Draft Bicycle Comfort Index (BCI) Methodology

January 31, 2023

Purpose and Goals

Toole Design is supporting the SFMTA to update the agency's 2017 Bicycle Comfort Index (BCI) methodology and map. The updated BCI score will meet the SFMTA's implementation needs by:

- Capturing a variety of quantitative and qualitative factors that impact comfort, customized for the San Francisco context
- Applying a nuanced, defensible methodology that can be regularly updated and easily maintained
- Allowing the SFMTA to test and measure the impact of different design interventions on levels of comfort

Defining Bicycle Comfort

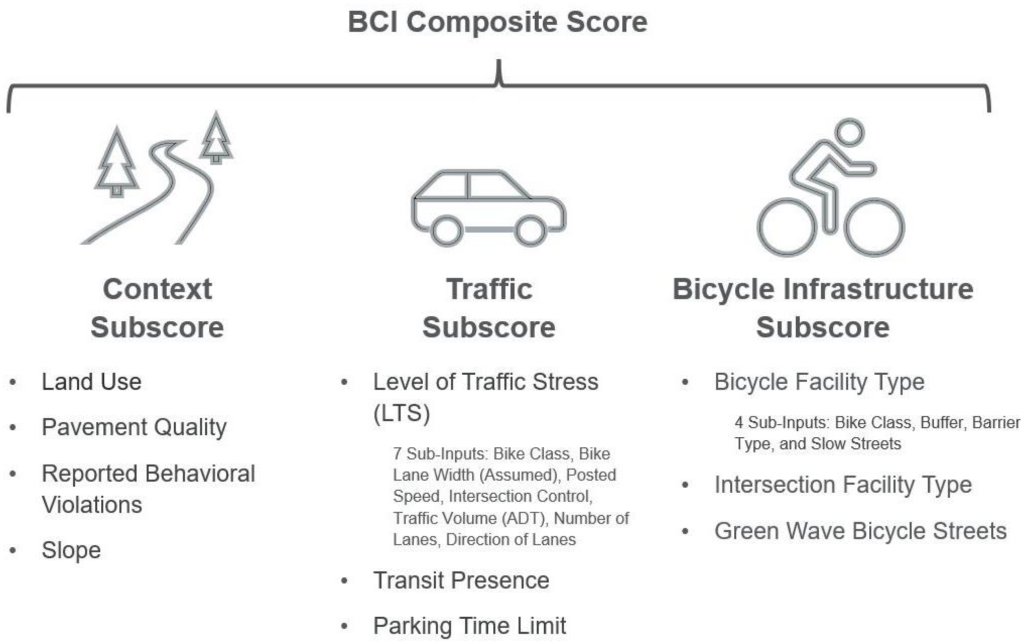
San Francisco's bicycle network is made up of five facility types (protected bikeway, bicycle lane, bicycle route, off-street multi-use path, and slow streets). But these categories do not capture how people experience these facilities while biking and rolling. The Bicycle Comfort Index evaluates San Francisco's street network using quantitative indicators of comfort. San Francisco's 2023 BCI builds upon and expands the nationally standardized Bicycle Level of Traffic Stress (LTS). LTS considers prevailing speed, ADT, number of lanes, lane width, facility type, and facility width. This iteration of San Francisco's BCI takes the LTS model a step further to consider other factors that influence perceptions of comfort, such as the type of vertical delineation along a bike lane, pavement quality, elevation, and surrounding land use conditions.

Proposed BCI Framework

Toole Design worked with the SFMTA staff to develop a BCI framework that tells a nuanced story about bicycle (and micromobility) comfort in San Francisco. The project team developed a framework for calculating BCI that is inspired by the questions: *"Of all the factors that influence comfort, which factors does SFMTA have influence over? Which factors fall outside of SFMTA's sphere of influence?"* With these questions in mind, the BCI is broken down into three "subscores". The subscores are generally organized to distinguish between those factors that the SFMTA can feasibly impact to improve comfort (such as type of bicycle facility), and factors that the SFMTA cannot influence (such as slope/elevation). In this way, **the BCI score will support the SFMTA staff to identify and invest in physical infrastructure or pursue policies that influence bicyclist comfort.**

Figure 1 illustrates the proposed BCI framework, including the ten inputs that make up each of the three subscores.

Figure 1: San Francisco 2023 BCI Draft Framework: 1 Composite Score, 3 Subscores, 10 Inputs



Three Subscores

Subscore #1: Context

The Context Subscore is made up of four (4) inputs. Table 1 shows how they mathematically contribute to the subscore and interact with one another. Table 1 also shows how they are weighted relative to one another. Segments can receive a maximum Context Subscore of 50.

Table 1: Context Subscore Inputs

Input	Mathematical Formulas	Point Range	Relative Weight in Subscore
Land Use	Additive	30 (16 to 46)	Highest
Pavement Quality	Additive	12 (-8 to 4)	Middle
Reported Behavioral Violations	Additive	8 (-8 to 0)	Lowest
Slope	Multiplier	NA	NA

The interaction between the four inputs can be described by the following formula:

$$(\text{Land Use} + \text{Pavement Quality} + \text{Behavioral Violations}) * \text{Slope}$$

Table 2 illustrates how different combinations of inputs can produce different Context Subscores. The examples described below are examples only and are not associated with specific real-world locations in San Francisco.

Table 2: Examples Context Subscores and Corresponding Input Scenarios

Context Subscore	Example Input Scenarios		
0 (Lowest possible score)	Commercial land use with poor pavement quality and many reported behavioral violations	Residential land use with an impassable slope	Public land use with poor pavement quality, many reported behavioral violations, and an uncomfortable slope
10 (Low)	Industrial land use with many reported behavioral violations	Public land use with poor pavement quality and many reported behavioral violations	Residential land use with a very uncomfortable slope
20 (Low-Mid)	Public land use poor pavement quality	Industrial land use with good pavement quality	Residential land use with an uncomfortable slope
30 (High-Mid)	Residential land use with poor pavement quality issues and a noticeable slope	Public land use with good pavement quality and many reported behavioral violations	Public land use with fair pavement quality and very few reported behavioral violations
40 (High)	Residential land use with poor pavement quality	Residential land use with several reported behavioral violations	Residential land use with good pavement quality and a noticeable slope
50 (Highest possible score)	Residential land use with good pavement quality and no slope	*(no other combinations produce this score)*	*(no other combinations produce this score)*

Subscore #2: Traffic

The Traffic Subscore is made up of three (3) inputs. Table 3 shows how they mathematically contribute to the subscore and interact with one another. Table 3 also shows how they are weighted relative to one another. Segments can receive a maximum Traffic Subscore of 50.

Table 3: Traffic Subscore Inputs

Input	Mathematical Formulas	Point Range	Relative Weight in Subscore
Level of Bike Traffic Stress (LTS)*	Additive	30 (20 to 50)	Highest
Parking Time Limit	Additive	12 (-12 to 0)	Middle
Transit Presence	Additive	8 (-8 to 0)	Lowest

*LTS is made up of a further seven inputs: Bike Facility Classification, Bike Lane Width, Prevailing Speed (Posted Speed Limit where Prevailing is not available), Intersection Control, Traffic Volume (ADT), Number of Lanes, and Direction of Lanes

The interaction between the three inputs can be described by the following formula:

LTS + Curbside Turnover + Transit Presence

Table 4 illustrates how different combinations of inputs can produce different Traffic Subscores. The examples described below are examples only and are not associated with specific real-world locations in San Francisco.

Table 4: Examples Traffic Subscores and Corresponding Input Scenarios

Traffic Subscore	Example Input Scenarios		
0 (Lowest possible score)	LTS 4 on a Transit corridor with extremely frequent Curbside Turnover	*(No other combinations for a zero score)*	*(No other combinations for a zero score)*
10 (Low)	LTS 4 on a Transit corridor	LTS 4 with very frequent Curbside Turnover	LTS 3 on a Transit corridor with extremely frequent Curbside Turnover
20 (Low-Mid)	LTS 4 without Transit and extremely infrequent Curbside Turnover	LTS 3 on a Transit corridor	LTS 2 on a Transit corridor with extremely frequent Curbside Turnover
30 (High-Mid)	LTS 2 with very frequent Curbside Turnover	LTS 2 on a Transit corridor	LTS 3 without Transit and extremely infrequent Curbside Turnover
40 (High)	LTS 1 on a Transit corridor	LTS 1 with very frequent Curbside Turnover	LTS 2 without Transit and extremely infrequent Curbside Turnover
50 (Highest possible score)	LTS 1 without Transit and extremely infrequent Curbside Turnover	*(No other combinations produce this score)*	*(No other combinations produce thus score)*

Traffic Subscores are used to moderate the comfort impact of different bicycle facility types under the Bicycle Infrastructure Subscore. To that end:

- Heavy Traffic Conditions (shown in orange) = Traffic Subscore of 10 or below out of 50
- Neutral Traffic Conditions = Traffic Subscore of 11 – 39 out of 50
- Light Traffic Conditions (shown in green) = Traffic Subscore of 40 or above out of 50

Subscore #3: Bicycle Infrastructure

The Bicycle Infrastructure Subscore is made up of three (3) inputs. Table 5 shows how they mathematically contribute to the subscore and interact with one another. Table 5 also shows how they are weighted relative to one another. Segments can receive a maximum Bicycle Infrastructure Subscore of 50.

Table 5: Bicycle Infrastructure Subscore Inputs

Input	Mathematical Formulas	Point Range	Relative Weight in Subscore
Bike Facility Type	Additive, Conditional	35 (5 to 40)	Highest
Intersection Bike Facility Type	Additive, Conditional	10 (0 to 10)	Middle
Green Wave Signal Streets	Additive, Bonus	5 (0 to 5)	Lowest

The interaction between the three inputs can be described by the following formula:

Bicycle Facility Type + Intersection Bike Facility Type + Green Wave

This subscore accounts for the fact that no facility exists in isolation from the surrounding traffic context. The same facility type may be either appropriate and comfortable OR inappropriate and uncomfortable, depending on the traffic context. For example, a Class II Bike Lane with a buffer may be appropriate and comfortable on quiet street with low volumes and speeds. That same facility is inappropriate and may be uncomfortable on a busy street with high volumes and speeds. **Therefore, the number of points allocated to each facility type is modified by the surrounding traffic.** Table 6 shows the number of points allocated to each bicycle facility type, depending on the traffic conditions. More specifically, it shows the number of points allocated depending on the Traffic Subscore. Table 7 shows the number of points allocated to each Intersection Facility Type, depending on the Traffic Subscore.

Table 6: Point Allocation per Bicycle Facility Type, Modified by Traffic Context

	Heavy Traffic	**Neutral Traffic**	**Light Traffic**
Traffic Subscore Range	**0-10**	**11-39**	**40-50**
Bicycle Facility Type			
Class III – Bike Route	5	10	10
Class II – Bike Lane no buffer	10	16	20
Class IV – SBL with “CURB”	10	16	20
Class II – Bike with buffer	16	20	25
Class IV – SBL with “SAFE-HIT POST”	20	23	30
Class IV – SBL with “CONCRETE” or “CONCRETE ISLAND”	25	27	35
Class IV – SBL with “K-RAIL”	35	30	40
Class IV – SBL with “BACK-IN ANGLED PARKING” or “PARKING”	35	35	40
Slow Street	20	35	40
Class I – Bike Path	40	40	40

Table 7: Point Allocation per Intersection Facility Type, Modified by Traffic Context

	Heavy Traffic	Neutral Traffic	Light Traffic
Traffic Subscore Range	**0-10**	**11-39**	**40-50**
Intersection Facility Type			
“Intersection sharrow” or “Mixing zone”	0	2	2
“Crossbike”	4	5	6
“Two-stage left” or “Jughandle” or “Bike Box” or “Bike Signal”	7	8	10
“Bike channel” or “Protected corner” or “Protected intersection”	10	10	10

Table 8 illustrates how different combinations of inputs can produce different Traffic Subscores. The examples described below are examples only and are not associated with specific real-world locations in San Francisco.

Table 8: Examples Bicycle Infrastructure Subscores and Corresponding Input Scenarios

Infrastructure Subscore	Example Input Scenarios		
0 (Lowest possible score)	“Heavy Traffic Condition” – Bike Route with a Sharrow	“Heavy Traffic Condition” – No facilities	Neutral Traffic Condition” – marked Crossbike
10 (Low)	“Heavy Traffic Condition” – Bike Lane without a Buffer	“Heavy Traffic Condition” – Bike Route with a marked Crossbike	“Neutral Traffic Condition” – Bike Route with a Sharrow
20 (Low-Mid)	“Heavy Traffic Condition” – Buffered Bike Lane with a marked Crossbike	“Neutral Traffic Condition” – Buffered Bike Lane with a marked Crossbike	“Light Traffic Condition” – Bike Lane without a Buffer
30 (High-Mid)	“Heavy Traffic Condition” – Concrete-protected SBL with a Two-Stage Left	“Neutral Traffic Condition” – K Rail-protected SBL	“Light Traffic Condition” – Safe Hit Posts-protected SBL
40 (High)	“Heavy Traffic Condition” – Bike Path	“Heavy Traffic Condition” – Green Wave Street with Parking-protected SBL	“Neutral Traffic Condition” – Slow Street with a marked Crossbike
50 (Highest possible score)	Any Traffic Condition – Bike Path with a protected intersection	“Light Traffic Condition” – Concrete-protected SBL with a Two-Stage Left	“Neutral Traffic Condition” – Green Wave Street with Parking-protected SBL and a Bike Box

Final BCI Score

The BCI score is the summation of all three subscores, weighted equally with their 50-point ranges, and has a total point potential of 150 points. The total equation for a segment's BCI is below.

((Land Use + Behavioral Violations + Pavement Quality) * Slope))
+ (LTS + Transit Presence + Curbside Turnover)
+ (Bike Facility Type + Intersection Bike Facility Type + Green Wave)

Every segment in San Francisco's street network will receive a BCI score between 0 and 150. The scoring range will be broken into even or proportional buckets. The draft methodology breaks the BCI range into five equal buckets. The final scoring breakdown and naming convention will be determined in coordination with SFMTA staff and the BCI Working Group. Table 9 provides example input and subscore scenarios that can produce scores in each of the five buckets.

Table 9: BCI Score point ranges and possible input scenarios to achieve each score

BCI Score	Example Subscores	Example Input Scenarios
121-150	Highest Context Subscore + High Traffic Subscore + High Bike Infrastructure Subscore	Residential land use with fair pavement quality, LTS 1 on a Transit corridor, and Safe Hit Posts-protected SBL with a Bike Signal
91-120	Highest Context Subscore + High-Mid Traffic Subscore + High-Mid Bike Infrastructure Subscore	Residential land use with good pavement quality, LTS 2 with frequent Curbside Turnover, and Green Wave Street with a Buffered Bike Lane and Protected Intersection
61-90	High-Mid Context Subscore + High-Mid Traffic Subscore + Low-Mid Bike Infrastructure Subscore	Public land use with good pavement quality and many reported behavioral violations, LTS 3 without Transit and extremely infrequent Curbside Turnover, and Buffered Bike Lane with a marked Crossbike
31-60	Lowest Context Subscore + Lowest Traffic Subscore + High Bike Infrastructure Subscore	Public land use with poor pavement quality and many reported behavioral violations, LTS 4 on a Transit corridor with extremely frequent Curbside Turnover, and K Rail-protected SBL with a Protected Corner
0-30	Low Context Subscore + Lowest Traffic Subscore + Lowest Bike Infrastructure Subscore	Residential land use with good pavement quality and a very uncomfortable slope, LTS 3 on a Transit corridor with extremely frequent Curbside Turnover, and Bike Route with a marked Crossbike

Mathematical Formulas

The draft BCI formula is designed to be a mathematical description of real-world interactions between the various factors that influence comfort. To capture the nuance of real-world interactions and interdependence, the formula uses weighting, multipliers, conditional formulas, and bonus points:

Additive Points and Weighting

Under the draft methodology, many inputs are additive (ie. they are assigned points, and those points are simply added together). To add nuance to additive inputs, each input is weighted according to how much it influences comfort in the real world, relative to other inputs. Weighting is achieved by assigning different inputs with different potential point ranges. For example, the Traffic Subscore is the summation of LTS + Transit Presence + Parking Time Limit. Each input is assigned a weighted point range: LTS = 30 Point Range (From 20 to 50), Transit Presence = 12 Point Range (From -12 to 0), Parking Time Limit = 8 Point Range (From -8 to 0). The variation in the point ranges produces varied weighting. In this case, LTS has the largest possible point range and is therefore is weighted most heavily. Point allocation, and therefor weighting, can be adjusted in coordination with SFMTA staff and the BCI working group.

Multiplier

Under the Context Subscore, "Slope" is treated as a multiplier

In contrast to land use, pavement quality, and behavioral violations, slope is un-changeable. Slope impacts comfort independent of the other three inputs. Slope is therefore multiplied with, rather than added to, the summation of the other three inputs. Therefore, severe, or impassable slope (>8%) can override any comfort provided by the other three inputs. Ranging from 0% to 100%, this multiplier input can only reduce the summation of the previous context inputs.

Conditional Performance

Under the Bicycle Infrastructure Subscore, "Facility Type" and "Intersection Type" are both treated as conditional, depending on the surrounding traffic conditions.

This BCI accounts for the fact that no facility exists in isolation from the surrounding traffic context. The same facility type may be either appropriate and comfortable OR inappropriate and uncomfortable, depending on the traffic context. For example, a Class II Bike Lane with a buffer may be appropriate and comfortable on quiet street with low volumes and speeds. That same facility is inappropriate and may be uncomfortable on a busy street with high volumes and speeds. Therefore, the number of points allocated to each facility type is modified by the surrounding traffic

Bonus Points

Under the Bicycle Infrastructure Subscore, "Green Wave Streets" are treated as bonus points.

The proposed BCI model allows street segments to receive the highest possible Bicycle Infrastructure Subscore (50 out of 50 points), without even considering the presence of Green Wave Streets. Segments can receive a maximum of 40 points for Bicycle Facility, and a maximum 10 points for intersection type. Under that scenario, the presence or absence of Green Wave signals is moot. However, if a segment has a combined Facility Type + Intersection Type score of 45, the presence of Green Wave signals can contribute up to 5 bonus points for a total of 50 points. Note that the maximum subscore possible is capped at 50. If a segment has a combined Facility Type + Intersection Type score of 48, the presence of Green Wave signals will bring the facility to 50 points, but will not result in points beyond 50.

Assumptions and Limitations

Due to data availability or form, simplification of the methodology, and/or other reasons, this BCI is limited in its ability to exactly express the expected or true comfort on every facility. Some of these limitations include:

- **Impact of Land Use:** Under the proposed methodology, Commercial, Mixed Use, and Industrial land uses are all considered “uncomfortable” for bicyclists. However, commercial areas can contribute to a sense of personal safety or comfort due to "eyes on the street", placemaking, or streetscaping. Similarly, industrial areas can feel comfortable when traffic volumes and speeds are low. This BCI methodology does not account for these possible positive impacts. The Residence Preference Survey will help calibrate and adjust the methodology as it relates to this assumption/ limitation. For segments that have different land uses on each side of the street, the "more comfortable" (higher point earning) land use is assumed to take precedence (e.g., a segment with commercial on one side and residential on the other will be classified as residential).
- **Reported Behavioral Violations:** By nature of publicly reported data, this 311 source may skew frequency in the raw data to poorer areas of San Francisco or generally have different patterns in differently reporting neighborhoods, falsely showing an increase in one area over another.
- **Parking Time Limit (Proxy for Curbside Turnover):** The methodology does not adjust the comfort impact of parking turnover for different facility types. For example, parking turnover will have the same impact on the Traffic Comfort Score at locations with bike lanes, parking protected bike lanes, and separated bike paths. We know that parking-protected bike lanes and Class I paths may not feel the full effect of curbside turnover, but this nuance is not captured by the model.
- **Bike Lane Width and Buffer Width:** Discrete data for these potential inputs is not readily available. Bike Lanes are assumed to be 6 feet wide and the Buffer input is used as a binary (either present or not present). Therefore, this BCI is not able to further distinguish between facilities with wide buffers and narrow buffers or allocate points to wide bike lanes that could accommodate side-by-side riding.
- **Speed Limits:** Posted speed limit data is older than the implementation of the Slow Streets Program and Slow Streets segments. Therefore, all Slow Streets segments are assumed to have a speed limit of 15 mph to match with the intention of the program.
- **Temporal Changes/Differences:** This BCI does not account for changes in context, traffic, etc. throughout the day, throughout the week, and throughout the year. Different times of day, days of the week, and seasons may affect the performance or data (e.g., ADT near schools will decrease in the summer months), but this BCI is stagnant in time.
- **Different Users:** This BCI does not account for different comfort levels experienced by different user types (e.g., e-bikes may not experience steep slope as uncomfortable). This BCI will be used in tandem with the cross-tabulated findings from the Residence Preference Survey to tell the story of how different demographics feel about different contexts/ facility types.