Appendix D

Technical Report on Methodology of Bikeway Conditions Analysis: Bicycle Level of Service Model, version 2, for Segments

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Methodology of Bikeway Conditions Analysis: Bicycle LOS Model, v.2

Overview of Analysis

A level of service analysis developed by Sprinkle Consulting[1] was used to analyze the existing bicycle infrastructure conditions on streets and roads (segments, not intersections). This method has been used by state Departments of Transportation and MPO's across the nation, and has been incorporated into the 2010 edition of the Highway Capacity Manual (HCM 2010). The HCM 2010 defines some of the variables differently and consequently uses different notation in the formula, but the results are the same as the original Sprinkle Consulting model. See the end of this report for a comparison of how various cross-sectional elements are interpreted in each of the two versions. CORE MPO staff had begun applying the model with the Sprinkle Consulting notation before obtaining the HCM 2010, and therefore the former version is the one explained in this report.

The Bicycle Level of Service (LOS), Version 2 (v.2) model (from Sprinkle Consulting) for road segments results in numeric scores for each segment of the proposed bicycle network, except for segments intentionally excluded. (Segments were excluded from the analysis if they already exist as an off-road path, are known to be installed as off-road paths in the future, or are bicycle facilities proposed on roads that do not yet exist.) The numeric scores were then categorized into grades A through F, with A being an extremely good level of service and F being an extremely poor level of service, as shown in Table 1, below. The Bicycle LOS map in the Non-motorized Transportation Plan displays the results of the bikeway conditions analysis.

Some types of data required by the model were not readily available for all segments under analysis, without location-specific collection efforts, which, given the county-wide coverage of the proposed network, could not be conducted in the time-frame allotted to the development of the Non-motorized Transportation Plan. Thus assumptions were employed. Data sources, assumptions and the basis for assumptions are presented in Table 2 below.

This model focuses on overall segments. Conditions at intersections and interchanges within segments can be substantially different than those of the segment overall. A separate model exists for bicycle level of service at intersections, but analysis of intersections throughout the county requires additional data and is beyond the scope of the Non-motorized Transportation Plan.

The Bicycle Level of Service Model, v.2 for segments

$$\text{Bicycle LOS} = a_1 \ln (Vol_{15}/L_n) + a_2 S_{Pt}(1+10.38HV)^2 + a_3(1/PR_5)^2 + a_4 (W_e)^2 + C$$

Variables

Vol_{15} = Volume of directional traffic in 15 minute time period

Vol_{15} = (ADT x D x Kd) / (4 x PHF), where:

ADT = Average Daily Traffic on the segment or link

D = Directional Factor

Kd = Peak to Daily Factor

PHF = Peak Hour Factor

[1] Sprinkle Consulting, Inc., (2007, April). Bicycle Level of Service: Applied Model. Retrieved from: http://sprinkleconsulting.com/Transportation-Research-Page.aspx?id=77.

L_n = Total number of directional through lanes

SP_t = Effective speed limit

$SP_t = 1.1199 \ln(SP_p - 20) + 0.8103$, where:
SP_p = Posted speed limit (a surrogate for average running speed)

HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
PR_5 = FHWA's five point pavement surface condition rating

W_e = Average effective width of outside through lane:
where:
$W_e = W_v - (10 \text{ ft} \times \% \text{ OSPA})$ and $W_l = 0$
$W_e = W_v + W_l (1 - 2 \times \% \text{ OSPA})$ and $W_l > 0$ & $W_{ps} = 0$
$W_e = W_v + W_l - 2 (10 \times \% \text{ OSPA})$ and $W_l > 0$ & $W_{ps} > 0$ and a bike lane exists

where:
W_t = total width of outside lane (and shoulder) pavement
OSPA = percentage of segment with occupied on-street parking
W_l = width of paving between the outside lane stripe and the edge of pavement
W_{ps} = width of pavement striped for on-street parking
W_v = Effective width as a function of traffic volume

and:
$W_v = W_t$ if ADT > 4,000veh/day
$W_v = W_t (2-0.00025 \times \text{ADT})$ if ADT ≤ 4,000veh/day,
and if the street/road is undivided and unstriped

Coefficients and constants:
$a_1 = 0.507$
$a_2 = 0.199$
$a_3 = 7.066$
$a_4 = -0.005$
$C = 0.760$

Table 1: Bicycle Level of Service Categories

LOS Grade	Bicycle Level of Service Score	Interpretation
A	≤ 1.5	Extremely good LOS
B	> 1.5 and ≤ 2.5	Very good LOS
C	> 2.5 and ≤ 3.5	Moderately good LOS
D	> 3.5 and ≤ 4.5	Moderately poor LOS
E	> 4.5 and ≤ 5.5	Very poor LOS
F	> 5.5	Extremely poor LOS

Table 2: Data Sources and Assumptions

Variable	Data Source	Assumption and Basis
ADT	GDOT STARS; local data ("Traffic Counts"	When data not available, staff estimates were based on known values of nearby segments and assumed break points.

	database in folder: O:\Transportation-7010\Technical Analysis\Traffic Models\Temp Folder of 2035 Model Files); concept reports of current projects; or staff estimates	In Landmark Historic District -- based on a few GDOT count stations on Barnard and one on Bull, assumption for other streets with squares was: • Bull and Abercorn, two-way segments: 3300 • Bull and Abercorn, one-way around squares: 2000 • Barnard and Habersham, two-way segments: 1700 • Barnard and Habersham, one-way around squares: 1000
D		0.6 for two-way roads, 1.00 for one-way roads. GDOT Design Policy Manual, 13.1.1: http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/roads/DesignPolicy/GDOT-DPM-Chap13.pdf
K_d		From FDOT Traffic Monitoring Guide, Chapter IV. Abbreviations and Definitions: Higher AADT generally means lower K_d (less variability in volume). Greater development density generally means lower K_d. Highest to lowest K_d (most variable volumes to least variable) are generally: recreational facilities; rural/suburban facilities; urban facilities. From Washington State DOT's *Peak Hour Report, 2007*. Transportation Data Office, Olympia, Wash. (Cited in HCM 2010): Average K-factor by AADT: 0-2,500 = 0.151 2,500-5,000 = 0.136 5,000-10,000 = 0.118 10,000-20,000 = 0.116 20,000-50,000 = 0.107 50,000-100,000 = 0.091 100,000-200,000 = 0.082 >200,000 = 0.067 For one-lane, one-way streets or segments that are part of a one-way pair, staff chose to base the K_d on the volume of the combined pairs.
PHF		From HCM 2010: PHF in urban areas generally range between 0.80 and 0.98. PHF over 0.95 are often indicative of high traffic volumes, sometimes with capacity constraints on flow during the peak hour. PHFs under 0.80 occur in locations with highly peaked demand, such as schools, factories with shift changes, and venues with scheduled events. From HCM 2000: Typical PHF: Urban = 0.92 Rural = 0.88 Staff defined Rural as any segment outside of the 2010 Census Savannah Urbanized Area and outside of other 2010 Urban Clusters. Staff used .80 on segments accessing schools (except if schools were on high volume roads).
Vol_15	Calculated from the four variables above	Field cannot be Null (e.g. instances of off-road features, or facilities on future roads, not intended to be scored at this time) or rounded down to zero (e.g. features with very low ADT), or else Calculate Field for the LOS_score field will fail because of the application of natural log in LOS

		expression. If the case of the former, values of 99 were entered, even though calculated LOS_score would be ignored for off-road paths and non-existing road segments. In case of the latter, the estimated AADT for those records was increased slightly to avoid a Vol_15 of zero.
L_n	Aerial Imagery	Field cannot be Null (e.g. instances of off-road features, or facilities on future roads, not intended to be scored at this time), or else Calculate Field for the LOS_score field will fail because of the application of natural log in LOS expression. Staff modified the L_n attribute for off-road paths and segments prposed on not-yet-existing roads to be 99, even though calculated LOS_score would be ignored for off-road paths and non-existing road segments.
Sp_p	City of Savannah Code, Chatham County Code, Google Street View	Speed limits at 20 or below result in an error in the calculation of natural log used in the formula for Sp_t and therefore the minimum value entered for Sp_p is 21.
Sp_t	Calculated from Sp_p	
HV	GDOT STARS or defaults	.02 (Low) was the maximum percentage present in the segments used to develop the model. If staff selected default values for segments, staff judged from the following guidelines, and considered neighboring segments in same corridor. From HCM 2010, Vol. 4, State-specific defaults for HV (Rural: <5,000 pop. Sm. Urban: 5,000-50,000 pop. Med. Urban: 50,000-250,000 pop.) Georgia Freeways Rural = 19% Sm. Urban = 7% Med. Urban = 12% Georgia Multi-lane Highways Rural = 6% Sm. Urban = 6% Georgia Two-lane Highways Rural = 8% Sm. Urban = 5% Staff defined Rural as any segment outside of the 2010 Census Savannah Urbanized Area and outside of other 2010 Urban Clusters. Staff assumed 10% HV on many streets in center of Savannah Historic District, unless GDOT % known, due to trolley buses, CAT buses (on CAT routes), and delivery trucks. (A GDOT traffic station downtown showed 11% trucks in a previous year.)
PR5		5 (Excellent) used only if staff knows of recent repaving 4 (Good) used as default value for regular paving. 3 (Fair) Defects may include rutting, map cracking, and extensive patching. Staff assumed concrete (non-asphalt) streets and bridges to be in this category due to seams. 2 (Poor) Flexible pavement has distress over 50%-75%or more of the surface. Rigid pavement distress includes joint spalling, patching, etc. For Savannah, staff judged this category includes brick streets and asphalt stamped with brick pattern. 1 (Very Poor) Distress occurs over 75% or more of the surface. For Savannah, staff judged this category includes cobblestone streets and dirt roads.
Wt	Aerial Imagery	If rumble strips consume full width of the shoulder or leave only a couple feet of regular pavement on the outside edge of shoulder, then the measure of Wt and Wl stops at the inside edge of rumble strip, thus reducing Wv and We. Rumble strips that leave at least 4 feet of regular pavement on the outside edge of shoulder are included in the

		calculations of widths (same as if rumble strip not present).
OSPA		Qualitatively estimated average from multiple aerial imagery sources, usually categorized as 0.75, 0.50, 0.25, 0.10, or 0.05.
Wl	Aerial Imagery	See mention of rumble strips for Wt above.
Wps	Aerial Imagery	This is only recorded for segments that have parking striped to the RIGHT of a bike lane. All other segments have Null value.
Wv	Calculated from Wt and ADT	
We	Calculated from Wv, Wl, and OSPA	
Undivided_ Unstriped	Aerial Imagery	0= No, the street meets only one of those criteria or it meets neither one. 1 = Yes, the street does meet both criteria. Value is left Null if AADT is over 4000, because the variable is not needed in that case.

Notes on Decisions during Application of Model

During application of the model to the many segments of the bikeway network, various types of questions arose. These are documented here to encourage continued consistency.

Question: What is the Wv if the AADT <= 4000 but the street is NOT both Undivided AND Unstriped (e.g. the street is a typical, low volume, undivided road with a centerline)?

Note: When ADT is above 4000 then $W_v = W_t$ (2-0.00025 x ADT) results in Wv < Wt, which is not allowed. Thus the rule "If ADT > 4000 then Wv = Wt.

- Treat the streets that did not meet both criteria of being undivided AND unstriped as though they were like streets with ADT > 4000 (i.e. use $W_v = W_t$ if ADT > 4,000veh/day to determine Lane Width as a Function of Traffic Volume).
- One-way, one-lane streets are considered to be "divided" streets, as often these are in pairs on the north and south edges of the squares.
- The intent of the rule is interpreted to be for two-way streets without centerlines, where traffic negotiates the space with each other.

Questions related to the classification of shoulders, on-street parking, and bike lanes for the calculation of We (effective width of the outside through lane):

Certain cross-sectional conditions created ambiguity about which of the three alternative formulas for We should be used. The HCM 2010 Bicycle LOS variables and equations were referenced to confirm appropriate interpretations in the Sprinkle Consulting model (e.g. whether Wt includes the un-striped, on-street parking area, whether Wl includes the untriped, on-street parking area, etc.). The table below explains how each source treats various cross-sectional scenarios.

COMPARISON OF INTERPRETATIONS FOR VARIOUS EXAMPLE SITUATIONS, using Sprinkle method or HCM method
In these examples Wv = Wt (volume > 4000 AADT) in order to focus only on the cross-sectional differences. For situations in which ADT is less than or equal to 4000, see above in this report for Sprinkle Consulting method or refer to HCM 2010 otherwise.
Variables notated identically between each version (e.g. Wt) are not necessarily defined the same way in each. See Notes below.

If segment has neither a paved shoulder nor bike lane (e.g. a rural 12 ft lane with no paved shoulder)…						
Sprinkle Consulting	Wv (=Wt)	OSPA	Wl	Wps	We	
This is the Wl = 0 situation, and therefore use	12	0	0		12	
We = Wv - (10ft*%OSPA)						
HCM	Wv(=Wt)	Wol	Wbl	Wos	Ppk (OSPA)	We
Ppk = 0 and thus Wt = Wol + Wbl + Wos	12	12	0	0	0	12
Wbl + Wos < 4 feet and thus						
We = Wv-10*Ppk						
If segment has a minimal paved shoulder (e.g. a rural 12 ft travel lane with 2 ft paved shoulder)…						
Sprinkle Consulting	Wv (=Wt)	OSPA	Wl	Wps	We	
This is the Wl > 0 and Wps = 0 situation, and therefore use	14	0	2		16	
We = Wv + Wl (1-2*%OSPA)						
HCM	Wv(=Wt)	Wol	Wbl	Wos	OSPA	We
Ppk = 0 and thus Wt = Wol + Wbl + Wos	14	12	0	2	0	14
Wbl + Wos < 4 feet and thus						
We = Wv-10*Ppk						
Note: The HCM treats paved shoulders or bike lanes that are less than 4 feet wide the same as situations without paved shoulders or bike lanes.						
If segment has wider shoulder pavement outside of an outside lane stripe, which may or may not be used for parking (e.g. a rural 12 ft lane with 8 ft paved shoulder)…						
Sprinkle Consulting	Wv (=Wt)	OSPA	Wl	Wps	We	
This is the Wl > 0 and Wps = 0 situation, and therefore use	20	0	8		28	
We = Wv + Wl (1-2*%OSPA)						
HCM	Wv(=Wt)	Wol	Wbl	Wos	OSPA	We
Ppk = 0 and thus Wt = Wol + Wbl + Wos	20	12	0	8	0	28
Wbl + Wos is NOT < 4 feet and thus						
We = Wv + Wbl + Wos - 20*Ppk						
If segment has no bike lane and on-street parking is occurring in either T-marked stalls or in unmarked area (e.g. an urban 20 foot lane [to gutter] with 25% parking occupied but with NO continuous stripe between the lane and the parking area) …						
Sprinkle Consulting	Wv (=Wt)	OSPA	Wl	Wps	We	
This is the Wl = 0 situation, and therefore use	20	0.25	0	0	17.5	
We = Wv - (10ft*%OSPA)						
HCM	Wv(=Wt)	Wol	Wbl	Wos	OSPA	We
Ppk does NOT = 0 and thus Wt = Wol + Wbl	20	20	0	0	0.25	17.5
Wbl + Wos < 4 (they're both 0) and thus						
We = Wv-10*Ppk						

If segment has a bike lane and on-street parking (e.g. a 12 foot lane, a 6 foot bike lane, and an 8 foot parking lane having 75% parking occupied) …						
Sprinkle Consulting	Wv (=Wt)	OSPA	Wl	Wps	We	
This is the Wl > 0 and Wps > 0 and a bike lane exists situation, so therefore use						
We = Wv + Wl - 2(10*%OSPA)	18	0.75	14	8	17	
Note for Sprinkle method: Wt includes bike lane but not the parking area (because of separation by continuous stripe), while Wl includes bike lane and the parking area. Wl is clearly defined as area between outside lane stripe and edge of pavement, regardless of whether used for bike lane, shoulder, or parking, or whether additional markings appear in that area.						
HCM	Wv(=Wt)	Wol	Wbl	Wos	OSPA	We
Ppk does NOT = 0 and thus Wt = Wol + Wbl	18	12	6	8	0.75	17
Wbl + Wos is NOT < 4 feet and thus						
We = Wv + Wbl + Wos - 20*Ppk						

Notes:
Sprinkle Consulting variables are defined on pages 1-2 of this report.

HCM variables are defined as follows (from Exhibit 17-21 in HCM 2010):

- Wt = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
- Wol = width of outside through lane (ft);
- Wos= width of paved outside shoulder (not counting gutter pan or curb);
- Wbl= width of bicycle lane = 0.0 if bicycle lane not provided (ft.);
- Wv= effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (ft). (In our table above, this is assumed to be equal to Wt, for simplification.);
- Ppk= proportion of on-street parking occupied (decimal);