Measuring and Evaluating Bikeability in San Francisco

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Executive Summary

The past quarter has been a worthwhile journey of coming together as a collaborative group to improve the current bikeability metric used for the diverse community and hilly geography of San Francisco. When we first met with Janice Li, the Advocacy Director of the San Francisco Bicycle Coalition (SFBC), we were presented with an overview about our tasks. We were all eager to begin taking on this project that would not only improve the bikeability metric used today, but would also cultivate important sustainable practices through the promotion of a biking culture in a major city such as San Francisco.

As we worked with our community partner through Sustainable Cities, we soon learned that service is about truly listening and adhering to the needs of the community. One of the first steps we had to take in order to effectively carry out the procedures that our project entailed was to inform ourselves about the values that the SFBC stands for. The mission of the SFBC is to "transform San Francisco's streets and neighborhoods into more livable and safe places by promoting the bicycle for everyday transportation." Therefore, our goal as a group of dedicated individuals was not just to devise the project deliverables, but to ultimately create a project that would make a positive contribution to the efforts of the SFBC.

Our goal was to conduct a literature review on the history and methodology of Level of Traffic Stress (LTS) as a bikeability metric and to explore metrics used in other cities to formulate our own recommendations relevant to the circumstances of San Francisco. These suggestions would be displayed in a sample map of the metric. We first had to familiarize ourselves with the 2013-2018 Bicycle Strategy created by the San Francisco Municipal Transportation Agency (SFMTA) in order to obtain greater insight into the progress and effectiveness of the LTS bikeability metric used in SF.

In terms of data collection and research methodology, we went out to work in the field. In other words, we took our bikes on the CalTrain up to San Francisco to experience biking in the hilly city on a rainy day, which was a genuine experience that showed us the reality of many people who use biking as their main source of transportation. In addition to getting a tour of the SFBC headquarters, we also talked to SFMTA senior planners Jamie Parks and Monica Munowitch about the strengths and shortcomings of LTS. We learned that intersections were not a major consideration in the maps currently depicting LTS, so after discussing with our community partner, we decided to focus on intersections in Districts 6 and 11. District 6 is known to have many collisions and District 11 is known for its steep topography; therefore, we aimed to create maps for these areas of concentration. After researching the bikeability metrics of Long Beach and Copenhagen as well as examining other metrics such as the HCM Bicycle Level of Service and Bicycle Environment Quality Index (BEQI), we agreed that slope and pavement quality

would be our recommended additions to the SFMTA's current version of LTS. We then set out to design our maps using GIS.

Considering the significance of our project in the scope of creating a more sustainable city, we look forward with the anticipation that our work will make a lasting positive impact in promoting a safe and vibrant bicycling culture all across San Francisco.

Acknowledgements

Project Purpose

Background about the project
Our project's focus is on researching and recommending a bikeability metric that would be relevant to San Francisco. Currently, San Francisco uses the Level of Traffic Stress (LTS) bikeability metric, as dictated by the SFMTA's 2013-2018 Bicycle Strategy (SFMTA, *SFMTA Bicycle Strategy* 15-18). However, the LTS metric has been difficult for San Francisco to measure and track as the City continues to seek how to best monitor its progress toward increased transportation by bicycle.

The following questions will be essential to helping us obtain the necessary information to provide a strong recommendation for how the City of San Francisco and community partners such as the San Francisco Bike Coalition can better understand bikeability in San Francisco:
1. What are the most widely used or discussed metric systems for bikeability?
2. What are the strengths/weaknesses of each bikeability metric?
3. Which aspects of bikeability are most likely to drive consistent behavior desired by San Francisco?
4. Which metric or series of metrics/guidelines would be the best fit for San Francisco's bikeability assessment needs?

Answers to these questions will provide vital information on the resources the City and community partners have to track and analyze bikeability information, which will help us create and/or identify an ideal bikeability metric that suits the needs of stakeholders. This is important in order for San Francisco to efficiently identify new opportunities for improving bicycle infrastructure and incentivize more people to utilize biking as a form of transportation. Finally, through conversations with stakeholders, we will ensure our final recommendation is politically effective and economically feasible for implementation in the near future.

Project Location
The location of our project is in San Francisco, California. San Francisco has a population of 837,442 as of 2013. Specifically, our project focuses on District 6 (South of Market/SOMA, Tenderloin, but not including Treasure Island) and District 11 (Excelsior, Oceanview, Merced Heights, and Ingleside). District 6 has a population of 104,429 and District 11 has a population of 73,665. We are focusing on these districts because District 6 has a high number of bicycle collisions and District 11 is hilly and difficult to bike. Also, the South of Market (SOMA) area that is part of District 6 is formerly industrial and thus has a history of being more auto-oriented.

Description of community partner and organization's mission
The San Francisco Bicycle Coalition, one of the most effective nonprofit bicycle advocacy groups in the country, has a mission to promote the bicycle for everyday transportation. This group recognizes how beneficial it is to get San Franciscans to use bicycles as their main form of transportation. In order to do so, they work daily in association with city partners and those in the community. This organization serves to create a community filled with safe streets for all San Franciscans. The SFBC has been advocating for the bicycle community for over 45 years. During this time they have been educating the public on safety, volunteering, holding classes, and advocating for the betterment of the bicycle community. The end goal of this project is to research and recommend a bikeability metric that would be relevant for San Francisco.

What did we set out to accomplish?
By partnering with the San Francisco Bicycle Coalition on our project--Measuring and Evaluating Bikeability in San Francisco--we planned to study the current bicycle methodology (how it works, possible improvements, etc.) as well as other communities around the world. We originally were tasked with creating a new bikeability metric to replace Level of Traffic Stress (LTS). However, after conversations with the SFMTA, we realized that the City prefers to continue using LTS but was certainly open to adding data to enhance the metric. Using information provided by our community partner and outside research, we set out to create and publish a map, using ArcGIS Online, that takes the data about San Francisco's bikeability and our research on other communities' methodologies to present a sample map of possible ways to improve the bikeability metric for San Francisco. The map would focus on the intersections

within Districts 6 and 11. In addition to this map, we would produce a written report that includes a literature review on the history and methodology of LTS as a bikeability metric, a measure of the progress and effectiveness of LTS so far in San Francisco, data on other researched bikeability metrics, and recommendations that could enhance the current LTS bikeability metric.

Why is this project important?
This project is important because it provides research on bikeability methods of other cities around the world and applies it to San Francisco's current bikeability metric. In doing so it analyses LTS and Bicycle Environment Quality Index (BEQI) to find what can be improved or should not be changed to aid the San Francisco Bicycle Coalition in successfully adhering to their mission of creating a community filled with safe streets for all San Franciscans. Specifically, with our project we focused on the intersections districts six and eleven to provide information that the LTS system does not have yet. Including this information allows us to provide information about intersections that the LTS system does not talk about as well as slope, income, and pavement quality.

How does this project relate to broader themes in sustainable cities?
This project relates to broader themes in sustainable cities as this project can aid in enhancing environmental quality, economic vitality, social equity, and cultural continuity, which is what sustainability is all about. Even though this project may be small, it can help improve environmental quality by promoting biking as an efficient and safe way for community members of all ages to get around San Francisco. This can lower the rate of those driving cars in the City, thus improving air quality. Also, it can help with economic vitality by providing a affordable source of transportation that people can be creative with by getting ones with batteries, that can seat multiple children, hold pets, deliver food, etc. It is likely that many tasks and routines that we have can be done with a bicycle instead of the car. In terms of social equity, promoting the efficacy and safety of biking in San Francisco offers San Franciscans equal access to affordable and efficient daily transportation. Finally, this project can help with cultural continuity as the implementation of biking as a new form of highly recommended transportation can allow all different cultures to use this method of transportation to support their daily lives. Overall, this project can promote biking as a sustainable efficient method of transportation that can improve air quality, lower noise pollution, conserve energy, and save money.

Literature Review

For a bicycling network to attract the widest possible segment of the population, its most fundamental attribute should be low-stress connectivity, which is providing routes between people's origins and destinations that do not require cyclists to use paths that exceed their tolerance of traffic, such as busy highways or interstates, with little to no added detours. A city's bicycling network can be defined in various ways, such as its bicycling infrastructure, or the paths or roads where cyclists are permitted and feel comfortable using. Considering that the majority of Americans use a vehicle as their main mode of transportation, those who do not own a car often refuse to convert to biking because of the lack of safe routes to ride, longer commute times, or are not comfortable cycling near traffic. Because of this, an improved way of defining a bicycling network, known as Level of Traffic Stress, was created to evaluate the streets and paths that do not exceed people's tolerance of traffic stress, as well as improve the streets that do.

Past research has revealed that Americans have varying levels of comfortability and tolerance for traffic stress, which is defined as the potential dangers and other annoyances associated with riding a bike in close proximity to vehicle traffic. This includes the possibility of crashes and inconveniences such as poor pavement quality, lack of bike lanes and cross-traffic turn lanes, little to no separation between cyclists and vehicles, etc. While statistics like bicycle commuting rates and collisions tell planners about the popularity and safety of bicycling, they do not necessarily reflect the subjective stress experienced by people bicycling on individual roads (Furth et al. 4). Similarly, guides like the NACTO Urban Bikeway Design Guide compile lists of bicycle facility options, but they do not always tell planners which would make people on bicycles feel the most comfortable in a street's particular context (Parks et al. 3). To address this gap, planners have created a variety of metrics to assess the quality of service or bikeability of existing or planned bicycle infrastructure. Level of Traffic Stress (LTS), created by the Mineta Transportation Institute in San Jose, California, is one such bikeability metric that strives to develop measures of low-stress connectivity that can be used to evaluate and guide bicycle network planning. The basic structure of LTS is build on the foundation of classifying the small amount of people who bike into three groups according to their tolerance of traffic stress rather than skill (Furth et al. 2). Group A is made up of the most advanced cyclists whose great skill allows them to navigate confidently on roads with motor traffic. Group B consists of basic adult cyclists, who lack the skills to confidently integrate with traffic. Group C is composed of children cyclists, who are the least capable group when it comes to adapting to traffic, and are most prone to irrational and sudden movements. The categorization based on tolerance of traffic stress rather than skill of the cyclists seems to be more efficient for bicycle network planning. This is because of the small percentage of people who ride bikes, the majority of

those bikers are highly skilled. Therefore, there will be a very small percentage of bikers within Group B, rendering the classification of bikers by skill as a useless method. Using tolerance of traffic-stress reveals consistencies with studies that show how people have increased affinity for low-stress, biker friendly environments and reinforce the fact that traffic danger is the most significant hindrance to biking (Furth et al. 11-12) .

Because LTS evaluates a bikers tolerance and contentment of traffic, another more detailed classification scheme was formed with four different levels of traffic stress, which respond directly with the three groups of the biking population described earlier. LTS 1,2,3,and 4 are levels that describe the traffic-stress of a particular street or region and are defined as follows:

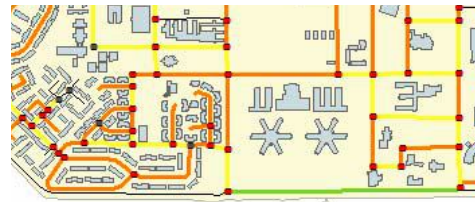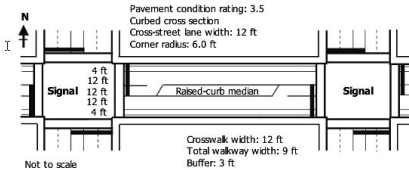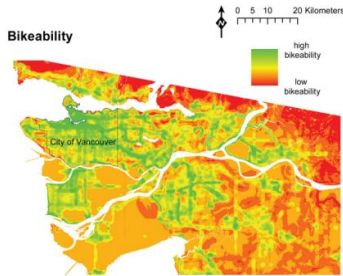| Table 1. Levels of Traffic Stress		
LTS	Description	Type of Infrastructure
LTS 1	Presenting little traffic stress and demanding little attention from cyclists, and attractive and safe enough for a relaxing bike ride. Suitable for almost all cyclists, including children.	Bike lanes are physically separated from traffic and are at least six feet wide, and have speed limits of 25 mph or less. There is ample space for bikers alongside a parking lane outside the zone into which car door are open. Intersections are easy to approach and cross.
LTS 2	Presenting a small amount of traffic-stress and is therefore suitable for most adult cyclists, but demands more attention for the safety of children.	Cyclists are physically separated from traffic, have adequate clearance from a parking lane, or are on a shared road with moderate traffic stream with a low speed differential. Intersection crossings are not difficult for most adults.
LTS 3	More traffic stress than that of LTS 2, yet considerably less than the stress of integrating with multilane traffic, and therefore welcome to the majority of cyclists in American cities.	Bikers have an exclusive bike lane next to moderate -speed traffic (35 mph) or shared lanes on streets that are not multilane and have moderately s\low speed. Intersection crossings may be longer or across higher-speed roads than allowed by LTS 2, but are still considered acceptably safe to most adult pedestrians.
LTS 4	Beyond all of the stresses defined by LTS 3	

(Furth et al. 14)

As a case study, every street in San Jose, California was evaluated and classified by the LTS metric. Stress maps show that even though 64 percent of the roads in San Jose have low levels of stress (mostly residential areas), those low-stress roads are poorly connected. Since urban planners often lay out streets in a way to prevent through traffic from using local streets, this lack of connectivity is not surprising. Maps that show the streets that are LTS 1 or 2 reveal many gaps where low-stress roads are separated by barriers of high-stress links. Barriers to low-stress connectivity have three general types: natural and man-made barriers that require separated crossings such as freeways, railroads, or creeks, arterial streets whose crossings lack the combination of a low-stress approach and a safe crossing, and lastly, a barrier that causes breaks in the neighborhood street grid, which is a common feature of newer developments in order to force all traffic to use arterials to access the local streets. Because of these barriers, San Jose is divided into islands of low stress connectivity, which are areas in which one can find a low-stress route, but will require the use of high-stress roadways in order to get from one island to another. By using LTS in San Jose, researchers were able to indicate the city's problems regarding bikeability and make assessments for improving the streets. The stress levels that create the barriers within the city can be reduced by including traffic calming, intersection safety measures like median refuge islands, bike lanes, and separated cycle tracks (Furth et al. 4-6).

Connectivity may be the most critical aspect of a bicycling network, and should definitely feature prominently in network planning. Lack of connectivity is not a necessary characteristic of a bicycling network based on user tolerance, but it is unfortunately a real characteristic of bicycling networks in many American cities, where many people find it impossible to get where they want to go by bike without riding on roads with tremendously high traffic stress. For bikers, lack of connectivity is critical with respect to potential and actual bicycle use (Furth et al. 8). Bicycling in America is completely discretionary, and if people cannot get from their origin to their destination on a safe, low-stress bike route, the majority of them will resort to different means of transportation. For bicycling networks, connectivity at a reasonable level of traffic stress without excessive detours is the most fundamental measure that determines how efficiently a network serves the community. Although there are many factors behind the control of government policy that influence bicycle use, the main aspect that can be controlled by government planning and engineering is how many bikers have an acceptable route from their origin to their destination. The number of miles of a bike lane gives a misleading commute time unless those facilities offer a low stress bicycling environment that are connected together in a functioning network that provides relatively direct access between peoples homes and destinations. San Jose, for example, has low-stress roadways that are separated by different barriers, reducing the connectivity of the city. San Francisco on the other hand, has similar problems in certain regions of the city where there are high traffic stress, such as South of Market and Chinatown.

Comparing LTS and other metrics

LTS is just one of many bikeability metrics. We will investigate four others, as shown in Table 2.

Table 2. Characteristics of several bikeability metrics					
Name	Creator	Basis	Interpretation	Display	Images
Level of Traffic Stress, LTS (Furth et al.)	Mineta Transportation Institute, San Jose, 2012	Dutch standards	Four stress categories from 1 (good for children) to 4 (for the strong and fearless)	Colored streets and connectivity clusters	Source: City of Pasadena Furth et al. 34
Bicycle Environmental Quality Index, BEQI (SFDPH)	SF Department of Public Health, San Francisco, 2009	Written survey of Bay Area experts and bicycle community members	Weighted score from 0 (not suitable for bicycles) to 100 (ideal)	Colored streets and intersection points	Source: SFDPH 16
Bicycle Level of Service, HCM BLOS (Morris et al.)	Highway Capacity Manual, Transportation Research Board, 2010	Video survey	Six grades from A (best) to F (worst)	Tabulated grades for links/ intersections, aggregated into segment/ facility scores	Source: Morris et al. 36; ch. 16
Bicycle Level of Service, Danish BLOS (Jensen)	Danish Road Directorate, 2007	Video survey	Six grades from A (best) to F (worst)	Tabulated grades and distribution of satisfaction	None
Bike Score (Winters et al.)	Simon Fraser University researchers, 2013	Focus groups, opinion survey, travel behavior survey	Average score from 1 (least bikeable) to 10 (most bikeable)	Colored regions	Source: Winters et al. 874

The Transportation Research Board's Highway Capacity Manual (HCM) was originally created to evaluate level of service for cars on a scale from A - F. In the late 1990s, two different studies

done by Landis et al. and Harkey et al. applied the level of service concept to biking (Parks 4). In the Landis et al. study, participants rated their experiences while biking on public streets in Florida (Huff and Liggett 7), while those in the Harkey et al. study rated videotaped bike facilities (Jensen, "Ped and Bicyclist LOS on Roadway Segments" 43).

Inspired by these and other experiments, the HCM expanded to include biking, walking, and transit, a framework known as the Multimodal Level of Service (MMLOS). HCM BLOS is the bicycle component of MMLOS. (Morris et al. 9; ch. 1; Parks et al. 4). Like the Harkey et al. study, HCM BLOS was based on video experiments (Parks et al. 6). Based on the results, the researchers created a formula that takes in relevant variables and spits out a numerical score. This number is then converted to a letter grade from A through F. Separate scores were created for intersections and links (lengths of street between intersections). Moreover, each one of an intersection's four legs is evaluated separately. These individual scores can be aggregated for segments, which consist of one link and one intersection, and for facilities, which consist of multiple segments. (Huff and Liggett 10-12)

The Danish Road Directorate was also inspired by the Harkey et al. video surveys to develop its own Bicycle Level of Service. The Directorate designed an improved video survey and gave it to randomly selected Danish subjects. (Jensen, "Pedestrian and Bicyclist" 43-51; Jensen, "Pedestrian and Bicycle" 14-16) While both HCM BLOS and Danish BLOS use the A-F grading scheme, Danish BLOS is much more sensitive to innovations like separated and buffered bikeways. Danish BLOS also uses a unique "cumulative logit model," which lets it predict the breakdown of user satisfaction in six categories, from very satisfied to very dissatisfied. (Jensen, "Pedestrian and Bicyclist" 43; Parks et al. 13)

In contrast to HCM BLOS and Danish BLOS, SFDPH's BEQI was based on a written survey distributed to 88 transportation experts and bicycle community members (SFDPH 12; Parks 7). Many of BEQI's 22 variables do not have existing datasets and must be determined through in-person field work. Like HCM BLOS and Danish BLOS, each variable is weighted based on the survey results and added to produce a final numerical score from 0 to 100 for each street and intersection. (SFDPH 2-3). Unlike HCM BLOS, which scores each leg of an intersection separately, BEQI gives a single score to the entire intersection.

Bike Score, developed in 2013 by Canadian researchers, rates areas rather than individual roads (Winters et al. 867; Ledsham et al. 51). Its five indicators - bike route density, bike route separation, connectivity, slope, and land use - were based on focus groups, an opinion survey, and travel behavior studies (Winters et al. 868 - 869).

As described previously, the SFMTA uses Level of Traffic Stress. Rather than using surveys or experiments like the other metrics, LTS is based on Dutch bicycle infrastructure standards (Furth et al. 2). Moreover, it uses lookup tables rather than complex numerical formulas, which makes it the only metric with discrete categories. HCM BLOS and Danish BLOS also report discrete grades from A to F, but these are actually translated from numerical scores.

It is important to note that the SFMTA altered the original LTS to fit its own needs and available datasets. Though we do not know the SFMTA's precise methodology, we do know they added several factors not in the original LTS, such as the presence of a Muni route, truck route, or highway ramp. They also calculate an intermediate comfort score from 1-6 before converting to one of four stress levels.

Each metric has its own set of indicators, which are compared in Tables 3 and 4. Note that even if an indicator is part of multiple metrics, it is often used differently. For instance, LTS, Bike Score, and BEQI determine connectivity in distinct ways. In BEQI, connected bike facilities receive higher scores (SFDPH 13). In Bike Score, areas with a higher density of improved intersections (i.e. intersections connected to at least one bicycle-friendly road) received higher connectivity scores (Winters et al. 872-3). Meanwhile, connectivity in LTS is determined *after* designating LTS scores. As shown in Table 2, the original LTS researchers created "connectivity clusters," or collections of interconnected roads where a person biking can avoid high stress routes. They also calculated the fraction of trips connected by a bike network using only low stress routes. This analysis helps planners identify gaps in the bike network and target investments to where they will benefit connectivity the most. (Furth et al. 31, 45)

Land use is another example where various metric diverge. LTS is worse in commercial areas because the researchers assumed bike lanes are blocked more frequently by parking cars (Furth et al. 20). By contrast, retail use is a positive factor in BEQI and Bike Score because it is associated with mixed use areas and higher cycling rates (SFDPH 10; Winters et al. 869, 873).

Table 3. Comparison of LTS with other metrics for street links				
LTS Indicators	BEQI	HCM BLOS	Danish BLOS	Bike Score
Physical separation	x		x	x
Bike lane	x	x	x	x
Bike lane width	x	x	x	
Street parking	x	x	x	
Number of car lanes	x	x	x	
Median				
Speed limit	x			
Land use	x		x	x
Connectivity	x			x
Not in LTS	BEQI	HCM BLOS	Danish BLOS	Bike Score
Traffic speed		x	x	
Traffic calming	x			
Traffic volume	x	x	x	
Pedestrian volume			x	
Sidewalk			x	
Percent heavy vehicles	x	x		
Pavement condition	x	x		
Driveway cuts	x			
Slope	x			x
Bike/ped lighting; bike parking	x			
Bike lane signs and markings	x			
Line of sight	x			
Trees	x			
Outside through lane width		x	x	
Presence of curbs		x		
Paved shoulder width		x	x	
Bus stop			x	

Table 4. Comparison of LTS with other metrics for intersections				
LTS Indicators	BEQI	HCM BLOS	Danish BLOS	Bike Score
Traffic signal		x	x	
Speed limit			x	
Number of crossed lanes				
Median refuge				
Right turn car lane				
Pocket bike lane				
Not in LTS	BEQI	HCM BLOS	Danish BLOS	Bike Score
No turn on red	x			
Lane markings in intersection	x		x	
Zebra markings			x	
Left turn bike lane	x			
Left turn wait time			x	
Crossing length		x		
# of through lanes		x		
Through road width			x	
Outside through lane width		x		
Bike lane width		x	x	
Type of bicycle facility before intersection			x	x
Paved shoulder width		x		
Traffic volume		x	x	
Presence of curb		x		
Street parking		x		
Bike signal			x	
Roundabout radius			x	

After researching other biking metrics and learning more about LTS, we decided that LTS is the best biking metric to use in San Francisco. LTS takes many different variables and stresses that are imposed on bikers into account, such as speed limits, bike lanes, street width, connectivity, and other factors, and organizes it into four categories that are easy to distinguish and understand. By contrast, the other metrics use unintuitive numerical scores or grades. Whereas LTS 2 has a clearly defined meaning (suitable for "interested but concerned" adults who do not want to integrate with fast traffic), a BLOS grade of B or a BEQI score of 85.6 are not easy to interpret. Moreover, even small changes in the numerical score of BLOS can change a street's grade by an entire rank. Another advantage to LTS is its flexibility. While the other metrics apply the same numerical formula to every street, LTS uses different criteria for physically separated bikeways, bike lanes, and mixed traffic. This fits well with the SFMTA's new *Pedaling Forward* bicycle plan for 2017-2021, which hopes to implement mixed traffic "neighborways" on residential streets and "protected bikeways" on higher volume roads (8). Additionally, LTS is a research based bikeability metric, and focuses on factors that government planners and engineers can control. Finally, while some metrics require many data-sets and extensive fieldwork, LTS uses relatively easy to find data.

Nevertheless, LTS can be improved. Table 5 summarizes some of its flaws and potential lessons from other metrics, which is explored further in the "Improving LTS" section. We can also look to case studies from other cities for inspiration, as discussed in the next section.

	Table 5. Pros and Cons of Various Bikeability Metrics				
	LTS	BEQI	HCM BLOS	Danish BLOS	Bike Score
Pros	- Intuitive score based on discrete categories rather than numbers - Distinguishes "neighborways" and larger streets - Based on Dutch standards - Focuses on controllable factors - Easy to find data	- Comprehensive - Includes pavement/slope - Intersections displayed as points - Survey based	- Includes pavement - Intersection legs considered separately - Part of multimodal LOS - Survey based	- Comprehensive - Survey based, large sample	- Includes slope, physical separation - Rates entire areas - Survey/research based
Cons	- Missing variables - Lacks intuitive intersection display	- Requires fieldwork	- Not sensitive to new treatments - Potentially misleading grade	- Complex formula - Potentially misleading grade	- No scores for individual streets

Lessons from Long Beach and Copenhagen

One of the locations that we decided to study and analyze was Long Beach California. Long Beach is the fifth largest city in California with a population in 2013 of 469,428 (Bureau). Since 2008, Long Beach has seen an increase of over 30% in those who ride bikes, with significant increases in biking by 130% during morning rush hours and 91% increase in biking during the afternoon (Lee). Like San Francisco, Long Beach has implemented a bike master plan (BMP) with specific recommendations for further development of the bicycle community. This bike master plan was designed by the City of Long Beach Public Works in 2001, to be achieved by 2020. The goals of this were to make "bicycling safer, more convenient and more enjoyable for all types of bicyclists, transportation and recreation related, with a goal to increase bicycle use by 5% by the year 2020" (Public). The end goal is to motivate more people to bike as a form of transportation to offer an appealing and healthy transportation option. As a result, this will reduce traffic congestion, air pollution, noise pollution and develop an "economical transportation option that promotes social equity" (Long). In promoting this the city has engages the Long Beach Cyclists, LBC, which is their local advocacy group that helps to promote bicycling in the Long Beach community. They focus on promoting an environmentally friendly transportation and educate the public about the benefits of biking and how to safely bike about the community. This group is constantly trying to get the city members to make improvements for safer roads and overall improve the bicycle environment. In addition, the City communicates with other bicycle groups including; Los Angeles County Bicycle Coalition (LACBC), Bikes 90800, and the Long Beach Area Transportation Resource Association (LBATRA) (Public). Following this master plan, the Long Beach Developmental Services came up with an updated Bicycle Master Plan that is an addition to the effort Long Beach is making to become a city that is "known for its bicycle friendliness and as an active, healthy, and prosperous place to live work, and play" (Long). Within this plan it expands on bicycle planning, design, and further recommendations for further projects.

Long Beach has a similar methodology to other bicycle communities, and wants to make their community a comfortably livable place for all ages to ride a bicycle safely to work, school, recreational activities, public transit, shopping, and any other daily events. Currently with their expansion, they are implementing bicycle support facilities including: Bicycle parking, bicycle detection at signals, bicycle wayfinding program, automated bicycle counters and hydration fix stations. Employing these facilities helps to create a more comfortable environment for the bicyclists. For the bicycle parking they have short term and long term goals to create more convenient parking for those at work, shopping, etc. An issue they are having is not enough bike racks in busy locations and they are trying to find a sufficient way that they can produce enough racks without taking up a lot of space. Bicycle detection at signals with pavement markings, is another aspect that Long Beach is using to increase the safety for bicyclists and motorists and to help with traffic flow. In addition, bicycle wayfinding program is a network

that helps bicycles to navigate the roads and helps residents and visitors to find their destinations by biking. This includes signs and information that they look to update every five years. In similarity, they have put automated bicycle counters to calculate how many bicyclists they have going in certain areas to make sure that those facilities and roads are being maintained. Hydration and fix-it stations is a new program that Long Beach is trying to find more funding for to provide bikers with stations to keep them hydrated and provide tools to fix bike issues. Besides having bicycle support facilities they are increasing bicycle education for people of all ages. In addition, they have created design guidelines for several projects including green colored pavement in intersections, mixing zones, two stage turn box, and more. Their intersection crossing marks help to "guide bicyclists on a safe and direct path through the intersection and provide a clear boundary between the paths of through bicyclists and vehicles in the adjacent lane" (Long 26). This is applied in locations where there ate buffered bike lanes, separate bikeways, direct paths at intersections, streets with high LTS, and anywhere with potential conflicts between bicyclists and other traffic. This has a huge safety impact as a study found marking through the intersections reduced collisions by 10% and injuries by 19% (Long 26). Another design Long Beach implements is the bike box. These are located at the front of traffic at signaled intersections that provide bicyclists with "safe and visible space to get in front of queuing traffic during the red signal phase" (Long 32). This allows for bicyclists to clear the intersection when there is a green signal. It is applied at any areas with potential conflict at right or left turn locations between bicyclists and vehicles and signalized locations with heavy bike volume. This has a huge safety impact that a study found decreases conflicts by 35% (Long 32). Another study done in Portland found that 77% of bicyclists felt bicycling in intersections was safer with bike boxes. Something Long Beach also incorporates well is the two stage turn box, which "offers bicyclists a safe way to make turns at multi-lane signalized intersections from a separated bikeway or on-street bike lane" (Long 50). They recommend implementing this on streets with two or more lanes and provide a safer way and angle to cross street car tracks. How the City of San Francisco can implement this will be further discussed in the methodology, however, I think adding more protected bike lanes (including the painted intersections and the bike box) in San Francisco could be beneficial as there was a 64% increase after protected bike lanes were installed in Long Beach (Lee).

The second city we decided to further examine was Copenhagen, Denmark. One of the major reasons behind this location choice was because Copenhagen is currently known to be the most bikeable city in the world due to its highly advanced cycling transport network. If we explore Denmark as a whole, there is an overwhelming public consensus to "improve public health and combat climate change" (Ruby). In fact, over 80% of the Danish population has a bike at their disposal (Rask). It is clear that the cycling culture is deeply ingrained within the Danish society, therefore, a way to shift public perception about biking in a more conceptual way other than

adjusting infrastructure and changing the current bikeability metric is to integrate biking within the San Franciscan culture.

According to the Danish Cyclists Federation, the expansion of the cycling culture is aided by societal development and impactful political initiatives. In fact, several large Danish cities have led branding campaigns through advertising billboards and online marketing that promote bicycling in a positive manner (Ruby). If San Francisco were to carry out large marketing campaigns throughout the city as well, perhaps bicycling as a main mode of transportation could become more widely accepted and become woven into the cultural norm over time.

As the City of Copenhagen's Bicycle Strategy 2011-2025 claims, when the residents of a city feel safe to cycle even in traffic, then more people would be willing to ride their bikes on a normal basis (Bicycle Strategy 13). An implemented strategy that could benefit those who bike often in San Francisco is the concept of "Conversation Cycling," which is common throughout Copenhagen. With conversation cycling, there are "3 lanes in each direction and 4 lanes in total on stretches where the cycle tracks are bi-directional," which essentially reinforces the idea that a Copenhagener could be carrying a conversation with the person bicycling on their right or left (Bicycle Strategy 6). The expansion of more conversation cycling would ensure the safety and protection of people who bike around the city on a daily basis. This would reduce the amount of collisions in areas with high levels of traffic stress such as District 6. Constructing more side-by-side lanes for bikers in San Francisco would definitely make the cycling experience more agreeable and inviting since it also cultivates a sense of community.

Improving LTS

Even though LTS is the best biking metric, it still possesses a few problems within the City of San Francisco. Our team aims to use the information we know about LTS, its use in San Jose, other bikeability metrics, and case studies from Long Beach and Copenhagen to identify possible improvements for the biking metric and help make the streets of San Francisco safer for bikers. As summarized in Table 6, we identified three main areas for further investigation: intersection comfort, street conditions, and equity. These are discussed further in the methodology and deliverables sections.

Though the original LTS included intersection comfort, the SFMTA's version does not. Considering that a third of all bike fatalities happen within intersections, our research on LTS reveals the importance of intersection approaches and street crossings in network connectivity. Also, improving intersection comfort will help connect low-stress roads to other low-stress roads that were otherwise blocked by unsafe crossings or turn lanes. The original LTS rates intersections based on length of crossings, traffic signals, speed limits, right turn lanes, and medians. However, after researching Long Beach, seeing San Francisco's latest intersection

improvements, and learning about other metrics, we found that the original LTS does not take many innovative intersection treatments into account. We hope to improve on LTS by including elements like specific traffic signals for bikers and protective infrastructure for improving the safety of left and right turns.

We also hope to examine the relationship between LTS and equity. Here, we examine median household income. Because LTS focuses on bicycle comfort, we cannot add equity concerns directly to the LTS score. However, we can look at how low and high stress bike routes are distributed across the City to identify vulnerable areas that need better infrastructure.

While the SFMTA's version of LTS already includes most of the important street conditions, adding slope and pavement quality could make it even more comprehensive. The abundance of hills in the city is a big problem when considering the comfortability and tolerance of bikers. Even fearless bikers willing to bike next to traffic might avoid very steep hills. Incorporating the existence of hills into the LTS classification methods could possibly help analyze which streets are most attractive to bikers and propose alternatives to reduce the stress that hills have on bikers. Pavement quality is also a variable that has an effect on the comfortability of bikers, which we experienced first hand while in biking in San Francisco.

Table 6. Proposed additions to LTS		
Topic Area	Indicators	Data Source
Intersection comfort	Original LTS indicators	TransbaseSF.org
	Innovative treatments	SF OpenData
Equity	Median household income	US Census
Street conditions	Slope	TransbaseSF.org
	Pavement quality	

Methodology

In this section, we discuss our methodology for evaluating each of the three topic areas. Table 7 also shows general recommendations from Copenhagen that are not included in the revised LTS metric.
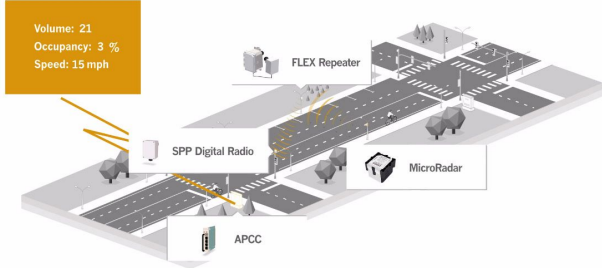
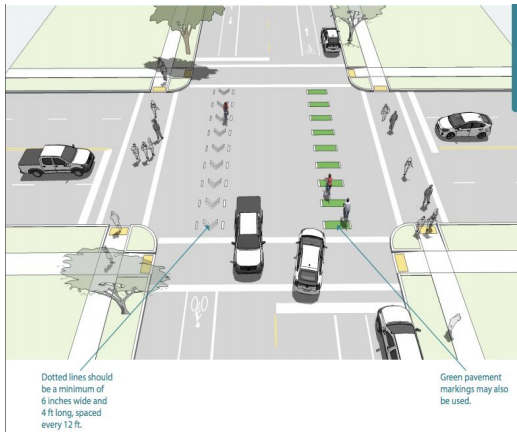| Table 7. General Applications	
Recommendation	**Application**
"Conversation" Cycling (CPH) Source: Alternet.org	2-3 lanes in each direction (bikers could have a "conversation" due to close proximity) - Side-by-side bike lanes ensure: - Ensure safety and protection - Reduce collisions in district 6
Advertising (CPH) Source: BlogQpot	- Large branding campaigns - Use advertising billboards to promote biking culture - Encourage cycling in less popular areas like district 11

Intersection Comfort

Low-stress intersections are vital to a bike network's comfort and connectivity. As a starting point, we looked at the original LTS's intersection rating system. This system applies intersection ratings to connecting street links (Furth et al. 28). While this is useful for network connectivity analysis, it is technically difficult and hard to interpret when displayed on a map. Thus, in our revised LTS metric, we followed BEQI's method of symbolizing intersections as points.

Including modern infrastructure innovations like bike boxes and dedicated bike signals is an important part of intersection comfort, too. As shown in Table 8, Long Beach has implemented many of these innovations. In our updated metric, we included the bike boxes, two-stage turn boxes, and intersection cross markings found in Long Beach. Dedicated bicycle signals, which we encountered on the Wiggle, are also taken into account. In future iterations of LTS, protected intersections, such as the one at Division and 9th, and left turn pockets, such as the one at Market and Valencia, can also be incorporated.

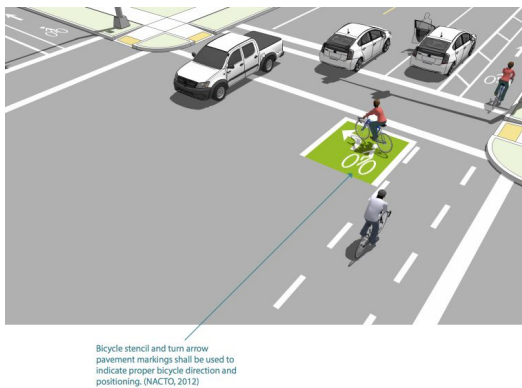| Table 8. Intersection Applications	
Recommendation	**Application**
Bike Box Source: Long Beach Bicycle Master Plan 2016	• "Safe and visible space to get in front of queuing traffic during the red signal phase" and for them to quickly pass through the intersection when the light turns green • Creates safety for bikers 　○ For district 6, there is a lot of biker traffic and this can provide more space for bikers to pile in at red lights.
Bicycle Detection at Signals Source: Long Beach Bicycle Master Plan 2016	• Increase efficiency of traffic flow • Allow the city to track data 　○ For district 11, they could use this to see where there are people biking and try and figure out what they can change to get more people to bike in this hilly district. 　○ For district 6, this can help to monitor collisions and show where they need to change traffic signals to lower bicycle traffic and back up.

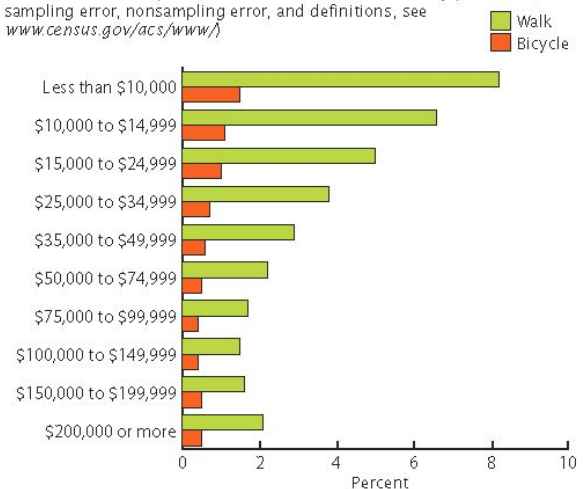| Intersection Cross Markings	• Enhance safety for bikers
 Dotted lines should be a minimum of 6 inches wide and 4 ft long, spaced every 12 ft. Green pavement markings may also be used. Source: Long Beach Bicycle Master Plan 2016	○ In district 11, may increase the amount of bikers due to providing more protection and direction. With it being hilly it can be hard to go across an intersection without a visual aid for help. ○ In district 6, with there being many collisions it would create a clear path for bikers and keep vehicles in their lane.
Two stage Turn Box	• A safe way to make turns at multi-lane signalized intersections from a separated bikeway or on-street bike lane.
 Bicycle stencil and turn arrow pavement markings shall be used to indicate proper bicycle direction and positioning. (NACTO, 2012) Source: Long Beach Bicycle Master Plan 2016	○ Provide a safer way to cross railroad and streetcar tracks, by providing a safer angle to cross. • In District 6, with it being a popular place to bike, this can help bikers to make the hard left turns in major intersections.

Equity

We chose to examine median household incomes obtained from the US Census. According to the 2014 American Community Survey, bicycle commuting rates are higher for very low income households, as shown in the graph (McKenzie 7, 11). It is also interesting to note that very high income households have higher bicycle commuting rates than middle income ones. However, trends in San Francisco could differ. Determining the profile of people who bike in San Francisco is a potential avenue for further research.

Figure 11.
Walking and Bicycling to Work by Household Income: 2008–2012
(Data based on sample. For information on confidentiality protection, sampling error, nonsampling error, and definitions, see www.census.gov/acs/www/)

Source: U.S. Census Bureau, American Community Survey, 2008–2012.

Street Conditions

Table 9. Slope Grading System				
Slope	0-1%	2-3%	4-5%	6%+
Grade	A	B	C	D

San Francisco is a hilly city, which we experienced while biking up Market Street and down Page Street. Steep slopes are difficult barriers for bikers to navigate. Slopes above 5% can be uncomfortable and are only acceptable for short spans, and slopes should be 2% or less for longer distances. Going downhill can be dangerous for those who are not experienced in controlling their bike's speed and going uphill is a challenge for many bikers. (SFDPH 9; Bicycle Network) Though the City cannot change alter topography, it can use slope data to identify streets where people on bikes need even more protection from traffic than usual.

To keep our suggested additions distinct from the existing LTS, we propose incorporating slope in the revised metric as a separate grade, where the flattest slope (0-1%) receives an A grade and the steepest slope (6%+) receives a D grade. Slope data was obtained from the San Francisco Department of Public Health's TransbaseSF.org page.

Table 10. Pavement Quality Grading System				
PCI	85-100 (Excellent)	70-84 (Good)	50-69 (At-risk)	<50 (Poor/very poor)
Grade	A	B	C	D

While LTS does not measure pavement quality, we found that the low quality pavement on Townsend Street in San Francisco was a negative aspect of our bike ride. One reason for the poor pavement is that Townsend is a "unaccepted" street, meaning local property owners are responsible for maintaining the road.

These qualitative observations should play an important role in the revised LTS metric. As with slope, we propose adding a separate pavement grade to the existing LTS, using the stratification in Table 10. The grades are based on the pavement condition index (PCI) collected by San Francisco Public Works and made publicly available on TransbaseSF.org.

Deliverables

Story map

Short link: http://arcg.is/2mX8Z8F

Full link: http://stanford.maps.arcgis.com/apps/MapSeries/index.html?appid=8f
7c97e98dc847408263e1ccdbccc699

Intersection comfort

We found that the original LTS methodology rates almost all intersections as LTS 1 or 2, which is inaccurate. This is in part because the original LTS researchers designated all signalized intersections as LTS 1. Moreover, they had loose speed limit and lane width requirements requirements and did not account for intersection treatments.

After including innovative intersection treatments, lowering acceptable speed limits, and decreasing the thresholds for crossing length, we developed a more accurate picture of intersection comfort. Still, more work can be done, as described in under "Conclusion".

Equity

The median household income for District 6 as of 2010 is $37,431, the lowest of all 12 supervisorial districts in San Francisco. The next lowest supervisorial district is District 3 with an increase in median household income by an additional $6000. The median household income for District 11 is $71,504. (City and County of San Francisco, Board of Supervisors) In our map, you can click on each Census tract to see the total length of low and high stress bike routes within each part of the City.
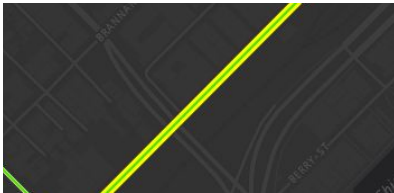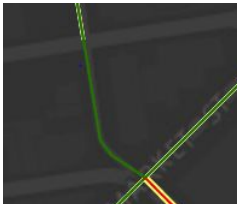
Two equity considerations we did not include are car ownership rates and diversity. Car ownership varies by district. In District 6, 59 percent of households do not own cars. District 11 is a different story with only 11 percent of households not owning cars. The table to the right shows the city population by supervisorial district and race/Latino ethnicity. (City and County of San Francisco, Board of Supervisors)

Figure A: 2010 City Population by Supervisorial District and Race/Latino Ethnicity								
Supervis-orial District	American Indian/ Alaska Native	Asian	Black/ African American	Native Hawaiian/ Pacific Islander	White	Other	TOTAL	Latino
1	243	30,706	1,617	317	31,465	5,199	69,548	4,755
2	162	8,769	1,392	181	55,773	3,329	69,606	3,918
3	380	33,458	2,389	99	31,033	3,280	70,638	4,834
4	109	41,689	565	480	26,560	3,086	72,489	4,221
5	199	13,031	8,627	152	47,082	5,672	74,764	7,211
6	422	24,854	6,825	461	33,148	7,956	73,665	11,946
7	338	25,645	2,170	150	39,504	5,111	72,918	7,414
8	246	8,512	2,165	66	58,865	5,649	75,503	10,763
9	593	18,143	3,108	178	45,424	9,277	76,723	29,381
10	969	25,215	16,849	863	23,436	5,231	72,563	15,668
11	410	36,376	5,061	419	25,622	8,931	76,818	21,663
Total	4,071	266,398	50,768	3,366	417,912	62,721	805,235	121,774

Source: U.S. Census Bureau, American Community Survey 2006-2010 sample & Census 2010 SF1: Calculated by the Budget and Legislative Analyst from San Francisco Planning Department.

Street conditions

The average slope of the City's bike network is about 4%, though there is significant variability. For example, Supervisor District 11 is much hillier than District 6. Table 11 shows examples of what LTS might look like with street condition grades added. Thicker highlights indicate lower pavement quality, while thicker lines indicate steeper gradients. We chose to display pavement and slope separately to avoid overcrowding the map.

Table 11. Examples of LTS with street condition grades		
Townsend Street	Goethe Street	Polk Street
LTS 2	LTS 2	LTS 1
Slope A	Slope D	Slope C
Pavement D	Pavement C	Pavement A

Conclusion

With the information we communicate in this document and through our final deliverable maps, the SFBC and SFMTA can work with a shared understanding of best practice bicycle infrastructure to move forward with using LTS, but also considering a focus on intersections and other factors not considered by traditional LTS measures.
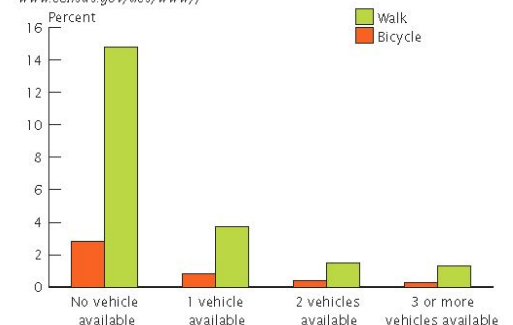
Additional work could focus on refining the intersection analysis. Like BEQI, we give a single score to the entire intersection. A more nuanced approach is to rate each leg of the intersection separately, as HCM BLOS does. To be even more comprehensive, an improved LTS can include score each possible turn and crossing separately. These scores can either be stored in a single table for each intersection, or as individual points for each movement through the intersection.

In addition, future students could investigate equity indicators beyond income. For instance, higher bicycle commuting rates are associated with lower car ownership (McKenzie 13-14). Percent of income spent on housing and transportation and the Metropolitan Transportation Commission's Communities of Concern are other potential avenues of research. Of course, no metric can replace face-to-face collaboration. Students can gather information from the community, perhaps through surveys focused on our proposed additions to the current LTS metric. This information would help the City assess how much residents value each of the factors we propose to add to LTS.

Figure 13.
Vehicles Available by Bicycling and Walking to Work: 2008–2012
(Data based on sample. For information on confidentiality protection, sampling error, nonsampling error, and definitions, see www.census.gov/acs/www/)

Source: U.S. Census Bureau, American Community Survey, 2008–2012.

Students can also examine other ways to assist the SFBC and SFMTA with prioritizing streets for infrastructure upgrades. LTS is just one component in the SFMTA's complex decision-making process, which involves community meetings, collision rates, bicycle demand analysis, and resource optimization through Decision Lens. While talking with us, planners at the SFMTA described difficulties with using online forums as a part of that decision-making process. They expressed interest in developing moderated websites for more productive engagement, which could supplement existing community meetings.

This project has taught us that transportation planning and nonprofit bicycle advocacy are challenging, but also rewarding. Seeing San Francisco's progress towards becoming more bicycle-friendly is exciting, and we are grateful for this opportunity to play a role in that journey. We have learned so much from engaging with the organizers and planners at the SFBC and SFMTA, and we hope that they too will also have something to gain from our work.

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