REVIEW OF THE HCM6 CAPACITY ESTIMATION METHODOLOGY FOR FREEWAYS

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ABSTRACT

Chapter 26 of the HCM6 suggests a procedure for the empirical estimation of freeway capacity, which is based on the direct estimation of breakdown probabilities for bins of traffic volumes. The paper expounds that this methodology is unsuitable to obtain reliable capacity estimations. The theoretical analysis of the deficiencies of the methodology is supported by empirical capacity estimations for twelve freeway sections in California. Based on the empirical results, alternatives for the HCM6 capacity estimation methodology based on statistical models for censored data as well as the distribution of pre-breakdown volumes are proposed and validated.

INTRODUCTION

- The HCM6 quality-of-service assessment procedure for basic freeway segments provides base capacities depending on the free-flow speed, which represent ideal roadway, environmental, traffic, and control conditions. These base capacities can be further calibrated by capacity adjustment factors to account for systematic influencing factors including driver population, share of connected and automated vehicles, weather conditions, incidents, and work zones.
- For applications in which detailed traffic data from field measurements are available, chapter 26 of the HCM6 suggests a procedure for the empirical estimation of freeway capacity. This procedure is based on the direct estimation of breakdown probabilities for bins of traffic volumes. Traffic volumes measured in fluid traffic are allocated to bins of flow rates and distinguished on whether or not they were followed by a traffic breakdown. The ratio of the number of pre-breakdown intervals and the total number of observations is then regarded as the probability of breakdown at the average flow rate in each bin.
- Previous investigations have revealed that the direct approach implemented by the HCM is unsuitable to obtain reliable capacity estimations. In this paper, the theoretical deficiencies of the methodology are expounded and supported by empirical capacity estimations for twelve freeway cross sections in California.
- Based on the empirical results, alternatives for the HCM6 capacity estimation methodology based on statistical models for censored data as well as the distribution of pre-breakdown volumes are discussed.

METHODOLOGY

Capacity Estimation based on Models for Censored Data

- If $v(i) > v_t$ and $v(i+1) \le v_t$ → interval i is uncensored
- If $v(i) > v_t$ and $v(i+1) > v_t$ → interval i is censored
- If $v(i) < v_t$ → interval i is not considered

Once the censored and uncensored intervals are determined, the Product Limit Method (PLM) is applied to estimate a non-parametric capacity distribution function:

$$F_c(q) = 1 - S_c(q) = 1 - \prod_{i:q_i<q} \frac{k_i - b_i}{k_i}, \; i \in \{B\} \quad (1)$$

where

q = flow rate (veh/h)

q_i = flow rate in interval i (veh/h)

k_i = number of intervals with a flow rate of $q \ge q_i$

b_i = number of breakdowns at a flow rate of q_i

$\{B\}$ = set of breakdown intervals

The Maximum Likelihood Estimation (MLE) technique is used to estimate a parametric capacity distribution function:

$$L = \prod_{i=1}^{n} f_c(q_i)^{\delta_i} \cdot [1 - F_c(q_i)]^{1-\delta_i} \quad (2)$$

where

$f_c(q_i)$ = statistical density function of the capacity c

$F_c(q_i)$ = cumulative distribution function of the capacity c

n = number of intervals

δ_i = 1, if interval i contains an uncensored value

δ_i = 0, if interval i contains a censored value

The Weibull distribution is assumed as the capacity distribution function:

$$F_c(q) = 1 - e^{-\left(\frac{q}{\beta}\right)^{\alpha}} \quad (3)$$

where

$F_c(q)$ = cumulative capacity distribution function

q = traffic volume (veh/h)

α = shape parameter

β = scale parameter (veh/h)

Direct Estimation of Breakdown Probabilities

For the direct estimation of breakdown probabilities, the measured traffic data are binned into groups of traffic volumes. For each group i, the breakdown probability $F_c(q_i)$ is calculated as the ratio of the number of pre-breakdown intervals N_i and the total number of observations n_i:

$$F_c(q) = \frac{N_i}{n_i} \quad (4)$$

where

$F_c(q_i)$ = probability of breakdown at volume q_i

q_i = average flow rate in group i (veh/h)

N_i = number of pre-breakdown intervals in group i

n_i = total number of intervals in group i

The method delivers a set of average flow rates and corresponding breakdown probabilities for each group. The Weibull distribution is then fitted to breakdown probabilities and its parameters are estimated by means of nonlinear regression.

EMPIRICAL RESULTS

Twelve urban freeway bottlenecks with different parameters were selected for analysis. All data samples cover at least one year to ensure reliable estimation of the capacity distribution.

Figures 1 shows the capacity distribution functions estimated based on the HCM6 method as well as the PLM and the Maximum-Likelihood method for a freeway section in California.

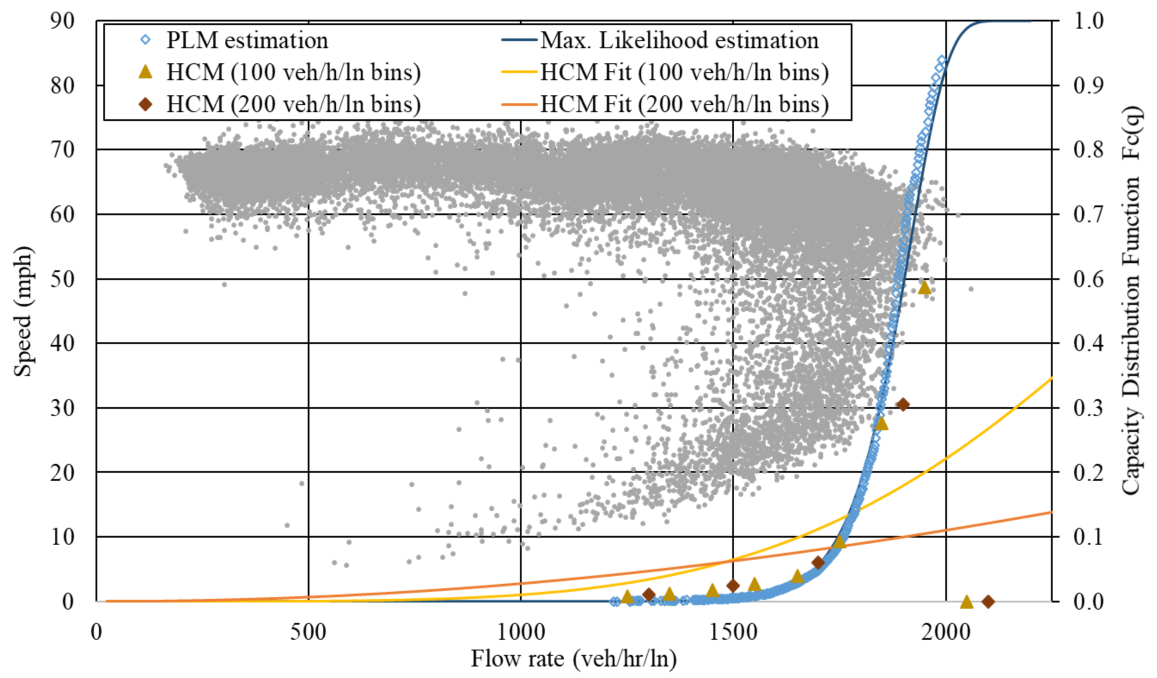

Figure 1. Capacity distribution functions estimated based on the HCM6 procedure as well as the PLM and the Maximum-Likelihood method for the 2-lane freeway cross section no. 808945 near Riverside, CA.

To compare the variability of the Weibull distribution functions estimated by both methods, the shape parameters α of the estimated distribution functions were compared. A higher shape parameter results in a lower variance of the capacity distribution function, which results in a more reliable capacity estimation.

Also, the coefficients of variation (c_v) of the distribution functions, which indicate the size of a standard deviation relative to the mean, were estimated. A lower coefficient of variation suggests a lower level of dispersion around the mean.

The results of the capacity estimation with the HCM6 method, presented in Table 1, show a considerable variation of the distribution parameters for different bottlenecks. The estimated Weibull shape parameters are remarkably small in most cases, which is often due to the low share of breakdown intervals in the bins with the highest flow rates.

Table 1. Shape and scale parameters α and β, coefficients of variation cv, and 5th and 15th percentiles of the Weibull distribution function estimated with the HCM6 capacity estimation procedure based on 5- and 15-minute data.

No.	Bin	5-minute intervals				15-minute intervals			
		Weibull α (-)	Weibull β (veh/h/ln)	c_v (-)	$q_{5\%}$ (veh/h/ln)	Weibull α (-)	Weibull β (veh/h/ln)	c_v (-)	$q_{15\%}$ (veh/h/ln)
1	100	4.3	3,167	0.26	1,586	4.6	2,631	0.25	1,774
	200	2.6	5,043	0.41	1,592	2.1	5,351	0.50	2,221
2	100	3.9	3,789	0.29	1,781	9.1	2,300	0.13	1,882
	200	7.5	2,774	0.16	1,864	7.7	2,403	0.15	1,898
3	100	2.7	5,578	0.40	1,852	7	2,441	0.17	1,886
	200	3.1	4,878	0.35	1,898	7.6	2,402	0.16	1,891
4	100	3.3	4,120	0.33	1,665	8.4	2,116	0.14	1,704
	200	6.3	2,716	0.19	1,692	8.7	2,108	0.14	1,712
5	100	7.6	2,479	0.16	1,680	12.3	2,004	0.10	1,729
	200	11.7	2,278	0.10	1,769	10.1	2,068	0.12	1,727
6	100	4.6	3,090	0.25	1,621	12.5	2,057	0.10	1,780
	200	2.6	5,173	0.41	1,647	10.6	2,109	0.11	1,777
7	100	2.9	5,157	0.37	1,836	10.9	2,400	0.11	2,032
	200	2.9	5,153	0.37	1,866	9	2,484	0.13	2,028
8	100	16.7	2,275	0.07	1,903	15.8	2,088	0.08	1,861
	200	14.7	2,325	0.08	1,901	13.7	2,142	0.09	1,875
9	100	4.9	3,494	0.23	1,914	8.7	2,341	0.14	1,901
	200	3.4	4,754	0.32	1,990	9	2,323	0.13	1,898
10	100	19.9	2,379	0.06	2,049	12.3	2,288	0.10	1,974
	200	10.1	2,617	0.12	1,950	11.1	2,318	0.11	1,967
11	100	13.6	2,247	0.09	1,805	15.1	2,029	0.08	1,799
	200	11.2	2,276	0.11	1,747	10.6	2,116	0.11	1,783
12	100	2.9	4,242	0.37	1,523	3.9	2,887	0.29	1,822
	200	2.1	5,851	0.50	1,447	1.6	8,501	0.64	2,751

The results of the capacity estimation with the Statistical Models for Censored Data and the average pre-breakdown flow rates are given in Table 2. The variances of the estimated distributions are significantly lower than those estimated with the HCM6 capacity estimation procedure and differ much less between the analyzed bottlenecks.

Table 2. Average pre-breakdown flow rates $q_{pre\text{-}bd}$, shape and scale parameters α and β, coefficients of variation c_v, and 5th and 15th percentiles of the Weibull distribution function estimated with the Maximum-Likelihood method in 5- and 15-minute intervals.

No	5-minute intervals					15-minute intervals				
	$q_{pre\text{-}bd}$ (veh/h/ln)	Weibull α (-)	Weibull β (veh/h/ln)	c_v (-)	$q_{5\%}$ (veh/h/ln)	$q_{pre\text{-}bd}$ (veh/h/ln)	Weibull α (-)	Weibull β (veh/h/ln)	c_v (-)	$q_{15\%}$ (veh/h/ln)
1	1,768	20.2	2,095	0.06	1,809	1,715	22.5	1,920	0.06	1,771
2	1,917	22.5	2,191	0.06	1,919	1,866	26.3	2,028	0.05	1,893
3	1,801	17.2	2,195	0.07	1,848	1,741	19.4	1,997	0.06	1,819
4	1,756	19.2	2,055	0.06	1,761	1,739	24.3	1,889	0.05	1,753
5	1,880	26.7	2,065	0.05	1,847	1,819	26.8	1,935	0.05	1,808
6	1,831	21.4	2,116	0.06	1,841	1,785	23.3	1,961	0.05	1,814
7	2,130	20.1	2,506	0.06	2,162	2,075	22.2	2,312	0.06	2,130
8	1,902	21.1	2,204	0.06	1,914	1,851	20.6	2,069	0.06	1,895
9	1,984	23.9	2,238	0.05	1,977	1,955	27.2	2,098	0.05	1,963
10	2,028	23.1	2,292	0.05	2,016	1,975	23.0	2,162	0.05	1,998
11	1,873	22.6	2,101	0.06	1,842	1,813	23.1	1,981	0.05	1,831
12	1,680	28.6	1,856	0.04	1,673	1,646	34.5	1,747	0.04	1,657

CONCLUSIONS

- The procedure for estimating freeway capacity based on field data given in chapter 26 of the HCM6 is based on the direct estimation of breakdown probabilities for bins of traffic volumes. It was shown that this approach is unsuitable to obtain reliable capacity estimates, because demand and capacity observations are not treated separately.
- An empirical capacity analysis carried out for twelve freeway bottlenecks in California confirmed that the theoretical deficiencies of the approach result in implausible capacity estimates in many cases. In particular, the variance of the estimated capacity distribution functions is unrealistically large, which is due to rather low and sometimes even decreasing breakdown probabilities obtained at the highest flow rates.
- In contrast, the capacity estimation methods based on statistical models for censored data provide a well-established framework for the estimation of consistent capacity distribution functions. Applying this concept in the HCM6 procedure would only require a minor revision, because the definition of a traffic breakdown, the selection of suitable detectors, and the traffic data requirements could remain unchanged.
- As a simple alternative to estimating a complete capacity distribution, the use of the average pre-breakdown flow rate measured in 5 minute intervals, which turned out to be a good estimate of the 15th percentile of the capacity distribution, might also be considered. However, further research based on a higher number of data samples would be required to confirm the validity if this approach.