Proposed Framework For Evaluating Spillback in the HCM

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Background and Objectives

INTRODUCTION:

The procedures detailed in the Highway Capacity Manual (HCM 2010) estimate capacity and several operational measures dictating level of service for freeway facilities as well as surface streets.

However, the existing methods do not consider cases in which spillback occurs from one facility type to another.

- The signalized Intersections procedure (HCM 2010 Chapters 18 and 31) predicts the average expected queue length at an approach given any combination of geometric- or traffic-related inputs.
- The Freeway Facilities procedure (HCM 2010 Chapters 10 and 25) estimates the maximum expected queue length at an on-ramp in the case of oversaturated conditions on the freeway mainline.

NO examinations on the effects of these queues as they propagate upstream

OBJECTIVES:

- Propose a series of modifications to existing HCM 2010 procedures provided in Chapter 13 (Freeway Merge and Diverge Segments), Chapter 12 (Freeway Weaving Segments), and Chapter 18 (Signalized Intersections) in order to address spillback conditions.

Literature Review

Spillbacks from Surface Streets to Freeways:

Lighthill et al. 1955
Newell, 1993
Daganzo, 1997
Newell, 1999
Munoz and Daganzo, 2000
Cassidy, Anani and Haigwood, 2002
Munoz and Daganzo, 2002

- **Difficult to anticipate the wide variety of possible driver actions**
- **Trends and observations are considered for future development**

Spillbacks from Freeways to Surface Streets:

HCM 2010 Merge/Diverge Segments
HCM 2010 Interchange Ramp Terminals
Tian, Messer and Balke, 2004

- **Tools available to estimate the lost time**
- **Extensive data are necessary for discharge rates**

Spillback from Surface Streets to Freeways

Spillback occurs as the result of inadequate capacity of the ramp proper/the ramp terminal.

QUEUE LENGTH AND SPILLBACK DETERMINATION:

1. Capacity Check

Is capacity exceeded at ramp proper or downstream signalized ramp terminal?

2. Queue Length Estimation (**Q**)

A) demand > capacity at the ramp proper

$$Q = (v_R - c_{rp}) * f_{HV} * PHF * f_p * t$$

B) demand > capacity at downstream signal ramp terminal
HCM 2010 Chapter 31 – maximum queue length

C) demand > capacity at downstream unsignalized ramp terminal
HCM 2010 Equations 19-68, 20-33, and 21-20

3. Queue Storage Ratios and Spillback Checks

Queue storage ratio ($\mathbf{R_Q}$) $= \frac{L_h Q}{L_a N}$ if $\mathbf{R_Q} > 1$, spillback occurs

4. (if $\mathbf{R_Q} > 1$) Queue Length Upstream ($\mathbf{Q_{SP}}$)

A) $Q_{SP} = (v_R - c) * f_{HV} * PHF * f_p * L_h$

B) and C) $Q_{SP} = (R_Q - 1)L_a$

SPILLBACK EFFECTS ON ISOLATED DIVERGE JUNCTIONS:

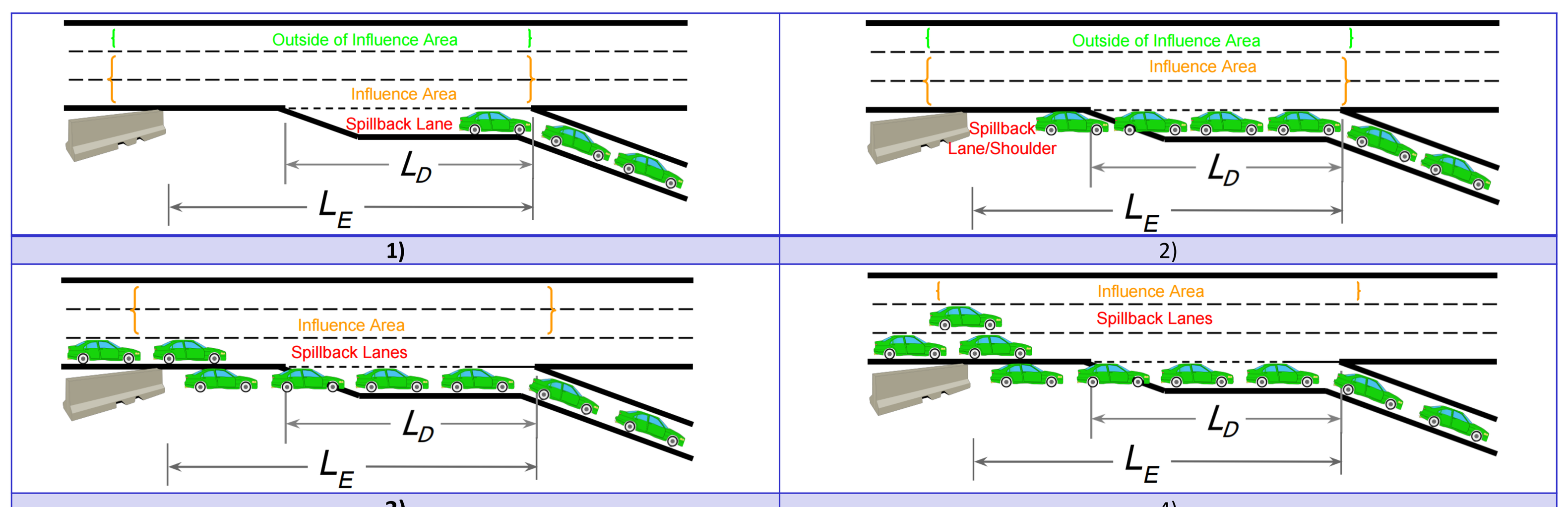


FIGURE 1 Regimes at a diverge segment.

SPILLBACK EFFECTS ON DIVERGE RAMP OF A WEAVE:

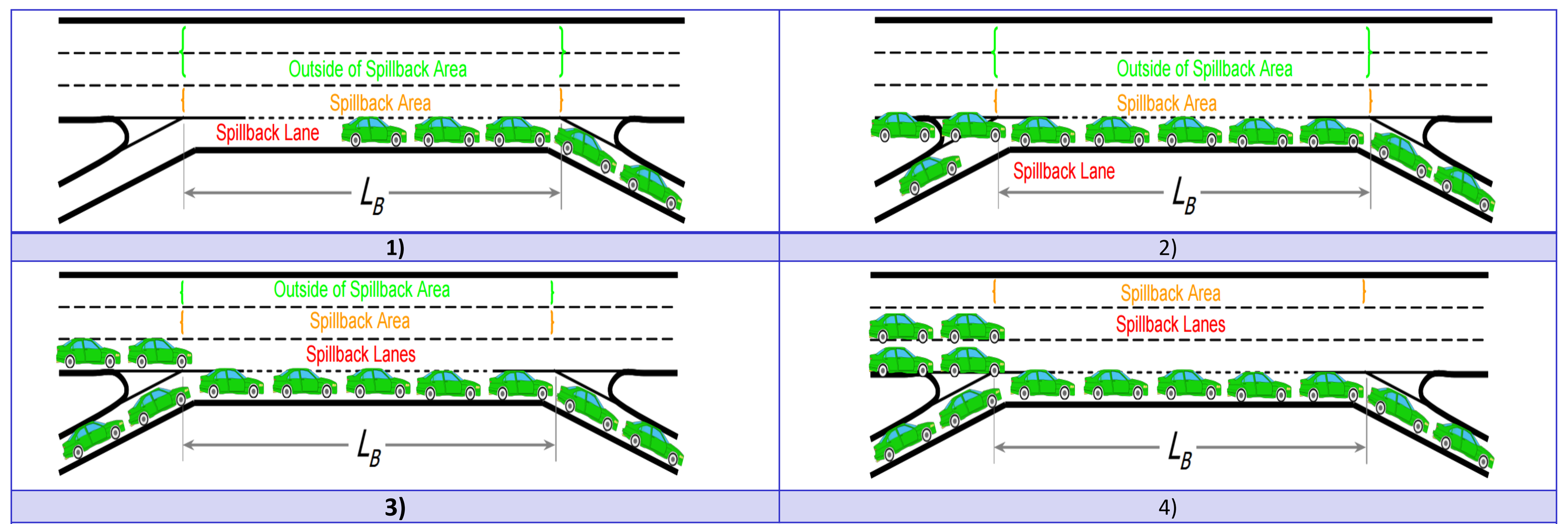
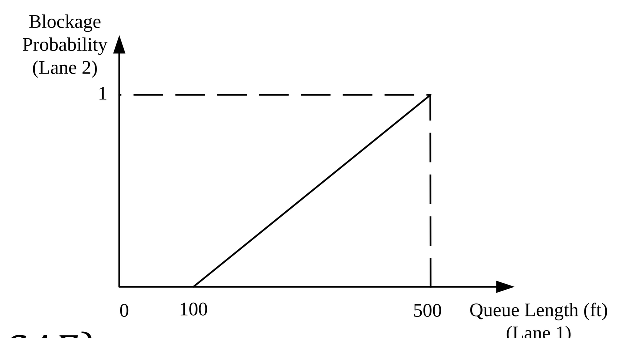


FIGURE 2 Regimes within a weaving segment.

$$S = \frac{v_{SA} + v_{IA} + v_O}{\left(\frac{v_{SA}}{S_{SA}}\right) + \left(\frac{v_{IA}}{S_{IA}}\right) + \left(\frac{v_O}{S_O}\right)}$$

Regime 1&2: $c = \frac{c_d}{N}\{N_O + CAF * N_{IA}\}$

Regime 3&4: $c = \frac{c_d}{N}\{N_O + CAF * N_{IA} + (1 - P_B) * CAF\}$



Spillback from Freeways to Surface Streets

Spillback occurs as the result of arrival rates greater than ramp throughput

METHODOLOGY:

1. HCM Signalized intersections Steps 1 – 6 ⇨ effective green and capacity
2. Departure Rate (**μ**) ⇨ User-defined
3. Arrival Rate for Lane Groups Approaching the On-ramp ($\boldsymbol{\lambda_i}$)

$$\lambda_i = min\left(\frac{s_i N_i}{3600}, \frac{v_i}{3600}\right)$$

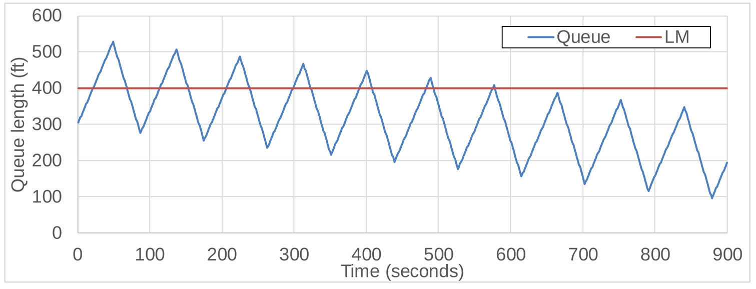
4. Queue Length at the End of Each Phase

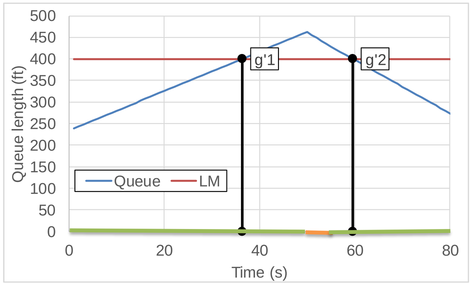
A) One cycle $Q_{SP1} = Q_{SP0} + \Delta Q; \Delta Q = \sum_i^n[(\lambda_i - \mu)g_i + (-\mu Y_i)]L_h$

B) Multiple cycle $Q'_{SP0} = max\begin{cases} Q_{SP0} + {}^{nC\times\Delta Q}/_2; nC = {}^{900}/_C \\ 0 \end{cases}$

5. Capacities and Green Times $c'_i = N * s\frac{g_i'}{C}$

$g'_i = \frac{L_M - Q_{SP_{i-1}}}{(\lambda_i - \mu)L_h}, if\ Q_{SP_{i-1}} < L_M$; or $g'_i = g_i - \frac{L_M - Q_{SP_{i-1}}}{(\lambda_i - \mu)L_h}, if\ Q_{SP_{i-1}} > L_M$





Conclusions

- This paper proposes a series of modifications to the existing HCM 2010 procedures in order to address spillback from one facility to another.
- In the absence of nationwide field data, the methodology uses assumed values to implement the methods.

✓ Spillback from surface streets to freeways: An enhancement of the HCM procedures once data are obtained. A Freeway Facilities analysis is necessary for multiple periods and for the entire distance when the off-ramp queue extends beyond the ramp proper.

✓ Spillback from freeways to surface streets: A method was proposed to account for the reduction of effective greens and capacities as a result of spillback from freeways

Future Development:

- % freeway mainline traffic per lane ~ spillback regime & queue length
- Speed per freeway mainline lane ~ spillback regime & queue length
- Lane-by-lane capacity adjustments ~ spillback regime & queue length
- Discharge rates for on-ramps in congested conditions ~ freeway and ramp geometry & demand

Acknowledgement

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