MEMO

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DATE: August 31, 2021

SUBJECT: VDF Parameter Updates in ABM2+

This memo describes changes to volume-delay parameters for freeways in highway assignment and examines the reasonableness of the new parameters. The changes were due to a minor calibration to improve model performance after fixing a bug in the calculations of model speeds. It was discovered that the model was calculating link speeds based on link travel times inclusive of (un)reliability. (Un)reliability is a travel time delay added on top of congested travel time to account for travel time variance within a time period. The travel time with (un)reliability is used in demand models to represent perceived travel time more accurately in making activity choices. However, actual link travel time or speed should be without this delay.

The updated calculations, after removing the (un) reliability component, produced faster link speeds and resulted in 1.5% higher SB375 GHG emissions from the EMFAC 2014 in 2016[1]. Note that the updated 2016 run has a couple other changes as well: fix to a warm-up trip table bug[2], and updated CVM light truck scaling factors[3]. Even though the regional VMT was 1.0% lower than the VMT with the speed bug, the increase in GHG emissions was a result of higher number of freeway links in upper speed bins, which are critical inputs to the EMFAC tool affecting GHG emissions. To resolve this issue promptly, SANDAG performed a minor calibration of the volume-delay function (VDF) applied for freeway facilities.

Table 1 presents the VDF parameters for freeways before, and after the speed bug fix and the calibration. Note that throughout the memo, these “before” and “after” terms are used with the same definitions as here.

[1] Two 2016 scenarios are used: 384 (speeds after removing (un)reliability) and 87 (speeds with reliability)
[2] The bug was related to warm-up trip tables not being imported into assignment trip matrices; therefore, initial skims were free flow.
[3] cvm.scale_light (id=87): (1,1,2.8,1,1), cvm.scale_light (id=384): (1,2,3.5,2,1)

TABLE 1. VDF PARAMETERS FOR FREEWAYS

PARAMETER	BEFORE	AFTER
Alpha	0.24	0.6
Beta	5.5	4.0

The new (“after”) parameters produce model flows that exhibit performance similar or slightly better than the “before” model flows. Due to calibrated parameters, freeway volumes match better with observed traffic counts, regionally as well as in peak periods (AM and PM).

Rest of this memo first describes the VDF formulation used in the AB model and then focuses on examining the reasonableness of the new VDF parameters by discussing VDF estimation, past analysis of observed speed data, parameters used by neighboring sister agencies, and model validations.

1.1 VOLUME-DELAY FUNCTION

The volume-delay function describes the relationship between traffic volume and the operating speed of a road segment. Equation 1 presents the mathematical formulation of the VDF used in the latest version of the model[4]. However, as described earlier, the updated speed calculations include travel time without (un)reliability, our focus is on the VDF formulation shown in Equation 2.

EQUATION 1. VOLUME DELAY FUNCTION WITH (UN)RELIABILITY

Static (un)reliability

LOS (un)reliability

$$T_{f+r} = T_f + T_f * \left[\sum_{t=1,n} \left(\gamma_t * \frac{v}{c} - t + 0.01\right) + R\right]$$

Where:

T_{f+r} = Travel time with (un)reliability

T_f = Travel time without (un)reliability

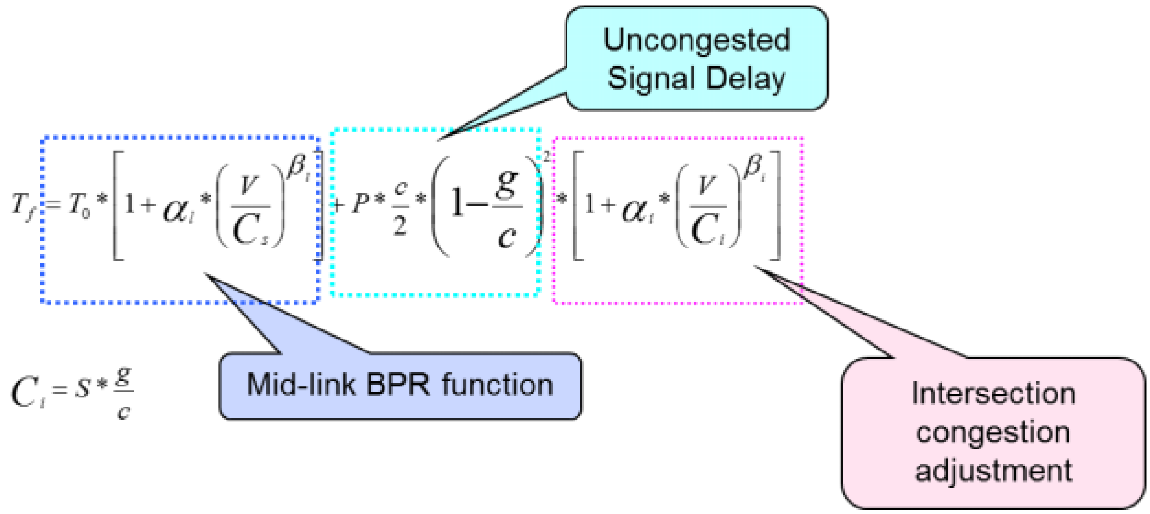
t = v/c thresholds (C, D, E, F-low, F-high)

γ_t = Coefficients for v\c thresholds

R = non-v\c link (un) reliability

[4] It was originally developed for use in the Prima Association of Governments travel model, and subsequently adopted by SANDAG.

EQUATION 2. VOLUME DELAY FUNCTION WITHOUT (UN)RELIABILITY



$$T_f = T_0 * \left[1 + \alpha_l * \left(\frac{V}{C_s}\right)^{\beta_l}\right] + P * \frac{c}{2} * \left(1 - \frac{g}{c}\right)^2 * \left[1 + \alpha_i * \left(\frac{V}{C_i}\right)^{\beta_i}\right]$$

$$C_i = s * \frac{g}{c}$$

The travel time (T_f) formulation consists of three components: mid-link BPR function, uncongested signal delay, and intersection congestion adjustment. The last two components are applied on the facilities that have intersection controls (ramps, arterials, and collectors). As the VDF calibration is applied only to the freeway facilities, we focus our discussion on the first component, mid-link BPR function.

As shown in Equation 2, congested speed (or time) on freeway facilities is dependent on three factors: free-flow speed, the volume-over-capacity (VOC) ratio, and the two parameters (alpha and beta). A higher VOC ratio results in a slower speed indicating congested conditions. However, magnitude of the impact is controlled by the two parameters, alpha and beta. The parameters provide greater flexibility to fit various traffic and local conditions in the assignment process.

Figure 1 plots speed factor (=real speed/ free-flow speed) as a function of VOC ratio and alpha parameter by keeping the beta parameter fixed at 4.0. The speed factor curve shows that increases in the alpha value results in slower speeds. This is because a larger value will enhance the impact of congested conditions (high VOC ratio) in the delay added to the free-flow travel time - a value of 0 means no impact and 1.0 means full impact of the VOC ratio.

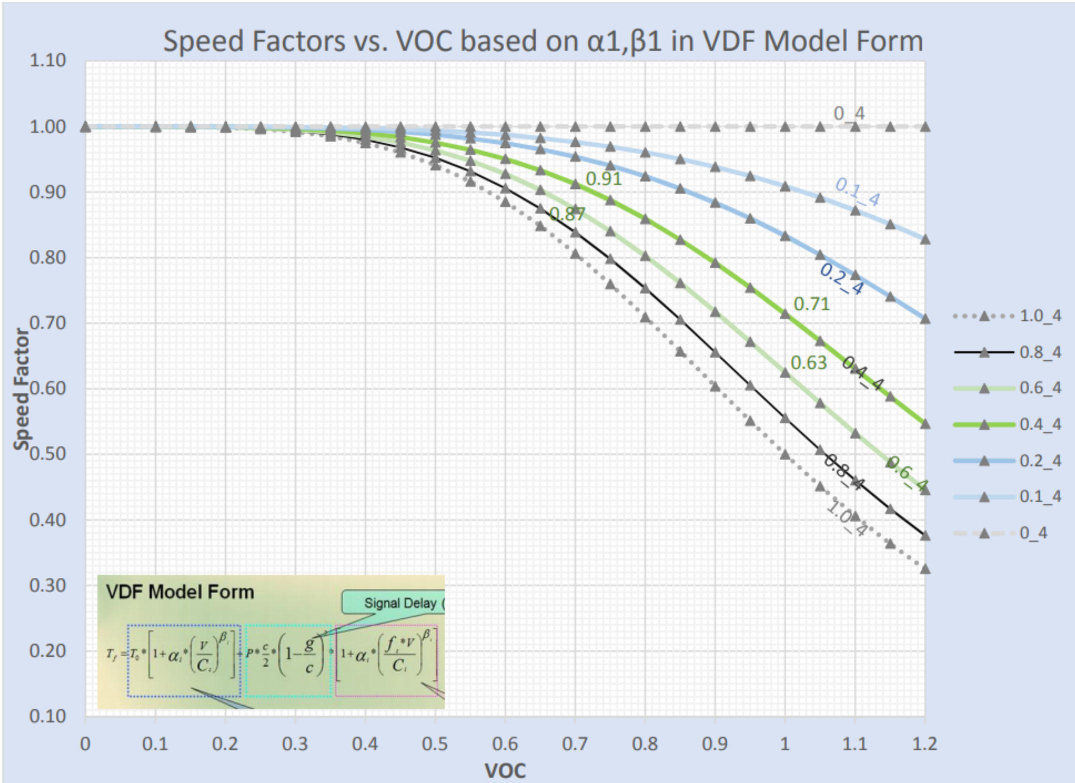


FIGURE 1. SPEED FACTORS VS VOC BY ALPHA AND BETA PARAMETERS

1.2 VDF ESTIMATION

The "before" alpha and beta parameters for freeways were estimated using the 2015 INRIX data[5]. The estimation is likely impacted by two obvious sources of errors in the dataset. First, the vehicle flows in VOC ratio were not observed, instead extracted from the model. Second, the INRIX speeds were by Traffic Message Channel (TMC) segments which are typically consists of multiple model network links, so the developed correspondence for model flows is likely to have errors, especially when a TMC segment includes interchange(s) or intersection control(s). Due to these issues, the estimated parameters for freeways may not completely represent observed travel conditions and may require adjustments (calibration) to better match model flows with observed data.

The above-mentioned issues introduced greater error in estimation of VDF for facilities that included an intersection component (ramps, arterials, and collector) and produced not reasonable parameters. Therefore, for facilities other than freeways, older parameters were retained. Given the competition among different facilities, estimated parameters from the same data source are preferred. However, when not possible (as the case here), adjustments to estimated parameters may be necessary to represent right competition with other facilities.

[5] VDF estimation is described in the ABM2 model update report here: (https://github.com/SANDAG/ABM/wiki/files/abm2_model_update_2018.pdf)

Observed Speed Data

SANDAG's past analyses of observed speeds and VOC ratios provide insight into how the real-world experiences speeds in congested conditions. The analyses based on two datasets are noteworthy here: Performance Measurement System (PeMS) and INRIX. Both datasets represented 2012 conditions and for each, similar to Figure 1, SANDAG staff plotted observed speed factors with VOC ratio and the alpha parameter (0.1-0.8) by keeping the beta parameter fixed at 4.0 - see Figure 2 for PeMS and Figure 3 for INRIX. Due to our focus on freeways, only the analyses of the freeway facilities are included here.

A quick comparison of the two plots shows that the VOC ratios in PeMS analysis are lower than 1.0 but INRIX analysis includes the ratios higher than 1.0 as well. This is because the PeMS data, in addition to observed speeds, included observed flows and therefore the VOC ratios represent real world conditions (vehicle flows are capped by road capacity, hence, VOC ratio is always less than or equal to 1.0). However, the INRIX data included only observed speeds and therefore, the VOC ratios are extracted from the model which allows flows to exceed road capacity, hence, VOC ratios of higher than 1.0.

The INRIX plot, Figure 3, indicates that the "before" alpha value of 0.24 would provide an average fit of the speed factor curve with higher VOC ratios (congested conditions). However, the PeMS analysis, Figure 2, suggests that a higher alpha value may be required to have a better fit of the speed factor curve with observed condition.

With the apparent sources of inaccuracies in "before" parameters estimation dataset (see 1.2 VDF Estimation)and the PeMS data analysis suggesting a higher alpha value, the new alpha value of 0.6 is well within a reasonable range.

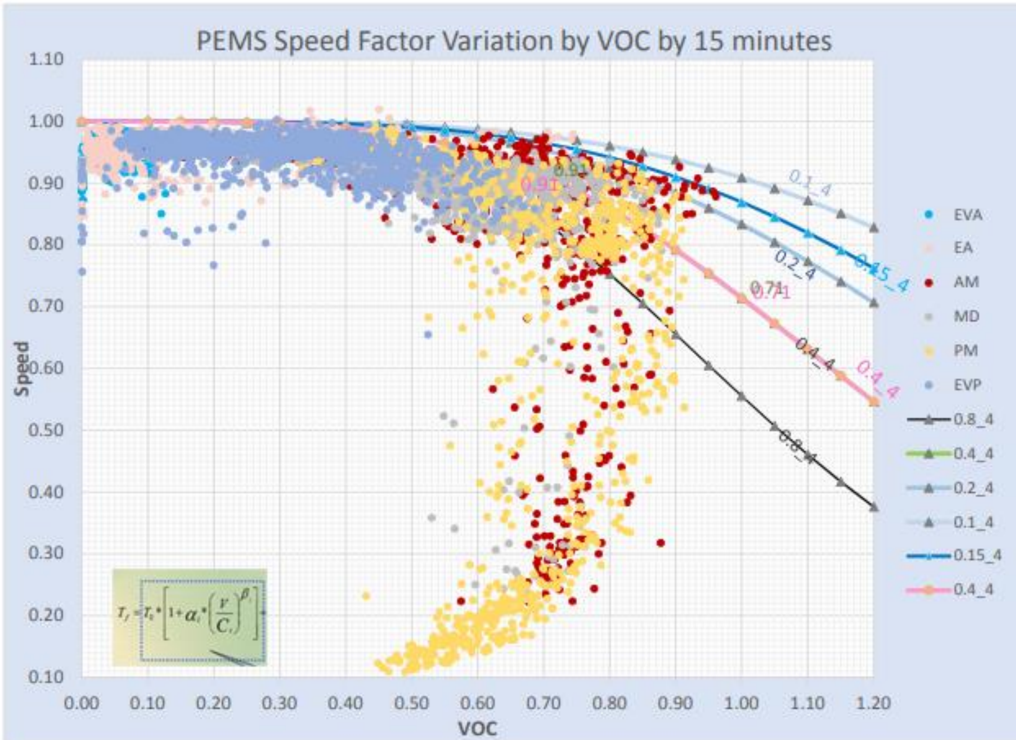


FIGURE 2. PEMS SPEED FACTORS VS PEMS VOC (BY 15MINS)

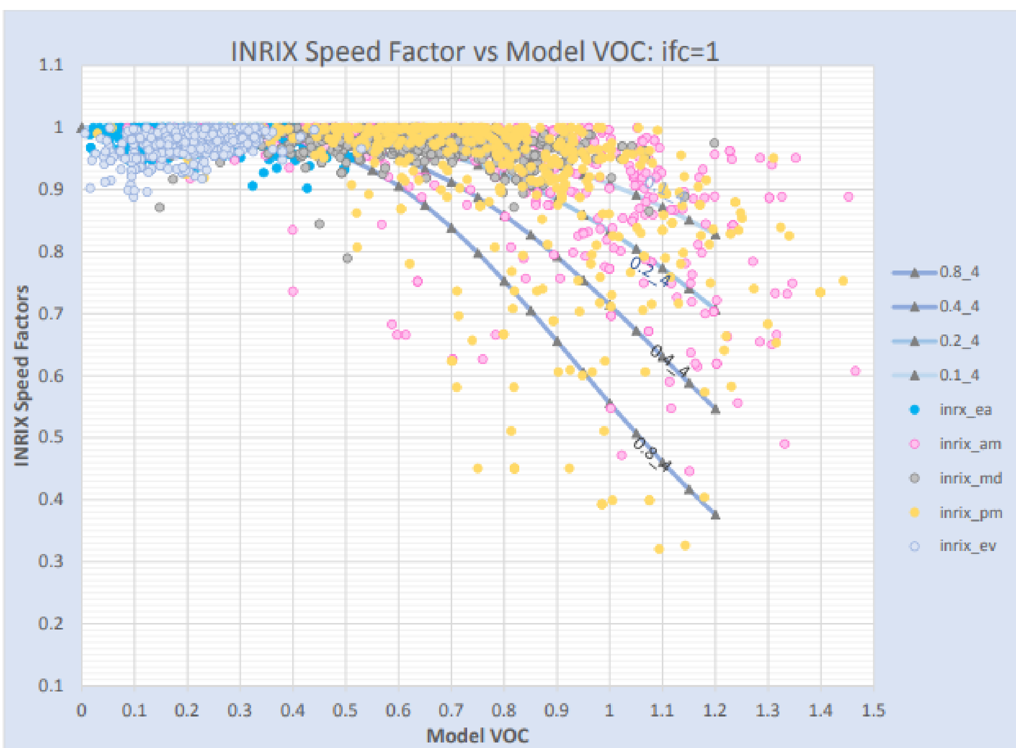


FIGURE 3. INRIX SPEED FACTOR VS MODEL VOC

1.3 COMPARISON WITH OTHER AGENCIES

The new ("after") VDF parameters for freeway facilities compare well with the values used by two neighboring agencies - Maricopa Association of Governments (MAG) and Southern California Association of Government (SCAG). As presented in Table 2, both alpha and beta values are still lower than the values used by the two agencies.

TABLE 2. FREEWAY VDF PARAMETERS – COMPARISON WITH OTHER AGENCIES

PARAMETER	MAG	SCAG	SANDAG (AFTER)
Alpha	0.71 – 0.87	0.8	0.6
Beta	3.47 – 5.00	5.00 – 8.00	4.0

1.4 MODEL VALIDATION

When compared with observed traffic counts, model highway flows (2016) with the calibrated ("after") VDF parameters are similar to the model flows with before parameters[6]. Note that the "after" model results also include a bug fix related to warm-up trip tables[7] and updated CVM light truck scaling factors[8]. Table 3 presents the comparison by facility type. The validations focus on three measures – slope, r-squared, and % RMSE. The "after" (calibrated) VDF parameters slowed down speeds on freeways, resulting in fewer vehicles on the facility type. This is evident in the "after" slope of the fitted line which now underestimates traffic counts by 2% instead of 1% overestimation before. However, the %RMSE on freeways improved a little.

TABLE 3. HIGHWAY VALIDATION BY FACILITY TYPE

FACILITY	BEFORE			AFTER		
	Slope	*R-Squared*	*%RMSE*	*Slope*	*R-Squared*	*%RMSE*
Freeway	1.01	0.93	12.48	0.98	0.93	12.07
Ramp	0.96	0.7	37.55	0.95	0.7	37.32
Arterial	0.93	0.67	36.87	0.93	0.67	36.41
Collector	0.83	0.44	57.07	0.84	0.44	56.73
Regional	**1.01**	**0.96**	**21.57**	**0.97**	**0.96**	**21.08**

[6] The model validation summaries use two 2016 scenarios: 87 ("before") and 422 ("after")
[7] The bug was related to warm-up trip tables not being imported into assignment trip matrices, therefore, initial skims were free-flow.
[8] cvm.scale_light ("after"): (1,2,3.5,2,1), cvm.scale_light ("before"): (1,1,2.8,1,1)

Freeway validations by model time periods show more significant improvements. As presented in Table 4, slope of fitted line and the %RMSE in the peak periods (AM and PM) have improved substantially. Not surprisingly, this resulted in slightly worse statistics in the off-peak periods.

TABLE 4. HIGHWAY VALIDATION BY TIME PERIOD - FREEWAYS

PERIOD	BEFORE			AFTER		
	Slope	*R-Squared*	*%RMSE*	*Slope*	*R-Squared*	*%RMSE*
EA	1.13	0.54	60.98	1.12	0.54	60.33
AM	1.14	0.86	26.59	1.06	0.85	21.61
MD	1.00	0.88	14.69	1.00	0.87	15.33
PM	1.13	0.82	26.38	1.05	0.82	20.50
EV	0.67	0.76	40.67	0.65	0.76	42.07
Daily	**1.01**	**0.93**	**12.48**	**0.98**	**0.93**	**12.07**

On the transit side, as shown in Table 5, impact of the new VDF parameters is close to none as the “before” and the “after” validations look very similar.

TABLE 5. TRANSIT VALIDATION BY SUB-MODE

TRANSIT MODE	BEFORE	AFTER
Commuter Rail	-33	-26
LRT	-4	-1
Express	30	26
Rapid	17	17
Local	10	10
Regional	**6**	**7**

Not surprisingly, due to slower speeds, vehicle delays on freeways increased. In particular, heavy-duty trucks, Table 6, see 36% rise in daily delays (vehicle hours) compared to the “before” model. Increased delays on freeways are not desired, however, acceptable given a better fit of flows with observed traffic counts in the peak periods.

TABLE 6. DAILY HEAVY-DUTY TRUCK DELAY (VEHICLE HOURS) BY FACILITY TYPE

	BEFORE		AFTER		DIFF (%)	
Truck Class	*Freeway*	*Arterial*	*Freeway*	*Arterial*	*Freeway*	*Arterial*
Light	1,120	8,071	1,536	8,512	37%	5%
Medium	501	3,479	666	3,441	33%	-1%
Heavy	1,215	6,063	1,658	5,956	36%	-2%
ALL	**2,836**	**17,613**	**3,859**	**17,909**	**36%**	**2%**

1.5 SUMMARY

This memo examines the reasonableness of the new alpha and beta parameters in the VDF function for freeway facilities resulted due to a bug fix in model speed calculations. For this purpose, four pieces of evidence are presented: VDF estimation, analysis of observed speed, parameters used by two neighboring agencies, and model validation. All four pieces of evidence support the use of new parameters with values well within the expected range and improved model validations.