An Analysis of Urban Travel Times and Traffic Volume Characteristics

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● AS PART of the Nashville Metropolitan Area Transportation Study, several studies were carried out which were somewhat of a departure from normal urban practices. Travel time has been generally used for before-and-after studies at specific locations. Here the study included the entire urban area and is used as a basis to compare the "level of traffic service" of the various traffic carrying arteries.

In many cities there was not an abundance of information concerning traffic volumes. In others, Nashville included, there was considerable information on file. The intent of the volume study was to get the available information into use and establish a volume counting program to obtain additional information to round out the over-all picture.

This paper is intended to show some of the analyses and results of these two studies; not so much for the sake of specific values found in Nashville, but to discuss some of the general findings of the studies.

To date the Travel Time Study covers the major arterial system. Data were collected during the morning peak hour and off-peak periods for automobiles. The evening peak hour study also included transit.

The data collected covers approximately 150 mi of major arterial streets. All but the outlying control sections of this system have had around 20 travel time passes at various times of the day. With exceptions, the morning peak hour passes were inbound and the evening peak hour passes, including transit, were outbound. The exceptions were one-way streets, circumferential streets and radial streets which appeared to offer a poorer level of service in the off-peak direction of flow. The off-peak period passes were made in both directions on all streets.

During the data collection phase, several analyses were accomplished to determine sample adequacy. The National Committee on Urban Transportation study program prescribes an adequacy check for sample size for travel time studies. It is based on average deviation and assumes normality in the sample.

The National Committee on Urban Transportation check for adequacy states that the sum of the deviations from the calculated mean of six travel times shall be equal to or less than the mean for the same to be considered adequate.

For this discussion let:

T_1, T_2, etc. = travel time on any pass;
T_m = mean travel time;
$D_1 = T_1 - T_m$; $D_2 = T_2 - T_m$ etc.;
s = standard deviation;
S_m = standard error of the mean; and
N = number of passes on which the check is based, in this case 6.

Therefore:

$$D_1 + D_2 + D_3 --- + D_6 = T_m \qquad (1)$$

The average deviation = $\frac{T_m}{6}$. In other words if Eq. 1 is true, then the average deviation in time on a given pass is equal to one-sixth the mean.

By definition average deviation equals 0.7979 standard deviations (0.7979s):

$$0.7979 = \frac{T_m}{6} \text{ or } s = 0.209\ T_m \qquad (2)$$

Assuming that each of the six passes is an estimate of the true mean it is seen that the standard deviation of these sample means about the true mean (S_m) is:

$$S_m = \frac{s}{\sqrt{N}} = \frac{0.209\ T_m}{\sqrt{6}} = \frac{0.209T_m}{2.449} = 0.085\ T_m \qquad (3)$$

Therefore, six passes meeting the conditions of this check will yield accuracy within 8.5 percent in 67 percent of the cases.

The normality assumption was checked by making 51 passes in each direction over three control sections on one street. The street ran from downtown to the city limits and had characteristics comparable to other major streets. The chi square "goodness of fit" test was applied to the results. For the purpose of this test, there were six control sections (three control sections with passes in each direction). The results are given in Table 1 and, based on these results, it was assumed that normality could not be disproved.

The National Committee procedure states that on control sections where the travel times do not meet the conditions of the check for six passes, four additional passes shall be made. This occurred on 20 of the 149 control sections. A check was made to determine the difference between travel times calculated from six passes and that

TABLE 1

RESULTS OF CHI SQUARE "GOODNESS OF FIT" TEST[a]

Control Section		Inbound						Outbound					
					Freedom						Freedom		
Limits	Length (mi)	T_m (min)	s (min)	X^2	Deg.	Sign. Level	X^2	T_m (min)	s (min)	X^2	Deg	Sign. Level	X^2
Church St.- Lea Ave.	0.57	2.39	0.385	7 92	4	0.05	9.49	2.18	0.404	23.891	4	0.05	9.49
Lea Ave.- South St.	0.51	1.38	0.197	26.63	4	0.05	9.49	1.39	0.246	13.72	3	0.01	11.34
South St.- Bradford Ave.	1.25	2.81	0 292	10.07	4	0.025	11 14	2.76	0.240	2.32	4	0.5	3.357
Church St.- Bradford Ave.	2.33	6.36	0 429	5.14	3	0.10	6.25	6.22	0.646	10.63	4 4	0.05 0.025	9.49 11.14

[a]As applied to 51 travel time passes in each direction on 8th Ave. between Church St. and Bradford Ave.

calculated from ten passes. On 17 of the 20 sections, there was 1 mph or less difference. Only one section had as much as 3 mph difference and this section was somewhat of a special case. It was only about two blocks long and was called a control section only because of geometric characteristics substantially different than either of the adjoining ones. All this seems to indicate that even if the check is not met after six passes, that more passes will not necessarily alter the average travel time.

On completion of the data collection, the average speed for each control section was calculated for the various periods of the day. Figure 1 shows the speeds for each section for the evening peak hour. This presentation shows at a glance where the lower speeds are found during this period. The solid black lines represent average speeds of 5 to 10 mph. The clear lines show speeds of more than 40 mph. Similar figures were prepared for the morning peak hour and off-peak periods.

The time contour map is a well-known tool developed from travel time data (Fig. 2). There are two sets of time contours on this map and the picture they present is of interest. The solid lines were plotted from morning peak travel times which were inbound to the central business district. The dashed lines were plotted from evening peak hour times which were outbound from downtown. The same streets are involved but there is considerable difference in the two patterns. The morning pattern is shifted to the southwest relative to the evening pattern. Thus, some streets which offer rather poor service during the morning peak hour offer better service during the evening peak

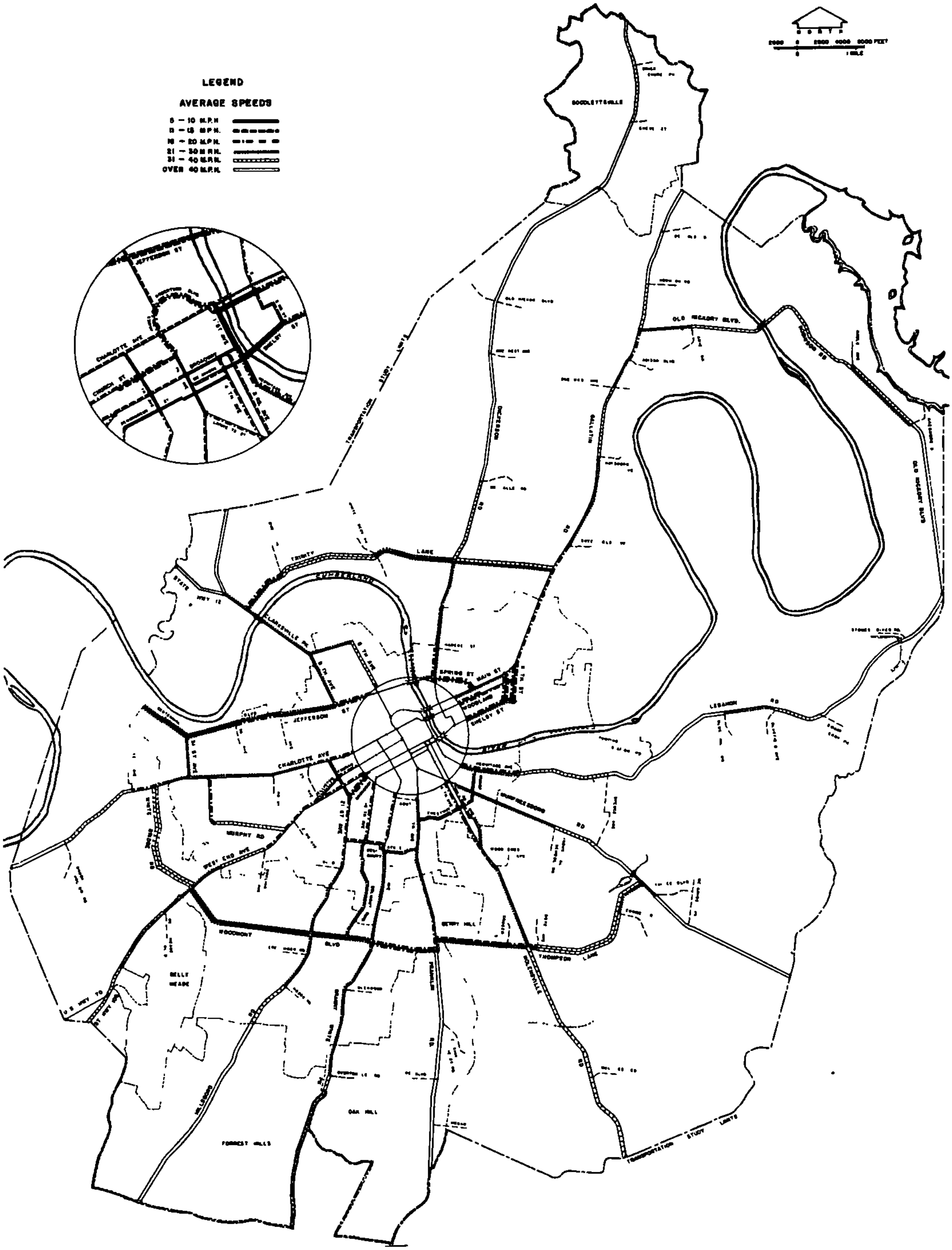


Figure 1. Average over-all speeds on major arterial streets during PM peak hour (winter 1958-1959).

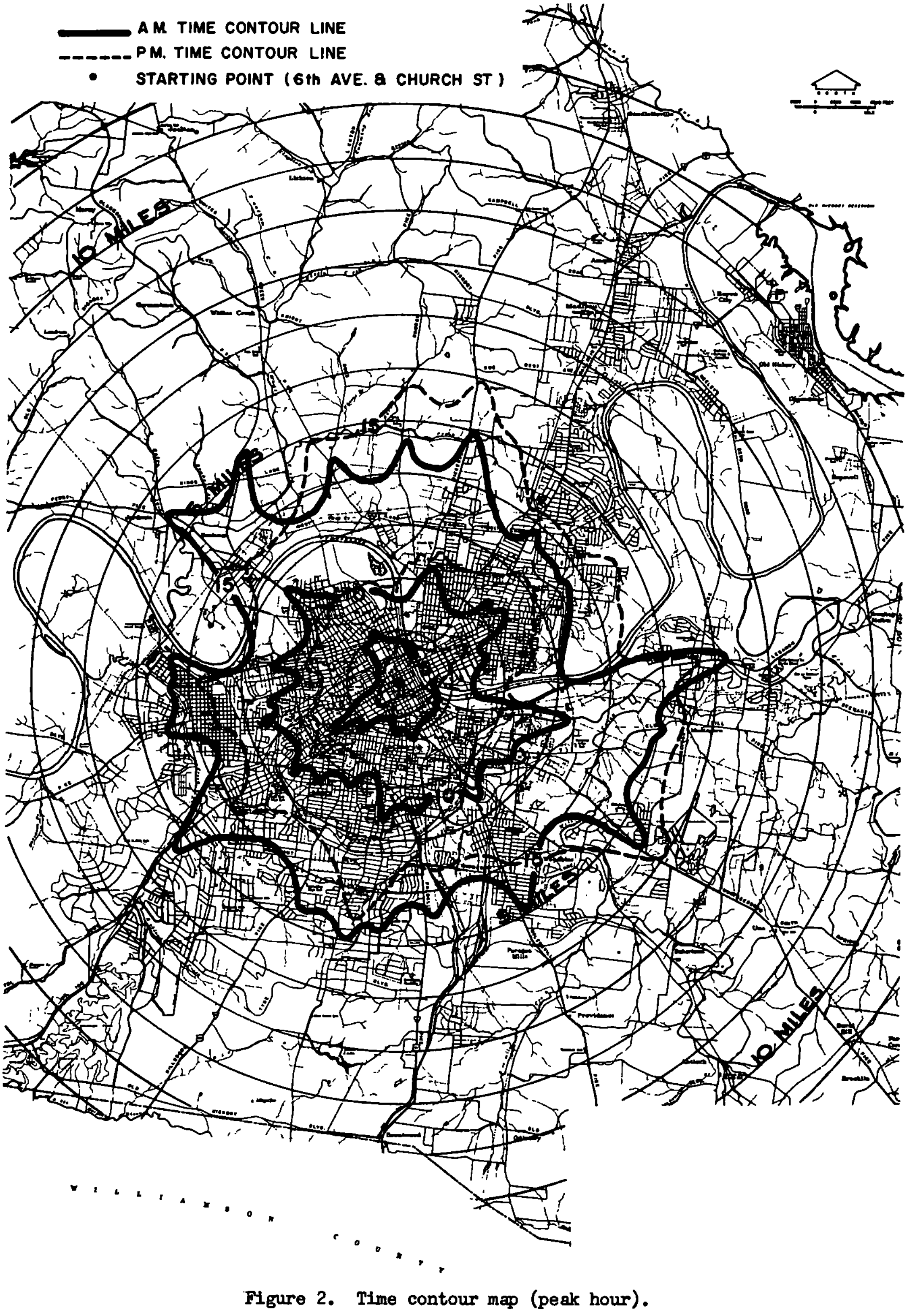


Figure 2. Time contour map (peak hour).

and vice versa. Figure 3 illustrates this in another manner. It is a cumulative frequency diagram and shows the evening peak hour speed for each control section as a percent of the morning peak hour speed. The variation is quite large. The PM speed varies from 0.5 to 3.5 times the AM speed. On only about 40 percent of the control sections is the difference less than 10 percent. This is significant in that is shows the need for data representative of both peak hours in order to say the level of service on this or that street is more deficient than that on another street.

The original intent of the Travel Time Study was to produce a measure of street deficiency. To accomplish this, the following desirable peak hour speed criteria were agreed on by the Technical Coordinating Committee: downtown — 15 mph, and more than 1 mi from the center of downtown — 25 mph. The speed on each control section was compared to the applicable criteria. The difference between the actual speed on a control section and the criterion speed constitutes a speed deficiency or sufficiency for the section. A deficiency is converted from miles per hour to minutes per mile and multiplied by the peak hour volume for the control section. The result is the delay experienced by traffic on the control section. It is expressed as vehicle minutes of delay per mile. Adding the delay experienced during both peak hours gives the total peak period delay.

Considerable delay was experienced on some control sections during the evening peak hour and on others in the morning peak. There was delay on still other sections during both peaks. Combining the delay for the two peaks gives a more nearly complete picture of the comparative level of service on each control section. This is in agreement with the fact that there was considerable variation in the speeds for the AM peak and the PM peak. Figure 4 shows this vehicle delay for the two peak hours. A glance at this figure shows where the more serious delays and congestion exist.

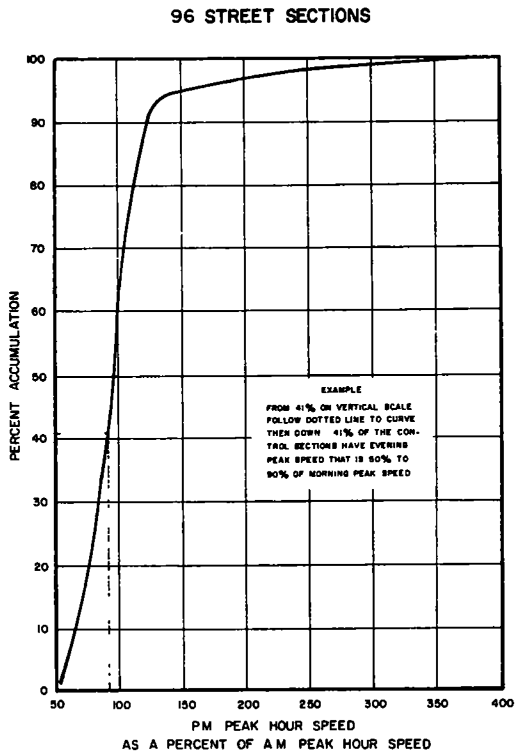


Figure 3. Cumulative frequency curve showing PM peak hour speed as a percent of AM peak hour speed.

Finally the travel times were combined to produce over-all times between various parts of the urban area. These were again compared to desirable or criterion travel times to determine deficiencies. The criteria used are as follows:

MINIMUM DESIRABLE AUTO TRAVEL TIME[a] FOR TRIPS OF VARIOUS LENGTHS
(Measured on the Basis of Airline Distance)

Average Weekday Peak Hour	
Length of Trip (mi)	Travel Time (min)
2	7
4	12
6	16
8	20
10	24
12	28

[a]"Better Transportation for your City." NCUT, Pub. Adminis, Service, Chicago, p. 49.

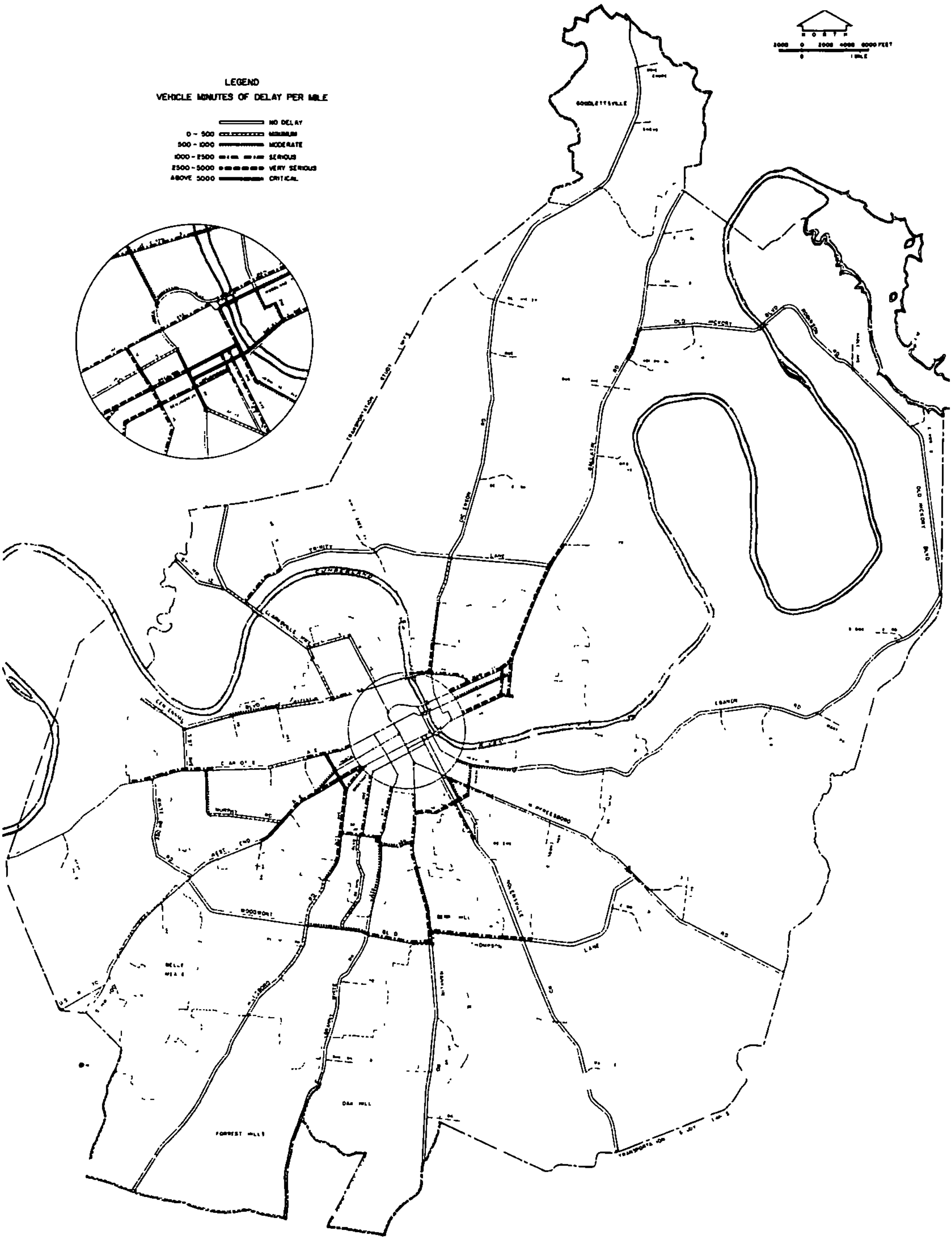


Figure 4. Vehicle minutes of delay per mile on major arterial streets during AM and PM peak hours (fall-winter 1959).

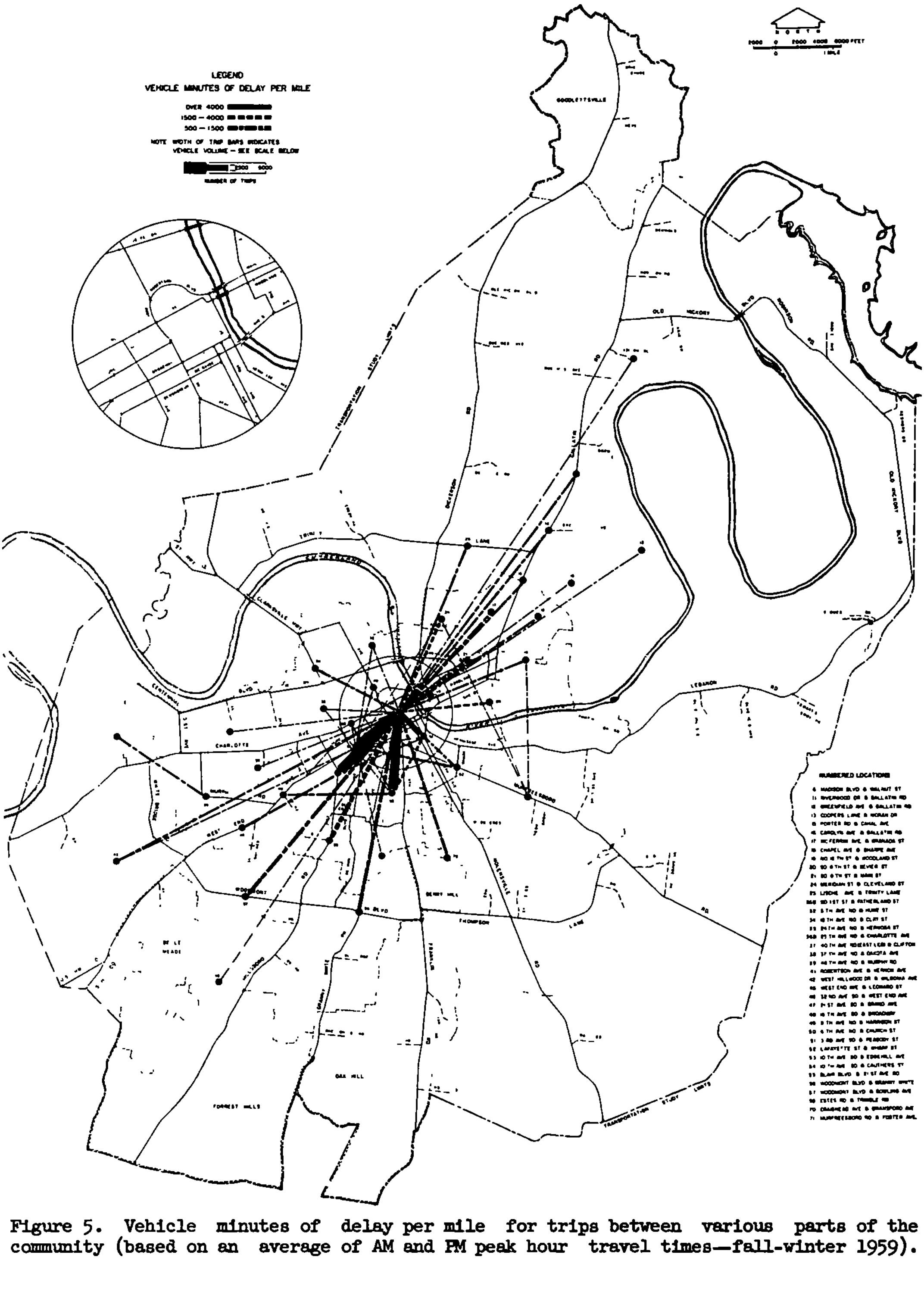


Figure 5. Vehicle minutes of delay per mile for trips between various parts of the community (based on an average of AM and PM peak hour travel times—fall-winter 1959).

The resulting deficiencies are relative, and show the level of service between any two areas as it compares to that between other areas.

The actual 24-hr volume of trips between the different areas was furnished by Wilbur Smith and Associates in the Origin-Destination Study. The vehicle delays obtained by multiplying these volumes by the average peak hour travel time deficiency are relative delays, but give a good picture of the comparative over-all deficiencies in the area.

Figure 5 shows the vehicle delay thus calculated. Each of the lines shown represents, by pattern, the amount of vehicle delay for the trip. The width of the line represents the number of vehicles making the trip in a 24-hr period. The lines are shown for only those trips having a delay of more than 500 vehicle minutes of delay per mile. It might

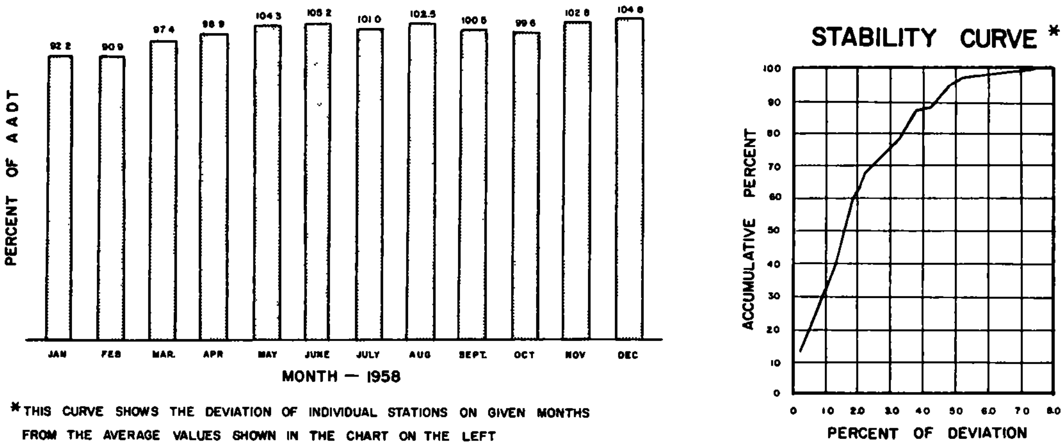
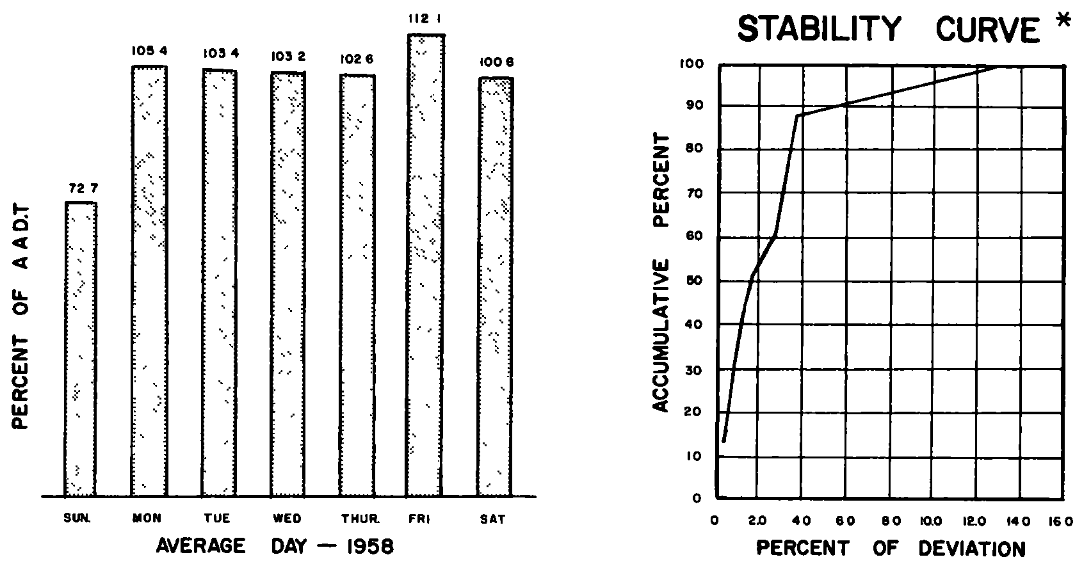


Figure 6. Average daily traffic for each month of the year as a percent of the annual average daily traffic (for 5 permanent counter stations in Nashville—major arterial streets).



* THIS CURVE SHOWS THE DEVIATION OF AVERAGES FOR INDIVIDUAL STATIONS FOR VARIOUS DAYS OF THE WEEK FROM THE AVERAGE VALUES SHOWN ON THE LEFT

Figure 7. Traffic for each day of the week as a percent of the annual average daily traffic (for 5 permanent counter stations in Nashville—major arterial streets).

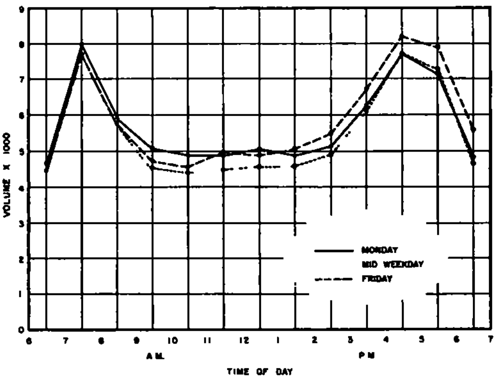


Figure 8. Comparison by hour of Monday and Friday daytime volume to other weekdays at all major arterial permanent counter stations.

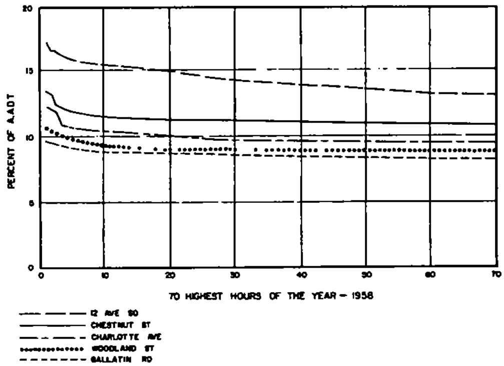


Figure 9. Seventy highest hours as a percent of annual average daily traffic (for arterial stations in Nashville).

be explained that some trips not shown had more delay than some that are shown. (In one instance, the actual time delay was over 11 min per mile.) However, the volumes were so low (zero in many cases) that the vehicle minutes of delay were negligible. Travel delay represents economic loss only to the extent that road users are affected. Thus with no one making the trip, it was of little immediate concern whether or not such a trip would have a travel time deficiency.

This sort of analysis shows very definitely where relative deficiences exist in the level of service offered by the major

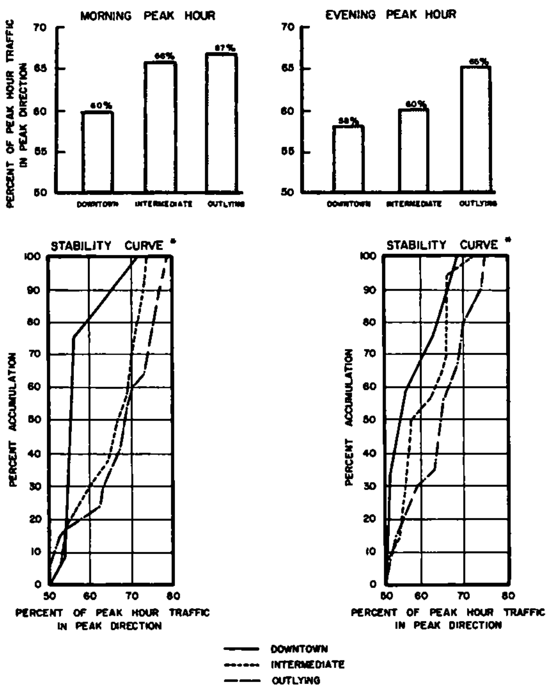


Figure 10. Percent of peak hour traffic moving in the peak direction (for 48 downtown, intermediate and outlying directional count stations).

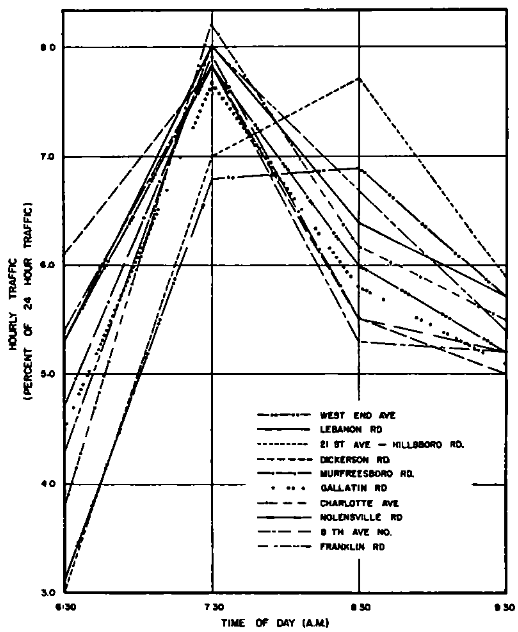


Figure 11. AM peak hour traffic as a percent of 24-hour traffic (for various traffic corridors).

TABLE 2

TIME OF OCCURRENCE OF THE 70 HIGHEST HOURLY VOLUMES OF THE YEAR AT 5 PERMANENT COUNTER STATIONS

Location	Percent of Highest 35 Hours That Occur During			Percent of Highest 70 Hours That Occur During		
	Weekday AM Peak (%)	Weekday PM Peak (%)	Other (%)	Weekday AM Peak (%)	Weekday PM Peak (%)	Other (%)
Gallatin Rd.	-	74	Sat. midday, 26	-	73	Sat. midday, 27
Charlotte Ave.	9	89	Mon. 3-4, 2	11	88	Mon. 3-4, 1
Woodland St.	91	9	-	89	11	-
12th Ave. So.	100	-	-	86	14	-
Chestnut St.	11	89	-	13	86	Sun. 5-6, 1
Average	42	52	6	40	54	6

street system. The analysis points up the areas connected by major arterials having the greatest travel delay.

When the Traffic Volume Study was begun, Nashville was perhaps more fortunate than some other cities. The State of Tennessee maintains five permanent count stations on the major arterial system. There were several years' data which, for the most part, were simply filed away. In addition, there were approximately 100 volume counts made at locations on the major arterial or collector street system. These counts were made by both Nashville and the State of Tennessee and were all less than 2 yr old. In many cases there were counts for 2 yr. These were compared to be sure that the one that was used was not an abnormal count. It was felt that they would be quite adequate for studying various volume patterns.

The permanent counter data were used first to determine the monthly factors. Data

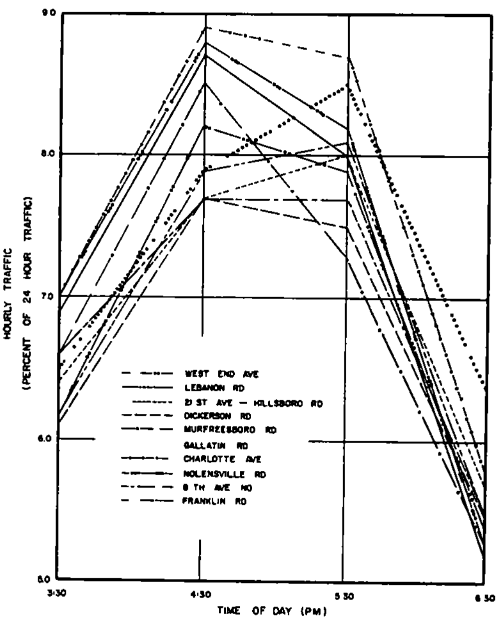


Figure 12. PM peak hour traffic as a percent of 24-hour traffic (for various traffic corridors).

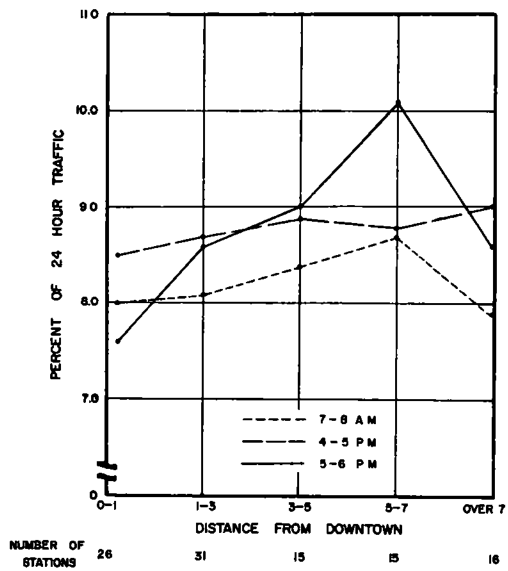


Figure 13. Peak hour traffic as a percent of 24-hour traffic at various distances from downtown (103 stations in the Nashville urban area—weekdays).

from the five permanent counters, mentioned earlier, were averaged for each month (Fig. 6). To determine the reliability or stability of these factors, the cumulative frequency curve was prepared. It shows the deviation for each station for each month from the average. The monthly average daily traffic at none of the locations deviated from the average more than 7.5 percent of the annual average daily traffic for any month and 75 percent of the time the deviation was less than 4.0 percent. This analysis indicates what sort of errors might be introduced by using these monthly factors. Actually, there are deviations between locations that are greater than the variations between the months.

The same type of analysis was used to arrive at Figure 7 which shows the traffic for each day of the week as a percent of the annual average daily traffic. As is normal, Friday has the highest traffic volumes. Monday's traffic is also higher than the other weekdays. The stability curve was prepared in the same manner as the previous one and shows that 88 percent of the time the volume, for any given day of the week, at one of the stations will deviate less than 4.0 percent of the average daily traffic from the average shown.

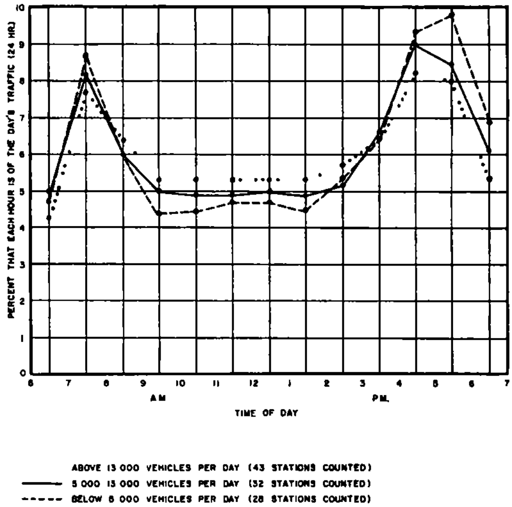


Figure 14. Hourly traffic as a percent of daily traffic for three volume groupings (103 stations in the Nashville urban area).

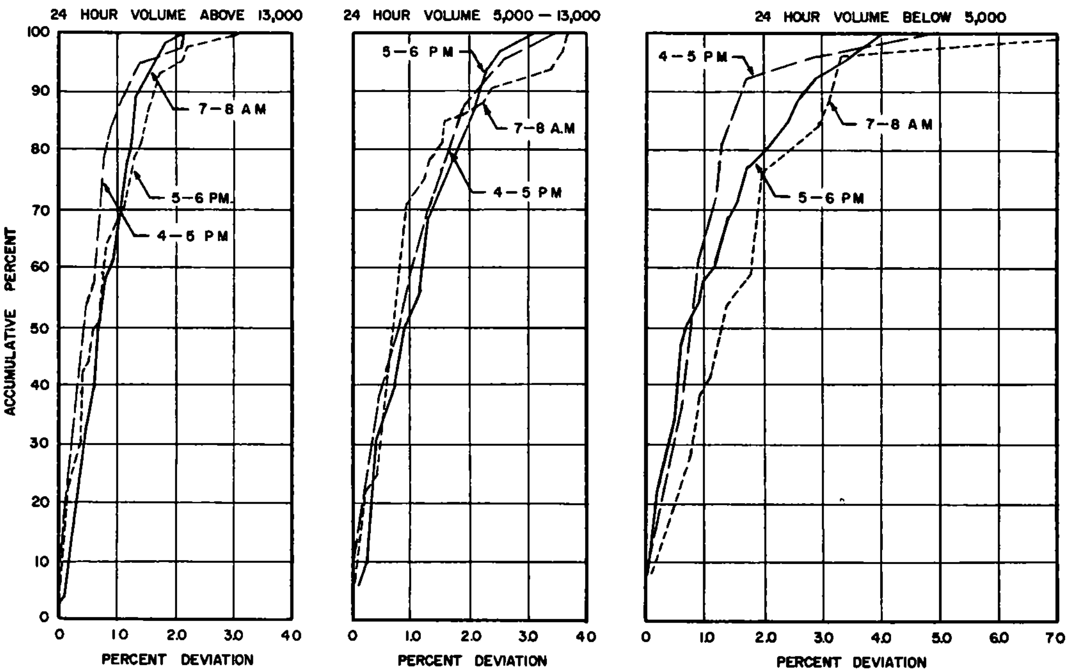


Figure 15. Stability of hourly variation curves—weekday (deviation of each of 103 stations for peak hours from the average shown in Figure 14).

The higher traffic volumes on Monday and Friday introduced the following questions: (a) Is this volume increase uniform throughout the day or does it occur during a certain part or parts of the day? and (b) Does this reason hold true for both Monday and Friday?

Data from the permanent counters were analyzed and the result is Figure 8. Actually there is little difference in the morning peak hour. Monday has a very slightly higher peak than the other weekdays. The higher volume results from greater volumes during the mid-day off-peak hours. Friday, on the other hand, has a very high evening peak hour volume. In fact, it is 10 percent higher than any other weekday. In addition, the Friday volumes from mid-morning on are considerably higher than those of mid-week days.

Figure 9 shows the 70 highest hours for each station as a percent of the average daily traffic for that station. In exploring the old 30th highest hour idea, it can be seen that in Nashville's case almost any hour between the 10th and the 70th would be usable. To say that 10 percent of the average daily traffic will be used as a design hour volume is not far afield. The street which is the exception here has one of the highest peak hour volumes relative to its daily traffic of any of the 103 locations studied. It serves a predominately residential area and has almost no commercial traffic and thus its resulting hourly pattern is not considered very representative of the major streets in Nashville.

Also of interest is the time of occurrence of the 70 highest hours on the various streets. Table 2 shows that 54 percent of them occurred during the evening peak hour, 40 percent during the morning peak and the other 6 percent at various other times. Actually three of the five stations had most of their high hours during the evening peak hour. The other two had their highest hours during the morning peak.

Forty-eight of the counts used in the Volume Study were directional counts.

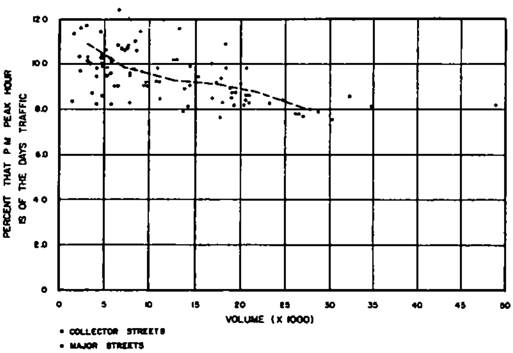


Figure 16. Peak hour traffic volume vs 24-hour volume (at counter stations within the Nashville urban area).

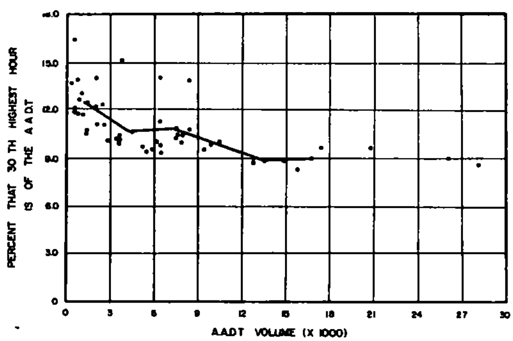


Figure 17. Thirtieth highest hour traffic volume vs annual average daily traffic (at urban permanent counter stations in Tennessee).

Past these locations, the percent of peak hour traffic in the peak direction ranged from 50 percent to 78 percent. Several groupings of data were tried to "narrow" this spread.

The following were tried without success:

1. Group by distance from downtown — four groups were used, but no pattern could be established.

2. Group by 24-hr volume. The data were split into two groups with the dividing point at 20,000 vehicles per day. The average peak direction volume (as a percent of the day's traffic) was the same in both groups.

Finally the counts were grouped according to whether the individual location was classified as downtown, intermediate or outlying, based on the Highway Capacity Manual definitions. Figure 10 shows the relationship found from this grouping. It should be mentioned that when an area, and all count locations within that area, were classed as downtown, intermediate, or outlying, no pattern could be established. Although the trend toward greater splits at outlying locations is not pronounced, it appears to definitely be present. The "stability" curves bear this out. These are simply cumulative frequency curves. The one for outlying stations is to the right of the intermediate one which is in turn to the right of the downtown curve. This indicates generally higher peak direction percentages at intermediate locations than downtown and still higher ones at outlying locations.

One of the more interesting analyses involved the hourly variation at the 103 locations. As is normally found, three patterns were noted. The normal weekday with work trips creating the peaks; Saturday, with a combination of commerce, shopping and recreation and finally Sunday, with its church and recreation traffic. The weekday traffic is the most significant because it occurs five days out of seven and about 95 percent of the highest traffic hours occur during these days.

The wide spread found in peak hour volumes (expressed as a percent of 24-hr traffic) was a cause of concern. A look at the data showed that evening peak hour volumes varied from about 6 percent of the day's traffic to over 11 percent. Obviously this does not tell very much about peak hour traffic.

The data were grouped in various fashions to find a pattern or group of patterns which would be more representative and allow more accurate estimation of day to day peak hour traffic.

These groupings are worthy of comment even though they did not produce the desired end result:

1. Corridor Analysis. — The urban area was divided into corridors, each one bisected by a major radial street. Several 24-hr counts made at different locations along the bisecting street were averaged to determine the hourly pattern for each corridor. The hourly volume patterns for the two peak periods are presented in Figures 11 and 12. In each corridor more variation was found between the various stations within a corridor than between the average patterns for the various corridors. It is noted in Figure 11 that two streets have a decidedly different pattern than all the other streets. These two streets serve residential areas in the higher economic brackets.

2. Street Classification Analysis. — The 103 volume counts referred to above were separated into major arterial and collector street groups. The collector street volume pattern in general had higher peak hour volumes percentagewise than major arterials. However, some major arterials had higher peak hour volumes percentagewise than many collectors. Again, there was as much as or more variation between individual stations within a group than between the groups.

3. Distance from the Center of the City (Ring Analysis). — The volume counts were grouped this time according to distance from the center of the city. The average hourly pattern was established for each group. Peak hour traffic for each distance group is shown in Figure 13. It appeared that there was possibly a pattern related to distance from the center of the city, because there is an indication that peak hour traffic, as a percent of 24-hr traffic, increases as distance from the central business district increases. This is especially true of the curve representing 4:00 PM to 5:00 PM. It was decided, however, that because traffic volumes in general decrease as distance from the central business district increases, this was another indication that the peak hour traffic, as a percent of the day's traffic, increases as the 24-hr volume decreases. Discussion of this follows.

4. Volume Grouping Analysis. — The 24-hr volume counts were separated into three volume groups, as follows: 0 - 5,000 vehicles per day, 28 counts; 5,000 - 13,000 vehicles per day, 32 counts; and 13,000 and above vehicles per day, 43 counts — total counts = 103. The resulting hourly volume patterns are shown in Figure 14. The deviation from these curves by the individual stations was calculated for the peak hours. It is the difference between the percent of the day's traffic in the peak hour at each station and the average percent of the day's traffic in the peak hour for that volume

group. Figure 15 shows these deviations as cumulative frequency curves. The use of this figure is illustrated by the following example:

Assume a given street falls into the 5,000 - 13,000 vehicles per day volume grouping. From Figure 14 it is seen that on the average, the traffic flow from 5:00 - 6:00 PM will be 8.5 percent of the 24-hr traffic. Figure 15 shows that the 8.5 percent value will be correct within 2.0 percent for 85 percent of the streets within this volume range; that is, the value will fall between 6.5 percent to 10.5 percent, 85 percent of the time based on existing data.

To add more support to the argument that peak hour volumes decrease percentage-wise as 24-hr volume increases, Figure 16 was prepared. It shows the percent of the day's traffic during the peak hour plotted against the 24-hr volume for each count station. Although there is considerable "scatter" to these data, there is a definite trend toward proportionately lower peak hour volumes with an increase in the 24-hr volume.

This same trend is in evidence in comparing the 30th highest hour volume as a percent of the average daily traffic to average daily traffic for urban counting stations in various parts of the state (Fig. 17). Stations having higher average daily traffic in general have lower 30th highest hour volumes when expressed as a percent of average daily traffic.

CONCLUSIONS

From these analyses there are certain conclusions which are indicated although admittedly the data are somewhat limited in some cases. These conclusions, as a result, are of a general nature.

1. Travel time can provide a good measure of the level of traffic service provided by a street. To present a complete picture of this service, data representing more than just the evening peak hour is necessary.
2. The procedures prescribed by the National Committee on Urban Transportation will give an adequate sample for travel time measurement.
3. Morning peak hour travel time passes may be made on any weekday. Evening passes may be made any weekday except Friday. Weekday morning peak hour traffic volumes are fairly constant and the same is true of evening peak hour volumes except that for Friday, which is about 10 percent higher.
4. As 24-hr traffic increases, the peak hour traffic as a percent of this 24-hr traffic decreases.

There were a few other conclusions drawn which applied specifically to Nashville and are not mentioned here for that reason. It is hoped that the discussions in this paper will add to the present knowledge of factors affecting urban transportation.