Predicting Peak-Spreading Under Congested Conditions

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As the resources for expanding street and highway capacity in urban areas have become increasingly scarce, interest has risen in accurately predicting the peak-hour capacity requirements for future years. Much of the travel demand forecasting performed around the country for highway planning has been performed on a twenty-four-hour basis, and peak-hour capacity needs have been estimated by applying a regional factor for the specific facility type or by using the current ratio of peak-hour to twenty-four-hour volume for a specific highway segment under consideration. This method is most often static and does not reflect the reduction in peaking that generally occurs as facilities become congested during the peak hour and trip makers adjust their travel time to avoid the peak. This paper reports the results of research on the peak-spreading phenomenon using traffic data from highway corridors in Arizona, Texas, and California. The data from each corridor covered a period of five to twenty years during which the congestion level in the peak period changed significantly. The research demonstrated that a clear and consistent pattern of peak-spreading emerged for highway facilities as congestion occurred during the three-hour morning and evening peak periods. The relationships derived from the research on peak-spreading have allowed the authors to develop a submodel for the UTPS UROAD assigned package. The new submodel will predict, for each link in the highway network, a peak-hour volume. That peak-hour volume reflects the level of congestion that would result from the predicted three-hour, peak-period volume for the forecast year and the level of capacity planned for each link; and it reflects the effect of peak-spreading that results from the predicted congestion on the facility. More accurate prediction of the peak-hour volumes is also expected to result in better prediction of peak-hour speeds for forecast years. This in turn should result in more accurate forecasting of travel time savings and air quality improvements from highway improvement projects.

In the past ten years, there has been a clear trend away from federal funding of transportation projects. An increasing share of the cost of highways and public transportation must now be borne by state and local governments, for which generating the necessary revenue is far more politically sensitive and, therefore, more difficult. With the shift to state and local finance has come not only an increase in the detail by which capacity needs are evaluated but also an increase in the concern about the benefits that are gained from improvements. Travel time savings, air quality improvements, and improvements in traffic safety are all being examined with greater attention to quantitative estimation. For that reason, it is important that modeling systems accurately predict not only the volume of travel during the periods of peak demand but also the speed at which that travel will occur.

This paper presents the results of research conducted for the Arizona Department of Transportation (ADOT) on the phenomenon of peak-spreading on congested roadways. The research was conducted using a national cross-section of data but with specific application to the Phoenix metropolitan area. The research was designed to result in recommended changes to the UTPS-based forecasting system used by the Maricopa Association of Governments (MAG) Transportation Planning Office that would allow them to reflect peak-spreading phenomena in future-year forecasting.

Considerable research has been conducted on the impacts of time of day on travel volumes, facility speeds, and trip-making behavior. Variations in traffic volumes over the hours of the day have long been observed, and typical patterns for specific types of facilities in a range of urban contexts are provided in the transportation literature (*1*, *2*). Similarly, relationships between facility speeds and volumes have been studied extensively, and a range of mathematical functions has been proposed to represent these relationships (*3*, *4*). More recently, behavioral approaches to travel modeling have focused on how individual travelers make their travel choices, in many cases including considerations of time of day (*5–8*).

There has also been considerable research on the incorporation of travel choice theory into network modeling systems (*9–11*). A major deficiency, however, has been in the area of incorporating peak-spreading as a result of traffic congestion into the large-scale traffic assignment and network equilibrium systems, such as UTPS, required for detailed highway system analysis in major metropolitan areas. Because these modeling systems cannot feasibly be applied at the behavioral or individual traveler's level, the focus in this project was limited to identifying and implementing aggregate representation of peak-spreading phenomena.

The most common practice in modeling of peak-hour travel is to produce a twenty-four-hour assignment and

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predict peak-hour trips as a constant percentage of the twenty-four-hour volume (often 10 percent). Some agencies have developed peak-period models by using the percentage of each trip type that occurs during a peak period to create a peak-period trip table (*12*). Even using this approach, however, the percentage of travel occurring in the peak one-hour period is generally a fixed percentage of the peak period, and no effort is made to relate peaking characteristics to the anticipated level of congestion for the assignment. The result is generally an overprediction of the peak-hour volume and often an underprediction of peak-hour speeds.

The need for more accurate modeling of peak-hour volumes was demonstrated by an examination of the variation in peak-hour volume as a percentage of twenty-four-hour volumes for forty-nine freeway and arterial corridors in Arizona, Texas, and California. The data from these forty-nine corridors formed the basis for most of the analysis in the project. The corridors for which historical data were available included:

13 in Arizona
17 in California
19 in Texas

The corridors included thirty-three freeways and sixteen major arterials. The corridors were selected because each had historical hourly count information covering at least a five-year period, and each facility had at least 20 percent growth in traffic during that period. Also available for each facility were number of lanes and capacity.

The range in average a.m. peaking factors (the ratio of maximum one-hour counts to daily counts) across sites was .081 to .126 in the a.m. period and .077 to .123 in the p.m. period. Although the midpoint in the range is almost exactly .100, in both the a.m. and p.m. peak periods (the same as the value most often assumed), the high end of the range of averages in both cases is more than 50 percent larger than the low value in the range. The significant variation strongly suggests the need for more accurate modeling of peak-hour volumes.

APPROACH

The approach in the research for ADOT was to improve the overall modeling of peak-period volumes and speeds by attempting to increase the accuracy of modeling in two areas:

1. Modeling of the peak periods
2. Modeling of peak-spreading within the peak periods as a facility becomes congested

The modeling process that was recommended to implement the research findings of the project is illustrated in Figure 1. The first step is to produce separate trip tables for each of the three time periods: a three-hour a.m. peak, a three-hour p.m. peak, and an off-peak that includes all other times. For MAG, this step was implemented using UMATRIX, but other matrix manipulation programs could be used.

The actual forecasting of peak-spreading in the package implemented for MAG occurs within UROAD. Following development of the peak-spreading models described in this paper, and of peak-hour volume-speed models, an augmented version of the UROAD network equilibrium traffic assignment program was prepared. In this program the new peak-spreading and volume-speed models are applied to each link every time that link speed updating is required. The added steps consist of the following:

- Compute ratio of current assigned (three-hour) volume to three-hour link capacity.
- Apply peak-spreading model to provide peaking factor: the ratio of one-hour volume to three-hour volume.
- Determine peak-hour volume as the product of the peaking factor and the assigned volume.
- Compute ratio of peak-hour volume to hourly link capacity.
- Apply peak-hour speed model to estimate revised link speed.

This link updating process continues throughout the iterative equilibrium procedure.

When the network assignment is complete, link volumes represent peak-period (three-hour) flows, but link speeds correspond to peak-hour conditions. The UROAD modifications provide the option, at this point, either to use the peak-spreading model to determine a final set of peak-hour volumes or to retain the peak-period volumes.

The two key elements of this package of modeling procedures are the peak-period factors that specify the percentage of travel for each purpose that occurs in the peak three-hour period and the peak-spreading model that predicts the percentage of travel in the peak three-hour period occurring in the peak hour. These two elements were the focus of the research, and the results of the research in both areas are reported in the remaining pages of this paper.

MODELING OF PEAK PERIODS

The first step in the production of peak-hour assignments was the division of total daily travel by trip purpose into three periods:

a.m. Peak—6:00 a.m. to 9:00 a.m.
p.m. Peak—3:00 p.m. to 6:00 p.m.
Off-Peak—All other hours

These periods were selected because it was felt that there would be some degree of stability within each period; travelers would not tend to shift out of these peak periods to avoid congestion. As a result, the percentage of travel predicted for each peak period should not vary with the level of congestion. To test this hypothesis, a regression

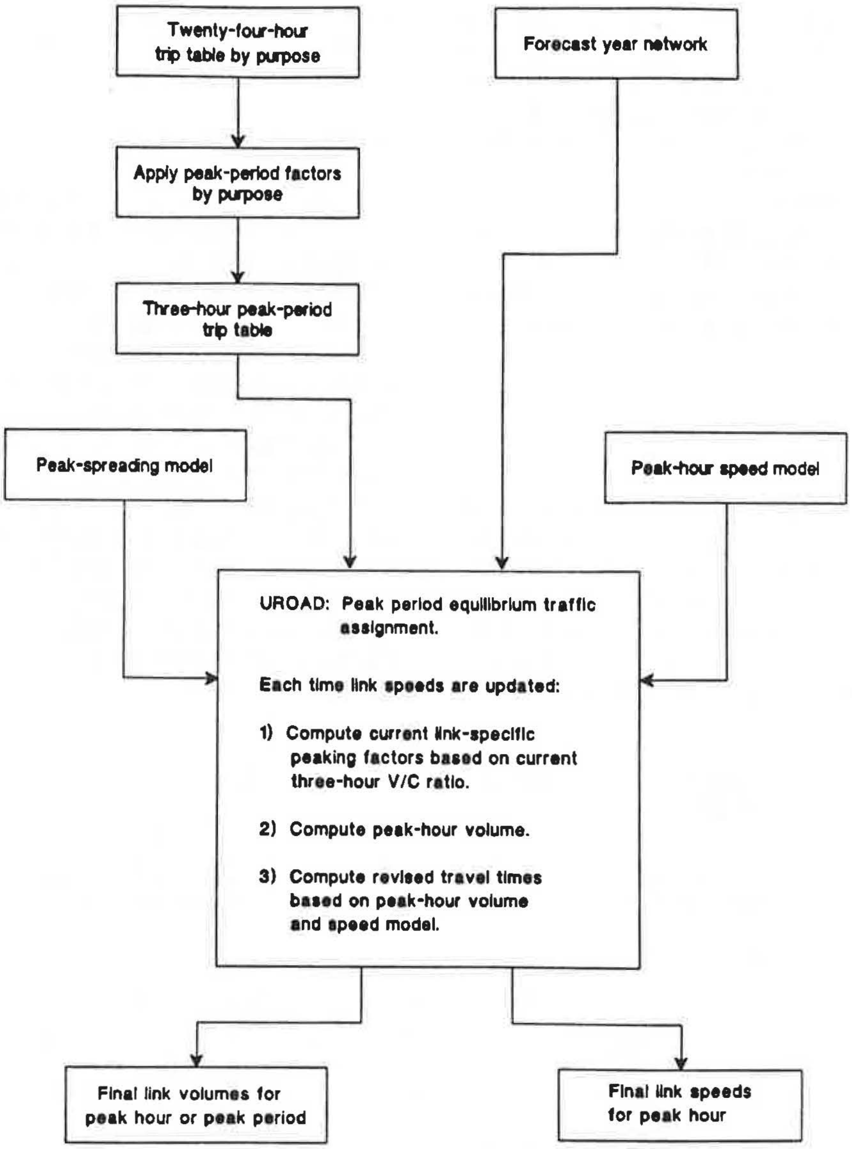

FIGURE 1 Structure of methodology for model enhancement.

analysis was performed for eighteen of the forty-five corridors for which historical data were available. The eighteen corridors were those for which a significant relationship between congestion and peak-spreading within the three-hour peak had been established.

In this analysis, the dependent variable, the ratio of three-hour volume to twenty-four-hour volume, was regressed on the peak three-hour V/C (volume/capacity) ratio as the independent variable. A coefficient for the independent variable that is significantly different from zero would indicate a relationship between the ratio of three-hour volume to twenty-four-hour volume and the three-hour V/C ratio and would lead one to reject the original hypothesis. Only five of the eighteen corridors yielded results that were of the correct sign (negative, indicating a reduction of the fraction of twenty-four-hour volume occurring in the peak three-hour period as a facility becomes congested) and statistically significant at a 95 percent confidence level. Separate regressions were run for the a.m. and p.m. peak periods for each of the eighteen corridors for a total of thirty-six regressions. In twenty-eight regressions the coefficients estimated were of the correct sign, but most could not be considered significantly different from zero at the 95 percent confidence level. This analysis indicates that there is some tendency for peak-spreading to affect hours other than the three hours in the designated peak period, but the tendency does not appear to be a statistically significant one.

The division of trips in Phoenix into the three time periods was based primarily on the reported time of travel by trip purpose by respondents in the Phoenix 1981 Household Survey. In prior work by MAG, each trip record in the household survey was assigned a weight according to the location of the residence of the trip maker and the characteristics of the household from which the trip record was taken. The weights were designed to expand the sample of household trips to represent the full population. The percentage of trips in the a.m. and p.m. peak periods was determined by developing a frequency distribution of trips by trip purpose and by hour of the day, and summing the hourly percentages for each trip purpose in the two peak periods. Table 1 presents the results of those frequency distributions.

For all home-based trips, a distinction was made between trips made from the home (*P* to *A*) and trips made to home (*A* to *P*). The frequency distributions were also calculated using three different measures of travel volume:

- trips
- vehicle miles traveled
- vehicle hours traveled

To obtain the distribution of vehicle miles traveled, each trip was weighted by the length of the trip. Likewise the distribution of vehicle hours of travel was determined by weighting each trip by the time required to make the trip as reflected in a peak-hour skim tree developed from the MAG 1980 base network. Comparison of the results with observed traffic volumes by time of day indicated that the VMT-based distribution provided the best results and was the distribution recommended for use by MAG.

MODELING OF PEAK-SPREADING

The most significant advancement in peak-hour modeling and the primary focus of this paper came in the development of a model to represent the effect of peak-period congestion on the temporal distribution of demand during that period. It has long been recognized that as a facility becomes congested, some trip makers will adjust the time at which they travel to avoid the congestion, and that this leads to some flattening of the peak period. However, this behavior has not been captured in the common UTPS travel forecasting process used by most planning agencies.

In this part of the research the historical data from the forty-nine freeway and arterial facilities in Arizona, California, and Texas were used to estimate a functional relationship between the peak-hour factor (the ratio of the volume of traffic in the single highest hour to the volume during the three highest hours) and the *V/C* ratio during the three-hour peak.

TABLE 1 COMPARISON OF ALTERNATIVE PEAK PERIOD TRIP FACTORS

	A.M.			P.M.		
Trip Type	Trips	VHT	VMT	Trips	VHT	VMT
PRODUCTION TO ATTRACTION						
HBW	0.329	0.340	0.344	0.033	0.030	0.029
HBNW	0.067	0.082	0.086	0.086	0.079	0.076
HBShop		0.021	0.022		0.102	0.102
HBO		0.066	0.071		0.072	0.068
HBSchool		0.335	0.329		0.056	0.061
Ext-Int	0.056			0.119		
Airport	0.041			0.113		
ATTRACTION TO PRODUCTION						
HBW	0.011	0.009	0.008	0.285	0.300	0.303
HBNW	0.009	0.008	0.007	0.128	0.085	0.133
HBShop		0.003	0.002		0.172	0.183
HBO		0.010	0.009		0.117	0.119
HBSchool		0.007	0.008		0.107	0.102
Ext-Int	0.077			0.100		
Airport	0.089			0.031		
NHB TOTAL	0.051	0.055	0.057	0.201	0.225	0.231
EXTERNAL-EXTERNAL	0.131			0.205		
TOTAL	0.152	0.179	0.197	0.242	0.243	0.266

Note: The factors for all home-based trips are to be applied to the total number of home-based trips produced; those from the production to attraction and those from attraction to production. The total to which the factor is applied is generally twice the number of trips for the direction indicated.

The functional form chosen for the peak spreading model was:

$$P = \tfrac{1}{3} + A\, e^{b(V/C)}$$

where

P = the ratio of peak-hour volume to peak-period (three-hour) volume,
V/C = the volume/capacity ratio for the three-hour period, and
a, b = model parameters.

The functional form was chosen because it has the general shape illustrated in Figure 2 and the following desirable characteristics:

- It always has a value of one-third or greater.
- P approaches one-third for large values of V/C.
- Valid values of P are defined for values of V/C greater than one.

The parameters in this equation were estimated using ordinary least squares regression for the transformed equation:

$$\ln(P - \tfrac{1}{3}) = \ln a + b(V/C)$$

or

$$\ln(P - \tfrac{1}{3}) = g + b(V/C)$$

where $g = \ln a$.

The regression model was estimated using data from the forty-five corridors for which historical data were available. The parameters g and b in the model were estimated for each corridor for the peak direction using data from both the a.m. and p.m. peak periods. The results are illustrated in Tables 2 and 3. Because the model was to be recalibrated for use in Phoenix by adjusting the value of g, the primary focus in this part of the analysis was on the estimates of b.

The existence of the peak-spreading phenomenon is clearly demonstrated for freeway facilities by the results in Table 2. The peak-spreading would be expected to occur only under congestion conditions, so the regression analysis was performed using only peak direction travel. Of the thirty-two freeway corridors included in the analysis, nineteen had V/C ratios in excess of .75 at some time during the period observed. Of these nineteen corridors, eighteen were of the correct sign (negative), and more than half (eleven) had t-statistics greater than 2 (reflecting statistical significance at roughly a 95 percent confidence level). Three additional corridors had t-statistics between 1.5 and 2.0 and two, between 1.0 and 1.5.

The only corridor for which the estimated coefficient was of the incorrect sign (positive) was the Bay Bridge in the San Francisco Bay Area. This particular corridor, however, reflects the need for close attention to the variation in V/C ratio observed. The range in variation for the Bay Bridge was only .92 to 1.00, indicating severely congested conditions throughout the period of observation. When both peak and nonpeak directions were used for the Bay Bridge, the variation in the V/C ratio was .61 to 1.00 and the estimated coefficient (b) was significantly different than zero at a 90 percent confidence level.

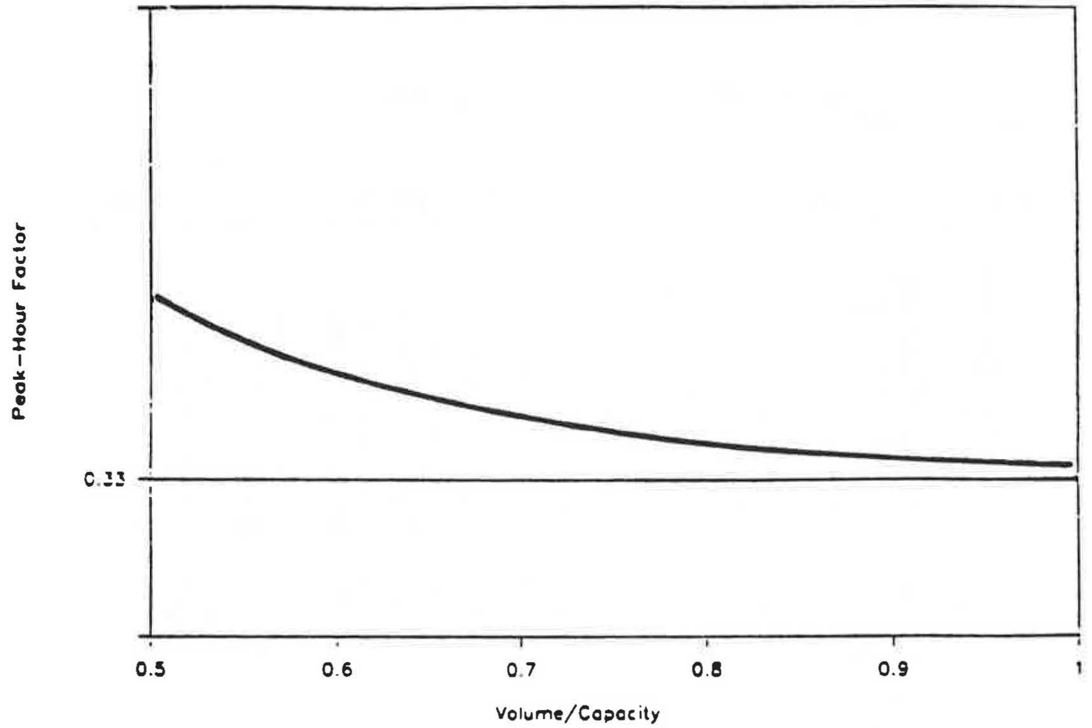

FIGURE 2 Theoretical relationship between peaking factor and volume/capacity ratio.

TABLE 2 FACILITY-SPECIFIC RESULTS OF REGRESSION ANALYSIS OF PEAKING FACTORS—FREEWAYS

CITY	CORRIDOR	b	g	# OBS	R- SQRD	ST ERR b	T-STAT b	V/C Range	
								Low	High
ARIZONA									
PHOENIX	I-10 & 49TH ST.	-2.19	-1.14	18	0.33	0.77	-2.83	.27	.41
CALIFORNIA									
BRENER PK	RT. 91 & HOLDER	-2.14	-2.60	8	0.05	3.65	-0.59	.67	.90
CASTAIC	I-5 AT RT. 126 W	-16.43	-1.38	7	0.27	12.16	-1.35	.16	.22
LOS GATOS	HWY 17 AT RT. 9	-8.66	3.26	10	0.65	2.24	-3.87	.73	.85
OAKLAND	HIGHWAY 24	-2.08	-1.08	8	0.18	1.81	-1.15	.82	1.17
PLEASANTON	I-580	-1.15	-2.61	10	0.43	0.47	-2.46	.60	.87
SAN DIEGO	I-5 AT ENCINADOS	-1.11	-2.60	9	0.06	1.71	-0.65	.42	.74
SAN FRAN.	GOLDEN GATE BR	-3.97	-0.46	4	0.09	8.86	-0.45	.57	.60
SAN FRAN.	BAY BRIDGE	0.92	-5.49	10	0.00	5.70	0.16	.912	1.04
SAN LUIS OBISPO	HWY 101 & LOS OSO RD	-5.17	-1.76	10	0.19	3.76	-1.37	.26	.37
SAN RAMON	HWY 580 & HWY 880	-1.85	-2.58	8	0.23	1.37	-1.35	.43	.66
SANTA ROSA	HWY 101 AT RT.12	-3.17	-1.15	10	0.38	1.44	-2.20	.65	.94
WILMINGTON	RT. 110 AT C ST	0.41	-3.22	6	0.01	2.42	0.17	.50	.61
TEXAS									
ARLINGTON	I-30	-2.18	-1.00	8	0.32	1.29	-1.69	.53	.78
AUSTIN	US-183	-1.14	-1.97	22	0.03	1.38	-0.83	.12	.36
AUSTIN	I-35	-2.48	-0.76	8	0.57	0.88	-2.82	.45	.87
AUSTIN	I-35	-1.31	-2.69	22	0.08	1.02	-1.28	.17	.56
DALLAS	I-635	-5.10	0.84	22	0.57	1.00	-5.11	.62	1.05
DALLAS	I-30	-3.22	-0.62	22	0.10	2.13	-1.51	.75	.94
DALLAS	I-35E	-1.58	-1.44	22	0.34	0.50	-3.18	.71	.89
DALLAS	US-75	-0.29	-3.00	22	0.00	1.69	-0.17	.66	.93
DALLAS	I-35E	-2.73	-1.73	22	0.12	1.63	-1.68	.47	.84
HOUSTON	I-45	-0.48	-3.12	22	0.09	0.34	-1.41	.50	1.03
HOUSTON	I-610	-4.78	0.59	20	0.35	1.53	-3.12	.55	.81
HOUSTON	US-59	-0.83	-2.57	22	0.34	0.26	-3.19	.31	.99
HOUSTON	US-59	-3.18	-0.83	18	0.33	1.13	-2.82	.69	.94
HOUSTON	I-10	-2.46	-1.03	22	0.20	1.09	-2.26	.70	.94
HOUSTON	I-610	-2.75	-1.25	22	0.19	1.28	-2.15	.32	.63
SAN ANTON.	I-37	-2.44	-1.34	20	0.26	0.96	-2.53	.30	.66
SAN ANTON.	I-410	-1.61	-1.62	18	0.15	0.94	-1.71	.25	.73
SAN ANTON.	US-281	1.04	-3.17	16	0.06	1.11	0.94	.26	.70
SAN ANTON.	I-410	-2.03	-1.29	20	0.37	0.62	-3.25	.48	1.00

REGRESSION EQUATION: LN(peak vol/3-hr vol - 1/3)= g + b(V/C)

TABLE 3 FACILITY-SPECIFIC RESULTS OF REGRESSION ANALYSIS OF PEAKING FACTORS—ARTERIALS

LOCATION	CORRIDOR	b	g	# OBS	R- SQRD	ST ERR b	T-STAT b	V/C Ratio	
								Low	High
ARIZONA									
PHOENIX	UNIVERSITY AT STANDAGE	-8.35	-1.80	21	0.31	2.86	-2.92	0.18	0.35
PHOENIX	BROADWAY AT STAPLEY	-6.84	-2.17	18	0.26	2.86	-2.39	0.18	0.32
PHOENIX	SCOTTSDALE AT THOMAS	15.82	1.45	10	0.50	5.60	-2.82	0.27	0.41
PHOENIX	US-60 AT CURRY	-3.41	-1.13	18	0.17	1.89	-1.81	0.30	0.59
TUCSON	WILMOT AT 22ND ST-SB	-1.38	-2.46	5	0.27	1.32	-1.04	0.43	0.74
TUCSON	WILMOT AT BROADWAY-SB	8.22	-10.56	3	0.99	0.81	10.15	0.69	0.82
TUCSON	WILMOT AT BROADWAY-WB	1.45	-3.62	5	0.19	1.70	0.85	0.50	0.68
TUCSON	SPEEDWAY AT CAMBELL-WB	-6.12	-0.05	3	0.71	3.90	-1.57	0.72	0.92
TUCSON	WILMOT AT BROADWAY-NB	-0.64	-4.56	3	0.00	6.66	-0.04	0.43	0.55
TUCSON	WILMOT AT 22ND ST-EB	-0.76	-2.92	3	0.93	0.20	-3.74	0.32	0.69
TUCSON	WILMOT AT SPEEDWAY-WB	-1.08	-2.28	3	0.08	3.59	-0.30	0.35	0.45
TUCSON	WILMOT AT SPEEDWAY-SB	-6.05	-0.51	5	0.43	4.05	-1.49	0.45	0.61
CALIFORNIA									
LOS ANG.	VENTURA AT SEPULVEDA	-2.31	-1.68	6	0.65	0.84	-2.75	0.54	0.85
LOS ANG.	WILSHIRE AT VENTURA	0.72	-4.49	10	0.03	1.53	0.47	0.83	1.06
LOS ANG.	WILSHIRE AT SEPULVEDA	-2.53	-1.65	6	0.16	2.93	-0.86	0.66	0.94
LOS ANG.	WILSHIRE AT WESTWOOD	2.72	-6.41	6	0.06	5.21	0.52	0.57	0.78

REGRESSION EQUATION: ln (peak vol/3-hr vol - 1/3) = g + b(V/C)

Thirteen freeway corridors did not have *V/C* ratios in excess of .75, and only three of these corridors produced coefficient estimates with *t*-statistics of 2 or greater. This provided support for the hypothesis that peak-spreading was significant only under congested conditions. For the freeway corridors with values of *b* significantly different than zero at a 95 percent confidence level, the range of values of *b* was −0.83 to −8.66 with a mean value of −2.96. Among the arterial corridors the range of values for the corridors with values of *b* significantly different than zero was −0.76 to −15.82; however, only one corridor had values of *V/C* that exceeded .75 for the three-hour period, reflecting the presence of congestion. The value of *b* for that corridor, Ventura Boulevard in Los Angeles, was −2.31.

The average value of *b* for each facility type was estimated by aggregating the data from all of the individual corridors but using only observations with a *V/C* ratio of .5 or greater. This screen was based on the evidence that peak spread occurs only at higher levels of *V/C*. Table 4 presents the results of the aggregate analysis for freeways and for arterials.

A single model was run using all data for freeways, but differences in the value of the aggregate freeway regression for freeways by number of lanes were also explored. Table 4 includes the results of regressions for freeways segmented by size of facility. Each regression produces values of *b* that are significantly different than zero, and the regression results together reflect a general trend of decreasing *b* (more negative) with increasing number of lanes. The regression results, by number of lanes, for the freeway data are presented graphically in Figure 3. Grouping the observations with four and five lanes or grouping those with two and three lanes produces the same pattern of decreasing *b* with increasing number of lanes, but the difference between the two values of *b* is relatively small. These values for *b* for the two size classes of freeways were used in the MAG models.

As reflected in Table 4, the results of the aggregate analysis for the arterial corridors was of limited usefulness primarily because of the lack of data from corridors with high *V/C* ratios. The aggregate regression did not produce values of *b* that were significantly different than zero at even a 90 percent confidence level. Because of the lack of useful aggregate results, the results from the Ventura Boulevard corridor in Los Angeles were used to represent arterial corridors in the MAG models.

CALIBRATION TO PHOENIX

To reflect current conditions (1985 and 1986) in Phoenix more closely, the model was recalibrated for different facility type and area type combinations in the Phoenix network using observed 1985 data. The calibration is performed using the relationship

$$a_{af} = (P_o - 1/3)/e^{b_f (V/C)_o}$$

where

P_o = the observed value of the peaking factor for the area type–facility type combination;
$(V/C)_o$ = the value of the *V/C* ratio for the area–facility type combination;
a_{af} = the value of *a* calibrated to a specific link type; and
b_f = the value of *b* previously estimated for the specific area type–facility type under consideration.

The values of P_o and $(V/C)_o$ are the average observed 1985 values for the links in each area type–facility type combination.

An analysis of current peaking factors was performed on 1985 data collected in Phoenix. Traffic counts were available for 517 locations in the metropolitan area. Most locations were two-way facilities and produced count data for two one-way links in the network. In all, 988 links had count data.

An analysis of the current peaking factors and *V/C* ratios for Phoenix supported the theoretical arguments for

TABLE 4 AGGREGATE RESULTS OF REGRESSION ANALYSIS OF PEAKING

Corridors Included	b	g	# Obs.	R-Sqrd.	St.Err. b	T-stat b
FREEWAYS						
All corridors	-2.207	-1.460	388	.215	.214	-10.6
4 or 5 lanes	-2.369	-1.377	196	.238	.304	-7.8
2 or 3 lanes	-2.003	-1.575	192	.189	.301	-7.6
ARTERIALS						
All corridors	-0.977	-3.112	48	0.040	.706	-1.4

Regression equation: ln(peak vol./3-hr. vol. - 1/3) = g + b(V/C)

Only observations for which the V/C ratio exceeded .5 were in the regressions.

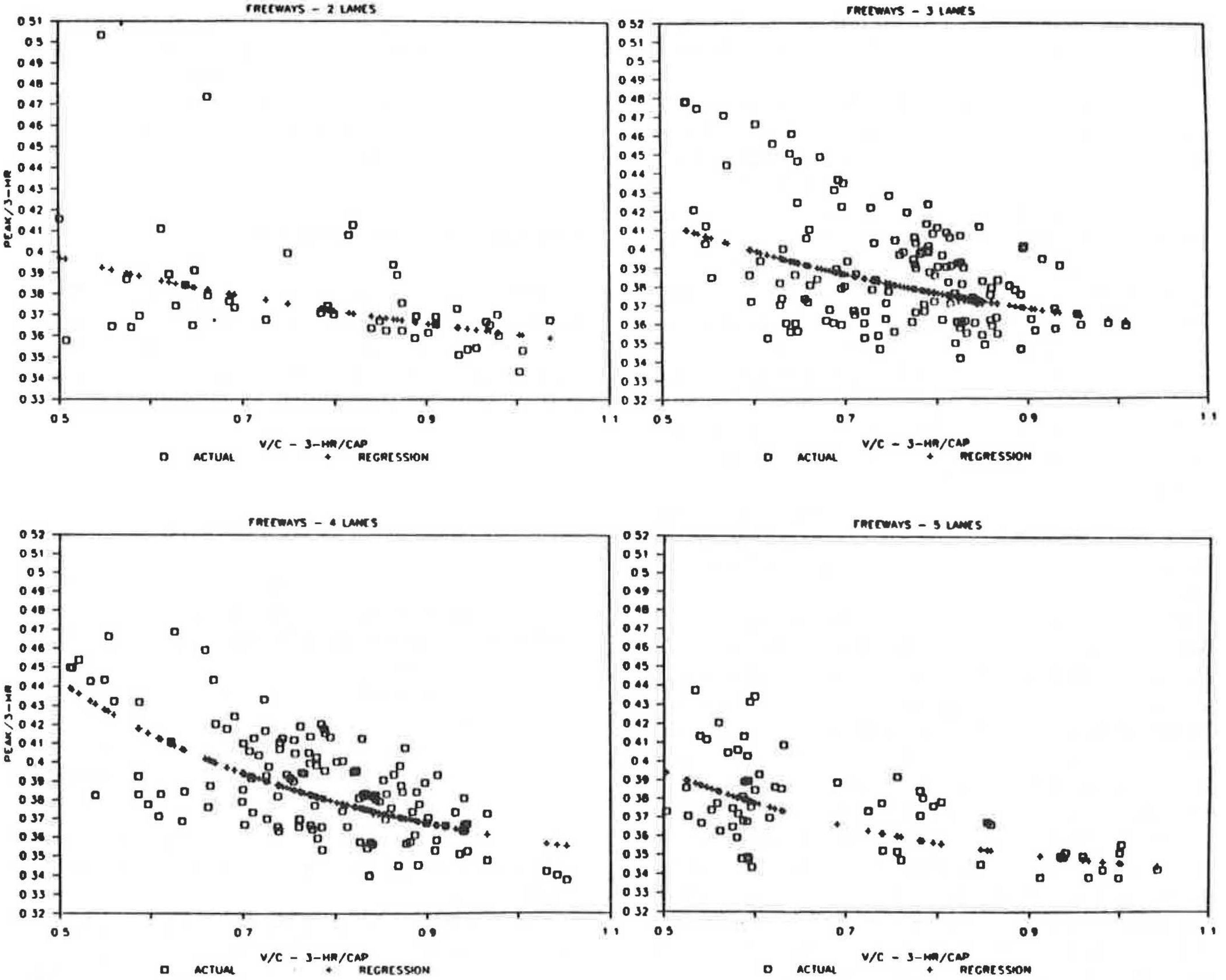

FIGURE 3 Plot of regression analysis of peaking factors for freeways.

the model of peak-spreading—that as facilities become congested, the peaking of traffic is reduced. This was demonstrated by the significantly higher peaking factors in the a.m. period when the average *V/C* ratio was generally much lower than in the p.m. period. The peaking factors were also generally lower in the denser areas where the *V/C* ratio was also generally higher.

VALIDATION OF RESULTS

A test of the peak-spreading procedures was performed by preparing assignments for 1985 and comparing the new assignments with observed data on the links where counts and speeds were available. The combination of the procedures described in this paper, the use of a three-hour peak-period trip table and a peak-spreading model, produced a significant increase in the accuracy in the assignment for 1985, when a comparison was made based on the peak-hour prediction of link volumes and speeds. The procedure used in the baseline assignment to which the new forecasts were compared was to produce a twenty-four-hour assignment and to assume that the peak hour was always 10 percent of the twenty-four-hour volume.

Figure 4 illustrates the results of the comparison. One of the principal motivations for the project was to produce better estimates of speeds, because the speeds being predicted by existing procedures were well below those observed on the links. As Figure 4 demonstrates, the desired result was produced with almost a doubling of peak-hour speeds. The resulting improvement in accuracy is illustrated in a reduction in the root mean square error (the square root of the sum of the squared differences between observed and estimated speeds on links) by 35 percent—from 56.0 to 36.6.

The improvement in accuracy in the estimation of link volumes is illustrated by the percent error in the overall estimate of vehicle miles of travel (VMT) on the links for which counts were available. The error was reduced from 16.4 to 2.2 percent.

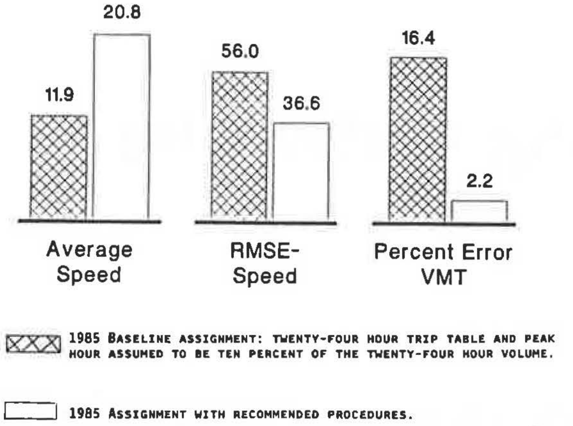

FIGURE 4 Validation results.

CONCLUSION

The research reported in this paper clearly demonstrates the need for accurate modeling of peak-hour travel volumes in planning for new or improved facilities. The standard practice around the country has been to produce twenty-four-hour assignments and to assume the peak hour to be a fixed percentage of the twenty-four-hour volume (usually 10 percent). And yet the variation from thirty-two freeway facilities examined as part of this research showed a range of plus or minus 25 percent of the mean value.

The research has also identified a clear pattern of peak-spreading as facilities become congested. Of nineteen facilities that exceeded a three-hour V/C ratio of .75, all but one produced regression coefficients of the correct sign (indicating peak-spreading), and more than half (eleven) were statistically different from zero at the 95 percent confidence level.

The research findings reported in this paper have been incorporated into the UTPS system of the Arizona Department of Transportation, and peak-hour assignments have been produced. Comparison of the assignment results from the new procedures with the results previously obtained by MAG for the Phoenix area using a twenty-four-hour assignment and constant peak-hour factor shows a significant improvement in accuracy from the new procedures.

There are some limitations to the new procedures. First, there is no guarantee of continuity of flow in the peak-hour prediction. Differences in the three-hour V/C ratio predicted for two adjacent links could result in a different amount of peak-spreading predicted for each. While this could and does occur, its impact is likely to be small because of the calibration of the peaking model on a facility type (rather than link-specific) basis, thereby averaging the effects over a facility.

A second limitation is that the peak-spreading model is applied at the link level, while the peak-spreading on a specific link may occur as a result of a single congestion point on some other link in the network or because of travelers' perception of the average level of congestion in the corridor. To the extent that links in a corridor are fairly homogeneous and the capacity on each link is generally proportional to the peak-period flow on the link, this limitation will not be a serious one.

A final limitation of the recommended procedures for peak-spreading is that they do not reflect spreading of the peak outside of a three-hour period. For the southwestern cities from which data were collected, this does not appear to be a significant limitation, but if the procedure is to be implemented in another part of the country, a broadening of the definition of the peak period may be appropriate.

Despite the procedures limitations, the improvement in modeling of the peak hour that they provide appears to be significant for Phoenix. This improvement has been demonstrated in terms of the prediction of link volumes and speeds. These limitations do, however, represent areas in which procedures might be improved in future research efforts.

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