Forecasting Peak Hours of Travel

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Urban transportation planning calls for an accurate forecast of peak hour traffic patterns. Evidence presented in this paper indicates that because of the wide disparity in the ratio of the peak hour to the average daily traffic and in the directional distribution of traffic found on urban streets, existing techniques for forecasting peak hour travel from origin and destination data should be revised.

In line with the results from eight cities a technique has been developed which should be sensitive to these variations in peak-hour travel. The technique calls for the application of a mathematical model and certain revision in existing O-D procedure.

● A KNOWLEDGE of the characteristics of peak-hour traffic is fundamental to the planning, design and operation of urban transportation systems. In the planning phase it is essential to be able to forecast peak-hour volumes so that transportation facilities can be designed to accommodate these needs. Such data are necessary to evaluate the proper role of highway and transit services in handling travel desires.

The magnitude of the peak-hour traffic, and the direction of it are both important in determining lane requirements of freeways and arterial streets as well as ramp locations. Certainly a knowledge of peak-hour travel patterns is basic for the development of sound operational improvements. In the city planning field, knowledge of peak hour patterns with respect to volume and direction of traffic is very valuable in shaping land use plans.

In the past, forecasts of peak-hour travel that have been based on O-D data have been determined by taking a percentage of the estimated 24-hr pattern. The reason that the peak hour was not analyzed separately was that it was feared that such an analysis would be plagued with many statistical problems. In effect, it would be dealing with only 1/10 of the trips related to the 24-hr pattern. Recent information on the characteristics of urban travel seem to raise serious questions about this approach.

PEAK-HOUR TRAVEL VARIES

In Cincinnati where several year-round counting stations were recently established, it was found that the ratio of peak hour traffic to average daily traffic varied as much as 100 percent between locations. (1) (See Fig. 1.) The highest portions were observed on arterial streets feeding primarily residential areas. In Portland, Oregon, it was found that the peak hours on some of the one-way streets in downtown area where there were capacity deficiencies ran as low as 6 percent. (2) In Baltimore a radial arterial street which ran through an industrial area had a balance in the direction of flow traffic, while another radial arterial street located in a residential area had a marked unbalance in the flow of traffic. (3) Traffic across a screen in Baltimore (Table 1) gave substantially the same results found in Cincinnati. The variation seemed to be keyed to land use difference.

Another example of such variations is the traffic crossing the Anacostia and Potomac Rivers in Washington, D.C. In this case the peak hour traffic observed on the bridges crossing these rivers was between 7 and 13 percent of the average daily traffic. The peak directional flow ranged from 4.5 to 9 percent of the average daily traffic. On one bridge 9 percent of the average daily traffic occurred in the outbound direction during the evening rush hour, while inbound it amounted to only 2 percent of the average. (4) This very unbalanced condition was related primarily to land use. The land on one side of the bridge was limited to residential development.

PEAK RELATED TO CAPACITY AND LAND USE

In light of these observations it would appear that peak hour travel was largely influenced by two factors: (a) capacity of the transportation system, and (b) land use factors.

There are cases in which the limited capacity of a street or highway has affected the hourly pattern of traffic. One of the most notable examples is the Holland Tunnel where there is little variation between various hours of the day. Drivers and truckers have adjusted their travel habits to conform to the available capacity of the tunnel. In other cases the overflow during the peak hour of traffic on an arterial street is found on adjacent local streets.

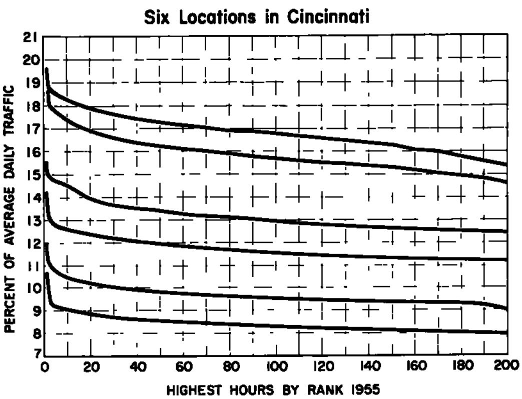

Figure 1. Variation in Peak Hour Vs. Average Daily Traffic. (1)

It is also known that if capacity is added to transportation facilities there is a tendency to accentuate the peak. For example, with the completion of the subway in Toronto it was found that 10,000 more people were traveling in the peak hour than during the year before though there was little increase in the daily traffic. (5)

Land use affects traffic patterns in two ways—trip production during the peak hour and orientation of trips during the same period. For example (Fig. 2), land uses have different patterns of trip production during the peak hour. (6) In the core of the downtown area in Washington, about 23 percent of the daily trips leaving the area occurred during the peak hour. However, in some of the important areas adjacent to this core it was found that this percentage ran as high as 36 percent.

TABLE 1

PEAK HOUR TRAFFIC CHARACTERISTICS FOR SCREEN LINE IN BALTIMORE 1957

Crossings	24-hr Volumes 2-way	Peak Hour A.M. East No.	A.M. 1-way %	A.M. 2-way No.	A.M. 2-way %	P.M. West No.	P.M. 1-way %	P.M. 2-way No.	P.M. 2-way %	% by Direct P.M. 1-way 2-way
Kelley Ave.	10132	732	7.2	1148	11.4	665	6.6	1020	10 2	65
Belvedere	13622	855	6.2	1410	10.3	815	6.0	1482	10.8	55
Cold Spring	13697	540	3.9	998	7.3	750	5.5	1273	9.3	59
41st St.	13845	538	3 9	1194	8.6	593	4.3	1179	8.5	50
Union Ave.	3476	43	1.3	225	6.5	234	6.8	344	10.0	68
Wyman	8003	529	6.6	928	11 6	625	7.8	1192	14.8	52
29th St.	22278	1037	4.7	1691	7.6	1016	4.6	2354	10.6	43
North Ave.	31937	957	3.0	1801	5.7	1333	4.2	2302	7 2	59
Howard St.	23020	813	3 5	1736	7.5	600	2.6	2179	9 4	28
Maryland[1]	19003	-	-	2797	14.6	966	5.1	966	5.1	-
Charles[1]	28707	1414	4.9	1414	4.9	-	-	2869	10.0	-
St. Paul[1]	27741	-	-	3009	10.8	1612	5.8	1612	5.8	-
Guilford[1]	15465	869	5.6	869	5 6	-	-	2290	14.7	-
Preston	13725	504	3.7	947	6.9	669	4.9	1092	8.0	61
Biddle	4575	183	4.0	421	9.2	346	7.6	562	12.2	62
Chase	3988	147	3.6	241	6.0	178	4.6	445	11.2	41
Eager	2165	33	1 5	175	8.1	195	9.0	288	13.3	68
Madison[1]	7790	631	8.1	631	8 1	-	-	854	11.0	-
Monument[1]	10708	-	-	955	8.9	1154	10.7	1154	10.7	-
Hillen	11484	265	2.3	990	8.6	414	3.6	995	8.6	42
Gay	13606	334	2.4	1152	8.5	416	3.0	916	6.7	45
Lexington	2852	168	5.9	255	9.0	206	7.2	426	14.8	48
Fayette	23129	741	3 2	1825	7.9	1153	5.0	2146	9.3	54
Baltimore	15539	543	3.5	980	6.3	645	4.1	1378	8.9	46
Lombard	6209	151	2.4	465	7.5	363	5.8	527	8.5	68
Pratt	44583	1474	3.3	3152	7.1	1896	4.2	3605	8.1	52
	391,279							35,450	9 1	

[1] One-way

Such a variation would have a significant bearing upon the location and frequency of ramps and the number of freeway lanes needed to serve this area. If a straight percentage had been taken of average daily traffic, the number of freeway lanes that would be needed to serve Zone 1 (Table 2) would have been under-estimated by two lanes, since most of the travel in and out of the zone undoubtedly would be on the freeway planned to traverse this section.

Similarly, the pattern of trips will vary during different hours of the day. Figure 3 shows that the peak of shopping trips occur largely in the downtown area in the morning, while the peak for suburban shopping occurs during the evening rush hour. (7) Such variations are of importance in planning and design of a freeway and arterial street system. In the downtown area the shopping trips have little impact upon peak traffic demands, while in the suburban area they complicate the issue in that they occur at the same time as the heavy work movement.

Thus, it would appear that peak hour patterns in urban areas are related to three factors: (a) orientation of trips during peak hours, (b) trip production of land uses during peak hours and (c) capacity of transportation facilities.

It would probably be fairly easy to get agreement on such a general thesis but the problem is to apply it in the analysis of origin and destination data.

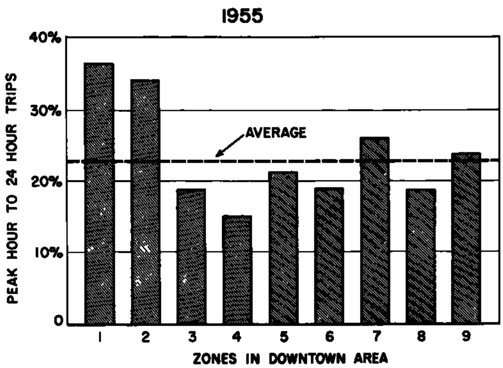

Figure 2. Variation in Peak Hour Traffic Generations for Zones in Downtown Washington. (6)

TRAFFIC MODEL

To overcome the sampling problem in determining the orientation of trips during the peak hour, the development of some suitable mathematical model offers the best prospect. Though there are many types of models that might be considered, the gravity model in light of past research seems to have the most advantages. This model adapts Newton's Law of Gravity to traffic behavior. It says, in effect, that the number of trips produced by any zone will be at-

TABLE 2

COMPARISON OF NUMBER OF TRIPS LEAVING DOWNTOWN WASHINGTON DURING A 24-HR INTERVAL WITH PEAK HOUR[a]

Downtown Zones	Reported Trips in 24 hr	Reported Trips During Peak Hr	Estimated Peak (23.0 % of 24 hr)	Difference between Estimate of Reported Peak	Percent Reported Peak of 24 hr
01	21984	8006	50500	+ 2956	36.5
02	8257	2827	1900	+ 927	34.3
03	19494	3669	4500	- 831	18.8
04	11236	1719	2580	- 861	15.3
05 (core)	35378	7587	8100	- 613	21.4
06	28220	5394	6500	- 1106	19.0
07	19747	4855	4300	+ 555	26.0
08	29980	5642	6850	- 1208	18.8
09	5949	1421	1340	+ 81	23.8
	179245	41120	40910		23.0

[a] Source: ref (6).

tracted by other zones in the area in direct proportion to their size, and indirectly in proportion to the length of the trips. (8) This gravity model can be expressed in the following formula in which M denotes the size of the zone in some appropriate unit, D represents the length of trip, and X is the exponent which is determined empirically:

$$T_{1-2} = (T_1) \frac{\dfrac{M_2}{D_{1-2}^{X}}}{\dfrac{M_2}{D_{1-2}^{X}} + \dfrac{M_3}{D_{1-3}^{X}} + \dots \dfrac{M_n}{D_{1-n}^{X}}}$$

The gravity model can be applied in two general ways to traffic problems. The first is to use a single model for all trips. The other is to develop separate models for each trip purpose or group of purposes.

In applying the gravity model to peak hour patterns it is necessary to use the trip purpose model, since the all-trip model would not indicate direction. The trip purpose model has certain other advantages in that it defines the impact of land use patterns on traffic patterns more effectively.

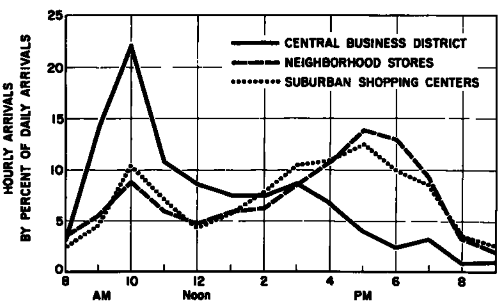

Figure 3. Arrival Pattern of Shopping Trips in Houston. (7)

Table 3 shows the percentage of purposes of trips that occur during the peak hour. This figure is based upon a special study made in San Diego of a suburban area well served by freeways. This table has certain other modifications which are usually not made in such tabulations. Trips made to serve passengers, stops at a grocery store on the way home, or other side trips were not considered in this analysis—only basic traffic desires. This means that most of the trips were from home to their main destination and return. However, in addition to this there were a certain number of trips made by salesmen, etc., which were not involved with residential areas at all. These were considered separately and have been indicated as non-residential trips.

On the basis of this tabulation it is clear that the work trip is very important in fore-

TABLE 3

RELATIONSHIP BETWEEN STREET USE AND TRIP PURPOSE SAN DIEGO, CALIFORNIA - 1956 [a]

Trip Purpose	24 Hour Pattern: Used Freeway (%)	24 Hour Pattern: Other Streets (%)	Peak Hour Pattern: Used Freeway (%)	Peak Hour Pattern: Other Streets (%)
Work	61	31	82	40
Shopping				
Convenience goods	2	30	-	50
Shopping goods	5	10	-	-
Social & recreational	23	4	13	-
Other	4	15	-	-
Non-residential	5	10	5	10
Total	100	100	100	100

[a] Source: ref. (16).

casting peak hours of travel. It will probably account for about 80 percent of the freeway usage during the peak hours. Therefore, it is vital to develop a model which is accurate for such travel. Over a period of several years the author has examined origin and destination of work trips in six American cities, and the investigations indicate that the gravity model can be used effectively in forecasting traffic. Research conducted in Detroit and Toronto also verified these findings. (9)

Figure 4 shows the close similarity in work trip patterns based upon a sample of O-D data obtained for South Bend, Oklahoma City, and Fort Wayne. (10) This figure depicts the ratio between probable zonal interchanges and observed interchanges for movements of varying lengths. Distance was expressed in terms of auto travel time during the peak hour between zones.

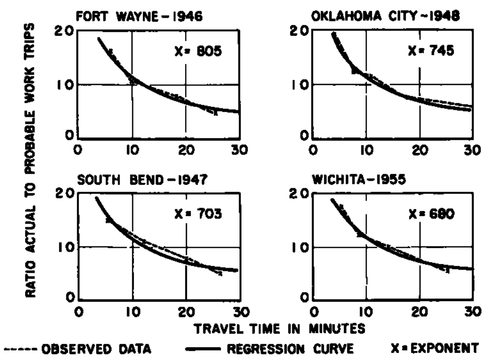

Figure 4. Comparison of Work Travel in Various Cities. (10)

To insure statistical stability, data were grouped by travel time as shown by the points on the chart. The exponents which were determined by the least-square method range between 0.6 and 0.8. Tests in Baltimore and Philadelphia also gave similar results (Baltimore, 0.647 and Philadelphia, 0.805). (11) Recognizing that such range in the exponent would have less than a 10 percent variation in trip estimate for most interzonal movements, and furthermore that much of the travel time data used was weak (usually based on estimates of the traffic engineers), the correlation between cities is significant.

In addition, studies were made for Baltimore and Wichita to see if these exponents varied for residential areas at different distances from the central business district. In both instances the analysis revealed that the exponents range was between 0.65 and 0.85. (In determining the exponent the travel time related to the mode of travel was used—transit users and auto drivers were studied separately.) Furthermore, there

TABLE 4

COMPARISON OF ZONE TO ZONE MOVEMENT DETERMINED BY HOME INTERVIEW METHOD OF DIFFERENT SAMPLE SIZES WITH THE GRAVITY MODEL [a]

CINCINNATI, OHIO

Zone to Zone Movement	Theoretical Trips	Percent						
		100	20	12½	10	8⅓	6⅔	5
573-103	11	11	20	-	-	24	-	42
112	14	16	30	42	-	-	-	-
113	19	22	15	25	10	-	30	42
150	24	18	25	25	42	12	30	-
153	7	6	7	25	21	-	-	-
506-103	23	25	31	16	31	-	15	-
112	27	26	21	16	-	-	31	-
113	28	35	26	56	21	49	-	83
130	19	14	10	33	51	24	-	-
135	7	13	21	-	-	-	-	-
144	19	13	-	16	10	24	-	42
150	12	7	10	-	-	-	-	-
153	5	8	10	-	20	-	31	-

[a] Source: ref. (12).

was no consistent relationship between these slight variations in the size of the exponent and the location of the residential area. Such findings would seem to indicate that urban work trips patterns are substantially the same throughout the country.

The correlation coefficients associated with these various curves were usually in the 90's, but such indices cannot be used to determine the accuracy of zone-to-zone interchange since the interzonal movement had been grouped. However, to obtain an indication of the statistical reliability of these curves, chi-square tests were made for Wichita and Oklahoma City. The probability level for Wichita was over 50 percent and for Oklahoma City over 40 percent, thus further substantiating the validity of the use of the gravity model.

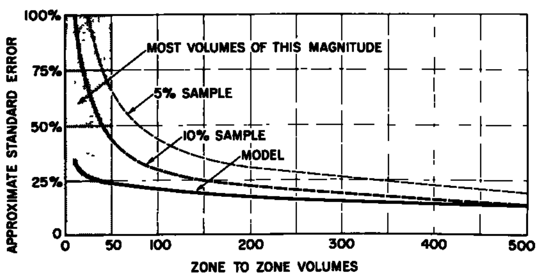

Figure 5. Comparison of Error Related to Sampling and Traffic Model. (12, 13)

Although these statistical tests were satisfactory they do not give an estimate of the error which is inherent to the model itself. Unfortunately, such estimates are difficult to derive without 100 percent observations.

In one of the few areas where such data were available, an attempt was made to establish the error. This was based upon a special study made by the Ohio State Highway Department of two zones in Cincinnati. (12) The results that would be obtained by different sample sizes are compared with the model in Table 3. This table clearly shows that good results were obtained by the gravity model—in fact, considerably better than you could get from a 20 percent sample. The standard deviation from zonal interchanges of 10 to 20 trips was about 25 percent. Because of the characteristics of the sample it is believed that this deviation is somewhat below the normal that would be found for this traffic movement, but it does give the general size of the error related to the model.

Another appraisal in Philadelphia was made for interzonal movements exceeding 1,000 trips a day. (13) There it was found that the standard error was about 15 percent, if it is assumed that all the error was related to the model. (The exponential curve gave slightly better results than the hyperbolic curve test by Lapin.) In Baltimore a check was made of traffic crossing a screen line running through the heart of the city. In that case the error was only 5 percent. However, the trips crossing this screen line were 100,000. (11)

In light of these observations it would appear that as the number of trips between zones increased, the percentage error associated with the model would decrease somewhat as shown by Figure 5. This figure also compares the error of the model with normal sampling errors. Obviously, the model gives better answers for daily zone-to-zone interchanges which are less than 500 for both 5 and 10 percent sample.

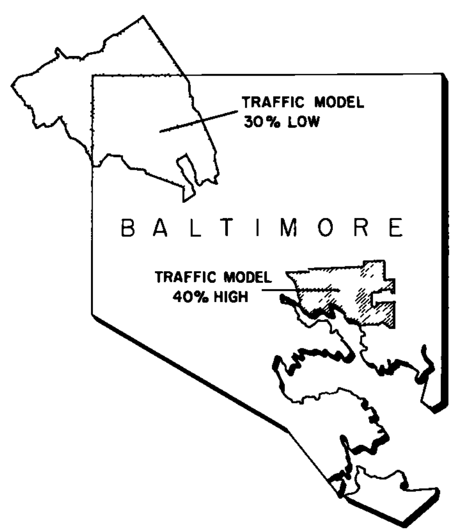

Figure 6. Residential Areas Where Observed Travel to Downtown Baltimore Varied from Traffic Model. (11)

And what is probably of more importance is that the model gives much better results for zone volumes less than 50. In most origin-and-destination studies these volumes constitute the bulk of the traffic. For example, in the 1948 Washington study more than 90 percent of all the trips were made between zones having such volumes. (14)

These tests as to relative error of the model apply to the 24-hr pattern of the work trip. Unfortunately, there were no data available to make such tests for peak hour conditions but it would appear that if adjustments are made for trip production throughout the peak hour the error of the model would be about the same as that shown by Figure 5. Certainly the sampling error would greatly increase for peak hour travel thereby leaving the model as probably the only practical alternative.

In applying the gravity model in these 6 cities the work trips were brought into balance. That is, if in applying the model too many trips were allocated to a particular employment center, they were adjusted to conform to the known number of trips made to the center. This was achieved by multiplying all trips to the center by an appropriate adjustment factor. In many instances this balance procedure improved the results of the model.

The only modification made in applying the model was for trips to the downtown area. This was done to adjust for differences in relationship between homes and employment for different social, economic, and occupational classes. From experiences in these cities it would appear that this correction is only necessary for trips to the downtown area.

It appears from these studies that correction for these differences is more important in the older Eastern cities, where there has been a considerable amount of colonization of various social and economic classes. Therefore it is recommended that in developing a model for such cities appropriate tests be made to determine the weight that should be given to these characteristics. This can be achieved by analyzing the O-D data on a district basis (groups of zones) and by studying the difference between the work trip patterns determined by the model and those observed for such districts.

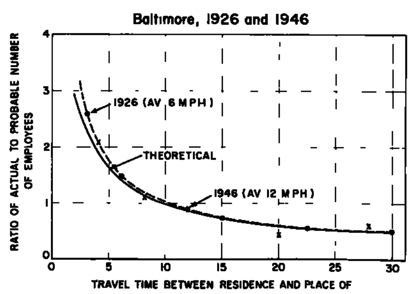

Figure 7. Comparison of Residence and Place of Employment. (15)

The correction that was made for downtown trips was quite simple. It involved the determination of just how much the gravity model was off with respect to trips to the downtown area. Figure 6 gives the important areas in Baltimore which did not conform to the model and the percentage by which these areas were in variance with the model. (11) Taking account of the social and economic characteristics of these areas, projections can be made to show where such areas will occur in the future.

Though the gravity model is quite adequate for evaluating existing traffic patterns, the question is, can it be used for evaluating future patterns? The answer seems to be yes. In Baltimore such a model proved itself in 1926 and again in 1946 (Fig. 7). The exponent of the gravity model was 0.605 in 1926 and 0.645 in 1946, a remarkable correlation. (15)

In applying the gravity model in both of these cases the travel time for the particular era was used. In 1926 the average travel speed during the peak hour was 6 mph; in 1946 it was about 12 mph. This assumes that the work trips in 1926 were largely oriented to transit; in 1946, to the automobile.

Hence, the gravity model probably can be used effectively in forecasting traffic changes that will occur with improvements in transportation services. It can, in other words, estimate generated traffic.

This particular Baltimore study provides a glimpse of what the future may have in store. The doubling of speeds between 1926 and 1946 increased the average length of work trips by 50 percent. Therefore, it is probably not unrealistic to expect comparable increases in trip length it cities double travel speeds with the construction of freeway systems.

To repeat, then, the gravity model, if adjusted for local conditions, can be used effectively in forecasting work trips during the peak hour. Other trips for other purposes which may occur during this period may be predicted by similar techniques. The exponents can be determined by appropriate analysis of origin and destination data. It is recognized that estimates for these other types of trips may not be as accurate as those obtained for work trips, but their significance during the peak hour is rather small and therefore such inaccuracies will not have much impact on the estimated peak-hour pattern.

TRIP PRODUCTION

To reveal variations in peak hour production of trips for different land uses, special analyses should be made of O-D data. This can be readily done if trips are related to land use, as has recently been done in St. Louis and Chicago studies. Land use categories should probably conform to the traditional breakdown of land uses—residential, commercial, industrial, etc.

In addition, production of trips for various purposes during the peak hour should also be established for different land uses. The categories of trip purposes should be held to a minimum and should correspond to those used in the traffic model. Furthermore, it might be advisable to make comparable studies for major traffic generators like the central business district.

Development of such data from home interview O-D surveys would certainly be helpful in understanding the nature of peak hour travel.

CAPACITY EVALUATION

To determine the impact that capacity is having on travel habits an attempt should be made to evaluate the differences in travel patterns for various types of land uses under varying degrees of traffic congestion. Such a comparison should indicate what adjustment in the production and correlation of peak hour travel will come about with changes in traffic conditions.

To measure the impact capacity is having on street usage, an urban transportation study should assign traffic to a complete highway network. This is a difficult problem since it involves many so-called "feed-back" adjustments. Such adjustments are necessary because travel patterns change with variations in travel speeds which in turn vary with fluctuations in traffic volumes. At the present time there is no mathematical method devised which is dynamic enough to adjust for such variations in speed and volumes on a network basis.

But even if such a method were available there are still other problems related to lower volume streets (arterial streets in larger cities and collector streets in smaller communities). For example, work done by the Ohio State Highway Department indicates that the home interview type or origin and destination surveys miss from 1 to 2 trips per dwelling unit. (12) Many of these trips may in fact be stops enroute, but such stops may be important in arterial street assignment. Beside these errors, the limitations of predicting the behavior of small volumes of traffic are a handicap.

However, despite these difficulties of assigning trips to a highway network some sort of assignment should be made to a freeway and an evaluation taken of the arterial streets.

The first step should be that of assigning traffic to freeways. This can be carried out by several of the methods that are now employed, if estimates of travel speed on the various highways are made.

To carry out the second phase a separate evaluation should be made of the trips that will use the arterial streets. This might be done by allotting these trips to districts (groups of zones) through which they are made. Then the relationship between speed and volume should be determined for streets within these districts. With such data, travel speeds through these districts can be estimated in light of anticipated volumes. Travel speed estimates should then be checked with original assumptions on speeds.

If these speeds are at variance, adjustments in assignment procedure should be made and the new assigned values should be studied again to determine the effect they will have on travel speeds. If this process is repeated enough a balance between the speed and volume relationships can be obtained for the highway system, thereby giving an effective forecast of the use of the highway network.

KEEPING IT UP TO DATE

Another point that should be stressed with regard to traffic models is that traffic pattern forecasts should be checked periodically to verify their accuracy. This can be done by establishing screen lines over which traffic is counted annually. With the development of land use models by the city planning agency, it is hoped that both land use and traffic models can be tested periodically and adjusted accordingly.

If the projection technique that has been described is to be employed, it is apparent that certain changes should be made in the sample design and the standard interview form used in obtaining trip information. For example, the sample design should be such as to test the model. This may call for a very small over-all sample to obtain general patterns of traffic movement and a series of cluster samples to measure the variation travel characteristics of different social and economic groups.

In obtaining data on trips it may be advisable to depart from the standard classification of trips. For example, a trip to work on which one picks up two passengers might be designated as only one trip. Stops enroute to pick up passengers might be designated as secondary trips.

The general technique which has been suggested for forecasting peak hour traffic patterns may seem rather involved at first glance. However, studying it closely, it is not much more complex than the present method. The main difference is that instead of applying a growth factor a traffic model is used. The traffic model technique need not be too time consuming or expensive, since it can be readily programmed for electronic computers.

On the other hand, determination of peak production of trips for various land uses and the analysis outlined are quite similar to what is being done today.

In short, the main advantage of this new method is that it gives better forecasts of peak hour travel in that it establishes the magnitude and directional characteristics of traffic throughout the urban area.

CONCLUSION

1. The wide disparity in the ratio of the peak hour to the average daily traffic and in the directional distribution found on urban streets today indicates that existing techniques of forecasting peak hour travel from O-D data need to be revised particularly for critical traffic areas like the central business districts.

2. Since peak-hour traffic patterns are related to (a) orientation of trips during the peak hour, (b) trip production of land use during the peak hour, and (c) capacity of transportation facilities, it is essential that these factors be taken into consideration in projection procedures.

3. Results from this study indicate that the gravity model can be used to obtain accurate forecasts of the orientation of trips during the peak hour. Trip production of land use during the peak hour can be developed by techniques already in use and the capacity of transportation facilities can be approximated with certain adjustments in existing procedures.

4. Since this technique for forecasting traffic considers change in travel time it can be used to estimate the impact that adjustments in transportation service will have on travel patterns. A good dynamic test of this technique would be to see if it can effectively forecast traffic generation.

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13. Based on special analysis of data reported in The Analysis of Work Trip Data: Relationship and Variances, Howard S. Lapin, Traffic Quarterly, April, 1957.

14. Based on data from the Washington Metropolitan Area Transportation Study, 1948.

15. 1946 data were based on special analysis of work trips obtained from the State Roads Commission of Maryland.

1926 data were based on information of data reported in Report on Street Railway Routing and Improvements of Traffic Conditions, Baltimore.

16. San Diego Metropolitan Area Transportation Studies.