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Bulletin 281

Traffic Volume and Speed Studies

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Estimating the Daily Vehicle-Miles of Travel in The Chicago and Pittsburgh Metropolitan Areas

LOUIS E. KEEFER, Director, Pittsburgh Area Transportation Study

●ESTIMATING the daily vehicle-miles of travel (DVMT) in a metropolitan area is an uncomplicated matter. One vehicle-mile of travel results from one vehicle traveling one mile, or from two vehicles each traveling one-half mile, or from other obvious combinations. Estimating the DVMT on any particular street requires simply extending its length in miles by its average daily traffic count. Estimating the DVMT in any particular metropolitan area requires only that street lengths and traffic counts be available for the area.

Work of this nature has now been done for at least two different sizes of metropolitan areas, in Chicago by the Chicago Area Transportation Study, and in Pittsburgh by the Pittsburgh Area Transportation Study. In Chicago, it was planned and executed as a minor accuracy check of trip survey data but was finished well after the standard accuracy checks and final trip factoring, based on screen line comparisons, had been completed. In Pittsburgh, as a result of the encouraging results obtained in Chicago, it was planned from the start as the major accuracy check.

This paper reports both the Chicago and the Pittsburgh experiences and makes a general comparison of the two.

ESTIMATING DVMT IN CHICAGO METROPOLITAN AREA

First Estimate

Traffic Counts Program and Analysis.—During the summer of 1957 the Chicago Area Transportation Study (CATS) began planning a traffic counts program designed for estimating the DVMT in its local and arterial street systems. The designation of these systems was according to its own classification criteria and such systems did not, therefore, correspond to any others. CATS arterial system within the city of Chicago, for example, was closely patterned after the "Preferential Street System" designated by the Chicago Planning Commission, but with adaptations to satisfy CATS purposes of traffic assignment analysis. The extent of the CATS arterial street system, which included expressways, is shown in Figure 1.

The program called for one 24-hr machine count on each of four local and two arterial street sections in a sample zone in each of 43 of the 44 districts of the study area. From the variable number of zones within each district, or ring and sector segment of the study area, one sample zone was chosen by a random draw. The district comprising the Chicago Central Business District (CBD) was omitted from the program.

Inasmuch as the sample zones were of two basic sizes (that is, either 1 sq mi or 4 sq mi), there were either four or sixteen ¼ sq mi "grids" in each. Where there were four, it was decided to locate the first local street count in one of the four northwest grids, the second in one of the four northeast, the third in one of the four southeast, and the fourth in one of the four southwest grids. The particular grid in each group of four was chosen randomly.

The next step was to choose the actual local street count location in each grid. For purposes of the 1956 trip survey origin-and-destination coding, each block within each grid had been numbered sequentially in a set of "geographic" coding maps. It was only necessary, then, to draw one block from each chosen grid, randomly, according to its

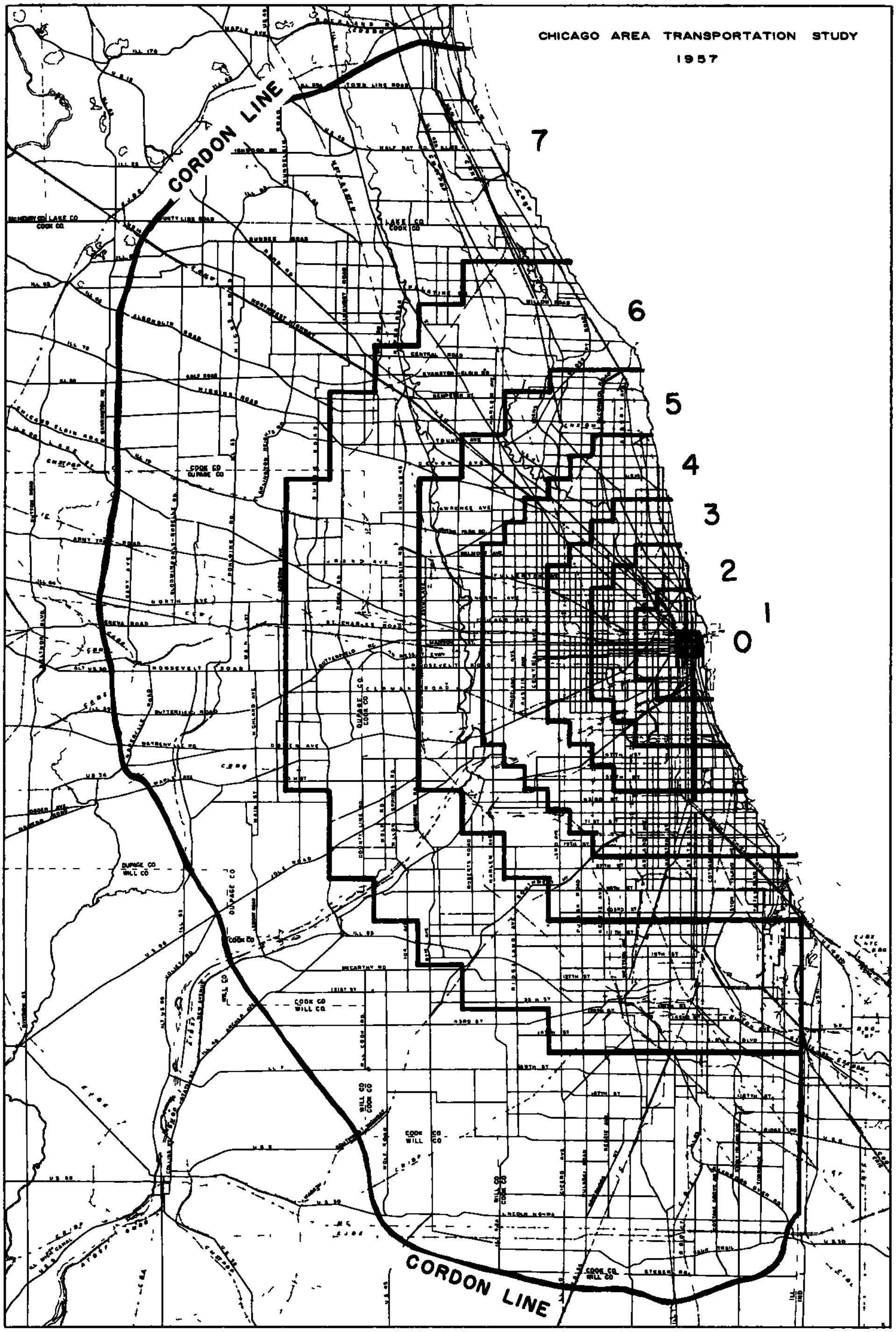

Figure 1. CATS arterial street system and rings.

trip-end coding number. If the block ended with an odd number, the north-south street bounding the eastern edge of the block was programmed for a count; if the block ended with an even number, the east-west street bounding the southern edge of the block was programmed.

There were some exceptions to this technique. Where the programmed street was not a local street a substitution was necessary. Also, it was decided that within a particular sample zone, the same local street would not be programmed twice. This, also, made a substitution necessary on several occasions.

The programming of the arterial streets to be counted in each sample zone was quite arbitrary. It was decided that one north-south and one east-west arterial street would be taken. All the arterial streets in each sample zone were assigned sequential numbers left to right and top to bottom, and one of each grouping chosen by a random draw.

The traffic counts program was started during September and completed during November 1957, by one counter setter using Streeter-Amet-type RC equipment. As the counts were taken, the tapes were edited for completeness and accuracy. If acceptable, they were transmitted to key punchers who prepared a punch card for each hour's count, showing the 15-min totals and the grand total. If unacceptable, recounts were taken. In general, there was no control over when the counts were taken, this being left to the counter setter, nor were the counts factored for daily or monthly variations.

Along with each tape that was sent to the key punchers, went a code sheet containing 40 columns of coded information concerning the street counted and the zone in which it was located. The latter included the total mileage (scaled from aerial photographs) of the local and arterial streets, respectively, in each of the sample zones, and the total land area and street area (taken from land use survey records) in each of the sample zones and the districts represented by these zones.

Following certain machine calculations (for example, the peak hour and peak 15-min percentages) punch card summary listings were made from which the DVMT in the local street system was found for each district as follows: the four local street counts in each sample zone were averaged and the average extended by the local street mileage in the represented district (X), as found through the ratio: local street mileage in the sample zone/X: street area in the sample zone/street area in the represented district. The ratio method was used because time limitations did not permit scaling the exact mileage throughout the study area.

The DVMT in the arterial street system was found in a different way. For every route section in the system there was already on hand (as a result of the previously completed arterial street inventory) a punch card showing the route length in tenths of miles and the 1953 annual average daily traffic (among other items). These were extended for every route section and the resulting 1953 DVMT summarized by ring. The 1957 arterial street sample counts were totaled and compared, by ring, with the 1953 counts at identical locations, to obtain 1953 to 1957 factors. These ring factors, given in Table 1, were used to convert the DVMT for 1953 to a 1957 basis.

Findings.—There were 38.0 million DVMT traveled on a typical weekday during September-November 1957, in the study area. Of this total, 82.6 percent, or 31.4 million DVMT were traveled over 2,921 miles of arterial streets, representing 25.2 percent of the total of 11,614 miles of streets in the study area. The remaining 17.4 percent, or 6.6 million DVMT, were traveled on 8,693 miles of local streets, or 74.8 percent of the total street mileage. The travel by system by ring is given in Table 1.

The average local street count, as calculated from the sample of 167 count locations, was highest in ring 1. Except for ring 2, the average count fell off successively through ring 7. The average local street count for all rings, excluding ring 0 for which no counts were made, was 1,046.

The average arterial street count, as calculated from the sample of 86 count locations, was highest in ring 3 and fell off successively through adjoining rings, with an abrupt drop in ring 7. The average arterial street count for all rings, excluding ring 0, was 15,650.

As expected, the proportion of travel occurring in the peak traffic hour decreased with increasing volume. The average peak hour percentage was comparatively constant for local streets throughout all rings, decreasing slightly toward the CBD as volume increased. The over-all weighted peak hour percentage on local streets was 13.7 percent. The average peak hour percentage for arterial streets was almost equally constant. Note, however, that while the local peaks ranged from 11.3 to 14.8 percent, the arterial peaks ranged only from 7.5 to 9.7 percent.

TABLE 1

DAILY VEHICLE-MILES OF TRAVEL (IN THOUSANDS) IN THE STUDY AREA ON A TYPICAL WEEKDAY DURING OCTOBER-NOVEMBER 1957, WITH OTHER PERTINENT DATA, BY ANALYSIS RING

Item	Analysis Ring								Total All Rings
	0	1	2	3	4	5	6	7	
Local streets									
Number of local counts	0	4	26	28	26	27	28	28	167 [1]
Average local count	5,000 [2]	3,223	1,430	2,230	1,160	544	412	228	1,046 [1]
Average peak hour percent	10.0[2]	11.3	12.2	14.0	14.2	14.2	14.8	14.0	13.7[1]
Number of miles Local streets	2.0[3]	226.7	472.6	719.4	1,338.0	1,754.5	1,868.8	2,310.7	8,692.7
1957 vehicle-miles in thousands	10 [2]	731	646	1,529	1,580	859	750	523	6,628
Arterial streets									
Number of arterial counts	0	2	14	14	14	14	14	14	86
Average arterial count	16,000 [2]	14,340	16,236	23,068	19,271	17,232	12,507	5,731	15,650 [1]
Average peak hour percent	7.0[2]	7.5	8.3	7.6	8.1	9.4	8.9	9.7	8.7[1]
Number of miles Arterial streets[5]	14.1[4]	92.5[4]	138.9	191.4	305.4	393.4	687.3	1,098.3	2,921.3
1953 vehicle-miles in thousands	292	2,054	2,879	3,827	4,859	4,398	3,977	3,311	25,597
1953 to 1957 count ratio	1.00[2]	0.92	1.10	1.09	1.05	1.19	1.58	1.58	1.16[1]
1957 vehicle-miles in thousands	292	1,890	3,167	4,171	5,102	5,234	6,284	5,231	31,371
All streets 1957 vehicle-miles in thousands	302	2,621	3,813	5,700	6,682	6,093	7,034	5,754	37,999

[1]Excluding ring 0.
[2]Estimated.
[3]Scaled from USGS maps.
[4]Known to be low because of combining route sections in coding network.
[5]From network punch cards.

Based on the sample of 86 counts, the growth of travel on arterial streets between 1953 and 1957 (the 1953 to 1957 count ratio) was most rapid in the outlying areas. The increase, while modest in rings 2 through 5, was a resounding 58 percent in rings 6 and 7. Somewhat surprisingly, there was an apparent decrease in ring 1. The overall weighted increase of 16 percent for all rings represented an average annual increase of four percent.

The growth of travel on local streets during a similar duration cannot be found for lack of comparable counts. It is interesting to speculate that, while arterial street counts were decreasing in ring 1 and increasing but little in rings 2 through 4, local counts may have increased considerably in the same rings. Thus, arterial streets in the highly built-up inner rings might be thought of as operating near capacity, so that additional traffic would be diverted to local streets for greater portions of trips.

Although existing traffic counts were not a determining factor in CATS street classification, the results of the traffic counts program, nevertheless, showed a rather consistent relationship between CATS street classification and existing traffic counts. The principal finding was that the streets in the CATS area might well have been classed as arterial or local, according to whether they carried more or less than 3,000 vehicles per day.

Only 11 of the 167 local streets counted had traffic exceeding 3,000 vehicles during the 24-hr count period, six exceeding 5,000 vehicles, but none exceeding 10,000 vehicles. On the other hand, only nine of 86 arterials had less than 3,000 vehicles, and seven of these were in rings 6 and 7 where arterial counts might be expected to be lower.

The 11 local streets having counts greater than 3,000 were examined to find reasons for the high counts. Several emerged: the particular street was a short-cut path between two arterial streets, often avoiding a turn prohibition or traffic signal or providing a slightly shorter travel distance; it was heavily enough traveled but of insufficient length to be classed as arterial for CATS purposes; or it was located in a manufacturing area near a large traffic generator such as Goose Island or the Union Stock Yards.

The nine arterial streets having counts less than 3,000 were similarly examined. Generally, these proved to be in the outer rings, linking small towns and villages, but of a low type, occasionally even metal-surfaced, and simply lacking a higher count.

Second Estimate

Traffic Counts Program and Analysis.—As a result of the considerable interest generated by the first estimate of the DVMT in the Chicago metropolitan area, a second traffic counts program was planned and executed. To distinguish them, the former was called sample A and the latter, sample B.

The two samples were drawn in the same manner, but involved entirely different count locations. Randomly located 24-hr weekday traffic counts were taken during April through July 1958, in a randomly selected analysis zone in each of the 44 districts in the study area. The schedule called for four counts on local streets (except in the district constituting the Chicago CBD) and two counts on arterial streets in each sample zone. The same general method of finding the local and arterial street DVMT was used as for sample A, except that the counter tapes were not key punched as previously.

Findings.—There were 36.5 million DVMT traveled on a typical weekday during April-July 1958, in the study area. Of this total, 30.0 million vehicle-miles, or 82.2 percent, were traveled on 2,921 miles of arterial streets, representing 28.3 percent of the 10,314 miles of streets estimated in the study area. The remaining 6.5 million vehicle-miles, or 17.8 percent, were traveled on 7,393 miles of local streets, or 71.7 percent of the total street mileage estimated in the study area. The travel by system by ring is given in Table 2.

The results compared closely with those from Sample A. Calculation of the local street mileage by district, by the ratio described previously, yielded lower totals than before, but because the average local street counts were slightly higher, the total DVMT in the local street system was almost the same (6.4 to 6.6 million).

The sample A vs sample B comparison of the DVMT in the arterial street system was nearly as good (31.4 to 30.0 million). The variations in ring totals resulted from the calculation of new expansion factors by which the known 1953 totals were updated.

The average local street count, as calculated from the sample of 167 count locations, was highest in ring 1 and decreased successively through ring 7. The average local street count for all rings, excluding ring 0 for which no local counts were taken (there were only two miles of local streets in ring 0) was 1,166 vehicles. This compared closely with the average of 1,046 vehicles derived from sample A.

TABLE 2

DAILY VEHICLE-MILES OF TRAVEL (IN THOUSANDS) IN THE STUDY AREA ON A TYPICAL WEEKDAY DURING APRIL-JULY 1958, WITH OTHER PERTINENT DATA, BY ANALYSIS RING

Item	Analysis Ring 0	1	2	3	4	5	6	7	Total All Rings
Local streets									
Number of local counts	0	4	27	27	28	28	26	27	167 [1]
Average local count	5,000 [2]	2,505	2,114	1,645	1,409	664	584	370	1,166 [1]
Miles local streets (calc.)	2.0 [3]	201.6	322.6	566.5	1,229.7	1,327.1	1,622.0	2,121.8	7,393.3
1958 vehicle-miles in thousands	10	505	682	932	1,733	881	947	785	6,475
Arterial streets									
Number of arterial counts	2	14	14	14	13	14	13	13	97
Average									
Arterial count	13,436	16,507	15,533	14,609	14,723	10,789	7,383	3,339	11,976
Average peak hour percent	8.1	8.4	8.7	8.4	8.8	9.3	9.6	9.7	8.8
Miles arterial streets [5]	14.1 [4]	92.5 [4]	138.9	191.4	305.4	393.4	687.3	1,098.3	2,921.3
1953 vehicle-miles in thousands	292	2,054	2,879	3,827	4,859	4,398	3,977	3,311	25,597
1958/1953 Ratio	0.96	1.12	0.92	1.06	1.09	1.29	1.45	1.20	1.10
1958 vehicle-miles in thousands	280	2,300	2,649	4,057	5,296	5,673	5,767	3,973	29,995
All streets 1958 Vehicle-miles in thousands	290	2,805	3,331	4,989	7,029	6,554	6,714	4,758	36,470

[1] Excluding ring 0.
[2] Estimated.
[3] Scaled from network maps.
[4] Known to be low because of combining route sections in network coding.
[5] From network punch cards.

A similar pattern was disclosed for arterial streets; the highest average count, as calculated from the sample of 97 count locations, found in ring 1, and decreasing successively through ring 7. This contrasts with sample A where the highest count was found in ring 3, decreasing successively in both higher and lower adjacent rings. The average arterial street count for all rings was 11,976 vehicles. Both the ring averages and the over-all average were lower for sample B than for sample A. This indicated only that different samples were taken.

As a matter of curiosity, the average count on all arterial street sections was calculated from the arterial street inventory punch cards, by ring, as given in Table 3. Comparison of the averages shown in Tables 2 and 3 indicate that the arterial streets chosen for counts in sample B had lower counts, on the average, than did the universe of arterial streets, in rings 0 through 4.

TABLE 3

AVERAGE ARTERIAL STREET SECTION TRAFFIC COUNTS, BY RING, CALCULATED FROM THE ARTERIAL STREET INVENTORY PUNCH CARDS

Ring	Number of Sections Averaged	Average Arterial Traffic Count
0	112	20,783
1	248	23,720
2	401	18,629
3	485	20,000
4	675	15,977
5	701	10,715
6	954	6,120
7	1,113	2,488
Total all rings	4,689	11,157

The average peak hour percent for arterial streets increased from ring 0 outward, just as it did for sample A, ranging from 8.1 to 9.7 percent. The over-all weighted peak hour was 8.8 percent for 97 counts, while sample A was 8.7 percent for 86 counts. No record of peak hour counts on local streets was obtained for sample B because of the type of equipment used. (Streeter-Amet "Junior" instead of "RC" counters were used for local counts, as a matter of convenience in handling and operation.)

The growth of travel on arterial streets between 1953 and 1958 was most pronounced in the outer rings. Not all arterial street counts in sample B had a 1953 or 1955 counterpart. (The 1953 flow maps did not show every street on the CATS arterial street system, and thus no direct comparison was possible.) Only those that did were used to derive the 1953 to 1958 expansion factor used in Table 2. Based on this comparison, the factors ranged from 0.92 for ring 2 to 1.45 for ring 6. While there was rough correspondence of factors between samples A and B, those of sample B were lower generally, as reflected by the over-all weighted factors of 1.16 and 1.10, respectively. No attempt was made to correct the 1958 counts to 1958 ADT by the use of daily and monthly factors.

As a way of verifying the accuracy of such factors, a comparison was made between the 1953 and 1956 editions of the Chicago Metropolitan Area Traffic Map prepared by the Illinois Division of Highways. An expansion factor was calculated for each matching route section in rings 6 and 7. The unweighted average of 137 factors for ring 6 was 1.37; of 266 factors for ring 7, 1.39. This indicated that the sample B factor of 1.45 for ring 6 was approximately correct, but that the factor of 1.20 for ring 7 was possibly too low. Table 2 was prepared without regard to this additional evidence.

Again it appeared that the classification of streets in the CATS area could have been accomplished, in large measure, by the use of traffic count criteria. Only 15 of the 167 local street counts analyzed exceeded 3,000 vehicles during the 24-hr count period, two exceeding 5,000, but none exceeding 6,000 vehicles, and these, generally, for the reasons previously cited. Only 15 of the 97 arterial street counts analyzed were less than 3,000 vehicles, and 10 of these were in rings 6 and 7 where arterial street counts were expected to be lower.

Comparison With Trip Survey Data

Two estimates of the total DVMT in the study area were now available. The first for September-November 1957; the second for April-July 1958. The estimates were 38.0 and 36.5 million vehicle-miles, respectively. These represented excellent sources of independent data with which to check with the total DVMT calculated from the CATS trip surveys of April-October 1956. While the data did not correspond time-wise, an approximate check was expected to be interesting, nevertheless.

The screenline-factored results of the internal (or home-interview) trip survey were converted to vehicle-miles of travel by taking the 'L' distance trip frequency distribution, multiplying by the average distance for each distance range, and totaling, as given in Table 4. The total was factored by 0.493 to rēduce person-trips to automobile trips, and by 1.20 to account for truck, taxi, and external trips. The resulting total of approximately 34.0 million vehicle-miles (57,792,000 x 0.49 x 1.20) comes out close to, but under, estimates from samples A and B.

ESTIMATING THE DAILY VEHICLE-MILES OF TRAVEL IN THE PITTSBURGH METROPOLITAN AREA

Traffic Counts Program, Analysis, and Findings

Arterial Street System DVMT.—From the beginning, the Pittsburgh Area Transportation Study (PATS) planned for a traffic counts program for estimating the DVMT in its local and arterial street systems.

As in Chicago, the designation of these systems was determined by the purposes of traffic assignment analysis. The reasoning behind this might be explained as follows: Transportation planning for the future starts with a comparison of present total travel supply (streets) and future total travel demand (trips). If demand is expressed as trips between pairs of analysis zones (zonal interchange), then supply must be expressed

TABLE 4

ESTIMATED PERSON-MILES OF TRAVEL IN THE STUDY AREA DURING AN AVERAGE WEEKDAY IN APRIL-NOVEMBER, 1956, FROM RESULTS OF THE CATS TRIP SURVEYS

Right-Angle Trip Distances (in miles)	% Distribution of Auto Driver Trips	Median Distance for Each Distance Range	Person Miles of Travel
0.0 - 0.9	2.7	0.6	162,000
1.0 - 1.9	23.6	1.5	3,550,000
2.0 - 3.9	25.1	3.0	7,550,000
4.0 - 5.9	15.8	5.0	7,900,000
6.0 - 7.9	7.7	7.0	5,400,000
8.0 - 9.9	7.4	9.0	6,650,000
10.0 - 11.9	4.8	11.0	5,300,000
12.0 - 13.9	4.8	13.0	6,250,000
14.0 - 15.9	3.5	15.0	5,250,000
16.0 - 17.9	1.3	17.0	2,200,000
18.0 - 19.9	1.1	19.0	2,080,000
20.0 +	2.3	24.0	5,500,000
Total	100		57,792,000

as streets connecting pairs of analysis zones. But how many streets? The technique of comparison determines this. Assuming that traffic assignment, or allocation of trips to specific streets, is the technique chose, then the method of assignment used is the determining factor. At PATS the minimum travel time path "all or nothing" method of assignment will be used. This means that all trips between a pair of zones are allocated to the minimum path connecting them. The path may consist of only one street (later referred to as a route section) if the zones are contiguous, or of many streets with turns at intersections if the zones are distant. Thus there need be only enough streets to interconnect all pairs of zones, but these must provide the minimum path leading from every zone center, preferably in at least four directions. Hence, the working definition of an arterial street as used at PATS: "An arterial street is a street having significant capacity for interzonal trip movement as a link in an anticipated minimum travel time path." Expressways are self-defining and local streets are the residua

It should be added, however, lest the arterial street system seem too circumscribed, that experience has demonstrated this specialized method of street classification virtually assures inclusion of all streets which by the criteria of other methods would be included. On the other hand, a number of streets may be included which would not otherwise qualify as arterials. In outlying portions of the study area, for example, an unpaved road between adjoining zones may be designated as an "arterial" for lack of any other connecting link.

As part of the arterial street inventory, but primarily in connection with the development of an area-wide traffic flow map, 1958 traffic counts were obtained at the mid-points of most of the limited access and arterial street sections (Fig. 2). The type of counts obtained are given in Table 5.

TABLE 5

NUMBER OF TRAFFIC COUNTS OF DIFFERENT TYPES MADE FOR THE PATS ARTERIAL STREET INVENTORY

Type of Count	Number
24-hr manual classification	95
8-hr manual classification, expanded to 24 hr by an area factor	529
24-hr machine	789
24-hr machine, from a previous year factored to 1958	189
Estimated	14
Total	1,616

Most of the manual counts were made during July through September 1958; most of the machine counts were made during August through November 1958. No attempt was made to factor the counts to the average annual daily traffic for 1958, or to the average daily traffic for the fall quarter of 1958.

These 24-hr counts, the peak hour percents, the light, medium, and heavy commercial vehicle percents, and the lengths in hundredths of miles, along with other inventory data, were punched into an inventory card for each street section. After checking for accuracy, the total DVMT for each section was machine-calculated, and the peak hour and commercial vehicle DVMT machine-calculated in turn. A machine summary of the calculated values, by ring within type of street, produced the values in Table 6.

Several interesting features emerge in Table 6. It can be seen that the average traffic count on arterial street sections decreases more or less regularly with increasing distance from the CBD, but that due to the increasing arterial street mileage of the outer rings, the total DVMT by ring increases rapidly. Ring 7, of course, is an incomplete ring, accounting for the decrease in that ring. The percent of travel occurring in the peak hour increases from inner to outer rings, as it did in Chicago. The percent of travel by light commercial vehicles (panel and pickup trucks and other 4-wheel types) likewise increases from inner to outer rings. This may be partly explained by the frequent substitution of pickup trucks for personal automobiles in the outlying and

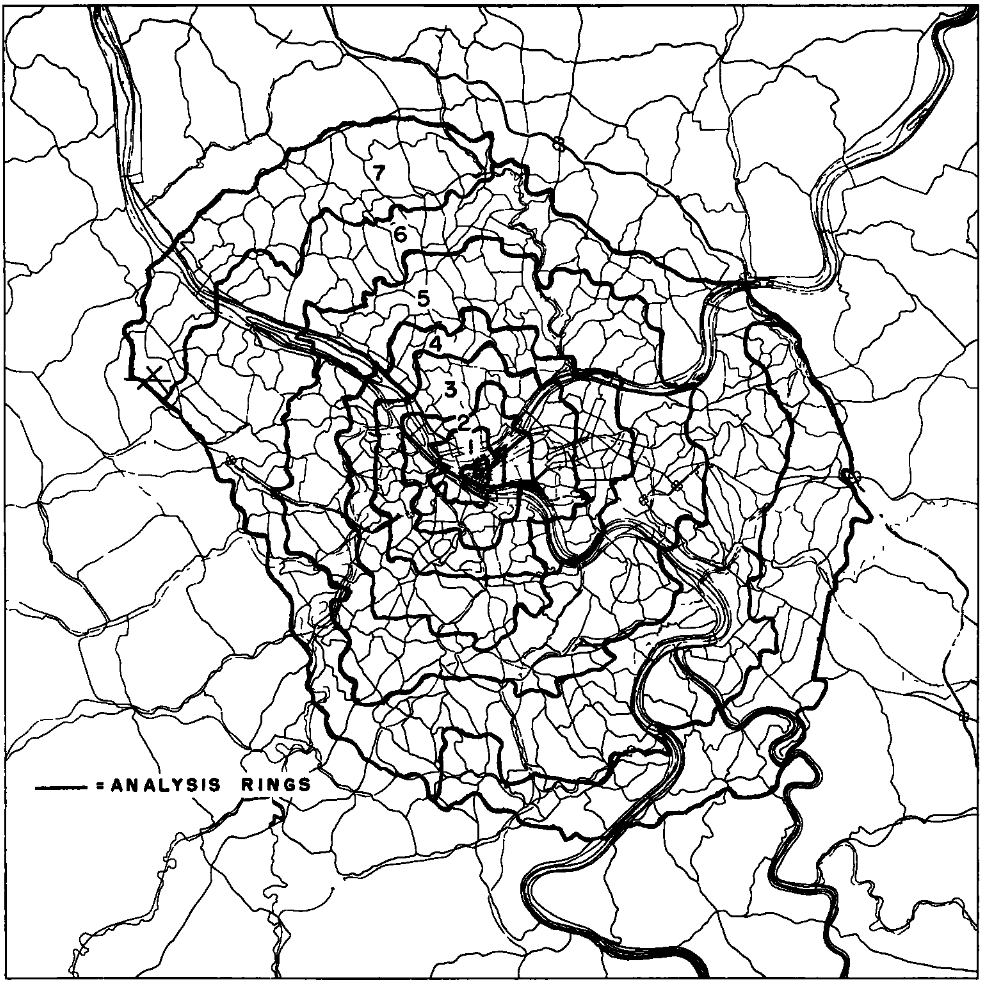

Figure 2. PATS arterial street system and rings.

rural areas. The percents of medium (straight body types with 6 or more wheels) and heavy commercial vehicles (all combination units plus buses) show no definite tendency.

In many respects these facts correspond closely with the experience in Chicago. An interesting difference lies in the more narrow range of values found. For example, the peak hour percents ranged from 8.1 to 9.7 in Chicago; the average arterial count ranged from about 16,507 to 3,339. This is probably a function of the type of study area. In Chicago, there was a rather regular thinning out of the concentration of population with increasing distance from the CBD. In Pittsburgh population concentrations exist along the river valleys as far out as the cordon line. The same narrowing of value ranges is reflected in the local street DVMT information described next.

Local Street System DVMT.—By definition, all streets in the study area that were not included in the arterial street system were local streets. No detailed inventory of these was made, although in mileage the system of local streets was about four times as long as the arterial street system. To get a complete picture of the total DVMT within the study area, of course, the travel on this system was also measured.

Inasmuch as it was impractical to obtain a 24-hr count on every section, a random sample of local streets was chosen for counting. The purpose was to obtain an average count applicable to all streets in an analysis ring. At the time these counts were

TABLE 6

DAILY VEHICLE-MILES OF TRAVEL (IN THOUSANDS) IN THE ARTERIAL STREET SYSTEM IN THE STUDY AREA ON A TYPICAL WEEKDAY DURING JULY-NOVEMBER 1958, WITH OTHER PERTINENT DATA, BY ANALYSIS RING

Item	Analysis Ring								Total All Rings
	0	1	2	3	4	5	6	7	
Number of counts	178	87	94	191	191	313	362	196	1,612
Average count	10,693	13,208	12,263	10,916	11,003	8,300	6,229	4,761	8,796
Arterial mileage	17.39	31.83	56.18	96.50	113.22	233.29	344.88	196.16	1,089.45
Total VMT	208.7	454.1	706.7	1,143.6	1,133.6	1,777.7	1,814.8	790.4	8,029.6
Peak hour VMT	16.8	37.9	57.3	93.6	95.7	158.7	167.2	73.4	700.6
Percent	8.0	8.3	8.1	8.2	8.4	8.9	9.2	9.3	8.7
Light Commercial									
VMT	11.0	27.5	45.4	76.7	77.5	124.3	126.4	55.8	544.6
Percent	5.3	6.1	6.4	6.7	6.8	7.0	7.0	7.1	6.8
Medium Commercial									
VMT	12.9	35.6	49.3	72.8	70.0	121.6	119.5	41.2	522.9
Percent	6.2	7.8	7.0	6.4	6.2	6.8	6.6	5.2	6.5
Heavy Commercial									
VMT	8.0	18.3	23.1	38.3	33.4	59.0	64.9	27.0	272.0
Percent	3.8	4.0	3.3	3.3	2.9	3.3	3.6	3.4	3.4
Passenger Car									
VMT	176.8	372.7	588.9	955.8	952.7	1,472.8	1,504.0	666.4	6,690.1
Percent	84.7	82.0	83.3	83.6	84.1	82.9	82.8	84.4	93.3

scheduled, PATS had not yet designated its analysis ring boundaries, so that a systematic sample by ring could not be drawn as it was in Chicago. The sample was drawn instead by judgment. To compensate for lack of some more systematic method, a comparatively large sample of 189 count locations was drawn. It was decided that 1 in 5 of these would be 8-hr manual classification counts, the rest, 24-hr machine counts.

The counts were made during November and the first week of December 1958, or concurrent with the home-interview and truck-taxi trip surveys. As the counts were made, they were checked for apparent accuracy, and if accepted, recorded on a worksheet. At this time, counts at 6 locations were discarded as non-typical of local streets. Analysis was delayed until about May 1959, when analysis rings were established. The count information was then totaled by ring to obtain the summary given in Table 7.

Table 7 shows some interesting results. Like arterial streets, local streets carry progressively lower volumes as distance from the CBD increases. The proportion of travel occurring during the peak hours rises gradually toward the outer rings, but not as markedly as it does on arterial streets. The higher range in peak hour travel, of 12.5 to 13.7 percent, excluding ring 0, indicates that the level of service during off-peak hours is much better, and more nearly uniform, for local streets generally, as would be expected. The percents of commercial vehicle travel show no definite trends, and this may be a function of the relatively few classification counts taken in each ring. The percents for rings 6 and 7 in Table 7 are weighted averages of the percents in rings 2 through 5, since, inadvertently, no classification counts were made in rings 6 and 7.

While a progressive decrease in the average local street count, as the distance from the CBD increases, is probably not consistent with the usual concept of the local street, it is the natural result of the method of street classification used. Thus, the designated "arterial" system in the inner rings of the study area generally omits a considerable mileage of streets that might otherwise be considered "arterial", as, for example, by the criteria established by the National Committee on Urban Transportation. This would tend to result in relatively high counts for "local" streets therein. The average "local" street counts both in Chicago and Pittsburgh were higher, in fact, than the averages found in Cincinnati, as reported by Howie and Young in their report, "The Traffic Counting Program in Cincinnati" (HRB Proceedings, 1957). It must again be emphasized that the criteria of street classification used in Chicago and Pittsburgh does not correspond to more usual criteria, and that the terms "arterial" and "local" as used in this paper have a special connotation for analysis purposes only.

A comparison shows that the 1,089.5- mile arterial street system (including express-

TABLE 7

DAILY VEHICLE-MILES OF TRAVEL (IN THOUSANDS) IN THE LOCAL STREET SYSTEM IN THE STUDY AREA ON A TYPICAL WEEKDAY DURING NOVEMBER 1958, WITH OTHER PERTINENT DATA, BY ANALYSIS RING

Item	Analysis Ring 0	1	2	3	4	5	6	7	Total All Rings
Number of counts									
Machine	-	6	24	23	16	28	31	24	152
Manual	8	4	4	8	4	1	-	-	29
Weighted average count	1,997	1,749	1,188	1,140	996	718	515	466	939
Local street mileage	3.3	88.6	181.7	263.3	350.5	607.3	699.4	372.9	2,567.0
Total VMT	6.6	155.0	215.9	300.2	349.1	436.0	360.2	173.8	1,996.8
Peak hour									
VMT	0.5	20.8	27.0	38.4	46.4	58.9	49.3	22.9	264.2
Percent	7.2	13.4	12.5	12.8	13.3	13.5	13.7	13.2	13.2
Light commercial									
VMT	0.7	14.1	18.1	28.8	20.6	37.9	29.9	14.4	164.5
Percent	10.4	9.1	8.4	9.6	5.9	8.7	8.3	8.3	8.2
Medium commercial									
VMT	0.6	14.4	10.4	13.5	12.6	29.2	16.2	7.8	104.7
Percent	8.8	9.3	4.8	4.5	3.6	6.7	4.5	4.5	5.2
Heavy commercial									
VMT	-	2.6	3.5	3.3	3.3	0.4	1.8	0.9	12.8
Percent	0.1	1.7	1.6	1.1	0.1	0.1	0.5	0.5	0.1
Passenger cars									
VMT	5.3	123.9	183.9	254.6	315.6	368.5	312.3	150.7	1,714.8
Percent	80.7	79.9	85.2	84.8	90.4	84.5	86.7	86.7	86.5

ways) accommodates 8.0 million DVMT, and that the 2,567.0-mile local street system accommodates 2.0 million DVMT. Thus 29.8 percent of the total street mileage in the study area carries 80.1 percent of the total travel, while the remaining 70.2 percent of the mileage carries only 19.9 percent, as summarized in Table 8.

TABLE 8

SUMMARY OF DAILY VEHICLE-MILES OF TRAVEL IN THE STUDY AREA BY STREET SYSTEM

Item	Local Street System	Arterial Street System, Excluding the Parkway	Parkway System	Total Systems
Total mileage	2,567.0	1,054.6	34.9	3,656.5
Percent	70.2	28.8	1.0	100.0
Total VMT	1,996.8	7,226.3	803.3	10,026.4
Percent	19.9	72.1	8.0	100.0

These proportions are very much the same as were found in Chicago. A further breakdown shows that the Penn-Lincoln Parkway system of 34.9 miles, including all ramp connections, representing only 1.0 percent of the street mileage, carries 8.0 percent of the total travel.

Comparison with Trip Survey Data

Trip Survey Data by Airline Distance.—Every trip card resulting from the PATS trip surveys shows the calculated airline distance between the trip origin quarter-square-mile grid and the trip destination quarter-square-mile grid. Summary tabulations were made by type of vehicle for the different trip surveys (Table 9) to develop the total airline distance DVMT represented.

TABLE 9

AIRLINE DAILY VEHICLE-MILES OF TRAVEL WITHIN THE STUDY AREA, AS DEVELOPED FROM PATS TRIP SURVEYS, ON A TYPICAL WEEKDAY DURING SEPTEMBER-NOVEMBER 1958

Vehicle Type	Home Interview Survey (trips entirely within the study area only)	Truck-Taxi Survey (trips entirely within the study area only)	Roadside Interview Survey (all trips, but distance with the study area only)	All Surveys
Passenger cars	3,295,142	-	1,417,195	4,712,337
Taxis	-	59,101	-	59,101
Light commercial	-	230,706	113,163	343,869
Medium commercial	-	132,462	88,421	220,883
Heavy commercial	-	8,768	91,151	99,919
Total	3,295,142	431,037	1,709,930	5,436,109

Conversion of Airline Distance to Over-the-Road Distance.—The difficult problem was to convert airline distance to over-the-road distance. To find a correction factor, the airline versus over-the-road distance by shortest arterial street route was measured for a randomized sample of 70 pairs of quarter-square-mile analysis "grids." When these were plotted (Fig. 3) a linear relationship was found. The correlation of airline (x) and over-the-road distance (y) was $r^2 = 0.939$, and the equation $y = 1.175 + 1.349\ x$.

The conclusion, however, was that this factor was too low. It was reasoned that not all trips would follow the shortest route. Social-recreation trips, for example, would frequently take the long way around. Trips for other purposes might do the same—to avoid congestion, to relieve monotony, or simply to look at something in passing. Lost or unfamiliar drivers probably could not follow the shortest route, nor could truckers restricted from segments of the route. For these reasons, a correction factor of 1.6 was used to convert airline to over-the-road distance.

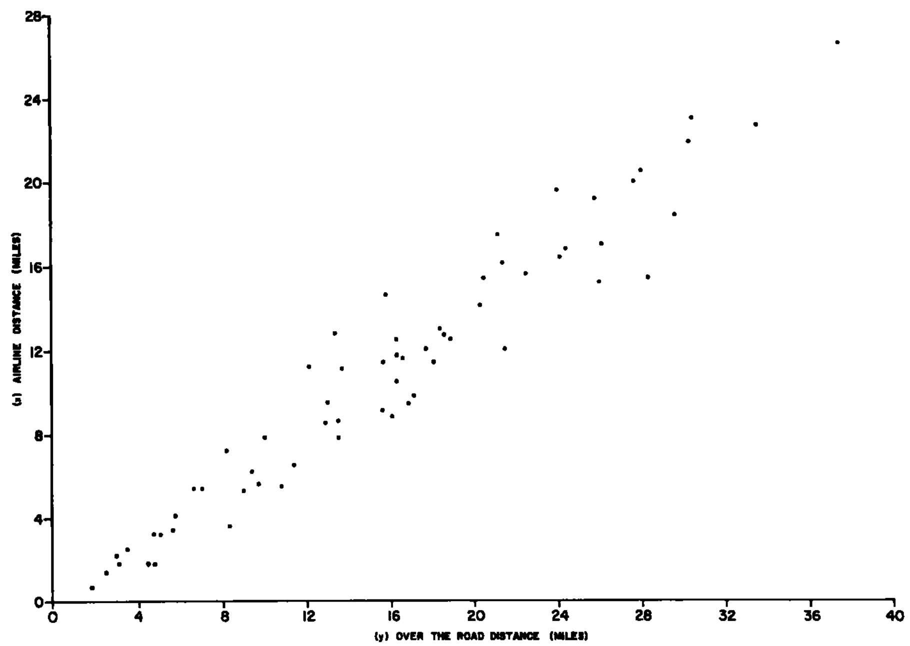

Figure 3. Scattergram comparison of airline and over-the-high road distances between 70 selected grids.

Accuracy Check.—The accuracy check obtained is given in Table 10. Because the independent estimate includes bus travel and the trip surveys did not (except in terms of person trips only), 80,000 VMT for buses were added to the trip surveys total for commercial vehicle VMT.

The 90.8 percent check for passenger cars is very good. The combined 70.5 percent check for commercial vehicles is fair. It seems probable that the latter may be accounted for, in part, by a large number of trips inside the study area by commercial vehicles garaged outside the study area. The first trip entering and the last trip leaving the study area, of course, are intercepted at the cordon line and recorded in the roadside interview, but subsequent and preceding trips inside the study area, on the same day, are not accounted for by any of the trip surveys. There is no way to measure the extent of this kind of tripmaking, but it is felt that in the Pittsburgh area it might be significant. The 87.5 percent total check for passenger cars and commercial vehicles combined must, nevertheless, be rated as very good.

In the months that have passed since this check was made there have been various suggestions regarding the use of the 1.6 factor—the principal one being that the factor was too high and hence exaggerated the percent of check, and that, despite the findings shown in Figure 3, a curvi-linear relationship actually exists and should have been used for the conversion of airline to over-the-road trip distances, particularly for the truck trips. This suggestion may very well be valid. It certainly points up the need for better information regarding the actual routes of travel chosen by drivers. An ideal method of obtaining this in an origin-destination study might be to have a sub-sample of home-interview respondents trace actual trip travel routes on a small-scale street map of the study area, the map to be appended to the home-interview schedule for later measurement and coding of the true over-all trip length. Besides derivation of airline versus over-the-road distance ratios, the results could well be useful for obtaining expressway usage diversion curves appropriate to the area, whenever that method of traffic assignment is anticipated. While getting such information would involve some problems, it is felt to be not impractical.

The vehicle-miles of travel accuracy check has several advantages over the standard accuracy checks previously reported. Most importantly, it compares the results of the combined trip surveys against the true universe of tripmaking (except by streetcar and railroad) in the study area, not just trips to particular places (like the CBD accumulation and work place checks), or across particular lines (like the screenline check), or by particular modes (like the mass transit check), or for particular purposes (like the labor force check). Furthermore, in the course of making the independent estimate from traffic counts and street mileage measurements, considerable data are developed which have other important uses. The check might well become standard procedure in all major transportation planning projects.

TABLE 10

COMPARISON OF OVER-THE-ROAD DAILY VEHICLE-MILES OF TRAVEL AS DEVELOPED FROM PATS TRIP SURVEYS AND AS CALCULATED FROM TRAFFIC COUNTS AND STREET MILEAGE MEASUREMENTS

Vehicles	From Trip Surveys	From Traffic Counts	Percent Check
Passenger cars (includes taxis)	7,634,301	8,404,900	90.8
Light commercial	550,190	709,100	77.6
Medium commercial	353,413	627,600	56.3
Heavy commercial (includes buses)	239,870	284,800	84.2
Total	8,777,774	10,026,400	87.5

CONCLUSIONS AND RECOMMENDATIONS

Some conclusions can now be stated in a summary fashion, ranging from the particular to the general. Where these conclusions refer to arterial or local streets specifically, the method of street classification used in Chicago and Pittsburgh must be kept in mind. Unless otherwise noted, the conclusions refer to both the Chicago and Pittsburgh work, inasmuch as more or less comparable results were obtained in both places.

In addition, some recommendations can be made with reference to future work of the type reported, which in themselves are another kind of conclusion.

Conclusions

The average daily traffic count on both arterial and local streets generally decreased with increased distance from the CBD, although arterial counts in the CBDs themselves were lower than in the first several analysis rings. Over-all, the progressive decrease was smoother for local streets, the arterial counts tending toward a plateau in the first several analysis rings. To some extent, these patterns were a result of the method of street classification used.

The peak hour percents on both arterial and local streets generally increased with increased distance from the CBD and with decreased traffic counts.

While existing traffic counts were not a specific criteria for street classification, it was found in Chicago that, had an average daily traffic count of 3,000 vehicles been used as the dividing line between an arterial and local classification, much the same street systems would have been designated except in the outer analysis rings.

The estimation of the daily vehicle-miles of travel in a metropolitan area is a relatively easy procedure requiring only traffic counts and street mileage measurements. Where no breakdown by vehicle type is required, a rather small manpower investment is required.

The results of such estimation are not only valuable in themselves but have other important uses, notably as an accuracy check of origin-destination study trip data. Another use, not discussed in this paper, is to verify and to compare with the output from certain traffic assignment programs.

Recommendations

In future work of this kind, particular attention should be paid to improving the techniques of count location selection. This is especially true where a sample is taken for updating existing, arterial flow maps (as in Chicago), or for obtaining counts on local streets (as in both Chicago and Pittsburgh); but it is also true with regard to the exact count locations on specific route sections wherever these run to rather long lengths.

At the same time, consideration should be given to long-range programming and to the use of either repetitive or accumulative count locations. In Chicago, since the original work described in this paper, two more "samples" have been drawn making four in all, and it is expected that an annual census-taking of the daily vehicle-miles of travel will become a feature of the continuing transportation agency.

The scheduling of counts over the period of count taking should be explicitly related to the problem of factoring counts to the average for a particular time period; for example, to the average annual daily traffic.

To conserve cost, great care should be taken in the scheduling of manual classification counts. This should be kept to the minimum possible, and a technique of short counts employed wherever feasible.

Where the results of this kind of work are used as an accuracy check of origin-destination study trip data, there is a great need for more reliable information concerning over-the-road trip lengths. This may be obtained from a sub-sample of home-interview trip respondents in several ways and should prove useful as well for deriving so-called diversion curves appropriate to particular areas.

ACKNOWLEDGMENTS

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Estimating Traffic Volumes by Systematic Sampling

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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

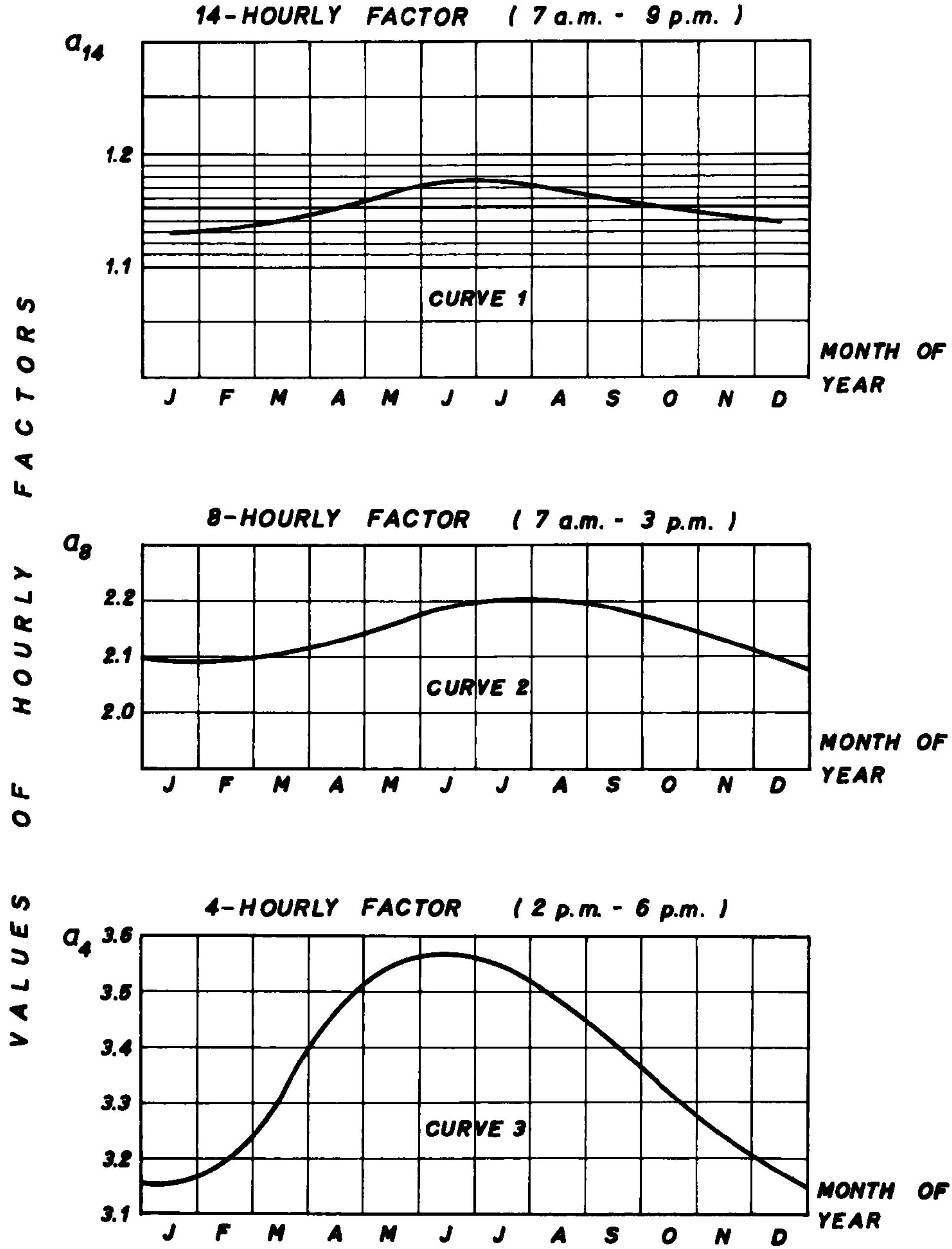

Figure 1. Seasonal fluctuations of hourly factors (Swiss rural highways, 1953-1955).

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

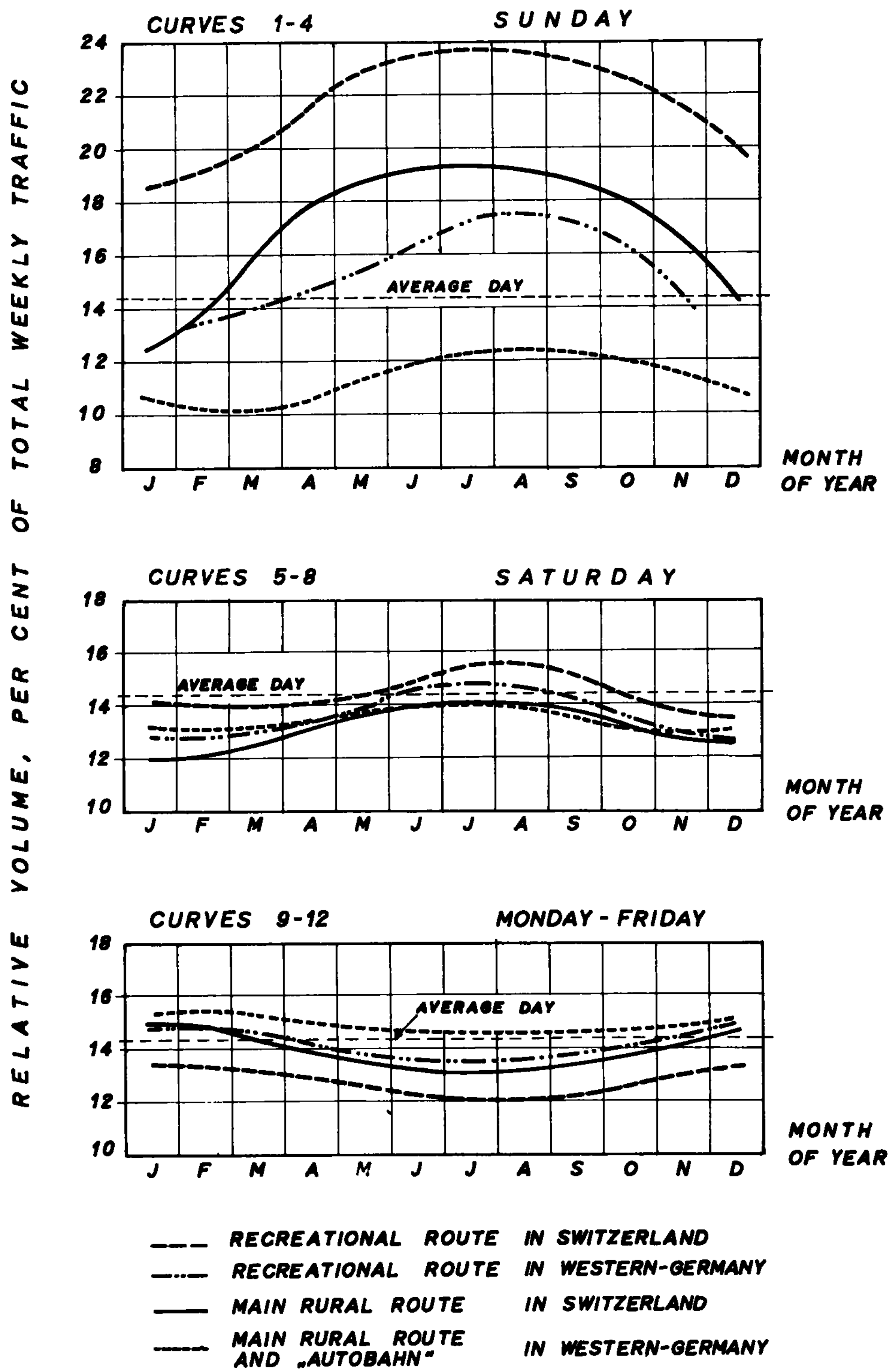

Figure 2. Weekly time patterns of traffic flow (Swiss rural highway system 1955 and rural highways in the Federal Republic of Germany, 1955-1958).

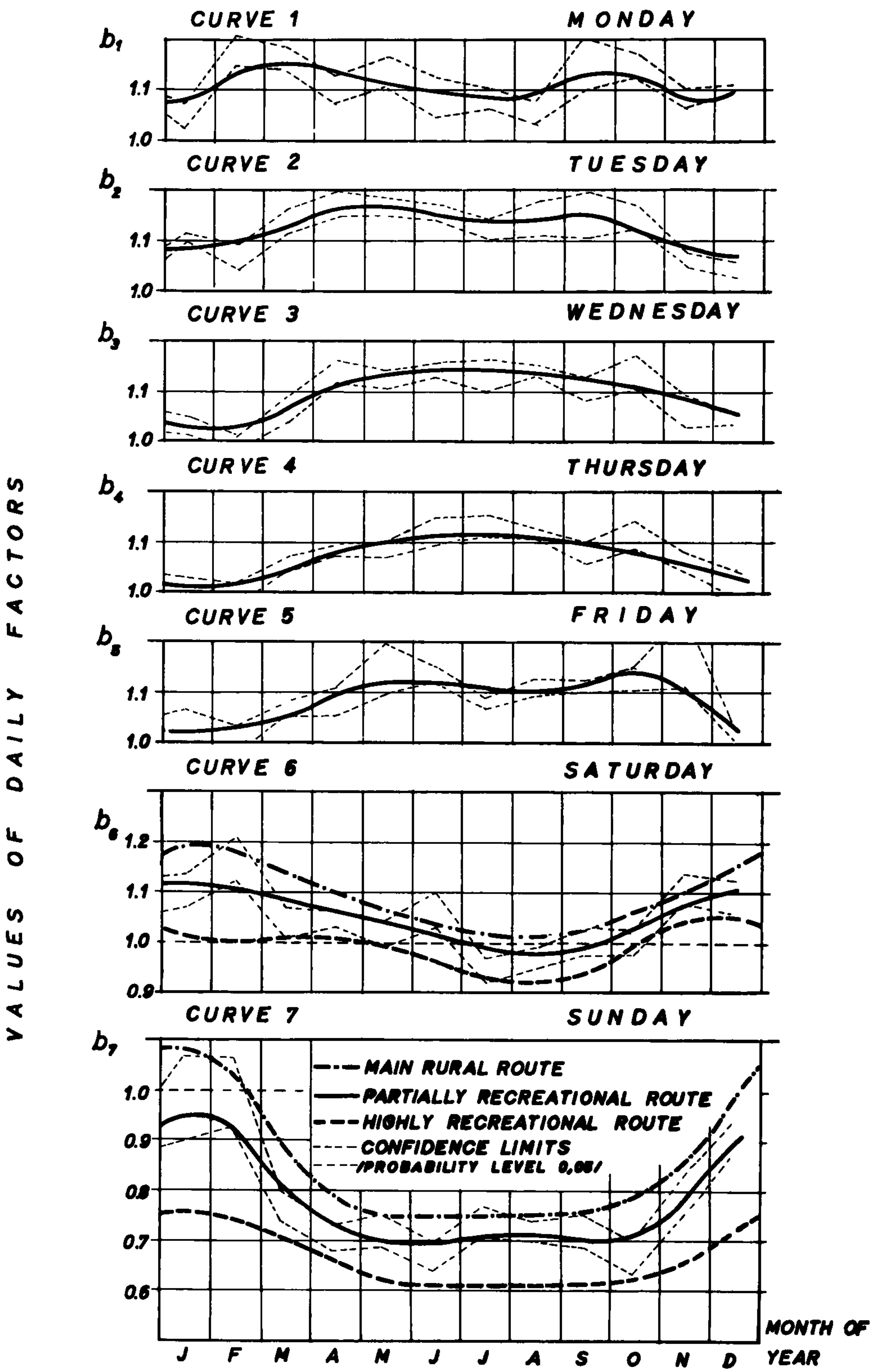

Figure 3. Seasonal fluctuation of daily factors (Swiss rural highways), 1955.

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:

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

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:

$$T_a = a_x b_i r_i c_i t_x \quad (2)$$

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

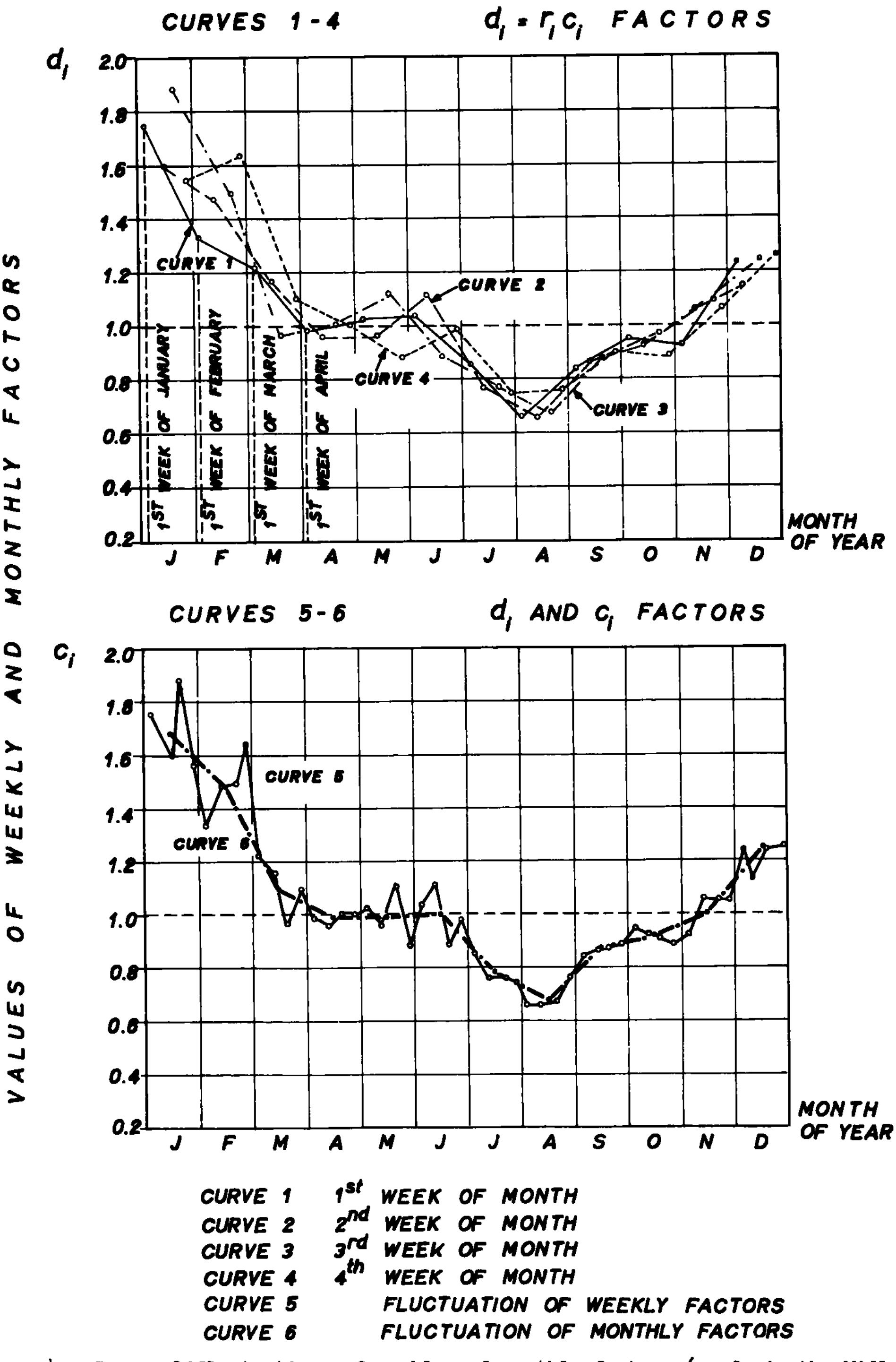

Figure 4. Seasonal fluctuations of weekly and monthly factors (roads in the Midlands and Jura Mountains, Switzerland, 1955).

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

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

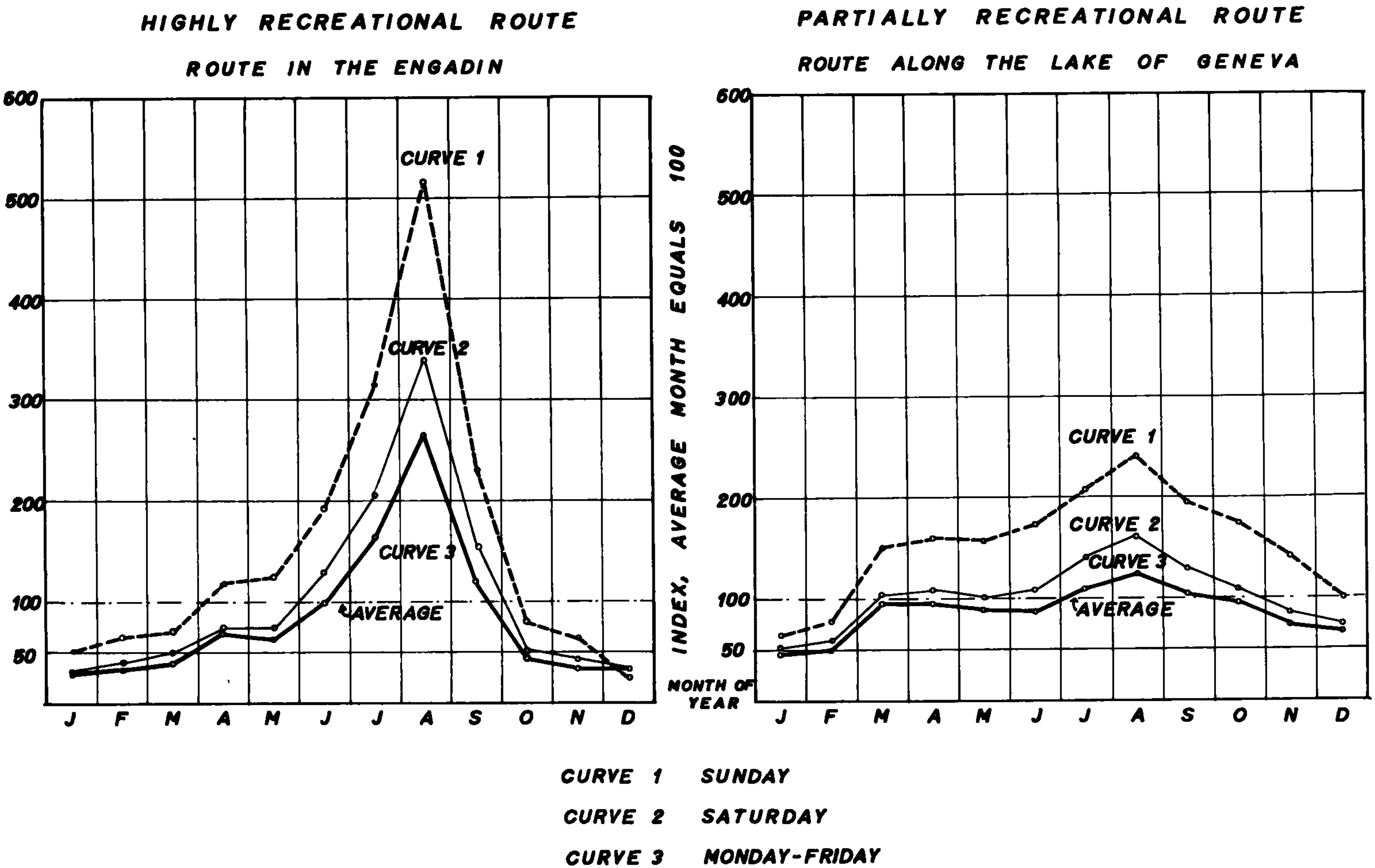

Figure 5. Monthly time patterns of traffic flow (Swiss rural highways, 1955).

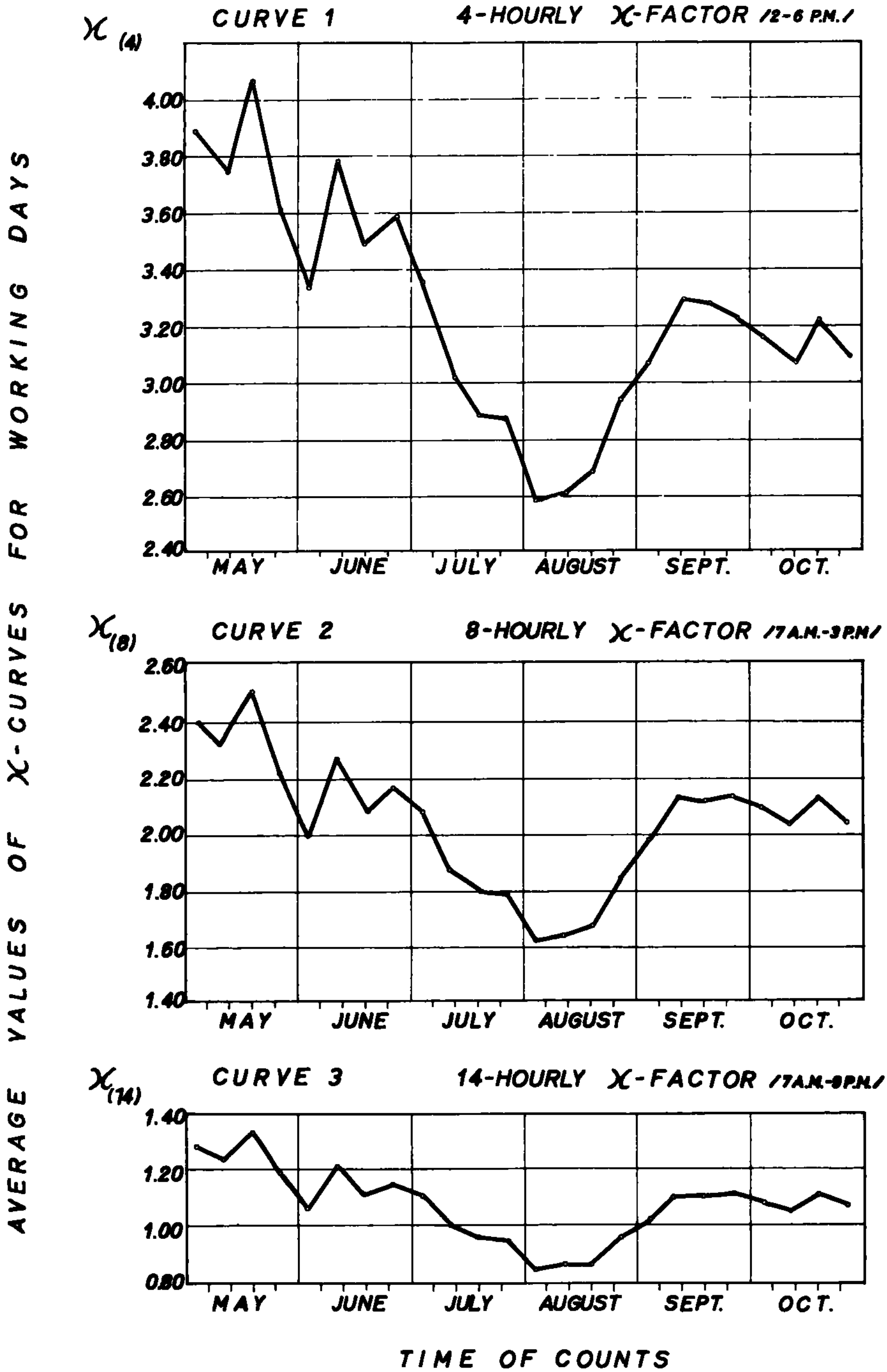

Figure 6. κ_x-curves (roads in the Midlands and Jura Mountains, Switzerland, 1955).

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 $\bar{c}_7$,

$$\bar{z}_3 = \frac{1}{\frac{1}{\bar{c}_5} + \frac{1}{\bar{c}_6} + \frac{1}{\bar{c}_7}} \tag{5}$$

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 ± 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

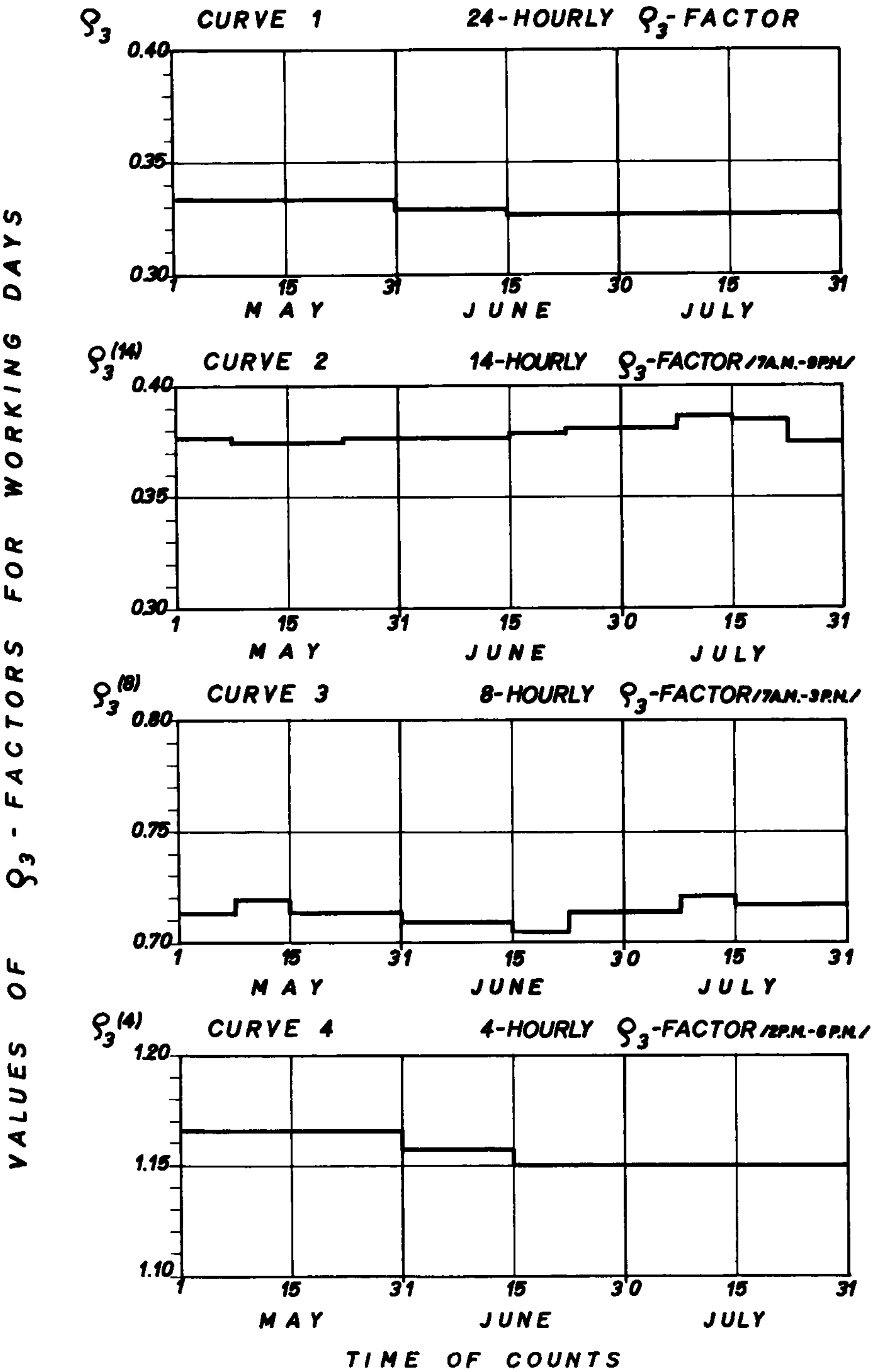

Figure 7. ρ_3-curves (Swiss rural highways, 1955).

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

$$T_a = \rho_3 (q_5 + q_6 + q_7) = 0.3 (q_5 + q_6 + q_7) \quad (11)$$

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		Standard Deviation, ρ_D
		Mean, $\bar{d}_{(i)}$	Limits, $\bar{d}_{(i)} \pm 2s_{\bar{x}}$	
(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.

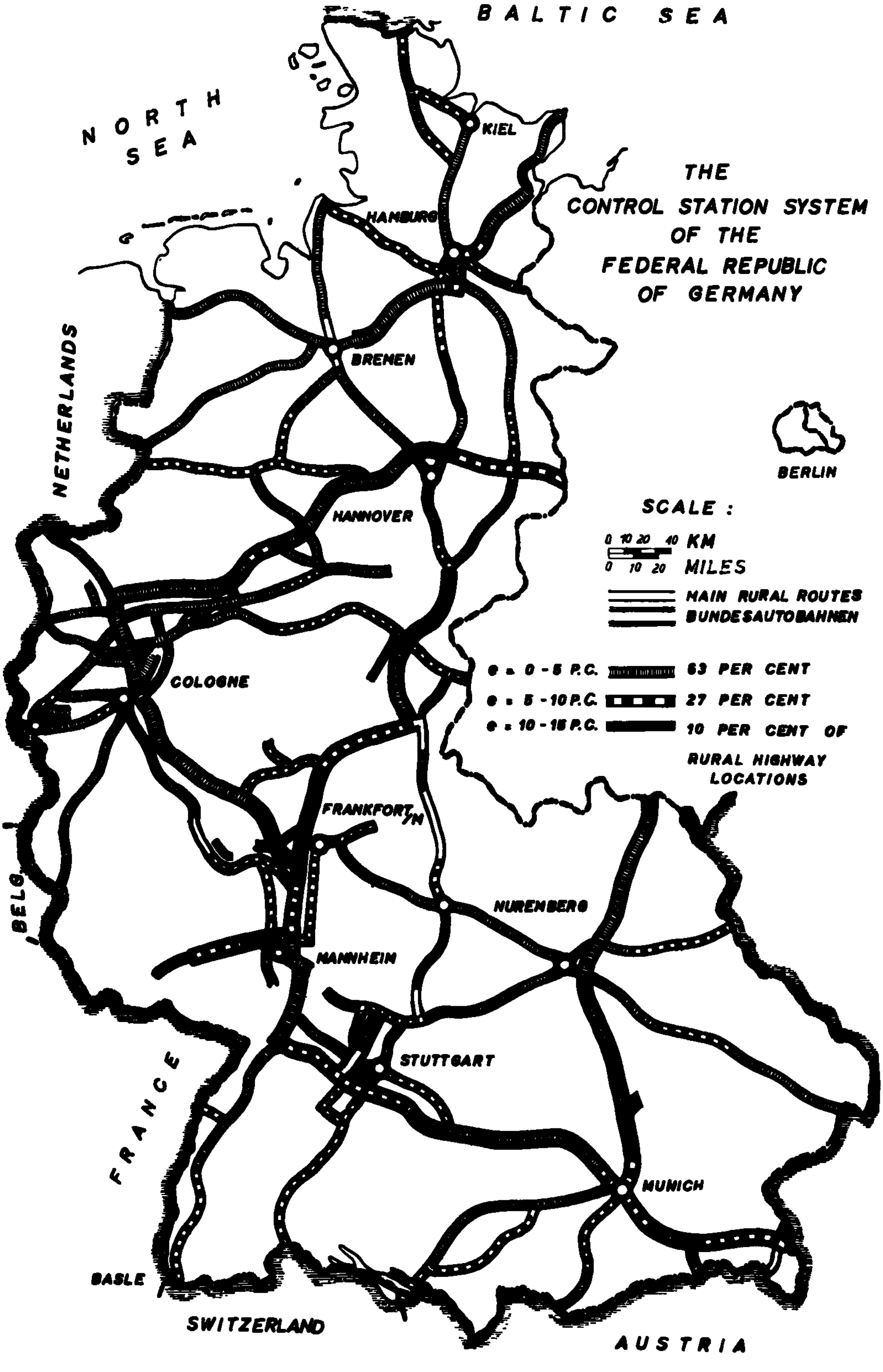

Figure 8. Empirical checking of errors in the ADT obtained by means of ρ_3- curves (main European international arteries in the Federal Republic of Germany, 1955-1958).

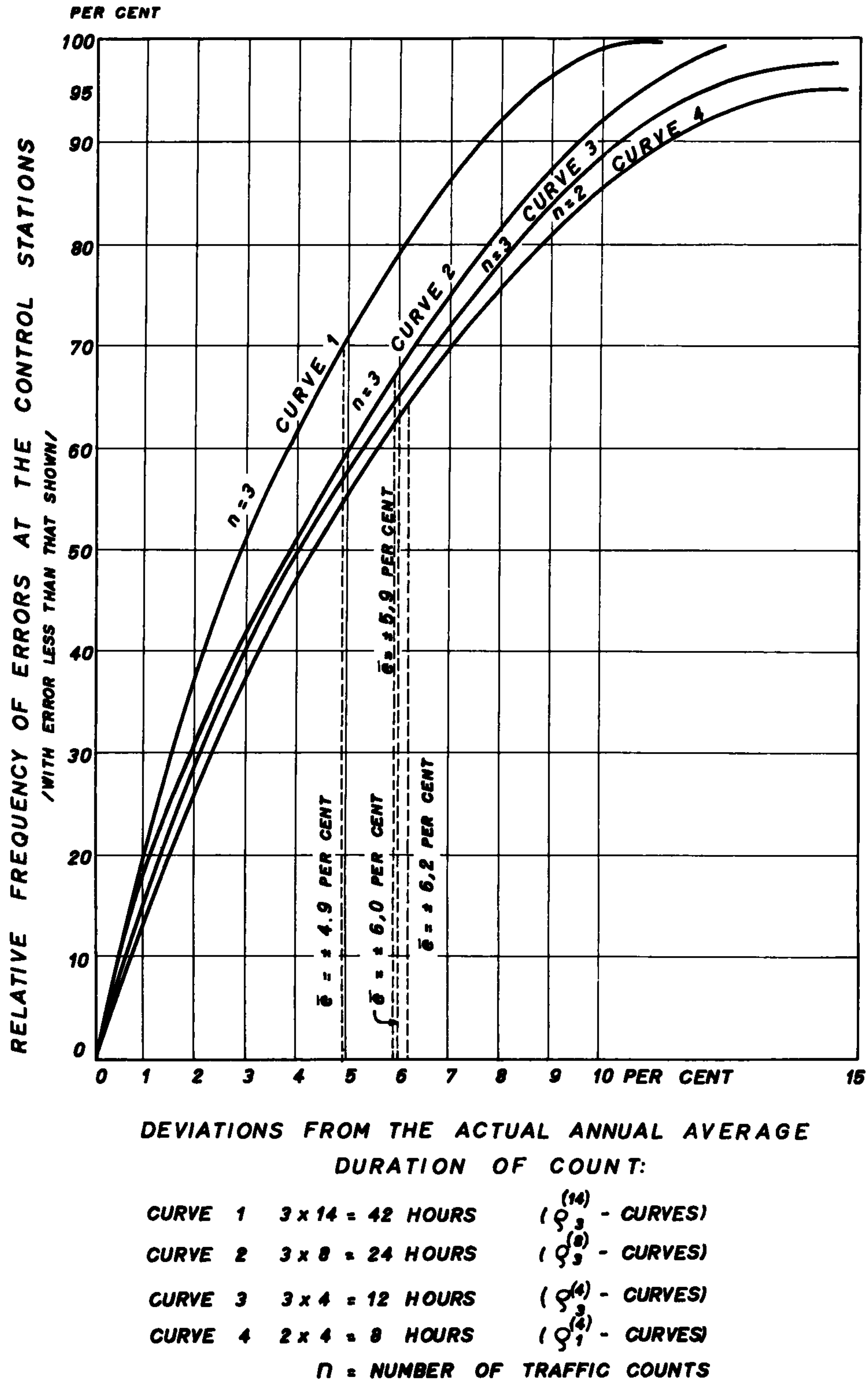

Figure 9. Empirical checking of errors in the ADT obtained by means of ρ-curves (Swiss rural highway system, counts made by Union Suisse des Professionnels de la Route, 1955).

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.

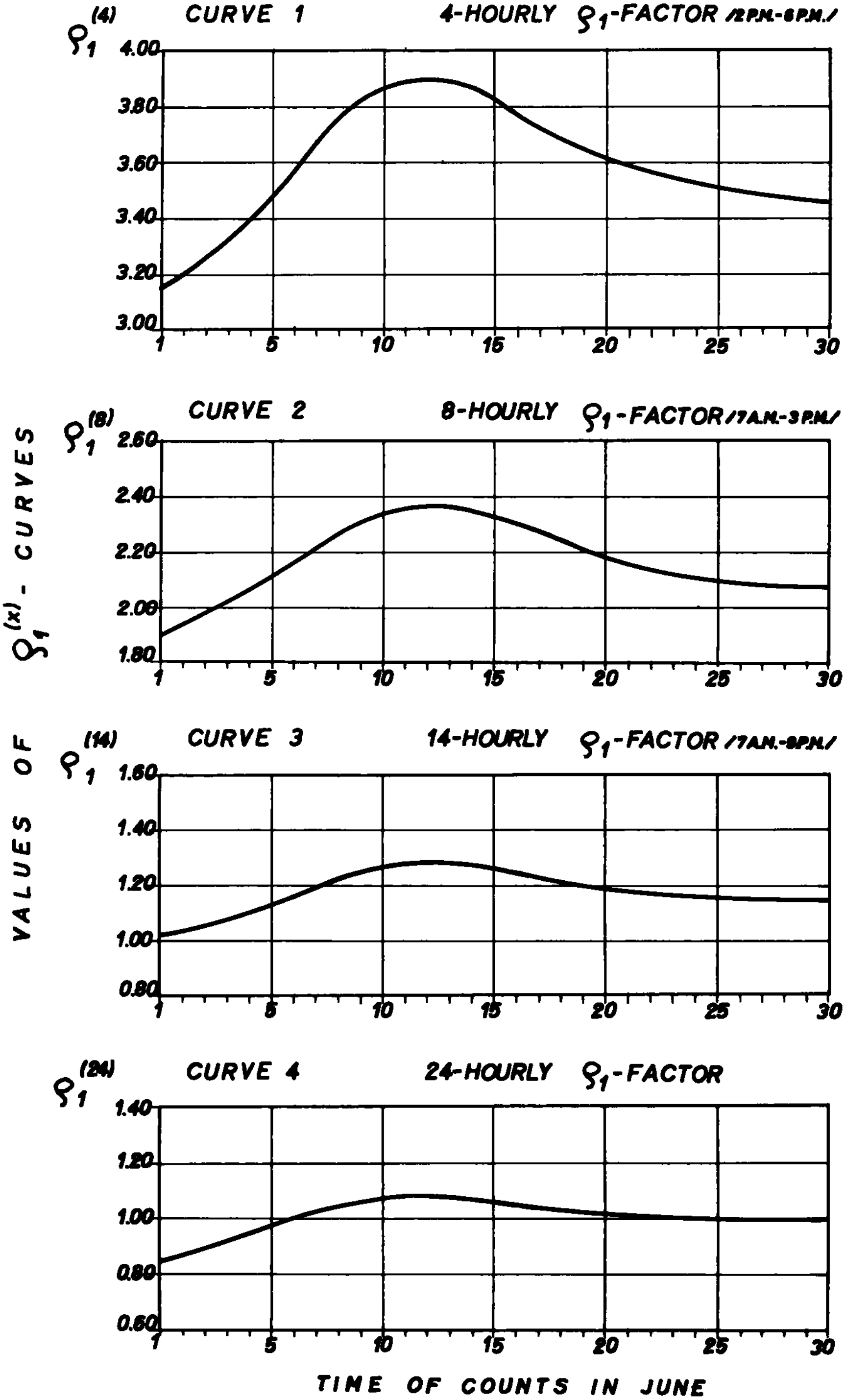

Figure 10. ρ_1-curves (Swiss rural highway system, 1953-1955).

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

$$\delta_p = 100 \frac{t_{max}}{t_{24}} \qquad (15)$$

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

$$\delta_{max} = 13 \text{ percent} \qquad (16)$$

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

$$\delta_p = \text{constant} \qquad (17)$$

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

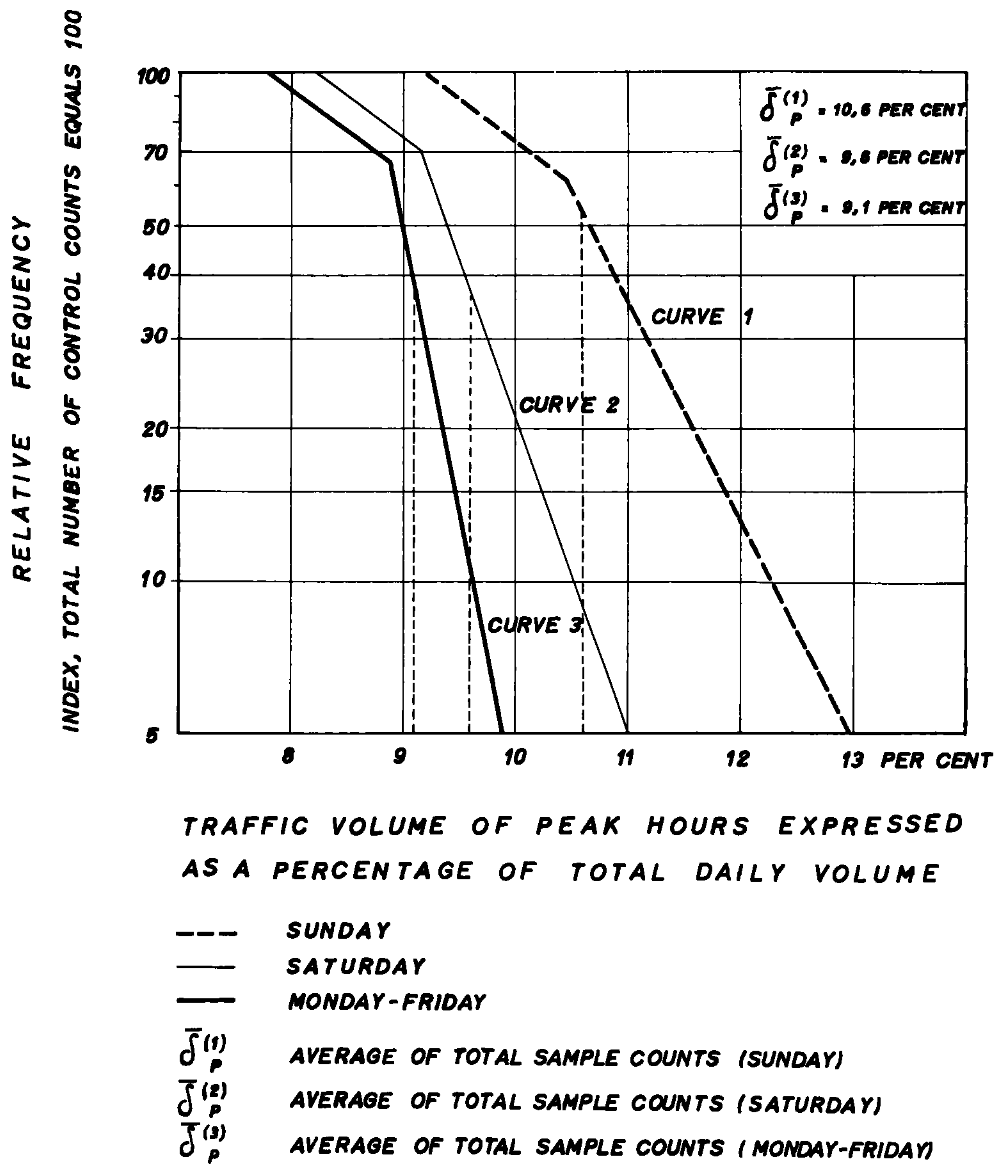

Figure 11. Frequency distribution of hourly traffic volume as a percent of 24-hour daily traffic (Swiss rural highways, 1953-1955).

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

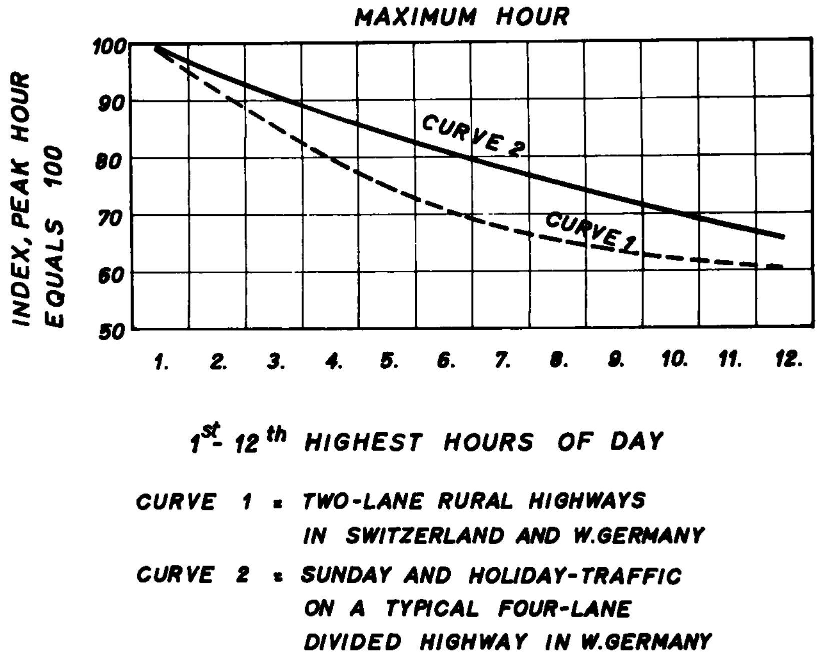

Figure 12. Peak hours of traffic volume (Swiss rural highway system and rural highways in the Federal Republic of Germany, 1955).

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 δ_p-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 (δ_p = 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).

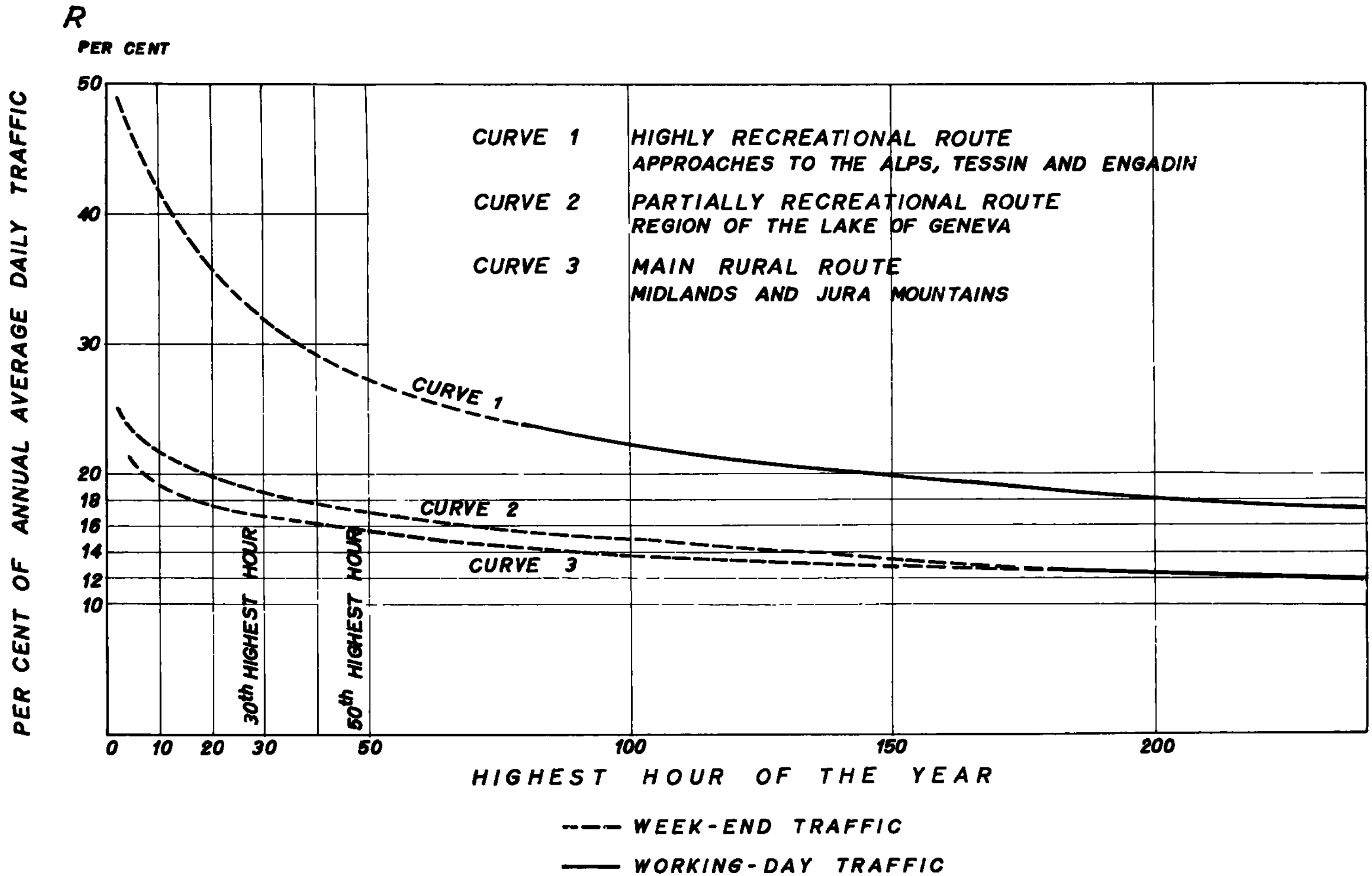

Figure 13. Relation between peak hourly flows and annual average daily traffic on two-lane rural highways (Swiss rural highways, 1955).

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 preceded 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).

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

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

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

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

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

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

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

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

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

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*Assuming 50 percent distribution of traffic by directions.

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

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:

$$T_a = b_i\, d_i\, t_{24} \qquad (28)$$

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

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

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

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

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

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:

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

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 ρ_3-Curves			ADT (veh/24 hr) Calculated from "Short Count" and from ρ_1-Curves			Cen-sus*	Deviations in the ADT Between that Actually Tested and that Derived from ρ_3-Curves			Deviations in the ADT Between that Actually Tested and that Derived from ρ_1-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).

Volume and Speed Characteristics at Seven Study Locations

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This paper reports on those portions of the research project, "Fundamental Characteristics of Traffic Flow," which pertain to volume and speed characteristics on major urban arterials.

Seven study locations in the vicinity of two Michigan cities, Detroit and Lansing, were representative of a wide variety of urban arterials, ranging from a controlled-access expressway to a surface arterial with heavy parking along commercially developed frontage.

At each of the study locations at least one continuous week of data was successfully collected. This involved: (a) detecting traffic volume, speed, and headway information for each individual lane of the direction being studied; (b) transmitting this information from the detection units to a central office; whereupon (c) the information was summarized on graphical and digital recorders. Various analyses were then performed on the data by manual and mechanical means.

The most important findings with regard to traffic volume were the similarities in certain volume characteristics which were found to exist between the seven arterials studied. Ratios, in percentage form, of shorter peak period volumes to longer peak period volumes were computed, and comparisons between routes revealed surprising similarities. Similarities in the cumulative distribution curves of daily minute traffic volumes permitted devising a method for estimating percentile minute volumes for any of the seven routes.

The distribution of minute volumes, by lane, as related to total minute volume was investigated, and the equation for average minute volume in the middle lane as a function of the total minute volume for three lanes in one direction was formulated. Computations were made of approximate confidence intervals for this relationship.

The variation of 15-min average lane speeds, by time of day, and the distribution of 1-min average lane speeds for the seven study locations were determined, and pertinent observations and comparisons were made. By combining lanes on the facilities and plotting the variation of 15-min average speeds, it was found that during the period from 11 a.m. to 3 p.m. the deviations of individual 15-min average speeds from 24-hr average speed were extremely small — smaller, in fact, than the normal accuracy of the speed detection instruments.

● THE MAJOR OBJECTIVE of the research project was to investigate the fundamental characteristics of traffic flow (volume, speed, density, and headway) and the interrelationships of these characieristics on major urban highways. The design of the experiment permitted a secondary objective, that of relating roadway features, as defined by varying degrees of medial and marginal friction, to the fundamental characteristics of traffic flow.

The design of experiment was based on the four friction concept (5, 6) which, in essence, classifies road and traffic characteristics which resist traffic flow into four types of friction — internal, medial, marginal, and intersectional. Internal friction, defined as that friction which exists between vehicles traveling in the same direction, was present in varying degrees at each of the seven study locations as a result of heavy traffic volumes. Intersectional friction, that friction which exists between vehicles traveling at right angles to one another, was eliminated by selecting study locations away from the influence of intersectional movement. The experiment was designed (Table 1) to include the study of arterials with various degrees of medial friction (occurring between vehicles traveling in opposite directions) and marginal friction (existing along the margin of the road).

TABLE 1

Medial Friction / Marginal Friction	None (Wide Median)	Moderate (Narrow Median)	Heavy (No Median)
None (access control)	1	2	3
Moderate (no parking)	4	5	6
Heavy (parking)	7	8	9

Each combination of medial and marginal friction was defined as a "cell", and the cells were assigned numbers one through nine (Table 1). It was originally planned to study nine locations, one for each cell. Locations which fit the definitions of cells one through seven were selected; however, no locations for cells eight and nine could be found which were free from the influence of intersectional friction.

At each study location, a radar speed detector and volume detector were installed for each lane to detect the speed of each vehicle, the time headway between each pair of vehicles, and the volume of traffic for any period of time. In all cases, only one direction of traffic was studied.

The measured traffic characteristics were transmitted to a 17-ft trailer which housed the recording equipment. The volume impulses were channeled to a 20-pen recorder which had four pens operating — one for each lane and a fourth pen with manual control for daily volume checks. The chart speed of the recorder was 6 in. per minute, which permitted measuring time headways directly from the chart to the nearest ¼ sec. The speed impulses were routed to graphical speed recorders, one for each lane, which were operating at 1½ in. per minute. The trailer was located in a position that permitted the person in the trailer to observe the traffic characteristics that were being measured and recorded.

A check of the accuracy of the volume and speed detection equipment was made each morning and afternoon, for each lane, while the station was in operation. The volume check was made by counting vehicles using the manually actuated pen of the 20-pen recorder. The speed checks were made by timing, with a stop watch, vehicles passing through a measured speed trap. These checks indicated that the minute volumes were normally accurate to within ± 0.7 percent and the minute average speeds were normally accurate to within ± 1.5 mph.

VOLUME CHARACTERISTICS

This section presents the results of analyses pertaining to traffic volume characteristics. Not only the characteristics on each of the seven types of facilities are evaluated, but also the similarity and differences in volume characteristics between the various types are discussed.

Comparison of Various Peak Period Traffic Volumes

For each of the seven facilities, the peak 1-min, 5-min, 15-min, and 1-hr periods were determined. The volume during these periods is given in Table 2. The periods indicated are consecutive but do not necessarily start and end on an hour or on an even 5 min. For example, the values given in the 15-min col. are representative of traffic volume during that consecutive 15-min period during which more vehicles were passed than during any other consecutive 15-min periods during the day.

TABLE 2

PEAK PERIOD TRAFFIC VOLUMES

Marginal Friction	Medial Friction	Cell	Route	Traffic Volume 1 Min	5 Min	15 Min	1 Hr	6a.m.-6p.m.	6p.m.-6a.m.	Tot. 24-Hr Vol
None	None	1	Ford Exp.	115	496	1,424	5,268	37,742	11,989	49,731
	Mod	2	Davison Exp.	63	283	775	2,763	18,812	7,887	26,699
	Heavy	3	Schaeffer Road	58	159	351	1,186	10,242	4,218	14,460
Moderate	None	4	Mich. Ave., E. Lansing	27	110	322	1,053	7,160	3,035	10,195
	Mod	5	Mich. Ave., Dearborn	53	237	603	2,172	14,075	4,688	18,763
	Heavy	6	Grand River, E. Lansing	39	157	437	1,423	7,008	3,150	10,158
Heavy	None	7	James Couzens Highway	84	334	878	3,360	21,059	10,014	31,073

Table 2 also gives the daytime (6 a.m. to 6 p.m.), nighttime (6 p.m.-6 a.m.), and total 24-hr volumes. Notice the wide range of 24-hr volumes—from nearly 50,000 vehicles on the Ford Expressway (cell 1) to approximately 10,000 vehicles on the two routes in East Lansing (cells 4 and 6). It is also interesting that cell 7, the James Couzens Highway, which had heavy marginal friction in the form of parking, carried more traffic during the periods shown than did the Davison Expressway.

To determine if patterns exist in the ratios of the volumes between any of the time periods, these ratios, in the percentage form, were computed and are given in Table 3. Shown are the percentages that volumes during the peak periods listed across the top of the table are of the volumes during the peak periods listed along the left side of the table. For example, on the Ford Expressway the peak 1-min volume (115) is 23.2 percent of the peak 5-min volume. For each of the comparisons an average percentage for all seven cells was computed. It can be seen that there does not seem to be large variation of the peak volume ratios between routes, and usually the percentage for any given cell differs very little from the average for all cells. This is of greater significance considering the numerical differences in 24-hr volumes, the wide variety of geometric design features, and the considerable difference in size and character of the areas from which traffic is attracted to the various routes. Another important factor is that two of the routes studied were in East Lansing whereas the remainder were in the Detroit area.

The ratio of 1-min volumes to 5-min volumes, and of 1- and 5-min volumes to 15-min volumes for Schaeffer Road traffic, is much larger than for the six other routes studied. A detailed review of the minute volumes indicates that the maximum minute volume (58 vehicles) is extremely greater than the second highest minute volume of 41

TABLE 3

COMPARISON OF PEAK TRAFFIC VOLUMES

	Cell No.	Study Location	1 Min.	5 Min.	15 Min.	1 Hr	6 a.m. to 6 p.m.	6 p.m. to 6 a.m.
5 Min.	1	Ford	23.2%*					
	2	Davison	22.3					
	3	Schaeffer	36.5					
	4	Mich. Ave., E. Lansing	24.5					
	5	Mich. Ave., Dearborn	22.4					
	6	Grand River, E. Lansing	24.8					
	7	James Couzens	25.1					
		Average	25.5					
15 Min.	1	Ford	8.1	34.8%				
	2	Davison	8.1	36.5				
	3	Schaeffer	16.5	45.3				
	4	Mich. Ave., E. Lansing	8.4	34.2				
	5	Mich. Ave., Dearborn	8.8	39.3				
	6	Grand River, E. Lansing	8.9	35.9				
	7	James Couzens	9.6	38.0				
		Average	9.8	37.7				
1 Hr	1	Ford	2.2	9.4	27.0%			
	2	Davison	2.3	10.2	28.0			
	3	Schaeffer	4.9	13.4	29.6			
	4	Mich. Ave., E. Lansing	2.6	10.4	30.6			
	5	Mich. Ave., Dearborn	2.4	10.9	27.8			
	6	Grand River, E. Lansing	2.7	11.0	30.7			
	7	James Couzens	2.5	9.9	26.1			
		Average	2.8	10.7	28.5			
24 Hr	1	Ford	0.23	1.0	2.4	10.6%	75.9%	24.1%
	2	Davison	0.24	1.1	2.4	10.4	70.5	29.5
	3	Schaeffer	0.40	1.1	2.4	8.2	70.8	29.2
	4	Mich. Ave., E. Lansing	0.26	1.1	3.2	10.3	70.2	29.8
	5	Mich. Ave., Dearborn	0.28	1.3	3.2	11.6	75.0	25.0
	6	Grand River, E. Lansing	0.38	1.5	4.3	14.0	69.0	31.0
	7	James Couzens	0.27	1.1	2.8	10.8	67.8	32.2
		Average	0.29	1.2	2.9	10.8	71.3	28.7

*Example: On the Ford Expressway the peak 1-min volume (115) is 23.2 percent of the peak 5-min volume (496).

vehicles. On the other hand the peak 5-min volume is relatively small because it includes minute volumes as low as 12 and 13 vehicles per minute. The net result is a high 1-min to 5-min volume ratio and 1-min to 15-min volume ratio. The proximity of the Ford Motor River Rouge plant may be partially the reason for the abnormal 1-min and 5-min peak volume periods.

Although not absolutely true in all cases, it may be generally observed that the higher volume routes (cells 1, 2, and 7) are characterized by lower percentages in the table. This indicates that on the higher volume routes the demand is spread out over longer periods — that is, the peak periods are less accentuated than on the lower volume routes. It is felt, however, that the importance of this presentation lies in the close agreement of the percentages rather than in the explanation of the relatively minor differences.

The practical use of these results is for estimating any of the peak period volumes. By entering the table with any of the listed peak period traffic volumes, any other peak period volume may be estimated.

Hourly Variations of Traffic Volume

To obtain a pictorial view of the variations of traffic volume during the day in each of the cells, and to compare the cells with each other, a plot was made of hourly volume — as a percentage of 24-hr volume (one direction) — versus time of day. This plot is shown in Figure 1. The hourly variation for each of the seven cells is shown by a different type of line as indicated by the key. Before discussing the variations, it should once again be noted that traffic in one direction only was observed. Consequently, it can be seen that some of the facilities depicted have peak periods during the morning, while others have their peaks during the afternoon. Regardless of this fact, there is recognizable similarity in the traffic volume variations from cell to cell. The cell which seems to deviate farthest from the general pattern is cell 4 (Michigan Avenue, East Lansing). The hourly volumes during early afternoon on this facility are a considerably higher percentage of 24-hr volume than on the other facilities. Notice, also, the sharp evening peak for cell 4 reaching a maximum of 7.0 percent of the 24-hr volume between 9 and 10 p.m. Much of the traffic contributing to this peak originated from a nearby shopping center which remained open until 9 p.m.

It can be generally observed in the figure that those routes with comparatively high peaks in the morning had comparatively low peaks during the afternoon and vice versa. There is nothing startling about this, but the results do follow an expected pattern.

One result which was being sought from this analysis was to determine whether some period during the day was particularly well suited as a volume estimating period. In other words, it would be desirable to select a period when the percentage of the hour

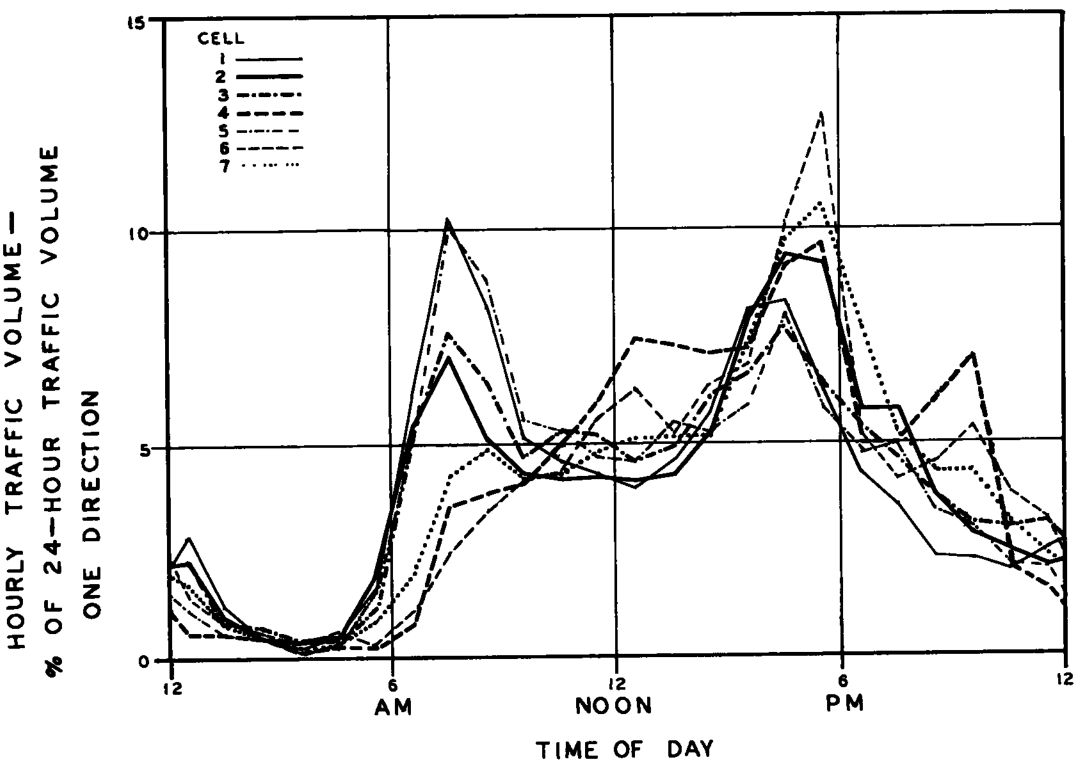

Figure 1. Hourly traffic volume fluctuations.

volume to the 24-hr volume was relatively uniform for all the cells studied. By inspecting Figure 1 it seems that the most uniform period is from 10 to 11 a.m. For this hour the range of values for the seven cells is from 4.2 to 5.3 percent of 24-hr volume, and the average value is 4.73 percent. If, then, it is desired to make an hour directional volume count and to estimate the 24-hr directional volume, the data indicate that the best period for the short count would be from 10 to 11 a.m. For the data presented, an estimate based on the 10 to 11 a.m. volume will yield a smaller range of percent differences from the actual 24-hr volume than will estimates based on any other 1-hr period.

The figure also reveals that the peak hour expressed as a percentage of the 24-hr volume for the seven cells was 10.3, 9.3, 7.8, 9.6, 10.2, 12.7, and 10.7 percent. The hour volumes selected in computing the percentages began on the hour and consequently are slightly lower than similar percentages given in Table 3.

Distribution of Daily Minute Traffic Volume

Traffic volume for each minute of the selected 24-hr period was measured; therefore, it was possible to determine the distribution of the minute volumes for each cell. Because volume is more commonly expressed in terms of 24 hours rather than as minute volumes, it was felt desirable, in this case, to do so.

The procedure used was to plot 24-hr percentile minute volume versus the percent that these minute volumes were of the 24-hr volume. Two such graphs are shown in Figure 2 — the upper graph indicating the accumulative minute volume distribution for each of the cells, and the lower graph with an "average" curve representing the distribution of minute volume for all seven cells. It is of significant value to note the high degree of similarity between the cells, and it was for this reason that the average distribution was plotted.

The legend of Figure 2, "Method of Estimating Various Percentile Minute Volumes," implies the usefulness of the relationship. That is, by entering the lower graph with any desired percentile minute volume, the percent that volume is of the 24-hr volume can be determined. As an example, consider a study of traffic flow on an urban arterial highway where the 24-hr traffic volume was determined to be 20,000 vehicles. Suppose it is desired to determine the value of the 24-hr, 90-percentile minute volume (that volume which is exceeded by 10 percent of the minutes during the day and is greater than the remaining 90 percent of the minutes). Entering the graph with 90-percentile minute volume enables determination that it is 0.135 percent of the 24-hr volume. Hence, the 90-percentile minute volume equals 0.00135 x 20,000, or 27 vehicles per minute. When the percent that a certain minute is of 24-hr volume is known, the percentile rank of that minute volume can be determined from the graph.

A number of interesting observations concerning the differences in the accumulated distributions of minute volume can be made from the upper graph in Figure 2. In the middle percentile range the seven distribution curves form a very narrow band. However, the curves spread out considerably in the lower and higher percentile ranges. There does seem to be a pattern in the way in which the curves spread out. First, remember that the two lowest volume routes were cells 4 and 6 (Michigan Avenue and Grand River in East Lansing, respectively), and the three highest routes were cells 1, 2, and 7 (Ford, Davison, and James Couzens). Then note that in the low percentile ranges the curves for cells 4 and 6 are lowest; and, in the upper percentile ranges, the cells 1, 2, and 7 curves are among the lowest four. This indicates that the low 24-hr volume routes have a greater number of minutes whose volumes are a small percentage of 24-hr volume than do the higher 24-hr volume routes. The 95- to 100-percentile minute volumes on the high volume routes are not generally as large a percent of the 24-hr volume as on the lower volume routes. More simply stated, it was generally the case on the routes studied that the lower volume routes had a higher number of low minute volumes and also had relatively larger peak minute volumes. This observation reinforces the statements and observations made earlier. The 100-percentile minute volumes are the same as that indicated in Table 3 relating the peak minute to the 24-hr volume.

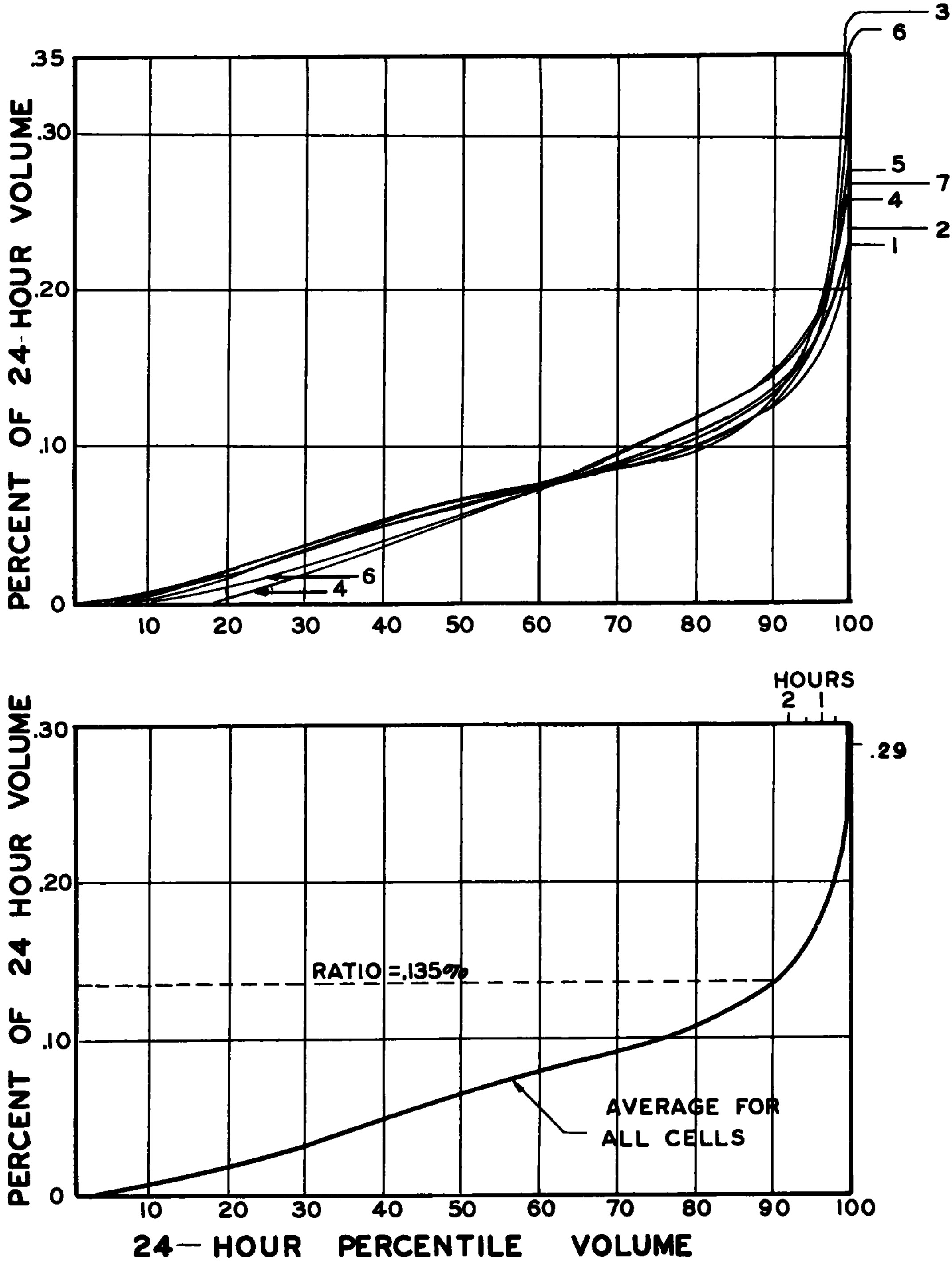

Figure 2. Method of estimating various percentile minute volumes.

An analysis was made to determine where each distribution curve departs from the approximately linear path that it follows in the lower percentile ranges. It is felt that this point demarks what can be considered as the separation between peak minute volumes and non-peak minute volumes. Finding this point on each of the curves then was a matter of determining the point following which an increased rate of change (or slope) occurs. The rate of change is determined on the basis of the ratio of vertical to horizontal rate of growth

$$\left(\frac{\Delta V}{\Delta H}\right)$$

which is the tangent of the angle between the curve segment and the horizontal axis. To determine the point following which a rapid increase in slope is noticeable, attention was also given to the rate of change of this ratio. Based on both of these considerations, the points were found after which a departure from the linear rate of growth occurs, and these are listed, as follows:

Cell	Cumulative Percentage
1 — Ford Expressway	84
2 — Davison Expressway	82
3 — Schaeffer	92
4 — Michigan (East Lansing)	88
5 — Michigan (Dearborn)	89
6 — Grand River (East Lansing)	82
7 — James Couzens	80
Average	85.3

The 85.3 percent indicates that the peak minute volumes extend for about 3 hours and 32 minutes. Again the fair degree of similarity between cells with regard to the location of this point is noticed. This analysis also indicates that, generally speaking, the peak periods last longer on the high volume routes (cells 1, 2, and 7) than on the lower volume routes.

There also seems to be a point higher up on each of the distribution curves where another rapid rate of change of slope occurs and the curves become nearly perpendicular. Using the same technique, the following points were found after which the most rapid rate of change occurs:

Cell	Cumulative Percentage
1 — Ford Expressway	98.9
2 — Davison Expressway	97.6
3 — Schaeffer	99.4
4 — Michigan (East Lansing)	98.9
5 — Michigan (Dearborn)	98.0
6 — Grand River (East Lansing)	98.4
7 — James Couzens	95.6
Average	98.1

The 98.1 percent indicates that this minute volume level is exceeded approximately 27 min per day. These percentiles are analogous to the 30th highest hourly volume in that they have a possible use as design volumes. It is economically unfeasible to design the road so that it will have sufficient capacity during every single minute. It can be seen on the lower graph of Figure 2 that 98 percentile corresponds to a minute volume which is approximately 0.20 percent of 24-hr volume. The 100 percentile minute volume is approximately 0.29 percent of 24-hr volume. Consequently, if the road is to satisfy the requirements of the highest 2 percentile of the 24-hr period (in other words the highest 29 min), it must be designed to carry nearly 50 percent more traffic.

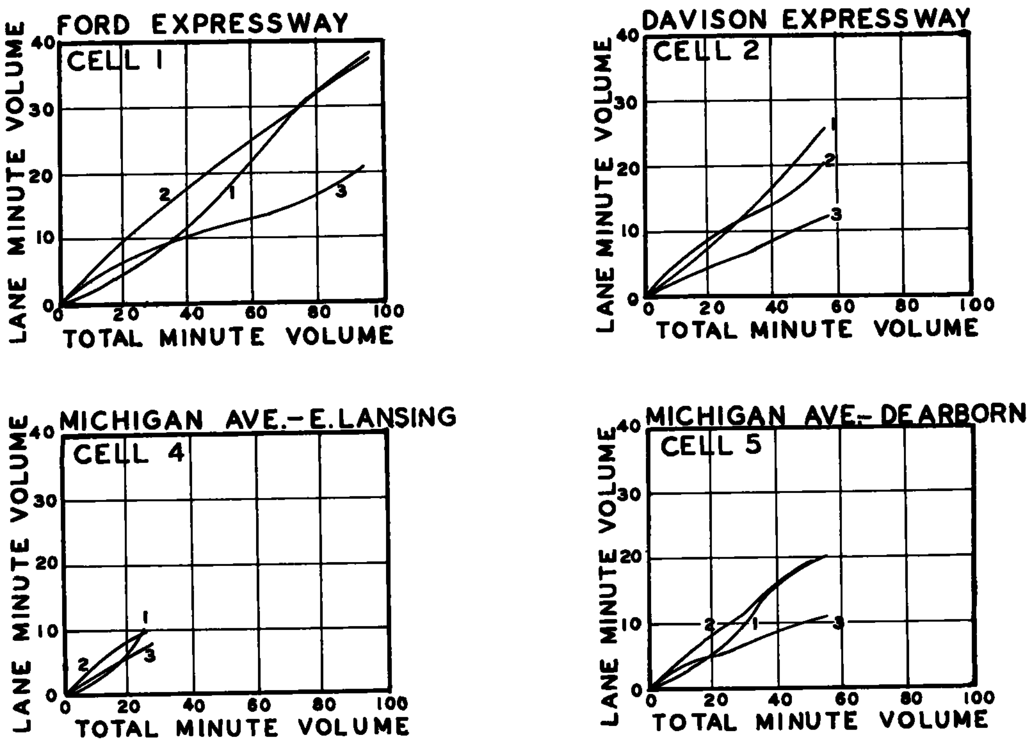

Figure 3. Lane use on test routes.

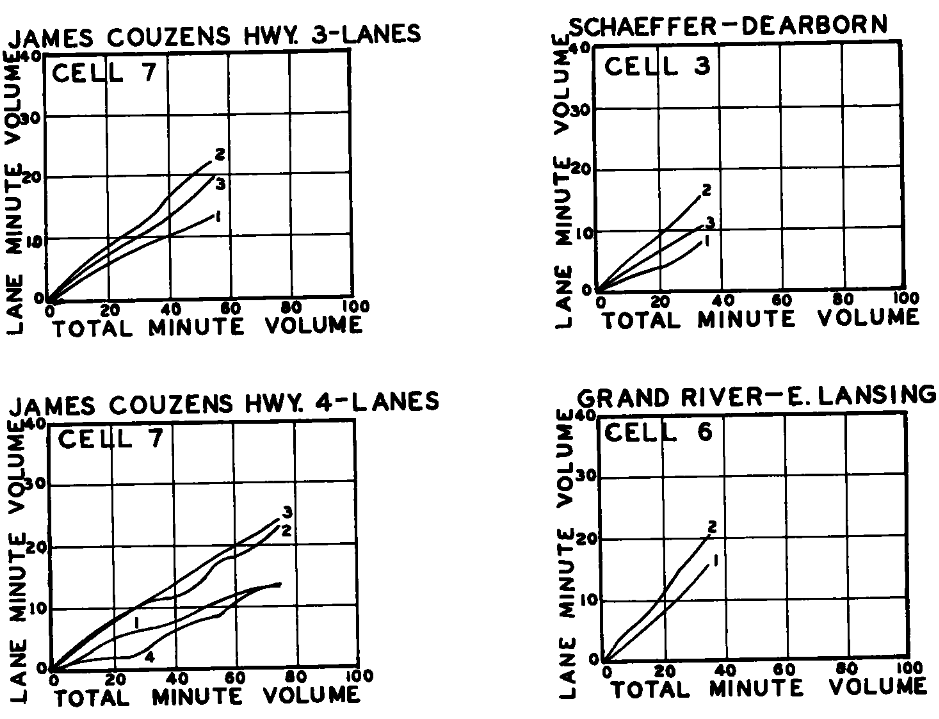

Figure 4. Lane use on test routes.

The Effect of Traffic Volume on Lane Distribution

For an analysis of the relationship between total volume and lane use for each of the cells, the graphs shown in Figures 3 and 4 were constructed. On each of the graphs the vertical scale is lane minute volume, and the horizontal scale is total minute volume. There is one graph for each cell, with the exception of cell 7, the James Couzens Highway, which is depicted in two graphs — one for the normal periods when there are three moving traffic lanes, and one for the period from 4 to 7 p.m. when parking is prohibited and there are four moving traffic lanes. The graphs are constructed in such a way that a point on a curve represents the average minute lane volume for a given total minute volume.

A definite pattern exists between lane use and traffic volume and can be seen from Figures 3 and 4. In each of the seven graphs, beginning with the lowest minute volume and proceeding to the largest minute volume, there is an apparent interplay between the use of the lanes. First, lane 2 (middle lane) carries the greatest lane volume with lane 3 (curb lane) carrying the second highest lane volume. As the minute volume increases, lane 2 continues to carry the highest lane volume, while the use of lane 1 increases faster than lane 3, and in several of the cells lane 1 begins to exceed lane 3. At the highest minute volume ranges the volumes in lane 1 approach or, in several cases, exceed the volume in lane 2 while the volume in lane 3 is approximately only one-half as great as in either lanes 1 or 2.

There are two additional observations that can be made in regard to the general pattern of volume distribution between lanes: (1) For any total minute volume, the average minute volume in lane 3 is never greatest; and (2) for any total minute volume, the average minute volume in lane 2 is never smallest. Another factor which is apparent in Figure 3 is that when total volume is high, lane 3 is carrying a considerably lower volume than either of the other two lanes. In other words, when it is really needed, the lane next to the shoulder is not carrying its share of the load.

To be able to better compare cells with each other, the curves were plotted in a slightly different manner as is shown in Figure 5. Each lane was plotted separately so there are three graphs, and the lane volume curve for the cells is shown on each graph. Cell 6 (Grand River in East Lansing) was omitted in this case because it has only two lanes in the direction studied, whereas all the other cells had three lanes.

Note the very narrow band formed by the cell curves in the lane 2 graph, and also that the slopes of the curves are relatively constant. The lane 3 and particularly lane 1 curves, however, are decidedly more spread out and have more fluctuating slopes. Because of the close agreement of the lane 2 curves, a statistical analysis was performed to determine an average line for all six cells.

The average volume for lane 2 of all six cells under scrutiny, and for total minute volumes varying from 0 to 60, is represented by a nearly straight line. The equation

$$\bar{\bar{V}}_2 = 0.415\ V_t$$

representing a straight line passing through the origin closely approximates the values determined from the collected data. The constant 0.415 implies that 41.5 percent of the total minute volume uses lane 2. In this equation V_t = total minute volume, and $\bar{\bar{V}}_2$ = the mean of the average lane 2-min volumes.

Assuming that the average volumes for the individual facilities represented a random sample from a population of such facilities, and assuming that the variables are normally distributed, 95 percent confidence intervals for the mean were computed for certain levels of the traffic volume. These confidence intervals lie in the range as indicated in the following table:

Range of V_t	Range of 95 Percent Confidence Interval
5 - 25	$\bar{\bar{V}}_2 \pm 0.5$
25 - 45	$\bar{\bar{V}}_2 \pm 1.5$

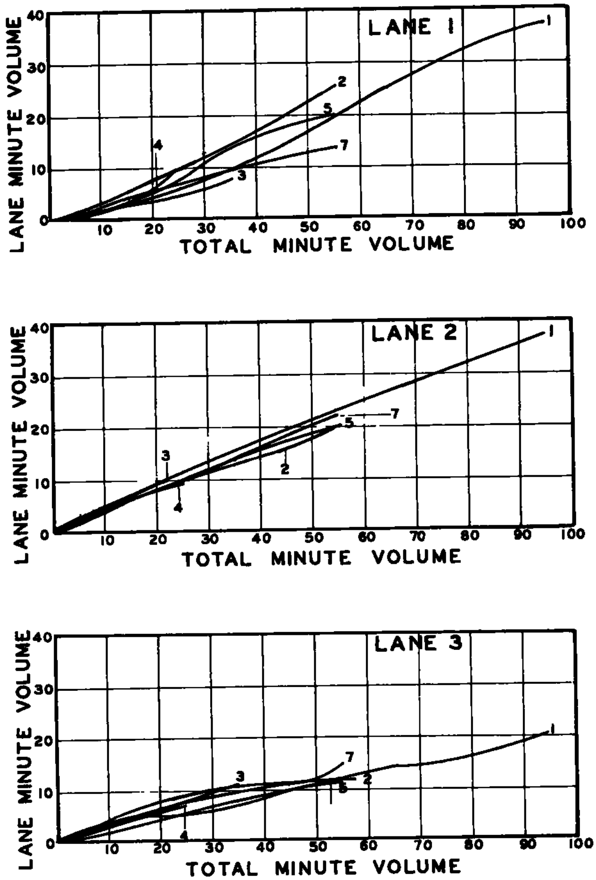

Figure 5. Comparison of lane use by lane.

For V_t's higher than 45 vehicles per minute, the 95 percent confidence interval is considerably wider. For example, when $V_t = 53$, the 95 percent confidence interval on $\overline{V}_2$ is ± 4.19.

For a given lane 2 average minute volume, $\overline{V}_2$, between 1 and 10, a reasonable estimate of the total minute volume, based on the present data, is

$$V_t = \frac{\overline{V}_2}{0.415} \pm 2.$$

For values of $\overline{V}_2$ between 11 and 15 inclusive, the estimated total minute volume is

$$V_t = \frac{\overline{V}_2}{0.415} \pm 3.$$

Beyond a value for $\overline{V}_2$ of 15, the spread is considerably wider.

A few more interesting observations may be made from the lane 3 and lane 1 graphs of Figure 5. It appears that for a total volume of from 0 to 30 vehicles per minute, lane 3 carries on the average of 30.5 percent of the total volume. For a total volume of 30 to 50, lane 3 carries on the average only 23.5 percent of the total volume, and, furthermore, the percentage decreases even more with larger total minute volume. Conversely, inasmuch as the proportion carried by lane 2 remains relatively constant, the percentage of vehicles carried by lane 1 increases with increased total minute volume. Using the aforementioned percentages for lanes 2 and 3, and knowing the total volume, the amount of traffic using lane 1 can be estimated.

SPEED CHARACTERISTICS

This section presents the results pertaining to the speed characteristics on the seven facilities which were studied. First comparisons are made within each individual cell, and then the results of investigations of similarities and differences between cells are discussed.

Variation of Average Speed by Time of Day

For all seven facilities studied, at least 24 consecutive hours of individual vehicle speed detection in each lane were recorded. The individual speeds were averaged for 1- and 15-min intervals. Because of the small number of vehicles during the 1-min intervals, rather large fluctuations occur from minute to minute (particularly during early morning hours), and it was decided not to attempt to plot the minute-to-minute variation in average speed for the 24-hr period, but rather to plot 15-min average speeds.

Figures 6 and 7 include the variation of 15-min average speed, by lane, for each of the seven cells. For four of the cells (1, 2, 4, and 6) the 15-min average speeds for the total 24-hr period were computed and plotted on the graphs shown. Notice the relatively large fluctuations which occur during the early morning hours, mainly a result of the low volumes during these periods. Because the analysis of individual speeds from the graphical recorder tape is so time consuming (5 minutes of analysis for each 1 minute of data per lane), it was necessary to eliminate those analyses which were felt to be relatively unimportant. Consequently, for the remaining cells (3, 5, and 7) only the

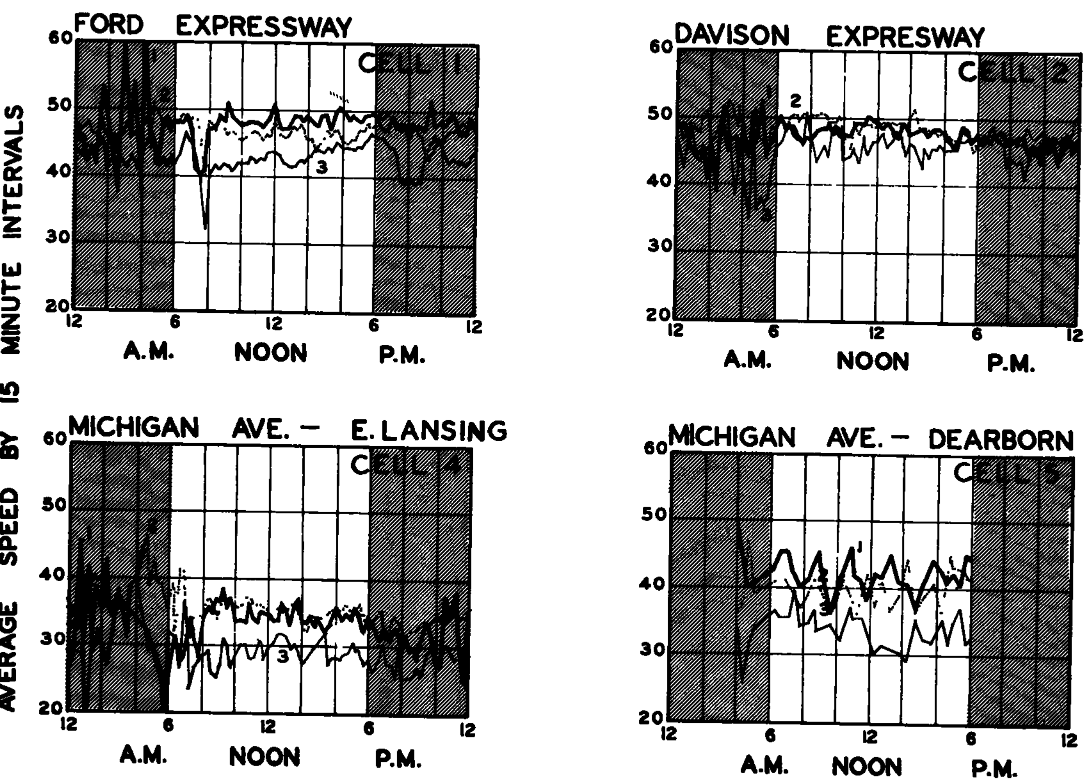

Figure 6. Variation of average lane speed by time of day.

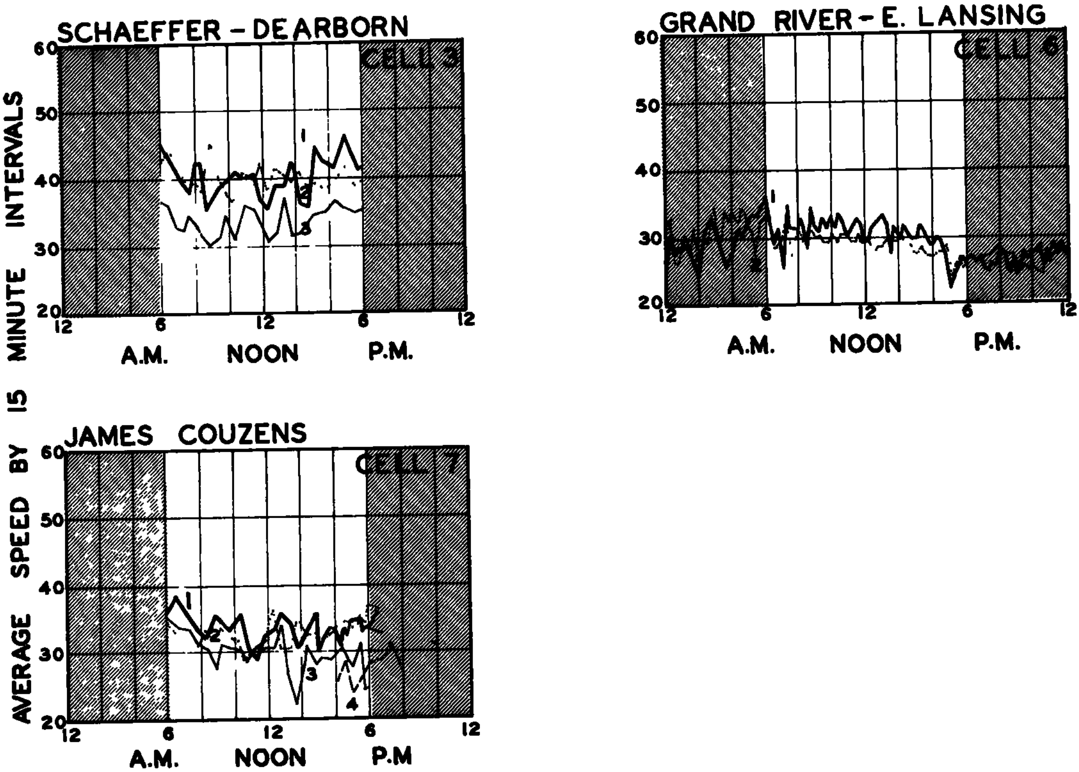

Figure 7. Variation of average lane speed by time of day.

periods from 6 a.m. to 6 p.m. have been analyzed. For these three cells, additional time-saving procedures were employed. First, five 30-min periods were selected, and these were completely analyzed — every individual speed observation being considered. Then, for the remaining 30-min periods, a sampling technique (1-min sample for each 30-min period) was used to compute estimates of average speed. If the average speeds computed from the 1-min samples were 5 percent greater or less than the composite average obtained from the five 30-min samples, a second 1-min sample was taken and considered in computing the average speed.

More careful scrutiny of each of the graphs allows a number of observations to be made. Notice, for example, the magnitude of the fluctuations in 15-min average speed for the daytime period (6 a.m. to 6 p.m.). Particularly in cells 1, 2, 4, and 6 these fluctuations are very small for all lanes of the facilities. Note in cell 1 (Ford Expressway) the one large drop in average speed between 7 and 8 a.m., which, unlike the very early morning fluctuations, is caused by an excessive volume. For cells 3, 5, and 7 the average speeds plotted have slightly greater fluctuations from period to period. This was expected, however, because of the sampling procedure which was used to analyze the data.

Another interesting observation which can be made is a comparison of the average speeds between lanes for a given cell. Notice, for all cells, that lane 3 is characterized by lowest average speed, and lane 1 is generally characterized by highest average speed. The mean average lane speed for the total period analyzed was computed for each cell, and it was found that: (a) in all cases, without exception, lane 3 had the lowest mean average speed; and (b) in nearly all cases (excluding cells 2 and 4) lane 1 had the highest mean average speed.

To better compare the magnitude and variability of 15-min average lane speed between cells, three graphs were plotted (Fig. 8), one for each lane. On each graph all

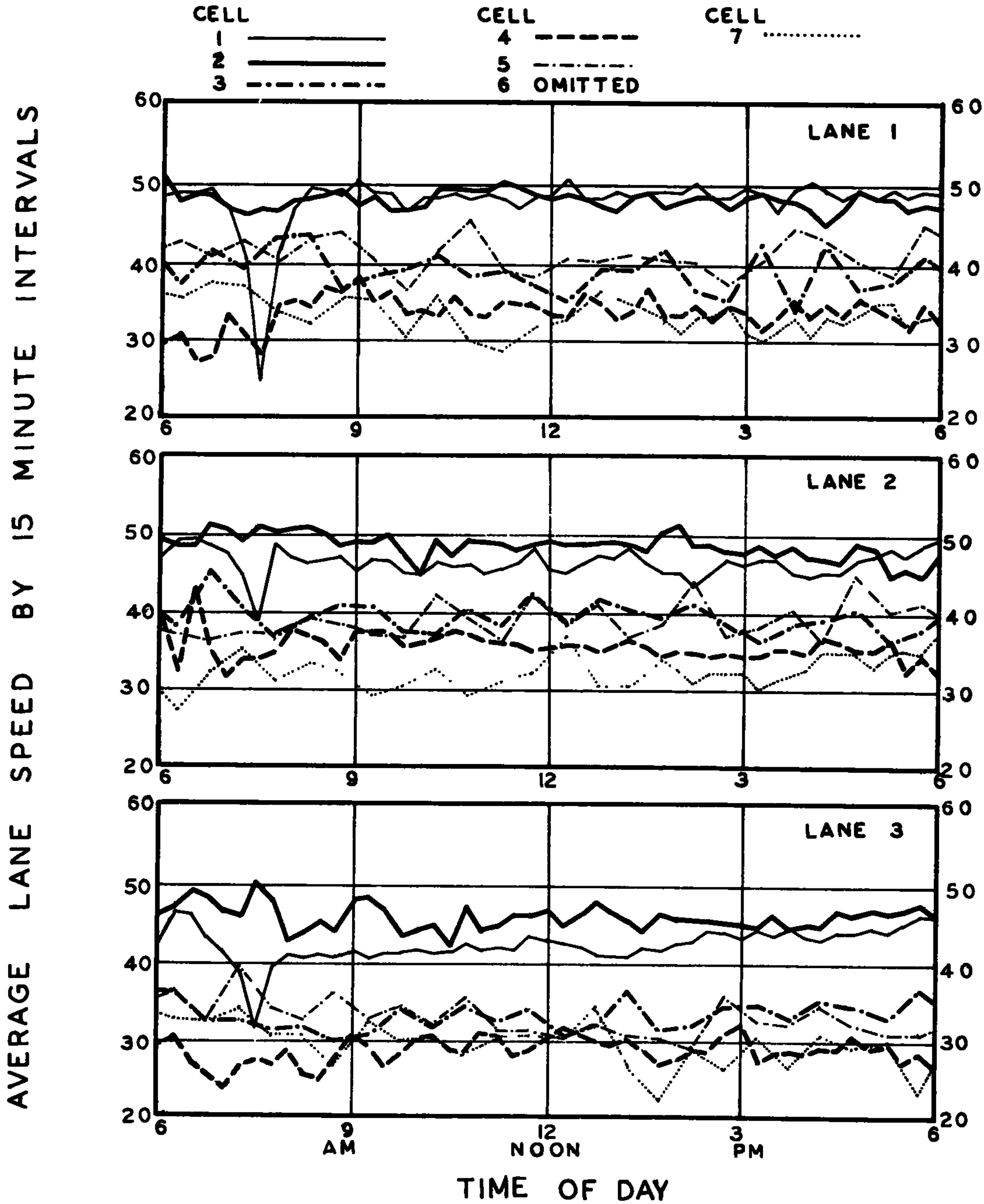

Figure 8. Variation of average lane speed by time of day for all cells.

the cells with the exception of cell 6 were plotted as indicated by the key at the top of the figure. The reason for not plotting cell 6 on this figure was that it had only two traffic lanes in the direction studied while all the other cells had three lanes. Because of the less important random fluctuations during much of the low volume "nighttime" period, only the period of 6 a.m. to 6 p.m. is shown on the graphs.

It seems that the most important observation to be derived from Figure 8 is that for all cells, and for each lane, the 15-min average speed variations generally form a series of parallel, horizontal lines. This is especially noticeable from 9 a.m. to 6 p.m. Of course, there are upward and downward fluctuations from period to period, but the magnitude of the fluctuations seems to be fairly constant from 9 a.m. to 6 p.m. For those cells (1, 2, 4, and 6) in which every individual speed observation was included in the analysis the lines appear to be extremely horizontal; whereas, for the cells which were analyzed on a sampling basis, the fluctuations are slightly larger as would be expected.

For the period from 6 a.m. to 9 a.m. most of the lines still appear to be of the same character as for the rest of the day. As discussed previously, the only major exception seems to be the Ford Expressway (cell 1) which has a large drop in average speed in all three lanes caused by congestion of traffic during the morning peak period (7 to 8 a.m.).

The last investigation in regard to speed variations was an attempt to determine if there were small intervals of time during which speeds could be measured, and this average speed thus computed to estimate the 24-hr average speed. To perform this investigation, lane speeds were averaged for 15-min periods and then lane average speeds were combined resulting in 15-min average speeds for each of the facilities. Only those facilities (cells 1, 2, 4, and 6) where the speed of each vehicle was determined are included in this analysis and only the period from 6 a.m. to 6 p.m. was studied.

The results of this investigation are shown in Figure 9. It is observed that averaging the lane speeds has the effect of eliminating incidental variations which were very pronounced in the graphs of average 15-min speeds for each lane separately. As a result, it is noted that there are several long periods during which the variation in 3-lane, 15-min average speed does not differ from the over-all 24-hr average by more than ± 1 mph. The period between 11 a.m. and 3 p.m. seems to be especially well suited to

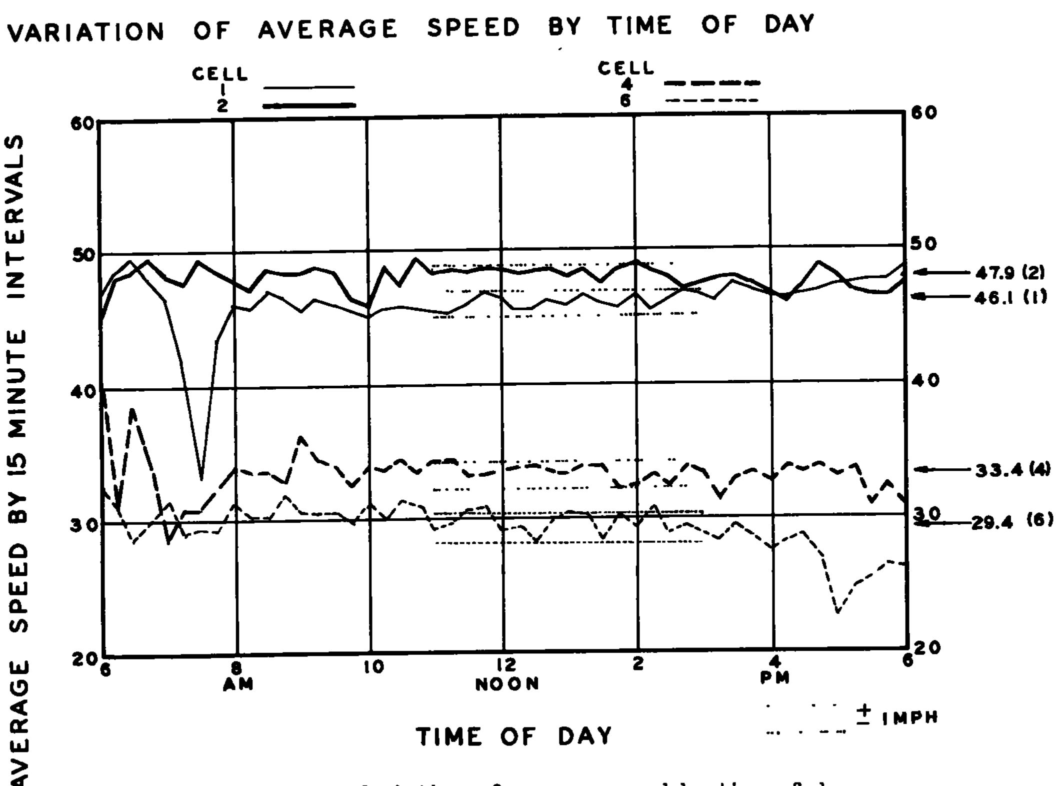

Figure 9. Variation of average speed by time of day.

the determination of the daily average speed. The ± 1 mph confidence limits for each of the four facilities from 11 a.m. to 3 p.m. are indicated on the figure. The practical significance of this result is that by measuring the speeds for any period of 15 minutes between 11 a.m. and 3 p.m. an estimate of the 24-hr average speed can be made, and it would be accurate to within ± 1 mph.

Distribution of Minute Average Speeds

The distribution of minute average speeds at each of the seven locations was determined and is presented in Figures 10 and 11. Cells 1, 2, 4, and 5 are depicted in Figure 10, while cells 3, 6, and 7 are included in Figure 11. The horizontal scale of each graph is 1-min average speed while the vertical scale is an accumulative percent

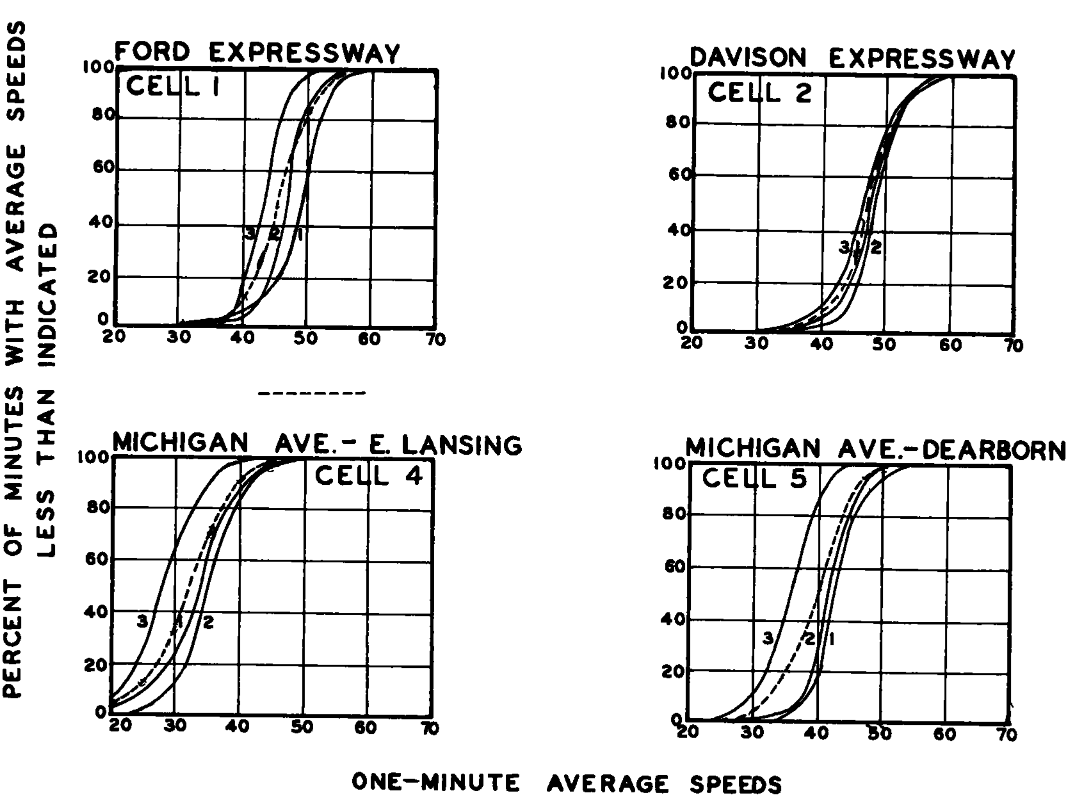

Figure 10. Distribution of minute average speeds.

of minutes with average speeds less than indicated on horizontal scale. First comparisons between lanes on the same facility are discussed, followed by a discussion comparing similar lanes of all the cells.

In each of the graphs depicted in Figures 10 and 11, the distribution curve of minute average speeds for lane 3 for all cells is offset to the left 2 to 7 mph, while the distribution curves for lanes 1 and 2 for each of the cells are quite similar. For five of the cells (excluding Davison Expressway and Michigan Avenue in East Lansing), the distribution curve for lane 1 is offset to the right indicating a higher average speed. The distribution curves for the lanes for Davison Expressway and Grand River are close together indicating little difference in speed distributions between lanes.

The construction of such graphs permits the measurement of certain statistical characteristics, such as the median, 15 percentile, 85 percentile, 15-85 percentile

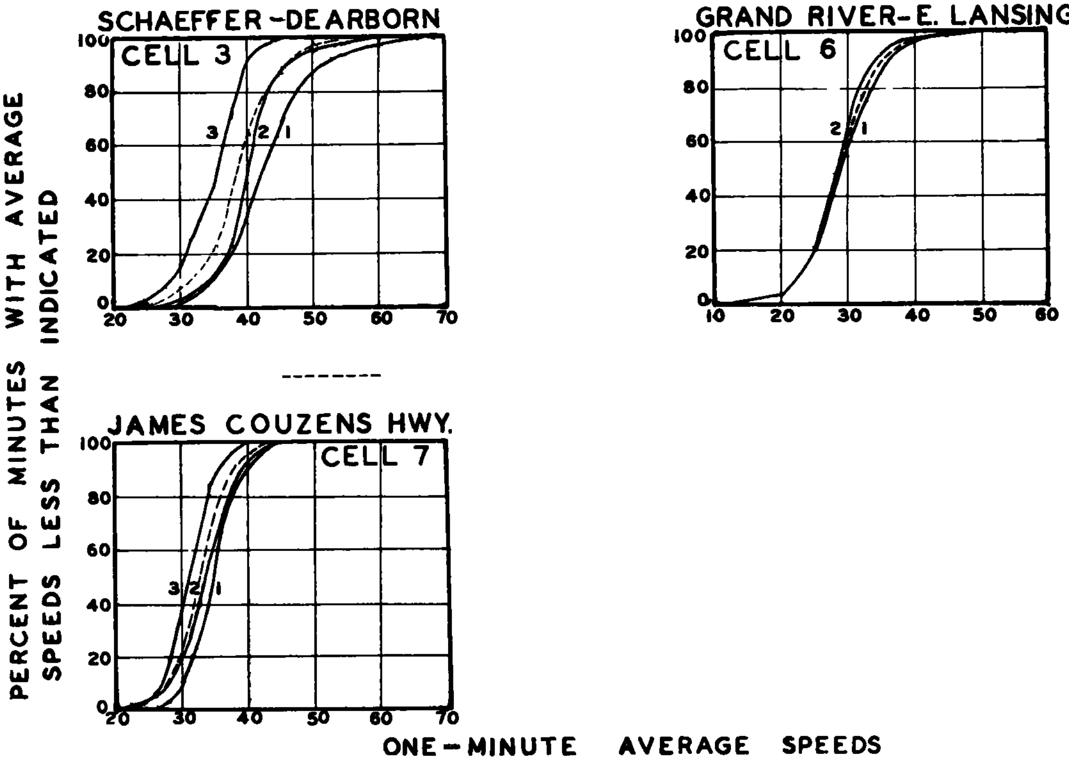

Figure 11. Distribution of minute average speeds.

range, 10-mph pace, and percent of vehicles within the 10-mph pace. These statistical characteristics are summarized in Table 4. Additional analyses were made in order to summarize the speed distributions for daytime (6 a.m. to 6 p.m.) and nighttime (6 p.m. to 6 a.m.) for the Ford and Davison Expressways. The minute average speed distributions at the James Couzens location were determined for the period when three lanes are used for traffic movement and also for the period (4 to 7 p.m.) when four lanes are used for traffic movement.

Although there is little difference between daytime and nighttime average speeds (45.3 and 45.4 mph on the Ford Expressway; and 47.4 and 46.3 mph on the Davison Expressway), the daytime minute average speeds are much more uniform. For example, the 15-85 percentile range on the Ford and Davison Expressways during the daytime was 5 to 6 and 6 to 9 mph, whereas during the nighttime the 15-85 percentile range was 8 to 11 and 9 to 13 mph. Another method that can be used to show the difference between speed distributions is to compare the percent of vehicles included within the 10-mph pace. This percent on the Ford and Lodge Expressways during the daytime was 89 to 93 and 77 to 88 percent whereas the similar percent for nighttime was 68 to 80 and 60 to 72 percent.

In comparing the speed distributions of the seven cells many similarities exist. Note in Table 4 that the average median and mode for each lane for all seven facilities are within 2 mph of one another. The 15-85 range for each lane for all seven facilities is always between 7 and 13 mph. This means that 70 percent of the minutes have an average speed never greater than ± 6.5 mph from the 24-hr average speed and on some lanes of some facilities never greater than ± 3.5 mph. A review of the percent of vehicles included in the 10-mph pace indicates that the percent varies from 58 to 88 which means that the average speed during 58 to 88 percent of minutes during the 24-hr period is never greater than ± 5.0 mph from the 24-hr average speed.

Another area in the investigation of speed distributions was to compare the minute

TABLE 4
SUMMARY OF MINUTE AVERAGE SPEED DISTRIBUTIONS

Facility	Test Period	Lane	Speed Characteristics: Speed (mph) Avg.	Med.	Mode	15 Pctl.	85 Pctl.	15-85 Pctl. Range	10-Mph Pace	Included in 10-Mph Pace (%)	Over-all Average (mph)
Ford Exp., cell 1	Day	1	47.7	48	50	45	50	5	44-53	89.5	
		2	46.0	45	46	43	48	5	42-51	93.3	45.3
		3	42.4	42	41	39	45	6	38-47	90.5	
	Night	1	47.0	47	48	41	52	11	44-53	68.4	
		2	46.6	46	48	42	51	9	42-51	74.5	45.4
		3	42.6	42	41	38	46	8	38-47	80.4	
	24 Hr	1	47.4	48	50	48	51	8	44-53	80.7	
		2	46.3	46	46	46	49	7	42-51	85.3	45.4
		3	42.5	42	41	42	46	7	38-47	85.5	
Davison Exp., cell 2	Day	1	47.9	47	48	43	51	8	44-53	88.4	
		2	48.3	48	49	45	51	6	44-53	90.6	47.4
		3	46.1	46	45	41	50	9	41-50	77.0	
	Night	1	46.1	46	47	40	51	11	41-50	66.5	
		2	47.8	47	47	43	52	9	42-51	72.6	46.3
		3	45.0	45	46	38	51	13	42-51	60.8	
	24 Hr	1	47.1	47	47	43	51	8	43-52	78.0	
		2	48.2	48	49	44	51	7	44-53	84.5	46.9
		3	45.5	45	45	40	50	10	42-51	70.5	
Shaeffer Rd. cell 3	-	1	42.8	43	41	37	49	12	38-47	58.9	
		2	40.0	40	42	37	44	7	35-44	80.2	39.1
		3	34.5	35	34	30	39	9	32-41	74.3	
Michigan Ave., E. Lansing cell 4	-	1	33.1	34	34	27	40	13	30-39	62.2	
		2	35.3	35	34	31	41	10	31-40	70.9	32.5
		3	29.1	29	30	23	34	11	25-34	64.9	
Michigan Ave., Detroit cell 5	-	1	42.3	42	42	38	47	9	38-47	77.0	
		2	41.6	42	43	38	45	7	36-45	88.6	39.4
		3	35.1	35	34	31	40	9	31-40	78.8	
Grand River, E. Lansing, cell 6	-	1	28.8	29	28	24	35	11	23-32	64.3	28.3
		2	27.9	28	27	24	33	9	23-32	74.8	
James Couzens (3 lane) cell 7	-	1	34.1	34	34	31	38	7	29-38	86.3	
		2	32.9	33	32	29	38	9	29-38	76.8	32.5
		3	30.5	31	31	27	35	8	26-35	84.4	
James Couzens (4 lane) cell 7	-	1	34.2	35	37	32	37	5	29-38	96.7	
		2	34.7	35	37	31	40	9	29-38	75.0	
		3	30.8	32	31	28	34	6	26-35	86.7	31.4
		4	26.0	26	26	23	30	7	22-31	85.0	

average speed distributions of similar lanes on the seven different facilities (Fig. 12). Again the horizontal scale is minute average speed, and the vertical scale is percent of minutes with average speeds less than indicated minute average speed. The numbers (1 through 7) positioned near each curve refer to the cell number. The top diagram is for lane 1, the middle diagram for lane 2, and the lower diagram for lane 3.

The lane speed distributions of the seven facilities appear to be in pairs from left to right: cells 4 and 7, cells 3 and 5, and cells 1 and 2. The speed distribution curves for cell 6 (Grand River in East Lansing) only appear in the upper two diagrams because there are only two lanes. The curves in the lower diagram are positioned slightly to the left indicating a lower average speed in lane 3. Note the parallel position of the curves for lane 2 which implies that the 15-85 percentile ranges are approximately equal. The curves in the two top diagrams have steep slopes indicating greater uniformity in speed.

In summary, those cells with a combination of minimum marginal and median friction (cells 1 and 2) have distribution curves farthest to the right and have steep slopes. Those facilities (cells 6 and 7) with the combination of greatest median and marginal friction have distribution curves farthest to the left and have relatively flat slopes. It would appear from the study data that as traffic friction increases, average speed decreases and the speeds become less uniform.

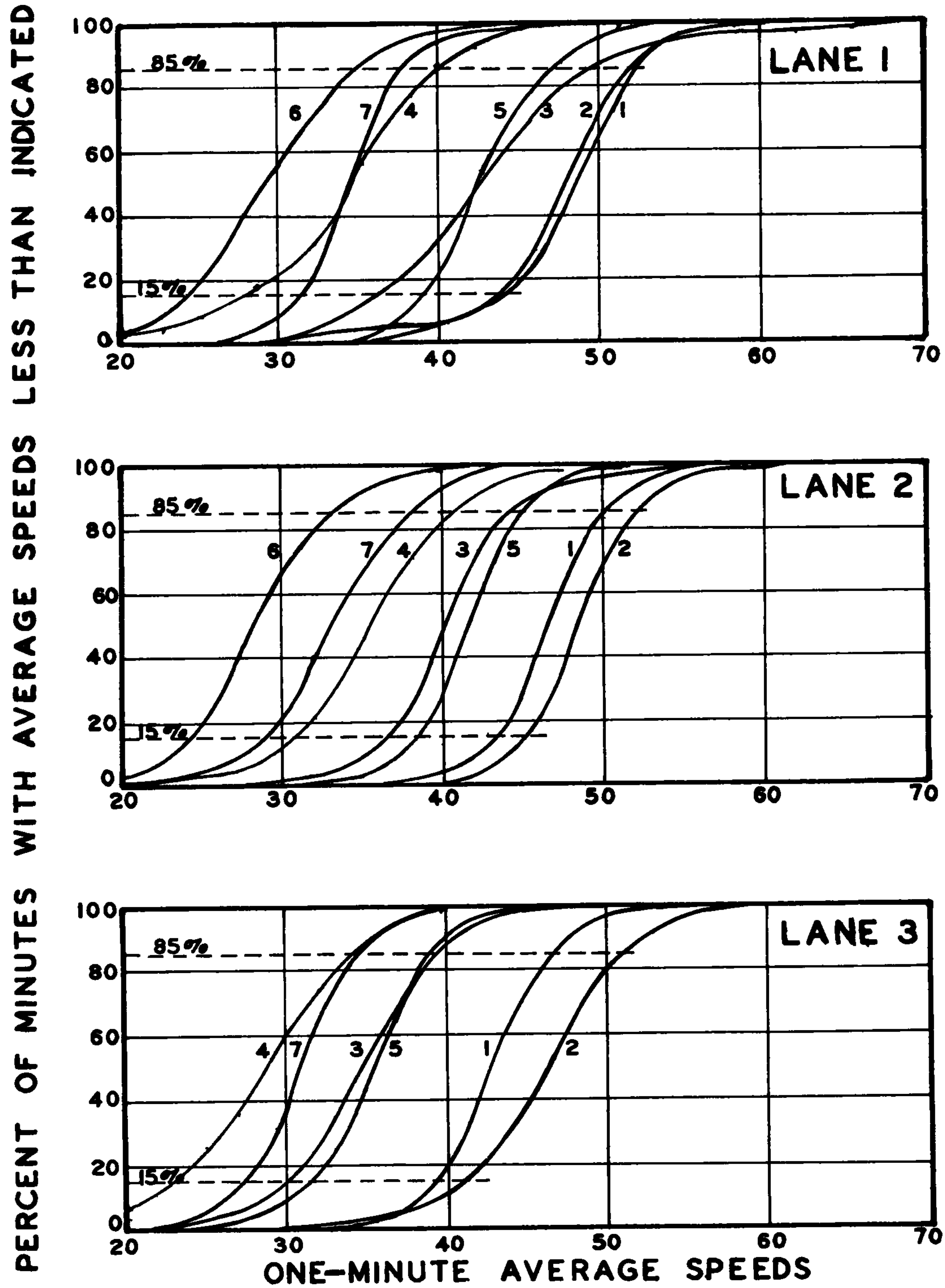

Figure 12. Distribution of minute average speeds by lane.

SUMMARY

The more important findings pertaining to the volume and speed characteristics of the seven locations on major urban arterials are summarized, as follows:

1. The ratio of various peak traffic volumes for different intervals of time for the seven locations are similar.
2. A method of estimating various 24-hr percentile minute volumes when applied to the seven locations give similar satisfactory results.
3. Traffic volume affects lane use and distribution of traffic volume between lanes follows very definite patterns.
4. The shoulder lane (lane 3) at each of the seven locations had the lowest average lane speed, whereas the median lane (lane 1) at five of the seven locations had the highest average lane speed.
5. The variations in average lane speeds between 9 a.m. and 4 p.m. at the seven locations were extremely small.
6. The average speed determined for any 15-min period between 11 a.m. and 3 p.m. was within ± 1 mph of the 24-hr average speed.
7. There was no significant difference between daytime and nighttime average speeds at the locations on the Ford and Davison Expressways. Nighttime average speeds were more dispersed.
8. The average minute lane speeds are quite uniform throughout the 24-hr period with 70 percent of the minutes having average speeds within ± 3.5 to ± 6.5 mph of the 24-hr average speed.
9. Routes having greater medial and marginal friction generally have lower average speed and speeds which are less uniform.

ACKNOWLEDGMENT

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Sample Size Requirements for Vehicular Speed Studies

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The purpose of this paper was to determine the minimum number of observations required for the estimation of various vehicular-speed percentiles. Based on the assumption that spot speed data has an approximately normal distribution, an equation has been derived to estimate the required sample size in terms of the percentile, tolerance limit, desired confidence level, and standard deviation. The standard deviation of the speeds is the only variable of the sample size determination that is directly influenced by vehicular speeds; the other three factors are arbitrarily selected.

To aid in the selection of these minimum sample size requirements, it was possible to determine relationships between the estimated population standard deviation of vehicular speeds and various factors peculiar to the study sites under consideration. For two-lane highways in rural areas, linear regression analysis established a significant correlation of standard deviation of the speeds with the average annual daily traffic (ADT), the 30th highest hourly traffic volume (30th HV), and the possible capacity of the spot speed site for the combination of daytime and nighttime vehicular speed observations.

If the standard deviation of the vehicular speeds at a given spot speed site on a two-lane highway is not known from previous speed studies, then the ADT value of a given location is recommended for estimating the standard deviation of vehicular speeds at this site. This correlation was the most significant of those site factors studied, and the ADT is usually known for most highway sections. Although the small number of speed sites did not permit an accurate evaluation of standard deviation and ADT for four- and six-lane rural facilities, the averages of these values are given to permit a first approximation of the necessary sample size requirements.

Under traffic conditions in rural areas, the standard deviation approaches its maximum value because most motorists are free to choose their desired speed. On this basis, the standard deviations are representative of low traffic volumes and are acceptable for either rural, intermediate-area, or urban highways. By using charts prepared for various percentiles, tolerance limits, and desired confidence levels, this standard deviation indicates the required minimum sample size for the desired statistical accuracy of the spot speed study.

● IN ANY EXPERIMENT designed to predict the statistical measures of a given population through a sampling technique, determination of a sufficient and economical sample size is mandatory. Highway and traffic engineers are confronted with this problem in programming many field and laboratory investigations. The number of units sampled must be sufficient to produce results with acceptable accuracy. However, the limitations of time, finances, and personnel preclude the selection of excessive sample sizes to insure statistical accuracy.

This matter of proper sample size is important in the establishment of spot speed studies conducted at various highway and street locations. At present there is no procedure outlined for the determination of the required sample size to estimate accurately the population characteristics of highway motor vehicle spot speeds. Therefore, the purpose of this research investigation was to develop a method for determining the minimum number of observations required for the estimation of various vehicular-speed percentile values.

The general procedure for conducting spot speed studies is to measure the speeds of passing motor vehicles for a fixed period of time or until a specified minimum number of observations are recorded. Thus, no consideration has been given to the statistical properties of spot speed data in their analysis and evaluation.

Inasmuch as vehicular spot speeds exhibit an approximately normal distribution, a theoretical analysis of the properties of a normal curve has permitted the development of an expression to compute minimum sample size requirements. These sample size requirements can be determined from a knowledge of the standard deviation of the vehicle speeds at a given location, derived from the results of previous spot speed surveys. However, a correlation analysis was necessary to aid in the determination of sample sizes without first performing, at a location where the speed characteristics have not been evaluated, a spot speed study to estimate the standard deviation of the speeds. The procedures and results of these two analyses are presented in the following sections.

It is anticipated that use of the results of this report will enable highway and traffic engineering personnel to ascertain sample size requirements for conducting spot speed studies with acceptable statistical accuracy at a minimum expense of time and manpower assignments.

PROCEDURE

Theoretical Analysis

As the results of many field studies have illustrated, the distribution of spot speed data closely approximates the normal curve. To verify a normal distribution in the data used for this investigation, the following statistical tests were applied: chi-square test, moment test, percentile method for testing normality (2), and normality test using probability paper. All these statistical techniques indicated that the spot speed data significantly conformed to a normal distribution.

The chi-square test, in testing normality, produced a value that was non-significant for the given degrees of freedom. To confirm further this assumption of a normal distribution, the moment test was applied to the speed samples. The measure of skewness, β_1, was almost zero for all the data tested, thus indicating a symmetrical distribution. The calculations for kurtosis, β_2, produced values approximately equal to three. Therefore, the degree of kurtosis, measure of peakness, for the data was nearly the same as that for a theoretically normal distribution.

A value of approximately one as computed from the percentile method for testing normality further substantiated the normal-distribution assumption. A true normal distribution is represented by a value of exactly one in this evaluation. The final test was performed by plotting the cumulative distributions of the speed data on probability graph paper. The nearly straight lines represented a normal distribution for the spot speed samples.

By concluding that the spot speed populations were significantly depicted by a normal distribution, an analysis of the properties of a normal curve has permitted the derivation of an equation for the required minimum sample size to determine a given percentile speed with a specified accuracy. This analysis was proposed by Berry and Belmont (2). A similar derivation of the minimum sample size expression is given in Appendix A and produces the following equation:

$$N = \frac{v^2 S^2 (2 + u^2)}{2d^2}$$

in which

N = minimum sample size,
v = normal deviate corresponding to the desired confidence level,
S = standard deviation of the sample,
u = normal deviate corresponding to the percentile being estimated, and
d = permitted error in the estimate.

The sample standard deviation of spot speeds is the only variant directly affected by vehicular speeds. The other three variables are selected at the engineer's discretion for the required purposes and accuracy of the spot speed study.

Correlation Analysis

The equation derived for minimum sample size determinations can not be used unless the standard deviation of vehicular speeds at the desired location and time is known. Therefore, a spot speed study, the end result, must be conducted with a relatively large number of speed observations to estimate the standard deviation of the speed population at the given time and site location. The trial sample size must be in excess of the unknown, required minimum number to insure proper accuracy.

To aid in the use of this minimum sample size equation, it was necessary to investigate the influence of time-of-observation on estimated population standard deviations and to determine any possible significant relationships between standard deviations of the speeds and some factor or factors peculiar to the spot speed sites under consideration. The Bartlett test for testing the homogeneity of the variances was used to discern any significant differences in standard deviations at a given site location for different periods of time. The time elements were analyzed according to variations during the time of day, day of week, and month of year. The results are discussed in the following section of this paper.

If any significant relation can be established and evaluated between standard deviations of spot speeds and some known factor or factors characteristic of the speed sites, then this relationship can be employed to estimate accurately the standard deviation from this given factor or factors where standard deviations are not known.

It is reasonable to assume that the standard deviation of the speeds for a given highway or street location is not constant, but that it varies with traffic volume. At low volumes the highway user has relatively free operational conditions and can select his desired speed of travel. When conditions permit drivers to travel at their desired speeds, there is a wide range in speeds at which various operators drive their motor vehicles (3). Under these circumstances the standard deviation at a given speed site should approach a maximum value because standard deviation is a measure of the average discrepancy of values about their mean or central tendency.

As the volume on a given traffic facility increases, the average difference in speeds between successive vehicles decreases linearly and becomes zero at a traffic volume equal to the possible capacity of the facility (3). Thus, standard deviations also decrease as volumes increase because individual drivers are affected more and more by other traffic, and the range in speeds is reduced. Standard deviations of the speeds approach or become zero as the volume increases to the possible capacity of the facility when all traffic is moving at approximately the same speed.

This reasoning indicated that a possible correlation may exist between the standard deviations of vehicular speeds and traffic volumes. The derived expression for minimum sample size requirements increases in a direct relation to the square of the standard deviation (variance). Therefore, it was desirable to compare sample standard deviations of the speeds measured during periods of low traffic flow with volume counts indicative of low traffic flow in order to approach the maximum standard deviations of vehicular speeds occurring at the various study sites. Any correlation of maximum standard deviation with some corresponding minimum traffic volume measure maximizes the minimum sample size requirement, thus providing a sample size that is always statistically adequate.

Spot speed data were collected at 71 sites in rural areas. These sites were selected on level, tangent highway sections that were not near any intersections. Large samples of the vehicular speeds were obtained with radar speedmeters for low volume conditions during the day and the night. To insure the statistical independence of the speed observations, only the speeds of free-flowing vehicles were recorded. The speeds of highway vehicles in the act of passing or tailgating were not observed. Thus, a good estimate of the maximum standard deviation of the speed population was ascertained at each location for a combination of daytime and nighttime travel.

The measures of traffic volume considered in this investigation were average annual daily traffic (ADT), 30th highest hourly volume (30th HV), and possible capacity. The two volume counts for each spot speed site were abstracted from information published by the Illinois Division of Highways (6), while the possible capacity at each speed study location was computed with the procedure presented in the "Highway Capacity Manual" (3). This data, ADT, 30th HV, possible capacity, and standard deviation are summarized in Appendix B for each spot speed location.

Graphical plots of standard deviation versus ADT, 30th HV, and possible capacity indicated linear relationships with negative slopes. This decrease in standard deviation with an increase in volume confirmed the previously discussed reasoning and validated the previous assumptions.

These linear trends of the dependent variable, standard deviation, and the independent variable, volume, were analyzed by linear regression analysis and linear correlation analysis using the method of least squares. The regression coefficients, a and b, in the general equation $S = a + bV$, in which S = sample standard deviation and V = volume, were computed by the following formulas:

$$a = \frac{\Sigma V^2 \Sigma S - \Sigma V \Sigma VS}{n\Sigma V^2 - (\Sigma V)^2}$$

$$b = \frac{n\Sigma VS - \Sigma V \Sigma S}{n\Sigma V^2 - (\Sigma V)^2}$$

in which

n = number of observations.

Correlation coefficients were calculated by the following formula to measure the degree of linear association between standard deviation and volume:

$$r = \frac{n\Sigma VS - \Sigma V \Sigma S}{\sqrt{\left[n\Sigma V^2 - (\Sigma V)^2\right]\left[n\Sigma S^2 - (\Sigma S)^2\right]}}$$

The results of the correlation analyses are discussed in the following section.

RESULTS

Minimum Sample Size Requirements

The theoretical expression for determining the minimum number of observations to predict the properties of a normal distribution by a sampling procedure has been presented in the preceding section. The solution to this equation yields the minimum number of spot speed observations to be made for the desired degree of statistical accuracy. Thus, engineering personnel can determine accurate and economical sample sizes for spot speed studies having various purposes and requirements.

For the specified requirements of a spot speed study, this equation can be solved to indicate the required sample size to produce acceptable statistical accuracy. By solving this equation for a range of conditions, the sample size requirements can be presented in tabular or graphical form. The solutions to this minimum sample size expression for desired confidence levels of 90, 95, and 99 percent and permitted errors or tolerances from 1 to 4 mph at 1-mph intervals are expressed in graphical form as a function of sample standard deviation in Figures 1 to 3 for the 50th-percentile speed, Figures 4 to 6 for the 15th- and 85th-percentile speeds, and in Figures 7 to 9 for the 5th- and 95th-percentile speeds.

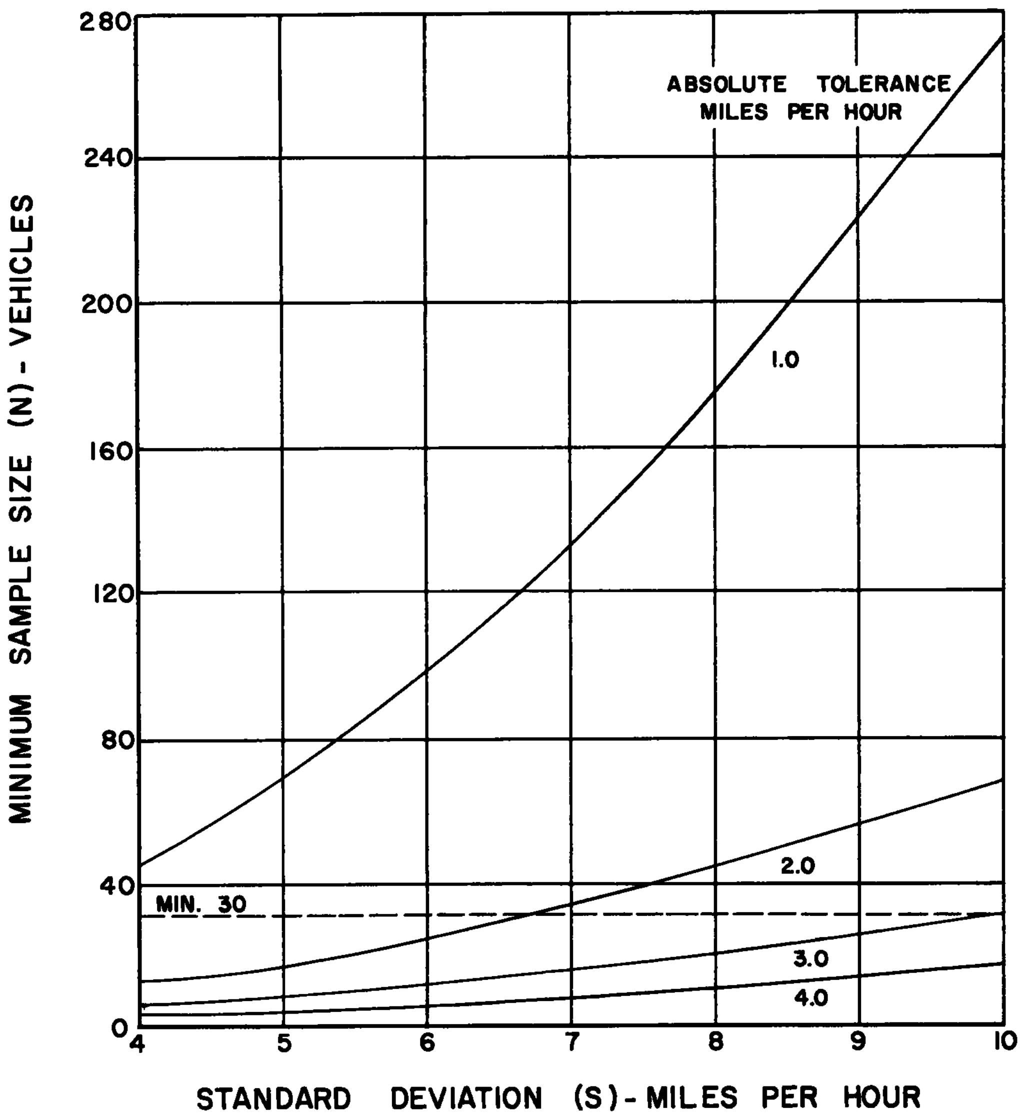

Figure 1. Minimum sample size vs standard deviation (percentile = 50%, desired confidence level = 90%).

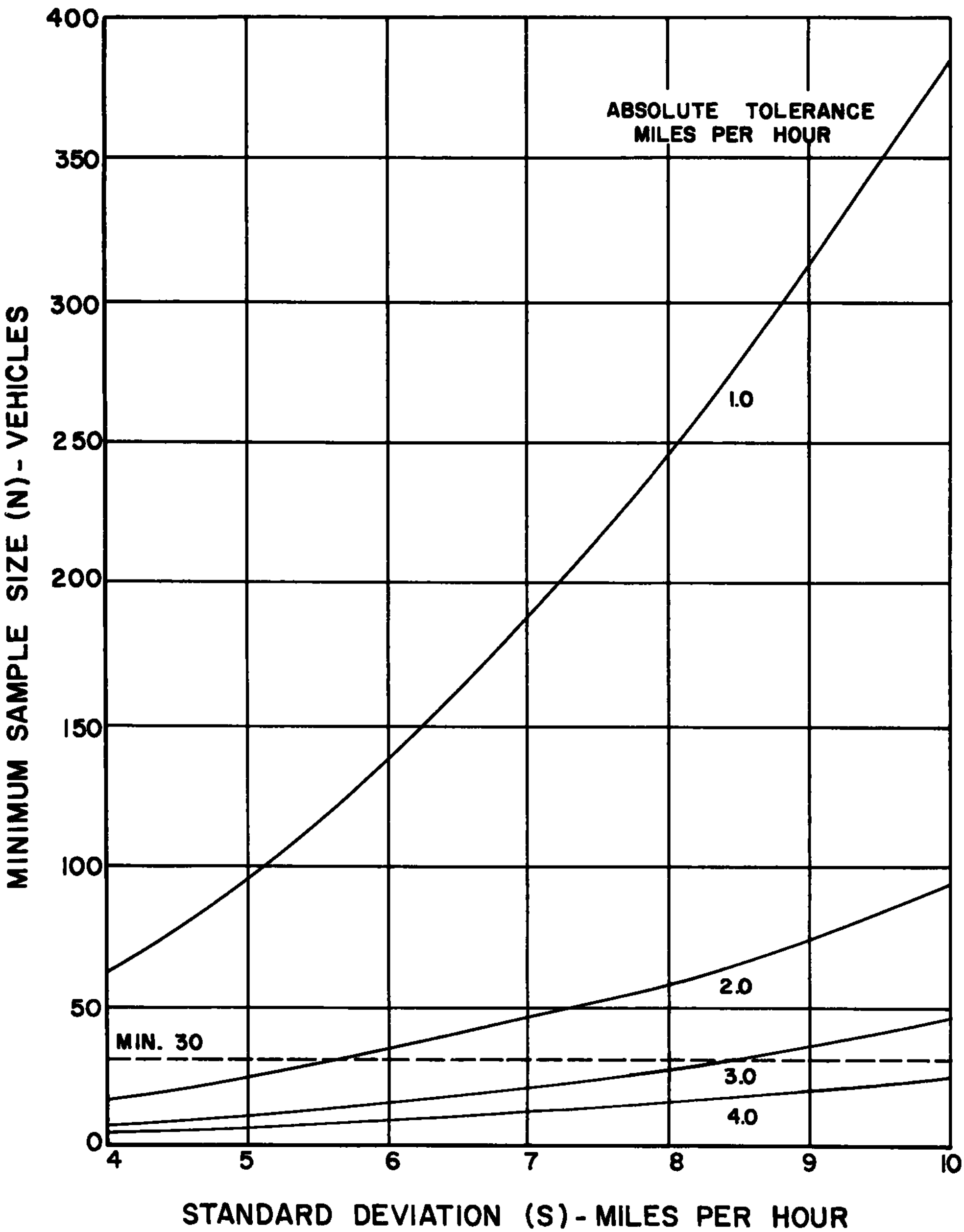

Figure 2. Minimum sample size vs standard deviation (percentile = 50%, desired confidence level = 95%).

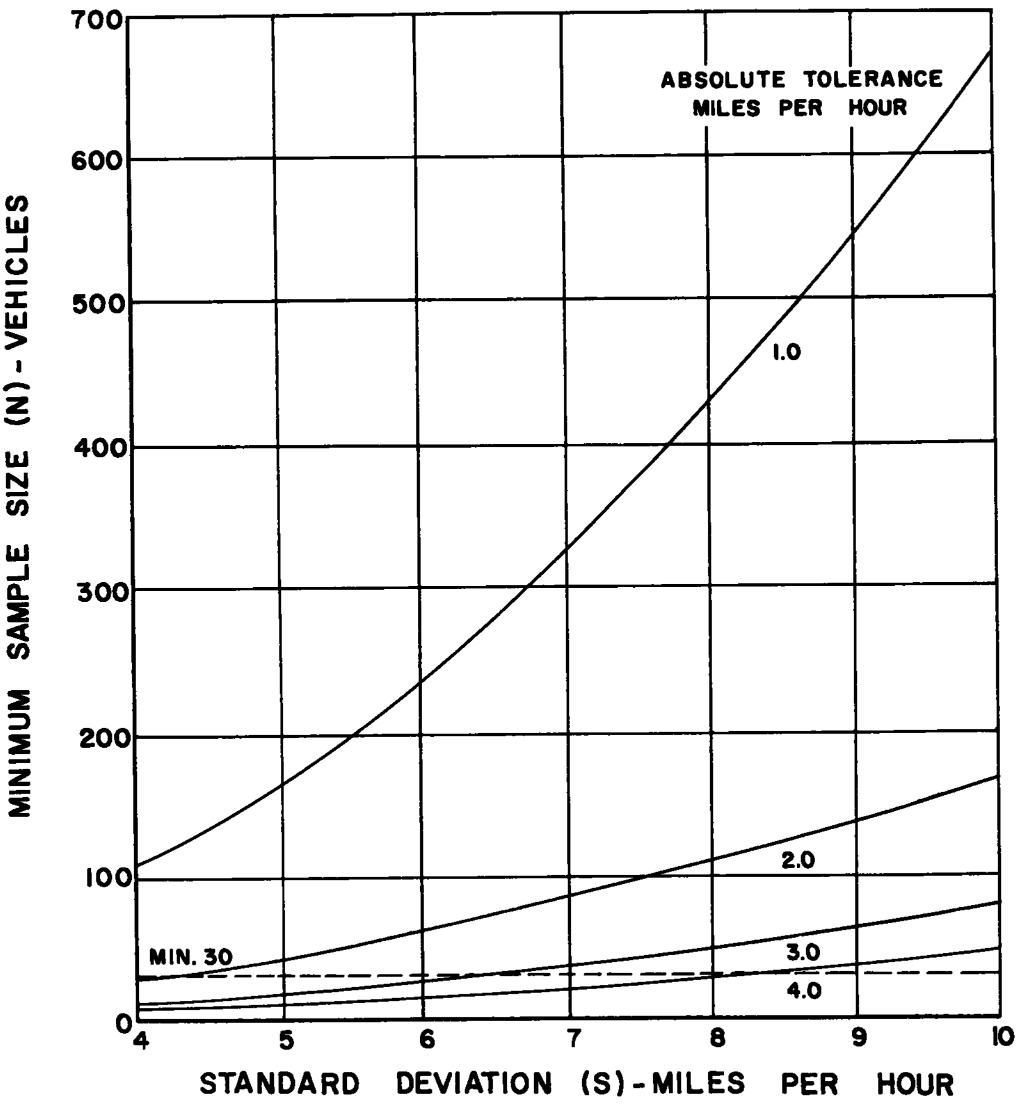

Figure 3. Minimum sample size vs standard deviation (percentile = 50%, desired confidence level = 99%).

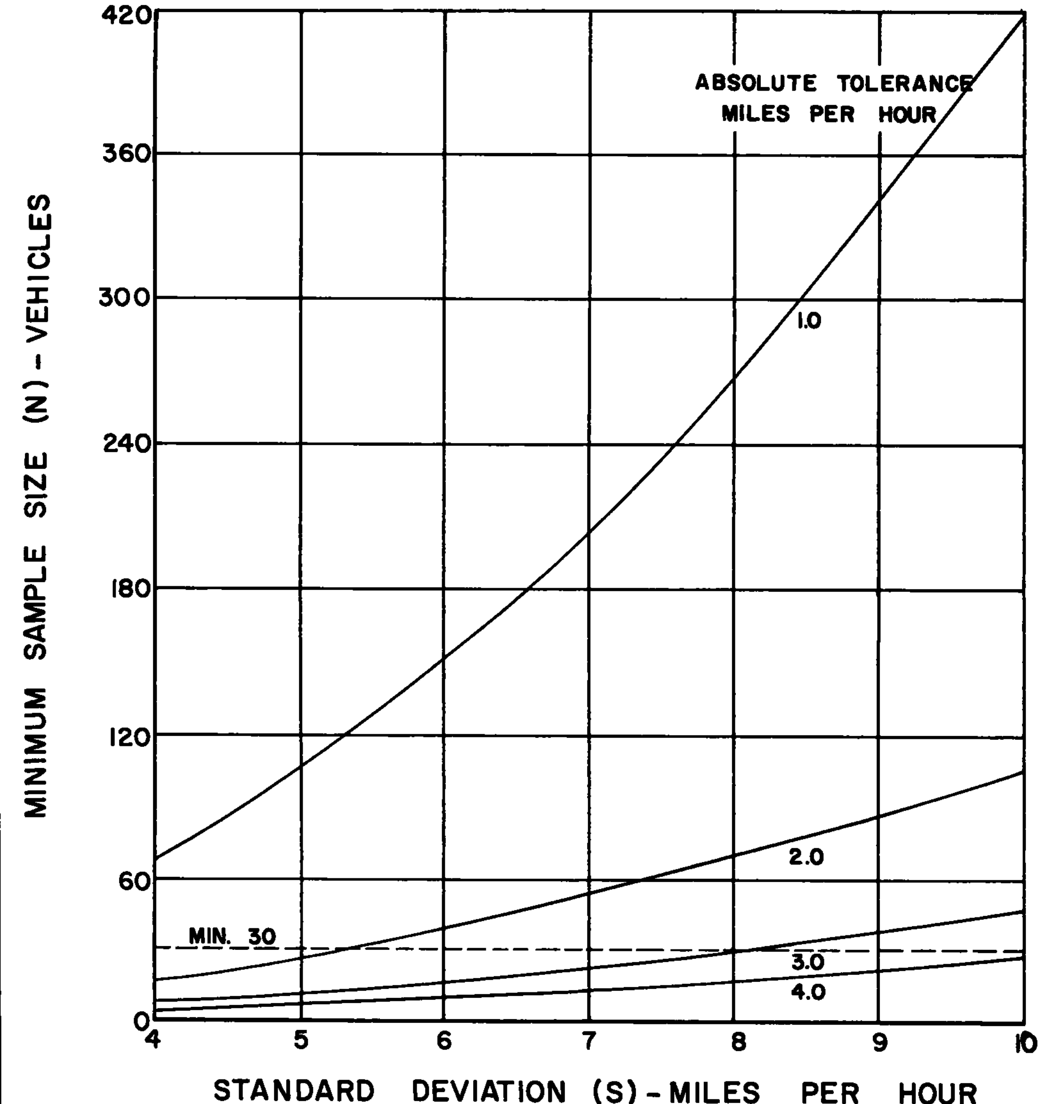

Figure 4. Minimum sample size vs standard deviation (percentile = 15% and 85%, desired confidence level = 90%).

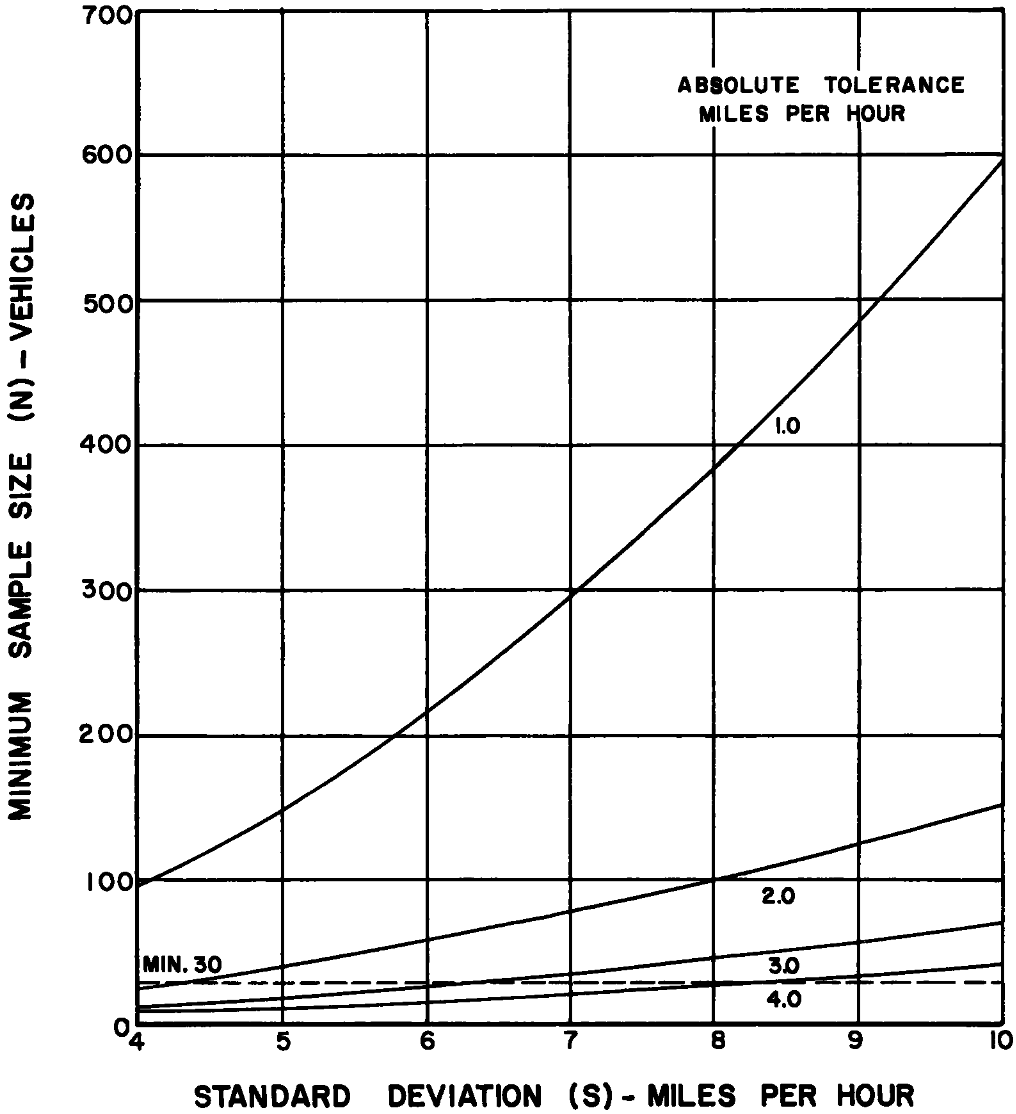

Figure 5. Minimum sample size vs standard deviation (percentile = 15% and 85%, desired confidence level = 95%).

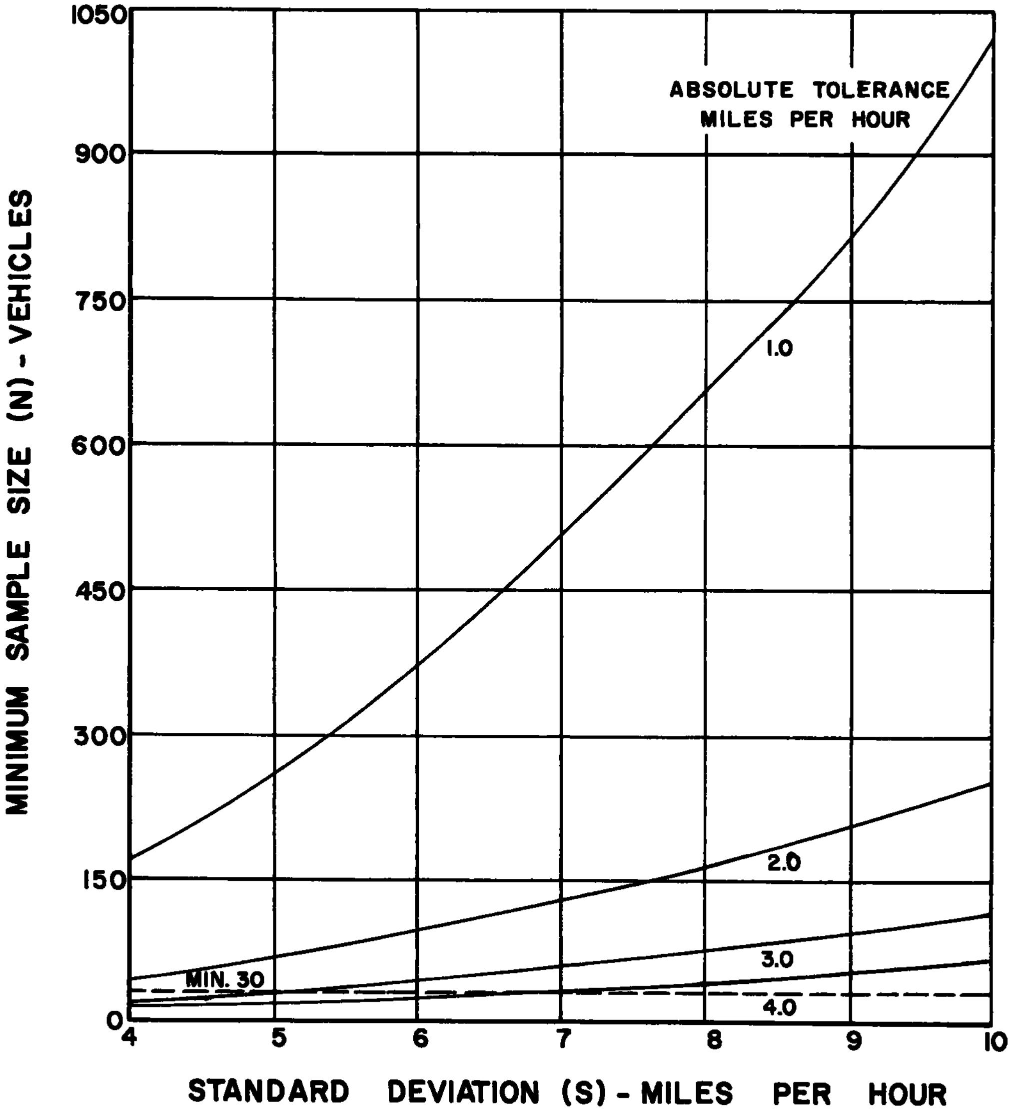

Figure 6. Minimum sample size vs standard deviation (percentile = 15% and 85%, desired confidence level = 99%).

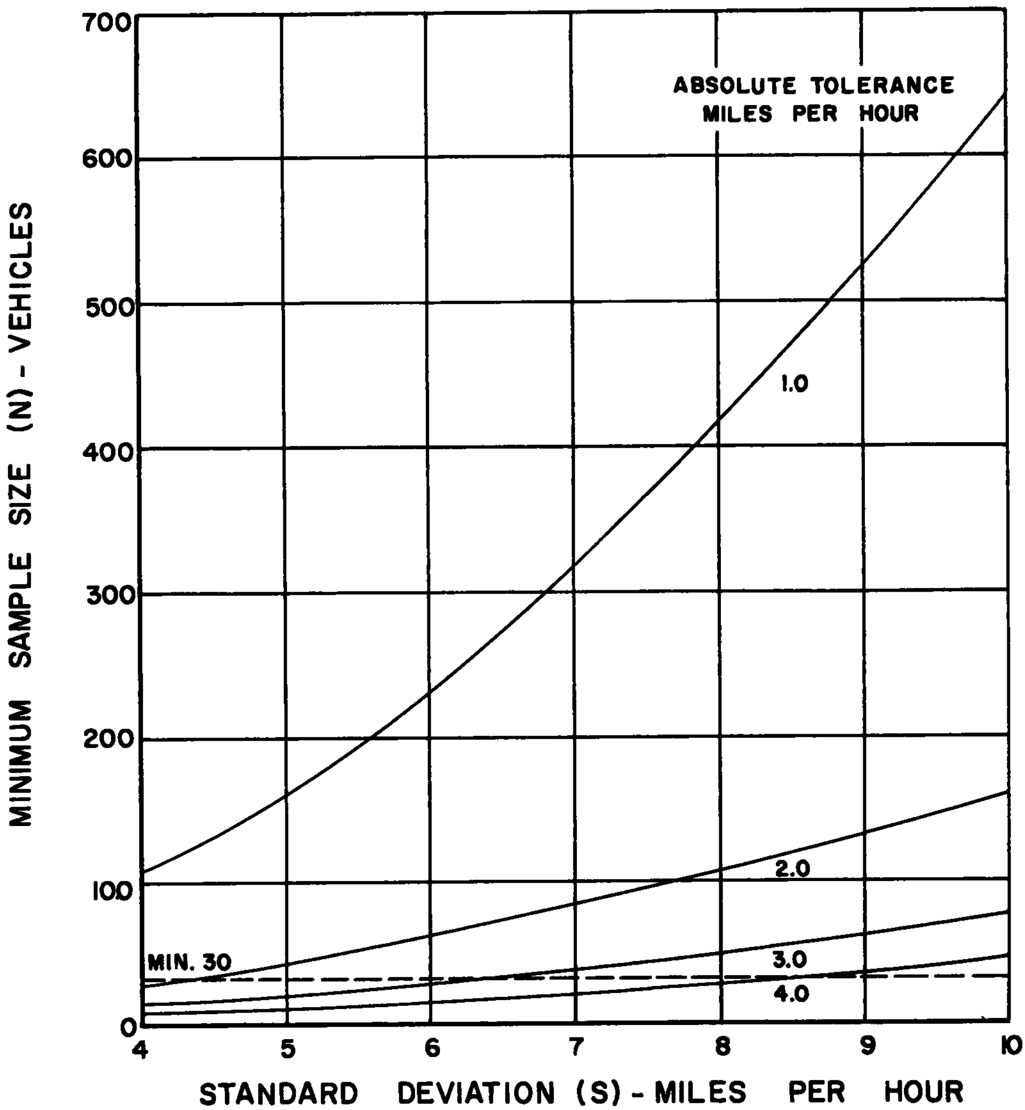

Figure 7. Minimum sample size vs standard deviation (percentile = 5% and 95%, desired confidence level = 90%).

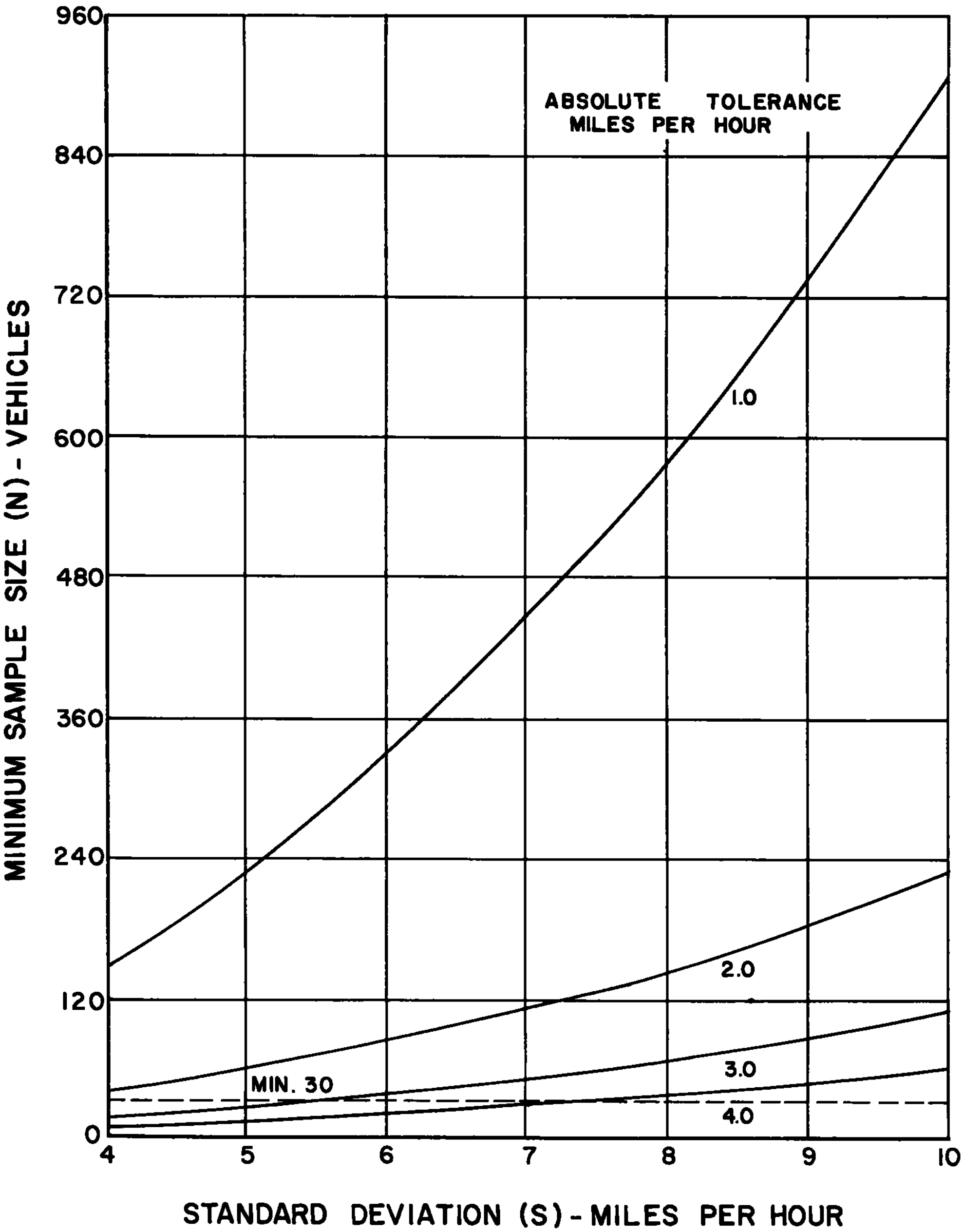

Figure 8. Minimum sample size vs standard deviation (percentile = 5% and 95%, desired confidence level = 95%).

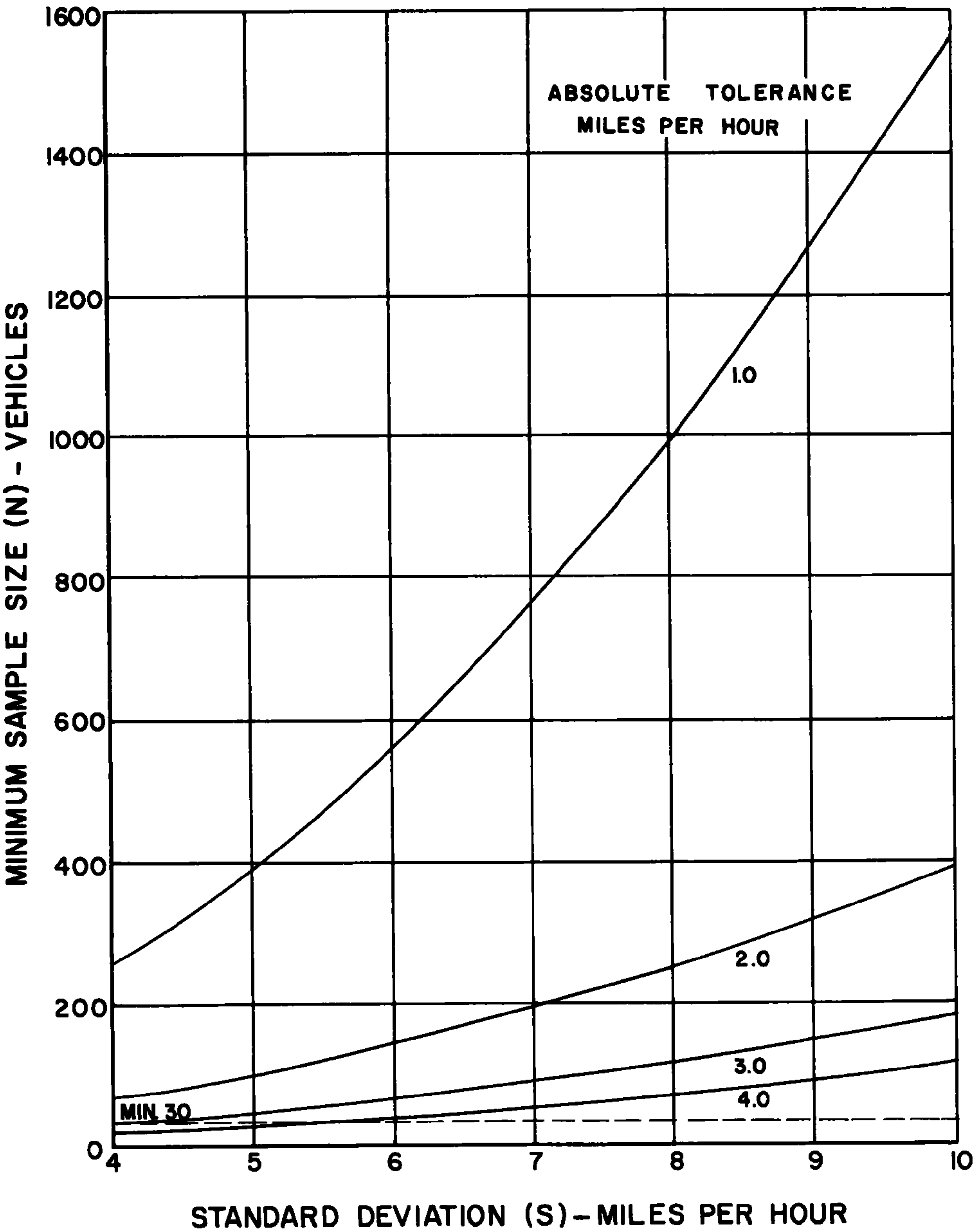

Figure 9. Minimum sample size vs standard deviation (percentile = 5% and 95%, desired confidence level = 99%).

TABLE 1

RESULTS OF THE REGRESSION AND CORRELATION ANALYSES

Variables	Intercept (a)	Slope (b)	Correlation Coefficient (r)	r^2
y = S, X = ADT (1,000)				
Two-lane sites, n = 55	9.61	-0.2718	-0.501[a]	0.251
Four-lane sites, n = 12	9.07	-0.0903	-0.381	0.145
Six-lane sites, n = 4	8.39	-0.0692	-0.804	0.646
y = S, X = 30th HV (100)				
Two-lane sites, n = 55	9.42	-0.0015	-0.412[a]	0.170
y = S, X = possible capacity (100)				
Two-lane sites, n = 55	11.79	-0.2175	-0.416[a]	0.173

[a]Significant at the 1 percent level.

To insure statistical accuracy for a normal distribution, the required minimum sample size must exceed the value of thirty. This has been indicated on the nine graphs by a dashed line.

Correlation of Speed Standard Deviation with Site Characteristics

The results of the Bartlett test for testing the homogeneity of the variances in measuring the influence of time-of-collection on standard deviation of spot speeds were not significant for the variations of time of day, day of week, and month of year. Although the literature contains many references to cyclical variations in traffic volumes according to time of day, day of week, and month of year, the speed observations for this study were obtained during periods of traffic volumes that were very low relative to the practical capacities of the highway sections. Thus, any change in volume with time did not significantly alter or modify the speed characteristics; therefore, it was assumed that the standard deviation of vehicular speeds at a given location was independent of the time of data collection during these low traffic flows in rural areas.

Linear regression and correlation analyses produced the results given in Table 1. The most significant result obtained was the correlation of sample standard deviation with ADT for the spot speed sites on two-lane highways in rural areas. This relationship is presented in Figure 10. Although the correlation coefficient was highly significant, only 25 percent of the variation in the standard deviation can be explained by the ADT. Therefore, confidence interval lines have been added to the linear regression analysis in Figure 10 at plus and minus one and two standard errors of estimate. These permit the estimation of standard deviations for various ADT volumes with 68 percent and 95 percent confidence, respectively. With lower correlation coefficients, significant linear relations of standard deviation were also established with 30th HV and possible capacity.

The regression and correlation analyses produced non-significant results for four- and six-lane highways. This discrepancy was attributed to the small number of speed sites on these multi-lane facilities. Because the slopes of the regression lines closely approached zero, it was assumed that the standard deviations were approximately constant for four- and six-lane highways. Therefore, average values and corresponding standard errors, as given in Table 2, were developed for these facilities to determine sample size requirements. Until more data is collected, this modified procedure permits a first approximation for the estimation of the required sample size to insure the desired level of statistical accuracy.

CONCLUSIONS

This research study has developed a technique for determining the minimum sample size requirements for spot speed studies. These sample sizes are the minimum

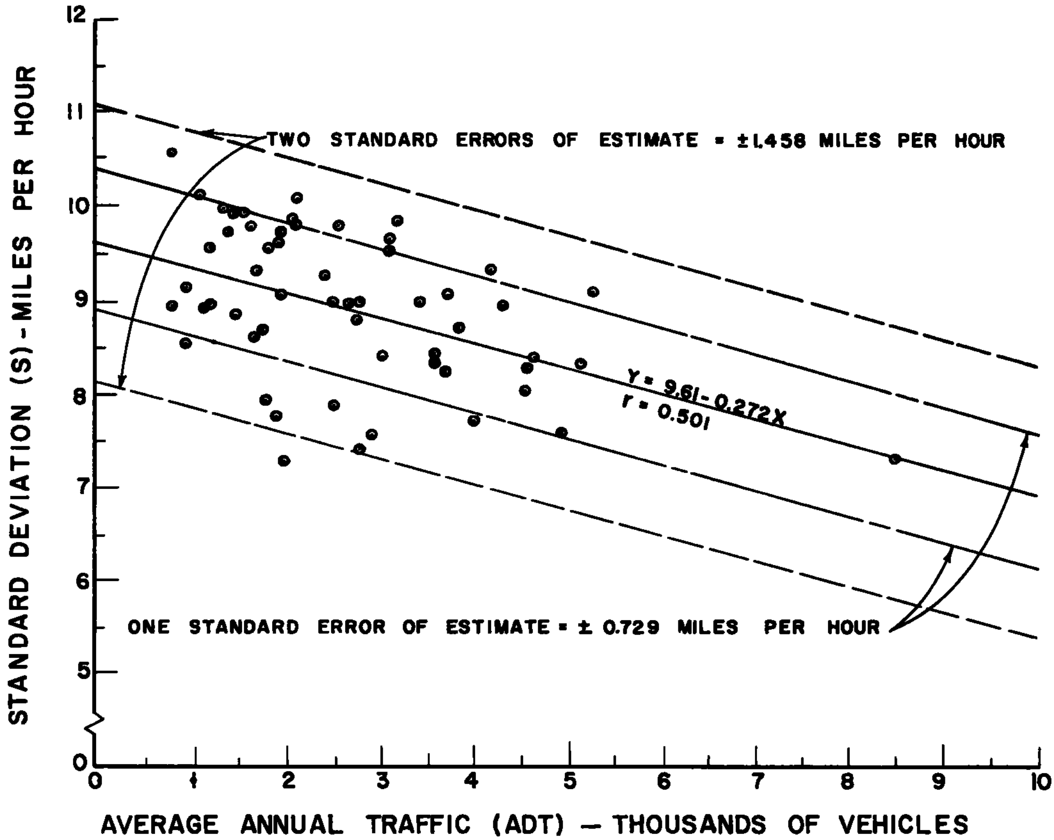

Figure 10. Standard deviation vs average annual daily traffic (for two-lane rural highways).

TABLE 2

AVERAGE STANDARD DEVIATIONS FOR FOUR- AND SIX-LANE RURAL HIGHWAYS

Highway Type	Average Standard Deviation (mph)	Standard Error of Estimate (mph)	Average Standard Deviation ± One Standard Error of Estimate (mph)	Average Standard Deviation ± Two Standard Errors of Estimate (mph)
Four-lane	9.15	0.84	9.99	10.83
			8.31	7.47
Six-lane	6.22	0.40	6.62	7.02
			5.82	5.62

required to produce the desired statistical accuracy in the results, thus conserving time and personnel by the elimination of over-sampling and superfluous values in the reduction of speed data.

The ADT value is generally known for most important highway and street sections where spot speed studies might be conducted. Also, the correlation between sample standard deviation and ADT was the most significant for the site characteristics investigated. Therefore, it was concluded that the ADT of a two-lane highway is a good measure for estimating the standard deviation of vehicular speeds at a site where the standard deviation is not known from previous spot speed studies. For four- and six-lane highways insufficient data necessitated the use of average values for standard deviation where spot speed studies have not been previously conducted.

Because these standard deviations are representative of low traffic volumes, they are observed maximum values which are acceptable for any highway location in rural, intermediate, and urban areas. The sample size is always statistically adequate regardless of the traffic volume at the time of the study.

EXAMPLE

The following example illustrates the rather simple procedure developed in this report for determining the required sample size of a spot speed study for a highway location where the standard deviation of the vehicular speeds is unknown. It is assumed that the highway location of the spot speed site has an ADT of 8,000. From Figure 10 the sample standard deviation is estimated at 7.45 mph on the regression line. If the engineer in charge of the speed study desires to estimate the 85th-percentile speed within ± 2 mph at a desired confidence level of 95 percent, then a minimum sample size of 85 vehicular speeds to be measured is indicated by Figure 5.

If the estimate of the standard deviation is made with 95 percent confidence, then the standard deviation is 8.90 mph. For the same conditions this produces a sample size of 125 speed observations. Because of the low degree of correlation between standard deviation of vehicular speeds and average annual daily traffic, the use of the larger sample size is recommended to place the results on the safe side.

SUGGESTIONS FOR FURTHER RESEARCH

To appraise more accurately the relationships between standard deviation of vehicular speeds and ADT, more speed sites on four- and six-lane highways must be studied for various levels of ADT. The results of this analysis will permit a refinement of the assumption of average values for these facilities as presented in this report.

Although the various relationships established in this research study provide reasonable statistical accuracy in estimating spot speed characteristics at any highway or street location, the standard deviations of speeds during low volume conditions in intermediate and urban areas may be less than those in rural areas for a comparable ADT because of the effect of speed zones, intersections, roadside development, etc., on individual vehicle speeds. If this assumption is true, then the development of relationships between sample standard deviation and ADT for these two traffic-condition areas will produce more economical sample size requirements when vehicular speeds are being evaluated in these areas.

These additional research projects are contemplated in the near future when sufficient speed data are collected on the different types of highways in the three traffic areas.

ACKNOWLEDGMENTS

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Appendix A

DERIVATION OF THE FORMULA FOR THE MINIMUM SAMPLE SIZE REQUIREMENTS

ASSUMPTIONS:

1. The population is assumed to be normal.
2. The sample size is sufficiently large.

NOMENCLATURE:

$\bar{X}$ = sample mean — μ = population mean

S^2 = sample variance — σ^2 = population variance

INTRODUCTION:

Since $\bar{X}$ is normally distributed with mean μ and standard deviation $\frac{\sigma}{\sqrt{N}}$, $\bar{X} = \mu + \frac{k\sigma}{\sqrt{N}}$, where k is the standard normal variate which can be obtained from the Cumulative Normal Table for a given probability. Also, $S = \sigma + \frac{k'\sigma}{\sqrt{2N}}$, where k' is the standard normal variate and the standard deviation of S is approximately equal to $\frac{\sigma}{\sqrt{2N}}$

The true value of a percentile (P) is theoretically $P = \mu + u\sigma$, where μ and σ are unknown parameters and u is the standard normal variate. An estimate of P ($\hat{P}$) is written as $\hat{P} = \bar{X} + uS$.

DERIVATION:

The probability (Pr) of $(|P - \hat{P}| \leq d)$ is equal to $1 - \alpha$, where α is the level of significance and $1 - \alpha$ is the confidence level.

$$Pr(|P - \hat{P}| \leq d) = 1 - \alpha$$

$$Pr(P - d \leq \hat{P} \leq P + d) = 1 - \alpha$$

Substituting the values of P and $\hat{P}$ in the above equation,

$$Pr(\mu + u\sigma - d \leqslant \bar{X} + uS \leqslant \mu + u\sigma + d) = 1 - \alpha$$

Substituting the values of $\bar{X}$ and S in the last expression,

$$Pr\left(\mu + u\sigma - d \leqslant \mu + \frac{k\sigma}{\sqrt{N}} + u\left[\sigma + \frac{k'\sigma}{\sqrt{2N}}\right] \leqslant \mu + u\sigma + d\right) = 1 - \alpha$$

$$Pr\left(-d \leqslant \frac{k\sigma}{\sqrt{N}} + \frac{uk'\sigma}{\sqrt{2N}} \leqslant d\right) = 1 - \alpha$$

$$Pr\left(\left|k + \frac{uk'}{\sqrt{2}}\right| \leqslant \frac{d\sqrt{N}}{\sigma}\right) = 1 - \alpha$$

The linear combination of k and k' is a normal variate with mean zero and variance $1 + \frac{u^2}{2}$.

$$\text{Mean} = E\left(k + \frac{uk'}{\sqrt{2}}\right) = E(k) + \frac{uE(k')}{\sqrt{2}} = 0$$

$$\text{Variance of } k + \frac{uk'}{\sqrt{2}} = (\text{variance of } k) + \left(\frac{u^2}{2}\text{ variance of } k'\right) = 1 + \frac{u^2}{2}$$

Let V' be equal to $k + \frac{uk'}{\sqrt{2}}$. Therefore, the standard normal variate (V) is $\frac{V' - 0}{\sqrt{1 + \frac{u^2}{2}}}$.

$$Pr\left(\left|\frac{k + \frac{uk'}{\sqrt{2}} - 0}{\sqrt{1 + \frac{u^2}{2}}}\right| \leqslant \frac{d\sqrt{N}}{\sigma\sqrt{1 + \frac{u^2}{2}}}\right) = 1 - \alpha$$

$$Pr\left(|V| \leqslant \frac{d\sqrt{2N}}{\sigma\sqrt{2 + u^2}}\right) = 1 - \alpha$$

For the given confidence level of $1 - \alpha$,

$$|V| \leqslant \frac{d\sqrt{2N}}{\sigma\sqrt{2 + u^2}}$$

$$V^2 \leqslant \frac{2d^2N}{\sigma^2(2 + u^2)}$$

$$N \geqslant \frac{V^2\sigma^2(2 + u^2)}{2d^2}$$

Therefore, the formula for the minimum sample size requirement (N) is.

$$N = \frac{V^2\sigma^2(2 + u^2)}{2d^2}$$

where V = normal deviate corresponding to the desired confidence.

u = normal deviate corresponding to the percentile being estimated.

d = permitted error in the estimate.

σ = standard deviation of the population

Because of the second assumption, the sample standard deviation (S) can replace σ in the above equation.

$$\therefore N = \frac{V^2S^2(2 + u^2)}{2d^2}$$

Appendix B

DATA

Site	ADT (v/day)	30th HV (v/hr)	Pos. Cap. (v/hr)	Std. Dev. (mph)	Site	ADT (v/day)	30th HV (v/hr)	Pos. Cap. (v/hr)	Std. Dev. (mph)
1-1	19,500	2,965	6,720	7.69	6-4	1,800	230	1,160	8.70
1-2	2,750	570	1,540	8.82	6-5	1,650	190	1,340	8.62
1-3	3,050	370	1,560	8.38	6-6	1,100	140	1,240	8.88
1-4	5,150	715	1,360	8.35	6-7	2,750	305	1,400	7.44
1-5	4,300	560	1,520	8.93	7-1	1,100	165	1,400	10.11
1-6	7,900	1,030	5,760	8.45	7-2	2,100	275	1,180	10.04
1-7	7,700	1,095	6,000	9.23	7-3	3,400	355	1,420	8.97
2-1	3,200	515	1,280	9.80	7-4	2,800	355	1,460	8.99
2-2	1,900	275	1,220	9.59	7-5	4,200	470	1,240	9.30
2-3	1,650	190	1,220	9.32	7-6	5,300	575	1,320	9.10
2-4	4,600	540	1,500	8.30	7-7	2,000	195	1,480	9.79
2-5	2,500	260	1,240	9.75	8-1	6,400	810	6,240	8.23
2-6	1,750	250	980	7.89	8-2	750	100	1,200	8.93
2-7	4,200	560	6,640	8.84	8-3	1,900	245	1,160	9.05
3-1	2,700	465	1,500	8.94	8-4	1,300	160	1,260	9.69
3-2	750	90	1,100	10.55	8-5	3,700	360	1,320	8.24
3-3	1,900	285	1,240	9.68	8-6	1,450	170	1,180	9.84
3-4	6,200	820	6,400	10.10	8-7	2,500	375	1,220	8.99
3-5	2,200	265	1,640	9.50	9-1	1,450	175	1,300	8.81
3-6	2,200	805	1,460	9.67	9-2	1,850	260	1,360	7.77
3-7	1,620	195	1,220	9.77	9-3	4,600	670	1,480	8.36
4-1	1,350	175	1,180	9.91	9-4	850	95	1,120	9.18
4-2	10,400	1,135	6,960	9.41	9-5	900	140	1,380	8.51
4-3	3,800	560	1,220	8.72	9-6	2,850	275	1,560	7.57
4-4	2,400	310	1,340	9.24	9-7	2,000	240	1,380	7.32
4-5	1,800	205	1,180	9.52	10-1	3,700	530	1,480	9.06
4-6	1,500	185	1,200	9.83	10-2	30,200	3,565	10,440	5.74
5-1	3,600	440	1,420	8.41	10-3	38,700	4,565	10,560	5.99
5-2	4,900	855	1,660	7.56	10-4	9,800	1,340	6,400	7.91
5-3	4,550	560	1,280	8.01	10-5	20,400	2,225	10,200	7.21
5-4	1,200	155	1,140	8.93	10-6	11,200	1,580	6,160	7.83
5-5	3,550	380	1,320	8.26	10-7	8,500	1,290	1,560	7.33
5-6	1,100	130	1,200	9.54	10-8	28,000	3,920	10,280	6.49
6-1	6,000	845	6,400	7.87	10-9	10,800	1,860	6,960	6.57
6-2	2,500	290	1,320	7.84	10-10	6,900	870	5,840	7.81
6-3	4,000	470	1,580	7.69					

Variability of Fixed-Point Speed Measurements

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One of the most vexing problems in the study of speed arises from the lack of background information needed in developing necessary sampling methods. In the most common method, speed measurements are taken at a fixed point. This raises the question of whether or not samples taken at different hours of the day, days of the week, or months of the year may be used to infer changes in speed behavior brought about by an artificially induced variable.

A study of vehicle speeds under normal conditions covering a period of six months suggests that a number of observations alone is insufficient as a measure of adequacy of sampling. Samples of vehicle speeds should be collected within fixed time intervals. The data for the study were collected in southern Wisconsin on a typical section of the rural state and Federal highway system.

Specific tentative conclusions reached are:

1. Hourly mean speeds show differences greater than chance would account for even after any possible effect produced by differences between days and months is eliminated.
2. The differences between Monday, Tuesday, Thursday, and Friday mean speeds are real and material.
3. The differences between monthly mean speeds are larger than can be accounted for by chance.
4. As sample sizes are increased without regard for the time interval involved, differences in the sample mean speeds provide estimates not only of the true changes in speed behavior but also changes in speed arising from differences in the hours, days, and months.
5. The quality of speed estimates can be improved by matching sampling periods by hour of day, day of week, and month of the year.

MEASUREMENT of vehicle speeds in the traffic stream and subsequent interpretations have perhaps had too much attention since the motor car came to be a substantial factor in the national economy. The fact that most authorities on traffic accident prevention postulate a causal relationship between vehicle speeds and traffic accidents has been a major spur to investigations in this area.

Speeds in a traffic stream are most commonly measured with fixed-point measuring techniques, or spot speed studies, as they are usually called by traffic engineers. This method involves the measurement of an arbitrary number of vehicle speeds at a single point on a highway, using one of several mechanical or electronic speed-measuring devices currently available. From the speeds themselves, or from various computed statistics, certain inferences are drawn about the speed in the traffic streams under study.

This method is useful to the traffic engineer and others who seek to evaluate the effects of change in geometric design, signing, or increased law enforcement, for obvious and very practical reasons. Moreover it is applicable in research requiring an evaluation of speeds before and after modification of a single variable. The method requires a minimum capital investment in equipment and large amounts of data may be collected at a low per-unit cost as compared with other methods.

The measurement of vehicle speeds using fixed-point methods and subsequent interpretation would seem at first to be a relatively simple and straightforward problem.

Unfortunately, in spite of this deceptively simple appearance, the method has many and subtle shortcomings. Vehicle speeds occur within a time continuum bounded by an almost infinite number of dimensions, many of which directly affect speeds observed at a given point within the continuum. The problem of obtaining samples of vehicle speeds at a fixed point, which will adequately reflect the nature of the real world being studied, is complex. The more precise the measurement being attempted (as in the case of attempting to determine slight but real changes in speeds brought on by enforcement activity), the greater is the sampling problem.

A detailed inquiry into the development of sampling methods in speed measurements is necessary before experimental study of speed behavior on a large scale can be under taken. The nature of the real world and the theoretical considerations that underlie sar pling design suggest that sampling techniques now used for making fixed-point speed measurements are inadequate for refined experimental work. Before activity leading to real understanding of speed behavior can be undertaken, it is necessary to develop other, more satisfactory sampling techniques.

DEVELOPMENT OF THE STUDY

In September 1959, a series of exploratory samples of vehicle speeds were taken over a two-week period at several points on the state trunk highway system in southern Wisconsin. The purpose of these samples was to provide some initial insight into how vehicle speeds measured at a fixed location behave, and to provide the basis for assum tions necessary to develop a model for subsequent experimental investigation. The sar ples thus gathered were deliberately varied so that data from different days of the week as well as different hours of the day would be available for study. No sampling period covered less than four continuous hours and many covered longer periods.

Evaluation of these exploratory samples gathered during September revealed statistically significant differences between the means of samples taken at the same location, under identical weather and light conditions, but on different days of the week or at different hours of the day. No systematic factors could be related to these variations, other than the times at which the samples were taken. Not only did the samples tested show statistica ly significant differences in regard to mean, variance, and proportion of vehicles over the speed limit, but the absolute value of the differences was sufficiently great to make the assignment of any, but extremely large changes to an experimental variable, impossil

As a result of this initial evaluation it was decided to undertake a study of vehicle speeds over an extended period of time under conditions as nearly normal as possible. The purpose of this study was to develop a theoretical model specifying a required sam pling design, and to test it by empirical methods. The development of the theoretical model and testing by empirical methods have proceeded concurrently, with modifications of both being made as the information available at a given time dictated.

For the study, a highway location was sought which would meet certain minimal spe ifications. These were:

1. Marginal development, both at the measuring point and for at least 2 miles in either direction, should be minimum.
2. Enforcement activity, both present and past, must have been at a minimum.
3. Traffic volumes should be sufficiently high to assure an adequate number of observations and range of volume levels, but not high enough to produce congestion.
4. Speed limits should be the maximum permitted for rural hgihways throughout the state.
5. Highway design should be such as to minimize its effect on speed behavior.

In November 1958, a site was selected that approximated the desired specifications. The highway at this juncture consists of two 11-ft driving lanes with 4-ft gravel-packed shoulders. The surface is travel-worn asphalt in good condition. Road alignment approaching the sampling site is straight for 1.1 mi to the north and 1.8 mi to the south. The grade within 1 mi in either direction is negligible. The marginal development con sists of scattered farms and the legal speed limit is 65 mph in the daytime and 55 mph at night. The nearest zones requiring reduced speed are 4 mi to the north and 6 mi to the south.

Sampling was begun at this location during the first week of November. A continuous sample of vehicle speeds was taken for 16 hours each day, from 7 a.m. to 11 p.m., Monday through Friday. The procedure was repeated for each subsequent month with the exception of February, when weather conditions throughout the month made sampling impossible. At the present time sampling has been completed through October 1959. Sampling will be continued through November 1959, making a full year of representative samples available for evaluation.

FIELD METHODS

It is necessary to discuss briefly the method used to take measurements in the field. A recently published study (1) presents strong evidence that measurement techniques themselves may produce material bias in data. All measurements of vehicle speeds were made with an Electronic Radar Speed Meter consisting of a sensing unit, a standard indicating meter calibrated in miles per hour, and a 12-volt power source. The sensing unit is located adjacent to the highway in a specially constructed mailbox, with a 12-volt battery concealed in the base as a power source. The observer recording the data is housed in a station wagon placed well back in a farmyard concealed from the view of drivers passing along the highway. The indicating meter is connected to the sensing unit by means of a 500-ft cord. The entire unit is calibrated by a standard calibrating tuning fork before each day's sample, again after 8 hr of operation, and again at the completion of each day's sample.

Speeds are read from the indicating meter by an observer and recorded in 5-mph intervals on a specially prepared recording sheet. Samples are recorded by direction of travel and by hour to facilitate study of specific periods of the day. Vehicles are divided into three classes: passenger cars, light trucks, and heavy trucks. Unusual traffic units, such as vehicles pulling house trailers or road machinery, are not included in the general sample but are noted separately.

Periodic samples of the actual speeds of individual vehicles are taken at irregular intervals, usually covering all vehicles that pass in a given 2-hr period. The samples are used primarily for the purpose of analyzing the distribution of speeds for normalcy. Periodic tests are made for the purpose of determining sample bias by driving a vehicle with a calibrated speedometer past the sensing unit at a known speed. Normally, six northbound and six southbound tests are conducted. No bias has been detected in either direction.

The observers are off-duty highway patrolmen with extensive experience in the use of radar for enforcement purposes. Each observer spends a minimum of 2 hr with the field supervisor standardizing his reading techniques before actually making observations on his own. The reading accuracy of each observer is checked at periodic intervals by the field supervisor who takes a series of readings from the meter while seated directly behind the observer. Reading error has been determined to be within ± 1mph.

The speeds of all vehicles are measured regardless of whether they are in free flow. This was done because the interest is in studying the effects of volume, as well as other factors, on vehicle speeds. To avoid repetition, all comparisons are standardized as to weather and road conditions, unless otherwise noted. All samples used in the analysis were gathered in fair weather on a dry road surface.

RESULTS

The data on which the results are based include samples taken through May 1959. It was decided at the outset to use time as a variable of classification. Each observed vehicle speed was classified by the hour of the day, day of the week, and month of occurrence. The method used for the analysis is known as "analysis of variance." Inasmuch as it was necessary to test the effect of all three variables of classification (hours, days, and weeks), and because the number of vehicles observed varies from hour to hour, it is necessary to use the method of fitting constants or some equivalent procedure. The usual technique of analysis of variance for equal numbers of observations in each cell will not work unless there are no effects associated with the variables of classification not being tested.

The method of fitting constants involves the construction of maximum-likelihood estimates of the effects associated with each variable of classification. Estimates of the mean speed for a given hour of a given day of a given month can then be made by adding the appropriate hour, day and month effect estimates to the grand average.

This particular analysis-of-variance test is based on the same assumptions and derived by the same methods as the more usual and familiar "t" test for the difference in means. If, for example, there were only two samples, the test used would reduce to a test operationally identical with the "t" test.

The data processed were confined to observations made between 7 a.m. and 4 p.m. on weekdays, Monday through Friday. The observations between 4 and 5 p.m. were omitted because previous tests had shown them to be heterogeneous. The 7 a.m. observations were omitted because the data for one of the hours were missing. It is possible to allow for the asymmetry due to the absence of these data, but in this instance the computations were eliminated by removing all 7-8 a.m. data from the sample.

For each set of data the following null and alternate hypotheses were tested:

Null	Alternate
All $c_k = 0$	Some $c_k \neq 0$
All $b_j = 0$	Some $b_j \neq 0$
All $a_i = 0$	Some $a_i \neq 0$

The first null hypothesis is that there is no month-to-month or seasonal shift in mean vehicle speeds. Similarly, the second and third null hypotheses imply that there are no day-of-the-week or hour-of-the-day effects.

In this case the likelihood ratio test can be reduced to an "F" test of the ratio of two independent estimates of the variance of e_{ijkL}. The denominator of this ratio is computed in the following manner:

The term $\sum_{ijkL} Y^2_{ijkL}$, which is the sum of the squared values of the observations, is calculated. From this is subtracted R (m + a, b, c), a function determined in the process of computing the estimated values of a_i, b_j, c_k, m. This difference, when divided by the appropriate degrees of freedom, gives an unbiased estimate of σ^2, allowing for the fact that the constants except those being tested may not all be zeros. This estimate of the mean square is called E, which is used in all three tests of hypotheses in each case. The numerator to test the hupotheses that $a_1 = a_2 = . . . = a_R = 0$ is obtained as follows:

The constants for a model of the form $Y_{jkL} = m + b_j + c_k + e_{jkL}$, with the hour classification being ignored are estimated. A function R (m + c, b), similar to R (m + a, b, c) is derived. The difference between these two functions, R (m + a, b, c) - R (m + c, b), divided by the appropriate degrees of freedom, is an estimate of σ^2 if the null hypothesis is true. From construction this estimate is statistically independent of E. This estimate (corresponding to the null hypothesis that mean speeds are not related to time of day) is referred to as C_1. The ratio C_1/E, if the null hypothesis is true, has an F distribution with the appropriate degrees of freedom parameters. Values of $F\alpha$ may be picked from tables of the F distribution so that C_1/E will be more than $F\alpha$ only α percent of the time if the null hypothesis is true. In this instance values of α = 5 percent and α = 1 percent were chosen and, hence, F 0.05 and F 0.01 were selected. If, in fact, $a_1 = a_2 = . . . = a_R = 0$, the null hypothesis is true; and if this procedure is adopted, the null hypothesis will be rejected, with the decision that not all $a_i = 0$ about one time in 20 or one time in 100, depending on whether F 0.05 or F 0.01 is used.

It is not the best possible technique to test several hypotheses on the same observations. However, these tests are orthogonal; that is, in principle the results of one test do not depend on the state of the real world with respect to the others. This appeared to be the best method for developing the background necessary for producing a satisfactory test-interpretation technique.

Table 1 is a symbolic outline of the analysis of variance just described for the null hypothesis, all $a_i = 0$, against the alternative hypothesis, some $a_i \neq 0$. The actual results are summarized in Tables 2 and 3.

TABLE 1

SYMBOLIC* ANALYSIS OF VARIANCE TABLE
(Null Hypothesis: All $a_i = 0$; Alternate Hypothesis: Some $a_i \neq 0$)

Variance Due to	Degrees of Freedom	Sum of Squares	Mean Square
Fitting $m + c_k, b_j$	$S + T - 1$	$R(m + c_k, b_j)$	
Difference	$R - 1$	(by subtraction)	C_1
Fitting $m + a_i, b_j, c_k$	$R + S + T - 2$	$R(m + a_i, b_j, c_k)$	
Remainder	$N - R - S - T + 2$	(by subtraction)	E
Total	N	$\sum_{ijkL} Y^2_{ijkL}$	

*In this case, the symbols have the following definitions: R = number of hours within which the data are classified, S = number of days within which the data are classified, T = number of months within which the data are classified, N = total number of observations made, and $\sum_{ijkL} Y^2_{ijkL}$ = sum of the squares of the observed values.

If $C_1/E > F_\alpha (R - 1, N - R - S - T + 2)$, then the probability of this value of C_1/E being observed is less than α if the null hypothesis is true. For values of C_1/E which exceed F_α for some predetermined level of α, the null hypothesis that all $a_i = 0$ is rejected and the alternate hypothesis that some $a_i \neq 0$ is accepted.

If, in fact, the a_i are not all zero, then C_1 is no longer an estimate of σ^2. It can be shown that C_1 will estimate some number larger than σ^2. The amount by which $E(C_1)$ (the expected value of C_1) exceeds σ^2 depends both on the magnitude of the a_i and the distribution of the number of observations. With the number of observations fixed, the greater the magnitude of the a_i, the more likely it becomes that a C_1/E greater than F_α will be observed.

In a similar manner tests of the null hypotheses $b_1 = b_2 = \ldots b_S = 0$ and $c_1 = c_2 = \ldots = c_T = 0$ can be constructed by obtaining the function $R(m + a, c)$ and $R(m + a, b)$. The appropriate degrees of freedom may be obtained as follows: If there are R hours, S days, and T months of observations in the data, and in this period N observations have been made, the degrees of freedom for $R(m + a, b, c,) = N - R - S - T + 2$. For $R(m + a, b)$, $R(m + a. c)$, $R(b + m, c)$ appropriate degrees of freedom are $(T - 1)$, $(S - 1)$ and $(R - 1)$, respectively.

The first four sets of data consist of vehicle speeds collected Mondays through Fridays in November and December 1958, and January, March, April, and May 1959. Each of these sets contains data from 30 separate days. The hours of each day during which data were collected for each set were as follows:

Set 1 passenger cars — days: 8 a.m. - 4 p.m., total 240 hr.
Set 2 passenger cars — nights: 5 p.m. - 11 p.m., total 180 hr.
Set 3 trucks — days: 8 a.m. - 4 p.m., total 240 hr.
Set 4 trucks — nights: 5 p.m. - 11 p.m., total 180 hr.

For each set the following hypotheses were tested:

1. That the variation between all hours, allowing for variation between months and days, was not great enough to be significant.
2. That the variation between all days, allowing for variation between months and hours, was not great enough to be significant.
3. That the variation between all months, allowing for variation between hours and days, was not great enough to be significant.

The results of these tests are summarized in Table 2.

TABLE 2

SUMMARY OF DIFFERENCES IN MEAN SPEEDS

Data Set	Test	C_1/E Ratio	Significance Level
Cars — 8 a.m. - 4 p.m.	Hourly mean speeds	4.67	0.01
	Daily mean speeds	19.17	0.01
	Monthly mean speeds	9.28	0.01
Cars — 5 p.m. - 11 p.m.	Hourly mean speeds	29.58	0.01
	Daily mean speeds	24.36	0.01
	Monthly mean speeds	69.64	0.01
Trucks — 8 a.m. - 4 p.m.	Hourly mean speeds	2.17	0.05
	Daily mean speeds	3.13	0.05
	Monthly mean speeds	58.33	0.01
Trucks — 5 p.m. - 11 p.m.	Hourly mean speeds	14.30	0.01
	Daily mean speeds	14.39	0.01
	Monthly mean speeds	35.01	0.01

From an examination of the data in Table 2 it may be concluded that, with possible exception of the daily and hourly mean speeds for trucks in the daytime, the difference in mean speeds are larger than can be accounted for by chance. The differences between hourly mean speeds, even after any possible effect produced by differences between days and months is removed, is too great to be attributed to mere chance fluctuations. The same thing may be said about daily mean speeds and monthly mean speeds.

At the same time that the data described were processed, and before the results were known, two additional sets of data were processed. These data consisted of the following:

Set 5 passenger cars — 8 a.m. - 4 p m., Monday, Tuesday, Thursday, Friday.
Set 6 passenger cars — 8 a.m. - 4 p.m., Tuesday, Thursday.

The purpose of these tests was to determine whether there was any combination of days for which some of the differences previously noted were not material. The results of this series of tests are summarized in Table 3.

The data summarized in Table 3 suggest the following conclusions:

1. The difference in monthly mean speeds is great enough to be material in all cases.
2. The differcnces between Monday, Tuesday, Thursday, and Friday mean speeds are real and material.

TABLE 3

SUMMARY OF DIFFERENCES IN MEAN SPEEDS

Data Set	Test	C_1/E Ratio	Significance Level
Cars—8 a.m. - 4 p.m. Mon., Tues., Thurs., and Fri.	Hourly mean speed	1.55	N.S
	Daily mean speed	12.36	0.01
	Monthly mean speed	8.30	0.01
Cars—8 a.m. - 4 p.m. Tues. - Thurs.	Hourly mean speed	2.52	0.05
	Daily mean speed	-	N.S
	Monthly mean speed	3.56	0.01

3. The differences between hourly mean speeds for these days are not material if allowance is made for differences arising from changing days of the week and month.
4. The variation in daily mean speed between Tuesday and Thursday is not material if allowance is made for differences arising from changing days of the week and month.

It should be noted that the conclusions reached for set 5 in regard to differences in hourly mean speed differ substantially from the conclusions reached using set 1. The differences are attributed to the fact that set 1 contained a Wednesday sample taken under abnormal weather conditions. It is quite possible that the effect of weather on the Wednesday samples was sufficient to override the effects of the normal days included in the sample, and thus produced the significant hourly effect apparent in set 1. This point will be explored more fully when complete data are available.

Evaluating the results in total it would appear that the differences noted between months is sufficiently great to preclude the possibility that it will disappear even with matching of equivalent months. Monthly mean speeds consistently showed the highest C_1/E ratios and all differences in monthly mean speeds showed significance at the 0.01 level of probability.

There is some evidence that certain blocks of hours are homogeneous and may be treated as equivalent if daily and monthly variation are taken into account. There is also some hope that certain days of the week may be treated as equivalent. In both cases conclusive results must await testing of total data, "cleaned" of bad weather influence, to find which (if any) hours and days may be considered homogeneous.

DISCUSSION

The work completed thus far clearly indicates that the measurement and interpretation of vehicle speeds are extremely complex. Even when such obvious factors as weather, light conditions, and location of measurement are standardized, other variable factors still tend to make comparative evaluations difficult. The data evaluated so far strongly suggest that samples taken at different time periods, even though weather, light and location conditions are standardized, cannot be used to interpret the significance of a difference in the mean of samples. Samples taken at the same location a month or a year apart will tend to be unreliable as a measure of changes produced by a newly introduced variable.

The quality of sampling can undoubtedly be improved by matching hours of the day, days of the week, and months. In the collection of fixed-point speed samples there appears to be no great difficulties in matching sampling time in terms of hour, day, and month. However, there is considerable question at present whether even such matching will completely eliminate the inherent variability.

It seems clear that in any event speed samples should be collected within fixed time intervals, as opposed to simply taking some minimum "satisfactory" number of observations. The danger in relying on the number of observations alone as the criterion of the adequacy of the sample is that as the sample size grows, the differences in samp mean speed reflect not only true changes in speed behavior over the interval between sampling periods, but also the changes in mean speed arising from differences in the hourly, daily, and monthly variables. Larger samples involving unmatched sampling periods insure the rejection of the typical null hypothesis that there has been no real change in speed behavior even in those cases where no change exists.

Conclusions already drawn indicate that the classical statistics of measurement cannot be applied indiscriminately to problems of traffic measurement. It would seem that, before statistical tests can be used to evaluate traffic measurements, care must be taken to insure that the test selected is applicable. In the case presented here the classical method of using the number of observations as the sole criteria for determining the adequacy of a sample can result only in erroneous and misleading results.

With the variability found in the data, fixed-point speed measurements have a limited value until such time as corrective measures can be used. Unfortunately, the question of an adequate sampling method cannot at the moment be answered in a positive manner. When the complete data now being gathered in this study are available two things may be accomplished:

1. Limits within which true speed values may be expected to fall can be established, thus serving to specify limits within which fixed-point measuring techniques may be used.
2. Correction factors may be developed which can be used to eliminate the bias that occurs because of daily, hourly, and monthly variation.

From study of currently available data it would appear that both these objectives are within the realm of feasibility.

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Appendix

BACKGROUND FOR ANALYSIS OF VARIANCE

Assumptions

1. The speeds of cars observed within an hour constitute a random sample from a normal population.
2. Although the mean of the normal population may vary between hours, days, and locations, the variance of the underlying distribution remains unchanged.
3. The effects of the variables of classification are simply additive.

Notation

Let a_i be the effect associated with the ith hour, $i = 1, 2 \ldots R$.
Let b_j be the effect associated with the jth day, $j = 1, 2 \ldots S$.
Let c_k be the effect associated with the kth day, $k = 1, 2 \ldots T$.

Also, $\sum_{i=1}^{i=R} a_i = \sum_{j=1}^{j=S} b_j = \sum_{k=1}^{k=T} c_k = 0$

$Y_{ijkL} = m + a_i + b_j + c_k + e_{ijkL}$ where m is a constant, independent of the variables of classification and e_{ijkL} is a non-observable realization of a normal random variate with mean zero and variance σ^2. If we adopt the standard notation E (x) = the expected value of a random variable x, then our assumptions imply the following (in addition to the linear form):

1. $E(e_{ijkL}) = 0$

2. $E\,(e_{ijkL})^2 = \sigma^2$

3. $E\left[(e_{ijkL})\,(e_{wxyZ})\right] = 0$ unless $\begin{matrix} i = w \\ j = x \\ k = y \\ L = Z \end{matrix}$

et N_{ijk} be the number of cars observed in the ith hour of the jth day of the kth month.

ypotheses to Be Tested

For each set of data we wish to test the following null hypothesis against the cor-
esponding alternative hypothesis.

Null Hypothesis	Alternative Hypothesis
1. $a_1 = a_2 \ldots = a_R = 0$ All $a_i = 0$	Some $a_i \neq 0$
2. $b_1 = b_2 \ldots = b_S = 0$ All $b_j = 0$	Some $b_j \neq 0$
3. $c_1 = c_2 \ldots = c_T = 0$ All $c_k = 0$	Some $c_k \neq 0$

hese null hypotheses may be restated as:

1. The mean speed of cars varies from hour to hour.
2. The mean speed of cars varies from day to day.
3. The mean speed of cars varies from month to month.

We wish to be able to test each of the null hypotheses irrespective of whether or not
e remaining null hypotheses not immediately under test are true. Thus the question
e wish to ask about the variations in hourly mean speeds is: if the effects on average
peed associated with days and months are allowed for, does average speed change
rom hour to hour? The questions we ask about the day of the week and month of the
ear variables of classification are analogous.

eriving the Test Procedures

Under our assumptions a test may be derived from the likelihood ratio test proce-
ure. It may be shown that in all the cases of the linear hypothesis the test criterion
ecomes an F test of the minimum mean squared deviation under the null against the
inimum mean squared deviation under the alternative hypothesis (2).

Thus we wish to construct estimators of a_i, b_j, c_k, and m, ($\hat{a}_i$, $\hat{b}_j$, $\hat{c}_k$, $\hat{m}$, respec-
vely), which minimize $\sum_{ijkL} (Y_{ijkL} - \hat{a}_i - \hat{b}_j - \hat{c}_k - \hat{m})^2 = \sum_{ijkL} \hat{e}^2$. For a given set of
bservations, $\sum_{ijkL} \hat{e}^2_{ijkL}$ can be regarded as a function of $\hat{a}_i$, $\hat{b}_j$, $\hat{c}_k$, $\hat{m}$ the estimates
f the parameters, a_i, b_j, c_k, m. Let this function be represented by F ($\hat{e}$). Differ-
ntiate F ($\hat{e}$) with respect to the variables $\hat{a}_i$, $\hat{b}_j$, $\hat{c}_k$, $\hat{m}$, where (i = 1, 2 ... R, j = 1,
... S, k = 1, 2 ... T), and set the resulting partial derivatives equal to zero:

hus if $\dfrac{\partial F\,(\hat{e})}{\partial\,\hat{m}} = 0$ then $\sum_{ijkL} (Y_{ijkL} - \hat{a}_i - \hat{b}_j - \hat{c}_k - \hat{m}) = 0$*.

ince N_{ijk} is the number of observations in the ith hour, of the jth day, of the kth
onth we have the first normal equation:

$$\hat{a}_1 \sum_{jk} N_{1jk} + \hat{a}_2 \sum_{jk} N_{2jk} + \ldots + \hat{a}_R \sum_{jk} N_{Rjk} + \hat{b}_1 \sum_{ik} N_{i1k} + \hat{b}_2 \sum_{ik} N_{i2k} + \ldots + \hat{b}_S \sum_{ik} N_{iSk} +$$

$$\hat{c}_1 \sum_{ij} N_{ij1} + \hat{c}_2 \sum_{ij} N_{ij2} + \ldots + \hat{c}_T \sum_{ij} N_{ijT} + \hat{m} \sum_{ijk} N_{ijk} = \sum_{ijkL} y_{ijkL}$$

It may be shown that under our assumptions the second order conditions which require
e value of F (e) to be a minimum are also met.

Similarly we may derive a normal equation for a_r from the equation

$$\frac{\partial F(\hat{e})}{\partial \hat{a}_r} = 0$$

This implies for i = r

$$\sum_{jk1} (Y_{rikL} - \hat{a}_r - \hat{b}_j - \hat{c}_k - \hat{m}) = 0$$

Therefore

$$\hat{a}_r \sum_{jk} N_{rjk} + \hat{b}_1 \sum_k N_{r1k} + \hat{b}_2 \sum_k N_{r2k} + \ldots + \hat{b}_S \sum_k N_{rSk} + \hat{c}_1 \sum_j N_{rj1} + \hat{c}_2 \sum_j N_{rj2} + \ldots + \hat{c}_T \sum_j N_{rjT} + \hat{m} \sum_{jk} N_{rjk} = \sum_{jk1} Y_{rjk1}$$

In this manner a system of linear equations can be developed. Any non-trivial solutio provides a set of weights which will make orthogonal tests of hypotheses possible. W employed the additional constraints that

$$\sum_i \hat{a}_i = \sum_j \hat{b}_j = \sum_k \hat{c}_k = 0$$

in order to impose a specific solution.

Part of the total variation in Y_{ijkL} is accounted for by the fact that not all a_i, b_j, c_k, = 0. We wish to eliminate this part of the variation from the analysis. Let us de fine the corresponding sum of squares as R(m + a, b, c). Thus, R(m + a, b, c) =

$$\sum_i (\hat{m} + \hat{a}_i) \sum_{jkL} Y_{ijkL} + \sum_j \hat{b}_j \sum_{ikL} Y_{ijkL} + \sum_k \hat{c}_k \sum_{ijL} Y_{ijkL}$$

There are R + S + T - 2 degrees of freedom associated with this function. A similar analysis is possible under the null hypothesis that $a_1 = a_2 \ldots = a_R = 0$. The sum of squares accounted for in fitting the constants b_j, $c_k + m$ is denoted by R (b_j, $c_k + m$). There are S + T - 1 degrees of freedom associated with R (b_j, $c_k + m$).

It should be noted that by construction the estimates of a_i, b_j, c_k, m are maximum likelihood estimates under our assumptions. If the assumption that the e_{ijkL} have a normal distribution is relaxed, while the other assumptions are maintained, the esti-

mates $\hat{a}_i$, $\hat{b}_j$, $\hat{c}_k$, $\hat{m}$ are still the best linear unbiased estimates.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.