I-285 Matrix Variegator

Practical Method for Developing Trip Tables for Simulation Modeling from Travel Demand Modeling Inputs

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When trip tables from travel demand models are applied to simulation modeling, the demands are often unrealistically high. Unreasonable demands produce extreme congestion in simulation models, resulting in unusable results. This problem is often resolved by using travel demand model trip tables as seed matrices for matrix estimation procedures. Matrix estimation procedures leave simulation model developers with difficult decisions of how to factor estimated existing trip tables to produce future trip tables, which may also produce unreasonably high demands. Matrix capping reduces trip tables to ensure select links are not over capacity. And although matrix capping has been justified by assuming peak spreading occurs, historical efforts have not applied a systematic process for estimating peak spreading for all trip interchanges. A method is described to refine travel demand model trip tables for use in simulation modeling. Trip table refinement procedures are validated against observed traffic counts by using base year travel demand model trip tables as input. The validated procedures can then be applied to future year travel demand model trip tables to produce reasonable trip tables for simulation purposes. The selected method applies a unique temporal distribution to each origin–destination pair, when appropriate temporal distributions are based on the amount of congestion that is present between each pair. The experience of applying the procedures in the development of a large simulation model of Interstate 285, a major circumferential freeway around the city of Atlanta, Georgia, is summarized.

The Georgia Department of Transportation is developing a strategic plan for Interstate 285, a major circumferential freeway around the city of Atlanta. A microsimulation model is being developed as a tool in this effort. Since I-285 serves trips traveling throughout the Atlanta metropolitan area, the Atlanta Regional Commission's (ARC's) travel demand model plays an important role in developing trip tables for simulation purposes. Because of the size of the I-285 simulation, model developers decided to adopt a process that takes refined trip tables from the macroscopic travel demand model and applies those tables in a mesoscopic simulation. The planned process then intends to use mesoscopic modeling, including dynamic traffic assignment and more detailed treatment of operational conditions, to refine trip tables further, estimate reasonable travel paths, and assist in estimating signal timing patterns. The final step in the planned process applies the results of the mesoscopic modeling process within a microsimulation modeling environment. This paper summarizes the earliest step in the overall I-285 simulation model development process, in which ARC travel demand model trip tables are refined for use in mesoscopic modeling.

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Travel demand models are an important resource in producing travel demand flows for large-scale simulation models. But when trip tables from travel demand models are applied directly in a simulation modeling environment, the demands are often unrealistically high, resulting in overly saturated conditions. A common method of dealing with this is called "matrix capping." Matrix capping uses results of select-link analysis to reduce trips for all trip interchanges that are using prespecified links that are overly congested. This paper summarizes a variation of matrix capping that systematically adjusts temporal travel demands for all origin–destination (O-D) pairs, rather than only those pairs that cross selected links of interest. Daily demands are conserved by shifting hourly demands to adjacent hours on the basis of congestion levels between each O-D pair (i.e., peak spreading).

BACKGROUND

Travel demand models are usually validated by using daily traffic counts, with little attention paid to validation of peak period assignments. Those models that include multiple time periods usually apply regional factors by trip purpose to estimate period trip tables. The factors represent the percentage of trips of each trip purpose occurring in each time period that were observed in household surveys. The same regional factors also usually are applied in future years, and the same factors are applied to each O-D pair. This approach assumes that all O-D pairs follow the same regional average temporal distribution and that the regional average temporal distribution remains constant over time, regardless of the congestion levels. Both of these assumptions are likely incorrect.

The methodology outlined assumes a different temporal distribution for each O-D pair. The assumed temporal distribution also depends on the level of congestion between each O-D pair. If a trip includes little congestion, then little or no peak spreading will occur. If a trip includes high congestion levels, then significant peak spreading will occur. The methodology also assumes that additional peak spreading will occur for any particular O-D pair as congestion increases over time.

METHODOLOGY

A simple mechanism for introducing peak spreading into a travel demand modeling environment is outlined. The procedures assume that the degree of peak spreading that is likely to occur between any O-D pair depends on the amount of congestion that is present along the shortest travel path for each O-D pair. Margiotta (*1*) developed a set of temporal distributions that vary by the ratio of the annual average daily traffic volume to hourly capacity (AADT/*C*). These distributions were manually estimated as a simple means of moving demand from peak hours to off-peak hours as congestion increases. Since the distributions were manually estimated rather than being developed from observed data, temporal distribution curves were initially estimated for three ranges of AADT/*C*: less than or equal to 7, 7 to 11, and greater than 11.

Table 1 displays the initial assumed temporal distributions estimated by Margiotta et al. (*1*).

Table 2 displays logical assumptions that Margiotta et al. (*1*) made that allow for the development of temporal distributions for many levels of AADT/*C* by interpolating between the values that are shown in Table 1. These logical assumptions also help to smooth the progression of estimated volumes at the AADT/*C* boundaries used in Table 1.

Figure 1 displays example curves that result from the application of these assumptions. The curves display the shifting of demand from the peak hours to off-peak hours, most clearly seen in the significantly lower percentage of traffic in the p.m. peak hours when the AADT/*C* is 12 compared with 8.

For the I-285 simulation, this logical approach of developing temporal distributions based on the daily volume and hourly capacity appeared potentially applicable to O-D pairs. To investigate its potential application to O-D pairs, an appropriate methodology for calculating the AADT/*C* ratio for trips had to be developed. This was accomplished by "skimming" two-way daily volumes (AADT) and two-way hourly capacities (*C*) along the shortest travel path between each O-D pair:

$$\text{AADT}/C_{2\text{-way}} = \frac{\left(\sum \text{AADT}_{ij} + \sum \text{AADT}_{ji}\right)}{\left(\sum C_{ij} + \sum C_{ji}\right)} \quad (1)$$

Volumes and capacities accumulated in Equation 1 were limited to "congested" links, because many long trips experience congestion on only a portion of the trip, resulting in little or no predicted peak spreading for those trips. Links were considered "congested" if the ratio of the link's daily volume divided by the 1-h capacity exceeds 9.0, which according to the Texas Transportation Institute (*2*) is a "threshold of congestion . . . consistent with the public's tolerance."

TABLE 1 Initial Weekday Temporal Distribution by Two-Way AADT/*C*

Hour	AADT/*C* ≤7	AADT/*C* 7–11	AADT/*C* >11	Hour	AADT/*C* ≤7	AADT/*C* 7–11	AADT/*C* >11
1	1.00	1.01	1.01	13	5.36	5.43	5.53
2	0.60	0.61	0.59	14	5.47	5.56	5.68
3	0.48	0.48	0.44	15	6.05	6.08	6.12
4	0.45	0.42	0.36	16	7.27	7.08	6.81
5	0.67	0.63	0.56	17	8.28	7.81	7.10
6	1.85	1.81	1.78	18	8.27	7.71	7.06
7	5.01	5.06	5.04	19	5.89	5.86	6.04
8	7.73	7.64	7.17	20	4.18	4.22	4.48
9	6.13	6.56	6.70	21	3.32	3.33	3.48
10	4.82	5.05	5.47	22	3.03	3.13	3.28
11	4.79	4.84	5.17	23	2.44	2.58	2.73
12	5.12	5.22	5.42	24	1.77	1.88	1.96

TABLE 2 Modification Assumptions for Temporal Distributions

AADT/*C* Range	Modification
1–7	None; low range used
8	(1/3 of low range) + (2/3 of middle range)
9	None; middle range used
10	(2/3 of middle range) + (1/3 of high range)
11	(1/3 of middle range) + (2/3 of high range)
12	None; high range used
13+	[{high range pct * (24–AADT/*C*)} + {(1/24) * (AADT/*C*–12)}]/12 * 100

With an estimate of each trip's AADT/*C* ratio, it is possible to estimate a unique temporal distribution for each O-D pair by using curves such as those displayed in Figure 1 or locally estimated similar curves. A simple example will perhaps help to clarify how this results in peak spreading. Consider the two trip interchanges that are represented in Figure 2. Assuming the traffic and capacities shown are two-way data, a trip from Zone A to Zone B would have an AADT/*C* ratio of 8. A trip from Zone A to Zone C would have an AADT/*C* ratio of 12.

To determine the percentage of daily trips occurring in Hour 8, a temporal distribution curve such as that shown in Table 3 can be used. Table 3 highlights the percentages for Hour 8 for the respective AADT/*C* ratios for example trip interchanges.

Since the AADT/*C* ratio for a trip from Zone A to Zone B is 8, the percentage of daily trips occurring in Hour 8 would be 7.67. Likewise, since the AADT/*C* ratio for a trip from Zone A to Zone C is 12, the percentage of daily trips occurring in Hour 8 would be 7.17. If these two trip interchanges had an equal demand of 1,000 vehicles per day, the hourly demand between Zones A and C would be 77, and the hourly demand between Zones A and C would be only 72. More peak spreading occurs for trips between Zones A and C (i.e., five fewer trips) because that trip interchange is more congested than the trip between Zones A and B. This simple example does not address the directional split for the peak hour trips, but it conveys the basic concepts that were labeled during the I-285 simulation project as matrix variegation (note: "variegate" means to change something).

I-285 CASE STUDY

To apply the matrix variegation process to the I-285 simulation, a few additional preliminary steps were necessary to consolidate period trip tables into daily demands. The ARC travel demand model also uses separate trip tables for single-occupancy vehicles (SOVs), high-occupancy vehicles (HOVs), and trucks. Essentially the same matrix variegation process is applied to each vehicle type. It was also necessary to estimate the directional split of hourly demands. Directional split reflected in the ARC peak period trip tables was assumed to be applicable to hours within their respective period.

The following steps outline the I-285 matrix variegation process in more detail:

1. Sum travel demand model period trip tables to produce total daily trip tables by vehicle type (SOV, HOV, truck).

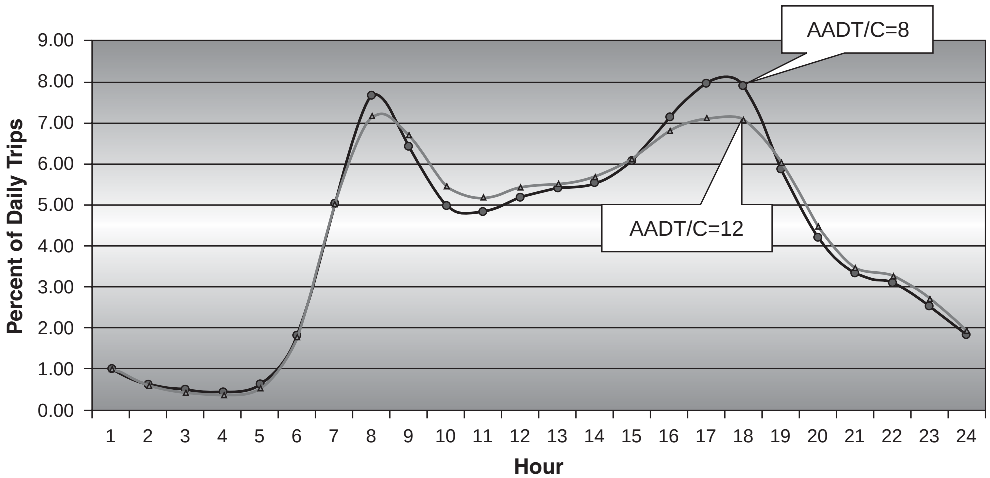

FIGURE 1 Weekday temporal distribution by hour (by two-way AADT/*C*).

2. Calculate peak period directional distribution factors from travel demand model period trip tables by vehicle type (SOV, HOV, truck).
3. Accumulate attributes (AADT, *C*) from "loaded" highway network.
4. Calculate two-way AADT/*C*.
5. Look up hourly percentage of trips based on AADT/*C*.
6. Determine hourly demands by direction.

Step 1. Produce Total Daily Trip Tables

The Atlanta region's travel demand model includes four time periods. Each period has a set of vehicle trip tables, with separate trip tables for SOVs, HOVs, and trucks. Daily trip tables for each vehicle type are prepared by summing the four time period tables. The three resulting tables are the control totals for daily demand. These demands are conserved in the matrix variegation process.

With data from the previous example, the daily demand of 1,000 vehicles per day might consist of 800 SOV trips, 150 HOV trips, and 50 truck trips. For the ARC model, these totals would have been obtained by summing the four time period tables for each vehicle type.

Step 2. Determine Trip Directional Distributions by Vehicle Type

Directional distribution factors by vehicle type are estimated from the Atlanta travel demand model time period trip tables. This is done by dividing the one-way trips by the two-way trips for each O-D pair. Two-way trips are calculated by summing the one-way trip matrix to its transposition. This results in a directional distribution of trips for each time period and for each vehicle type, producing 12 matrices.

To continue the example, it is assumed that 60% of all trips occurring in Hour 8 travel from Zone A to B, and 40% of the vehicle trips would travel in the reverse direction. The same directional distribution is assumed for all vehicle types.

Step 3. Accumulate Attributes

Before a trip's AADT/*C* ratio can be estimated, it is first necessary to accumulate the total daily volume and the total hourly capacity along the shortest travel path between each O-D pair by using a loaded highway network. Since the ARC travel demand model includes four

TABLE 3 Example Temporal Distribution Lookup Table

	Hour of Day									
AADT/*C*	1	2	3	4	5	6	7	8	9	10
7	1.00	0.60	0.48	0.45	0.67	1.85	5.01	7.73	6.13	4.82
8	1.01	0.61	0.48	0.43	0.64	1.82	5.04	7.67	6.42	4.97
9	1.01	0.61	0.48	0.42	0.63	1.81	5.06	7.64	6.56	5.05
10	1.01	0.60	0.47	0.40	0.61	1.80	5.05	7.49	6.61	5.19
11	1.01	0.60	0.45	0.38	0.58	1.79	5.05	7.33	6.65	5.33
12	1.01	0.59	0.44	0.36	0.56	1.78	5.04	7.17	6.70	5.47
13	1.27	0.89	0.75	0.68	0.86	1.98	4.97	6.92	6.49	5.36
14	1.54	1.19	1.06	0.99	1.16	2.18	4.90	6.67	6.28	5.25
15	1.80	1.48	1.37	1.31	1.46	2.38	4.82	6.42	6.07	5.14
16	2.06	1.78	1.68	1.63	1.76	2.58	4.75	6.17	5.86	5.04

period assignments, a "daily" network that combines the results of the four assignments must be prepared. Daily volumes are the sum of the four time period assignments. The congested time of each link is calculated as a weighted average of the four period assignment times, weighted by the vehicle miles traveled (VMT) in each period. Daily volume (AADT) and hourly capacities (C) are "skimmed" from the "daily" network as is typically done for travel times. Since many trips experience congestion in only part of the journey, simply accumulating the volumes and capacities for all links in the path can underestimate the severity of congestion for some trips, and thus the potential degree of peak spreading. To account for this fact, attributes are accumulated only for links with an AADT/C ratio greater than 9.0.

To keep the example simple, it will be assumed that all links in the skimmed direction have an AADT/C ratio greater than 9.0. Therefore, the results of this step would be the summed volumes and capacities displayed in Figure 2.

Step 4. Calculate Two-Way AADT/*C*

Departure times are generally dependent on the entire day's expected travel patterns. For example, if a person leaves for work early in the morning, that person more likely leaves work early too. For this reason, the degree of peak spreading is estimated by using the two-way AADT/C. Two-way AADT and C matrices are produced by summing the matrices of accumulated AADT and C to the transposition of each matrix:

$$\text{AADT}_{\text{2-way}} = \sum \text{AADT}_{ij} + \sum \text{AADT}_{ji} \tag{2}$$

$$C_{\text{2-way}} = \sum C_{ij} + \sum C_{ji} \tag{3}$$

Two-way AADT/C ratios can then be calculated by dividing the resulting AADT matrix by the resulting C matrix:

$$\text{AADT}/C_{\text{2-way}} = \frac{\text{AADT}_{\text{2-way}}}{C_{\text{2-way}}} \tag{4}$$

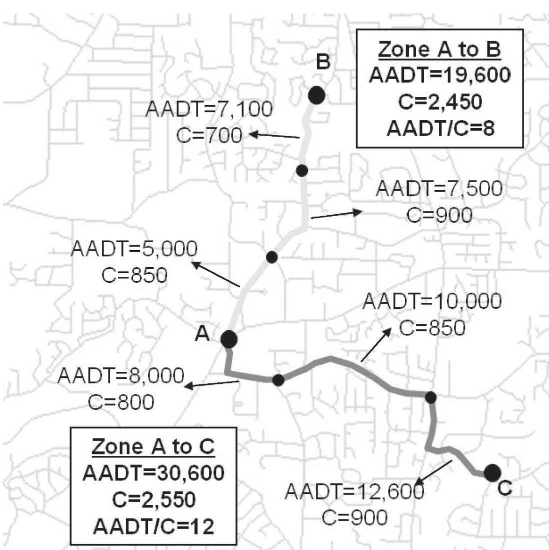

FIGURE 2 Example O-D pair data.

Since the example two-way AADT and C values remain unchanged, the example AADT/C ratios remain 8 and 12 and respective hourly percentages (Step 5) also remain unchanged.

Step 5. Look Up Hourly Percentages

The percentage of trips occurring in each hour for each O-D pair is based on the estimated AADT/C ratio. A lookup table of the assumed percentage of trips by hour for various levels of the AADT/C ratio allows daily trip tables to be split into two-way hourly demands.

Step 6. Determine Hourly Demands by Direction

Hourly trip tables are produced by multiplying the percentage of trips in the subject hour by the estimated directional distribution obtained in Step 2. With the example, the following demands by vehicle type would be estimated for Hour 8:

Zone A to Zone B:
SOV = 800 * 0.6 * 0.0767 = 37
HOV = 150 * 0.6 * 0.0767 = 7
truck = 50 * 0.6 * 0.0767 = 2

Zone A to Zone C:
SOV = 800 * 0.6 * 0.0717 = 34
HOV = 150 * 0.6 * 0.0717 = 6
truck = 50 * 0.6 * 0.0717 = 2

DEVELOPMENT OF TRIP-BASED TEMPORAL DISTRIBUTIONS

The initial application of the I-285 matrix variegator process used the temporal distribution curves for freeways from Margiotta et al. (*1*). It was anticipated that the process would require considerable refinement and calibration, but the initial outputs of the matrix variegation process indicated that only minor adjustments might be necessary to use the trip tables in the mesoscopic modeling process. Figure 3 displays comparisons of assigned volumes using hourly trip table output from application of the matrix variegator process versus observed hourly traffic counts for 3 h in the a.m. peak period and 3 h in the p.m. peak period. The most significant modification to the matrix variegator process was how trucks were treated. The changes involved separating heavy-duty trucks and light-duty trucks because, when modeled heavy-duty truck volumes were compared with observed truck counts, the differences were unacceptable for use in simulation modeling. To improve heavy-duty truck trip tables, matrix estimation techniques were used to estimate existing truck trip tables for each simulation hour. It is expected that future year truck trip tables will be prepared by factoring the estimated trip tables using district-level growth factors. Light-duty truck (i.e., commercial vehicle) trips were estimated by using the outlined matrix variegation process.

POTENTIAL METHODS OF CALIBRATION

Although detailed estimations of locally specific temporal distribution curves were deemed unnecessary for the I-285 simulation project, it would be relatively straightforward to produce AADT/C-based

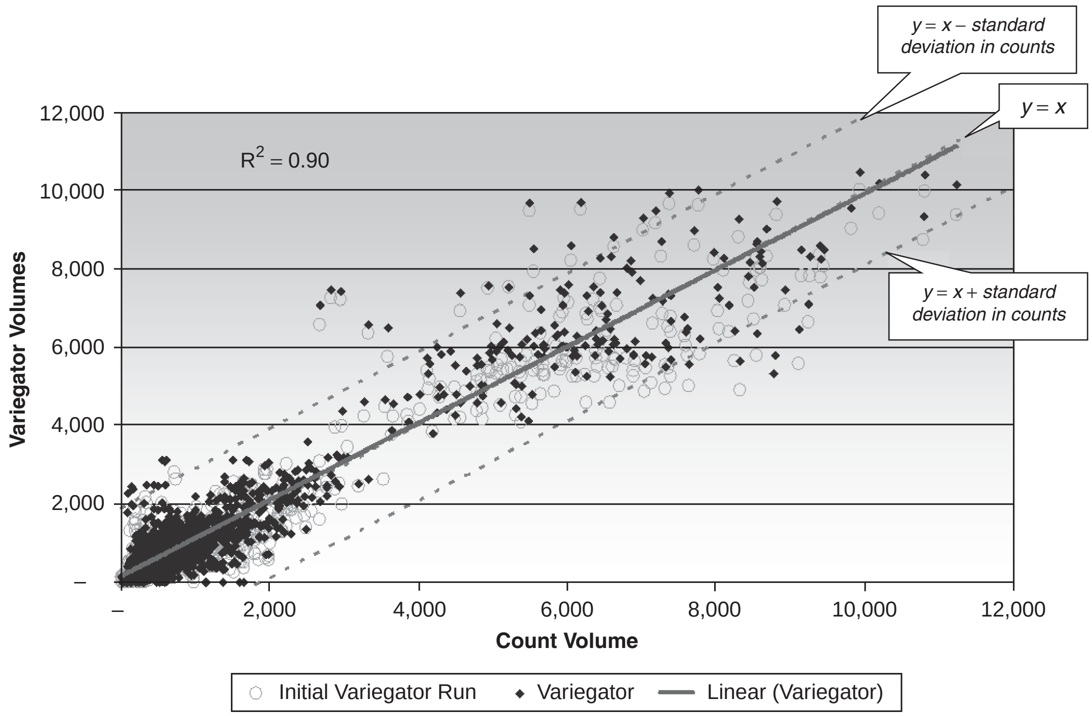

FIGURE 3 Matrix variegator volumes versus hourly counts.

temporal distributions for individual locations by using extensive hourly count data and estimated hourly capacities. Table 4 displays how a traffic count database could be used to do this. This example shows hourly and daily counts for 20 locations that all have an estimated AADT/*C* ratio in the 7-to-11 range. For simplicity, the estimated hourly capacity for each of these locations was assumed to be 1,000, but normally each location would have a unique hourly capacity. If the resulting temporal distribution will be used in a travel demand modeling environment, it would be appropriate to use capacities that are consistent with the capacity assumptions used in the travel demand model. To estimate the hourly percentage of trips in any given hour, the sum of the counts for that hour would be divided by the sum of the daily counts. For example, the sum of the hourly counts for Hour 7 is 10,920, and the sum of the daily counts is 182,000. The percentage of the daily trips occurring in Hour 7 would be estimated as 6.00% (10,920 ÷ 182,000). A complete AADT/*C*-based temporal distribution could be developed by compiling similar databases for AADT/*C* ranges of less than or equal to 7 and greater than 11. Then logical assumptions such as those in Table 2 could be applied to develop a detailed locally specific temporal distribution lookup table.

It also might be possible to apply matrix estimation techniques to estimate local AADT/*C*-based temporal distribution curves. If data were available to estimate a daily trip matrix and hourly matrices for every hour of the day, it would be possible to assign the trips and "skim" all the necessary data from loaded networks to build 24-h temporal distributions for various ranges of trip-based AADT/*C*. However, it is not practical to collect the required data and estimate matrices for every hour of the day. It would be practical to collect the necessary data and estimate daily, a.m. peak hour, and p.m. peak hour matrices. With these matrices and corresponding highway assignments, it would be possible to estimate the percentage of trips in each peak hour by various ranges of trip-based AADT/*C*. Similar to the way in which counts are summed in Table 4 to estimate the percentage of trips in each hour, daily and hourly trips for each O-D pair within a particular AADT/*C* range would be summed. The percentage of trips for the subject hour and AADT/*C* range would be calculated by dividing the hourly sum by the daily sum. Since it is generally impractical to do this for every hour, it would be necessary to use the results with typical temporal patterns to estimate complete daily lookup tables.

CONCLUSIONS

Since the matrix variegator process was being developed, initial I-285 mesoscopic model runs were made by using inputs derived directly from ARC model time-of-day trip tables. These early runs, when compared with subsequent runs using trip tables from the matrix variegator process, indicate that the variegator process helps to reduce the occurrence of extremely congested locations. The evaluation process is ongoing, and some overly congested locations remain; but it has been found that many of these have occurred where intersections and possible turning movements were not coded correctly in the mesoscopic model.

Since the mesoscopic model is currently under development, early microsimulation model development efforts are assigning trip tables from the matrix variegator process. These early assignments indicate that the matrix variegator process does not cap demands enough to avoid extremely congested conditions at particular intersection approaches. Since the travel demand model does not fully account for delays due to traffic signals, this is not unexpected. This typical problem is why the initial model development plan included mesoscopic modeling as an intermediate step.

TABLE 4 Estimating an AADT/*C* Lookup Table from Counts

Count Summary AADT/*C* Range 7–11				Hourly Counts						
				a.m.			Midday	p.m.		
Count Station	AADT	*C*	AADT/*C*	Hour 7	Hour 8	Hour 9	Hour 12	Hour 16	Hour 17	Hour 18
1	7,200	1,000	7.20	432	557	441	369	524	596	596
2	7,400	1,000	7.40	444	568	475	384	529	589	584
3	7,600	1,000	7.60	456	581	499	397	538	594	586
4	7,800	1,000	7.80	468	603	478	399	567	646	645
5	8,000	1,000	8.00	480	614	513	415	571	637	632
6	8,200	1,000	8.20	492	626	538	428	581	640	632
7	8,400	1,000	8.40	504	649	515	430	611	696	695
8	8,600	1,000	8.60	516	660	552	446	614	685	679
9	8,800	1,000	8.80	528	672	577	459	623	687	678
10	9,000	1,000	9.00	540	696	552	461	654	745	744
11	9,200	1,000	9.20	552	706	591	477	657	733	726
12	9,400	1,000	9.40	564	718	617	491	666	734	725
13	9,600	1,000	9.60	576	742	589	492	698	795	794
14	9,800	1,000	9.80	588	752	629	508	700	781	774
15	10,000	1,000	10.00	600	764	656	522	708	781	771
16	10,200	1,000	10.20	612	789	625	522	742	845	844
17	10,400	1,000	10.40	624	798	668	539	743	828	821
18	10,600	1,000	10.60	636	810	695	553	750	828	817
19	10,800	1,000	10.80	648	835	662	553	785	894	893
20	11,000	1,000	11.00	660	844	706	571	786	876	868
Total count	182,000			10,920	13,982	11,578	9,417	13,047	14,612	14,505
			Percent of total	6.00%	7.68%	6.36%	5.17%	7.17%	8.03%	7.97%

RECOMMENDATIONS FOR FUTURE RESEARCH

Because of time constraints on the I-285 simulation project, little time was available to investigate measures of congestion other than AADT/*C*. It is possible that research efforts could identify other measures of congestion that could better deal with trip length or could be a better indicator of the degree of peak spreading. It also would be beneficial to apply the matrix variegation process to multiple cities and to demonstrate statistically that the process offers consistently improved results over application of regional time-of-day production–attraction factors. If this can be demonstrated, the matrix variegator process has potential to be a fundamental means of building peak hour models.

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