Multimodal Level of Service Methodologies: Evaluation of the Multimodal Performance of Arterial Corridors

Natalia Zuniga-Garcia, M.Sc.
Research Assistant
nzuniga@utexas.edu
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
ECJ Bldg., Ste. 6.506 (C1761), Austin, TX 78712

Heidi W. Ross, M.Sc.
Research Fellow
heidiwross@austin.utexas.edu
Center for Transportation Research
The University of Texas at Austin
1616 Guadalupe St, Suite 4.320, Austin, TX 78701

Randy B. Machemehl, Ph.D.
Nasser Al-Rashid Centennial Professor in Transportation Engineering
rbm@mail.utexas.edu
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
ECJ Bldg., Ste. 6.908 (C1761), Austin, TX 78712

The following paper is a pre-print, the final publication can be found in Transportation Research Record, No. 2672: 142–154, 2018.

Zuniga-Garcia, N., Ross, H. W., & Machemehl, R. B. (2018). Multimodal Level of Service Methodologies: Evaluation of the Multimodal Performance of Arterial Corridors. Transportation Research Record, 2672(15), 142–154. https://doi.org/10.1177/0361198118776112

ABSTRACT

The principal objective of this research is to evaluate the multimodal performance of arterial corridors using currently available Multimodal Level of Service (MMLOS) methodologies. Eight different MMLOS approaches are applied to a case study using an arterial corridor section in Austin, Texas. The methods applied are (1) *Highway Capacity Manual*, (2) *Transit Capacity and Quality of Service Manual*, (3) Charlotte's *Urban Streets Design Guide*, (4) Pedestrian and Bicycle Environmental Quality indices, (5) Level of Traffic Stress, (6) Bicycle Compatibility Index, (7) Deficiency Index, and (8) Walk Score®, Bike Score®, and Transit Score®. The analysis is focused on the pedestrian, bicycle, and transit assessment. The methodologies are evaluated and contrasted. The paper provides a compressive review of the current state of practice of multimodal evaluation, and recommendations about the most appropriate approaches to assess multimodal performance of arterial corridors.

Keywords: Multimodal Level of Service (MMLOS), Pedestrian, Bicycle, Transit, Arterial Corridor.

INTRODUCTION

The idea that streets are places— not just paths to and through places—has increasingly guided transportation thinking and investment over the past decade [1]. The Transportation Equity Act for the 21st Century (TEA-21) and its predecessor, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), called for mainstreaming transit, pedestrian, and bicycle projects into the planning, design, and operation of the U.S. transportation system [2]. With an increase in transportation funding, the need arises to implement analytic tools that help measure the effects of investments and guide decisions regarding the effective planning, design, and operation of streets in multimodal environments.

The most common evaluation approach is to use qualitative measures that relate to the quality of service, also known as the level of service (LOS). Traditionally, the LOS metric has been focused on assessing automobile-oriented measures. The LOS assigns a letter from A to F based on the quality of transportation as defined by various performance measurements, such as speed, volume-to-capacity ratio, and delay, among others. The letter A corresponds to the best quality of service, while the letter F represents the most deficient condition.

The concept of LOS has been expanded beyond automobiles to include the quality of service as perceived by the cyclist, pedestrian, and transit users. This is known as multimodal level of service (MMLOS). While there are several different MMLOS metric approaches, there is no nationally accepted method for combining auto, transit, bicycle, and pedestrian modes into a unique performance measure. This factor could be a limitation for planning projects that require an overall estimation for an entire section.

The principal objective of this research is to evaluate the multimodal performance of arterial corridors using currently available MMLOS methodologies and to compare and contrast results obtained by using the methodologies. To date, it has not been common to develop a single LOS to characterize all modes in a corridor. This research further assesses the reasonableness of doing so. The analysis includes a case study of an arterial corridor section located in Austin, Texas.

The main contributions of this paper include: (1) a comprehensive review of the available MMLOS methodologies; (2) an evaluation and contrasting of the MMLOS approaches using a case study; and (3) insights about the most appropriate multimodal evaluation procedure for arterial corridors. The subsequent sections of this paper include "Measuring the Multimodal Performance," which presents the state of practice of the MMLOS methods; "Case Study," which provides details about the case study; and "Results and Discussion, which" presents the results and analysis of the application of the selected methods to the case study. The final section, "Summary and Conclusions," summarizes the main findings.

MEASURING THE MULTIMODAL PERFORMACE

The most prominent and widely used method to measure the performance of roadways is presented in the *Highway Capacity Manual* (*HCM*), which first introduced the concept of LOS in the second edition (1965). However, it was not until the fifth edition in 2010 when the *HCM* included a multimodal analysis framework. This was the first *HCM* to provide an integrated multimodal approach to the analysis and evaluation of urban streets from the point of view of automobile drivers, transit passengers, bicyclists, and pedestrians [3]. The most recent *HCM*, published in 2016, notably adds the subtitle *A Guide for Multimodal Mobility Analysis* and "underscore[s] the focus on evaluating the operational performance of several modes including pedestrian and bicycles, and their interactions" [4].

The main concern about the *HCM* editions prior 2010 is that the LOS reflected a motorist perspective with the emphasis on automobile traffic, density, delay, and speed. Additionally, there is a lack of interaction between automobile, pedestrian, transit, and bicycle LOS metrics [2]. For instance, the pedestrian LOS criteria for sidewalks is based on facility width and pedestrian volume. This concept is derived from the automobile LOS methodology where density plays a critical role. However, pedestrians may be more interested in other aspects such as the presence of buffers or adjacent automobile volume and speed.

In response to the limitations found in the *HCM* approach before the 2010 edition, and due to the increasing interest in evaluating multimodal scenarios, several scholars and local jurisdictions have developed their own MMLOS methodologies [5]. The methodologies can be classified into two groups. The first group includes methods that employ the traditional letter-grade (A to F) LOS metric. The second group consists of methods that use various score methodologies or checklists to evaluate multimodal characteristics

Level of Service Metric

Highway Capacity Manual

The research base for the *HCM* MMLOS framework comes from the National Cooperative Highway Research Program (NCHRP) Project NCHRP 3-70. The NCHRP Report 616 [2] obtained as part of this project summarizes the methodology used to develop the MMLOS framework. The study used as inputs models first developed by Bruce Landis and Theo Petritsch [6, 7, 8] in an effort by the Florida Department of Transportation (FDOT) to develop their own multimodal performance measures. The *HCM* uses four units of analysis: intersections, links, segments, and facility. The LOS estimation requires information about demand, control, and geometry. The equations provide a numerical score that is converted into a letter based on five ranges: A (≤2.00), B (2.00–2.75), C (2.75–3.50), D (3.50–4.25), E (4.25–5.00), and F (>5). The LOS results are provided for the different modes, and the procedure does not provide a single LOS measure that combines all of them.

Transit Capacity and Quality of Service Manual

The *Transit Capacity and Quality of Service Manual* (*TCQSM*) [9] is the transit counterpart to the *HCM*. The manual contains background, statistics, and graphics on various types of public transportation, and it provides a framework for measuring transit availability, comfort, and convenience from a passenger point of view. The manual contains quantitative techniques for calculating the capacity of bus, rail, and ferry transit services and transit stops, stations, and terminals [4]. The latest version is the third edition published in 2013.

The *TCQSM* method distinguishes between demand-responsive transit and fixed-route transit services. The analysis is applied at a street-segments level. The manual presents a two-dimensional LOS framework covering two service quality dimensions: availability, and comfort and convenience. The availability dimension considers frequency, service span, and access. The comfort and convenience dimension core measures are passenger load, reliability, and travel time.

Florida's Quality/Level of Service Handbook

The *Quality/Level of Service Handbook* (*Q/LOS*), developed by the Florida Department of Transportation (FDOT), provides LOS measures, thresholds, and estimation methodologies for automobiles, transit, bicycle, and pedestrian modes. For more than fifteen years, FDOT has been a national leader in research related to developing MMLOS metrics [10].

FDOT first developed the *Q/LOS* method, and subsequently led and supported extensive research on MMLOS that helped to inform the addition of MMLOS into the *HCM*'s fifth (2010) and sixth (2016) editions [10]. The most recent version of the *Q/LOS* was published on 2013 and includes new analytical techniques contained in the *HCM* 2010 [11]. The handbook provides a description of the simplifying assumptions and planning extensions FDOT has made to the *HCM*. Additionally, they specified six analysis techniques used only by the FDOT: generalized service volume tables (recently included in the *HCM Applications Guide* [12]), freeway facility capacities, rural freeway LOS criteria, arterial facility LOS criteria for automobiles, arterial free-flow speed, and passing lanes on two-lane highways.

Charlotte's Urban Street Design Guidelines

The City Council of Charlotte, North Carolina, adapted the *Urban Street Design Guidelines* (*USDG*) in 2007 [13] as a tool for planning and designing Complete Streets. In 2009, the guidelines received the U.S. Environmental Protection Agency (EPA) Award for Smart Growth Achievement [14]. USDG methodology identifies and evaluates features according to their influence on the comfort and safety of pedestrians and bicyclists.

The USDG is focused on pedestrian and bicycle LOS and its evaluation methodology consists of adding or subtracting points for the presence or absence of particular features. This method differs from the *HCM*, *TCQSM*, and *Q/LOS* manual, where a numeric score is obtained using formulas produced through linear regression. Finally, scores (ranging from 0 to 100) are compared to limits that determine the A to F level of service for each mode. The main limitation of this method is that it only applies to intersections, not to street segments. Additionally, there are concerns about the metric's lack of system-user validation, transparency in selection and development of variables, and weights for the points system [2].

City of Fort Collins' Multimodal Transportation Level of Service Manual

Fort Collins, Colorado, implemented a *Multimodal Transportation Level of Service Manual* in 1997 as part of its "Community Vision and Goals 2015" [15]. The manual provides LOS for automobile, pedestrian, cyclist, and transit. The automobile LOS is estimated using the *HCM* procedure [16]. The bicycle LOS standards are based on access to various facilities within connecting corridors. The analysis only includes bicycle facilities that are consistent with the city's minimum design standards, which is the principal limitation of the method. The pedestrian LOS methodology defines minimum LOS requirements according to the five types of areas established by the city: pedestrian district, activity corridor/center, transit corridor, school walking area, and other. The methodology considers pedestrian characteristics that are not included in other methods, such as continuity, security, and amenities, which are important from a pedestrian planning point of view. The transit LOS standards consider route service characteristics, and land-use features of the area served.

Bicycle Compatibility Index

The Bicycle Compatibility Index (BCI) [17] was developed to evaluate the capability of urban and suburban roadway sections to accommodate both motorists and bicyclists using geometric and operational characteristics such as lane widths, speed, and volume. It was possible to develop a linear regression model to predict the BCI using the results of a Video Laboratory survey. This model predicts a bicyclist's overall comfort-level rating using significant variables and adjustment factors. The BCI obtained using the model is compared to six compatibility levels: A, *Extremely High*; B, *Very High*; C, *Moderately High*; D, *Moderately Low*; E, *Very Low*; and F, *Extremely Low*. It is important to note that the BCI model is for midblock street segments only. The ratings do not account for major intersections along the route where the bicyclist may encounter a stop sign or traffic signal [17].

Modal Score Measures

Pedestrian and Bicycle Environmental Quality Index

In 2007, the San Francisco Department of Public Health (SFDPH) developed the Pedestrian Environmental Quality Index (PEQI) [18] and the Bicycle Environmental Quality Index (BEQI) [19]. The indices are observational surveys that quantify streets and intersection factors that affect pedestrians and cyclists, and evaluate what streetscape improvements could be made to promote walking and bicycling. Both indices are organized into five categories: intersection safety, traffic, street design, land use and perceived safety.

The methodology used to estimate the PEQI and BEQI scores is similar to Charlotte's *USDG*, where the user adds or subtracts points according to the indicators present in the section analyzed. Each index of the five principal categories has a scaling factor or weight. An expert panel was convened to assign weights to each attribute that reflect the level of importance each indicator has for pedestrians when evaluating street segments and intersections [20]. Both PEQI and BEQI, are scored on a scale from 0 to 100, where 100 is the most desirable. The indicators can be aggregated to create the final index, which can be reported as an overall index score or deconstructed by categories.

Level of Traffic Stress

Researchers at the Mineta Transportation Institute in San José, California, developed the Level of Traffic Stress (LTS) method [21] to evaluate the LOS for bicycle travel. The authors classified bicycle facilities into four groups. LTS 1 is meant to be a level that most children can tolerate, while LTS 2 is the level that will be tolerated by the typical adult population. LTS 3 is the level tolerated by cyclists who are "enthused and confident," but still prefer having their own dedicated space for riding. LTS 4 is the level tolerated only by those characterized as "strong and fearless."

The LTS methodology is applied at intersection and street-segment levels, and allows for an assessment of system connectivity without requiring data like traffic volumes and calculations of the *HCM* Bicycle MMLOS. LTS is well suited for high-level plans such as corridor and transportation system plans, and it is widely used. Notably, the Oregon DOT implemented it in its MMLOS guides [22], and a tool to estimate comfort measures to pedestrian and cyclist, called StreetScore+ [23], was developed using the LTS method.

Deficiency Index

The Deficiency Index (DI) is an alternative to the *HCM* urban streets method [24, 25]. The key aspects of this method include using step functions in a modular framework, using deficiency indices, addressing comparability of measures across modes, and incorporating the impact of modes on other modes [24]. DI classifies features into three groups: physical, operational, and intermodal. Characteristics from the HCM 2010 were included with selected additional components from other research sources to describe each group. Each characteristic is rated by assigning it a deficiency score (DS), which is determined by the user assigning a numerical value based on five ratings: Good (0), Fair (1), Poor (2.5), Very Poor (4), and Extreme (5).

Each characteristic is also assigned a weight (W) value, which was obtained through a survey of transportation professionals working in research, academia, and practice. The weights were rated as follow: Very Small Impact (1), Small Impact (2), Moderate Impact (3), Large Impact (4) and Very Large Impact (5). The DI is obtained by the multiplication of the DS (assigned by the user) and the W values for each characteristic. The DI values are averaged per feature group and then per each mode. The weights of characteristics and deficiency scores can be adjusted by users of the method.

Total Peak-period Travel Time

The Texas A&M Transportation Institute (TTI) first introduced the Total Peak-period Travel Time (TPPTT) in 2012 for its Urban Mobility Report [16]. The TTPTT is a multimodal performance measure that represents the door-to-door sum of all travel times during both morning and evening peak periods regardless of mode or travel path [26]. The method estimates the TPPTT in units of minutes per day. It also determines the Travel Time Index (TTI) obtained as the ratio of the travel time and the free-flow travel time. The key elements included are: number of miles traveled on each roadway classification, free-flow speed, congested speed, and commuter population.

Walk Score®, Bike Score®, and Transit Score®

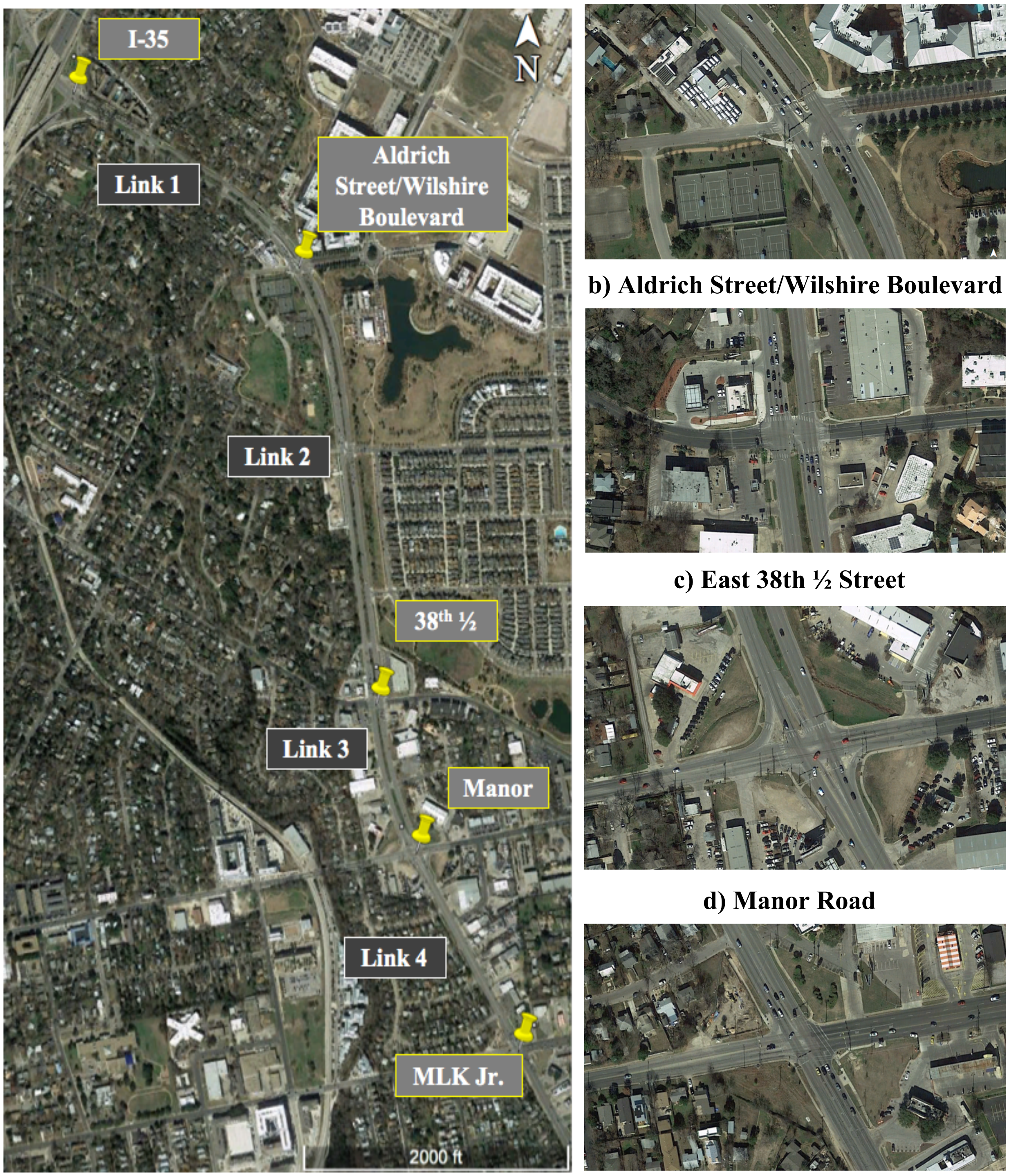
Walk Score®, Bike Score®, and Transit Score® are web-based tools (www.walkscore.com) developed by Front Seat Management, a software development company based in Seattle, Washington, that focuses on software with civic applications [27]. The software uses a variety of data sources, including Google, Education.com, Open Street Map, Localeze, city governments, the USGS, public transit agencies, and the U.S. Census. Scores range from 0 to 100. For each address, Walk Score analyzes hundreds of walking routes to nearby amenities, with points awarded based on the distance to amenities in each category. Bike Score is calculated by measuring bike infrastructure (e.g., lanes, trails), hills, destinations and road connectivity, and the number of bike commuters. Transit Score is estimated through a “usefulness” value calculated by the frequency, type of route (e.g., rail, bus), and distance to the nearest stop on transit routes. The “usefulness” of all nearby routes is summed and normalized to a score between 0 to 100 [28].

CASE STUDY

The present research aims to evaluate the multimodal performance of an arterial corridor section in Austin, Texas, using different MMLOS approaches to pedestrian, bicycle, and transit assessment. The methods applied are *HCM*, *TCQSM*, Charlotte’s *USDG*, BEQI/PEQI, LTS, BCI, DI, and Walk Score®, Bike Score®, and Transit Score®. The corridor sector evaluated is a 1.1-mile segment of the total 6.5-mile length of Airport Boulevard, which includes four major signalized-intersections: Aldrich Street/Wilshire Boulevard, East 38th ½ Street, Manor Road, and East Martin Luther King Jr. (MLK) Boulevard. Figure 1 presents the corridor along with a detail of the intersections.

The section from I-35 to Manor Road presents six median-separated lanes designed specifically to accommodate the significant peak hour traffic near the Airport Boulevard intersection with I-35 [29]. At Manor Road, the boulevard changes to a four-lane roadway with a continuous center left turn lane. The posted speed in the area is 45 mph. From I-35 to East 38th ½ Street, the corridor is lower in traffic volume with residential neighborhoods, parks, and landscaped buffers along the roadway, whereas from East 38th ½ Street to MLK Boulevard, the corridor is characterized auto-oriented, service, and warehouse uses.

The analysis is applied at intersection and street-segments levels. Table 1 provides a detailed characterization of the roadway elements of study. Data sources include a field evaluation, Google Earth, City of Austin's Airport Boulevard Corridor Development Program Report [29], Capital Metro users' information and its *System and Service Evaluation Report* [30]. Traffic volumes are based on counts collected on weekdays in June 2011 and September 2011 [29] that were converted into 2017 volumes using a 3 percent annual growth rate.



b) Aldrich Street/Wilshire Boulevard

c) East 38th ½ Street

d) Manor Road

a) Airport Boulevard Corridor

e) East MLK Boulevard

FIGURE 1 Airport Boulevard and intersection details (Google Earth, 2017).

TABLE 1 Airport Boulevard: Description of Segment and Intersection Characteristics

Link	Longitude (miles)		Sidewalk width (ft.)		Transit Routes	Transit Stops	Bike Lane
			NB	SB			
Link 1	0.4		4.5	4.5	350, 37, 485, 135	2 stops	None
Link 2	0.6		7.5	7.5	350, 485, 135	No stops	None
Link 3	0.2		6.0	0	350, 485, 135	1 stops	None
Link 4	0.3		6.0	6.0	350, 485, 135	2 stops	None
Intersection	**Lanes**				**Median Separated Approach**	**Crosswalk Treatment**	**Bike Lane**
	N	**S**	**E**	**W**			
Aldrich Street & Wilshire Boulevard	7	6	2	5	N, S, E	Ladder	E
East 38th ½ Street	7	7	3	3	N, S	Ladder	None
Manor Road	7	6	5	4	N, S	Ladder	None
East MLK Boulevard	6	5	5	5	N, S	Transverse marking	None

NB = Northbound; SB = Southbound; EB = Eastbound; WB = Westbound
N = North approach; S = South approach; E = East approach; W = West approach

RESULTS AND DISCUSSION

The Airport Boulevard evaluation utilized eight MMLOS methodologies. Table 2 provides a comparison of the characteristics evaluated in each. An exception was made for Walk Score®, Bike Score®, and Transit Score®, which were not included because there is not precise information available about the features that it evaluates. In addition, *HCM* and *TCQSM* methodologies complement each other since *HCM* covers pedestrian and bicycle modes and *TCQSM* covers transit. These methods have been combined in Table 2, resulting in a total of six columns to address seven MMLOS methods. Table 2 provides information required to evaluate the different modes and presents the differences in data input requirements between the different methods. For example, the table shows how the *HCM* method differs from PEQI/BEQI and DI, in that it does not consider features such as cross-walk treatment and ADA curb ramps. This assessment of the methodology differences is an important contribution of the present study.

Application of the methods to the case study are described in the following paragraphs. As per the outlined methodology, the *HCM* intersection LOS approach is applied separately for each intersection leg. The authors have deviated from *HCM* guidelines in calculating an overall intersection score (an average of scores for each intersection leg), a deviation justified so that results can be compared with other methods. Similarly, northbound (NB) and southbound (SB) street segments are evaluated and averaged for a final score. Again, averaging the directional score is justified so that results can be compared with other methodologies. The BEQI and PEQI used are based on the methodology as explained in the users' manuals [18, 19]. However, it is important to mention that the BEQI and PEQI have an updated version, Version 2.0. The DI method is used on sections that include both street segments and intersections. The Walk Score®, Bike Score®, and Transit Score® are obtained using the free online resource at www.walkscore.com. However, there is not precise information available about the features that this methodology evaluates to obtain results.

TABLE 2 Characteristics Comparison Across Methods Applied

Mode	**Characteristic**	***HCM/ TCQSM***	**Charlotte's *USDG***	**BEQI/ PEQI**	**LTS**	**BCI**	**DI**
Pedestrian	Presence of sidewalk	X	X				X
	Sidewalk width	X		X			X
	Sidewalk quality						X
	Side street geometry	X	X	X			
	Vehicle volume and speed	X		X			
	Vehicle right turns and permitted lefts	X	X	X			
	Pedestrian volume	X					X
	Pedestrian signal type	X	X	X			
	Presence of physical barrier and buffers	X		X			
	Distance from vehicles	X					X
	Intersection corner radius		X				
	Crosswalk treatment		X	X			X
	Traffic calming feature			X			
	ADA curb ramps			X			X
	Lighting levels			X			
	Visual interest and amenities			X			
	Mid-block and intersection crossing delay	X					X
	Auto, transit and bicycle impact						X
Bicycle	Auto volumes	X		X		X	
	Auto speeds	X	X	X	X	X	
	Percent of heavy vehicles	X		X		X	
	On-street parking percentage	X		X	X	X	X
	Pavement rating	X					X
	Presence of bike lane or paved shoulder	X	X	X	X	X	X
	Width of bicycle lane	X		X	X		X
	Width of outside lane	X	X		X		X
	Bike lane blockage				X		
	Presence of physical barrier and buffers				X		
	Intersection crossing distance	X	X				
	Right turns on red	X	X	X		X	
	Right-turn lane longitude				X		
	Traffic calming features			X			
	Bicycle parking			X			
	Connection to on-street lanes		X	X			
	Line of sight, street slope, lighting			X			
	Residential development					X	
	Auto, transit and pedestrian impact						X
Transit	Frequency of service	X					X
	Average transit travel speed	X					X
	Average excess wait time	X					
	Bus stop amenities	X					X
	Bus load factor	X					X
	Span of service						X
	Auto volumes and speed	X					
	Sidewalk width and connection to stop	X					
	Outside lane, shoulder, bike lane width	X					
	Number of travel lanes	X					
	Pedestrian crossing difficulty						X
	Accessibility by bicycle						X
	Delay caused by auto						X

Results are shown in Table 3. The rows describe each methodology and mode, while the columns include the unit analysis (i.e., links and intersections along the corridor). The final results obtained for each mode are comparatively illustrated in Figure 2, where scores from the methodologies are graphically compared to provide a clearer analysis of results.

TABLE 3 MMLOS Methodologies Results

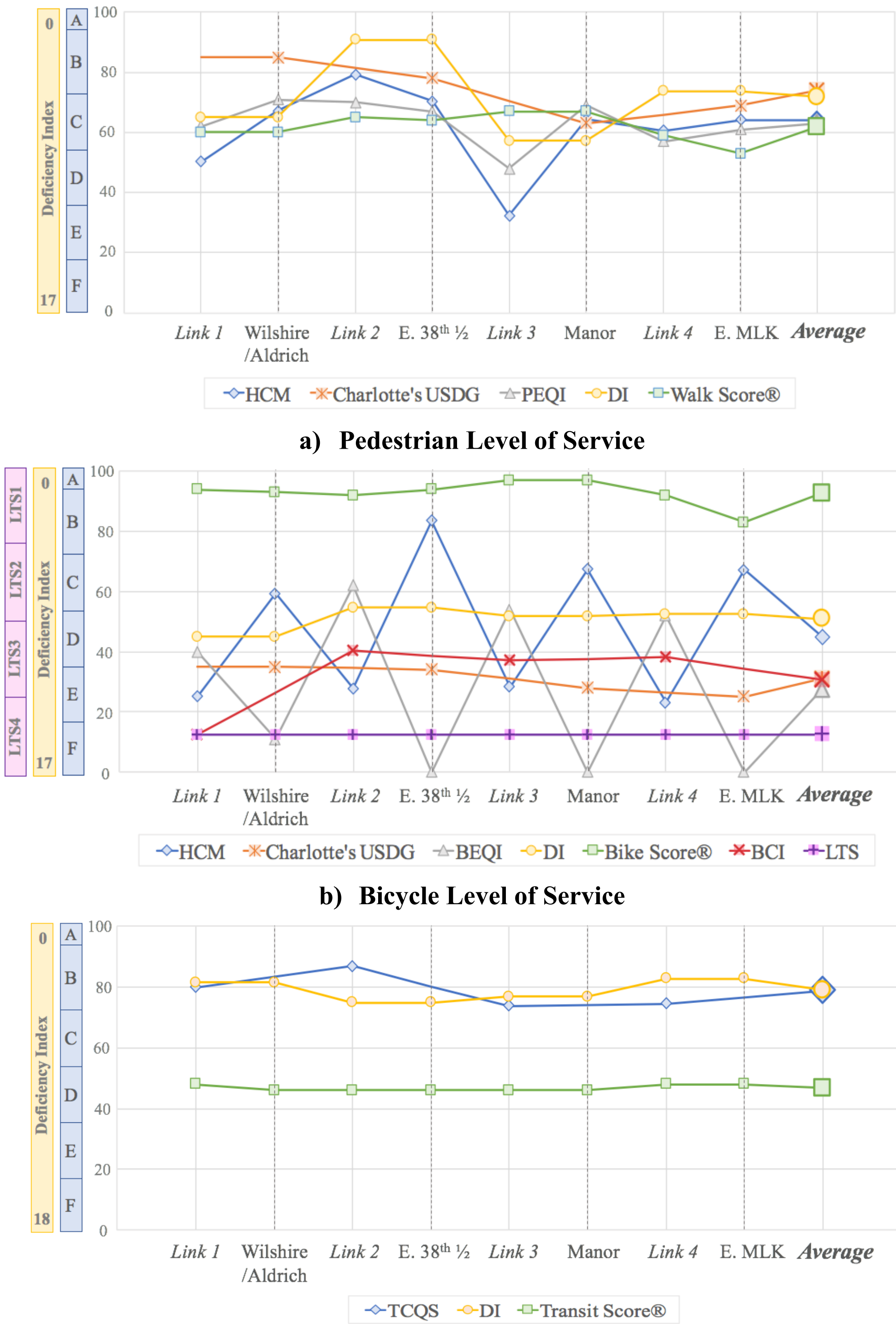
Method	Mode	Link 1	Airport Blvd & Wilshire/ Aldrich	Link 2	Airport Blvd & E 38th 1/2 St	Link 3	Airport Blvd & Manor	Link 4	Airport Blvd & E MLK Jr Blvd	*Average*
HCM	Pedestrian	D (3.66)	C (2.99)	B (2.53)	C (2.86)	E (4.41)	C (3.11)	C (3.27)	C (3.12)	***C (3.24)***
	Bicycle	E (4.73)	C (3.32)	E (4.61)	B (2.35)	E (4.59)	C (2.98)	E (4.82)	C (2.99)	***D (3.80)***
TCQSM	Transit	B (2.50)	-	B (2.21)	-	B (2.76)	-	B (2.73)	-	***B (2.55)***
Charlotte's *USDG*	Pedestrian	-	B (85)	-	B (78)	-	C (63)	-	C (69)	***B^-(74)***
	Bicycle	-	E^+ (35)	-	E^+ (34)	-	E (28)	-	E (25)	***E (31)***
BCI	Bicycle	F (5.83)	-	D (4.20)	-	D (4.39)	-	D (4.33)	-	***E (4.69)***
PEQI	Pedestrian	62	71	70	67	48	69	57	61	***63***
BEQI	Bicycle	40	11	62	0	54	0	52	0	***27***
LTS	Bicycle	LTS4	LTS4	LTS4	LTS4	LTS4	LTS4	LTS4	LTS4	***LTS4***
Deficiency Index (DI)	Pedestrian	5.93		1.54		7.25		4.44		***4.79***
	Bicycle	9.16		7.54		8.02		7.91		***8.16***
	Transit	3.29		4.48		4.13		3.07		***3.74***
Walk Score®	Pedestrian	60	60	65	64	67	67	59	53	***62***
Bike Score®	Bicycle	94	93	92	94	97	97	92	83	***93***
Transit Score®	Transit	48	46	46	46	46	46	48	48	***47***

Mode Evaluation

This section includes a discussion of the results obtained for each mode.

Pedestrian LOS

The pedestrian LOS results are shown in Figure 2a. The methodologies present similar evaluation results along the Airport Boulevard corridor. Charlotte's *USDG* shows the most favorable grades, but it only includes intersections. The intersection evaluation suggests similar pedestrian performance along the corridor. However, Charlotte's *USDG* presents a drastic variation from one intersection to other, with Manor having the lower performance. The link evaluation is consistent across methodologies to show Link 3 with the lowest grade due to the lack of a pedestrian sidewalk in the NB direction. However, the Walk Score® does not capture this link deficiency. Link 2 presents the best conditions for pedestrians due to the recreational area located along the NB direction that allows for a wider sidewalk and buffer. However, only the *HCM* and DI show the higher results for this link.



a) Pedestrian Level of Service

b) Bicycle Level of Service

c) Transit Level of Service

1 **FIGURE 2 MMLOS methodologies comparison.**

Bicycle LOS

The bicycle LOS results are presented in Figure 2b. In this case, the results are more dispersed along the score ranges and present higher variability along the corridor, compared to pedestrian LOS. For instance, the Bike Score® is the most favorable, with an average score of 93. Other methods provide lower scores, mainly due to the lack of a bike lane. The LTS present the lower score of the range across all units of study (street segments and intersections). The BCI and Charlotte's *USDG* provide similar results with low variability along the corridor, although one method evaluates only street segments (BCI) and the other only intersections (USGG). However, both methods use similar inputs, e.g., auto speeds, street parking percentage, and the presence of bike lanes (refer to Table 2).

The *HCM* and the BEQI scores present high variation between intersections and links. The street segment evaluation of the BEQI includes approximately twenty characteristics. However, the method only considers three aspects for intersections assessment: left-turn bicycle lane, dashed-intersection bicycle lane, and no-turn-on-red signs. For this reason, the score value is low if the intersection does not have any of them. The *HCM* street segment grades seem to be highly influenced by the lack of a bicycle lane, high auto speeds, and the presence of high traffic volumes. These limitations do not drastically affect the LOS result at intersection level. Also, the *HCM* intersection scores include the average of the four legs, and the crossing streets present significantly lower traffic volumes and better cyclist conditions than Airport Boulevard.

Transit LOS

Transit LOS results are shown in Figure 2c. The *TCQSM* and the DI present similar results. The main difference is observed in Link 2, which is a 0.6-mile segment that does not have transit stops. The positive higher value from the *TCQSM* can be related to the high pedestrian performance conditions because the method includes the interaction with this mode in the results. The Transit Score®, which gives more weight to the "usefulness" of the routes based on frequency, type of route, and distance to the nearest stop on the route, presents lower performance scores.

Methodologies Comparison

The methodologies are analyzed based on their applicability to the arterial corridor evaluation. Charlotte's *USDG* provides a detailed evaluation of intersections, and its procedure can be easily applied by the user with a spreadsheet tool. However, the USDG method does not evaluate street segments, which tend to be critical for pedestrians and cyclists in a corridor evaluation as noted in the other methods' results. Similarly, the BCI provides a useful street segments tool but does not evaluate intersections. Intersections are critical, especially in terms of pedestrian and cyclist safety.

PEQI and BEQI offer a checklist for field evaluation that can be applied by a user with minimal training. It provides results comparable to other methods. However, the main limitation of this method is its bicycle intersection score because it only considers three aspects, thus the results are not robust. The LTS method is considered as an evaluation resource that does not require intense data collection. Although the method provides only four ranges based on compatibility of the streets to different types of cyclists, it is considered a practical tool that gives easy-to-interpret results. However, in a multimodal evaluation, it would be difficult to compare bicycle results with other modes performance.

The *HCM* provides a pedestrian, bicycle, and transit (*TCQSM*) evaluation that considers the interaction of modes. This approach can evaluate intersections and street segments separately, and provides results comparable across modes. The DI method provides an accurate tool to compare across modes and sections. However, this approach is subjective since the scale to evaluate the characteristics does not provide a standard classification. For instance, when valuing the width of sidewalks on a scale from "good" to "extreme" there are no corresponding width measurements, and evaluation requires that the user has technical-experience and judgement to make such an assessment. Thus, DI is recommended when applied with other methods that can provide a more standard evaluation.

The Walk Score®, Bike Score®, and Transit Score® method presents an assessment of the accessibility of the location to pedestrians, cyclists, and transit users. However, the method presents higher scores on a section where infrastructure is inadequate, e.g., lack of sidewalk and bike lane. The method seems to average the characteristics of the surrounding areas, which in this case are more favorable than the corridor. Additionally, the methodology is not explained broadly, and the method cannot be applied directly by the user. A score is given only based on the location. Thus, this methodology is not recommended for the evaluation of roadway infrastructure assessment along a corridor.

Table 4 summarizes the pros and cons of applying each methodology to a corridor assessment.

TABLE 4 MMLOS Methodologies Applicability to Corridor Analysis

Method	Mode	Pros	Cons
HCM	*Pedestrian and Bicycle*	• Evaluates both intersection and links • Considers interaction of modes • Strong research background	• Not easy to apply • Requires training and technical knowledge • Requires detailed data collection
TCQSM	*Transit*	• Easy to apply using the spreadsheet tool • Considers interaction of modes • Strong research background	• Requires detailed data collection
Charlotte's *USDG*	*Pedestrian and Bicycle*	• Easy to apply using the spreadsheet tool • Detailed intersection assessment	• Does not evaluate link segments
PEQI/BEQI	*Pedestrian and Bicycle*	• Evaluates both intersection and links • Easy to apply • Requires minimal basic training	• Bicycle intersection assessment only considers three features
LTS	*Bicycle*	• Easy to apply • Evaluates both intersection and links • Does not requires intense data collection	• Does not evaluate pedestrian and transit
BCI	*Bicycle*	• Easy to apply • Does not requires intense data collection	• Does not evaluate intersections • Does not evaluate pedestrian and transit
Deficiency Index (DI)	*Pedestrian, Bicycle, and Transit*	• Evaluates pedestrian, bicycle, and transit using comparable measures • Considers interaction of modes • Can be used in conjunction with other methods	• Requires technical knowledge • Subjective scale of application (not and standard evaluation)
Walk Score® Bike Score® Transit Score®	*Pedestrian, Bicycle, and Transit*	• Easy to apply • Evaluates pedestrian, bicycle, and transit using comparable measures • Does not requires data collection process. • Evaluates both intersection and links	• Not sensitive to infrastructure deficiencies (e.g. lack of bike lane or sidewalk) • Methodology not reproducible

Corridor Multimodal Performance

The main objective of this study was to evaluate the multimodal performance of an arterial corridor using current methodologies. Results showed street segment and intersection LOS variability, mainly for the bicycle mode. This is important because an average of links and intersections across the corridor (as presented in Figure 2) show a rough estimate of LOS that does not include this variability. Thus, it may be relevant to consider separation of results in terms of intersections or street segments.

Also, an overall multimodal performance number should not be used. Combining LOS across modes would disguise the disparities in the perceptions of the quality of service of the independent mode. The main reasons not to combine modes are: (1) there is a not professionally and scientifically proven accepted method; (2) the weight of each mode should be established based on specific use, which will depend on relative importance, policy goals, or other criteria; (3) the purpose and travel patterns are different per mode.

SUMMARY AND CONCLUSIONS

This research study explored the current MMLOS methodologies with the objective of evaluating the multimodal performance of arterial corridors. A case study of a corridor section in Austin, Texas, is analyzed using different approaches: (1) *HCM*, (2) *TCQSM*, (3) Charlotte's *USDG*, (4) BEQI/PEQI, (5) LTS, (6) BCI, (7) DI, and (8) Walk Score®, Bike Score®, and Transit Score®. The evaluated section comprised 1.5-miles of the entire 6.5-mile corridor, with the analysis applied at intersections and street-segments levels using four links and four signalized intersections that include pedestrian, bicycle, and transit modes.

A summary of this study is provided below:

- Through the literature about the state of the practice, it was possible to describe six MMLOS procedures that use letter-metric grades and five approaches that use different score measures. A review of the most relevant methods allowed for an understanding of the use and limitations of each method was presented.
- The case study provided a comparison of methodologies that allows for the evaluation of the approaches according to their applicability to multimodal arterial corridors. The methods must analyze both street segments and intersections. It is necessary to provide comparability across modes. Thus, the recommended methodologies are *HCM*, *TCQSM*, and DI. However, it is recommended to combine the DI approach with other methodologies to provide a more standard evaluation.
- The study provides information that can help practitioners select an appropriate methodology for evaluating mode performance based on available information. Table 2 presents a comparison of the information necessary to apply the different methodologies and provides an overall understanding of features included in each. Table 4 summarizes the pros and cons of applying each method to a corridor assessment.

The major findings and conclusions from this study are:

- The *HCM* provides a MMLOS assessment that is suitable for a corridor evaluation. However, its application requires user training and significant data collection.
- *TCQSM* complements the *HCM* and provides transit assessment for corridor evaluation.
- Charlotte's *USDG* is not recommended for corridor evaluation because it does not assess link segments. However, it does provide a detailed intersection evaluation.

- The PEQI and BEQI offer an appropriate corridor assessment. However, the bicycle intersection LOS analysis does not provide a sufficiently robust evaluation and may cause significantly lower values than are found using other methodologies.
- LTS and BCI evaluate bicycle LOS with easy application and minimal data requirements. Application to a MMLOS corridor assessment requires the use of complementary pedestrian and transit methods.
- The DI is the most robust method. It can provide comparison across modes and considers interaction between modes. However, it requires technical knowledge and its application is subjective to user expertise. It is recommended to be used with other methods.
- The Walk Score®, Bike Score®, and Transit Score® provides comparability across modes and analyzes both intersections or street segments. However, the method seems to be insensitive to important roadway infrastructural features in a multimodal assessment (e.g., lack of sidewalks and bike lanes). Additionally, the methodology is not widely explained, and it is not possible to reproduce the score without using the proprietary web tool. Thus, this method is not recommended for arterial corridor evaluation.
- An overall MMLOS that includes multiple modes (i.e., automobile, transit, pedestrian, and bicycle) is not provided by any of the methods. The multimodal analysis should be applied separately for each mode. A further aggregation of the results to provide one overall score requires researcher judgement in terms of weights for the modes, and therefore biases results by assigning relative importance to individual modes through the act of aggregation.

A complimentary effort to this paper was the development of an MMLOS spreadsheet tool for the City of Austin to use in assessing LOS for transportation corridors. For that tool, the authors recommended applying *HCM* and *TCQSM* methodologies to assess the corridors. The methodologies were applied as directed, with minor deviations to tailor the analysis to the corridor in question, as well as to more easily compare analysis results across scenarios.

REFERENCES

1. Pande, A. and Wolshon, B. (2015) Level of Service Concepts in Multimodal Environments, in Traffic Engineering Handbook: Institute of Transportation Engineers, Seventh Edition, John Wiley & Sons, Inc, Hoboken, NJ, USA. DOI: 10.1002/9781119174738.ch5
2. Dowling, R., Flannery, A., Landis, B., Petritsch, T., Rouphail, N., and Ryus, P. Multimodal level of service for urban streets. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2071, 2008, pp. 1–7.
3. *HCM 2010: Highway Capacity Manual*. Washington D.C.: Transportation Research Board, 2010.
4. *Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis*. Washington D.C.: Transportation Research Board, 2016.
5. Brozen, M., Huff, H., Ligget, R., and Smart, M. Exploration and Implications of Multimodal Street Performance Metric: What's a Passing Grade? Report No. UCTC-FR-2014-09, University of California Transportation Center, 2014. https://pdfs.semanticscholar.org/2728/15cdd338f28df7054d84e0276699e761cfed.pdf. Accessed November 14, 2017.
6. Landis, B., Vattikuti, V., and Brannick, M. Real-time Human Perceptions Toward a Bicycle Level of Service. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1578, 1997, pp. 119–125.
7. Landis, B., Vattikuti, V., Ottenberg, R., McLeod, D., and Guttenplan, M. Modeling the roadside walking environment: pedestrian level of service. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1773, 2001, pp. 82–88.
8. Landis, B., Vattikuti, V., Ottenberg, R., Petritsch, T., Guttenplan, M., and Crider, L. Intersection level of service for the bicycle through movement. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1828, 2003, pp. 101–106.
9. Kittelson & Assoc, Inc., Parsons Brinckerhoff, Inc., KFH Group, Inc., Texas A&M Transportation Institute, and Arup. Transit Cooperative Highway Research Program Report 165: Transit Capacity and Quality of Service Manual, Third Edition. Washington, D.C., Transportation Research Board, 2013. DOI: https://doi.org/10.17226/24766
10. *Level of Service Case Studies Evolving Use of Level of Service Metrics in Transportation Analysis*. FHWA. U.S. Department of Transportation, 2017. https://www.transportation.gov/office-policy/transportation-policy/level-service-case-studies
11. 2013 Quality/Level of Service Handbook. State of Florida Department of Transportation, 2013. http://www.fdot.gov/planning/systems/programs/SM/los/pdfs/2013%20QLOS%20Handbook.pdf. Accessed November 14, 2017.
12. Dowling, R., Ryus, P., Schroeder, B., Kyte, M., Creasey, F.T., Rouphail, N., Hajbabaie, A. and Rhoades, D. NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual. Washington, D.C., Transportation Research Board, 2016. DOI: 10.17226/23632
13. *Urban Street Guidelines*. City of Charlotte, North Carolina, 2007. http://charlottenc.gov/Transportation/PlansProjects/Documents/USDG%20Full%20Document.pdf. Accessed November 14, 2017.
14. 2009 National Award for Smart Growth Achievement. U.S. Environmental Protection Agency, 2009. https://www.epa.gov/smartgrowth/2009-national-award-smart-growth-achievement-booklet. Accessed November 14, 2017.

15. Multimodal Transportation Level of Service Manual. City of Fort Collins, Colorado, 1997. http://www.larimer.org/engineering/gmardstds/ApdxH_03_01_2013.pdf. Accessed November 14, 2017.
16. Lasley, P. Developing Multimodal Performance Measures: Understanding What They Are and How to Develop Them. Presented at 95th Annual Meeting of the Transportation Research Board, Washington, D.C., 2016.
17. Harkey, D.L., Reinfurt, D.W., Knuiman, M., and Sorton, A. *Development of the Bicycle Compatibility Index: A Level of Service Concept*, Publication FHWA-RD-98-072, FHWA, U.S. Department of Transportation, Washington, D.C., 1998. https://safety.fhwa.dot.gov/tools/docs/bcifinalrpt.pdf. Accessed November 14, 2017.
18. The Pedestrian Environmental Quality Index (PEQI): An assessment of the physical condition of streets and intersections. San Francisco Department of Public Health, 2008.
19. Bicycle Environmental Quality Index Report (BEQI). San Francisco Department of Public Health, 2009.
20. Necessary, M. Technical Report 116: Developing an Infrastructure Informed Index for Pedestrians and Bicyclists. 2016. http://ctr.utexas.edu/wp-content/uploads/DSTOP116.pdf. Accessed November 14, 2017.
21. Mekuria, M.C., Furth, P.G., and Nixon, H. Report 11-19: Low-Stress Bicycling and Network Connectivity. San Jose, CA: Mineta Transportation Institute, 2012.
22. *Analysis Procedures Manual*: Multimodal Analysis (Chap. 14). State of Oregon Department of Transportation, 2016, pp. 14-1–14-73. http://www.oregon.gov/ODOT/TD/TP/APM/APMv2_Ch14.pdf. Accessed Nov. 14, 2017.
23. Fehr and Pears. Multi-Modal Level of Service toolkit: Bicycling Level of Traffic Stress. Not dated. http://asap.fehrandpeers.com/wp-content/uploads/2014/08/MMLOS-Tool-Level-of-Traffic-Stress.pdf. Accessed Nov. 14, 2017.
24. Kastenhofer, I.O. *Multimodal Assessment of Recurrent and Non-recurrent Conditions on Urban Streets*. Ph.D. Diss., Virginia Polytechnic Institute and State University, 2014.
25. Kastenhofer, I. O., Hobeika, A. G., and Abbas, M. M. A Method to Analyze Multimodal Conditions on Congested Urban and Suburban Arterials. *ITE Journal*, Vol. 87, No. 4, 2017, pp. 42–48.
26. Lasley, P., Lomax, T., Eisele, W., and Schrank, D. Developing a total peak period travel time performance measure: An updated concept paper. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2420, 2014, pp. 15–22.
27. Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., and Gortmaker, S. L. Validation of Walk Score® for Estimating Neighborhood Walkability: An Analysis of Four US metropolitan Areas. *International Journal of Environmental Research and Public Health*, Vol. 8, No. 11, 2011, pp. 4160–4179.
28. Front Seat. Walk Score Methodology. (2017). http://www.walkscore.com/methodology.shtm. Accessed November 14, 2017.
29. Report: Airport Boulevard Corridor Development Program. City of Austin Transportation Department, 2014. http://austintexas.gov/department/airport-boulevard-mobility-program. Accessed November 14, 2017.
30. Transportation Management & Design, Incorporated. Connections 2025 A Transit Plan for the Future Report: System and Service Evaluation. 2016. http://connections2025.org/wp-content/uploads/2016/07/Capital-Metro-Service-Review.pdf. Accessed November 14, 2017.