = 10-15 percent; and 7 percent of the control points tested show an error of $e>15$ percent.

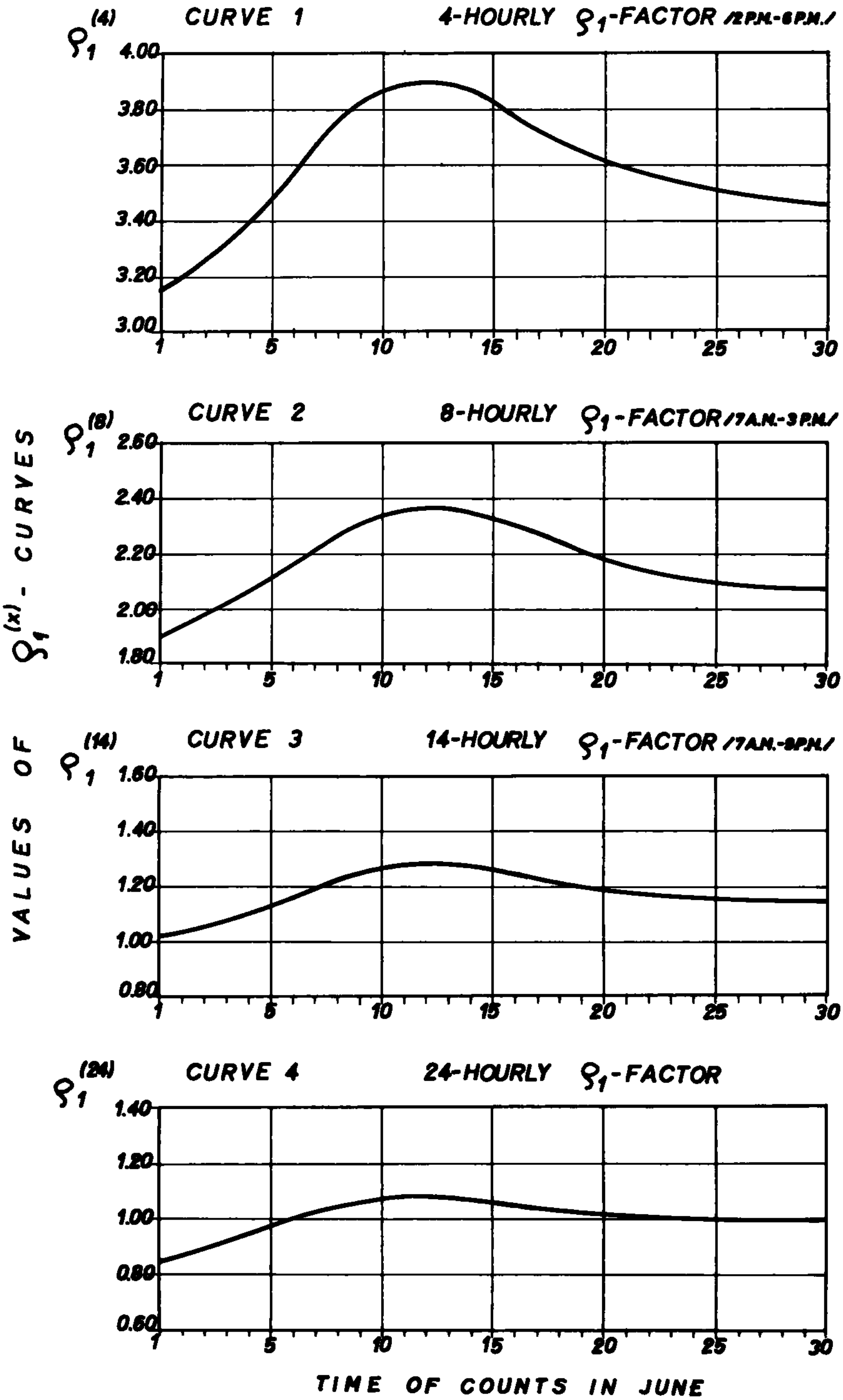


Figure 10. ρ_1-curves (Swiss rural highway system, 1953-1955).

DETERMINATION OF THE PEAK ANNUAL HOURLY TRAFFIC VOLUME

The significance of traffic peaks is so decisive for the dimensioning of roads that the laws governing changes in peak traffic must be examined separately along with a rational explanation of these phenomena. Even though some very broad investigations in this field have already been made in the United States, a new method for the determination of critical volumes during peak periods in Europe has become essential because there are not a sufficient number of permanent continuous-count stations which in the States serve as a basis for study.

The following demonstrates how it is possible without the aid of automatic permanent counts to determine reliably the relation between peak-hour flows and the ADT on the various road types of rural highways by means of the factors discussed in the first part of this paper.

Traffic During the Highest Hours of the Day

The factors (a, b, c) served primarily to obtain ADT with more rationality and greater reliability than heretofore. As an additional important criterion of traffic, that portion represented by peak-hour traffic was examined. To obtain a uniform picture, all data are shown in percentages of the 24-hr traffic on the day of count. The ratio of peak-hour traffic (t_{max} in veh/h) to 24-hr traffic (t_{24} in veh/24 h), expressed in percentages, is

$$\delta_p = 100 \frac{t_{max}}{t_{24}} \tag{15}$$

In addition to peak-hour traffic, the ratios of 2nd, 3rd.... 12th highest hours of 24-hr traffic on all of the road categories of rural highways were examined as well. The analysis of traffic counts for the criteria of hourly traffic flow occurred for both directions. Examinations were carried out separately for each month to test the validity of the data arrived at. Figure 11 contains the results of research as to peak-hour traffic on the rural highways of Switzerland.

Curves 1-3 show the δ-values derived from sample counts and their frequency. The most important results of these tests are as follows:

1. The values of daily peaks are relatively higher on Sundays and holidays than on other days of the week (see curve 1, Fig. 11). Even though the distribution of these relative peaks is greater on Sundays than on other weekdays, their maximum value exceeds

$$\delta_{max} = 13 \text{ percent} \tag{16}$$

only 5 times out of 100.

2. Peak-hour traffic on Saturdays (see curve 2, Fig. 11) is somewhat more marked than on working days.

3. δ_p is generally not subject to seasonal fluctuations. This relative value of daily peak traffic is neither smaller during winter nor larger during height-of-season summer traffic than is its average value.

4. On varying roads (recreational routes, main rural routes, etc.), δ_p merely indicates random changes. This proves that the δ_p factor of working days as well as that of Sundays and holidays may be regarded as a constant factor for the entire road network

$$\delta_p = \text{constant} \tag{17}$$

5. Similar regularity may also be observed for second-third, etc., highest hourly volumes of the day.

Curves in Figure 12 show the ratios of the second to 12th highest hours of the day expressed in percentages of peak traffic. Curve 1 represents two- and three-lane rural main roads in Switzerland. The traffic flow on the same type of road is quite similar in the Federal Republic of Germany. The Bundesautobahnen of Germany are

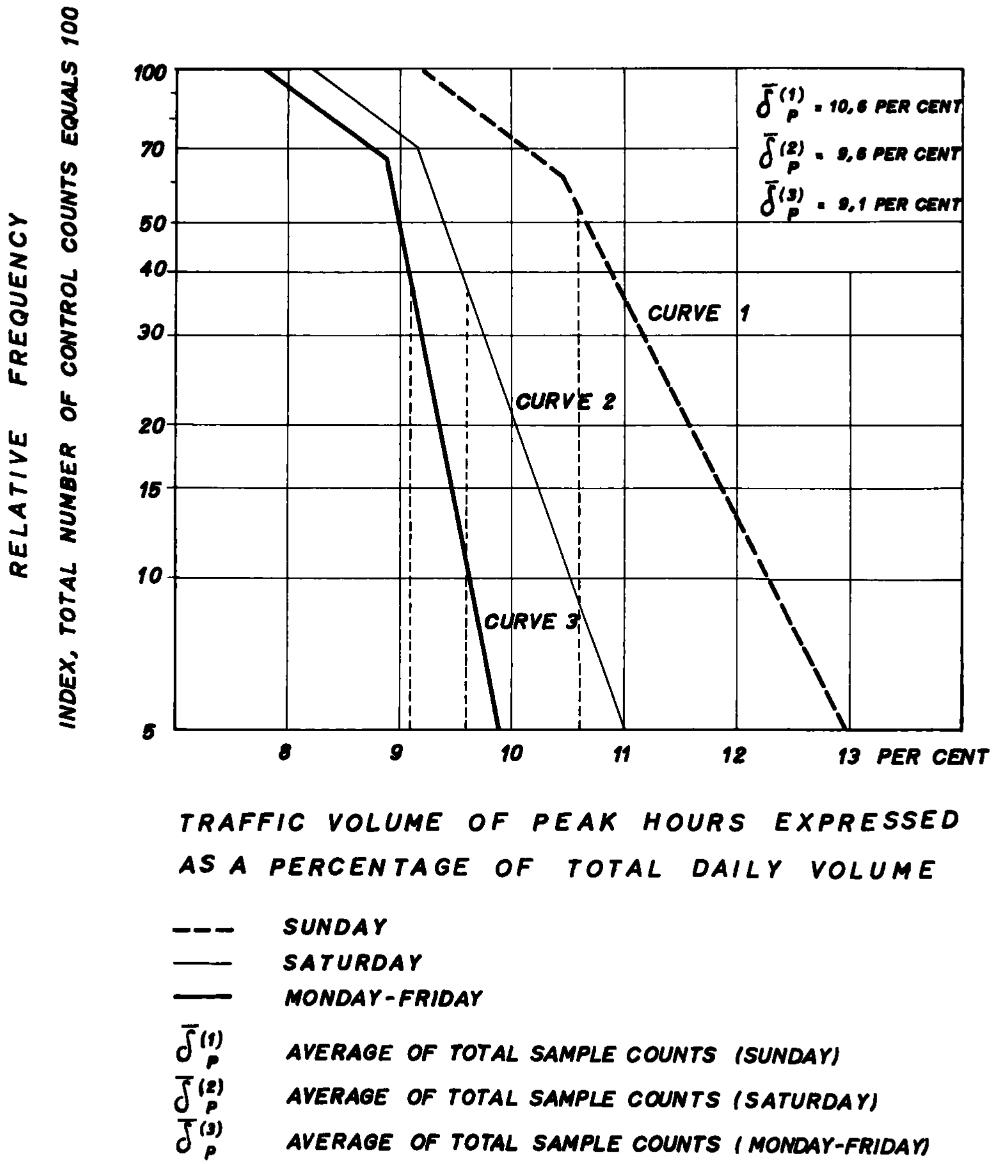


Figure 11. Frequency distribution of hourly traffic volume as a percent of 24-hour daily traffic (Swiss rural highways, 1953-1955).

especially attractive to weekend traffic. This is expressed by a near constant load during the 12 daylight hours (see curve 2, Fig. 12). From the fact that δ_p remains constant in spite of sizeable seasonal fluctuations in daily traffic in the course of a year, it may be concluded that the absolute volume of daily peak traffic is subject to the same weekly and monthly fluctuations as is the 24-hr day traffic.

Traffic During the Highest Hours of the Year

The determination of laws in the flow of traffic in terms of time made possible a statement of the direct relationship between daily peak traffic and the ADT. Eq. 3 demonstrates the relation between daily traffic (t_{24}) and the ADT (T_a). Eq. 15 expresses the relation between daily traffic (t_{24}) and its peak (t_{max}). Therefore, from

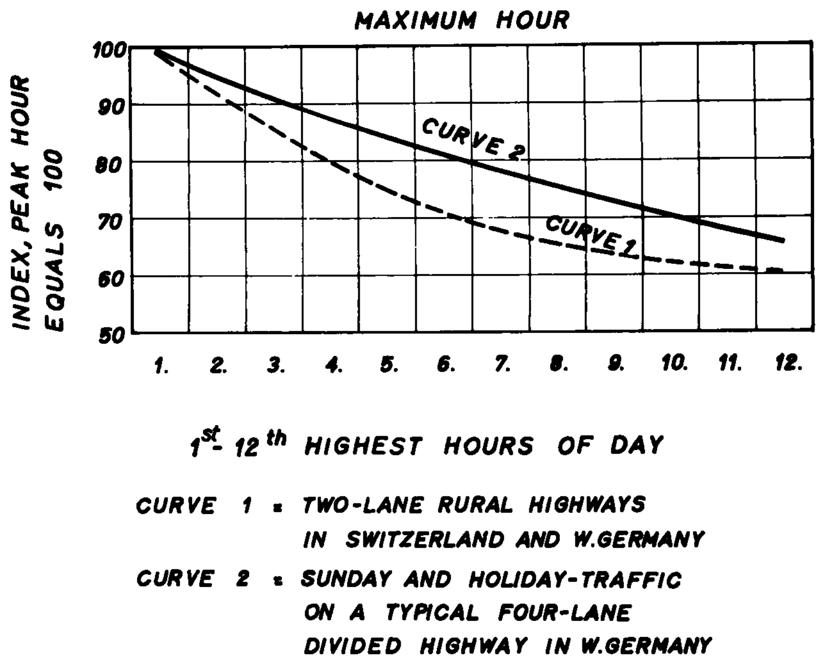


Figure 12. Peak hours of traffic volume (Swiss rural highway system and rural highways in the Federal Republic of Germany, 1955).

Eqs. 3 and 15 the relation between peak-hour traffic and the ADT may be derived, as follows:

$$T_a = \frac{\kappa}{0.01\,\delta_p}\, t_{max} \tag{17a}$$

or

$$t_{max} = \frac{0.01\,\delta_p}{\kappa}\, T_a \tag{17b}$$

If ω is introduced into Eq. 17,

$$\omega = \frac{0.01\,\delta_p}{\kappa} \tag{18}$$

The final form of the relation between the peak-hour traffic of a random day and the ADT is

$$t_{max} = \omega\, T_a \tag{19}$$

As already mentioned, the numerator of Eq. 18 remains constant. This implies that changes of ω are dependent only on the κ-factor of the denominator. The values of the κ-factor according to Eq. 2 are functions of daily factors, b, and weekly factors, d = rc, because the value of the hourly factor in 24-hr traffic amounts to $a_{24} = 1$. It follows that changes in value of ω are primarily influenced by b- and d-factors: symbolically,

$$\omega = F\left(\frac{1}{b_i}, \frac{1}{d_i}\right) \tag{20}$$

Because in Eq. 19 the daily peak-hour traffic fluctuates with ω, its maximum value is determined by κ_{min}; that is, max $1/(b_i d_i)$.

The fact that the same b- and d-factors are necessary for computation of peak-hour traffic for the year, R, as well as for the determination of the ADT, κ, adds a great practical advantage as well. The various types of road, as explained, demanded various κ-factors. The same classifications must therefore be applied to the critical traffic load. This means that each individual road type has a κ-line to find the ADT, and an R-curve to determine the traffic of the peak hours of the year.

Estimate of Traffic for Peak Hours of the Year by Means of δp, b and d Factors

Finding the ordinate of an R-curve (that is, the relative size of peak-hour traffic during the course of a year) can be done quite simply. Curve 1 in Figure 5, for example, shows the peak traffic for Sundays expressed in percentages of ADT as follows:

$$i_7 = \frac{100}{b_7 c_i} \text{ percent} \tag{21}$$

Similarly, calculation of Saturday traffic (curve 2)

$$i_6 = \frac{100}{b_6 c_i} \text{ percent} \tag{22}$$

and that of working days (Monday-Friday, curve 3)

$$i_w = \frac{100}{b_w c_i} \text{ percent} \tag{23}$$

The b_7, b_6 and b_W factors are similar for the two road types represented by Figure 5, because the distribution of traffic during the individual days of the week is the same for highly recreational routes as it is for partially recreational routes. Sizeable differences in traffic flow are a result of the greatly different c-monthly factors of these roads. If the values of curve 3 (Fig. 5) derived from Eq. 23 are multiplied by 0.01 δp-factor, the peak traffic of working days in percentages of ADT is

$$i_w \; 0.01 \; \delta p = \frac{\delta p}{b_w c_i} = \frac{9.1}{b_w c_i} \tag{24}$$

Calculation of the values of Saturday's peak traffic runs a similar course:

$$i_6 0.01 \; \delta_p = \frac{9.6}{b_6 c_i} \tag{25}$$

and that of Sundays and holidays

$$i_7 0.01 \; \delta_p = \frac{10.6}{b_7 c_i} \tag{26}$$

An example of manipulation according to Eq. 24 is given in Table 5.

In Table 5, Col. 1 lists those months which are likely to carry peak loads of traffic; Col. 9, the number of working days of these months (that is, the frequency of peak-hour traffic on these days). Cols. 2-4 require no further explanation; Col. 5 gives the maximum hourly traffic load on working days; Col. 6 gives the second highest hourly traffic load on working days; and Cols. 7-8 contain the third and fourth highest hourly traffic load on working days expressed in percentage of the ADT. The multiplication factor (δp = 9.1 percent) of Col. 5 is obtained from curve 3, Fig. 11. The multiplication factor ($\delta_{(2)}$ = 8.4 percent = 0.92 δ_p) is obtained from curve 1, Fig. 12, etc.

The peak values to be expected for Saturdays and Sundays may be computed according to Eqs. 25 and 26 and are analogous to the example in Table 5. The values of the peak hours of the year thus arrived at may be calculated from the peak values of all the weekdays of the critical months, while bearing in mind the corresponding frequencies (for example, working days, Col. 9, Table 5).

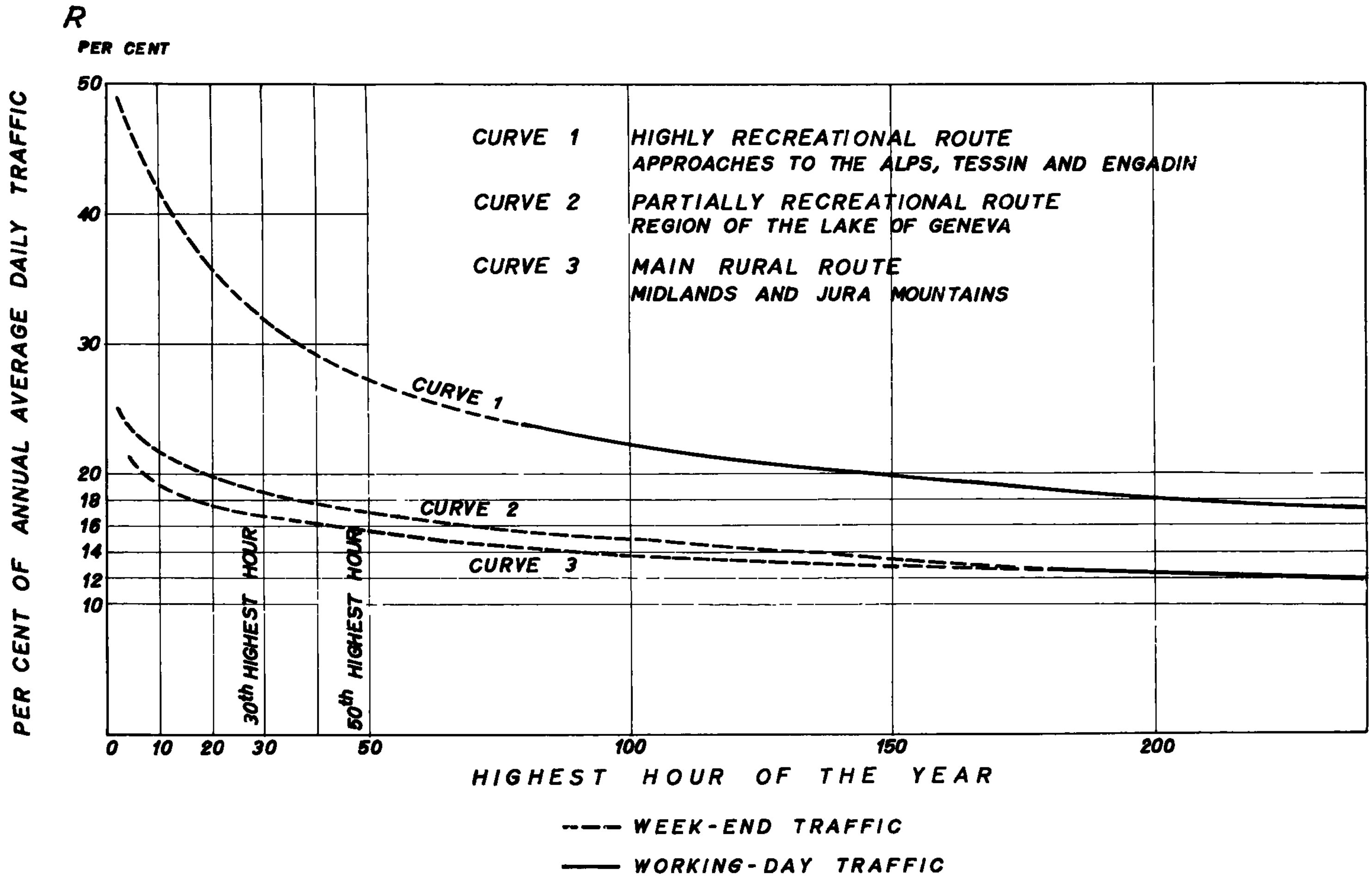


Figure 13. Relation between peak hourly flows and annual average daily traffic on two-lane rural highways (Swiss rural highways, 1955).

TABLE 5

COMPUTATION OF RELATIVE VOLUME IN THE PEAK HOURS OF TRAFFIC DURING THE WORKING DAYS OF A YEAR[a]

Month of Year	Factors: Daily, b_w	Factors: Monthly, c_i	$i_w = \frac{100}{b_w c_i}$ (%)	1st - 4th Highest Hours of Day[b] $0.01 \times i_w \times \delta_i$: 9.1	8.4	7.7	7.3	Frequency, f
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
June	1.06	0.86	109.7	10.0	9.2	8.4	8.0	22
July	1.07	0.65	143.8	13.1	12.1	11.1	10.5	21
Aug.	1.07	0.39	239.6	21.8	20.1	18.4	17.5	21
Sept.	1.06	0.86	109.7	10.0	9.2	8.4	8.0	22

[a]Highly recreational routes in Switzerland (approaches to the Alps; roads in the Tessin; the road network in the Engadin).

[b]As percentage of ADT.

The R-curves of Figure 13 have been drawn according to this method. The separate calculations of Sunday and Saturday and working day peaks make possible a further analysis of these curves. Curve 1 in Figure 13, for instance, demonstrates that the 80 highest peak hours of the year on approaches to the Alps occur as a result of weekend traffic. The highest working day peaks of Table 5 then are exceeded 80 times in a year.

Weekend traffic on the roads along the Lake of Geneva is so intense and constant (see curves 1 and 2, Fig. 5) as opposed to that of working days (curve 3), that even the highest hourly peaks of working days are exceeded 180 times in the course of a year. The considerable differences in the relative volume of the critical peak traffic loads of various road types (see curves 1 and 2, Fig. 13) demonstrate the importance of such analyses beyond doubt.

The presented factors a, b, c and δ characterize the laws of traffic in terms of time clearly and sufficiently. From data yielded by these short counts, a sufficient basis is provided for a large number of technical traffic investigations to be made once full knowledge of the true values of these factors is known.

The counting method itself is not enough to insure the success of a traffic survey intended to cover the road network in an extensive area. In the course of the introduction, reference is made to the fact that a certain knowledge of the traffic flows to be included in the survey is an essential prerequisite for a systematic choice of samples. The numerical values given to describe the flow of traffic represent indices of conformity with certain patterns of behavior which may be observed on the sections of road included in the survey. These numerical values for particular factors can properly be applied, however, only within a limited area and only on roads displaying the same traffic characteristics. Consequently, when the method to be described is to be applied to other countries, the particular features due to local conditions must first be ascertained. In all cases, the actual counts must be preceeded by findings provided by experimental control points established on a number of typical road sections.

If every precaution is taken in evaluating the experimental data, and if the special traffic conditions, which to some extent vary from country to country, have been sufficiently taken into account in devising the system of control points and in choosing the counting stations, this new method may be expected to yield results which can be regarded as technically and economically satisfactory.

Appendix A

APPLICATION OF SYSTEMATIC SAMPLING TO SPECIFIC PROBLEMS

The following examples applied to specific conditions illustrate how to apply correctly the data outlined in this paper.

Example 1

Problem:

What is the annual average of daily traffic on a section of road in the approaches to the Alps, when on Monday, September 12, 1955, a count of motor vehicles between the hours of 7 a.m. - 3 p.m. resulted in a total of t_8 = 1,325 (in both directions)?

Solution:

The annual average of daily traffic at this control point is, as follows:

$$T_a = \kappa_{(8)} t_8 = 2.11 \times 1,325 = 2,800 \text{ veh/24 h}$$

(Factor obtained from curve 2, Fig. 6.)

Example 2

Problem:

(1) What is the ADT on a section of road in the neighborhood of Geneva? Type of intersection: two-lane rural road, with partially recreational route.
(2) What is the expected total traffic volume during the highest hour of the year (vehicles per hour in both directions)?

Results of the Counts:

(1) May 10. Between the hours of 2 p.m. and 6 p.m. in both directions t_4 = 2,084 veh/4 hr. (Maximum hourly volume observed in both directions, t_{max} = 684 veh/hr.)
(2) June 21. Between the hours of 7 a.m. and 9 p.m. in one direction t_{14} = 3,209 veh/14 hr (t_{max} = 360 veh/hr).
(3) July 20. Between the hours of 7 a.m. and 3 p.m. in one direction t_8 = 1,973 veh/8 hr (t_{max} = 418 veh/hr).

Solution:

Computation of average annual daily traffic.

The three-month method: the ρ_3-curves (c-factors obtained from curves 2-4, Fig. 7).

$\rho_3^{(4)} = 1.165$; $\rho_3^{(14)} = 0.382$; $\rho_3^{(8)} = 0.716$

$T'_a = (\rho_3^{(4)} t_4 + \rho_3^{(14)} 2t_{14} + \rho_3^{(8)} 2t_8)^* = 1.165 \times 2,084 + 0.382 \times 6,418 + 0.716 \times 3,964$

$= 2,428 + 2,452 + 2,825 = 7,705$ veh/24 hr in both directions.

The κ-curves check (average values of κ-curves obtained from Fig. 6):

$\kappa_{(4)} = 3.75$; $\kappa_{(14)} = 1.12$; $\kappa_{(8)} = 1\ 77$

$T_a = \kappa_{(4)} t_4 = 3.75 \times 2,084 = 7,820$ veh/24 hr

$T_a = \kappa_{(14)} 2t_{14}^* = 1.12 \times 6,418 = 7,200$ veh/24 hr

$T_a = \kappa_{(8)} 2t_8^* = 1.77 \times 3,964 = \underline{6,990 \text{ veh/24 hr}}$

Average T''_a = 7,350 veh/24 hr

*Assuming 50 percent distribution of traffic by directions.

$$(\overline{T}_a) = \frac{T'_a + T''_a}{2} = \frac{7,705 + 7,350}{2} = 7,528 \text{ veh/24 hr}$$
$$\Delta T_a = 100\,\frac{T'_a - \overline{T}_a}{T_a} = 100\,\frac{177}{7,528} = 2.4 \text{ percent} \tag{27}$$

The ρ_1-curve check (values of ρ_1 obtained from Fig. 10):

$\rho_1^{(14)} = 1.17\ T_a = \rho_1^{(14)}\ 2t_{14}^{*} = 1.17 \times 6,418 = 7,500$ veh/24 hr

Computations of the highest traffic load of the year.

The 24-hr traffic on the day of count:

$t_{24} = a_4 t_4 = 3.52 \times 2,084 = 7,340$ veh/24 hr in both directions
$t_{24} = a_{14} t_{14} = 1.176 \times 3,209 = 3,780$ veh/24 hr in one direction
$t_{24} = a_8 t_8 = 2.20 \times 1,973 = 4,440$ veh/24 hr in one direction
(hourly factor obtained from Fig. 1)

Maximum hourly traffic (t_{max}) observed in relation to full day's traffic (expressed as a percentage of the 24-hr traffic)

$$\delta_p = 100\,\frac{t_{max}}{t_{24}} = 10.6 \text{ percent}$$

(δ_p - factor obtained from curve 1, Fig. 11)

The standard expression of the relation between the 24-hr traffic and the ADT is as follows:

$$T_a = b_i\ d_i\ t_{24} \tag{28}$$

Equating Eq. 28 to the maximum value of the yearly traffic to be expected:

$$t_{24}^{(max)} = \frac{T_a}{b_{min}\ d_{min}} = \frac{7,528}{b_{min}\ d_{min}} \tag{29}$$

On the basis of Figures 3 and 4 the factors of the traffic volume fluctuations are calculable as follows:

$b_{min} = b_7^{(8)} = 0.61$ (see Sunday values in August, Fig. 3)
$d_{min} = d_1^{(8)} = 0.66$ (first week in August, curve 1, Fig. 4)

Substitution of the values of $b_7^{(8)}$ and $d_1^{(8)}$ in Eq. 29 gives

$$t_{24}^{(max)} = \frac{7,528}{0.61 \times 0.66} = 18,700 \text{ veh/24 hr and} \tag{30}$$

$$t_{max} = \Delta_p\ t_{24}^{(max)} = 0.106 \times 18,700 = 1,982 \text{ veh/hr} \tag{31}$$

The absolute peak of hourly volume during the year expressed as a percentage of the annual average daily traffic derived from Eqs. 27 and 31 is as follows:

$$100\,\frac{t_{max}}{T_a} = 100\,\frac{1,982}{7,528} = 26.4 \text{ percent} \tag{32}$$

The Highway Research Board made extensive traffic analyses to throw light on this problem, the result of which was that in the United States the ratio between the highest hour of the year and the average daily traffic varied between 18 and 34 percent, averaging 24.9 percent (Bureau of Public Roads, Highway Capacity Manual, Table 22 and Figure 50).

Appendix B

EMPIRICAL CHECKING OF ERRORS IN ADT ESTIMATES OF THE SWISS RURAL HIGHWAY SYSTEM BY MEANS OF SAMPLES TAKEN DURING "NEUTRAL PERIODS"

High-way No.	Sta-tion No.	ADT (veh/24 hr) Calculated from "Short Count" and from ρ₃-Curves			ADT (veh/24 hr) Calculated from "Short Count" and from ρ₁-Curves			Cen-sus*	Deviations in the ADT Between that Actually Tested and that Derived from ρ₃-Curves			Deviations in the ADT Between that Actually Tested and that Derived from ρ₁-Curves		
	Duration of Count (hr)	42	24	12	28	16	12	210	42	24	12	28	16	12
	Time of Count Between the Hours of	7a.m.-9p.m.	7a.m.-3p.m.	2-6 p.m.	7a.m.-9p.m.	7a.m.-3p.m.	2-6 p.m.	7a.m.-9p.m.	7a.m.-9p.m.	7a.m.-3p.m.	2-6 p.m.	7a.m.-9p.m.	7a.m.-3p.m.	2-6 p.m.
	Number of Traffic Counts	n = 3			n = 2			n = 15	n = 3			n = 2		n = 3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	11	2,160	2,108	2,355	2,336	2,301	2,588	2,393	+ 9.7	+11.9	+ 1.6	+ 2.4	+ 3.8	- 8.1
1	12	8,009	7,936	7,131	8,312	8,360	8,336	7,986	- 0.3	+ 0.6	+10.7	- 4.1	- 4.7	- 4.4
1	13	4,360	4,404	4,549	4,540	4,609	4,650	4,258	- 2.4	- 3.4	- 6.8	- 6.6	- 8.2	- 9.2
1	14	3,152	3,215	3,173	3,188	3,270	3,251	3,078	- 2.4	- 4.4	- 3.1	- 3.6	- 6.2	- 5.6
1	15	2,594	2,748	2,565	2,566	2,686	2,637	2,602	+ 0.3	- 5.6	+ 1.4	+ 1.4	- 3.2	+ 1.3
1	16	2,887	3,008	2,908	3,104	3,088	2,898	2,975	+ 3.0	- 1.1	+ 2.2	- 4.3	- 3.8	+ 2.6
5	113	3,411	3,300	3,651	3,508	3,461	3,198	3,323	- 2.6	+ 0.7	- 9.9	- 5.6	- 4.2	+ 3.8
6	125	638	625	564	631	644	578	647	+ 1.3	+ 3.4	+12.8	+ 2.5	+ 0.5	+10.7
6	127	1,825	1,815	1,989	1,839	1,956	1,853	1,832	+ 0.4	+ 0.9	+ 8.6	- 0.4	- 6.8	- 1.1
6	128	1,927	1,795	1,900	1,823	1,815	1,908	1,926	0.0	+ 6.8	+ 1.3	+ 5.3	+ 5.8	+ 0.9
6	129	2,318	2,373	2,275	2,466	2,546	2,660	2,451	+ 5.4	+ 3.2	+ 7.2	- 0.6	+ 3.9	- 8.5
6	130	2,114	2,050	2,086	2,132	2,071	2,247	2,364	+10.6	+13.3	+11.8	+ 9.8	+12.4	+ 4.9
6	131	2,404	2,265	2,420	2,389	2,229	2,597	2,472	+ 2.8	+ 8.4	+ 2.1	+ 3.4	+ 9.8	- 5.0
6	132	2,897	2,701	2,869	2,836	2,619	2,926	2,968	+ 2.4	+ 9.0	+ 3.3	+ 4.1	+11.8	+ 1.4
6	133	3,954	3,753	4,143	3,943	3,744	4,311	4,012	+ 1.4	+ 6.4	- 3.3	+ 1.7	+ 6.7	- 7.4
6	134	4,413	4,243	4,572	4,382	4,190	4,883	4,560	+ 3.2	+ 7.0	- 0.3	+ 3.9	+ 8.1	- 7.1
6	135	4,146	4,095	4,342	4,179	3,996	4,676	4,497	+ 7.8	+ 8.9	+ 3.4	+ 7.0	+11.1	- 4.0
6	136	3,017	3,028	3,268	2,944	3,003	3,306	3,230	+ 6.6	+ 6.2	- 1.0	+ 8.8	+ 7.0	- 2.2
6	137	1,526	1,624	1,777	1,549	1,702	1,846	1,604	+ 4.9	- 1.2	-10.8	+ 3.4	- 6.1	-15.1
6	138	2,026	2,222	2,217	2,082	2,350	2,365	1,988	- 1.9	-11.8	-11.5	- 4.7	-18.2	-19.0
6	139	886	1,012	1,048	914	1,082	1,075	960	+ 7.7	- 5.4	- 9.2	+ 4.8	-12.7	-12.0
6	140	892	1,046	1,071	944	1,118	1,081	1,014	+12.0	- 3.2	- 5.6	+ 6.9	-10.2	- 6.6
10	168	1,206	1,193	1,190	1,236	1,246	1,292	1,317	+ 8.4	+ 9.4	+ 9.6	+ 6.2	+ 5.4	+ 1.9
10	187	1,918	1,803	2,010	2,012	1,884	2,167	1,856	- 3.3	+ 2.8	- 8.3	- 8.4	- 1.5	-16.8
10	188	1,013	986	1,075	1,065	1,020	1,136	1,043	+ 2.9	+ 5.5	- 3.1	- 2.1	+ 2.2	- 8.9
10	189	1,418	1,451	1,426	1,534	1,629	1,571	1,533	+ 7.5	+ 5.3	+ 7.0	0.0	- 6.3	- 2.5
12	200	1,829	1,722	2,025	1,871	1,786	1,995	1,870	+ 2.2	+ 7.9	- 8.3	0.0	+ 4.5	- 6.7
12	201	1,419	1,415	1,387	1,383	1,398	1,343	1,329	- 6.8	- 6.5	- 4.4	- 4.1	- 5.2	- 1.0
18	239	1,671	1,746	1,390	1,446	1,551	1,450	1,697	+ 1.5	- 2.9	+18.1	+14.8	+ 8.6	+14.6
18	240	1,760	1,816	1,615	1,771	1,861	1,670	1,956	+10.0	+ 7.2	+17.4	+ 9.4	+ 4.8	+14.6
20	253	577	635	617	594	708	597	624	+ 7.5	- 1.8	+ 4.3	+ 4.8	-13.5	+ 4.3
20	254	946	1,016	1,006	935	1,073	937	947	0.0	-77.3	- 6.2	+ 1.3	-13.3	+ 1.0
20	255	911	995	959	880	998	972	942	+ 3.3	- 5.6	- 1.8	+ 6.6	- 5.9	- 3.2
20	256	899	902	951	865	886	940	998	+ 9.9	+ 9.6	+ 4.7	+13.3	+11.2	+ 5.8
70	305	1,963	1,773	1,999	1,959	1,770	2,122	1,974	+ 5.6	+10.2	- 1.3	+ 0.8	+10.3	- 7.5
70	306	824	768	942	821	793	968	895	+ 7.9	+14.2	- 5.2	+ 8.3	+11.3	- 8.2
70	307	1,452	1,456	1,684	1,515	1,541	1,761	1,596	+ 9.0	+ 8.9	- 5.5	+ 5.1	+ 3.4	-10.3
72	309	913	949	1,027	918	990	984	1,002	+ 8.9	+ 5.2	- 2.5	+ 8.4	+ 1.2	+ 1.8
91	320	1,193	1,142	1,164	1,204	1,237	1,237	1,257	+ 5.1	+ 9.1	+ 7.4	+ 4.2	+ 1.6	+ 1.6
91	321	633	690	576	670	722	628	674	+ 6.1	- 2.4	+14.5	+ 0.6	+ 7.2	+ 6.8
94	323	1,590	1,623	1,529	1,542	1,601	1,534	1,657	+ 4.0	+ 2.0	+ 7.7	+ 6.9	+ 3.4	+ 7.4
94	324	669	670	644	698	746	674	702	+ 4.7	+ 4.6	+ 8.3	+ 0.6	+ 6.3	+ 4.0
95	325	1,014	1,031	1,045	1,051	1,070	1,069	1,051	+ 3.5	+ 1.9	+ 0.6	+ 0.5	- 1.8	- 1.7
Average deviation, e, of the sample group:									± 4.9	± 6.0	± 5.8	± 4.9	± 6.9	± 6.2

*Based on data of the Swiss Federal Statistics Office, Berne 1955.

Appendix C

THE ACCURACY OF THE STATISTICAL ESTIMATES OBTAINED BY MEANS OF $\rho_3^{(14)}$-CURVES

Control Point	Count Results[1,2] May 12[1]	June 1[1]	July 11[1]	ADT Calculated from[3] May 12[1]	June 1[1]	July 11[1]	$T_a = \Sigma \rho_3 t_{14}$	Act. Tested T_o[5]	Deviation from ADT (veh)	(%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)[4]	(9)	(10)	(11)
2	7,736	7,711	9,658	2,510	2,590	3,040	8,140	8,003	-137	- 1.7
3	4,245	4,252	5,320	1,378	1,430	1,678	4,486	4,721	+235	+ 5.0
4	4,318	4,567	5,404	1,403	1,535	1,702	4,640	4,674	- 34	- 0.7
6	1,577	1,691	1,843	511	568	580	1,659	1,656	- 3	- 0.2
2	8,168	8,865	8,341	2,655	2,980	2,625	8,260	7,732	-528	- 6.8
30	7,768	8,785	8,501	2,525	2,950	2,680	8,155	7,987	-168	- 2.1
31	2,841	3,084	3,141	922	1,038	990	2,950	2,877	- 73	- 2.5
39	1,810	2,013	2,473	588	675	778	2,041	2,100	+ 59	+ 2.8
42	1,988	2,005	2,578	645	671	812	2,328	2,118	-210	- 9.9
60	2,100	2,451	3,048	682	822	960	2,464	2,376	- 88	- 3.7
63	3,773	3,998	5,867	1,225	1,344	1,850	4,419	4,695	+276	+ 5.9
67	4,069	4,450	4,542	1,320	1,497	1,430	4,247	4,550	+303	+ 6.6
70	2,077	2,404	2,525	675	806	795	2,276	2,352	+ 76	+ 3.2
79	2,013	2,613	3,425	655	876	1,808	2,611	2,777	+166	+ 6.0
86	373	535	905	121	180	285	586	609	+ 23	+ 3.8
88	380	601	819	124	202	258	584	593	+ 9	+ 1.5
98	593	1,018	1,493	193	342	470	1,005	986	- 19	- 1.9
94	3,630	4,226	4,739	1,180	1,420	1,493	4,093	4,085	- 8	- 0.2
95	2,861	3,135	3,439	873	1,054	1,085	2,976	3,023	+ 47	+ 1.6
108	1,918	2,022	2,478	622	679	780	2,081	2,279	+198	+ 8.7
114	3,490	3,520	3,711	1,134	1,183	1,170	3,487	3,403	- 84	- 2.5
156	3,596	4,316	3,854	1,170	1,450	1,214	3,834	3,674	-160	- 4.4
158	835	1,179	1,012	272	396	319	987	950	- 37	- 3.9
171	3,939	4,366	5,548	1,280	1,468	1,750	4,498	4,625	-127	+ 2.8
176	2,144	2,436	3,216	695	816	1,014	2,525	2,633	+108	+ 4.1
180	1,295	1,367	1,895	420	459	596	1,475	1,311	-164	-12.5
195	3,203	3,193	2,750	1,040	1,072	856	2,477	2,677	-300	-11.2
199	1,148	1,246	1,402	373	419	441	1,233	1,329	+ 96	+ 7.2
221	4,562	4,464	4,819	1,482	1,500	1,520	4,502	4,218	-284	- 6.7
223	1,634	1,665	1,939	531	559	610	1,700	1,778	- 78	- 4.4
230	3,437	3,740	3,558	1,115	1,256	1,122	3,493	3,588	+ 95	+ 2.6
250	1,639	2,003	1,974	532	672	621	1,825	1,717	-108	- 6.3
275	317	504	783	103	170	246	519	489	- 30	- 6.1
279	603	829	1,157	196	278	364	838	851	+ 13	+ 1.5

[1] Counts made by Union Suisse des Professionnels de la Route, 1955.
[2] t_{14} = veh/14 hr.
[3] $\rho_3 t_{14}$.
[4] Col. 8 = Col. 5 + Col. 6 + Col. 7.
[5] Based on census data of Swiss Federal Statistics Office, Berne, 1955.

Discussion

BORIS B. PETROFF, Head, Traffic Inventory Section, U.S. Bureau of Public Roads — In each state hundreds and in many states thousands of points along the roads are established for traffic counting. Lately traffic counting activities have been progressively extended into the cities. With the constantly increasing demands for traffic information, the expenditures for obtaining these data have also been mounting. A few years ago the problem had reached the proportions where the scientific methods of efficiency of traffic counting work had begun to force out the procedures which originally were instituted to satisfy the expediency in providing the much needed information.

In the first part of this paper, the product under discussion is the estimate of annual average daily traffic volume (ADT) based on sampling. Using statistical measures the author evaluates the accuracy of the estimates.

In this country, since 1951, the accuracy of estimates of ADT obtained by various sampling procedures has been statistically measured in 31 states. These measures determine the efficiency of the procedures as they relate the cost of production of estimates of ADT to their accuracy (quality).

The common expression of accuracy of an ADT estimate is the error of this estimate in percent of the ADT. The statistical measure of such error is the standard error of estimate or the standard deviation of the percent errors. Using the data in Appendix B, Col. 11, the standard deviation of the percent errors is ± 5.39. This is based on three samples (May 12, June 1, and July 11). From this can be approximated the standard deviation for ADT estimates if they were based on single samples 5 = ± 5.39 x $\sqrt{3}$ = ± 9.3 percent.

In this country the prevailing number of states base their ADT estimates on single samples. In 16 states so far, rural traffic counting procedures have built-in statistical controls. These procedures were designed to produce the ADT estimates with standard deviation 5 = ± 10 percent. Actually, after the "smoothing out" process whereby small adjustments are made in the ADT estimates when they are examined for reasonableness in relation to the data at the adjacent stations on the map and compared with the records of the previous years, the final resulting errors are probably smaller than those indicated by the "raw score" measure of 5 = ± 10 percent.

Thus it can be concluded that the basic measures of accuracy of ADT estimates produced by the author and those used in this country are essentially the same.

There are several differences in the procedures that merit attention because the understanding of them may lead to even greater efficiency.

1. The manner of grouping of stations for computation of adjustment factors;
2. The statistical and administrative implications of the "neutral periods"; and
3. The use of weekly instead of monthly adjustment factors.

The author suggests for computation of factors for the adjustment of sample counts to the estimates of ADT, the grouping of roads intuitively on the basis of descriptive correlations; for example, groups of roads by predominate service types. For instance, he names three traffic regions in Switzerland.

Since 1951 when evaluations of efficiency of traffic counting programs was begun in this country on a large scale, it was observed that intuitive classification of roads either by route or by geographical areas, in the predominant number of states, caused the errors of estimates of ADT to be greater than when roads were grouped objectively ("Experience in Application of Statistical Method of Traffic Counting," Public Roads, Dec. 1956). At best, and only in a few instances, the measures of errors induced by subjective groupings were the same as when they were based on statistical principles. In some cases the error of ADT estimates is increased by 10 percent on the 95 percent confidence limit when area or descriptive correlations are used in grouping.

In the evaluation of the objective grouping, tests made in the Bureau of Public Roads indicate that when the monthly-group-mean adjustment factors differ by not more than ± 5 percent in any one month, such groups tend to be insignificantly different; variations due to chance could account for the small differences. On the other hand, two groups having a maximum difference of ± 15 percent in any one month indicated significance of the differences which lead to the conclusion that two or more sub-populations may be included in each such group.

From these observations of significance of differences between group means it was concluded that ± 10 percent range would appear to approach the limit of significance. Therefore, in the 15 states where traffic counting procedures are now based on statistical measures, objective grouping is used. The criterion is the same everywhere, allowing a maximum difference of ± 10 percent between the group means in any particular month for roads carrying about 500 vehicles per day or more.

The objective grouping has these consequences on the procedure: The dispersion of monthly adjustment factors within the ± 10 percent range of a group is small, about 5 = ± 4 or 5 percent. Thus with as few as four randomly placed continuous count stations within a group, the standard error of the monthly mean factors is ± 2 or 2.5 percent. This standard error is small as compared with the irreducible 5 = ± 8 percent of the sampling error of single 48-hr counts on work days in a month, thus contributing only about ± 2 percent in forming the final 5 = ± 10 percent in the ADT estimates. As there are usually three or four groups within a state, the number of continuous count stations needed for the purpose of determining the adjustment factors is relatively small.

In the actual grouping of roads in the various states the adoption of the Gestalt concept was found very helpful as it allows for the recognition of population characteristics by a relatively small number of observations. In grouping of hundreds or sometimes thousands of miles of roads, seldom more than ten continuous count stations are available in a group. Sometimes only one such station shows the existence of a significantly different group. The allocating of road sections to the different groups, however, was later verified in detail by a large number of stations where traffic counts were made four, six, or twelve times during the year, equally spaced.

The record of observation of characteristics of traffic volumes in Europe more and more underscores the similarities that exist between the behavior of patterns of traffic there and in this country. If what has been found in this country about the continuity of subpopulations of characteristics of monthly traffic volume variations extending over great mileages of roads also applies in Europe, then further improvements (small as they may be) might be expected in the author's results.

In the 1930's and later years a number of studies were made in this country (many published in the HRB Proceedings) from which it was observed that there exist periods of minimum dispersion of traffic volumes for various units of time, such as hours, days, and months. It was also observed that the mean work-day traffic volume in certain months, usually April or May, and October, closely approximates the annual average. Furthermore these months were also the months of minimum dispersion of work-day volumes about their monthly means and, therefore, of the annual averages. These characteristics were found to exist on the great majority of all rural roads regardless of their classifications. Thus, although there has been awareness of these months of minimum dispersion which the author calls "neutral periods," little use has been made of them, primarily for administrative reasons.

Most of the traffic counting is done with machines which require careful attention for efficient performance. The state officials feel that men who are permanently employed as traffic enumerators usually are more conscientious than temporary employees, thus preferring using men on traffic counting work the year around including the months of greater dispersion. The better mechanical quality of counts and the greater production rates per man more than offset the loss of accuracy because of the counts taken during the months other than "neutral periods."

In 1955 the statistical analysis of adjustment factors in one of the northern states revealed that the application of the weekly factors reduced the error of estimate of ADT's by approximately one-third as compared with the monthly factors. One of the mid-Atlantic states uses weekly factors to adjust to the ADT estimates based on sample counts made during the first and the last week of the month. On the other hand, the analysis of weekly factors in one of the southern states where the monthly and weekly variations are less pronounced did not show conclusively a significant improvement over the use of the monthly factors. Until now the principal obstacle to the study and use of the weekly factors has been the considerably greater effort mecessary for the production of these factors. With the increasing use of mechanical and electronic equipment in the analysis of traffic data, it may be well to give greater attention in this country to the improvement of efficiency which may potentially lie in the use of weekly factors.

This paper demonstrates the large area of agreement of human behavior as observed in the characteristics of automobile traffic volume measurements in Europe when compared with this country. Consequently new successful investigations on either continent should attract attention across the Atlantic.

THOMAS MURANYI, Closure — A comparison of the acquired results and an investigation of special conditions are the best means for judging the correctness of a research method and its practical application. It is to be appreciated that Mr. Petroff in his comments has taken this course. Some brief supplementary remarks may complete the picture.

When determining the number of the counting days, n, and the necessary duration of the counts, not the expected probable error, but the expected maximum error was taken as a standard. As a criterion for the accuracy of the computed ADT it was demanded: that its value must not exceed an error of $\pm$ 12-15 percent at any station of the examined network (on the 95 percent confidence limit). This condition was fulfilled in the most rational manner (under European circumstances) by counts made either in May, June and July, each lasting 4 hours (12-hr count, see curve 3, Fig. 9), or by counts made in June which lasted twice for 4 hours (8-hr count, see curve 4, Fig. 9).

The universal validity of the American investigations—according to which an evaluation of the objective grouping is the most adequate method—has been proved by the European traffic analyses.

The classification of roads is also a result of objective grouping. In the determination of the criteria for the classification according to this type of road, not only the monthly factors, c_i, but also the Sunday-daily-factors, b_7, were taken into account. Although the differing intensity of the weekend traffic is already expressed in the traffic volume of the respective months and thus also in the differing monthly factors, it is not unimportant for obtaining the annual peak-hour traffic volume (Eq. 21) to see how these monthly traffic volumes come about. This manner of grouping made it possible to ascertain for every road section within the groups one adjustment factor for the estimation of ADT and one for the determination of the peak annual traffic volume.

Contrary to American procedures, no continual traffic counts extended over the entire network are performed in Europe. Traffic surveys of that kind are performed every 5 years only, chiefly manually and not by permanently employed traffic enumerators. Thus the periods most convenient for counts can be taken into account. The special advantage of this method (as opposed to the κ-lines more applicable to American conditions) is to be seen in the countries where data necessary for a correct grouping of road sections and stations are not available. According to the universal validity of the periodic factors, z_3 and z_1, they can be satisfactorily ascertained by the count results of only a few stations (Eq. 4, Table 2).