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Subject: Transportation Network Speeds for SIP Modeling

Date: September 11, 2006

Given the time constraints imposed by the County's air quality modeling schedule, it is clear that a final decision on vehicle emissions modeling speeds is required in the next few days. I have prepared this memorandum in an effort to facilitate an informed decision. The following information generally provides a summary of my understanding of the basic issues surrounding the decision, as well as presents what I hope might be a methodology to move forward using as much local data as possible. Of course, all expressed opinions are mine alone and should be considered only to the extent that they do not conflict with other inventory development issues of which I may not be aware. Also, please recognize that this material was prepared in a very limited timeframe and should be viewed as ripe for future refinement should Clark County elect to move forward with the suggested approach.

Background: Modeled vehicular emissions are quite sensitive to assumed average travel speeds. Therefore, the accurate assessment of travel speed is a critical element of vehicle emissions inventory development. Ideally, such speeds will be based on comprehensive local studies of traffic movement over a range of roadway segments. The Regional Transportation Commission of Southern Nevada (RTC) has recently completed such a study, but has not yet adopted a local speed profile based on the collected data. In the absence of local speed profiles, alternative speed estimation techniques are required. Such techniques include (among other approaches) the estimation of speeds from local travel demand model (TDM) parameters, or the use of surrogate travel speeds from studies performed for similar road classifications in other areas.

Since the RTC has developed a comprehensive local TDM, upon which emissions modeling vehicle miles of travel (VMT) are based, it would be appropriate to utilize available speed parameters from that same model. Among the TDM data provided to DAQEM are speed-related parameters such as link volume, posted speed, free flow speed, hourly capacity, and daily capacity. To date, assumed travel speeds for DAQEM emissions modeling have been based on the application of the Bureau of Public Roads (PBR) speed-flow equation, which relates average speed to free-flow speed according to the following function:

$$\text{average mph} = \frac{\text{free flow mph}}{\left[1 + \alpha\left(\frac{\text{volume}}{\text{capacity}}\right)^{\beta}\right]}$$

where the coefficients, α and β, vary (locally) by road class. Although the source of the coefficients is not indicated, they are included with the TDM link data so I suspect that they have been developed (or at least adopted) locally as an integral component of the TDM process. This is important, as the indicated coefficients vary considerably from the "standard" coefficients established during the original development of the BPR function. For example, as compared to the standard coefficients, where:

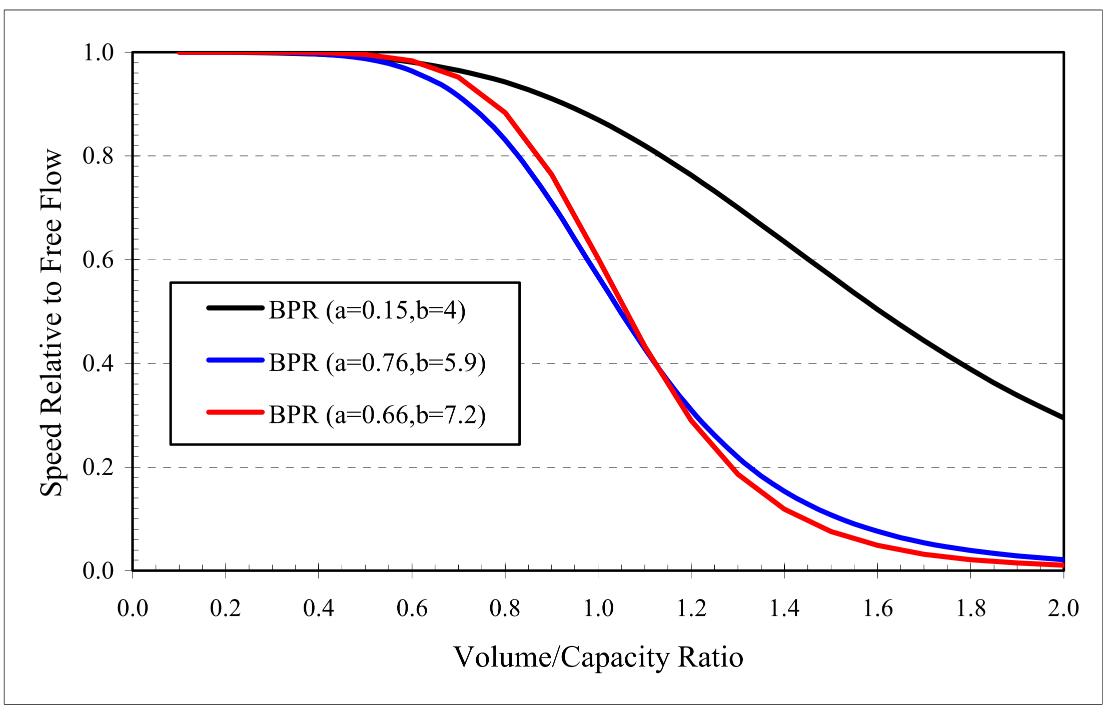
$\alpha = 0.15$, and $\beta = 4$,

coefficients in the link data file are:

$\alpha = 0.76$, and $\beta = 5.9$ (for arterials, collectors, and local roads), and
$\alpha = 0.66$, and $\beta = 7.2$ (for interstates, freeways, and expressways).

These differences are quite significant as they substantially increase the sensitivity of the BPR function to changes in volume-to-capacity ratio, as depicted graphically in Figure 1.

Figure 1. Sensitivity of the BPR Speed-Flow Function



DAQEM is developing the emissions inventory estimates on an hourly basis. To accomplish this TDM traffic volumes for seven time periods are disaggregated into 24 hourly traffic volumes. These hourly volumes are then compared to the TDM hourly capacities to determine the volume-to-capacity ratios that are then fed into the BPR speed-slow function to determine associated travel speeds.

Problem: Despite the sensitivity of the BPR speed-flow function when applied using the local coefficients, estimated average travel speeds are very close to the TDM free-flow speeds throughout the 24 hour modeling period. In effect, even travel during peak hours is accomplished with little variation from free-flow. As illustration, Table 1 shows the daily VMT-weighted volume-to-capacity ratios as well as the associated VMT-weighted free-flow and BPR-adjusted average speeds. As indicated, adjusted speeds generally vary from free-flow by only about five miles per hour.

Table 1. VMT-Weighted BPR Speeds Based on TDM Hourly Capacity

Roadway Type	Volume to Hourly Capacity	Free-Flow Speed (mph)	BPR Adjusted Speed (mph)	BPR Speed Adjustment (mph)
Collector	0.43	38	31	-7
Expressway/Beltway	0.50	50	44	-6
Freeway	0.53	58	54	-4
Interstate	0.53	58	52	-6
Major Arterial	0.56	40	35	-5
Minor Arterial	0.54	40	34	-6
Overall System	0.47	41	36	-5

Table 1 clearly shows that VMT-weighted volume-to-capacity ratios are generally around 0.5, implying that average travel occurs at well below the design capacity of the local roadways. From Figure 1, it is clear that the BPR speed adjustment is very low for such conditions, and the resulting estimated average travel speeds are near free-flow. It is quite unlikely that the local roadway network performs at this level of service during peak travel periods and, as a result, emissions are likely to be underestimated if this approach is maintained.

Discussion: The reason for the apparent "overdesign" of the local roadway network can be clearly tracked to the use of the TDM hourly capacities to determine the effective volume-to-capacity ratios for all 24 hours of the emissions modeling simulation. Such an approach inherently assumes that the hourly capacity can be maintained throughout the entire day, when in actuality, hourly capacities are more generally representative of the maximum rate of flow that can be accommodated in a *15-minute* interval. Thus, although expressed in hourly units (vehicles per hour per lane (vphpl), or vehicles per lane per hour (vplph)), stated hourly capacities actually reflect "sub-hour" peak capacities that would not be expected to be sustainable for even a full hour (let alone a full day) without significant flow impedance. This can be easily illustrated simply be comparing the stated daily and hourly capacities from the local TDM data file. On a VMT-weighted basis, the ratio of the stated daily capacity for each network link to 24 times the stated hourly capacity is about 0.44, clearly demonstrating that the use of the stated hourly capacity as applicable over a 24 hour period dramatically overstates the capacity of the local network.

One obvious alternative might be to substitute the use of the hourly equivalent of the stated daily capacity (i.e., daily capacity divided by 24) in place of the stated hourly capacity in the determination of hourly volume-to-capacity ratios. However, such an approach would certainly underestimate network capacity over the short (i.e., 15 minute) intervals reflected in the stated hourly capacities and likely over a substantial number of the daily one hour periods as well. The bottom line is that capacity declines as the interval over which it is measured increases. While short traffic flow spikes may be accommodated with little overall impact on performance, longer spikes become increasingly likely to negatively affect flow rates.

It is possible to theorize any number of hybrid approaches that estimate an effective 60-minute flow interval capacity on the basis of both stated hourly and stated daily capacities, but most, if not all, would have to be based on seemingly arbitrary factors in the absence of additional local data necessary to develop appropriate weighting factors. However, through a limited literature review conducted within the constraints of the available timeframe, I have developed what I believe might be a viable near term solution. I present this below as "Alternative 3," following brief discussions of two other "ready" approaches, so that the implications of all three approaches can be more fully considered.

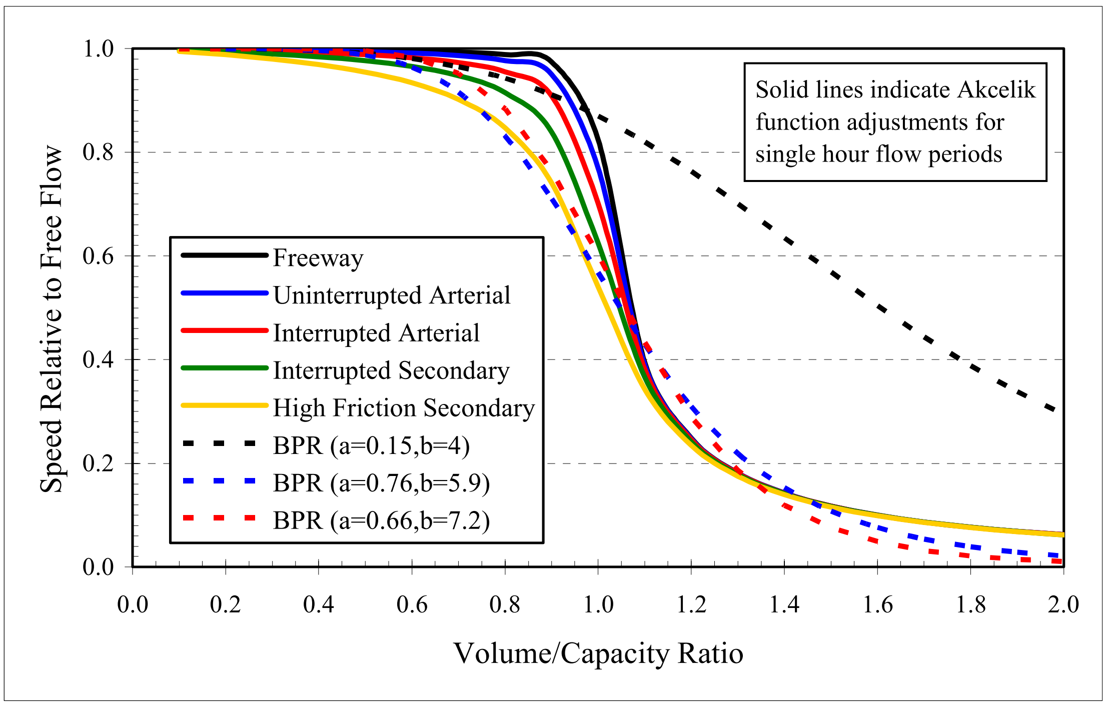
Before presenting these "solutions," let me briefly also discuss the Akcelik speed-flow function that was evaluated as a potential alternative to the BPR speed-flow function. The form of the Akcelik function is as follows:

$$\frac{1}{\text{average mph}} = \frac{1}{\text{free-flow mph}} + (0.25T)\left[\left(\frac{V}{Q}-1\right) + \sqrt{\left(\frac{V}{Q}-1\right)^2 + \frac{8J\left(\frac{V}{Q}\right)}{Q'T}}\right]$$

where: T is the flow period, in hours,
V/Q is the volume-to-capacity ratio for the period,
J is the Akcelik delay parameter, and
Q′ is the capacity, in vehicles *per hour*.

The Akcelik evaluation was conducted under the initial theory that the observed local speed insensitivity was resulting from the fact that the BPR function was not sufficiently sensitive to variations in the volume-to-capacity ratio. This theory was based on the faulty assumption that local speeds were being developed on the basis of the "standard" BPR coefficients ($\alpha = 0.15$, and β = 4). However, as discussed above, it subsequently became apparent that the local coefficients are significantly different from the "standard" BPR coefficients and result in a significantly more sensitive speed-flow function. Further investigation of the local TDM link data revealed that the speed insensitivity actually results from the (low) value of calculated volume-to-capacity ratios rather than the formulation of the speed-flow function itself. Nevertheless, I have carried the Akcelik speed-flow function throughout the analyses conducted in support of the data presented in this memorandum and present summary speed estimates for both the BPR and Akcelik functions below. Suffice to say that the two functions (with the BPR as "calibrated" using local coefficients) provide similar results, as is expected given their similar sensitivity, which is depicted graphically in Figure 2. Thus, while there are small differences and potentially viable reasons for selecting the Akcelik speed-flow function over the BPR, the net effect of such a decision will be minor for the issues of immediate interest.[1]

Figure 2. Akcelik Versus BPR and Modified BPR Speed-Flow Functions



[1] This conclusion assumes the continued use of "default" values for the Akcelik delay parameter (J). Should the development of more refined local values be possible, which seems unlikely at this juncture, there are features of the Akcelik function that could result in more robust average speed estimates. However, in its default implementation, it produces estimates very similar to those of the calibrated BPR function. It is also important to note that the Akcelik speed adjustments presented in this memorandum are *all* based on an assumed flow period of one hour, despite the fact that the link data to which they are applied are measured for seven sub-daily time periods ranging in length from two to seven hours. This approach was taken so that developed adjustments would be similar to those that would be calculated if the Akcelik function was applied to flows over 24 one-hour periods, as would be the case were it applied as a component of the Clark County motor vehicle emissions inventory process.

Solutions: The following three alternatives summarize what I believe are available near term solutions that would allow DAQEM to proceed with the modeling emissions inventory. I am actually proposing what is included below as Alternative 3 as the optimum near term solution, but I wish to emphasize the following before presenting that approach:

> *First, the suggested approach (Alternative 3) has been developed on the basis of limited data over a very limited timeframe. More extensive efforts might yield additional (and potentially superior) alternatives, but I believe that the approach is sound. Nevertheless, I suggest that DAQEM might wish to devote additional future research effort to validate and refine (or potentially replace) the suggested approach. In effect, the topic could be the subject of a dedicated (and significant) research project, rather than the focus of a few day research "fire drill."*
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> *Second, I would strongly suggest that DAQEM (and/or the RTC) conduct a detailed analysis of local speed-flow study data and develop local speed-flow functions. In support of this memorandum, I have conducted an abbreviated analysis of available local speed study data in an effort to validate the BPR (and Akcelik) speed-flow function coefficients, but in the interests of time I have been forced to reject a significant portion of the speed study data due to quality assurance concerns. It is almost certain that many of these rejected data are valid and should be considered in a more detailed analysis not constrained by time pressures. Additionally, followup studies of speeds on functional classes not represented in the existing study data would be beneficial. Such continuing work is critical to the proper estimation of local speed/capacity responses, for which any alternative is merely a placekeeper.*

Alternative Solution 1, No Change: Under this solution, DAQEM would proceed with the development of the emissions inventory using the existing approach (i.e., assuming hourly capacities can be maintained throughout all 24 hours in a day). The reasons for not moving in this direction are well understood, as described throughout the preceding sections of this memorandum, but the approach is viable and does follow EPA modeling protocol regarding the use of local data and estimation techniques.

Alternative Solution 2, Surrogate Data: Under this solution, DAQEM would proceed with the development of the emissions inventory using surrogate speed data developed for other (i.e., non-local) modeling exercises. Such data would be applied at the maximum level of resolution possible given the relationship between the surrogate and local data, and would include as much local data as possible in the development of surrogate speeds, but would inherently not be based on the most resolved level of locally generated data. In other words, while it is possible to apply surrogate data to local roadway links on the basis of corresponding characteristics (e.g., speeds for surrogate arterials can be applied to local arterials), it is unlikely that those surrogate data can be adjusted for differences between conditions on the surrogate network and conditions on the local network. In effect, such conditions will be inherently assumed to the similar.

One such alternative data set that could clearly be applied is that developed for the recent WRAP (Western Regional Air Partnership) emissions inventory development process. Since Clark County is a component of the WRAP modeling domain, it is entirely possible to adopt those modeling speeds utilized in the WRAP process for the current modeling analysis. However, unlike the current analysis, which is being conducted on an hourly basis, WRAP travel speeds represent daily aggregates. Therefore, some method to "disaggregate" WRAP travel speeds would be required. The simplest approach would be to adjust individual hourly travel speeds developed using the current approach by the ratio of daily aggregate WRAP speeds to daily aggregate current approach speeds. This would retain the hourly sensitivity of the current approach, including appropriate speed variation, while correcting for the generalized speed overestimation of the current approach.

Because WRAP speed data was itself developed through surrogate national data, this in not my preferred approach. However, the approach is viable and would result in speed estimates consistent with accepted existing inventories.

Alternative Solution 3, Modified Local Capacity Approach: Under this solution, DAQEM would modify the current speed estimation approach to utilize an alternative hourly capacity definition to better characterize an explicit 60-minute flow capacity in lieu of the current use of peak hourly capacity. Replacement of the BPR speed-flow function with the Akcelik speed-flow function could also be considered, but the net effect of such replacement would be minor. To illustrate the impacts of replacing the BPR function with an Akcelik equivalent, the data that follow include speed adjustments developed under both approaches.[2]

A limited research review was conducted in an effort to develop a viable capacity adjustment algorithm. In a paper entitled "A Probabilistic Approach to Defining Freeway Capacity and Breakdown," a statistical analysis of over 40 flow breakdown effects at two sites is described, and associated probability distributions are reported.[3,4] Moreover, these data were analyzed in terms of hourly capacity determined by one-minute, five-minute, and 15-minute flow intervals. This allowed for the development of rudimentary statistical relationships between capacity, flow interval, and the probability of flow breakdown.

The statistical analysis reported in the paper specifically evaluated the probability of breakdown occurring at various flow rates and intervals. Figure 3 is a reproduction of the data developed for a freeway site designated as Site B. The data for another freeway site, designated as Site A, is similar. As expected, the probability of breakdown increases with both flow rate and the length of the flow interval (as the potential for interactions between vehicles increases). In effect, high flow rates can be experienced with a low probability of breakdown for short periods, but

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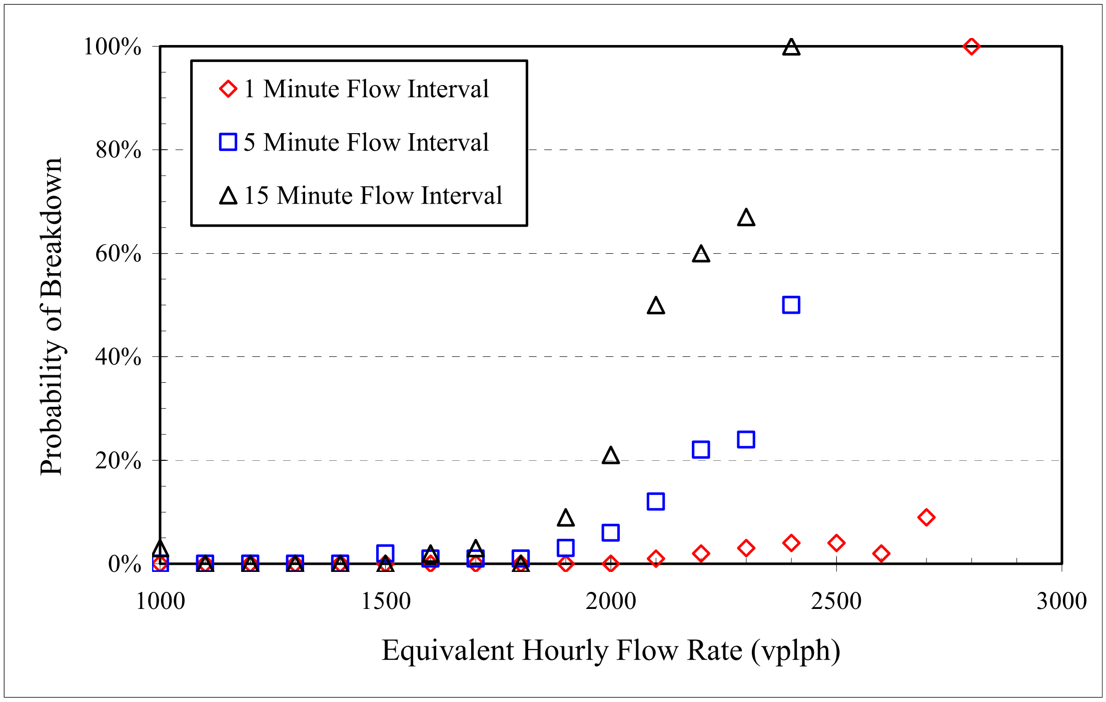
2 As previously stated, it is important to note that the Akcelik speed adjustments presented in this memorandum are *all* based on an assumed flow period of one hour, despite the fact that the link data to which they are applied are measured for seven sub-daily time periods ranging in length from two to seven hours. This approach was taken so that developed adjustments would be similar to those that would be calculated if the Akcelik function was applied to flows over 24 one-hour periods, as would be the case were it applied as a component of the Clark County motor vehicle emissions inventory process

3 Lorenz, M. and Elefteriadou, L., Pennsylvania State University, University Park, Pennsylvania, "*A Probabilistic Approach to Defining Freeway Capacity and Breakdown*," presented at the Fourth International Symposium on Highway Capacity, Maui, Hawaii, June 27–July 1, 2000.

4 In the study, breakdown is defined as a disturbance that results in a drop in average speed to below 56 miles per hour (from speeds of 62-75 miles per hour on two separate freeway sites) for a period of at least five minutes. However, in nearly all cases, breakdowns were observed to last substantially longer and were characterized by dramatic drops in speeds (e.g., to 10 miles per hour and less).

Figure 3. Breakdown Probability Distributions



breakdown probability increases dramatically *for the same flow rates* as flow intervals increase (short flow spikes are better tolerated than longer flow spikes of the same magnitude). This is a direct representation of the hourly versus daily capacity issue (albeit on a smaller flow interval scale), wherein peak hourly flow rates will result in a significant overestimation of network capacity if assumed to be valid throughout the course of an entire day.

To express these findings in a more generalized relation, I first conducted a monomial exponential regression of the reported breakdown probabilities for both Sites A and B, thereby allowing these data to be expressed in an equivalent functional form. From these regressions, I was able to estimate the "exact" equivalent hourly flow rate for specific breakdown probabilities at each flow interval (one-minute, five-minutes, and 15-minutes). This resulted in the production of three data points for each breakdown probability, which were subsequently regressed to estimate the equivalent hourly flow rate with the same breakdown probability at different flow intervals. By evaluating the resulting regression equations for a 60-minute flow interval, I was then able to estimate the hourly flow rate *for an hourly flow interval* that leads to a specific breakdown probability. The ratio of the estimated 60-minute interval breakdown flow rate to the 15-minute interval breakdown flow rate is a direct measurement of the factor required to convert peak hour (i.e., 15-minute interval) flow capacity to average hour (i.e., 60-minute interval) flow capacity.

As might be expected, several issues are important in interpreting the resulting data. First, the estimated capacities are only valid in the context of a specific breakdown probability. Therefore, it is necessary to select a specific breakdown probability to estimate the required capacity adjustment factor. I recommend the use of factors based on a breakdown probability of 50 percent, as, at that probability, the chances of any particular roadway segment being in a state of breakdown at the associated 60-minute flow rate are exactly 50/50. In effect, it would be expected that half of all roadway segments would be in a state of breakdown if carrying flows at the defined rate. Moreover, that half that would be in a state of breakdown would have broken down over a continuous range of flow rates, so that assuming an hourly capacity equal to the 50 percent breakdown capacity will actually overstate the capacity for the broken down roadway segments. However, since half of the roadways would be expected to be in a non-breakdown state, the 50 percent breakdown capacity understates (over a similarly continuous range) the capacity of these roadway segments. The net effect will be one of offsetting errors, wherein the average breakdown capacity of all roadway segments is approximated by the 50 percent probability breakdown factor. There could, of course, be nonlinearities in the continuum of breakdown flows and this is more likely to advocate using a smaller mean breakdown flow (i.e., the continuum extends further on the lower end of the breakdown flow scale). However, given the current state of the data supporting the analysis, it seems most appropriate to focus on the 50 percent probability flow.

Additionally, there are complications resulting from the fact that there are only a maximum of three explicit data points that can be used to extend the breakdown probability intervals beyond 15 minutes. As indicated above, data only exist for one-minute, five-minute, and 15-minute flow intervals, so that all estimates for longer intervals are extrapolated. Moreover, the one-minute interval data is of somewhat limited utility since the probability of breakdown increases from near-zero to virtually 100 percent over a very small flow range. In fact, for Site A, no significant breakdown flows were encountered over the one-minute interval data. This results in considerable uncertainty for the one-minute interval data.

Given the uncertainty associated with the one-minute interval data, extrapolations of the probability data were conducted using two separate methods. In addition, a third method was employed that relied on a fourth implicit bounding data point to better define the shape of the exponential capacity interval function.

In the first extrapolation method, a monomial exponential regression of the one-minute, five-minute, and 15-minute flow data was conducted. In the second method, a linear regression of only the five-minute and 15-minute flow data was conducted. Generally, one would expect a nonlinear relationship between breakdown and increasing flow interval given the expected ability of each roadway segment to indefinitely support at least some minimum flow level. In fact, if the stated local daily and hourly capacity values are accurate, we can estimate this minimum level of flow at approximately 0.44 times the stated hourly capacity (in accordance with the average hourly capacity divided by one-twenty fourth of the average daily capacity). However, determination of this expected steady-state daily capacity requires the extrapolation of 0.25 interval hours of data to include the remaining 23.75 interval hours of a day. In contrast, to obtain the expected 60-minute (i.e., one hour interval) capacity, we need extrapolate "only" to include an additional 0.75 interval hours of flow. Given that we are estimating only 0.75 hours of a 24 hour nonlinear relationship, it is reasonable to expect that an abbreviated linear function might approximate a limited portion of the larger nonlinear curve. This is analogous to approximating a circle as a series of short line segments placed between equally spaced points along the circumference of the circle, with the approximation becoming more precise as the length of the line segments decreases. Therefore, even though we are approximating a local region of a nonlinear function using a linear surrogate, the surrogate should be accurate if it is limited to small localized predictions.

Regardless of whether the three data point nonlinear approach or the two data point linear approach is considered, either results in perfect correlation since there is one curve that can be constructed through any three data points and one line that can be constructed through any two data points. Thus, uncertainty in the constructed regressions is not associated with goodness of fit, but rather limitations in data. Data for additional flow intervals would allow for a more definitive determination of the true slope of the breakdown flow relationship.

To approximate the impact that additional flow interval data might have on regression results, I constructed a third regression using the three research data points for each study site in combination with a fourth data point constructed for a 1440-minute (i.e., 24-hour) flow interval at each study site. The 1440-minute data points are based on the 15-minute interval breakdown flows reported for each site in the research study and the theoretical ratio of daily capacity to hourly capacity for freeways. Multiplying this ratio, which is equal to 10/24, by the observed 15-minute flow capacity provides a direct estimate of the daily capacity flow rate. This allows for the constrained construction of a monomial exponential regression through four data points that span the entire 24 hour flow period, providing a more robust estimate of the shape of the exponential curve and allowing any flow interval capacity to be estimated without extrapolation. Of course, the accuracy of the daily capacity estimate is itself an issue of concern, but this is balanced by the accuracy of extrapolation in the other two regression approaches.

Figures 4 shows the constrained exponential curve constructed for Site B. That for Site A is similar. Figure 5 shows a portion of the same curve for flow intervals up to two hours, providing a better view of the curve at the critical 60-minute flow interval. Additionally, Figure 5 shows the extrapolated curves for the three data point exponential and two data point linear regressions. Obviously, these approaches bound the constrained exponential curve.

I believe, for our purposes, that the constrained exponential curve is the most robust approximation currently possible given available data. The three data point extrapolated curve is simply based on data that are too limited. For local estimations (i.e., estimations not far removed from the "raw" data upon which the extrapolations are based), the linear regression should be accurate, but the constrained exponential curves for both Sites A and B imply that the area of reasonable extrapolation is limited to flows that are less than the desired 60-minute interval flows. For these reasons, I recommend the use of the 60-minute breakdown flow rates implied by the constrained exponential regression. Table 2 summarizes the estimated 60-minute interval breakdown flows for all three methods, but all subsequent data in this memorandum are based on the application of the 0.84 constrained exponential 60-minute flow interval capacity adjustment factor.

Finally, it is important to recognize that the relations derived through this approach are based entirely on freeway analyses. To the extent that relations for non-freeway roadway segments may be subject to influences that alter the fundamental relationship between stated hourly capacity (i.e., peak hourly capacity) and 60-minute interval hourly capacity (i.e., average hourly capacity), those influences will not be properly considered in the estimated relations. This is unavoidable given the current availability of data, but should be considered in subsequent research. To the extent that all provided estimates are expressed as the non-dimensional ratio of

Figure 4. Breakdown Flow by Flow Duration for 50% Breakdown Probability

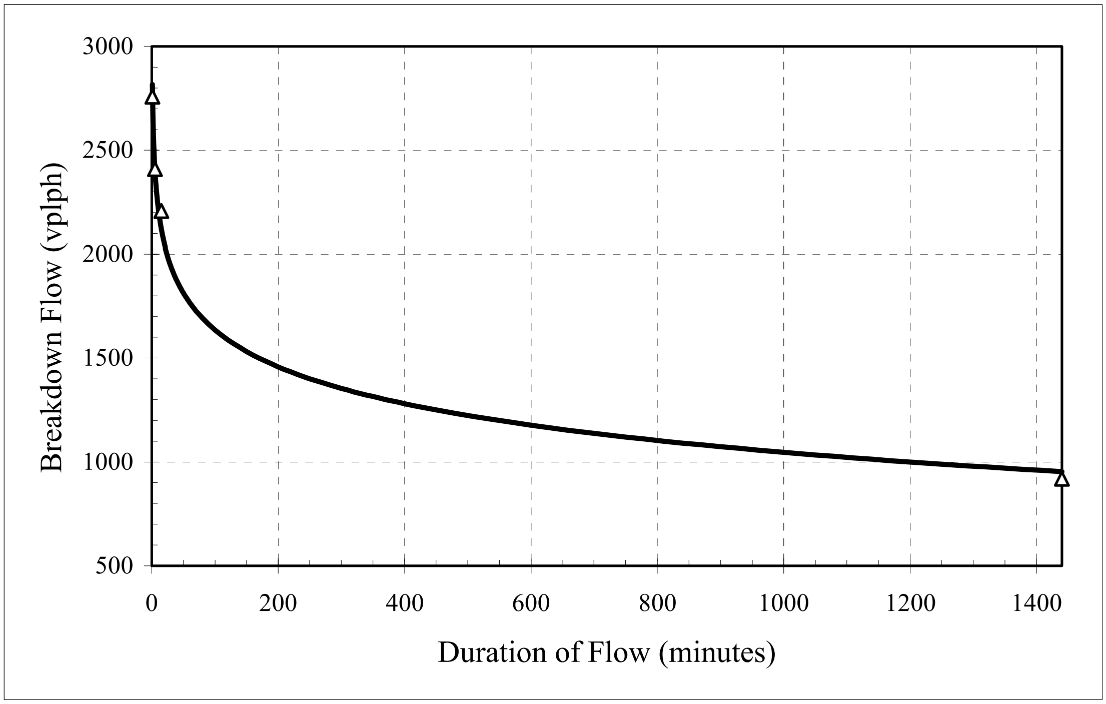


Figure 5. Breakdown Flow by Flow Duration for 50% Breakdown Probability

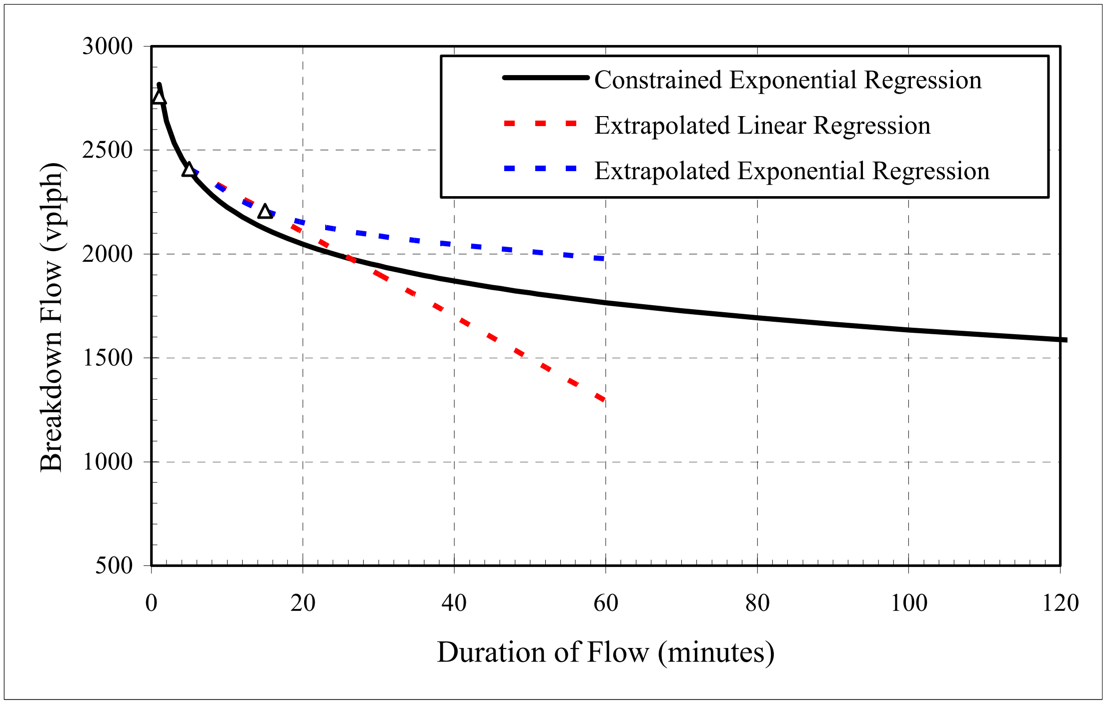


Table 2. Peak Capacity Adjustment Factors for 60-Minute Interval Flows at a Breakdown Probability of 50 Percent

Study Site	60-Minute Flows (vphpl)			Ratio of Flows to Peak Capacity		
	Exponential Extrapolation	Linear Extrapolation	Constrained Exponential Regression	Exponential Extrapolation	Linear Extrapolation	Constrained Exponential Regression
A	1694	1221	1431	0.93	0.67	0.84
B	1977	1294	1766	0.90	0.59	0.83
Average	1836	1258	1598	0.91	0.63	**0.84**

average to peak capacity (see Table 2), they can be applied to any roadway segment regardless of class. While it is hoped that the impact of unaccounted influences is minor, there is no way to be certain. It seems likely, however, that any such non-freeway influences would increase the differential between average and peak hourly capacity since non-freeway roadway segments are likely to be subject to a greater number of potential flow disturbances that freeway segments. If this is the case, then the estimated relations will continue to result in some over-prediction of travel speed on non-freeway segments. However, to the extent that TDM stated hourly capacities for non-freeway segments correctly subsume the increased disturbance potential into the stated non-freeway capacities, the application of a uniform capacity adjustment factor across all roadways may be entirely appropriate.

In general, the capacity adjustment data presented in Table 2 are consistent with expectations since they result in average (i.e., 50 percent breakdown probability) adjustment factors that are greater than the 0.44 (average) equivalent hourly adjustment factor implied by stated daily capacities. The estimated capacity adjustment factors would be expected to approach this 0.44 value as flow intervals increase beyond 60-minutes (assuming the stated daily capacities are not themselves arbitrarily defined). Additional, albeit anecdotal, support can be derived by the similarity of the adjustment factors to the rule of thumb approximation that “practical” hourly capacity is equal to about 80 percent of peak capacity.

Table 3 presents the VMT-weighted average travel speeds based on the TDM link data provided for analysis. As stated above, my preferred approach is based on the 0.84 adjustment factor, which equates to the constrained exponential 60-minute flow interval with a 50 percent breakdown probability.

The relatively low VMT-weighted average speeds for interstates, freeways, and expressways (hereafter referred to as “limited access roadways”), as shown in Table 3, are a direct result of the relatively low free-flow speeds for these same roadways, as shown in Table 1 above. Whereas I might expect free-flow speeds on limited access roadways to be in the 65-70 mph range, the TDM data indicate free-flow speeds of 50 mph on expressways and 58 mph on interstates and freeways. Correcting free-flow speeds to better reflect actual limited access

Table 3. VMT-Weighted Average Speeds for Various Adjusted Hourly Capacities, No Adjustment to TDM Model Free-Flow Speeds

Roadway Class	WRAP/NEI Average Speeds (mph)	BPR Average Speeds (mph) if Hourly Capacity Adjustment Factors are as follows:		Akcelik Average Speeds (mph) if Hourly Capacity Adjustment Factors are as follows	
		Adj. Factor=1	Adj. Factor=0.84	Adj. Factor=1	Adj. Factor=0.84
Centroid Connector	20	25	25	25	25
Collector	20	31	28	26	20
Expressway/Beltway	45	44	33	42	30
External Links		22	22	25	25
Freeway	45	54	47	57	46
Interstate	45	52	42	53	38
Local Road	20	25	25	24	24
Major Arterial	20	35	27	36	26
Minor Arterial	20	34	28	35	27
Ramp		29	26	31	28
Ssytem to System Ramp		47	39	51	42
System to System Ramp		50	47	52	50
Overall System		36	31	36	28
Relationship to Average Speeds Used for WRAP Emissions Inventory Preparation					
Centroid Connector		1.25	1.25	1.25	1.25
Collector		1.55	1.40	1.30	1.00
Expressway/Beltway		0.98	0.73	0.93	0.67
External Links					
Freeway		1.20	1.04	1.27	1.02
Interstate		1.16	0.93	1.18	0.84
Local Road		1.25	1.25	1.20	1.20
Major Arterial		1.75	1.35	1.80	1.30
Minor Arterial		1.70	1.40	1.75	1.35
Ramp					
Ssytem to System Ramp					
System to System Ramp					
Overall System					
Relationship to BPR Average Speeds at Unadjusted Hourly Capacities					
Centroid Connector			1.00	1.00	1.00
Collector			0.90	0.84	0.65
Expressway/Beltway			0.75	0.95	0.68
External Links			1.00	1.14	1.14
Freeway			0.87	1.06	0.85
Interstate			0.81	1.02	0.73
Local Road			1.00	0.96	0.96
Major Arterial			0.77	1.03	0.74
Minor Arterial			0.82	1.03	0.79
Ramp			0.90	1.07	0.97
Ssytem to System Ramp			0.83	1.09	0.89
System to System Ramp			0.94	1.04	1.00
Overall System			0.86	1.00	0.78

roadway speeds, if that is indeed appropriate, would likely result in speeds on these segments that are more in-line with anecdotal expectations.

Although I would recommend a more robust investigation in the future, I have re-estimated the potential free-flow speeds on the limited access roadways included in the TDM network using annual speed monitoring data published annually by the Nevada Department of Transportation (NDOT).[5] These data include annual average and 85th percentile speed values for two monitoring sites in the Las Vegas area. Site 002003 is located on I-15 between Sahara Avenue and Spring Mountain Road, while site 004005 is located on I-515 between Las Vegas Boulevard and Eastern Avenue. I assumed that the average of the 85th percentile speeds was representative of the free-flow speeds at these locations, and calculated the ratio of average free-flow speed to posted speed to develop a free-flow speed adjustment factor that could then be applied to all limited access roadways in the TDM network to re-estimate associated free-flow speeds. Table 4 presents a summary of the NDOT data for the two monitoring sites, as well as the developed free-flow speed ratio.

By applying the free-flow speed ratio to the posted speed data in the TDM link file, I re-estimated the associated free-flow speeds as summarized in Table 5. The only issue encountered in this process was that a number of links (25) designated as "expressway/beltway" did not include a posted speed. The majority of expressway/beltway links (66) indicated a posted speed of 35 (2 links), 40 (7 links), 45 (26 links), or 55 (31 links) mph. Based on the 48 mph average link speed implied by these data, I simply assigned a posted speed of 50 mph to the links without explicit data. Of course, this should be corrected for future work, but I believe it will produce reasonable initial free-flow speed estimates.

Using the revised free-flow speeds for limited access roadways, the VMT-weighted average travel speeds were re-estimated for the TDM link data provided for analysis. Table 6 summarizes the adjusted speed estimates. My preferred approach continues to be based on the 0.84 capacity adjustment factor, which equates to the constrained exponential 60-minute flow interval with a 50 percent breakdown probability.

To investigate the validity of the tabulated speed estimates, I performed a preliminary analysis of the recently collected RTC speed study data.[6] Due to time constraints, I utilized a rather blunt approach to quality control in an effort to ensure that only valid data are included in the statistics that follow, but it is likely that a portion of the rejected data are, in fact, valid and should be included in any future followup analysis. Additionally, RTC, to the best of my knowledge, has yet to conduct their own analysis of the data speed study data to develop appropriate local speed algorithms. Any such future analysis should certainly be considered in evaluating the validity of (and potentially refining) the speed estimates reported in this memorandum.

The context of the RTC speed study data should be understood. Basically, these data represent the average of repeated vehicle trips over a wide range of travel routes. All trips were conducted

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[5] Specifically, I obtained speed data from the "Annual Speed Monitoring Reports" published by in 1999, 2000, 2001, 2002, 2003, and 2004 by NDOT.

[6] See, "*Project Summation Report, RTC Travel Speed Study*," prepared by PBS&J for the Regional Transportation Commission of Southern Nevada, March 2006 (and associated data, as provided by the RTC).

Table 4. NDOT Speed Data for Limited Access Roadways

Data Year	Monitor 002003			Monitor 004005		
	Average Speed (mph)	85th Pctile Speed (mph)	Posted Speed (mph)	Average Speed (mph)	85th Pctile Speed (mph)	Posted Speed (mph)
2004	59.6	71.6	65.0	62.9	69.9	65.0
2003	52.8	70.0	65.0	63.2	70.0	65.0
2002	No Data	No Data	65.0	No Data	No Data	65.0
2001	No Data	No Data	65.0	No Data	No Data	65.0
2000	65.6	74.5	65.0	No Data	No Data	65.0
1999	62.2	71.5	65.0	59.5	70.3	65.0
1998	61.1	68.8	65.0	62.8	71.8	65.0
Average	60.3	71.3	65.0	62.1	70.5	65.0
Ratio of Monitor-Specific Averages to Posted Speeds						
	0.9271	1.0966		0.9554	1.0846	

Aggregate Monitor Statistics

	Average Speed (mph)	85th Pctile Speed (mph)	Posted Speed (mph)
Average Speeds	61.1	70.9	65.0
Ratio of Averages to Posted Speed	0.9397	**1.0913**	

Table 5. VMT-Weighted Free-Flow Speeds

Roadway Type	TDM Free-Flow Speed (mph)	Revised Free-Flow Speed (mph)	BPR Speed Adjustment (mph)
Collector	38	38	0
Expressway/Beltway	50	49	-1
Freeway	58	63	+5
Interstate	58	71	+13
Major Arterial	40	40	0
Minor Arterial	40	40	0
Overall System	41	42	+1

Table 6. VMT-Weighted Average Speeds for Various Adjusted Hourly Capacities, Including Adjusted Free-Flow Speeds for Limited Access Roadways

Roadway Class	WRAP/NEI Average Speeds (mph)	BPR Average Speeds (mph) if Hourly Capacity Adjustment Factors are as follows:		Akcelik Average Speeds (mph) if Hourly Capacity Adjustment Factors are as follows	
		Adj. Factor=1	Adj. Factor=0.84	Adj. Factor=1	Adj. Factor=0.84
Centroid Connector	20	25	25	25	25
Collector	20	31	28	26	20
Expressway/Beltway	45	43	32	41	29
External Links		22	22	25	25
Freeway	45	59	51	62	49
Interstate	45	64	52	63	43
Local Road	20	25	25	24	24
Major Arterial	20	35	27	36	26
Minor Arterial	20	34	28	35	27
Ramp		29	26	31	28
Ssytem to System Ramp		47	39	51	42
System to System Ramp		50	47	52	50
Overall System		37	32	37	29
Relationship to Average Speeds Used for WRAP Emissions Inventory Preparation					
Centroid Connector		1.25	1.25	1.25	1.25
Collector		1.55	1.40	1.30	1.00
Expressway/Beltway		0.96	0.71	0.91	0.64
External Links					
Freeway		1.31	1.13	1.38	1.09
Interstate		1.42	1.16	1.40	0.96
Local Road		1.25	1.25	1.20	1.20
Major Arterial		1.75	1.35	1.80	1.30
Minor Arterial		1.70	1.40	1.75	1.35
Ramp					
Ssytem to System Ramp					
System to System Ramp					
Overall System					
Relationship to BPR Average Speeds at Unadjusted Hourly Capacities					
Centroid Connector			1.00	1.00	1.00
Collector			0.90	0.84	0.65
Expressway/Beltway			0.74	0.95	0.67
External Links			1.00	1.14	1.14
Freeway			0.86	1.05	0.83
Interstate			0.81	0.98	0.67
Local Road			1.00	0.96	0.96
Major Arterial			0.77	1.03	0.74
Minor Arterial			0.82	1.03	0.79
Ramp			0.90	1.07	0.97
Ssytem to System Ramp			0.83	1.09	0.89
System to System Ramp			0.94	1.04	1.00
Overall System			0.86	1.00	0.78

on a Tuesday, Wednesday, or Thursday during one of three time periods. The period characterized in the RTC study as "off-peak" generally involves trips between 3:40 a.m. and 6:20 a.m. The period characterized as "morning peak" generally involves trips between 6:40 a.m. and 9:30 a.m., and the period characterized as "afternoon peak" generally involves trips between 3:40 p.m. and 6:45 p.m. Thus, these data are representative of travel between restricted hours of the day and cannot be directly compared to the daily average TDM link data (and associated estimates) summarized in the preceding tables of this memorandum. However, the speed study data should be comparable to estimated TDM-based network speeds for the following time periods:

- The off-peak speed study data should be comparable to 2400-0700 TDM data,
- The morning peak speed study data should be comparable to 0700-0900 TDM data, and
- The afternoon peak speed study data should be comparable to 1600-1800 TDM data.

Consistency (or non-consistency) of estimated and observed speeds within these specific periods can be taken to be indicative of general agreement (or non-agreement) between speed estimates and actual speeds for other daily time periods.

Of course, the speed study data were collected over a relatively small number of runs along each travel route, so it is difficult to access the absolute degree to which the data are representative of actual long-term average conditions on any specific road segment. However, in the absence of design flaws, the speed study data, when taken together, should provide a robust statistical representation of average conditions across any properly aggregated set of roadways. For example, while the travel speed on a specific minor arterial may deviate from the (unknown) long term average speed on that arterial, discrete errors in average travel speeds across all minor arterials should cancel out in statistics developed for the entire group.

To analyze the RTC speed study data, I initially cross-referenced the route segment identification numbers of the speed study data with the link identification numbers of the TDM network data. If the street names indicated in the respective files for a pair of matching identification numbers were identical, I considered the speed study data to be potentially useful. All speed study data with segment identification numbers that were not found in the TDM data, and all speed study data that matched a link identification number in the TDM network data but indicated an inconsistent street name were rejected as invalid. Of the 23,149 data records for individual speed study road segments, 18,572 (80%) passed this initial quality control step.

I next analyzed the remaining 18,572 speed study records to ensure that only one record for each unique combination of segment identification number, flow direction, and time period was represented. In cases where multiple records were included, they were collapsed into a single aggregate record by averaging the inverse of the reported travel speeds. I also rejected from further analysis any resulting records that indicated a directionality other than flow directions "A" or "B" (the only directions included in the TDM network data), and any segment/direction data that did not include speed observations for all three time periods. In this way, the retained speed data consisted of only segments with a complete set (i.e., data for all three time periods) of observed speed data, ensuring that developed statistics are comparable both across analysis classification (e.g., roadway group) and across time within a classification. The resulting dataset consisted of a set of 1,939 records (representing 5,817 individual time period records) for flows in direction A and a set of 1,920 records (representing 5,760 individual time period records) for flows in direction B. Thus, a total of 11,577 unique speed study records are reflected in the statistics that follow.

Table 7 summarizes the speed study observations, as well as presents comparative statistics for the corresponding time periods using the TDM-based speed estimation approach recommended above (i.e., BPR and Akcelik speed-flow adjustments based on the application of a stated hourly capacity adjustment factor of 0.84). Data for only those roadway classifications included in the RTC speed study are presented, and while data for the freeway classification is included, it should be recognized that only a very small portion of VMT on these roadways is represented (two percent for the off-peak and morning peak periods, and one percent for the afternoon peak period). As a result, the freeway data are considered insignificant and not included in any of the subsequent comparisons. The fraction of local roadway VMT represented in the speed study data is 100 percent for all three time periods, while the fraction of represented VMT on collectors, major arterials, and minor arterials ranges from 40-50 percent across all three time periods. So there are, in effect, significant data to support speed comparison for four roadway classifications.

In considering the stated VMT fractions, it is important to understand that they are not indicative of the actual VMT accumulated in the RTC speed study. Instead, they indicate the fraction of TDM-based VMT that is associated with links for which speed study data are available. In effect, speed study observed speeds are applied to the TDM link data as alternative speed estimates and aggregated in a manner identical to both the BPR and Akcelik speed estimates. The actual VMT accumulated in the RTC speed study is of no importance in this comparison (except to the extent that the mileage was not sufficient to provide truly representative speed data, an exception not evaluated in the constrained analysis that supports this memorandum).

In total, approximately 25 percent of total VMT (2.7 of 10.8 million miles) in the three time periods is covered by the RTC speed study data. This equates to the coverage of about 9 percent of total daily VMT (2.7 of 30.3 million miles).

Figures 6 though 10 present a graphic summary of the comparative speeds. Figure 6 shows the relationship of RTC speed study speeds for each time period and roadway classification. For convenience, I have also included the aggregate daily WRAP/NEI speeds in the figure. Generally, the local speeds are greater than the WRAP/NEI speeds for all three time periods. Moreover, while the local speed observations are generally consistent with declining speeds during peak periods, there are exceptions that are not immediately understandable. Additionally, the degree of observed speed change between the off-peak and peak periods is somewhat less than might be expected as one moves from generally free-flow to congested flow conditions. This may be an artifact of the fact that the speed study off-peak period was defined in such a way as to possibly encounter the early portion of the morning rush. However, without expending significantly more effort in analyzing the RTC speed study data, it is not possible to provide additional insight into the rationale for these apparent anomalies.

Figures 7 through 10 show the relationship between RTC speed study observations and BPR and Akcelik speed estimates. For collectors, the speed estimates are generally significantly higher than observation during the off-peak period, and less significantly higher during the peak periods. In general, the Akcelik estimates are more consistent with observation. Speed estimates

Table 7. Comparison of Observed Speed Study Data to Estimated Speed Data

Roadway Classification	BPR Estimated Speed (mph)	Akcelik Estimated Speed (mph)	Speed Study Speed (mph)	VMT Covered by Speed Study (miles)	Total VMT in RTC Network (miles)	Fraction of VMT Covered	BPR Speed to Study Speed	Akcelik Speed to Study Speed
Off-Peak Period (2400-0700)								
Collector	40	39	26	137,188	318,059	43%	1.54	1.50
Freeway	49	49	53	6,725	291,482	2%	0.92	0.92
Local Road	25	25	35	1,217	1,217	100%	0.71	0.71
Major Arterial	41	41	33	133,703	290,310	46%	1.24	1.24
Minor Arterial	40	40	32	500,816	1,126,841	44%	1.25	1.25
Aggregate	40	40	31	779,649	3,374,253	23%	1.29	1.29
Morning Peak Period (0700-0900)								
Collector	33	29	23	183,206	418,302	44%	1.43	1.26
Freeway	49	49	52	4,694	239,742	2%	0.94	0.94
Local Road	25	24	33	1,189	1,189	100%	0.76	0.73
Major Arterial	37	39	31	130,854	268,101	49%	1.19	1.26
Minor Arterial	32	31	26	505,327	1,142,872	44%	1.23	1.19
Aggregate	33	32	26	825,269	3,211,343	26%	1.27	1.23
Afternoon Peak Period (1600-1800)								
Collector	28	24	22	255,931	580,047	44%	1.27	1.09
Freeway	49	49	59	3,176	287,368	1%	0.83	0.83
Local Road	24	23	38	1,726	1,726	100%	0.63	0.61
Major Arterial	29	28	27	169,653	349,972	48%	1.07	1.04
Minor Arterial	25	23	22	689,064	1,545,590	45%	1.14	1.05
Aggregate	26	24	23	1,119,550	4,208,381	27%	1.13	1.04
Three Period Aggregate (2400-0700, 0700-0900, 1600-1800)								
Aggregate				2,724,468	10,793,977	25%		
Daily Aggregate								
Aggregate				2,724,468	30,250,979	9%		

for local roadways are consistently lower than observation, and this stems entirely from the TDM assigned 25 mph free-flow speed for local roads. Major and minor arterials exhibit similar characteristics, with estimates exceeding observations in the off-peak and morning peak periods, but generally showing good agreement during the afternoon peak period.

The observed speed study data can, of course, be used directly to produce emissions inventory estimates, but an approach to estimating speeds in non-covered time periods will be required. Alternatively, the speed study data can be used to further adjust either the BPR or Akcelik speed estimates, but adjustment factors will almost certainly have to vary by time period given the inconsistent differentials between observation and estimates across the three comparison time periods. Moreover, it will also be necessary to develop adjustment factors for non-covered time periods. In general, my opinion is such either the BPR or Akcelik estimates appear to be

Figure 6. Summary of RTC Speed Study Data

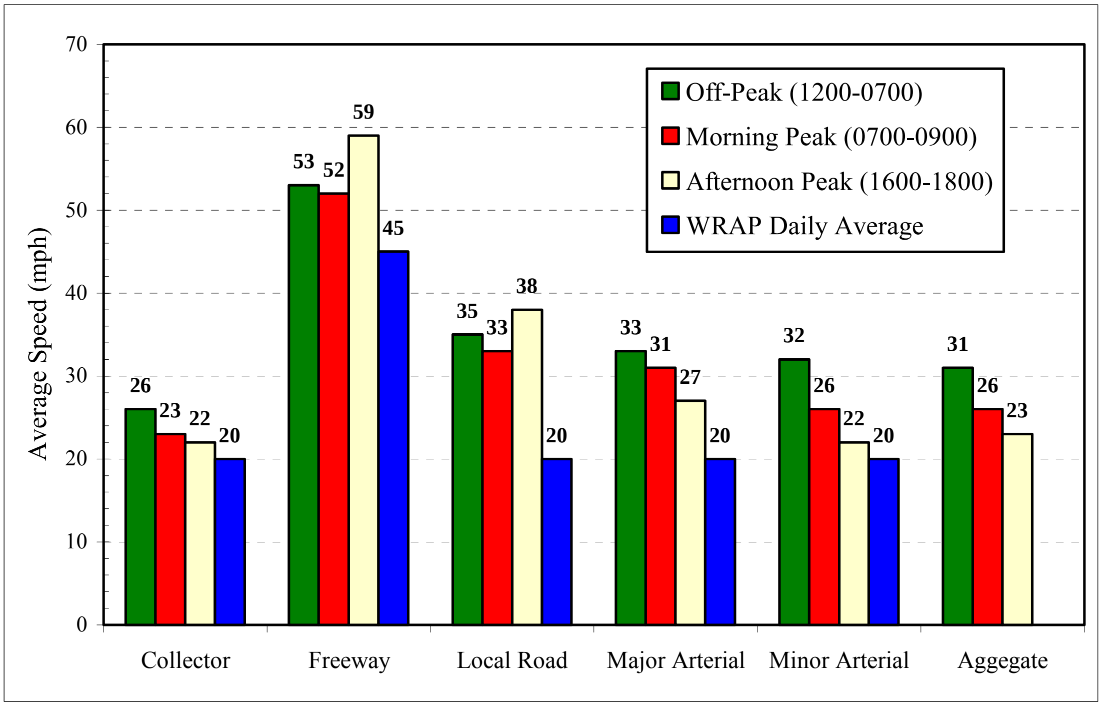


Figure 7. Speed Study Data Versus Estimated Speeds -- Collectors

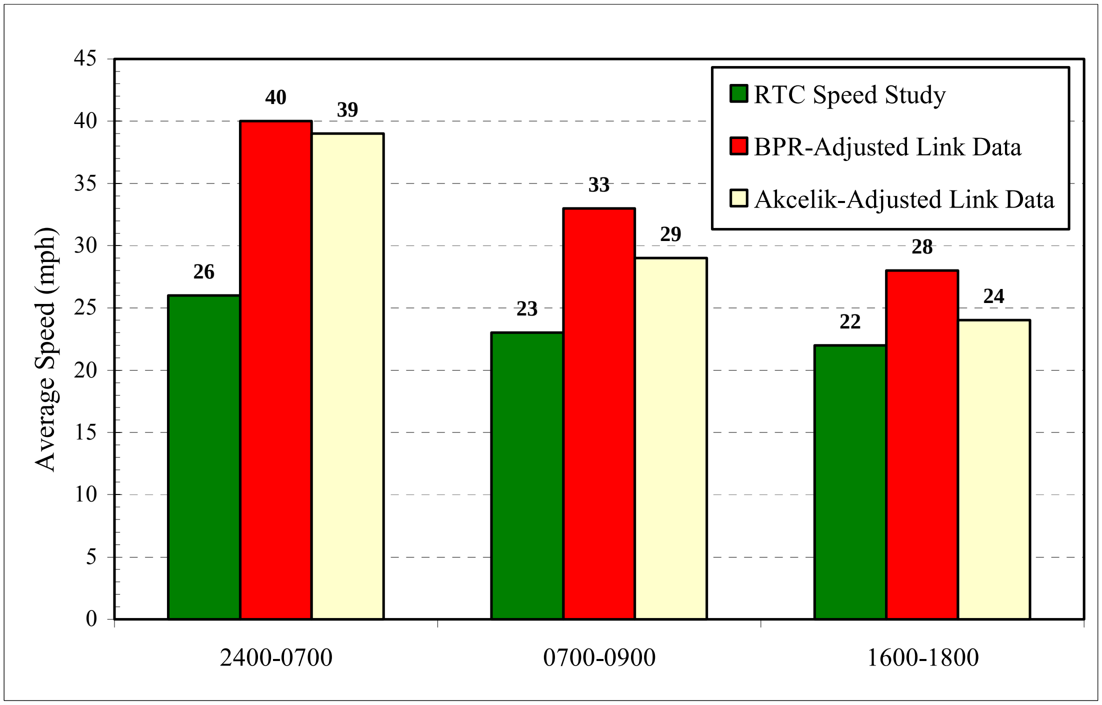


Figure 8. Speed Study Data Versus Estimated Speeds -- Local Roads

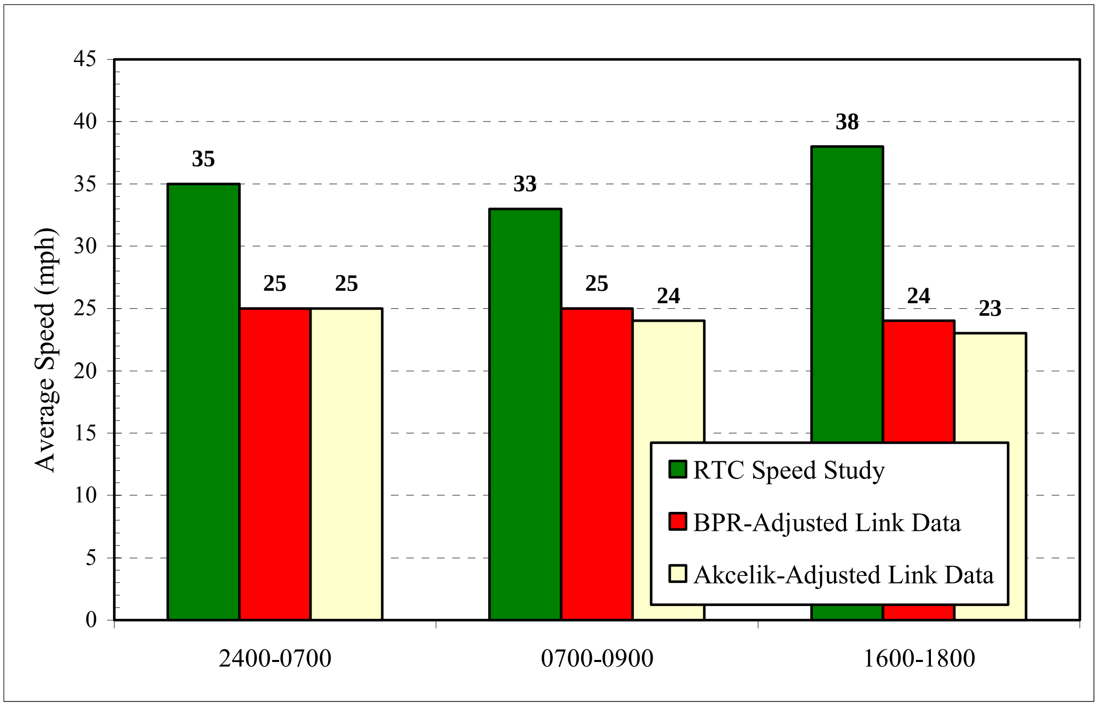


Figure 9. Speed Study Data Versus Estimated Speeds -- Major Arterials

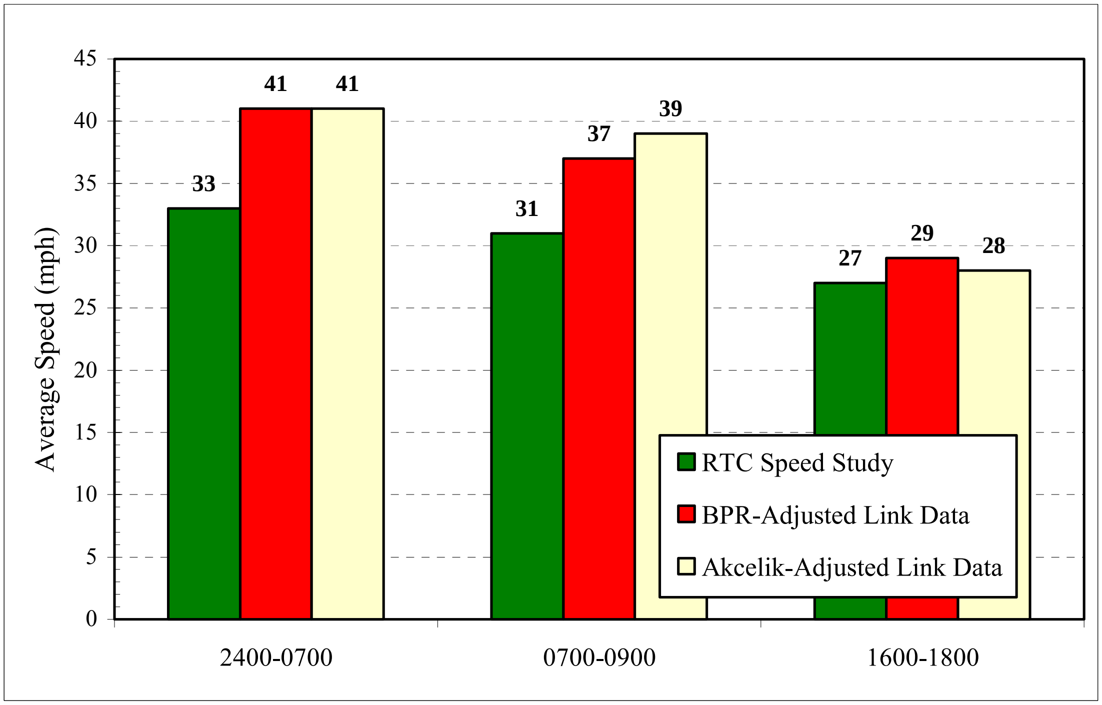
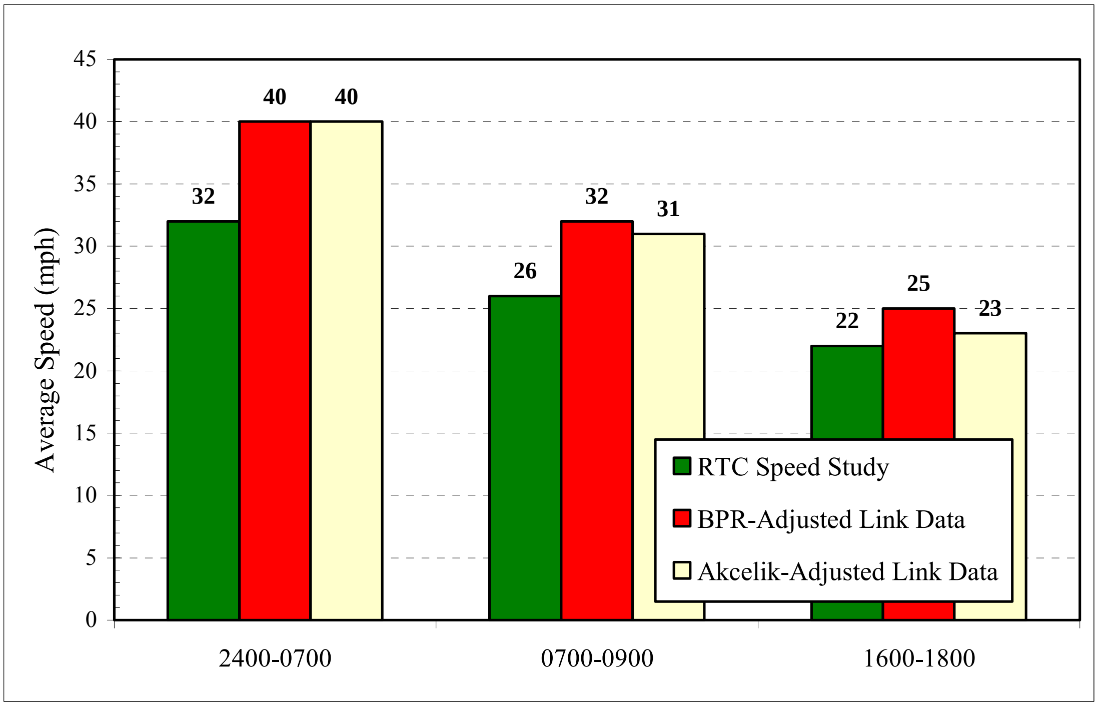


Figure 10. Speed Study Data Versus Estimated Speeds -- Minor Arterials



sufficiently accurate without further adjustment when the differences between estimates and observation are considered in combination with the potential anomalies inherent in the speed observations. Nevertheless, I would be happy to assist in the further development of adjustment factors if that is deemed appropriate.

It is my sincere hope that this provides sufficient information for Clark County to move forward with vehicle emissions inventory development. While there is considerable additional refinement analysis that could, and should, be conducted in the future, I believe the described data are generally indicative of local conditions. As always, please do not hesitate to contact me if you have any questions or require any additional information.