APPENDIX 11A - DETERMINING FREE-FLOW SPEED

Overview

This appendix describes recommended methods for determining the free-flow speed (FFS) of a freeway or multilane highway mainline. The preferred way to determine FFS is to measure it directly in the field; however, doing so may not be feasible for screening and broad-brush analyses. The methods described in this appendix can be used to estimate the FFS when direct measurement is not possible.

The FFS is the average vehicle speed measured during low-volume periods (i.e., 500 pc/h/lane or less), with good weather and no work activity or incidents. This speed can be determined (in order of preference) from continuously collected sensor data, continuously collected probe data, or from a shorter-term speed study of the facility. Section 3.5.2 discusses speed measurement techniques and data sources. When working with archived speed or travel time data, the analyst should verify that the speeds have not been capped artificially and should avoid using data from time periods where speeds have been estimated (e.g., due to a faulty detector or the absence of probe vehicles). Older speed data that may reflect different conditions than currently exist (e.g., different speed limits) should also be avoided.

If the FFS is directly measured, it can be used as-is and no further adjustments are needed. Otherwise, the FFS is estimated as described in the remainder of this appendix:

1. The FFS is estimated using one of the two methods described below.

2. If the study segment has different speed limits for trucks and autos, and trucks do not operate at crawl speeds, the FFS is adjusted to reflect a weighted average of auto and truck FFSs.

3. If the study segment is a freeway with an upgrade where trucks operate at crawl speeds, the FFS is adjusted using the mixed-flow method described in Chapter 26 of the HCM.

FFS Estimation Methods

The HCM provides two methods for estimating a roadway's free-flow speed (FFS). In order of preference, these are (1) estimation based on roadway characteristics, and (2) estimation based on the posted speed limit.

Estimation Based on Roadway Characteristics

The following equations are used to estimate FFS based on roadway characteristics, taken from Equations 12-2 and 12-3 in the HCM 6th Edition:

$$FFS = BFFS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84}$$ Freeways

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A$$ Multilane Highways

where

FFS = free-flow speed (mph);

$BFFS$ = base free-flow speed (mph);

f_{LW} = adjustment for lane width (mph) = 0.0 for lane widths ≥12 feet, 1.9 for lane widths less than 12 feet but ≥11 feet, and 6.6 for lane widths less than 11 feet but ≥10 feet;

f_{RLC} = adjustment for right-side lateral clearance (mph), from Figure 1;

TRD = total ramp density (ramps/mi) = the average number of on- and off-ramps per mile in a stretch extending 3 miles upstream and downstream from the midpoint of the segment;

f_{TLC} = adjustment for total lateral clearance (mph), from Figure 2;

f_M = adjustment for median type (mph) = 1.6 for undivided highways and 0.0 for divided highways and highways with a two-way left-turn lane; and

f_A = adjustment for access point density (mph) = 0.25 × the average number of access points per mile on the right side of the highway, counting only those accesses that influence traffic flow. The maximum adjustment is 10.0.

Figure 1 Right-Side Lateral Clearance Adjustment Factor f_{RLC} Values (mph)

Right-Side Lateral Clearance (ft)	Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Source: HCM 6th Edition, Exhibit 12-21.
Note: Interpolate for non-integer values of right-side lateral clearance.

Figure 2 Total Lateral Clearance Adjustment Factor f_{TLC} Values (mph)

Four-Lane Highways		Six-Lane Highways	
TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)	TLC (ft)	Reduction in FFS, f_{TLC} (mi/h)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9

Source: HCM 6th Edition, Exhibit 12-22.
Note: Interpolation to the nearest 0.1 is recommended.

The base FFS is taken to be the design speed (if available), or can be estimated as the speed limit plus 5 mph (for speed limits ≥50 mph) or the speed limit plus 7 mph (for speed limits <50 mph). If the segment contains one or more horizontal curves with an advisory speed less than the speed limit, use the lowest advisory speed as the base FFS.

Estimation Based on the Posted Speed Limit

This method estimates the automobile FFS as the posted speed limit plus 5 mph (in level or rolling terrain). However, if the segment contains one or more horizontal curves with an advisory speed less than the speed limit, the lowest advisory speed within the segment plus 5 mph is used as the automobile FFS.

Estimated Free-Flow Speed Adjustment with Differential Auto and Truck Speed Limits

This adjustment is applied when (1) a measured FFS is not available, (2) the posted speed limit is different for automobile and trucks, and (3) the segment is a downgrade, level, or rolling (i.e., no upgrades exist in the segment that cause trucks to operate at crawl speeds). Recent studies of differential rural speed limits in other states (Dixon et al. 2012, Savolainen et al. 2014) found that both average and 85th percentile truck speeds in rural areas in level terrain are roughly 10 mph lower than the corresponding auto speeds:

- Idaho (75-mph auto speed limit, 65-mph truck): average truck speeds 9.1 mph lower than autos, 85th percentile truck speeds 10.5 mph lower than autos.
- Michigan (70-mph auto, 60-mph truck): average truck speeds 11.8 mph lower than autos, 85th percentile truck speeds 13. 1 mph lower than autos.
- Indiana (70-mph auto, 65-mph truck): average truck speeds 9.8 mph lower than autos, 85th percentile truck speeds 10.6 mph lower than autos.

A study conducted by ODOT (2017) prior to increasing the speed limit on rural Interstates in western Oregon from 65 mph auto/55 mph truck to 65 mph auto/60 mph truck found a smaller differential in truck and auto speeds—in general, a difference of 2–3 mph in average speeds and 4–5 mph in 85th percentile speeds.

Based on these observations, the recommended method for estimating the FFS on freeways and multilane highway segments with differential speed limits is the following:

1. Estimate the auto free-flow speed FFS_{auto} from roadway characteristics (preferred) or the posted auto speed limit, as described above.

2. Estimate the truck free-flow speed FFS_{truck} as FFS_{auto} minus the difference in the posted auto and truck speed limits. However, on steep downgrades where truck advisory speeds are posted, the advisory speed should be used as the estimate of the FFS. Where multiple truck advisory speeds are posted, depending on the truck weight, a weighted average truck FFS can be estimated using the percentage of trucks in each weight range.

3. Calculate a weighted average free-flow speed FFS from the proportion of trucks in the traffic stream P_T (e.g., 6% = 0.06) as follows:

$$FFS = (1 - P_T)FFS_{auto} + (P_T)FFS_{truck}$$

Section 11.3.2 illustrates how a weighted average FFS is calculated.

Estimated Free-Flow Speed Adjustment for Freeways in Mountainous Terrain

This adjustment is applied when (1) a measured FFS is not available, (2) the roadway being analyzed is a freeway, and (3) the terrain is mountainous (i.e., an upgrade exists in the segment that causes trucks to operate at crawl speeds). This adjustment does not apply to steep *downgrades*; the adjustment for differential auto and truck speed limits described above is used instead.

This method is described in Section 3 of Chapter 26 of the HCM 6th Edition. First, a mixed-flow (auto and truck) capacity adjustment factor CAF_{mix} is determined from the CAF for auto-only conditions (including driver population and any other adjustments), the percentage of heavy vehicles, and the percent grade. Equations 26-1 through 26-4 are used to estimate CAF_{mix}, which replaces all other CAFs when calculating capacity. CAF_{mix} is also an input for calculating a mixed-flow speed adjustment factor SAF_{mix}.

Equations 26-6 through 26-14 in the HCM 6th Edition are first used to calculate a mixed-flow free-flow speed FFS_{mix}, based on the speed of auto-only traffic in the segment, the speeds of single-unit and tractor-trailer trucks at the end of the upgrade or segment (whichever comes first), and interactions between the auto and truck traffic. Equation 26-15 then calculates SAF_{mix} as FFS_{mix} divided by the segment's automobile FFS.

Section 11.3.2 illustrates how a FFS adjustment is performed for freeways in mountainous terrain.

References

Dixon, Michael, Ahmed Abdel-Rahim, and Sherief Elbassuoni. *Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho.* Report FHWA-ID-13-218. Idaho Transportation Department, Boise, October 2012.

Oregon Department of Transportation. *2017 Oregon Interstate Highway Speed Limit Engineering Investigation.* Executive Summary. Salem, June 1, 2017.

Savolainen, Peter, Timothy Gates, Elizabeth Hacker, Amelia Davis, Sterling Frazier, Brendan Russo, Emira Rista, Martin Parker, Fred Mannering, and William Schneider. *Evaluating the Impacts of Speed Limit Policy Alternatives.* Report RC-1609. Michigan Department of Transportation, Lansing, July 21, 2014.