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EXPLORATION AND IMPLICATIONS OF MULTIMODAL STREET PERFORMANCE METRICS: WHAT'S A PASSING GRADE?

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DISCLAIMER

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FOREWORD

Madeline Brozen

In September 2013, California Governor Jerry Brown passed California Senate Bill 743 into law and effectively removed auto level of service (LOS) from the state's environmental review process. This change, while limited geographically, signaled a tidal shift from interest to action in unsettling the hegemony of auto LOS. When we started this project in 2012, the landscape was still in the "interest" phase. The Highway Capacity Manual 2010 was recently released, and its multimodal level of service model was a major milestone in this post-auto-LOS world. This manual was the first complex and technical way to score the street for the quality of bicycle and pedestrian travel, but was not without precedents. Scoring tools were previously released from municipalities and other agencies, including public health departments. If you were sitting in a municipal or state department of transportation anytime over the last three to five years, it is likely you have postulated about a move away from measuring a street's performance based only on the ability to move private automobiles. But this exploration can be an exercise in complexity; what would a bicycle or pedestrian level of service look like? What would it measure? How would a measurement tool like this work? These are some of the many questions we came across during this project. One inherent problem with a multimodal approach is that the purpose of the measurement goal is not as clear. Should a street be graded on safety, comfort, or aesthetic appeal? When a street is graded for the quality of travel for bicyclists or pedestrians, what does each grade mean? Moreover, what would a street segment with a "B" grade look like?

We have spent the better part of two years trying to answer these questions and more. We have found that reaching consensus on how to measure a street's performance beyond auto traffic has proven to be considerably challenging. At times, it felt as though we had more questions than answers. We spent a lot of time waxing philosophical about walking and bicycling and the multi-dimensional experience while traveling by those modes. In professional practice, we saw new types of infrastructure being added to the proverbial toolkit; new bikeway types, new pavement types, and other innovations being implemented in cities across the U.S large and small. This is an exciting time as new analysis and infrastructure tools are becoming more and more available. This means our report reflects captures a moment in time in a field that will likely continue to grow and evolve. We are pleased to present this work contributing to a growing body of knowledge on multimodal street performance and transportation performance measures in general. On behalf of me, my co-authors and an exceptional group of graduate student researchers, we hope this report furthers knowledge on the topic and can assist researchers, planners, engineers, public health officials and other policy makers better understand some available tools at their disposal.

EXECUTIVE SUMMARY

Scholars, municipalities and federal agencies have proposed new measures for evaluating street performance for non-automobile modes including transit service, bicyclists and pedestrians. This is in response to the critique that the current street performance measure, traditional level of service (LOS), overemphasizes the free flow of automobile traffic while neglecting other users of the transportation system. We examine four often-cited multimodal level of service (LOS) metrics; those of the cities of Fort Collins, Colorado and Charlotte, North Carolina; metrics developed by the San Francisco Department of Public Health (BEQI/PEQI), and the multimodal LOS metrics of the 2010 Highway Capacity Manual; and explore the differences between each metric. We provide a literature review with an overview of each metric's development and the variables used to calculate performance scores, as well as their ease of use and threats to their validity. Finally, our literature review closes by offering our critique of the metrics, focusing on how the use of single-outcome metrics (even differentiated by mode) may skew our understanding of street performance by masking considerable variation among users.

Beyond describing the tools, we analyze the scores produced by these measures to document how these metrics compare to one another. We find that these tools, at times, can produce radically different scores for the same street segment. We then illustrate the contribution of specific variables to the overall score for each measure and mode to explain these scoring differences. While more research is needed to understand whether these differences always hold true, this analysis helps practitioners and the research community better understand the promise of these new measures and the challenges that lie ahead. We selected five street segments with different physical and operational characteristics and calculated the bicycle and pedestrian scores for each street segment using the three different tools (Charlotte, BEQI/PEQI, and HCM 2010). Overall, we found that if a street is performing "well" for cyclists and pedestrians, the tools produced fairly similar scores. But as the quality of the street deteriorated, the scores from each tool became increasingly different from each other. This exercise also elucidated some challenges in using the tools; including their inability to evaluate innovative or unusual infrastructure; in our case, a pedestrian mall. We also saw how all of these tools must reflect the goals of the particular agency using the tools and the agency goals and perspective should be included in the decision to select one tool over another.

Lastly, we turned our analysis towards understanding how sensitive each tool is to on-the ground change. The level of service calculation, regardless of mode, is used both to assess current conditions and to evaluate proposed future changes. We wanted to understand how the tools score realistic changes in the built environment. We selected one street segment (from the five in the comparative analysis) and proposed five different scenarios of improvements to both the bicycle and pedestrian environment. We found that all of the scoring mechanisms recommended a road diet scenario with a painted buffer next to a bicycle lane. But we also found that newer bicycle configurations and treatments were often difficult and sometimes impossible to evaluate using these tools. The favored pedestrian scenario was not the same as the favored bicycle scenario and the results were less consistent. Overall, the results demonstrate that these tools can evaluate changes to the street and guide future improvements. However, their ability to measure the effectiveness of innovative treatments is limited.

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INTRODUCTION

Since the inception of street controls and the professionalization of transportation planning and engineering, transportation planning agencies and firms have sought to evaluate the performance of roadways (Meyer & Miller, 2001). The standard metric for the evaluation of urban roadways in the United States has long been the so-called “level of service” (LOS) metric, a quantitative estimation of roadway performance from the traveler’s perspective (U.S National Research Council, Transportation Research Board, 2010). Early LOS concepts, as articulated by the Highway Capacity Manual (HCM) of 1965 (a publication of the Transportation Research Board), were defined in their simplest form as the ratio of two values: the actual use of the road (by motorists) to the intended design capacity of the road for automobile travel (Roess, et al., 2010). In this way, they reflected an automobile-centered understanding of street performance. Since the 1970s however, progressive transportation planners and advocates have suggested that this traditional LOS metric overemphasizes automobiles while neglecting the experience of transit passengers, bicyclists, and pedestrians (Khisty, 1994). Many practitioners, scholars, and advocates have challenged the Highway Capacity Manual’s definition of LOS, calling instead for a multimodal approach for determining the performance of urban roadways.

This literature review presents an overview of recent multimodal level of service metrics. We examine the variables used in calculating the “grades” that roadways receive for different user groups, and contrast the development and formulation of these metrics. This review may be of use to practitioners confronted with an array of choices for measuring roadway performance for a variety of users. We further critique the construction of single-outcome metrics and suggest that the metrics needlessly reduce the complex experience of using a road (as a bicyclist, pedestrian, or transit user) to a value on a single axis. In doing so, we echo Kittleson and Roess (2001) (Kittleson & Roess, 2001)principal concerns regarding traditional LOS models, but extend the concerns to newer multimodal metrics as well. They note that users’ experiences (and particularly, a diverse set of users, even within groupings such as “bicyclists”) cannot meaningfully be reduced to a single score, though this is precisely what LOS metrics attempt to do.

This chapter begins with an overview of the history of LOS metrics, focusing on the introduction of multiple users’ perspectives in recent years. We first present traditional LOS metrics and the first generation of multimodal metrics. We then devote the bulk of this chapter to examining the mechanics of five often-cited multimodal LOS metrics: the 2010 Highway Capacity Manual’s multimodal LOS metrics, the San Francisco Department of Public Health’s bicycle and pedestrian environmental quality indices, and the multimodal LOS metrics developed by the cities of Fort Collins, Colorado and Charlotte, North Carolina. Finally, we discuss what we see as potential problems arising from the adoption of multimodal LOS metrics.

MEASURING ROADWAY PERFORMANCE: HCM AND BEYOND

Early editions of the Highway Capacity Manual (HCM) reflected a growing concern among planners and engineers for accommodating automobile traffic within cities. The first edition of the manual, published in 1950, constituted the first such compendium of capacity concepts, definitions, and empirical data on automotive traffic throughput; its relative thoroughness, and the fact that it was the first compendium of its kind, led to its wide acceptance (May, 1994). It was published right as a massive road-building program (the Interstate Highway system) was beginning in the United States, which further solidified its predominance in the transportation planning and engineering fields (Kittleson & Roess, 2001).

Subsequent editions of the manual extended the original manual considerably, expanding the scope of guidelines to include a number of roadway and intersection types. The second (1965) version of the manual introduced the concept of level of service (May, 1994). The manual quickly became the most widely-distributed publication of the Highway Research Board. According to Kittleson (2000), the manual was soon translated into many languages and the LOS metric (the ratio of auto throughput to roadway capacity) quickly became the "de facto standard" for measuring roadway performance in the United States. Over time, the manual and its standards became enmeshed in local decision-making regarding traffic impact studies for development; this further entrenched the HCM in the U.S. context, as it became the legal standard by which development-approval procedures are often judged (Kittleson & Roess, 2001). Kittleson and Roess (pg 12; 2001) state that HCM's predominance means that it "is effectively changing legislation, a role that is completely unintended and quite troubling."

Indeed, the predominance of HCM in local decision-making has not gone unquestioned. Beginning in the 1970s, a number of government agencies, practitioners, and advocates began to develop alternative metrics for evaluating street performance. While the 1985 and 2000 editions of the Highway Capacity Manual both explicitly included LOS evaluation tools for modes other than the automobile, practitioners and academics continued to find a deficit in the HCM metrics' ability to understand roads from the perspective of pedestrians, cyclists, and transit riders (McLeod, 2000). In response, numerous researchers developed level of service methodologies that aimed to quantify the relationship of environmental factors to the behavior and experience of these users (Khisty, pg 9-14, 1994). Some states and municipalities fostered additional multimodal LOS research in response to heightened interest in measuring non-auto modes' performance, as well as to increased funding for such activities through the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act for the 21st Century in 1998 (TEA-21) (Baltes & Chu, 2002). These new evaluation tools constituted a large body of methods for estimating the performance of roadways for various users, though they differed widely in their specifics.

Responding to increased interest in measuring the performance of streets for non-auto modes, the 2000 version of the Highway Capacity Manual developed a new standard for multimodal level of service measurement. Researchers overseeing the publication convened expert panels to determine changes to existing LOS metrics, as well as the development of new performance metrics where appropriate. HCM 2000's methodology for measuring LOS largely considered user groups in isolation from one another, and did not account for the ways in which one user-group's use of the roadway influences the experience of other user groups. For instance, auto traffic volumes have no direct effect on the metric for transit level of service (Dowling, et al., 2008), when in practice, a transit rider's experience can be dramatically reduced by congested auto traffic leading to unpredictable delays. Additionally, the methodologies developed for bicycle and pedestrian metrics relied upon concepts that may be more appropriate for automobile traffic (such as throughput and speed of operation) than for walking and biking (Sanders & Cooper, 2013).

In response to critiques of the HCM 2000 methodology, and in general interest for developing their own multimodal performance measures, a number of scholars and local jurisdictions began developing multimodal metrics, both in the United States and abroad (Epperson, 1994; Dixon, 1996; National Research Council, 2003; Florida Department of Transportation, 2009; Orth, et al., 2012). These new metrics attempted to reflect the experience of pedestrians and cyclists better by incorporating environmental variables that are likely to influence the user's perception of the quality of the roadway experience. For instance, Florida DOT's metric, Quality/Level of Service (Q/LOS), specifically addresses the "quality" of a roadway, or the "traveler-based perception of how well a transportation service or facility operates (Florida Department of Transportation, 2009).

Responding to critiques of the existing HCM metrics, the 2010 Highway Capacity Manual represented a major overhaul of the HCM methodologies for non-auto users. In this iteration, the manual's authors attempted to address many of the critiques of earlier HCM versions by explicitly including various users' experiences and highlighting the interrelationship between modes. The updated manual further suggested alternative evaluation strategies and highlighted ways in which these strategies can be operationalized. In the following section, we examine this and a number of the publically available metrics available at the time of this writing[1], and contrast their approaches.

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[1] The proposal for this project was developed in 2011 and the project began in mid-2012. The authors recognize there are other measures that have shown great promise since the project began (such as Level of Traffic Stress) but because of funding restrictions, we are limited in our ability to expand our analysis.

APPROACH

In this review, we investigate the 2010 HCM multimodal framework, as well as four other metrics: San Francisco Department of Public Health's Bicycle and Pedestrian Environmental Quality Indices (BEQI/PEQI); the City of Fort Collins, Colorado's framework; and that of the City of Charlotte, North Carolina. We characterize these tools and identify the features that distinguish them from each other. We determine which variables in each metric influence the evaluation of urban street performance, how each framework measures these variables, and the ostensible application and utility of the metrics. Table 1 provides a brief overview to the four metrics.

Index	Year	Unit of Measurement	Modes Included	Rating System
Fort Collins	1997	Areas	Auto, Bicycle, Pedestrian, Transit	Letter Grades (A,B,C,D,E,F)
Charlotte	2007	Intersections	Auto, Bicycle, Pedestrian	Letter Grades (A,B,C,D,E,F)
BEQI/PEQI	2009 / 2012	Street segments, Intersections	Bicycle, Pedestrian	Ordered Categories
HCM 2010	2010	Multiple. Can measure individual street segments (links), intersections or these in combination	Auto, Bicycle, Pedestrian, Transit	Letter Grades (A,B,C,D,E,F)

TABLE 1: METRICS INCLUDED IN LITERATURE REVIEW

Notable measures that are missing from this analysis:

- "Level of Traffic Stress" (Mekuria, et al., 2012). This methodology only exists for bicycle and not pedestrian travel and was published as this project began so the original scope did not include this measure.
- "Danish Bicycle Level of Service" (Jensen, 2007). This methodology also only evaluates bicycle environments. Currently, only the segment tool is available in English; the intersection tool only exists in Danish.

FORT COLLINS

Since the late 1990s, officials of the City of Fort Collins, Colorado has used multimodal performance metrics to inform their city general plan, shape their municipal transportation master plan, design congestion management programs and to approve real estate development projects (City of Fort Collins, 1997). The metrics used by Fort Collins evaluate the performance of streets through letter grades for transit, bicycle, pedestrian and auto modes. For the Fort Collins and other measures analyzed in this report, we omitted the auto LOS metric to focus solely on bicycle and pedestrian measures.

BICYCLE

The Fort Collins bicycle methodology only considers roadways with bicycle lanes or routes and bicycle paths, and contains design standards for each. Therefore the methodology does not contain any design specifics; it assumes the facilities are designed to the city standards. At this point, we are not aware whether this is the case on-the-ground but for the purposes of this analysis, we assume it to be true. Since the facilities are designed to a city adopted standard, the performance grading scheme for the bicycle LOS system relates only to the *connectivity* of each facility to other facilities. For instance, in order to achieve a grade of “A,” a given segment of a bicycle facility must be directly connected to on-street lanes in both the north-south and east-west directions. The methodology assumes a hierarchy of preferred facility type: on-street lanes, off-street path and on-street routes, in descending order. Different areas within the city of Fort Collins have different minimum requirements under the city’s strategic plan. For instance, the minimum LOS standards are higher for public school sites (minimum grade of A), than for recreation sites and community/neighborhood centers (minimum of B).

Importantly, the metric does not explicitly consider the quality of bicycle infrastructure. The metric assumes that facilities are uniform and consistent with the city’s guidelines and consequently does not assign varying grades for various degrees of facility design quality. The city’s design guidelines for on-street bicycle lanes and off-street paths includes a variety of standards that govern or advise on factors such as lane width, signage, striping, adjacent tree cover, elevation, curves, slope, curb ramps, turning radius and more.

PEDESTRIAN

In contrast to the relatively straightforward bicycle LOS calculations, the Fort Collins metric for pedestrians is considerably more complex. The pedestrian LOS score is determined using five main inputs:

1. Directness;
2. Continuity;
3. Street crossings;
4. Visual interest/amenity;
5. Security.

Different types of neighborhoods and areas within the city have different minimum letter grade requirements. For instance, city-designated “pedestrian districts” must receive “A” letter grades in all areas except “street crossings,” while “transit districts” can receive grades of “B.” Each of the inputs receives a separate “A” through “F” letter grade based on a detailed rubric; the main inputs are described below.

DIRECTNESS

Directness is the defined “as the walking distance to destinations including transit stops, schools, park, commercial employment or activity areas” (ibid). Directness is calculated as a ratio of the “actual” distance (existing or proposed) between origin and destination divided by the “minimum” (straight-line) distance. The analyst selects a number of representative origins, representative as defined by the analyst, within an area and a number of nearby destinations, such as shops, schools, and parks. Areas with greater directness scores receive a higher grade; for instance, a ratio of 1.2 or lower is required for an “A” grade, while a ratio greater than 2.0 receives an “F” score.

CONTINUITY

Continuity implies a lack of gaps in the sidewalk/walkway system in an area. The analyst must ascertain the degree of sidewalk interruptions in a given area. For instance, a grade of “A” is assigned to integrated (gapless) networks, while areas with continuous sidewalks separated by the occasional landscaped parkway receive a grade of “B.”

STREET CROSSINGS

Street crossings are judged separately based on the number of lanes the pedestrian must cross and the type of intersection control used in each case. The street crossing index rates the quality of intersections based on several variables including geometry, signage, amenities, and markings. Crossings of different types (signalized versus unsignalized, for instance) have different thresholds for each of the letter grades. For instance, an unsignalized street crossing of a major roadway receives a grade of ”A” when there are fewer than three lanes to cross, has well marked crosswalks, good lighting, standard curb ramps, and a number of other features (for full table see Appendix A). A signalized crossing further requires automatic pedestrian phases (i.e. no push-to-walk button) to receive an “A” grade. Street crossings that have more lanes or fewer positive attributes (lighting, etc.) receive lower grades.

VISUAL INTEREST AND AMENITIES

Visual interest and the amenities of a street are a qualitative input to the overall grade. This input is based on the assessor’s subjective scoring of the facility’s aesthetics, compatibility with local architecture, and use of amenities such as fountains, lighting and benches. Visually interesting streetscapes with wide sidewalks, pedestrian-scale lighting, and pedestrian furniture may make the pedestrian feel more comfortable, and therefore receives high level of service scores.

PEDESTRIAN SECURITY

The Fort Collins methodology further incorporates a subjective evaluation of pedestrian security and safety. Pedestrian security is defined in two senses: 1) prevention of crimes committed on pedestrians along the right of way, and 2) prevention of potential collisions with vehicles and bicycles. Pedestrian facilities with clear lines of sight, presence of police or other pedestrians, and good lighting levels receive the highest LOS grade. Facilities that lack clear visibility to the street or along the sidewalk receive low LOS grades.

BEQI/PEQI

Beginning in 2007, the San Francisco Department of Public Health (SFDPH) developed the twin metrics of the Bicycle Environmental Quality Index (BEQI) and Pedestrian Environmental Quality Index (PEQI) (San Francisco Department of Public Health, 2008; 2009). These indices were developed as a component of a larger effort to link transportation infrastructure in the city to health and sustainability, as well as to provide an alternative to traditional LOS metrics. These street quality indices use analyst-collected or GIS-based data to measure an urban street segment (usually one side of a block) or intersection. The department developed the original indices in 2007, and last updated the PEQI index in 2012 (known as version 2.0) (San Francisco Department of Public Health, 2012). In both indices, the indicators and their response categories are assigned a scaling factor (weight). Both indices are scored on a 0-100 numerical scale, with a score of 100 being the most desirable; these numerical scores correspond to five grades, each of which is assigned a color: red indicates an environment unsuitable for bicyclists and pedestrians, while green indicates "ideal" conditions, with varying shades of orange and yellow in between. An example application is seen in Figure 1 below.

FIGURE 1: PEQI EXAMPLE APPLICATION AROUND ELEMENTARY SCHOOL SITE.

VARIABLES

The Pedestrian Environmental Quality Index is intended to reflect "the degree to which environmental factors supportive of walking and pedestrian safety have been incorporated into street segment and intersection *design*" (San Francisco Department of Public Health, 2008) [emphasis added]. This emphasis on design extends to scoring bicycle facilities, as well. Thus, most of the factors considered are "brick and mortar" features reflected in the physical infrastructure of the street or surrounding area. The major exception to this is vehicle traffic volume along the adjacent street, which is negatively associated with pedestrian and bicycle LOS. The metrics include dozens of additional variables as inputs, including:

1. *Intersection safety*: For instance, dashed bicycle lanes through intersections and no-turn-on-red signage increase BEQI scoring, while pedestrian refuge islands improve PEQI scores. Longer wait time for a walk signal and greater necessary crossing speed for pedestrians reduce the PEQI score.
2. *Vehicle traffic*: additional vehicle lanes, higher speed limits, and greater automotive traffic volumes all negatively influence both BEQI and PEQI scoring, while traffic calming features improve the scoring. BEQI scores are further reduced for greater heavy-vehicle traffic and more parallel parking near the bike lane.
3. *Street design*: More driveway cuts per block negatively influence both scores, while more tree coverage positively influences the scores. The quality of pavement on sidewalks (for PEQI) and roadways (for BEQI) strongly infleunces the scoring.
4. *(Perceived) safety*: Pedestrian- or cyclist-scale (smaller) lighting postively influences both the BEQI and PEQI scoring, while litter, graffiti, and empty space negatively influence PEQI. Bicycle-related signage increases the BEQI scoring for safety.
5. *Land use*: Greater presence of retail establishments improves both BEQI and PEQI scoring, while seating, public art, and public space improve PEQI only.

Staff at SFDPH selected the input variables for PEQI and BEQI after a review of the relevant literature on "existing pedestrian quality or 'walkability' indices and level of service metrics, design guidelines, and factors associated with increased walking and improved pedestrian safety in empirical research (ibid)." The contribution of the variables to the overall score was determined by a survey sent to academics, practitioners and non-motorized transportation advocates with 88 BEQI surveys responses and 20 PEQI survey responses. The scoring contributions were assigned on the basis of the median importance level indicated by the survey respondents.

APPLICATION

The San Francisco Department of Public Health maintains a GIS tool for analyzing the BEQI/PEQI scoring of streets within its jurisdiction, as well as for examining the impacts (to scoring) arising from proposed alterations to the roadway. Once BEQI/PEQI scores are calculated, aggregate scores and the results are often overlaid on images of San Francisco street networks to provide a "heat map" that is visually intuitive.

Additionally, SFDPH provides extensive technical assistance to others (for instance, non-profit organizations) who wish to use the BEQI/PEQI methodology, both within the San Francisco context and (to a lesser extent) outside that context. Downloadable checklist-style forms, technical documents, a Microsoft Access database, and other materials are available from the department on its website (San Francisco Department of Public Health , n.d.).

CITY OF CHARLOTTE

In 2007, the city council of Charlotte, North Carolina adopted the Urban Street Design Guidelines (USDG) with the explicit goal of building more "complete streets" in the city. The USDG adopted an explicit protocol for interventions that includes, in some cases, an assessment of bicycle and pedestrian LOS at signalized intersections. The Charlotte Department of Transportation (CDOT) and city planners use the USDG as a "diagnostic tool to assess and improve pedestrian and bicyclist levels of comfort and safety by modifying design and operational features (City of Charlotte, 2007)."

CDOT evaluates bicycle and pedestrian LOS separately by noting which of several different intersection features exist, using a checklist. Additionally, the department has included a range of alternative features on the checklist so officials can use the LOS materials as practical tools in assessing alternatives in the street (re)design process. The USDG's bicycle, pedestrian and automobile LOS scores are in the classic letter grade A-F (ibid).

VARIABLES

PEDESTRIAN LOS

CDOT constructs the pedestrian LOS score through a points-based checklists system with five areas (ibid). A minimum of 93 points are required to obtain a letter grade of an "A" while a minimum of 74 points is necessary for a "B."

Groups of input variables are listed below with brief explanations of their significance:

1. *Crossing distance:* Wider streets have a larger negative effect on pedestrian LOS (decrease points than any other factor. The presence of a median refuge can mitigate this by adding points, depending on its width.
2. *Signal phasing and timing*: Points are awarded "according to the type and level of crossing information provided to the pedestrian and whether the signal phasing minimizes, eliminates or exacerbates conflicts between pedestrians and turning vehicles (ibid)."
3. *Corner radius:* A smaller radius results requires vehicles to slow down to turn the corner and reduces the walking distance between corners. Hence, the smaller the radius, the more points awarded, and the higher the pedestrian LOS.
4. *Rights turns on red:* A vehicular right turn on red is a potential conflict point with crossing pedestrians; the absence of this feature increases scoring a small amount.
5. *Crosswalk treatment:* Whether or not a crosswalk is marked, and the degree to which it is visible, affects motorist awareness of pedestrians and thus pedestrian LOS. Points are taken off for a lack of a crosswalk. Points are awarded for ladder-type markings and textured or colored pavement.
6. *One-way-street adjustment*: An intersection with a one-way street has a greater potential number of conflict points between cars and pedestrians. A one-way street results in a point penalty that varies depending upon the number of vehicle-pedestrian conflicts resulting from the left-turn traffic signalization.

BICYCLE LOS

CDOT evaluates Bicycle LOS on a similarly constructed checklist for bicyclists. Two categories overlap from the pedestrian calculations: crossing distance and right turns on red. The additional bicycles variable categories are as follows:

1. *Bicycle travel way & speed of adjacent traffic*: The order of preferences for different facility types is: bicycle lanes, shared wide-curb lanes and shared auto lanes. Each type is awarded more points when the adjacent automobile speed limit is lower.
2. *Signal features – left turn phasing & stop bar location:* More vehicle left-turns increase the risk of conflicts between vehicles and cyclists and result in lower scoring. The checklist also favors intersections that have a bicycle stop line further into the intersection than the vehicle line.
3. *Right turn traffic conflict:* The checklist lists several possible ways an intersection's lane configuration and design can mitigate a conflict between a right turning vehicle and a bicycle passing through. The lower the risk of this type of collision, the more points awarded. A bicycle

lane to the right of the vehicle lane at the point of intersection results in a large penalty of twenty points.

4. *Right turns on red:* A prohibition on vehicular right turns at a red light adds points to increase bicycle LOS.
5. *Crossing distance:* An intersection with intersection crossing distance greater than three lanes decreases the points awarded to the bicycle LOS score.

HIGHWAY CAPACITY MANUAL 2010

The 2010 Highway Capacity Manual introduced a complex multimodal level of service (MMLOS) tool. The designers of this tool sought to develop a level of service methodology that explicitly addressed user concerns with the previous methodology's (HCM 2000) emphasis on automobile traffic and the lack of interaction between auto, pedestrian, transit, and bicycle LOS metrics (Dowling, et al., 2008).

The formulae in the HCM were developed in a series of studies led by Bruce Landis and Theo Petritsch in an effort from the Florida Department of Transportation to develop their own multimodal performance measures. These papers include a series of walking and bicycling courses referred to as "ride or walk for science" where people were sent out to routes within Florida cities and asked to provide their feedback on an A-F grading scale for the issue of interest. A summary of these studies is seen in the table below.

Source	**Focus of study**	**Location and date**	**Number of participants**	**ADT Roadway Variety**
(Landis, et al., 1997)	Bicycle link	Saturday, April 27, Tampa, Florida	145	550 – 36,000 mean of 12,000
(Landis, et al., 2001)	Pedestrian link	Saturday, March 18, Pensacola, Florida	~75 (no exact number listed)	200 – 18,500
(Landis, et al., 2003)	Bicycle intersection	Saturday, April 6, Orlando, Florida.	59 (66% male)	800 – 38,000 mean of 25,600
(Petritsch, et al., 2005)	Pedestrian intersection	Friday, April 30, Sarasota, Florida.	46 (67% female)	Not noted.
(Landis, et al., 2005)	Pedestrian intersection refinement via video simulation	Friday, April 30, Sarasota, Florida	~50 (67% female)	Not noted.

TABLE 2: STUDIES FOR THE DEVELOPMENT OF HCM MMLOS PREVIOUS TO NCHRP REPORT 616.

Each of the aforementioned studies took the participants through a course of regularly operating streets and roadways (or video simulations in a few cases). Test proctors stopped participants and had them complete response cards, grading the portion of roadway they just rode or walked through, on a scale from A to F. Depending on the study, participants graded links or intersections: these are formal units of analysis defined in the HCM and depicted below in Figure 2. The researchers then took respondents' grades and performed linear regression, aiming to explain the variation in scores using variables identified in the literature as being influential of that particular modes quality of service. Best-fit regression coefficients are the coefficients that appear in the HCM and in the formulas used to calculate the ultimate scores.

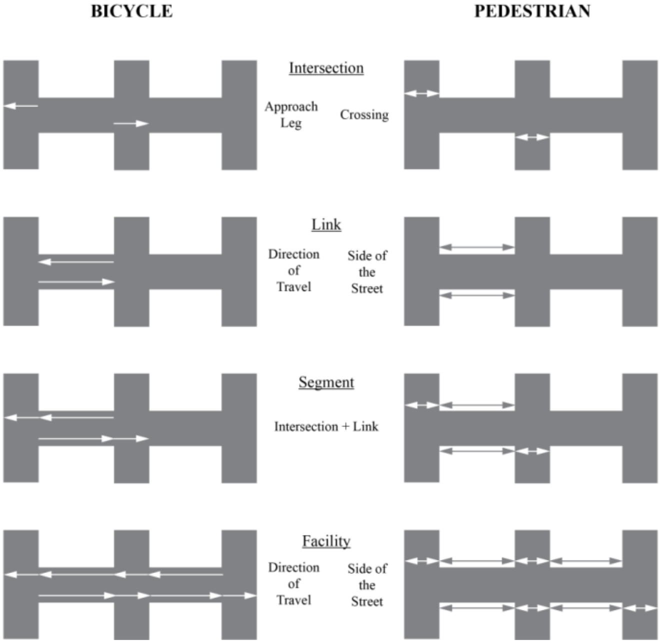

FIGURE 2: HIGHWAY CAPACITY MANUAL UNITS OF ANALYSIS

These models were then taken as a priori inputs in further experiments used to develop bicycle and pedestrian level of service calculations using participant ratings of video clips of various streets. This process is described in NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets (Dowling, et al., 2008). To our knowledge, neither the bicycle or pedestrian models were ever validated, calibrated, or otherwise tested on roadways and participants other than those used to develop the model. Furthermore, the original methodology raises some concerns: the small number of participants, the isolated locations and the age of these models and their testing. Each course for science was located in a different geography, with different participants and attempted to isolate a particular element of the transportation environment. It appears as though these isolated tests were adopted wholesale into the formulae that became the 2010 Highway Capacity Manual methodology.

VARIABLES

The predictive models developed in the survey phase use various geometric, operational, and interactive variables as inputs, recognizing that a variety of factors influence travelers' experiences of using the roadway, and that these factors differ from one mode to another (National Research Council, 2010). The specific variables selected for the each modal LOS model reflects a compromise between what is “found both intuitively and mathematically validated to be significant” to the users of each mode (Dowling, et al., 2008). The authors of the NCHRP Report 616 separated variables into four categories that are described below: facility design, facility control, transit service, and modal volumes.

FACILITY DESIGN

All four modal LOS models in the HCM 2010 MMLOS methodology use road geometry and other physical attributes of the urban streets as inputs. These attributes include the cross-street width at intersections, pavement conditions, the percentage of parking spaces on the streets that are occupied, sidewalk width, presence of trees, median type, and block length, to name a few.

FACILITY CONTROL

The models also use operational characteristics - the conditions that regulate the movements of autos, pedestrians, and bicyclists on a road facility - as inputs into all four LOS models. Specific attributes used in the model include auto stops (or delay), mean speed, speed limits, bus speed, parking occupancy, crossing delay, and signal time length, among others.

MODAL VOLUMES

Auto, transit, bicycle, and pedestrian volumes are the key cross-cutting variables in the MMLOS integrated framework. Every separate modal LOS score within the larger MMLOS framework is partially determined by the volume of urban street use by other modes. For instance, the model predicts that an increase in bicycle volume on a shared road segment will increase the auto delay and/or mean speed, potentially resulting in a negative influence on automobile LOS. The LOS model equations allow engineers and planners to calculate the level of service trade-offs between modes for potential operation and design modifications to urban street segments and intersections.

APPLICATION

The formulae developed through the HCM 2010 MMLOS project are available in at least two software toolkits. The first is a comprehensive software package developed by the principal consultant team that worked on developing the formulae and methodology for 2010 HCM (Kittleson and Associates, n.d.).This proprietary software package implements the full range of HCM 2010 MMLOS metrics. A separate spreadsheet-based analysis package was later developed by another consulting team, and is available free-of-charge on their website (Fehr and Peers, n.d.). However, the scope of this spreadsheet-based package is limited to analysis of roadway links, without support for evaluating intersections or facilities.

The full MMLOS suite enables practitioners to calculate separate LOS grades for urban intersections, segments, and urban street facilities. HCM 2010 defines urban streets as consisting of links and points. Links are lengths of roadways between intersections, while points represent intersections or ramp terminals (National Research Council, 2010). The intersection MMLOS tool evaluates signal-controlled and two-way stop-controlled intersections for pedestrians and bicyclists. Urban street segments are evaluated as both a link and by its boundary intersections (incorporating the intersection LOS scores). Finally, the MMLOS tool may evaluate an urban street facility, defined as a set of contiguous urban street segments and intersections (incorporating both intersection and segment LOS scores).

The automobile component of urban street facility MMLOS does not produce specific LOS grades for intersections between segments; rather intersections for automobiles are treated separately in the HCM 2010. Overall performance of urban street facility for autos is indicated by travel speeds defined as a percentage of free-flow travel speeds, and the volume-to-capacity ratio for through-movement at the downstream boundary intersections.

The scope of application is variable. Depending on an analyst's objectives and agency directives, he or she may apply the MMLOS tool to a variety of urban street scenarios (ibid). The analyst defines a scope of analysis and selects the MMLOS metric capable of characterizing the desired subject. After collecting field data on variables relevant to the analysis, the analyst uses the predictive LOS models to generate an LOS score for each mode. This score is then compared to thresholds based on a rating system of "A" through "F", including E, for determining the LOS grade for the subject. The letter grading system is intended as a useful measure "for describing street performance to elected officials, policy makers, administrators, or the public" (ibid).

DISCUSSION: LIMITATIONS TO EXISTING MULTIMODAL METRICS

The metrics included in this analysis differ from one another considerably. One rudimentary way to examine their differences is to examine the different inputs used in each model. Appendix A of this report includes a table providing a comparison of which inputs are used to calculate the scoring of each metric. In addition to these differences, we examine the potential applicability of these metrics outside the contexts for which they were developed, as well as other threats to their validity.

FORT COLLINS

A number of potential difficulties exist in applying the Fort Collin's LOS system (particularly, the bicycle metric) outside of the context for which it was developed; nor was this likely the intent of its designers. The bicycle LOS metric does not provide a rating of the relative importance of roadway features or of operational features. Bikeways (lanes, paths and routes) are simply up to the city's standard or they are not a part of that network and are not evaluated. This type of rating system provides little understanding of which elements of the bike infrastructure (lane width, etc.) are thought to be important to users. In a sense, this creates a pass/fail grading scheme for bicycle infrastructure, and a more nuanced grading scheme for corridors and networks. This methodology may not be appropriate for applications that call for a more differentiated set of infrastructure improvements, or where a wide variety of bicycle infrastructure types already exist.

BEQI/PEQI

One of the major threats to the validity of the BEQI/PEQI indices is the use of expert opinion, broadly defined, as a proxy for the average street users' perception of street quality. Experts' assessments may, of course, be wrong, or they may disagree so strongly that differing opinions negate one another entirely. When they arise, these disagreements may not reflect misunderstanding(s) of actual users' perceptions; they may instead reflect the fact that two reasonable people can value attributes of the roadway quite differently. Further, experts may have biases (for example, toward "hot, new" interventions) which do not reflect how laypeople will actually experience or react to the street or intersection.

SFPDH acknowledges further limitations to the indices:

1. PEQI does not consider the attraction of activity sites on pedestrians;
2. PEQI does not consider street connectivity at a network level;
3. PEQI design considerations are for the general population and do not consider the needs of the mobility impaired.
4. BEQI does not consider the effect traffic signals have on an intersections or street segments.
5. BEQI is not sensitive to different bicycle experience levels affect roadway perception. Experienced riders may, for instance, make certain routing decisions due to a desire for higher speed (San Francisco Department of Public Health, 2009).

CITY OF CHARLOTTE

A limitation of the Charlotte bicycle and pedestrian LOS measures is that they only apply to intersections and not to street segments. This may result in analytical errors if there is a spillover of effects, affecting safety or comfort, from the street segment in to the intersection. In addition, the metric lacks transparency regarding the selection and development of variables as well as their weights for the points system.

The LOS system, in addition to being limited to intersections, is largely focused on bicyclist and pedestrian safety as it is impacted by street design. A host of factors relating to walkability are not considered as part of the LOS grades in the Charlotte methodology. These considerations may be addressed in Charlotte's USDG, but are not directly part of the scoring of street performance.

HCM 2010

The principal threat to the validity of the MMLOS model is embedded in its analytical approach and the way in which that approach was developed. We found methodological concerns at each point of the project development. As mentioned previously, the equations in the final 2010 HCM are nearly identical to the equations developed in the paper series leading to the HCM. The threats to validity of the HCM are therefore the same threats to the validity of the development papers. We have listed the threats by each paper and then as a group below.

Source and topic	Threats to Validity
(Landis, et al., 1997) Bicycle link	- Only limited to bicycle infrastructure available in Tampa, Florida in 1997 - Participants provided responses for link only and were told to ignore intersections - "Although the course had an excellent variety and range of the roadway and traffic variables typically encountered by cyclists in metropolitan areas, only two segments had substantial high turnover on-street parking." Many urban streets have high turn-over of on-street parking so this may be problematic in many areas
(Landis, et al., 2001) Pedestrian link	- Less than 100 participants in study - Only relatively low volume streets were considered (max. ADT 18,500) - Does not include intersections and participants "were also encouraged to exclude from their consideration the surrounding aesthetics" while literature suggests that aesthetics do have an effect on peoples walking patterns and behavior[2] (Cunningham & Michael, 2004; Lee & Vernez Moudon, 2004; Handy 2005).(Cunningham & Michael, 2004) (Handy, 2005) (Lee & Vernez Moudon, 2004)
(Landis, et al., 2003) Bicycle intersection	- Only limited to the bicycle infrastructure available in Orlando, Florida in 2002 - Less than 60 participants, 2/3rds of whom were men; participants skewed towards cyclists who average more than 1000 miles per year. Yet participants described as "a good cross section of age, gender and geographic origin" - Striped bicycle lane *maximum* width was 4ft wide, narrower than the minimum in many standard design handbooks - Applications section left without citations to allow researchers to replicate claims, including "the bicycle LOS (segment) method is used by numerous jurisdictions to determine the level of accommodation provided to bicyclists on roadways between intersections."
(Petritsch, et al., 2005) Pedestrian intersection	- 50 participants and 2/3rds were women - Reports traffic volumes in vehicles per hour (with a minimum of 0) rather than ADT so difficult to judge how the volumes compared to previous work
(Landis, et al., 2005) Pedestrian intersections with video simulations	- 50 participants and 2/3rds were women

Table continues onto next page…

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[2] We acknowledge these citations were published after this article. However, many are reviews of the literature which suggests the evidence existed at the time of the writing of the article in question.

(Petritsch, et al., 2008) Pedestrian facility & (Dowling, et al., 2008) NCHRP-616 Bicycle and pedestrian segment	• No sociodemographic variables were collected; even though the authors postulate this could influence perceptions of level of service • Not all clips were shown to all participants. Only a few of the clips were shown consistently to the 4 different groups of participants • None of the clips scored an average "A" grade or an average "E" or "F" grade signaling issues in the variation among the clips or whether the participants could distinguish between the 6 different distinct categories • Adopts equations from previously mentioned studies without any validation from other places or replication of model results • Mentions budget constraints for field testing but did not collect video clips (affordable method) for locations outside of Tampa, Florida. • Maximum bicycle lane width was 4'. In the summary of bike lane width recommendations table in NCHRP 766 (Torbic, et al., 2014) the minimum is most frequently 5' while the recommended widths are wider than the 4' used in the study. • Males rated bicycle clips significantly higher than females. However, the report states "However, analysts would not generally have information on the sexual split between bicyclists, so sex was excluded from the bicycle LOS model development" (Downling, 2010; 53). Since the gender differences were significant, it would appear this should be taken into more consideration in further analysis • Participants in Chicago, where the participants walked the most, rated the pedestrian video clips significantly worse than the other areas; signaling there may be limits the Florida clips' applicability to areas where rates of walking are high.

TABLE 3: THREATS TO VALIDITY OF HCM 2010 EQUATION DEVELOPMENT

In addition to these study-specific threats referenced in Table 3 above, this methodology taken as a whole presents a number of threats to validity. This includes the following problems:

- No key was given for each letter grade; each participant may have different feelings as to what a "C" intersection would look like, for example. No standardization method was performed to analyze this or correct for any possible error. In one study, the authors noted that no segment received an average A or average E/F signaling that it may be difficult for participants to grade across the range of 6 categories. Dowling et al. explicitly recognize that average urban street users are capable of determining between only two or three levels of service, though it retains the six-letter grading system for the ease of communicating results.
- The participants in the field scored each component of interest on an ordinal scale from "A"-"F". The authors provided a table with a range of values that the letter grades correspond to but never explicitly state what value in the range was selected for the purposes of linear regression (see Table 4). The participant's rankings should be considered ordinal values; since the authors do not know that the range is the same for each participant nor that for each individual participant there is a standard measurement of differences between grades. Ordinal variables are most

appropriately modeled using ordered logit or ordered probit models, rather than stepwise or linear regression (Winship & Mare, 1984).

Grade	Score range (Landis, 1997; Landis 2001; Landis 2003; Petrisch 2005	Score range (NCHRP)
A	$x \leq 1.5$	$x \leq 2.00$
B	$1.5 < x \leq 2.50$	$2.00 < x \leq 2.75$
C	$2.50 < x \leq 3.50$	$2.75 < x \leq 3.5$
D	$3.50 < x \leq 4.50$	$3.50 < x \leq 4.25$
E	$4.50 < x \leq 5.50$	$4.25 < x \leq 5.00$
F	$x > 5.50$	$x > 5.00$

TABLE 4: LEVEL OF SERVICE SCORE RANGES

- The ranges of scores changed between the development papers and the NCHRP project as seen in table 4. The effect of this change was that high “B” grades became “A”, high “C” grades became “B”, low “D” grades were lowered to “E” and low “E” grades became “F.” The NCHRP report ignores this change in scoring and any implications of the change.
- Each model was based on one day of the field testing. Because of this, it is unclear whether the results would hold if the field testing was conducted more than once.
- No model was ever tested or validated outside of the original testing location. It is unknown whether the regression model would accurately predict the scores that would be given in another location with another set of study participants.
- Because each component (intersection and link) was developed separately, we do not know whether the results would be different if a participant scored both the intersections and the links on one corridor. The models do not account for the likely possibility that bicyclists’ and pedestrians’ perceptions at a given intersection are influenced by adjacent links, and vice versa.

CONCLUSION

Each of the indices studied here are to a degree dependent on limited field testing, experts’ framing of the issues, bounding of the units studied, and judgment on the relative importance of factors. While Fort Collins’ and the City of Charlotte’s methodologies are designed with specific contexts in mind, the designers of the HCM 2010 and BEQI/PEQI measures appeal to a more universal approach based on the measurement (self-report) of user experience. Yet perhaps this attempt at generalizability has obscured the assumptions made in constructing those rating systems. The indices made by municipal transportation authorities (Fort Collins and Charlotte) do not justify their methodologies by linking scoring to measured user satisfaction, but neither do they attempt to universalize the metrics created. In particular, the HCM metrics’ appeal to universality is based on satisfaction scores of a limited set of study participants. However, the complicated regression techniques of HCM suggest that the "universality" of the models is based on a number of assumptions: the selection of variables to model, the selection of roads to the field testing and video clips, and the specification of a functional form when estimating the model.

We echo the concerns of Kittleson and Roess (2001) in their analysis of the Highway Capacity Manual, but extend the concerns to newly-developed multimodal metrics. Kittleson and Roess' concerns are many, but they hinge on unease with the reliance upon single-outcome LOS metrics. These single-outcome metrics can result in an overly-simplistic, perhaps skewed understanding of how diverse user groups experience roadways in diverse ways. They argue that LOS, to which we add the multimodal metrics described here, offers the illusion of *accuracy* by providing *precision*. Analysts enter a number of inputs into a model and obtain a precise letter grade. But in doing so, these letter grades mask the variation in how different users perceive roads differently. What may be an annoyance and impediment for one pedestrian may be a desirable amenity for another. As with automobile LOS, a single grade can never capture diverse users' perceptions. We argue that for pedestrians and cyclists—where perceptions of physical exertion, safety, and other factors may differ tremendously from person to person—these single-grade scores are likely misleading.

We further share Kittleson and Roess' concern that LOS metrics, particularly through their use of single-outcome models, "retard intelligent consideration of the various available quality measures" (Kittleson and Roess, pg 12, 2001). To this we would add the potential for LOS metrics (even multimodal metrics) to guide (and perhaps skew) public debate about the purpose of streets and their performance by providing an "appropriate" framework for discussion. Rather than providing multiple, readily understood data points (for example, delay at signals at the rush hour, number of pedestrian or cyclist fatalities and injuries, rates of walking and biking, and so forth), these LOS metrics call upon expert knowledge and behind-the-scenes number-crunching to produce a single letter grade. Such a grade has a ready meaning for anyone who has ever gotten a report card, but the impression that the public and other stakeholders get from the LOS grade doesn't necessary correspond to how users experience the street being graded. We worry that these metrics may reduce the ability of laypersons to engage in public discourse about streets by further relegating the interpretation of streets to the realm of experts—though precisely the opposite is likely the intention of the designers of some of these metrics.

CHAPTER 2: COMPARING MEASURES AND VARIABLES

INTRODUCTION

This chapter seeks to compare and analyze some of the bicycle and pedestrian level of service measures referenced in the previous literature review chapter. We excluded the Fort Collins measure because the geographic unit differs from the other measures; Fort Collins is area based compared to intersections and links for the others. Each measure emphasizes different factors, (found in Appendix A) scaled differently. This chapter applies these measures to real world test segments to display the scoring differences. This process is similar to other studies (Parks, et al., 2013), but adds to the analysis through including both pedestrian and bicycle measures. This allows practitioners to better understand how these new methodologies compare to each other for both walking and bicycling. Our analysis uniquely contributes to the growing body of knowledge by describing the scoring mechanics in each formula which led to the differences and similarities in their scoring output. In the conclusion, we discuss how this analysis can be most helpful to practitioners.

METHODOLOGY

We selected three newly created measures for bicycle LOS and three for pedestrian LOS:

- Bicycle Environmental Quality Index (BEQI) and Pedestrian Environmental Quality Index (PEQI) created by the San Francisco Department of Public Health
- City of Charlotte Level of Service protocol, Bicycle and Pedestrian
- Highway Capacity Manual (HCM) 2010 multimodal level of service (MMLOS), Bicycle and Pedestrian

We recognize there are other measures not analyzed (City of Fort Collins, 1997; Jensen, 2007; Mekuria et al., 2012) including the Danish Bicycle Level of Service, the Fort Collins, Colorado Multimodal Transportation Level of Service Manual and Level of Stress calculation. The Danish Bicycle Level of Service provided fewer comparisons to traditional bicycle infrastructure in the US. The Fort Collins methodology presents a different spatial approach by evaluating an area rather than a street segment, not allowing for comparison to other measures.

Our test segment selection was limited by data requirements, including traffic volumes and turning movements and methodological constraints. The HCM requires signalized intersections in order to compute bicycle and pedestrian scores. Traffic volume data is required not only for the test segment, but also for all intersecting streets. Since the City of Santa Monica, California, regularly collects traffic information for autos, bicyclists and pedestrians at a fairly dense grid throughout the city, it proved to be an ideal location for the study. Even then, we were limited to find street segments which had three adjacent signalized intersections. Based on these limitations, we were able to find five test segments to analyze: Arizona Avenue, Main Street, 17th Street, 20th Street and Cloverfield Boulevard.

TEST SEGMENT DESCRIPTION

ARIZONA AVENUE

Arizona Avenue is a minor avenue that serves local auto trips and bicycle trips, with the highest level of pedestrian activity among the test segments. The right-of-way includes one travel lane in each direction, curbside parking, and bicycle lanes in both directions and is intersected by a pedestrian-only street. We hypothesized this segment would rank the highest because of low number of travel lanes and the intersection of the pedestrian-only street.

FIGURE 3: CROSS-SECTION OF ARIZONA AVENUE.

MAIN STREET

Main Street is in a commercial, moderate density, collector street. The right-of-way includes one travel lane in each direction, a dedicated center-turn lane, bicycle lanes on both sides of the street, curbside parking, and tree-lined sidewalks. This street is fairly similar to Arizona, with the addition of the center-turn lane and moderately higher traffic volumes. We expected this segment would rank moderately well, but not as high as Arizona.

FIGURE 4: CROSS SECTION OF MAIN STREET

17TH STREET

17th Street is a minor avenue, serving local auto trips and bicycle trips. The right-of-way between Broadway and Colorado includes one travel lane in each direction, bicycle lanes on both sides of the street, and some curbside parking. From Colorado to Olympic, 17th Street narrows and excludes curbside parking. This segment was hypothesized to rank in the middle among the test segments.

FIGURE 5: CROSS SECTION OF 17TH STREET

20TH STREET

This segment is parallel to 17th street, a few blocks away, featuring two travel lanes in each direction and a center turn lane. The street does not allow curbside parking and does not include bicycle lanes. It provides access to the Santa Monica Freeway and is designed to serve regional auto trips. Based on the freeway access and lack of bicycle facilities, we hypothesized this would rank lower than the aforementioned segments.

FIGURE 6: CROSS SECTION OF 20TH STREET

CLOVERFIELD BOULEVARD

Cloverfield Boulevard is a major avenue designed to serve regional automotive trips and provide access for all modes of transportation. Cloverfield Blvd. connects nearby streets to the Santa Monica Freeway with a high volume of traffic, including many heavy-duty vehicles with no curbside parking or bicycle lanes. From Broadway to Colorado, the right of way includes two travel lanes in each direction and a center turn lane. From Colorado to Olympic, Cloverfield Blvd. widens considerably to include three travel lanes in each direction and a two-lane median for dedicated left turns. Our hypothesis was that this segment would rank the lowest among the test streets.

FIGURE 7: CROSS SECTION OF CLOVERFIELD BOULEVARD

ANALYSIS OVERVIEW

Each segment includes three intersections and two connecting streets, known as "links." HCM can combine the intersection and link results to produce grades for the larger geographical units (segments and facilities), but those larger units are not included in this analysis. BEQI and PEQI produce scores for both intersections and street links while Charlotte measures only LOS at intersections (producing a score for each directional approach to the intersection and averaging these for an intersection score). This paper only covers intersection and link scores, as seen in the "b" section of Figures 8-12.

All measures first create a numerical index for the geographical unit in question. In the case of BEQI/PEQI and Charlotte these indices are constructed by adding and/or subtracting points for the presence or absence of particular features. HCM uses a complex formula, the product of regression modeling, to produce a numeric score, requiring specialized propriety software. These are then converted to grades according to a look-up table. HCM and Charlotte both give a letter grade ("A" through "F"), while BEQI/PEQI produce categorical scores from "ideal" to "not suitable." The final scores were plotted on a chart with two y- axes to account for the differences in the grading scale (see Figures 8-12). HCM and Charlotte both have six categories, while BEQI/PEQI produces five, the x-axis of the charts distinguish among the various geographical units being considered by each measure.

We also choose a single link and intersection in order to enumerate the contributing factors for each measure. Figures 13-17 use the middle intersection and the second link within each segment. First, to determine the weight assigned to each indicator in BEQI/PEQI and Charlotte LOS, we subtracted the worst score in each category from the best score in response category to establish the range of possible values. We added these ranges to find the total possible differential score. We calculated the weight assigned to each variable by dividing the best possible overall LOS score by the best possible score for each variable. The HCM analysis differed slightly as the model is based on a set of variables with each assigned a coefficient value. After inputting the characteristics of our test site in HCM, we modified each variable of interest while holding all others constant to determine the effect on the overall level of service. We discuss these contributions in the section below.

RESULTS

TEST SEGMENTS COMPARISON

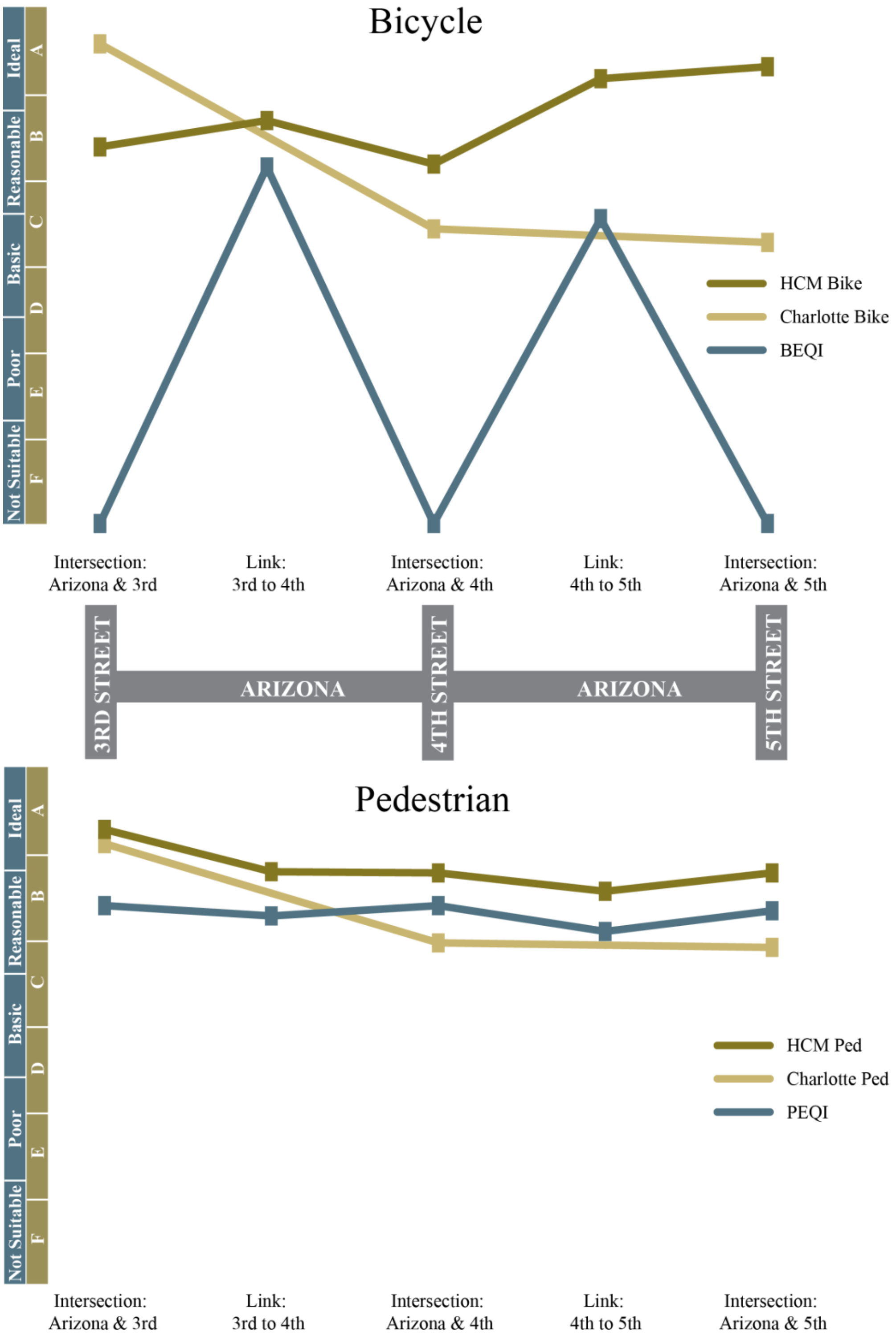

FIGURE 8(A) BICYCLE SCORES FOR ARIZONA AVE. (B) GEOGRAPHIES OF ANALYSIS (C) PEDESTRIAN SCORES FOR ARIZONA AVE.

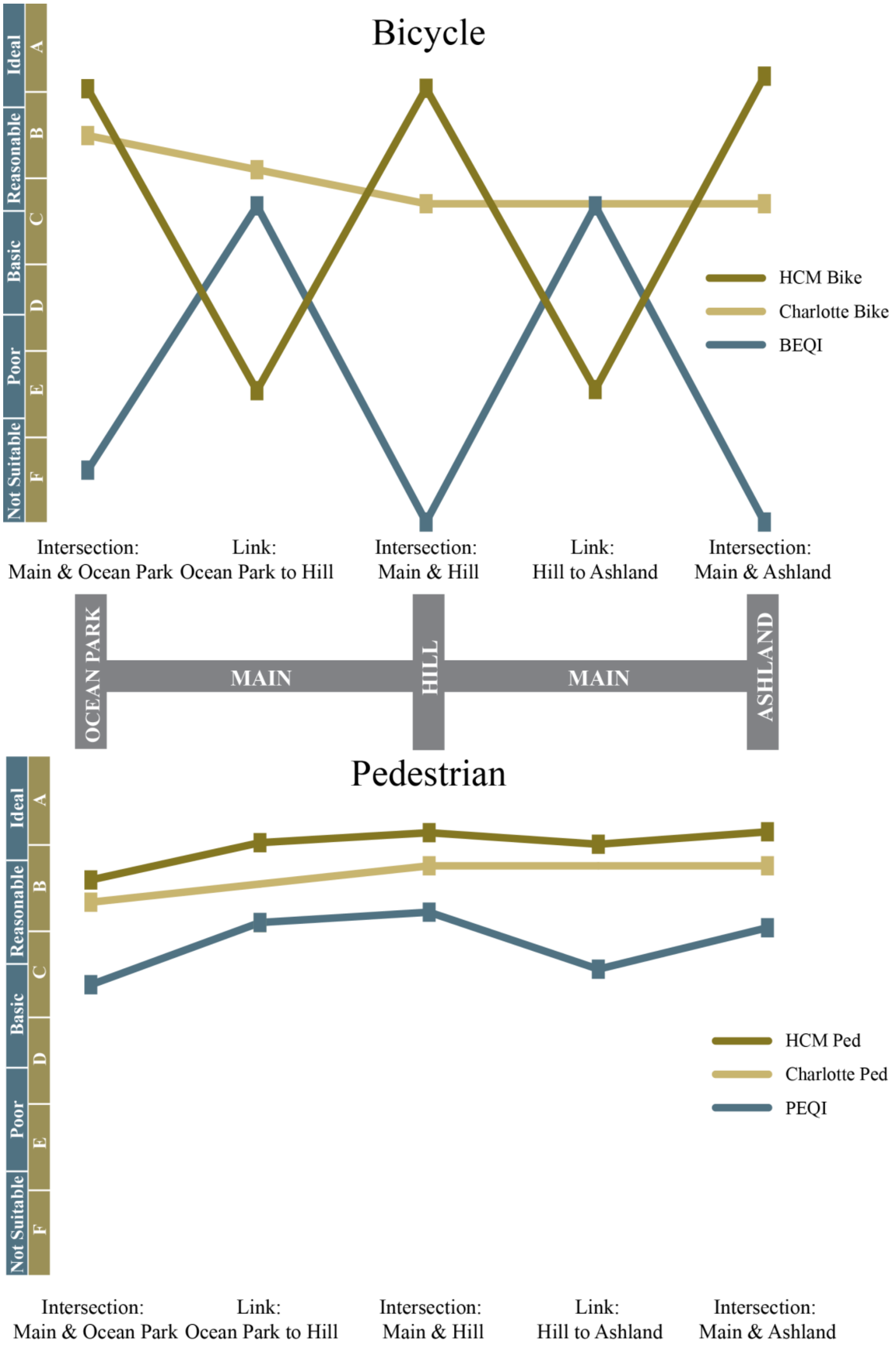

FIGURE 9(A) BICYCLE SCORES FOR MAIN ST. (B) GEOGRAPHIES OF ANALYSIS (C) PEDESTRIAN SCORES FOR MAIN ST.

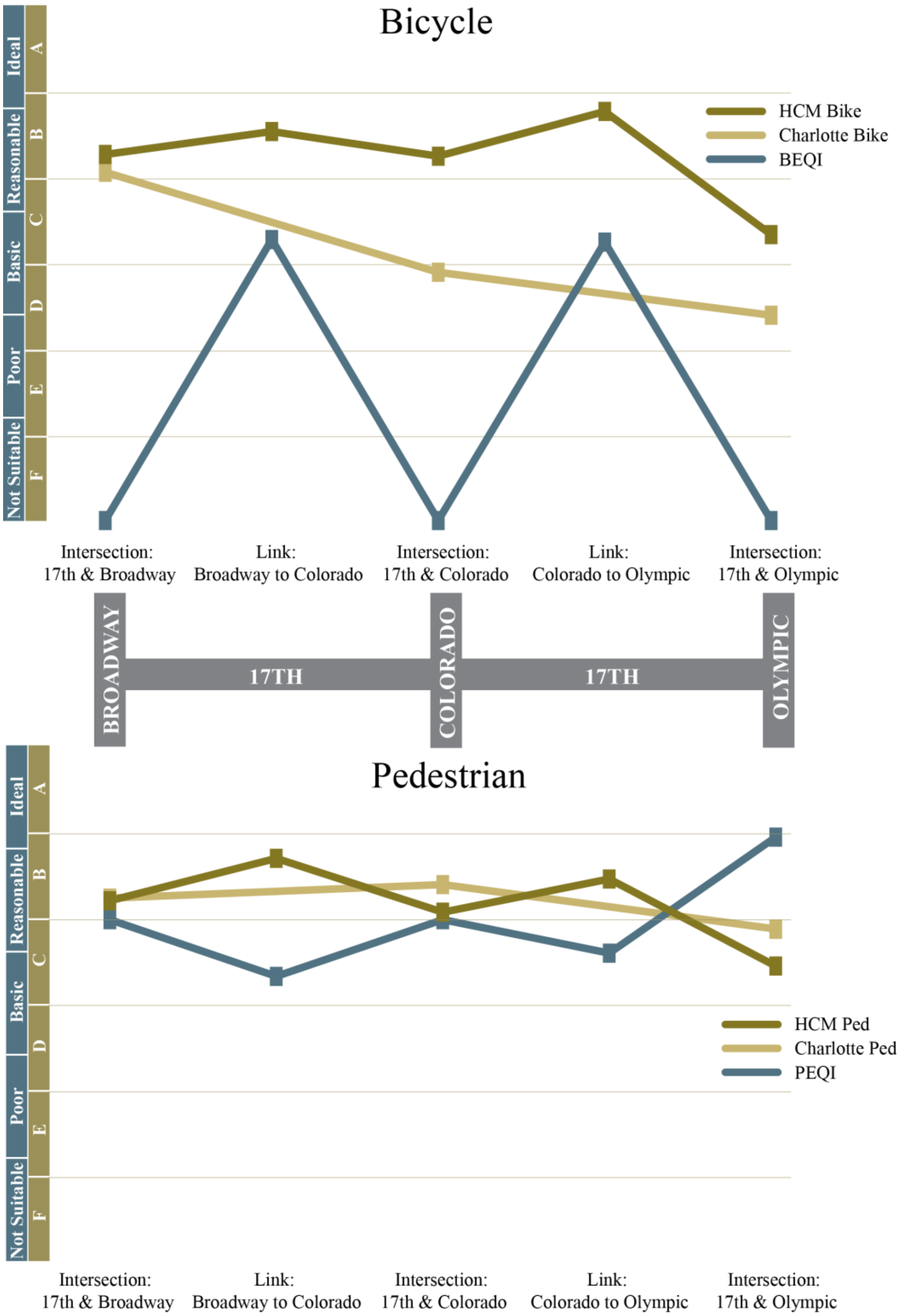

FIGURE 10: (A) BICYCLE SCORES FOR 17TH ST. (B) GEOGRAPHIES OF ANALYSIS (C) PEDESTRIAN SCORES FOR 17TH ST.

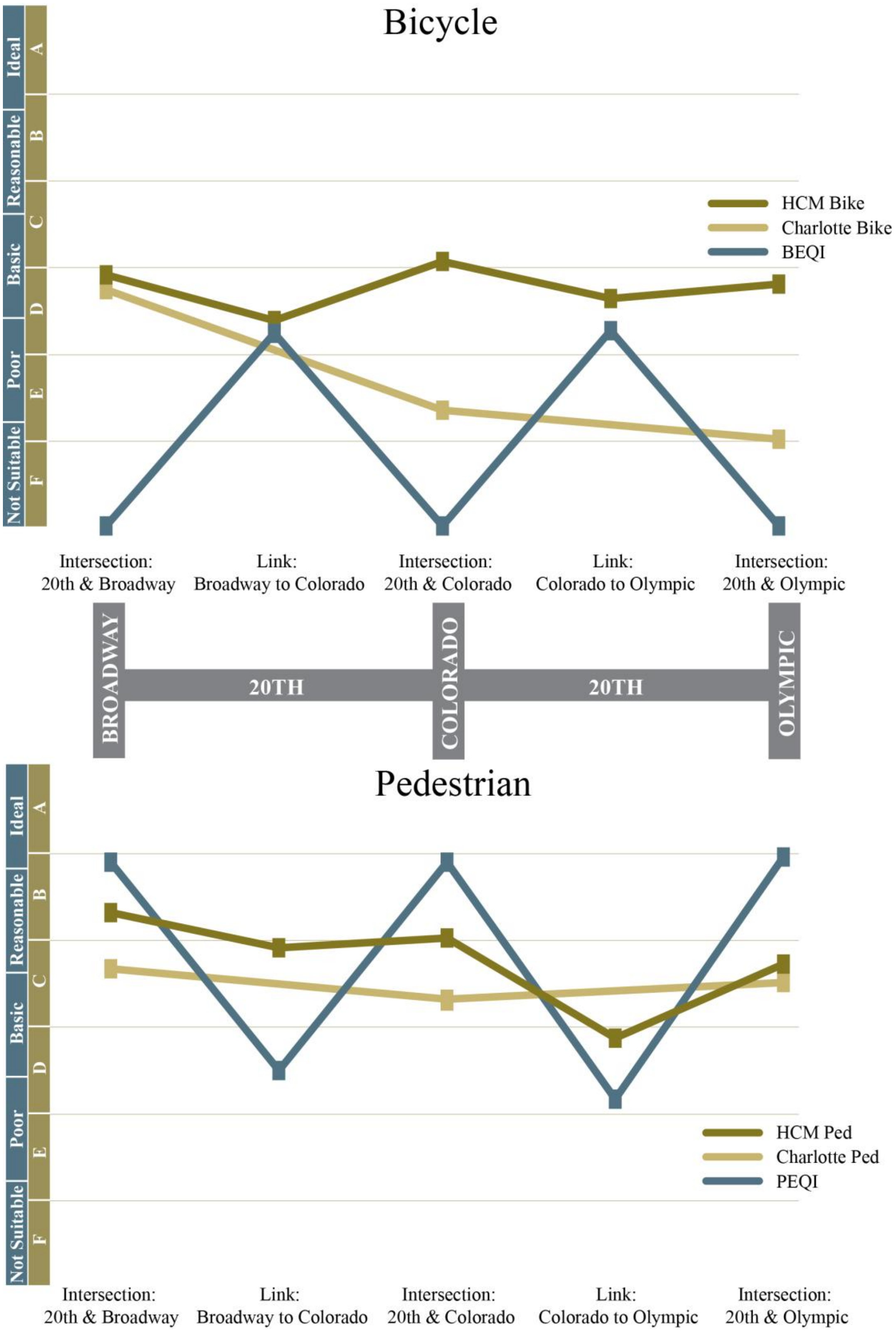

FIGURE 11: (A) BICYCLE SCORES FOR 20TH ST. (B) GEOGRAPHIES OF ANALYSIS (C) PEDESTRIAN SCORES FOR 20TH ST.

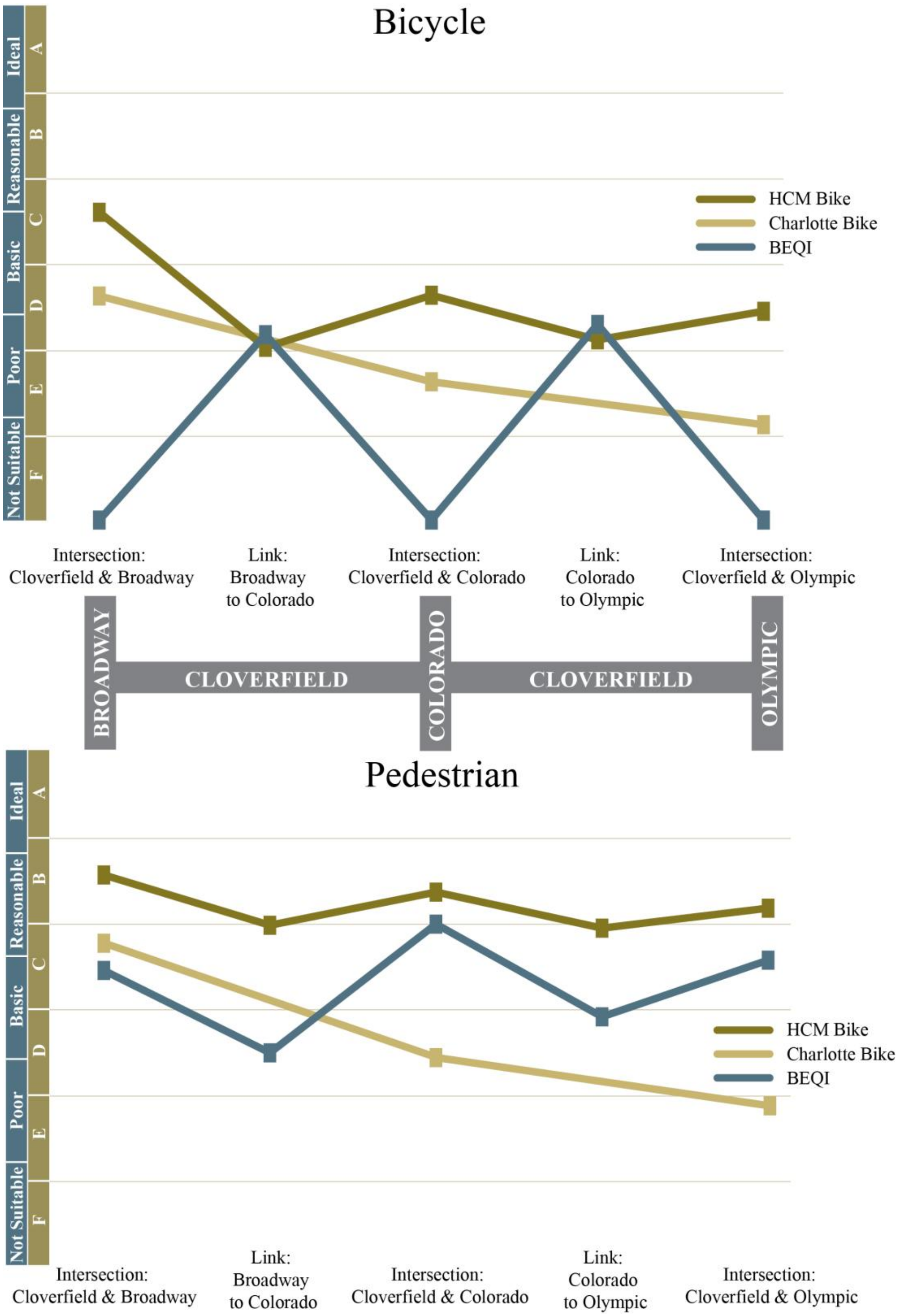

FIGURE 12: (A) BICYCLE SCORES FOR CLOVERFIELD BLVD.. (B) GEOGRAPHIES OF ANALYSIS (C) PEDESTRIAN SCORES FOR CLOVERFIELD BLVD.

Street Component	HCM Bike	Charlotte Bike	BEQI	HCM Ped	Charlotte Ped	PEQI
Arizona & 3rd - East	2.47 / B	115 / A	0 / Not Suitable	1.0 / A	95 / A	73 / Reasonable
Arizona & 3rd - West	2.56 / B			1.0 / A		
Link 1 - North	2.24 / B	N/A	69/ Reasonable	2.17 / B	N/A	71 / Reasonable
Link 1 - South	2.24 / B		67/ Reasonable	2.17 / B		66 / Reasonable
Arizona & 4th - East	2.62 / B	63 / C	0 / Not Suitable	2.18 / B	73 / C	73 / Reasonable
Arizona & 4th - West	2.62 / B			2.18 / B		
Link 2 - North	1.87 / A	N/A	68 /Reasonable	2.34 / B	N/A	68 / Reasonable
Link 2 - South	1.67 /A		67 /Reasonable	2.34 / B		64 / Reasonable
Arizona & 5th - East	1.39 / A	60 / C	0 / Not Suitable	2.18 / B	72 / C	72 / Reasonable
Arizona & 5th - West	2.68 / B			2.18 / B		
Main & Ocean Park - North	1.97 / A	83 / B	10 / Not Suitable	2.32 / B	80 / B	56 / Basic
Main & Ocean Park - South	1.97 / A			2.32 / B		
Link 1 - West	4.61 / E	N/A	61 / Reasonable	1.99 / A	N/A	68 / Reasonable
Link 1 - East	4.50 / E		59 / Basic	2.08 / B		61 / Reasonable
Main & Hill - North	1.96 / A	68 / C	0 / Not Suitable	1.76 / A	88 / B	70 / Reasonable
Main & Hill - South	1.74 / A			1.78 / A		
Link 2 - West	4.60 / E	N/A	61 / Reasonable	2.01 / B	N/A	59 / Basic
Link 2 - East	4.4 / E		61 / Reasonable	2.54 / B		60 / Basic
Main & Ashland - North	1.68 / A	68 / C	0 / Not Suitable	1.74 / A	88 / B	67 / Reasonable
Main & Ashland - South	1.68 / A			1.74 / A		
17th & Broadway - North	2.66 / B	75/B	0 / Not Suitable	2.57 / B	78 / B	73 / Reasonable
17th & Broadway - South	2.45 / B			2.66 / B		
Link 1 - West	2.52 / B	N/A	55 / Basic	2.06 / B	N/A	56 / Basic
Link 1 - East	2.19 / B		54 / Basic	2.43 / B		54 / Basic
17th & Colorado - North	2.41 / B	53 / D	0 / Not Suitable	2.57 / B	81/B	73 / Reasonable
17th & Colorado - South	2.73 / B			2.86 / C		
Link 2 - West	2.17 / B	N/A	62 / Reasonable	2.42 / B	N/A	57 / Basic
Link 2 - East	2.19 / B		62 / Reasonable	2.43 / B		60 / Basic
17th & Olympic - North	3.21 / C	44/ D	0 / Not Suitable	3.31 / C	71 / C	82 / Ideal
17th & Olympic - South	3.30 / C			3.06 / C		
20th & Broadway - North	3.63 / D	50 / D	0 / Not Suitable	2.55 / B	67 / C	81 / Ideal
20th & Broadway - South	3.53 / D			2.53 / B		
Link 1 - West	3.96 / D	N/A	37 / Poor	2.84 / C	N/A	40 / Poor
Link 1 - East	3.99 / D		37 / Poor	2.85 / C		42 / Basic
20th & Colorado - North	3.18 / C	25 / E	0 / Poor	2.79 / C	58 / C	81 / Ideal
20th & Colorado - South	3.75 / D			2.73 / B		
Link 2 - West	3.78 / D	N/A	38 / Poor	3.30 / C	N/A	35 / Poor
Link 2 - East	3.79 / D		37 / Poor	3.20 / D		48 / Basic
20th & Olympic - North	3.68 / D	19 / E	0 / Poor	3.11 / C	64 / C	82 / Ideal
20th & Olympic - South	3.64 / D			2.86 / C		
Cloverfield & Broadway - North	3.13 / C	48 / D	0 / Not Suitable	2.35 / B	69 / C	57 / Basic
Cloverfield & Broadway - South	2.99 / C			2.35 / B		
Link 1 - West	4.21 / D	N/A	36 / Poor	2.78 / C	N/A	39 / Poor
Link 1 - East	4.27 / E		36 / Poor	2.80 / C		43 / Basic
Cloverfield & Colorado - North	3.29 / D	30 / E	0 / Not Suitable	2.50 / B	43 / D	66 / Reasonable
Cloverfield & Colorado - South	3.53 / D			2.50 / B		
Link 2 - West	4.21 / D	N/A	34 / Poor	2.81 / C	N/A	45 / Basic
Link 2 - East	4.14 / D		41 / Poor	2.82 / C		51 / Basic
Cloverfield & Olympic - North	4.24 / D	21 / E	0 / Not Suitable	2.64 / B	33 / E	59 / Basic
Cloverfield & Olympic - South	3.61 / D			2.64 / B		

N/A = not applicable because Charlotte only provides intersection scores

TABLE 5: ALL SCORES BY MEASURE, GEOGRAPHY AND MODE

SCORING COMPARISONS ACROSS SEGMENTS

We found the resulting scores to display a great degree of variation. Out of the fifteen pedestrian intersection scores, only one intersection, Arizona and 3rd, received a top-category score from more than one measure, receiving "A" grades from both HCM and Charlotte and a second-tier score of "reasonable" from PEQI. In most cases, the measures do not produce scores that are similar. For example, Main and Ashland received an "A" from HCM and a third tier score from PEQI. These differences are not systematic. At 17th and Olympic, HCM gave a "C", a score two categories below the "ideal" score given by PEQI. HCM and Charlotte appear to produce the most similar scores, but still often disagree.

This discrepancy continues into the scores for the bicycle rankings, to an even stronger degree in some cases. All measures did appear to agree when the environment for bicycling was poor – as seen in 20th Street and Cloverfield Blvd. segments where neither segment received any rankings in the top two categories for any measure. The three other segments received a variety of scores, with less agreement than the pedestrian scores. Scores are in total disagreement on Main Street (Figure 9a). HCM ranked intersections well and links poorly, while BEQI ranked intersections low and links highly. Charlotte split the difference between the two. The following section examines the driving factors behind the various scores from each of the measures.

CONTRIBUTION OF VARIABLES TO BICYCLE SCORE

BEQI VARIABLES

BEQI scores both the intersection and the link between intersections, with a different set of inputs for each. Among all indices, BEQI gave the lowest score to the intersections across all segments because intersection scores are based on three inputs: the treatment of right turns on red, whether there is striping of bike infrastructure through the intersection, and the absence or presence of a left-turn bike lane. Fourteen of the fifteen intersections failed to have any of these treatments, and as such, received the worst possible score.

The test segments received scores of "reasonable" for Arizona, "basic" for Main and 17th, and "poor" for 20th and Cloverfield Blvd. BEQI scores for links are based on a more extensive list of variables, which fall into in four general categories: street design, vehicle traffic, safety and land use (Figure 8). The test segments lost the most points for the variables around traffic calming features and traffic volumes within the vehicle traffic category. Other notable losses were from the absence of bicycle signs and bicycle parking. With considerably more factors considered in the link score, it is easier for links to reach a basic average score. This drives the scoring disagreement between the intersections and the links.

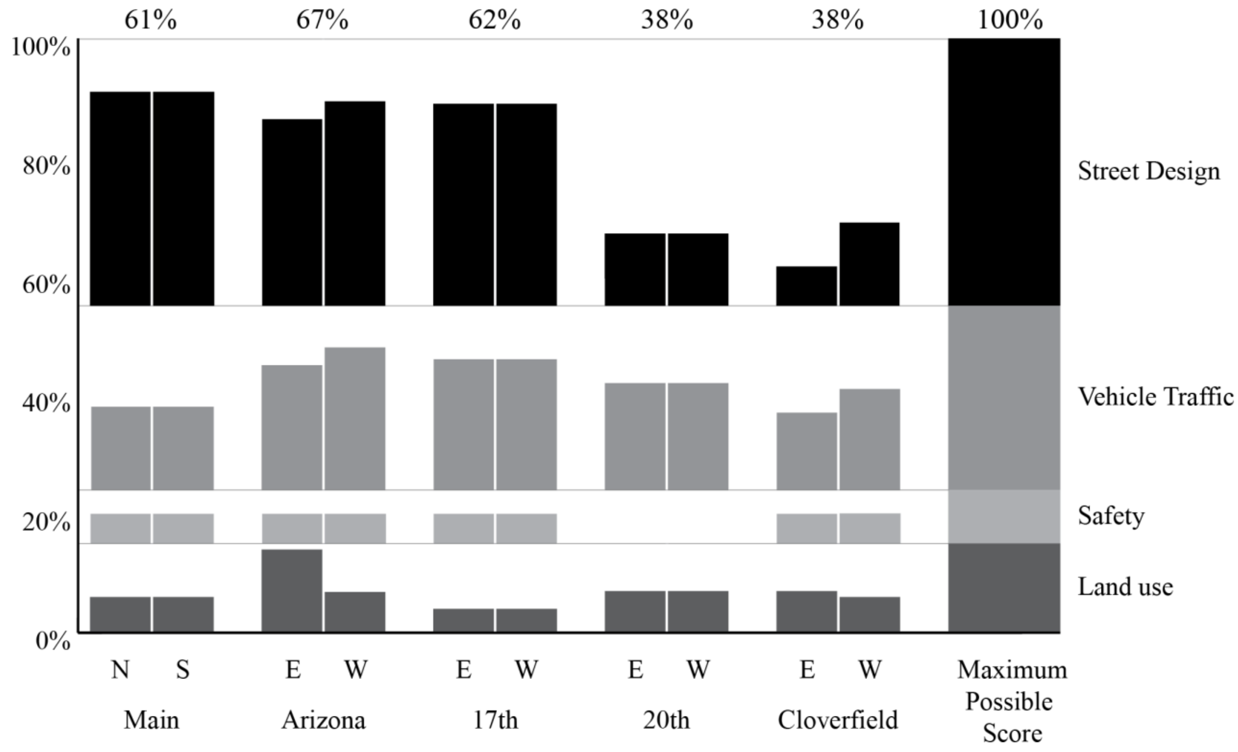

FIGURE 13: BEQI LINK COMPONENTS

CHARLOTTE VARIABLES

To calculate both the bicycle and pedestrian LOS, each directional approach is scored then is averaged to the overall intersection LOS. Charlotte only scores the intersections, without a separate score for the segment links. However, many factors seen in other link scores are included in the intersection. For example, if a bicycle lane is present on the approaching link, the intersection receives points captured in the "bike travel through intersection" category. These points are awarded whether or not the bicycle lane striping extends to the intersection.

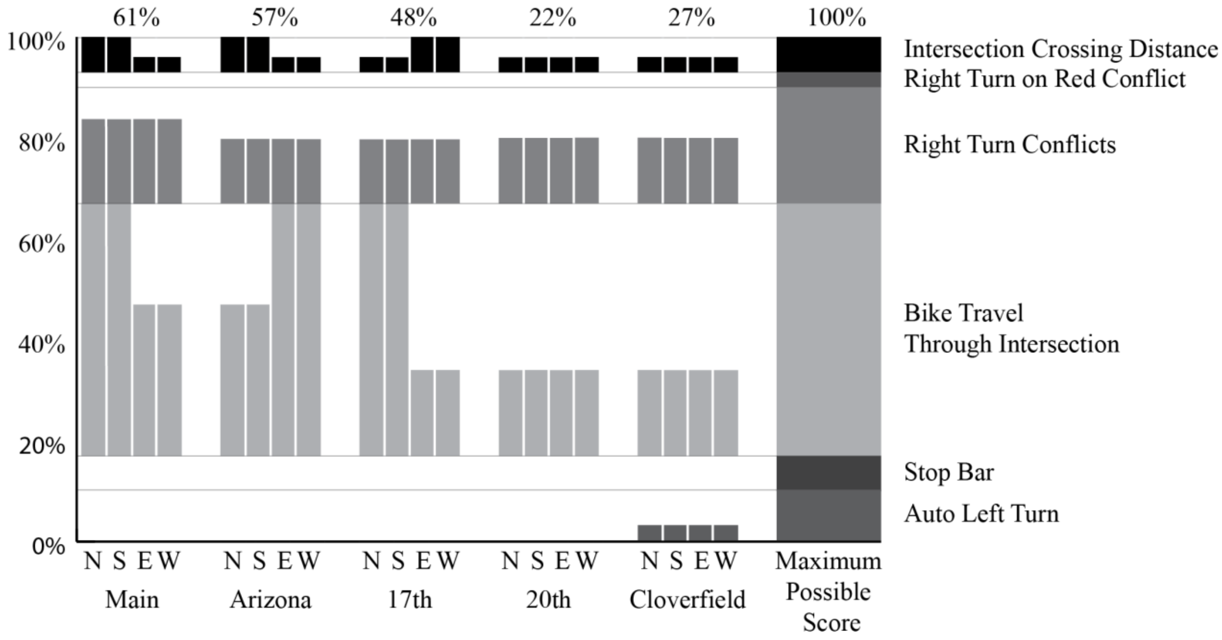

FIGURE 14: COMPONENTS FOR CHARLOTTE BICYCLE INTERSECTION SCORES

The "B" and "C" intersection grades assigned by the Charlotte LOS bicycle metric were mostly determined by the configuration of bicycle lanes entering and exiting the intersection (Figure 14). Arizona, Main and 17th Streets all have bicycle lanes and received points for the intersections, while 20th Street and Cloverfield Blvd. do not have any bicycle infrastructure. Where bicycle lanes are present, intersections with the bicycle lane to the inside of the right turn lane received additional points. The Charlotte LOS did not penalize the intersections for high traffic volume or presence of heavy vehicles. Instead, this measure is sensitive to changing the intersection signaling to restrict right-turns-on-red or provide protected left turns rather than permissive lefts; or to adding an advanced stop bar for bicyclists.

HCM VARIABLES

The HCM calculations are the most complex. Within HCM, calculating the bike intersection LOS is the most straightforward as it is a linear combination of three factors. The most important factor is the sum of the widths of the outside lane, bike lane and shoulder (total width). Greater total widths lead to better grades. Higher traffic volumes and a greater crossing distance (the width of the side street plus the median) result in lower grades. HCM provided the best average intersection scores across all test segments, due largely in part to the total width of the outside lanes at the intersection.

HCM bicycle link LOS is by far the most complex formula, using a weighted index of four factors: traffic volume, speed and the percent heavy vehicle traffic, pavement condition and the total width used in the intersection analysis modified by traffic volume and percent on-street parking. While total width was the primary determinant of “A” intersection grades, it made only a small contribution to the link LOS due to the presence of occupied on-street parking.   On-street parking occupancy on test segments ranged from 50 – 75% occupancy, which is relatively high and explains, in part, why the HCM link scores are lower than the BEQI link grades. Holding everything constant, a street with an “E” grade can be increase to a “B” grade by reducing on-street parking occupancy to 20%. Traffic volume was the other primary contributor to the low grades given to the links; which, at times, were two grades below that given by BEQI.

CONTRIBUTION OF VARIABLES TO PEDESTRIAN SCORE

PEQI VARIABLES

PEQI scores both the intersection and the link between intersections. Like the BEQI, auto traffic-related variables are much less important in the PEQI compared to HCM 2010. PEQI is driven by the contribution of many variables within a narrow range of weights, ranging from six to fifteen percent (Figure 15).

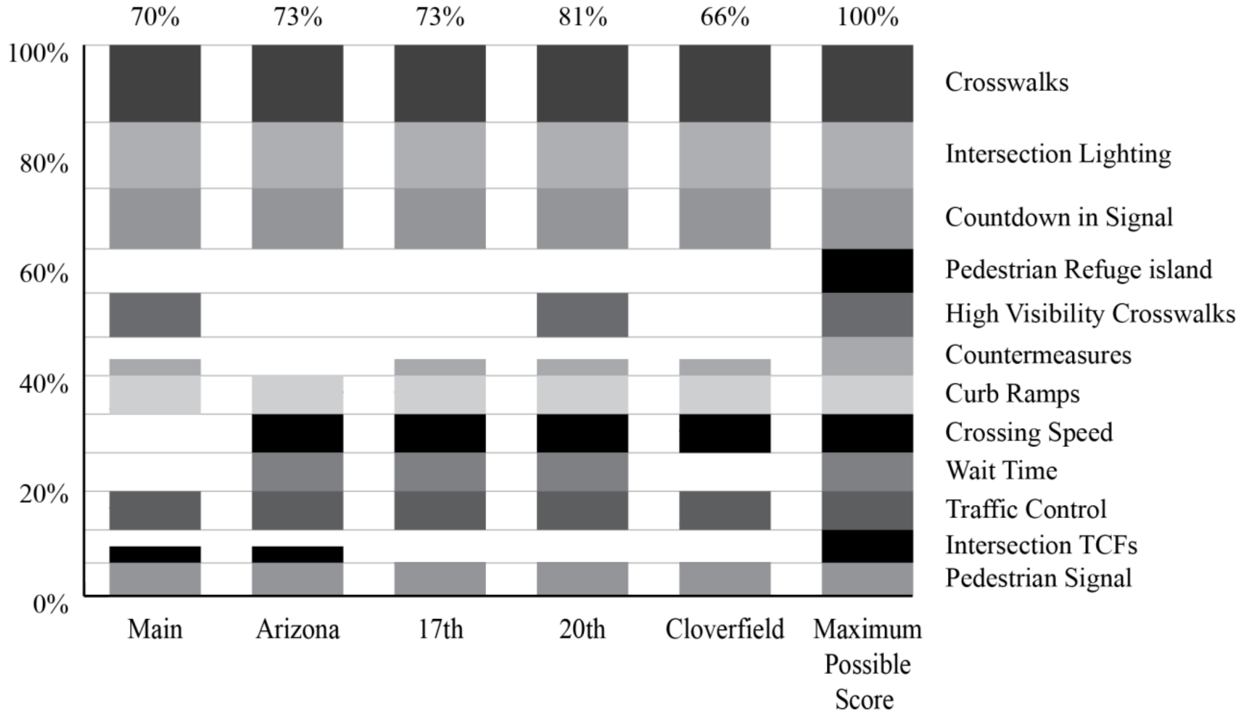

FIGURE 15: COMPONENTS FOR PEQI INTERSECTION SCORE

The test intersections scores received grades in the "ideal," "reasonable," and "basic" categories. The intersections received points based on high-visibility crosswalks, adequate intersection lighting, and pedestrian signal configuration. The "ideal" scores are clustered within intersections along the 20th segment. In comparison, these intersections received "B" and "C" grades from the other measures, because the PEQI intersection score does not factor in traffic volumes, a notable absence in scoring. PEQI scores can be improved by adding additional pedestrian infrastructure such as traffic-calming features, pedestrian engineering countermeasures such as an advanced stop line, or a pedestrian crossing refuge island.

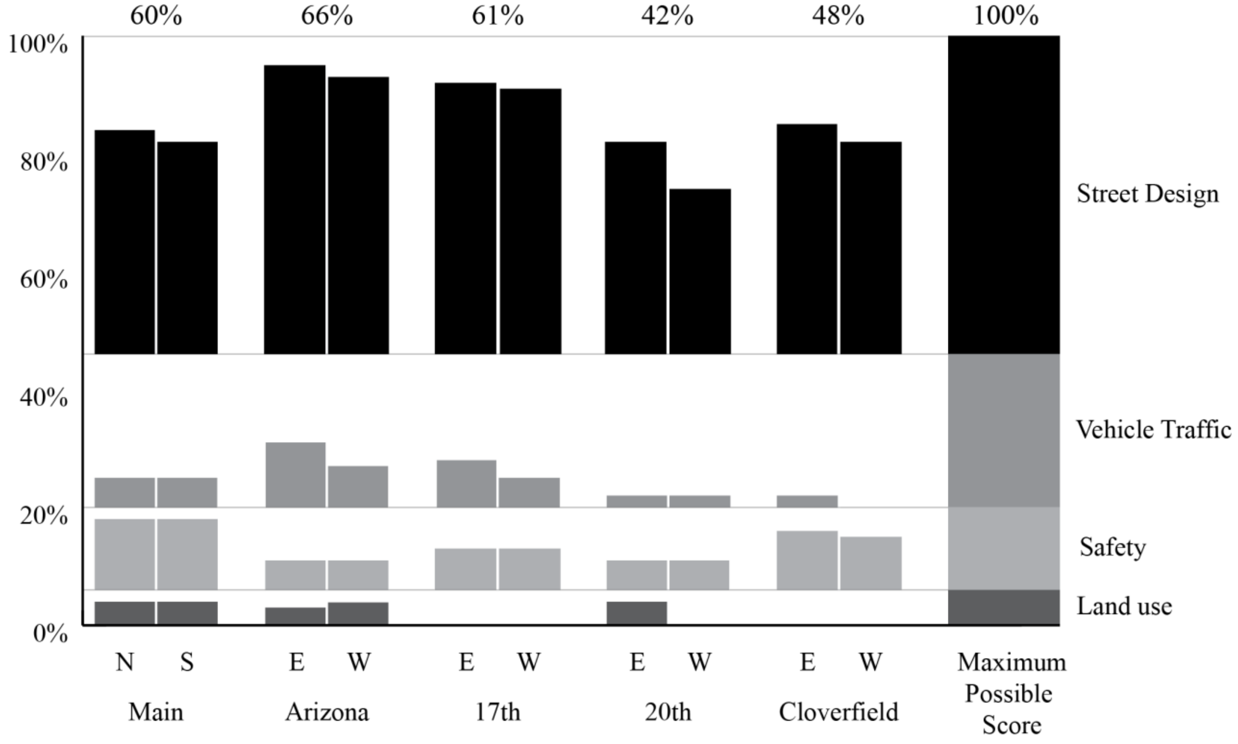

FIGURE 16: COMPONENTS FOR PEQI SCORE (LINK)

The resulting average link scores are "reasonable" on Arizona, and Main, "basic" on 17th street and Cloverfield Blvd. with the worst ranking of "poor" for the pedestrian link average on the 20th street segment. These "reasonable" results reflected high scores for many indicators unique to the PEQI such as street lighting, trees, nearby retail locations, and obstruction-free sidewalks. The vehicle traffic category has the most potential for improvement, where all links lost points (Figure 16). Specific indicators with the most potential include reducing the speed limit to below 25 mph, reduction in auto volumes, adding at least one traffic-calming feature such as a raised crosswalk, or reducing sidewalk impediments.

CHARLOTTE VARIABLES

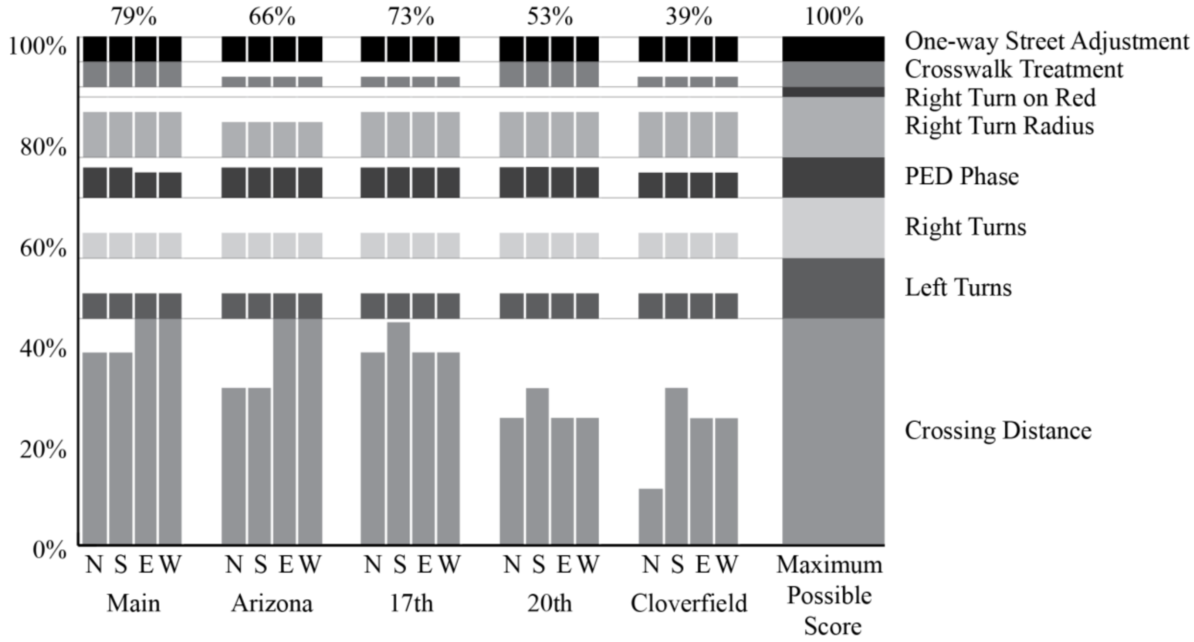

FIGURE 17: COMPONENTS FOR CHARLOTTE INTERSECTION SCORES

The intersection scores from Charlotte were the most in line with our hypothesis ranking of the test segments - Arizona intersections ranked the highest and Cloverfield ranked the lowest. The intersection of Arizona and 3rd received the only “A” grade as it has a pedestrian crossing distance of zero feet where it intersects a pedestrian only mall. Crossing distance is the largest factor in the Charlotte intersection scoring (Figure 17). Intersections with high grades received points beyond crossing distance because of the pedestrian signal configuration, small corner radius, and ladder-style crosswalks. The biggest additional improvements to the Charlotte score would be gained by restricting left and right vehicle turns to protected-only.

HCM VARIABLES

The most important variable in the HCM pedestrian intersection scoring is the number of lanes crossed. Additional contributors included traffic volume/speed, number of right/left turning vehicles, and pedestrian delay. Interestingly, while the Arizona and 3rd street intersection crosses zero lanes of traffic, the HCM software does not allow the user to input zero for number of lanes. In response, putting one travel lane (the minimum allowable value) and decreasing pedestrian delay to zero produced the same result as if there were zero lanes of traffic. However, this should be noted as a flaw in the mathematical function for

HCM pedestrian intersection score. Still, the increase in the number of right/left turning vehicles was the primary factor lowering intersection scores.

Link scores, which were mostly “B” and “C” (with one “A” and one D”) benefited from a high percentage of on-street parking; assumed to provide a buffer between traffic and pedestrians. Note, this is a major negative factor for bicycle LOS scores. Efforts toward improving the pedestrian score should be targeted toward the reduction of auto volumes and speeds. The only pedestrian-specific infrastructure improvements that might influence the HCM level of service would be those that increased the level of separation between cars and pedestrians, such as adding a continuous buffer such as trees spaced less than 20 ft apart.

DISCUSSION

BICYCLE

Overall, the different metrics were at complete disagreement in scoring intersections for bicyclists; the same intersections were graded as an “A” LOS by HCM 2010, “Not Suitable” by the BEQI, and between a “B” and “C” LOS by Charlotte (table 5). The BEQI intersection LOS is explained by the uniqueness of the three variables not mentioned in either of the other indices, a left turn bicycle lane and a dashed intersection while the Charlotte “bicycle travel through intersection” variable measures bicycle lane presence before and after the intersection. The “right on red” variable, contributing the last third to the BEQI intersection score, only contributes 3% to the Charlotte LOS and is absent in HCM scoring.

The links were scored fairly well by the BEQI, but quite poorly by HCM 2010. Two key drivers can explain the difference in scores: on street parking and traffic volume. On street parking in BEQI only contributes to the “presence of marked area” which makes up 7% of the BEQI score. In comparison, HCM is highly sensitive to change in the percentage of on-street parking, where moving from 0% occupancy to 100% occupancy will decrease the level of service by about 18% (Elias, 2011). Similarly, traffic volume is a key driver to HCM 2010, whereas it plays a much smaller role in the BEQI score; contributing 4% of the maximum BEQI score.

PEDESTRIAN

For intersections, HCM 2010 and PEQI measured completely different variables. The only variable found in both the PEQI and HCM 2010 intersection LOS is the pedestrian wait time, a fairly insignificant variable in each. Charlotte LOS incorporates variables from both. Like HCM 2010, the most important contributor is the crossing distance and number of lanes. Beyond crossing distance, however, Charlotte took into account many variables similar to those found in the PEQI, such as the pedestrian signal phase configuration and corner radii. Ultimately, as more vehicle-related variables are taken into account, the LOS for intersections improves modestly.

Despite grading on a completely different set of variables, the PEQI intersection grades were still reasonably close to grades assigned by Charlotte and HCM. The relative agreement on overall level of service does not stem from agreement on the relevant variables. Instead, Main St., for example, the segment appears to score fairly well against all three metrics because it scores well for both auto-oriented variables and pedestrian infrastructure variables. Because of the difference in inputs, changes targeted at improving the score for one index would unlikely influence the score of the other indices.

For links, the PEQI and HCM share a few variables - auto volume, auto speed, width of sidewalk, and the occupancy of on street parking. In HCM, these variables contributed to a relatively high grade. PEQI awarded these variables few points; links that received a “reasonable” score were the result of scoring well on other categories within the pedestrian infrastructure variables unique to PEQI. Since these variables such as auto volume, speed, and on-street parking are the main contributors to the HCM LOS, and these variables scored poorly against the PEQI, improvement on any would improve both the PEQI and HCM.

These differences in variable weights are explained, in part, by the different goals of each tool. Both the BEQI and Charlotte LOS include improved safety as a central goal, and both tools focus on infrastructure design to achieve that goal. The HCM focuses on general satisfaction; therefore, the metric excludes factors that increase safety but are not easily perceptible or do not contribute much towards general traveler satisfaction. Several of such factors, including crosswalk type, bicycle lane configuration, and pedestrian lighting, are featured in both the BEQI and Charlotte LOS, yet absent in HCM LOS. Since the different measures include different inputs, it is understandable that each comes up with different results.

The question remains: given these differences, which approach is best suited to measure streets for bicyclists and/or pedestrians? If none of the newly created measures are close to an optimal and consistent measure, what can we learn from these pioneering measures? In conclusion, this chapter demonstrates there are a great number of environmental factors that contribute to the experience of traveling by bicycle or walking and simplification of this experience down to one or two factors will inevitably be fraught with errors.

POLICY CONSIDERATIONS

For cities looking to move away from the sole use of vehicle LOS, the adoption of a tool to measure street performance for any mode should reflect the goals of the transportation agency. If the goal is to improve traveler satisfaction across all modes, HCM 2010 would be the best choice because it was designed with that specific purpose. Improved safety or geometric design would better be evaluated through the Charlotte LOS. The BEQI also includes variables not related to safety, such as the availability of bicycle parking, presence of bicycle signage, but has issues evaluating intersections.

Importantly, financial and time constraints should also be considered. BEQI/PEQI and Charlotte LOS are relatively easy tools to use for calculating current and potential LOS. In contrast, HCM 2010 does not explicitly prescribe ideal configurations for bicycle and pedestrian infrastructure. There is no mention of bulb-outs, crosswalks, advanced stop bars, signal phasing patterns, or signage. Without the direct link between physical infrastructure and score, the burden is placed on transportation agencies to determine which infrastructure elements will be effective in boosting the level of service.

CHAPTER 3 SENSITIVITY CASE STUDY

INTRODUCTION

Policymakers, decision makers, and the public alike, want to know how changes affect street performance, both for proposed projects and *ex post* evaluation. Although current project evaluation and traffic impact analyses often include pre- and post- operational aspects such as changes in travel times and vehicle volumes, these only concern changes for vehicles and not changes in the bicyclist and pedestrian environment. With a multitude of possibilities available for changing a roadway and the various ways that these changes and development patterns can affect the surrounding environment, how could each scenario be compared to others when thinking about bicyclists and pedestrians?

This chapter seeks to do two things to respond to the question above. Based on our initial research discussed in chapter 2, we found that some of the measures seeking to replace auto LOS provided inconsistent scores, relative to each other, when scoring the same street segment. Given this, we wanted to understand if the resulting measurement scores could be changed consistently. On a particular street, even if the current scores are inconsistent, could a given set of improvements raise the scores to the same degree? Our previous analysis suggests this would not be the case because each of the mechanisms ranks its criteria and inputs with varying levels of importance. We wanted to continue the exploration of these measures to understand, given a set of proposed improvements, if the scores could improve. The motivation for this work is to help agencies understand and select which metric may be most appropriate for their particular context. An understanding of how changes in the built environment will affect the resulting scores is likely to be a part of that decision making process.

METHODOLOGY

This chapter presents a case study of five proposed improvement scenarios along a street segment in Santa Monica, CA. For the case study, we applied a hypothetical set of scenarios, both along the street cross-section and at intersections, to a segment of 20th street in Santa Monica. Commonly, when an agency proposes roadway improvements, they are often proposed as a package of different treatments rather than one treatment in isolation (Los Angeles Department of Transportation, 2013; San Francisco Municipal Transportation Authority, 2014). Because of this, our analysis combines individual treatments as a set to create different proposed scenarios for this street segment of three intersections and two links between. 20th street serves as a laboratory for understanding whether our proposed improvements can increase the pedestrian and bicycle level of service scores. We collected data on existing conditions and calculated the baseline scores from three different metrics (City of Charlotte, North Carolina Department of

Transportation, 2007; San Francisco Department of Public Health, 2009; 2012; National Research Council, 2010):

1. City of Charlotte Level of Service Protocol
2. San Francisco Department of Public Health Bicycle Environmental Quality Index (BEQI) / Pedestrian Environmental Quality Index (PEQI)
3. Highway Capacity Manual (HCM) 2010 Multimodal Level of Service

We selected various improvements based on the contributions of different variables to this set of indices and the feasibility of implementation, in terms of what could physically fit within the right-of-way. We combined these improvements into a series of different cross section configurations and intersection improvements as described below and seen in Figure 18. The final score outputs for these scenarios were then plotted on charts (see figures 29-31), noting that the charts have different y-axes from each other to account for the differences in the grading scale. HCM and Charlotte both have six grade categories, while BEQI/PEQI produces five. The x-axis of each chart distinguishes among the various geographical units being considered by each measure. HCM and BEQI/PEQI provide multiple directional scores, as such; Figures 29-31 have averaged these for display purposes. The individual directional scores are found in Tables 8-11. The Charlotte scores do not have a table with the individual scores; they are plotted directly in the associated figure.

IMPROVEMENT OVERVIEW

Each measurement tool in this project has a slightly different focus and different inputs. The Charlotte measure focuses on physical elements of the built environment (curb radii, number of vehicle lanes, and vehicle turning restrictions). San Francisco's BEQI/PEQI indices pay special attention to design elements, such as street lighting and the level of sidewalk disrepair. The HCM incorporates operational characteristics to a much greater degree than the other two metrics. Some of the heaviest weighted variables in the HCM calculations include vehicle volumes and percentage of on-street parking. Additionally, there are other improvements that are absent from the inputs in any of the three measures analyzed but are used in practice such as a painted bicycle lane. There are also a host of new bicycle right-of-way configurations that cities are using and we wanted to understand how evolving infrastructure treatments can or cannot be evaluated using these existing tools. We thus selected elements included in the package of improvements that were in one of three categories: variables included in any of the three indices, both operational and design/built environment, documented safety countermeasures, and innovative right-of-way treatments.

Some of the improvements have associated political and forecasting constraints (Shoup 2004; Manville & King, 2013) including difficult implementation (like adding or removing on-street parking) and interactive constraints (knowing how much vehicle volumes may change after a road diet). Because of the particular difficulty of forecasting operational changes, did not change operational characteristics in response to any other proposed changes. We only included changes to the built environment and assumed no changes in vehicle volumes, vehicle speeds, or parking occupancy. Operational characteristics may change and indeed are expected to change with some of these built environment treatments, but predicting such changes adds significant analytical difficulty, and is outside the scope of this study as well as the capabilities of many local agencies. In large part, the assumption that operational characteristics do not change simply serves to isolate the effects of built environment changes.

SCENARIO AND INTERSECTION IMPROVEMENT DESCRIPTIONS

The existing roadway configuration of 20th St. is five motor vehicle travel lanes, two lanes in each direction and a center turn lane. The street is zoned as "light manufacturing studio districts" mostly featuring 1-3 story office buildings. The southern end of the street crosses a major freeway (I-10) but does not have access ramps for vehicles at this crossing.

We evaluated five possible scenarios for treatments to 20th Street, as seen in figure 18. In addition to cross sectional changes, we proposed a package of intersection related changes. At all intersections, right-turns-on-red were restricted, leading pedestrian intervals were added, perpendicular curb ramps were added (2 ramps per corner), a bicycle box was added on 20th on both north and sound approaches, and left turns from 20th street were changed to protected left only. At intersection 1 (20th at Broadway), a bus bulb was added and one redundant driveway entrance was closed. Additionally, a bus bulb was added at intersection 2 (20th at Colorado). A "nose" was added to the existing median to make a pedestrian refuge in the crosswalk at intersection 3 (20th at Olympic).

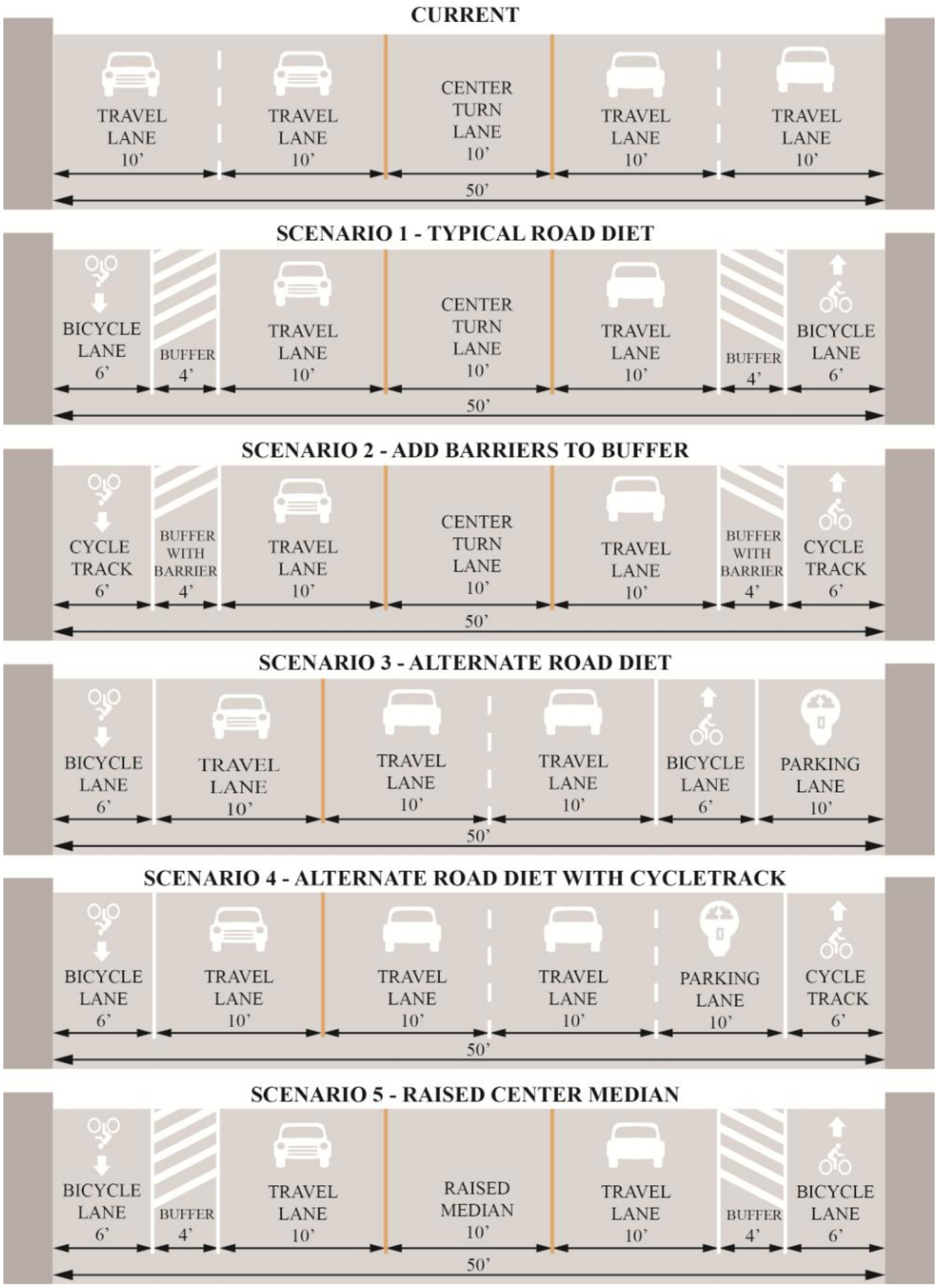

FIGURE 18: CURRENT AND PROPOSED CROSS-SECTIONS FOR SENSITIVITY CASE-STUDY ANALYSIS

Scenario	Change
1	Typical ‘road diet’ reconfiguration with 4’ painted buffers
2	Scenario 1 with physical barrier (cycle track)
3	Alternate ‘road diet’ with 1 lane in one direction, 2 lanes in other direction.
4	Scenario 3 with cycle track between parking and sidewalk
5	Scenario 1 with raised median

TABLE 6: PROPOSED IMPROVEMENT SCENARIOS

Category	Treatments[3]	Benefits
Striping Improvements	- Road diet (19) - Bicycle boxes (20)	- Road diets reduce capacity and can reduce likelihood of vehicle collisions, and reduce the severity of crashes that occur (Dill, et al., 2011) - Bicycle boxes increase cyclist visibility at intersections and reduce likelihood of "right-hook" collisions (Dill, et al., 2011) - Road diets and bicycle boxes can provide safety benefits for pedestrians; road diets that add on-street parking add separation and bicycle boxes increase yielding to pedestrians in crosswalk (Dill, et al., 2011; Federal Highway Administration, 2012)
Signal Operations and Turning Improvements	Right-turn-on-red restrictions Protected left turns (21) Leading pedestrian interval (22)	- All treatments provide increased safety for pedestrians because turning phase does not happen while pedestrians are crossing (Retting, et al., 2002; Van Houten, et al., 2007) - All treatments can improve vehicle flow, depending on context, because turns can be separated from straight-through traffic (Retting, et al., 2002) - All treatments increase pedestrian visibility and pedestrian comfort and perceptions of safety (Retting, et al., 2002)
Sidewalk improvements	Consolidating driveway access points Perpendicular curb ramps (23) Bulb-outs (curb extensions) (24) Bus bulb (25)	- Reducing number of driveway access points decreases the number of conflict points and decreases likelihood of collisions (Dixon, 2007) - Perpendicular curb ramps benefit those with impaired vision, wheelchair and other mobility devices, because the ramp is oriented with the crosswalk (a straight line of travel), reducing crossing distance (Harkey, et al., 2007) - Curb extensions and bus bulbs reduce crossing distance for pedestrians and provides extra space on sidewalk to reduce amenity clustering (Johnson, 2005; Daniel & Konon, 2005) - Bus bulbs decrease travel and dwelling time for buses (Daniel & Konon, 2005)
Right of way improvements	Cycle tracks (26) Raised median (27) Pedestrian refuge (29)	- Cycle tracks increase levels of perceived comfort for cyclists and increases the likelihood of riding for new cyclists (National Institute for Transportation and Communities, 2014) - Medians reduce non-intersection related pedestrian injuries and fatalities (FWHA Safety Program, 2010) - Medians and refuges reduce complexity of crossing as pedestrians can cross one direction of traffic at a time (FWHA Safety Program, 2010)

TABLE 7: DESCRIPTIONS OF PROPOSED CHANGES

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[3] The numbers on this page correspond to the photos and figures on the next page.

FIGURE 19: EXAMPLE ROAD DIET CROSS SECTION. CREDIT: FHWA

FIGURE 20: EXAMPLE BICYCLE BOX. CREDIT: PORTLAND DEPARTMENT OF TRANSPORTATION

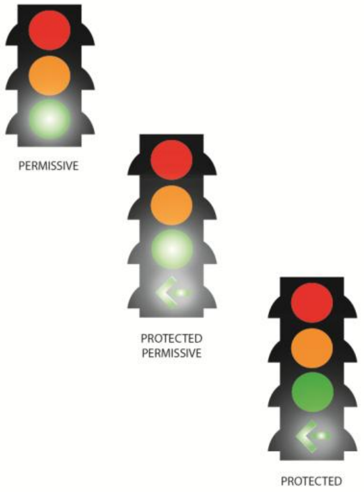
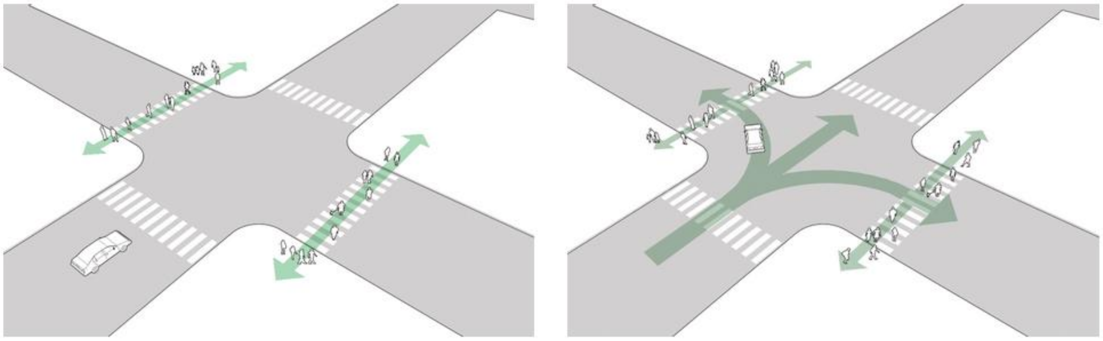


FIGURE 21: LEFT TURN SIGNAL PHASES. CREDIT: MICHELLE WEISBART



Phase 1: Pedestrians only

Pedestrians are given a minimum 3–7 second head start entering the intersection.

Phase 2: Pedestrians and cars

Through and turning traffic are given the green light. Turning traffic yields to pedestrians already in the crosswalk.

FIGURE 22: LEADING PEDESTRIAN INTERVAL. CREDIT: NACTO

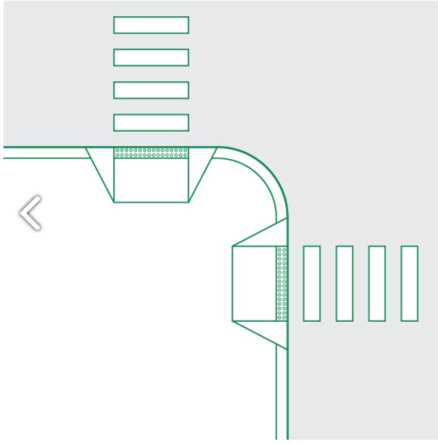


FIGURE 23: PERPENDICULAR CURB RAMPS CREDIT: NACTO

FIGURE 24: EXAMPLE CURB EXTENSION

FIGURE 25: BUS BULB DIAGRAM CREDIT: NACTO

FIGURE 26: CYCLE TRACK EXAMPLES. (L) BOLLARDS FROM SAN FRANCISCO (R) PARKING PROTECTION AND BOLLARDS, CHICAGO

FIGURE 27: RAISED MEDIAN WITH PEDESTRIAN REFUGE

FIGURE 28: PEDESTRIAN REFUGE WITH "NOSE" CREDIT: KIMLEY-HORN AND ASSOCIATES, INC.

RESULTS

BEQI/PEQI

The BEQI and PEQI tools provide one score for intersections and two scores for the street segment between intersections. Bicycle segment scores are based on the direction of travel and the pedestrian segment scores are based on a side of the street. BEQI and PEQI instruments provide scores between 0 and 100; categorized into 5 ranges of scores. 0-20 is “not suitable for bicyclists or pedestrians;”21-40 corresponds to “poor conditions exist;” 41-60 is “basic bicycle/pedestrian conditions;” 61-80 corresponds to “reasonable bicycle/pedestrian conditions exist;” and 81-100 represents “ideal bicycle/pedestrian conditions.”

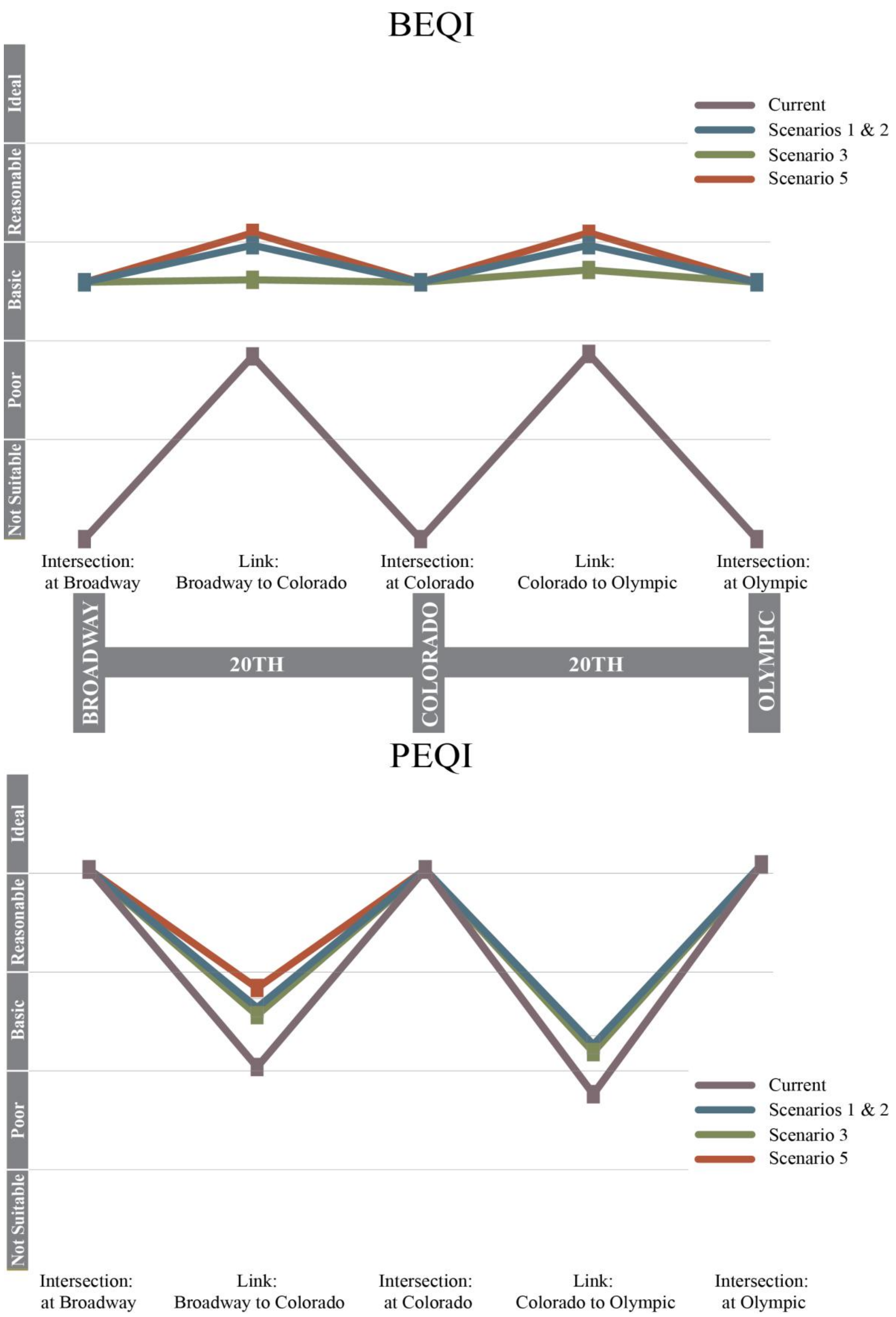


FIGURE 29 BEQI / PEQI IMPROVEMENT SCENARIO SCORES

BEQI Results

Segments	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Intersection 1 – 20th & Broadway	0 / not suitable	52 / basic	52 / basic	52 / basic	52 / basic	52 / basic
Link 1 - Northbound	37 / poor	59 / basic	59 / basic	55 / basic	37 / poor	62 / reasonable
Link 1 – Southbound	37 / poor	60 / reasonable	60 / reasonable	50 / basic	37 / poor	62 / reasonable
Intersection 2 – 20th & Colorado	0 / poor	52 / basic	52 / basic	52 / basic	52 / basic	52 / basic
Link 2 – Northbound	37 / poor	59 / basic	59 / basic	57 / basic	37 / poor	62 / reasonable
Link 2 – Southbound	38 / poor	60 / reasonable	60 / reasonable	52 / basic	38 / poor	63 / reasonable
Intersection 3 – 20th & Olympic	0 / poor	52 / basic	52 / basic	52 / basic	52 / basic	52 / basic

TABLE 8: BEQI IMPROVEMENT SCENARIO SCORES

None of the changes at the links or intersections were able to raise the scores to “ideal” (top category in the BEQI scoring.) Nonetheless, the BEQI intersection scores in all scenarios benefited immensely from the addition of bicycle boxes at two of the approaches and the prohibition of right-turn-on-red (RTOR), jumping from “not suitable” to “basic.” This confirmed the heavy weight assigned to only three factors, in the intersection score: treatment of right turns on red, whether there is striping of bike infrastructure through the intersection, and the absence or presence of a left-turn bike lane. The scoring would have increased more if we had proposed dashing the bicycle lane lines through the intersection. The heavy emphasis on this striping in all cases is questionable; given that the installation of dashed lines is not standard practice and is generally only recommended where bicyclists need extra guidance in the case of complex intersections (Oregon Department of Transportation, 2011). In June 2014, the national uniform traffic control bicycle technical committee proposed including bike lane striping through intersections in the update to the Manual on Uniform Traffic Control Devices, signaling this treatment may become standard practice in the future (Bicycle Technical Committee, 2014).

The improvement for the links was less pronounced compared to the intersection score improvement. This is due, in part, because the links scored relatively better than the intersections originally, giving less room for improvement. In scenario 1, the scores of both links increased from “poor” to almost “reasonable,” due in large part, to the addition of the bicycle lane. There was no change in score for scenario 2 because the BEQI scoring system does not award any additional points for barriers. The BEQI tool was unable to evaluate the effect of buffers; in this case, we scored the 4 foot buffer width as if it was additional bicycle lane width. For scenario 3, the improvement was less pronounced than seen in scenarios 1 and 2 because on-street parking (on one side only) was added next to the bicycle lane. Scenario 4, with the bicycle lane between parking and the sidewalk, could not be evaluated by BEQI. In scenario 5, both links received a few points from the presence of the median, which is classified as a traffic calming factor. The BEQI link scores could be further increased by:

- Increase number of traffic calming features;
- Reduce number of driveway cuts along each link;
- Add bicycle parking;
- Improve lighting.

PEQI Results

Segments	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Intersection 1 - 20th & Broadway	81 / ideal	81 / ideal	81 / ideal	81 / ideal	81 / ideal	81 / ideal
Link 1 – Eastside	42 / basic	54 / basic	54 / basic	52 / basic	42 / basic	58 / basic
Link 1 – Westside	40 / poor	52 / basic	52 / basic	51 / basic	40 / poor	56 / basic
Intersection 2 - 20th & Colorado	81 / ideal	81 / ideal	81 / ideal	81 / ideal	81 / ideal	81 / ideal
Link 2 – Eastside	41 / basic	51 / basic	51 / basic	49 / basic	41 / basic	41 / basic
Link 2 - Westside	30 / poor	40 / poor	40 / poor	39 / poor	30 / poor	30 / poor
Intersection 3 - 20th & Olympic - North	82 / ideal	82 / ideal	82 / ideal	82 / ideal	82 / ideal	82 / ideal

TABLE 9: PEQI IMPROVEMENT SCENARIO SCORES

The PEQI scores changed very little across the scenarios. The reduction in travel lanes increased the link scores slightly, from "poor" to "basic" —a one-category improvement. Although the intersections already ranked in the top category, none of the proposed intersection improvements including the perpendicular curb ramps, leading pedestrian interval, or bulb outs, improved the overall score. For example, PEQI awards points for the presence of curb ramps; however, it does not distinguish between diagonal ramps and perpendicular ramps. Since the site already had diagonal ramps, there was no corresponding improvement in the score from the installation of perpendicular curb ramps. The following improvements would increase the PEQI link scores:

- increase the width of the throughway (unobstructed area of sidewalk);
- repair sidewalk impediments;
- reduce the number of driveway cuts;
- improve street lighting;
- increase retail use of public space nearby.

CHARLOTTE

The Charlotte scoring system provides bicycle and pedestrian scores for intersections only. This single intersection score includes inputs from all four surrounding legs. The resulting scores are then split into

6 ranges each given a letter grade from A-F; the maximum score can vary based on the context of the intersection being scored. Above 93 is an “A”; 74-92 corresponds to “B”; 55-73 is a “C”, 37 – 54 is a “D”; 19-36 is an “E” and intersections receiving between 0-18 points receive an “F.”

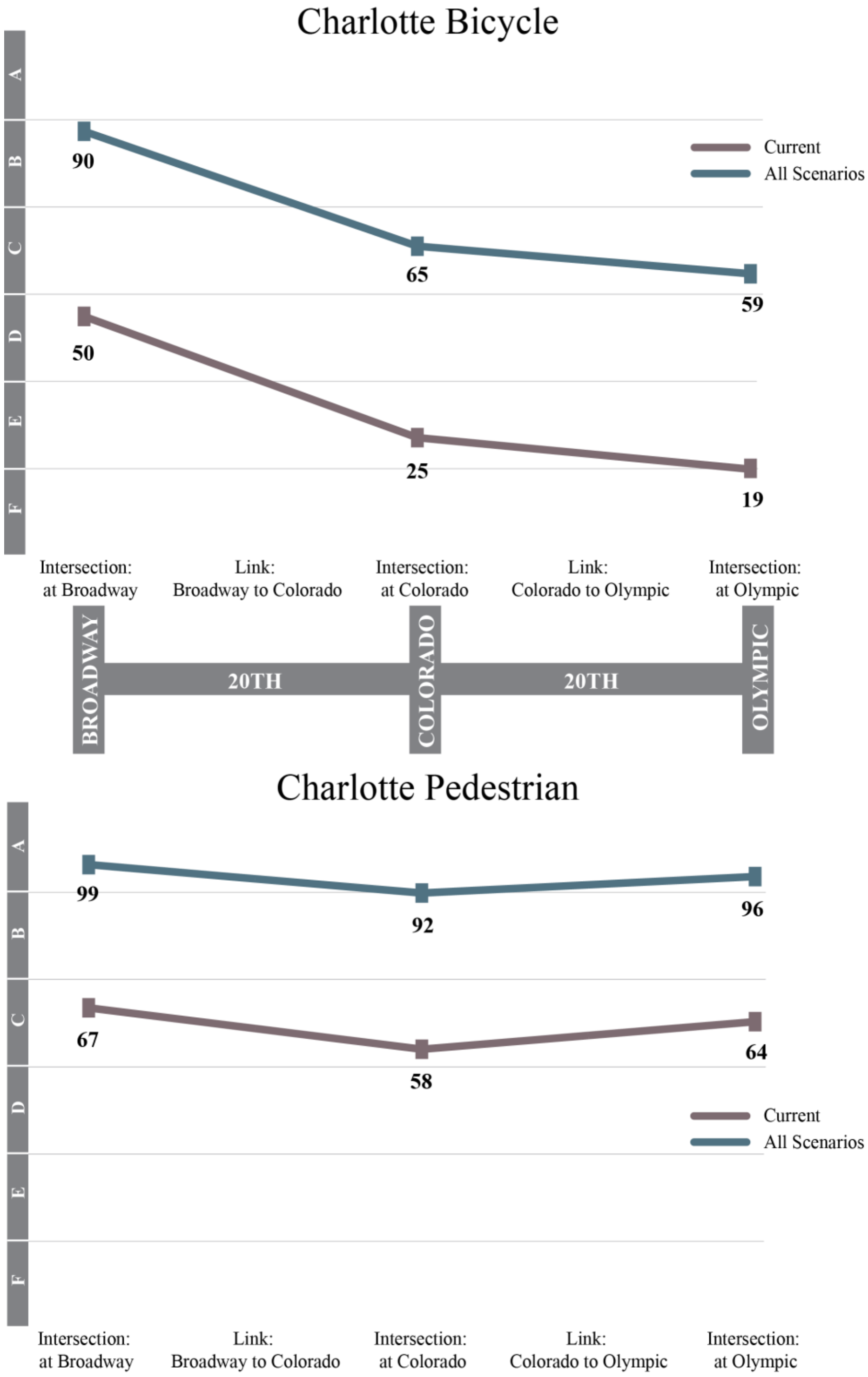


FIGURE 30 CHARLOTTE BICYCLE AND PEDESTRIAN IMPROVEMENT SCENARIO SCORES.

CHARLOTTE BICYCLE RESULTS

All five scenarios improved the scores by the same amount; from "D" to "B" at intersection 1 and from "E" to "C" at both intersections 2 and 3. Scores in scenario 1 increased largely because of the auto turning restrictions. Restricting left turns to protected-only turns and prohibiting RTOR made up about a third of the total score increase. The other two-thirds of the improvement are attributed to adding bicycle lanes, reducing the number of vehicle travel lanes, and adding bicycle boxes.

The Charlotte LOS tool does not account for the presence of physical barriers, so the scores for scenario 2 remained unchanged from scenario 1. Likewise, scenarios 3 and 4 also remained unchanged from scenario 1: Charlotte, unlike the other two metrics, does not distinguish between median left-turn lanes and general travel lanes. Since the total number of lanes remained the same, the score remained the same. Charlotte does not include the presence or absence of on-street parking, so the parking configurations in scenarios 3 and 4 did not factor into the overall bicycle score.

Despite the gains from the road diet and vehicle turning restrictions, none of the intersections increased above a "B" grade and most remained at a "C" grade. Intersections two and three continued to score poorly because the Charlotte LOS, unlike HCM but like the BEQI/PEQI, accounts for all four approaches to the intersection; the relatively low scores among all scenarios reflect the poor bicycling conditions at the cross-street approaches. For example, at 20th and Colorado, both approaches along 20th received a LOS of "A," while the approaches along Colorado received a LOS of "E." To create an overall intersection score, the Charlotte methodology totals the points from each crossing and divides the total by the number of intersection crossing legs. Most of the areas for improvement are on the cross-street approaches.

The following improvements would further increase the Charlotte bike score:

- restricting auto turn movements for cross-street approaches
- reducing the number of travel lanes for cross-street approaches
- adding of bicycle boxes on the cross-street approaches
- adding physical elements that would reduce the design speed limit to below 30 mph

CHARLOTTE PEDESTRIAN RESULTS

Similarly to the bicycle scoring improvement, all pedestrian improvement scenarios raised the scores equally. The pedestrian improvements in four of the five scenarios improved the intersections to near perfect levels. The existing pedestrian level of service was "C" at all three intersections. The improvements raised the levels to an "A" at intersections 1 and 3 and to a high scoring "B" at intersection 2. Scenarios 2, 3, and 4 scored no differently compared to scenario 1. Charlotte does account for the presence of a physical median. However, the number of awarded points for the median diminishes as the number of vehicle lanes decreases. For a crossing of three travel lanes, the benefit diminishes completely, and therefore scenario 5 does not score differently than scenario 1.

In scenario 1, the pedestrian score improvement is attributable to changing left turns to protected-only, the prohibition of RTOR, and the addition of a leading pedestrian interval. The road diet also contributed to some of the score improvement. As with HCM and BEQI, Charlotte was unable to directly evaluate the effect of the buffer, even though it may provide some benefit to the pedestrian environment.

Because the score is already quite high, little could be done to improve the Charlotte score beyond the improvements in the proposed scenarios. A few points can be earned by:

- Further reducing the number of vehicle travel lanes to two;
- Decrease curb radius to below 20';
- Further restrict right turning movements to protected-only (green arrow) turns.

HCM

The HCM scoring system provides separate bicycle and pedestrian scores at both the link and the intersection. At the intersection, the bicycle scoring considers each intersection approach in the direction of the link. If link includes northbound and southbound traffic, only the northbound and southbound intersection approaches will be included in the bicycle intersection level of service. For pedestrian intersection scores, the HCM provides two scores; one for each side of the intersection. Each score is an average of two intersection legs. For example, the intersection score for 20th & Broadway – North is an average of the intersection leg crossing Broadway (in the direction of vehicular travel) and the intersection leg crossing 20th (the other intersection leg one could reach from the SE corner). For the links between intersections, the bicycle scores are based on a direction of travel while the pedestrian scores are based on a side of the street. The resulting scores are then split into 6 ranges each given a letter grade from A-F. A lower score means a higher and better grade. Scores equal to or above 2.0 correspond to "A", scores above 2.0 to 2.75 receive a "B", from above 2.75 to 3.5 is a "C", scores from above 3.5 to 4.25 will correspond to a "D", scores from above 4.25 to 5.0 are "E", and any scores above a 5.0 will receive a "F."

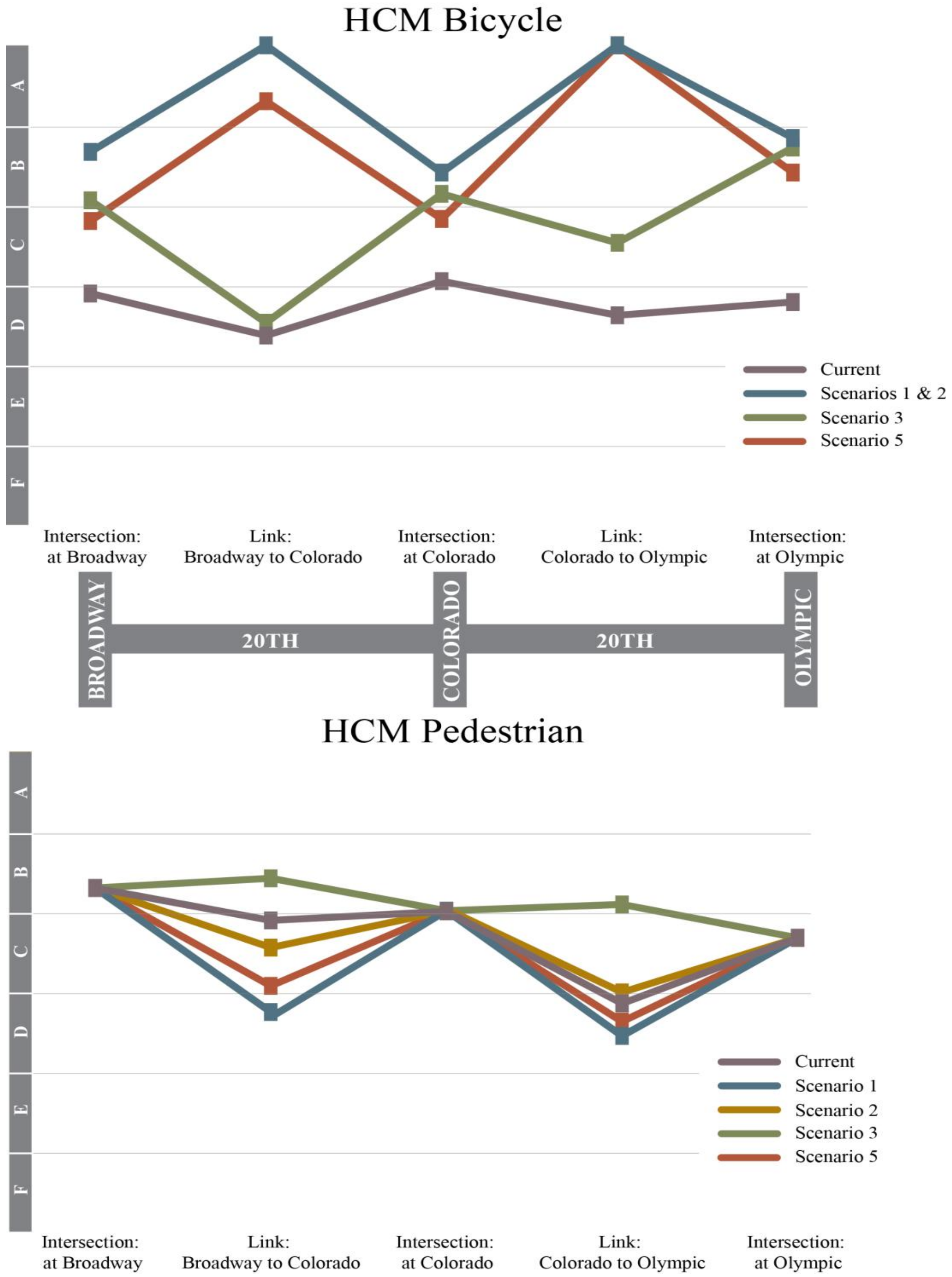


FIGURE 31 HCM BICYCLE AND PEDESTRIAN IMPROVEMENT SCENARIO SCORES

BICYCLE

Segments	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
20th & Broadway – North	3.63 / D	2.41 / B	2.41 / B	2.46 / B	N/A	3.06 / C
20th & Broadway – South	3.53 / D	2.09 / B	2.09 / B	2.95 / C	N/A	2.74 / B
Link 1 - West	3.96 / D	-0.27 / A	-0.27 / A	3.55 / D	N/A	1.35 / A
Link 1 - East	3.99 / D	-0.09 / A	-0.09 / A	4.16 / D	N/A	1.45 / A
20th & Colorado - North	3.18 / C	2.60 / B	2.60 / B	2.14 / B	N/A	2.82 / C
20th & Colorado - South	3.75 / D	2.29 / B	2.29 / B	3.15 / C	N/A	2.94 / C
Link 2 - West	3.78 / D	-0.81 / A	-0.81 / A	2.52 / B	N/A	-0.23 / A
Link 2 - East	3.79 / D	-0.78 / A	-0.78 / A	3.69 / D	N/A	0.11 / A
20th & Olympic - North	3.68 / D	2.10 / B	2.10 / B	1.60 / A	N/A	2.32 / B
20th & Olympic - South	3.64 / D	2.14 / B	2.14 / B	2.57 / B	N/A	2.57 / B

TABLE 10: HCM BICYCLE IMPROVEMENT SCENARIO SCORES

In Scenario 1, the road diet with bike lanes and painted buffers, the link scored a negative value, from "D" to "A". The formula has no lower or upper bounds; a negative value indicates the street link performs so well that the score is literally "off the charts." This confirms that HCM is very sensitive to the width of the bicycle lane and a wide enough bicycle lane can compensate for deficiencies found elsewhere. It is important to note, however, that as with BEQI, the buffer was reclassified as additional lane width. The software cannot compute the buffer that is added in scenario 2 providing the same score for scenarios 1 and 2.

Scenario 3 did improve over the existing conditions, but not to the levels seen in scenarios 1 and 2. The HCM bicycle score is particularly sensitive to the presence and occupancy of on-street parking. While we could include the presence of on-street parking, we used an assumed value, 75% for the occupancy levels, based on current occupancy of adjacent streets. Using an assumed value becomes problematic because if this tool was used in practice, this assumed value would weigh heavily on the overall score. Scenario 3 provided the most inconsistent results; the links were graded mostly "D" but the intersections improved from "D" to about a "B" on average (while the exact grades were "C," "B," and "A").

The HCM metric failed the most fundamentally in Scenario 4, where the bicycle lane was moved to the right of parked cars, in between the curb and the parking lane. This alternate configuration provides additional protection for bicyclists. Unfortunately, the HCM method is calibrated only for standard right-of-way configurations, where the bicycle lane is to the left of parking. HCM therefore was unable to assess the effect of this alternate configuration.

PEDESTRIAN

Segments	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
20th & Broadway – North	2.55 / B	2.55 / B	2.55 / B	2.55 / B	N/A	2.55 / B
20th & Broadway – South	2.53 / B	2.53 / B	2.53 / B	2.53 / B	N/A	2.53 / B
Link 1 - West	2.84 / C	3.48 / C	3.09 / C	1.89 / A	N/A	3.58 / D
Link 1 - East	2.85 / C	3.93 / D	3.11 / C	2.94 / C	N/A	3.34 / C
20th & Colorado - North	2.79 / C	2.79 / C	2.79 / C	2.79 / C	N/A	2.79 / C
20th & Colorado - South	2.73 / B	2.73 / B	2.73 / B	2.73 / B	N/A	2.73 / B
Link 2 - West	3.30 / C	3.96 / D	3.51 / D	2.14 / B	N/A	3.99 / D
Link 2 - East	3.20 / D	3.90 / D	3.53 / D	3.25 / C	N/A	3.60 / D
20th & Olympic - North	3.11 / C	3.11 / C	3.11 / C	3.11 / C	N/A	3.11 / C
20th & Olympic - South	2.86 / C	2.86 / C	2.86 / C	2.86 / C	N/A	2.86 / C

TABLE 11: HCM PEDESTRIAN IMPROVEMENT SCENARIO SCORES

For pedestrians, intersection scores remained practically unchanged for all scenarios. The pedestrian intersection score was a “B” or “C” for the existing condition and all improvement scenarios also received a low “B” or high “C.” The HCM pedestrian scores are largely driven by the number of lanes crossed and the number of auto turning movements. The scores do not receive any benefit from improvements such as curb extensions that increase pedestrian safety from turning vehicles. The calculations treat a center turning lane and a raised median equally, even though the software interface asks the user to distinguish between the two. Therefore, the raised median had no more affect on the scores than the road diet with the center turn lane.

As for the links between intersections, the resulting scores were again fairly similar with the exception of scenario 3. The link score in scenario 3 improved from a current “C” and “D” to an average “B” in both links. For both links 1 and 2, the west side of the street with added on-street parking received the greatest increase.

Scenario 2 proved to be the most counterintuitive for scoring. Although the barrier was intended to protect bicyclists, the only beneficiary of the bollards in terms of scoring was the pedestrian. As defined in HCM, the buffer variable, as long as it is at least 3 ft. tall and spaced 20 ft. apart or less, qualifies as a “continuous barrier,” providing a not insignificant boost to the pedestrian score. This single change was enough to boost the Link 1 score from “D” in scenario 1 to almost “B” in scenario 2. For this analysis, we assumed that the barriers were bollards in order to see the effect of satisfying the “continuous barrier” requirement. However, had the barrier been a wheel-stop or even a 2 ft. 11 in. tall bollard, there would have been no change to either score.

Overall, the pedestrian scores could be improved by adding on-street parking and recuing auto volumes and speeds.

DISCUSSION

All the measurement tools showed some response to proposed changes in the built environment. If these tools were used to select a package of improvements for bicycles along 20th street, the HCM, Charlotte and BEQI measures all recommend selecting either scenario 1 or 2. However, this result is underscored by the fact that none of the measures could appropriately handle the proposed parking-protected bicycle lane proposed in scenario 4. For the pedestrian scenarios, Charlotte and PEQI showed little distinction between any of the proposals, while the HCM scores improved the most for scenario 3. This result shows there may be a place for using multiple scoring tools to help validate results. The environments for pedestrians and cyclists do not exist in isolation. In practice, a city would want to select a suite of improvements that would best benefit pedestrians and cyclists alike. None of the various metrics identifies one scenario that increases both the pedestrian and cyclist scores. This signals a problem; one input could increase the LOS for one mode while degrading the other. This is true of on-street parking in the HCM.

Another problem found in this analysis is that the metrics are not flexible enough to account for the wide range of possible treatments for a street. This rigidity revealed itself in every one of the scenarios, where at least one of the metrics fell short in assessing the proposed changes. In most cases, only slight modifications to the scoring rubric were needed; however, in scenario 4, the shortcomings were so fundamental that the metric could not produce a score.

Beyond major right-of-way reconfigurations, the metrics are largely incapable of accounting for the small infrastructure elements such as painted buffers and physical barriers. These elements, which separate bicyclists from motor vehicle traffic, increase both the perceived comfort and safety for those using the facility as referenced in the improvement descriptions. But these changes, again, are difficult to evaluate using the various metrics.

CONCLUSION

Our work presented in chapter 2 comparing these three multimodal performance measures; HCM, City of Charlotte and BEQI/PEQI did not provide enough information to guide someone to select one measure over another, based on the scoring outputs alone. This case-study analysis appears to provide more guidance towards that goal. For the HCM tools, we again found that the HCM is the most difficult tool to use and that it has little ability to account for small infrastructure improvements. We found that if using the HCM, the improvements to the pedestrian environment may be shown to deteriorate the bicycle environment. The HCM provided the greatest range of results, particularly for the bicycle improvement scenarios. This does not necessarily mean that the HCM results are valid, but rather the software gives the appearance of the greatest differentiation and that this measure may be most sensitive to some changes. While the Charlotte tool could best interpret the various improvements, all scores increased equally, providing little help in selecting one improvement scenario over another. The PEQI tool showed little variation and therefore a small amount of sensitivity to change, while the BEQI tool returned large improvements from the current scores. But the BEQI intersection score is only based on three inputs; to see these score increases, the improvements must include either right-turn-on-red restrictions, striping of the bicycle lane through the intersection and the absence of a left-turn bicycle lane. This limited choice set greatly restricts the improvement options.

Overall, the range of variation among the scenarios is not necessarily a good or bad thing. This depends on how much a practitioner or someone traveling on this corridor would perceive the scenarios to be different from each other. From these perspectives, is a striped bicycle lane vastly different than a bicycle facility that is protected by parked cars? These treatments are rapidly evolving so there is not much documented evidence to answer this question (National Institute for Transportation and Communities, 2014). Regardless of the documented evidence, this type of case study analysis can allow decision makers and agencies to assess the validity of these metrics for evaluating alternatives.

Ultimately, each of the metrics is mired in the time period from which it was created. This is especially evident in their failure to evaluate road designs currently being developed throughout the United States. Designing for bicyclists and pedestrians is constantly innovating and the adoption of any one of these metrics as a guiding tool would likely not mirror this innovation and growth. For these metrics to remain relevant, they require constant updating to reflect these innovations.

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APPENDIX A: COMPENDIUM OF METRICS

Pedestrian	*HCM 2010*	*Fort Collins*	*Charlotte*	*PEQI*
Traffic Aspects				
Motorized traffic volumes	X			X
Motorized traffic speeds	X			
Parallel traffic volumes	X			
Parallel traffic speed	X			
Number of lanes	X			X
Two-way traffic	X			-
Vehicle speed limit	X			X
Intersections				
Crossing delay or wait time	X			X
Crossing speed	X		X	X
Conflicting traffic volumes	X			
Conflicting motorized vehicle speeds	X			
Crossing width	X	X	X	X
Presence of a median	X	X	X	X
Presence of right-turn channelizing islands	X		X	
Signal Phasing	X		X	X
Corner radius	X		X	
Right turns on red	X		X	X
Adjustment for one-way street crossings			X	
Crosswalk	X	X	X	X
High visibility crosswalk		X	X	X
Pedestrian signal	X	X	X	X
Pedestrian Network				
Diversion to nearest signalized intersection	X			
Directness		X		

Table continues on the next page…

Pedestrian (Continued)	*HCM 2010*	*Fort Collins*	*Charlotte*	*PEQI*
Sidewalk Aspects				
Density of pedestrians	X	X		
Sidewalk or facility continuity		X		
Sidewalk width	X	X		X
Free-flow walking speed	X			
Sidewalk impediments or obstructions	X			X
Presence of curb	X	X		
Driveway cuts				X
Presence of buffer	X			X
Width of buffer	X			
Calming measures				X
ADA curb ramps		X		X
Other Street Aspects				
Presence of on-street Parking	X			
Visual interest and amenity		X		
Police presence		X		
Lines of sight		X		
Lighting levels		X		X
Trees, planters, gardens	X*			X
Public seating	X*			X
Storefronts or retail use				X
Public art or historical sites				X
Illegal graffiti				X
Litter				X
Abandoned buildings				X
***Listed in HCM2010 as impediments**				

Table continues on the next page…

Bicycle	*HCM 2010*	*Fort Collins*	*Charlotte*	*BEQI*
Traffic Aspects				
Motorized traffic volumes	X			X
Motorized traffic speeds	X		X	X
Percentage of heavy vehicle	X			X
Presence of buses	X			
Number of vehicle lanes	X			X
Vehicle lane width	X			
Bicycle running speed	X			
Intersections				
Cross-street width	X		X	
Signal delay	X			
Stop-bar location	X			X
Intersection dashed bicycle lane				X
Left turn flow rate	X			
Right turn traffic conflict			X	X
No turn on red sign(s)			X	
Bicycle Network				
Connection to on-street lanes		X		X
Connection to off-street paths		X		
Connection to on-street route		X		
Traffic Separation				
Separation from traffic	X	X	X	
Traffic calming features				X
Presence of a marked area for bicycle traffic	X	X	X	X
Width of bicycle lane	X	X		X
Width of outside lane	X	X	X	
Paved shoulder	X		X	
Parking				
Parking presence	X			X
Other Street Aspects				
Trees				X
Pavement type and condition	X	X		X
Driveway cuts	X			X
Street slope		X		X
Bicycle/pedestrian scale lighting				X
Line of sight				X
Bicycle parking				X
Retail use				X