Do Complete Streets Offer Cyclists High Levels of Service? Applying David Harkey's Bicycle Compatibility Index to Seattle and Copenhagen's Complete Street Networks

Kerry Ann Tiedeman

A thesis

Submitted in partial fulfillment of the requirements for the degree of

Master of Urban Design and Planning

University of Washington

2021

Committee:

Rachel Berney

Cynthia Chen

Program Authorized to Offer Degree:

Urban Design and Planning

University of Washington

Abstract

Do Complete Streets Offer Cyclists High Levels of Service? Applying David Harkey's Bicycle Compatibility Index to Seattle and Copenhagen's Complete Street Networks

Kerry Ann Tiedeman

Chair of the Supervisory Committee:

Rachel Berney

Department of Urban Design and Planning

Cities like Seattle are looking to increase active transportation trips like cycling over automotive trips to meet sustainability and equity goals. Seattle works to create "complete streets," roads that provide infrastructure for safe travel for all transportation modes, to encourage cycling for those who may not feel as comfortable biking alongside cars. This study uses Harkey's bicycle compatibility index, a bicycle level of service model, to assess two cities' complete street networks to understand how compatible complete streets are with biking; Seattle and Copenhagen. After using Harkey's assessment tool on road samples that best imitate the complete street design standards, this study found varying bicycle compatibility scores within each cities' networks. Overall Copenhagen had higher bicycling compatibility across road segments. These results led to several conclusions, one being that while bicycle level of service may be important, it does not directly impact cyclist presence. Findings also revealed policy recommendations Seattle should consider if the city wants to improve its bicycle infrastructure.

Introduction

Automotive transportation has had devastating consequences on the environment due to massive levels of carbon emissions. Cities worldwide are looking to promote transportation alternatives and develop infrastructure that encourages sustainable mobility such as cycling and walking (Kimberley, 2015). One study in the U.K. found that a shift once a day from driving to cycling could reduce a person's carbon footprint by .5 tonnes per year, applied to a large population could represent a significant decrease (Brand, 2021).

Cycling may be a valuable alternative to motorized transportation; however, not everyone feels comfortable riding a bike through busy city streets, sharing the road with cars. Roger Geller (2013) established a well-known classification system that places cyclists into one of four categories; "the strong and the fearless," "the enthused and confident," "the interested but concerned," and the "no way, no how." City planners in Portland, Oregon rely on these categories to improve their bicycle infrastructure to appeal to the "interested but concerned," the type of cyclist who wants to ride and is more likely to if bike facilities are "low stress" (Geller, 2013).

One popular strategy to provide better bicycle infrastructure that engages a broader range of cyclist types is redesigning existing roadways into Complete Streets. Complete Streets are roads designed to safely accommodate all transportation types. The United States Department of Transportation (USDOT) defines complete streets as a policy and design approach to create streets that enable "safe use and support mobility for all users" (USDOT, 2015). The definition is left intentionally broad, allowing cities to adopt guidelines that work best for them. Smart Growth American National Complete Streets Coalition (2021) also maintains an ambiguous

interpretation, but unlike USDOT, specifies that policies regarding complete streets should "operate the entire right of way to prioritize safer and slower speeds for all people who use the road" (Smart Growth America, 2021). The coalition states that planners can create more complete streets by adding design elements such as

- bike lanes or wide paved shoulders;
- sidewalks;
- special bus lanes;
- comfortable and accessible public transportation stops;
- frequent and safe crossing opportunities;
- median islands;
- accessible pedestrian signals;
- curb extensions;
- narrower travel lanes;
- and roundabouts

(Smart Growth America, 2021)

To illustrate this concept visually, figure 1 shows NACTO's vision of a complete street. NACTO is an association of 91 major North American cities and transit agencies with the purpose to exchange transportation ideas, insights and practices. They often provide guidelines for bike lanes, sidewalks, and complete streets. This diagram shows that there are various modes of transport all sharing the same roadway.

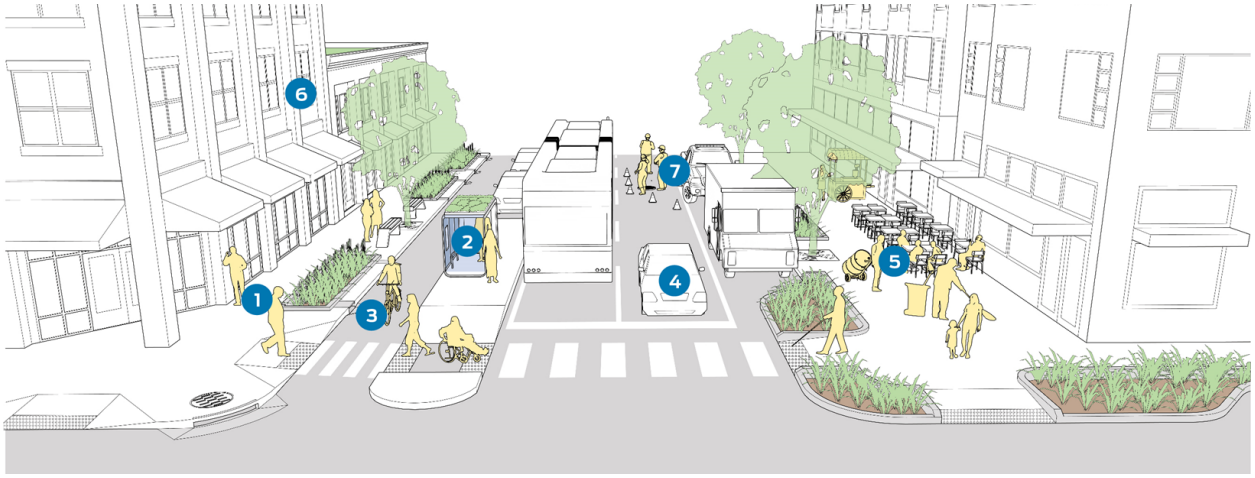

Figure 1 NACTO's depiction of a Complete Street (2021)

By using a Complete Street policy, urban planners implement designs that include or improve sidewalks, bike lanes or wide paved shoulders, designated bus lanes, vehicular traffic lanes, safe crossing opportunities, and medians. These infrastructure elements not only accommodate but help maximize safety for all transportation modes (Litman, 2015).

Research exists on the impact of Complete Streets from multiple standpoints; safety of users, cyclist and pedestrian allure, public health, and economic activity. However current research does not evaluate whether complete streets are the preferred bicycle facility type among cyclists compared to others. For example, since their purpose is to accommodate all transportation modes which includes cars, buses, and freight, Complete Streets may have high traffic volumes which can result in higher stress for cyclists. Complete Streets are just one part of a bicycle network that incorporates residential streets, roads with separated bike paths, roads with bike lanes but no separation, bike trails, and sharrows. Supposing there is a street hierarchy and Complete Streets rank low among cyclists, policymakers and planners should reconsider and advance other types of road designs and bicycle infrastructure that may be more likely to appeal to cyclists.

This study uses a Bicycle Level of Service (BLOS) assessment tool that quantifies roadway characteristics, assigning scores to Complete Street road segments. Bicycle Level of Service measures on-road bicycle comfort level based on a roadway's geometry and traffic conditions. BLOS scores help determine whether cities' complete street guidelines create roadways compatible with biking, and depending on those ratings, cities may want to reconsider or modify their Complete Street policies.

This study uses Harkey's BLOS model to assess complete streets in two cities, one in the United States (Seattle, Washington) and one in Europe (Copenhagen, Denmark). Seattle has a history of biking culture and a comprehensive complete street policy that provides detailed street design standards. In the 1990s, Seattle was "the biking city" with a bike-commute rate of 1.5%, high for a city within the United States at the time (Berney, 2018). The city intended to incentivize more cycling trips and set out plans for infrastructure improvements with the first Bicycle Master Plan and a Complete Street Ordinance, both in 2007. Seattle is committed to enhancing cycling conditions; however, the city has a long way to go. Over the years, other cities like Portland have surpassed Seattle in bike commute rates (Berney, 2018).

Copenhagen, Denmark, is known as having one of the best cycling networks globally, and many cities have adopted designs and policies that mimic the Copenhagen approach (Colville-Andersen, 2019). Copenhagen has different policy structures related to bicycle infrastructure; however, many of their streets could be considered "complete," with buses, cars, bikes, pedestrians sharing many of the same motorways (McCann, 2010). Using Copenhagen, the gold standard in cycling culture, as a case study provides a broader evaluation of complete street cycling compatibility. If BLOS scores demonstrate high compatibility for cycling in

Copenhagen, what lessons can Seattle apply to its complete street design standards to appeal to more types of cyclists? Suppose BLOS scores are low for both cities, what assumptions are possible about the importance of BLOS compatibility when the goal is to incentivize more cycling trips?

Literature Review

Transportation planners use a complete streets approach to safely integrate all transportation modes into the road network. The following literature review examines the impact of complete street policy on safety and its ability to motivate cyclist and pedestrian use. It also reflects on existing researchers' assessment instruments of road and network bikeability to better understand whether the complete street policy approach helps construct desirable bicycle networks.

Many researchers have viewed the complete street policy as a solution to various transportation and societal problems. Burden and Litman (2011) cite the aging population, health and environmental concerns, and increasing demand for walking, cycling, and public transit as reasons to reconsider road design. According to Burden and Litman (2011), complete streets are ideal because they provide multiple transportation options within the same roadway that improve safety, service, comfort, and performance for all. They assert that complete streets can offer a solution for arterial road safety issues such as pedestrian fatalities, and can improve overall public health by increasing fitness rates. McCann (2011) provides research to support the Burden

and Litman argument. She argues for redesigning roads to encourage more sustainable trips like biking, public transit, or walking, all while maintaining some road space for vehicles.

Mooney (2018) looks specifically at the correlation between complete streets and cyclist safety, investigating whether complete street policies over a 16-year window influenced the number of total bicycle fatalities in 183 counties within the United States. Through a G computation model, an algorithm created to help estimate the effects of exposures, treatments, and interventions, Mooney found that the policies saw a 2.4% increase in cyclists and produced a .7% increase in cyclist fatalities over various counties, therefore improving safety.

Schneider (2018) also addresses the correlation between safety and complete streets in qualitative data analysis on pedestrian fatalities and the effects of pedestrian safety policy in the state of Florida. Complete street policy in Florida began in 1984, and since then, the rate of pedestrian fatalities has decreased by 0.5%. While Florida may attribute the decrease in fatalities to complete street policy implementation, Schneider points out several issues with that claim. The author compares other low pedestrian fatality locations, especially in Europe, which indicate that automobile-free zones and mixed-use cities with slower-speed streets may be more effective in influencing pedestrian safety. Schneider argues for cities to consider land use policy changes that minimize distances between activities to make walking more convenient over adopting a complete street policy.

Lastly, MacLeod (2018) examines safety among all user types, not only pedestrians, with a study on complete street intersections. MacLeod performed a case study of an urban corridor in Los Angeles, studying the number of injuries and fatalities in two distinct intersections over six years, one of which was a complete street intersection. He found that the complete street

intersection had a higher pedestrian presence but greater conflict probability among all modes of transport, and consequently, a higher injury predictor. Macleod suggests using intersection typologies relating to traffic safety to form a treatment plan and conducting further research to determine how to reduce vulnerable road users' exposure to vehicles or vehicles' exposure to each other. He also concludes that alcoholism appeared to be the lead cause of many of these injuries/fatalities, suggesting an alternative area of research entirely. Therefore the relationship between cyclist safety and complete streets is inconclusive and requires further research.

Apart from safety and health issues, Litman and Burden (2011) assert that complete streets encourage sustainable transportation modes like cycling. Brown (2016) performed a case study of a complete street intervention that included the addition of a new light rail, bike lanes, and better sidewalks in Salt Lake City, Utah. Brown observed the number of trips among residents living near the street (<800m) and far away (>800m) by using GPS. Measuring both transit and non-transit walking and biking trips, Brown concludes that complete street interventions correspond to an increase in pedestrian and possibly cycling use.

Brown's research is limited for the purposes of this study since he primarily focuses on pedestrians and his findings are incomplete in regards to cycling comportment. His study does not specify which street interventions may be influencing an increase in usage, just that there is an increase. Pucher (2010), on the other hand, focuses on the impacts of street interventions on cycling, not just those related to typical complete street policy. Pucher evaluated examples like bike lanes, parking, integration with public transport, education and marketing programs, bicycle access programs, and legal issues. He found an integrated package of complementary interventions, including infrastructure provision and pro-bicycle programs, supportive land use

planning, and car use restrictions to boost cycling presence to be most efficacious, not all of which are typically part of a complete street policy.

The relationship between complete streets and cyclist preference remains unclear, but previous research examines which physical and policy elements other than complete streets incentivize cycling. Forsyth and Krizek (2011) question what may be unique to cyclists that makes an exceptional urban design response necessary. They focus on four main issues that offer a framework for considerations of cycling-oriented urban design: community layout, cycling facilities, analysis and design processes, and detailed design. They conclude that safety should not be the only parameter for creating better cycling infrastructure. How a cyclist feels within their physical environment should also be a factor.

Tilahun, Levinson, and Krizek (2007) defined five different cycling environments by categorizing facilities based on a hierarchy of cyclist appeal. They did so by determining which type of bike facility influenced a cyclist to choose a higher travel time versus a lower travel time. The five facilities were off-road facilities, in-traffic facilities with bike-lane and on-street parking, in-traffic facilities with no bike-lane and no on-street parking, and in-traffic facilities with no bike lane but with parking on the side. The higher the willingness to deviate from the fastest route indicated the more preferred bicycle facility. They found cyclists favored designated bike lanes followed by roads without parking lanes and off-road bike facilities. Therefore urban planners and policymakers should consider these three facility categories when designing bicycle infrastructure that encourages cycling.

Since the United States is not synonymous with a strong bicycle culture, many researchers have looked internationally to cities with stronger cycling cultures for guidance in

making cycling a more appealing mode of transport. Pucher (2008) investigated how Germany, Denmark, and the Netherlands made bicycling a safe, convenient, and practical way to traverse the city. Pucher found that separate cycling facilities located along heavily traveled roads and intersections combined with traffic calming in residential neighborhoods most effectively attracted cyclists. Other factors also contributed like substantial bike parking, integration with public transport, and traffic education. Driving in these countries is more expensive with higher taxes and less parking and higher density land-use policies make it easier to access more places through biking. Therefore a combination of factors may be essential in making cycling more attractive, requiring more than just a complete street policy.

BLOS Models

Various researchers and professionals have developed indicators and evaluation techniques to measure bicycle suitability (Pritchard, Frøyen, and Snizek 2019). One of these BLOS rating schemes is Mekuria's stress level hierarchy, a classification assessment tool to score roadways. Mekuria classified roads into four levels of traffic stress (LTS). Level 1 is suitable for children and considered very low stress; level 2 is a stress level most adults will tolerate; level 3 is suitable for about 10% of the population and considered moderate stress, and level 4 is high stress, only appropriate for 1% of the population. He applied this structure to the San Jose road network, searching for routes between people's origins and destinations that avoid links where cyclists will exceed their traffic stress tolerance, and that did not require an excessive detour.

Mekuria bases his level of stress hierarchy on the Dutch LTS 2 system, a benchmark of a stress tolerance level that most adults have. In the Netherlands, transportation planners apply

specific criteria to roadways so that all cycling routes have LTS 2 (Mekuria, 2012). Although Mekuria mentions multiple stressors such as topography, pavement quality, crime danger, noise, aesthetics of surroundings, and absence of lighting or snow removal, his model relies solely on car traffic as a stressor. He does not qualify other stressors in his hierarchy for various reasons, including lack of data and the belief that traffic stress is the most influential factor in determining who will cycle.

He separates streets into three categories:

1. Cycle tracks (what Denmark considers to be separated bike paths, signalized and buffered from traffic) or shared-use paths;
2. bike lanes which are not separated from mixed traffic but offer cyclists their own lane;
3. and streets with mixed traffic.

Both shared use paths or cycle tracks (roadways with bike lanes separated by either a curb, raised median, parking lane, or flexible bollard) receive an LTS of 1, regardless of traffic surrounding the separated bike lane. A bicycle lane without any form of separation from cars can have a varied LTS depending on its assorted traffic criteria such as street width, operating space, traffic speed, bike lane blockage, and mixed traffic (Mekuria, 2012). If applied to Seattle, Mekuria would assign the same LTS score to a cycle track along a busy downtown street as he would to the Burke Gilman Trail. The Burke Gilman Trail is a 27-mile shared-use path that was once an old train track, a completely separated byway for cyclists, runners, and walkers, used not only for commuting but recreationally. It is a place where families take their children to learn to

bike, an unlikely use for a downtown cycle track, and therefore it is an adequate assessment that both types receive the same stress tolerance score.

This study uses Harkey's Bicycle Compatibility Index to determine roadway BLOS. Harkey evaluates the compatibility of roads for cyclists using what he calls the Bicycle Compatibility Index (Harkey, 1998). His index draws considerably from the Highway Capacity Manual's definition of Level of Service, applying a level of service model intended for cars to bikes instead. The bicycle stress level concept is applied to understand the compatibility of roadways on a 5-point scale using a multiple regression model. He developed the system by having multiple cyclists with different comfort levels rate numerous road segments by video-based on stress. Harkey included geometric and operational variables such as the number of lanes, direction of travel, curb lane, bicycle lane, paved shoulder, parking lane, traffic volume, speed limit and 85th percentile speed, and roadside development type. He established a Bicycle Compatibility Index Range, and each range is associated with a level of service designation from extremely low to extremely high compatibility.

The primary reason for using Harkey's rating scheme instead of Mekuria's LTS in this study is that Mekuria's LTS system does not differentiate between a cycle track on a busy street and a stand-alone bike path like Seattle's famous Burke Gilman Trail. Harkey, instead, allots street scores based on a weighted system of variables regardless of the presence of a separated bike path. Harkey’s method is preferable since it does not assume, like Mekuria, that all experiences riding on a bike path separated from cars are the same.

Another reason for choosing Harkey's method to evaluate Complete Streets is that researchers have tested BLOS rating schemes and found Harkey’s to be the best predictor of real

route choice. Pritchard, Froyen, and Snizek (2019) tested four popular BLOS rating schemes, including Mekuria and Harkey's models, using route choice data of 467 university students in Trondheim, Norway. The study aimed to determine which BLOS rating scheme was most accurate in predicting route choice when applied to real-life study subjects. The study found that Harkey's BCI performed the best out of the four methods tested and was the best predictor of route choice in a group of individuals of varying ages.

Not only is understanding bicycle compatibility of road segments important for urban planners, but analyzing the entire bicycle or street network is also a valuable practice. There may be a considerable number of road segments highly compatible with cycling but if they do not connect to each other then potential cyclists may be discouraged from riding. Michael Lowry (2017) used Mekuria's rating scheme to look at Seattle's bicycle network connectivity, a network that includes bike lanes, neighborhood greenways, separated bike paths, and sharrows. By determining levels of connectivity across different neighborhoods for various levels of cyclists, Lowry concluded that to attract "interested but concerned" cyclists, Seattle should prioritize low-stress bike facilities across neighborhoods, citing the city's Neighborhood Greenways as a possible option (Lowry, 2017). The Seattle Neighborhood Greenway network comprises residential streets that serve both intra-neighborhood and at times inter-neighborhood travel. They have reduced speeds, additional signs, and pavement markings, but no designated bike lanes, meaning cars and cyclists share the road (Lowry, 2017). This last characteristic is interesting considering that a road may not require a separated bike lane if vehicular counts are low.

Lowry's conclusion that quiet, residential roads without separated bike lanes may serve as low-stress connectors for cyclists is similar to discoveries other researchers have made when looking at desirable road qualities for cyclists. Broach, Dill, and Gliebe (2012) found that while bike lanes can offset the impacts of traffic cyclists, cyclists do not prefer them to a low-traffic street without bike lanes. Lastly, Mekuria concludes in his study of San Jose that there is potential for local streets like those within the Seattle Neighborhood Greenway network to be used as routes for bike traffic, but not through motor traffic (Mekuria, 2012). Cyclists highly value neighborhood bikeways with traffic calming measures even without the presence of a separated bike lane.

Complete streets are likely not low-traffic streets and therefore questions emerge about their bicycle compatibility and whether they should be used to create more attractive bicycle infrastructure. Applying objective assessment tools to cities' complete streets can help identify the impact and appeal of these streets to different types of cyclists. The next section will look at the background of each case study's adaptation of the policy to better define the street types that Harkey's model will be applied to.

Background and Context of Seattle and Copenhagen

The purpose of this section is to provide background and context of both case studies to understand each city's policy surrounding complete streets, establishing the design standards this study measures for bicycle level of service. Finally, the context of current policy processes and

bicycle infrastructure challenges for both cities will help provide additional recommendations for Seattle's complete street and bicycle infrastructure policy.

Seattle

Seattle created its first Bicycle Master Plan in 2007 to research and understand how to make cycling a more appealing transportation option to help increase ridership (Berney, 2018). With its master plan, Seattle constructed 45 miles of bicycle network between 2016 and 2020 and anticipates the construction of 12-20 miles of new bicycle infrastructure in 2021 (City of Seattle, 2021). However, many cities in the United States, like Portland, have surpassed Seattle in terms of ridership and amount of infrastructure (Berney, 2018). Seattle faces many infrastructure-based challenges in increasing ridership, a lack of separated bike lanes and an overdependence on sharrows. The bicycle network also does not have strong connectivity, often having gaps within the network. Researchers acknowledge that if Seattle wants to keep up, and continue to attract tech workers who are more interested in bicycling, the city needs to do more (Berney, 2018).

Seattle also has challenging topography and geography for bicycling. The Seattle Bicycle Master Plan mentions how steep slopes can present challenges to cycling in Seattle (City of Seattle, 2007). Seattle consists of several hills and elongated hills that stretch north to south, meaning that traversing the city east to west means climbing several significant steep hills. In Seattle geography, downtown is actually one of the rare flatter sections of the city. (Booth, 2009). Because of geography and topography much of vehicular road traffic gets pushed into

Downtown, creating a busy street network. Seattle's Freight Master Plan map (figure 2) shows several downtown streets as major connectors for freight.

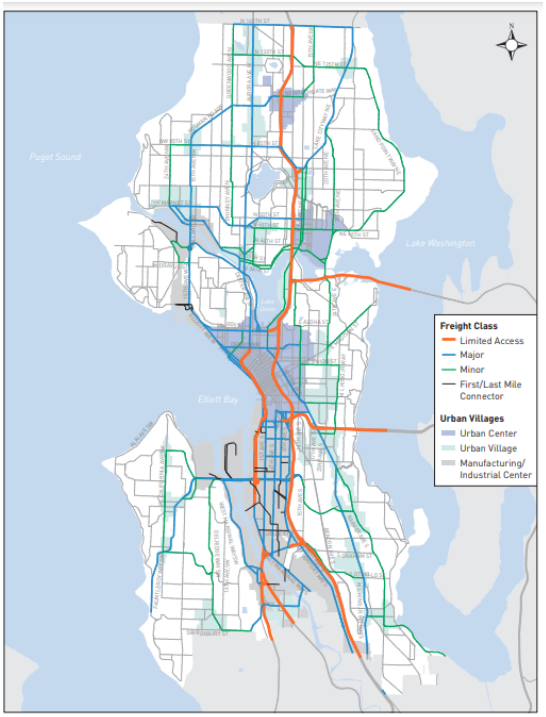

Figure 2 Freight Master Plan Network Map (SDOT, 2016)

A potential solution to climbing hills and avoiding higher traffic areas are the use of e-bikes which have become more prolific in recent years (Chisholm and Healy, 2018). However, e-bikes are often more expensive, and in Seattle bike theft is a major issue (Robertson, 2017), and therefore end of bike facilities such as secure bike parking needs to be improved. Bike theft is far less of a problem in Copenhagen, Denmark. Colville-Anderson (2019) boasts how he never locked his bicycle in Copenhagen. His bike was stolen eventually but only years later. Seattle acknowledges that secure bike facilities are necessary, but only requires corrals or bike racks for short term parking, which is considered to be four hours or less. Only for long term parking, more than four hours, are bicycle lockers, cages or rooms required (City of Seattle, 2020).

Residents of Seattle have had bikes stolen in less than that four hour period, and are likely less inclined to bike to their destination if they believe their bike may be stolen.

At the same time the City of Seattle instituted a bicycle master plan, it also created its "Complete Street Policy," also known as Ordinance 122386 (Seattle City Council, 2007). The Ordinance stipulates that "SDOT will plan for, design, and construct all new city transportation improvement projects to provide appropriate accommodation for pedestrians, bicyclists, transit riders, and persons of all abilities while promoting safe operation for all users" (Seattle City Council, 2007). Seattle's Department of Transportation envisions these initiatives happening over time through a variety of private and public projects that could include:

- street and sidewalk lighting;
- pedestrian and bicycle safety improvements;
- access improvements for freight;
- access improvements, including compliance with Americans with Disabilities Act;
- public transit facilities;
- pedestrian access improvement to transit stops and stations;
- streets trees and landscaping;
- drainage;
- And street amenities

(Seattle City Council, 2007)

An interesting aspect of Seattle's complete street policy is that the process occurs when there are already projects in the works, which could be both private or public. Private developers

are required to be part of complete streets, at minimum offering data on street characteristics, but they can also contribute by adding street improvements, a job usually reserved for urban and transportation planners. Similar to a State Environmental Policy Act checklist, project developers must complete a "Complete Street Checklist" (SDOT, 2021). A SEPA is an environmental checklist mandated by the state of Washington to determine if a construction proposal will have significant adverse environmental impacts (State of Washington Department of Ecology, 2018). While SEPA measures impacts, SDOT's "Complete Street Checklist" asks the project developer to provide data about the streets surrounding the project site, including opportunities to partner with city projects and with the goal of identifying specific areas to add streetscape improvements. Complete Street Reviewers from SDOT must approve the checklist, confirming they agree with the proposed street improvements. Seattle's Department of Transportation monitors the performance of this checklist policy by following data statistics, including the number of fatality/serious injuries reduced, rate of crashes involving pedestrians, number of safety spot improvements, and so forth (City of Seattle, 2019).

To help project developers through the checklist process, SDOT supplies a "Complete Streets Review Story Map" (SDOT, 2021). Developers must first identify their project site's street type classification and evaluate the street's pavement condition, flex lane/curb space, pedestrian infrastructure, and bicycle infrastructure. When filling out the checklist, they must refer to the Streets Illustrated design standards, and if there are any deviations from the design standard of the street type of their site, they must explain why (City of Seattle, 2019). Although SDOT does not define one single complete street example, these street types, of which there are

twelve in total, make up Seattle's complete street network. Therefore these street type design standards can be used to evaluate Seattle's complete street network bicycle level of service.

The description of the complete street policy process with developer involvement and procedural steps for street interventions demonstrates how slow and arduous making improvements to the streetscape like bicycle infrastructure upgrades can be. Bicycle infrastructure is only of only many improvements to the streetscape developers can make and therefore not the focal point. In fact, Seattle Complete Street guidelines only suggest separated bike lanes in five of the twelve street type design standards.

The Bicycle Master Plan provides a closer look at Seattle urban planning focused solely on bicycle infrastructure. Seattle also has a 2019 - 2024 Implementation Plan to evaluate and be accountable for the Bicycle Master Plan. Seattle mentions that much of the projects that were able to be implemented were done during times when SDOT already needed to conduct major work on a street, like paving a street or adding a rapid bus lane, and some were even done by private developers. Another interesting aspect of the Bicycle Master Plan is it does not designate distances and widths of design standards for bike lanes. Those distances are mentioned in "Streets Illustrated," the right of way improvements manual. The manual distinguishes between different types of bike lanes; "in road, major separation," "in road, minor separation," and sharrows. The in road, major separation category asks for a 5 feet wide bike lane with a barrier of 3 feet. Minor separation requires 5 feet in width and no barrier. These design requirements will be important when comparing Copenhagen whose bicycle infrastructure standards are different.

Copenhagen

Copenhagen, Denmark, has a strong history of multimodal transportation planning with excellent bicycle infrastructure and one of the highest cycling rates per citizen globally (Henderson and Gulsrud, 2019). Twenty-nine percent of all trips within the city are by bicycle, and during the weekday, trips increase to sixty-two percent (Henderson and Gulsrud, 2019). As a commuting cyclist in Copenhagen, it does not take long to realize that most streets, especially within the city center, have designated, separated bike paths.

It is important to note that maintaining streets for pedestrians and cyclists still presents a challenge for Copenhagen and other nearby local municipalities. In neighboring suburbs, many people use cars as a primary form of transport (Hederson and Gulsrud, 2019). Ideas to discourage car use consist of widening bike lanes, adding more bike parking, and enticing people to bike from outer areas to the city center with innovative infrastructure concepts like bicycle superhighways, bike paths that stretch over longer distances that consistently offer good pavement, winter maintenance, and safe intersections. As e-bikes become more available, there is potential for more interest in riding farther distances. Longer-distance commutes are 5-20 km, approx 3-12 miles. However, being caught at traffic lights can make a trip less efficient, even with bike lanes. Therefore bike superhighways will often incorporate traffic light timing that prioritizes cyclists if they maintain a minimum speed (Henderson and Gulsrud, 2019). The superhighway scheme has also had its challenges, requiring coordination with other municipalities, and some route efficiency suffers from car conflicts with cyclists having to

navigate a number of intersections with vehicular traffic and still the presence of vehicular parking in some areas adjacent to the superhighways.

Bike congestion is also a significant issue, which could decrease the number of cyclists. Back-ups of 20 or more riders can occur at traffic lights during rush hour, causing impatient cyclists stress. Copenhagen has outlined new plans in the "Copenhagen Bicycle Strategy 2011 - 2025" and the Plus Net Scheme to reduce cycling travel times by improving passability to combat issues like congestion. One solution has been widening lanes to allow faster riders to pass more quickly. The plan is to upgrade 80 percent of the network by 2025 by widening cycle tracks to two or three abreast (City of Copenhagen, 2011). In areas where street parking for vehicles was preserved, like the Fredericksburg neighborhood, cycle tracks have remained narrow, making it more difficult for cycles to pass one another. If Copenhagen wishes to widen cycle tracks, they will need to take more space back from automobiles, likely resulting in less parking in and outside the city center (Henderson and Gulsrud, 2019).

Copenhagen does not have a complete street policy like the one found in Seattle. However, Barabara McCann (2010) asserts that complete streets already exist without the designation in Copenhagen, since many streets already incorporate infrastructure for all transportation modes. The National Complete Street Coalition has recognized Copenhagen’s adoption of innovative street treatments as aligning with complete street policy by prioritizing safety for all users, especially cyclists (McCann, 2010). Providing barriers that create separation between bicycles and cars and using engineering techniques to promote a safe and efficient cycling experience like a signal and lighting system that times traffic lights to stay green for cyclists going at a minimum speed. Copenhagen also employs street sweepers to keep bike lanes

free from debris. This attention to detail makes the complete streets of Copenhagen a standout and success (McCann, 2010).

Although there are complete streets in both Seattle and Copenhagen, their policies regarding bicycle infrastructure are different. While Seattle uses both a bicycle master plan accompanied with a complete street policy that identifies twelve street types with design standards, Copenhagen uses a policy that focuses primarily on bicycle infrastructure, explaining when to build separated bike lanes or "cycle tracks" (Colville-Andersen, 2018). According to Danish traffic engineering guidelines, cycle tracks must be separated from car traffic with a curb, and roadways with different speed limits will have different engineering requirements (Henderson and Gulsrud, 2019).

Speed Limit	Cycle Track Requirements
Less than 40km/hr	None
40km/hr and less than 50km/hr	Cycle tracks must be separated and should run alongside the sidewalk and be a minimum of 2.3 meters or 7.5 feet wide
50km/ hr and less than 70km/hr	Cycle track must be separated with a minimum of 7.5 feet wide and should run alongside the sidewalk. Cycle tracks that have higher rider counts should have wider lanes to allow passing.
Greater than or equal to 70km/hr	For roadways with 70km/hr or above highway speeds, the track and car separation should be more expansive, requiring a buffer such as a grassy median or trees

Table 1 Road Speed Limits and Cycle Track Requirements (Henderson and Gulsrud, 2019)

Finally for all road types, if there is a parking lane, the parking lane should protect the cycle track. This way, drivers opening doors have less conflict with bicycles. For those conflicts

between cyclists and passenger doors, the solution is to widen the cycle track (Henderson and Gulsrud, 2019).

Besides bicycle infrastructure, Copenhagen uses other policy approaches to creating transportation infrastructure that results in a more pedestrian-friendly city. While most streets serve cars, bikes, pedestrians, and buses, the downtown area often restricts car access (Colville-Andersen, 2018). Making the downtown pedestrian-only began in the 1960s, one of the first examples being Greyfriar Square (Gehl, 1989). In the 1960s, the old medieval square was used as a parking lot, but the city transformed the square in the 1980s, prohibiting through traffic and providing a leisure space for pedestrians. Another example is the famous Strøget Street in Copenhagen, the world's longest pedestrian-only street. In the 1960s, when car and pedestrian congestion in Copenhagen's narrow downtown streets was becoming a significant problem, the city decided to make a section of Strøget street from the town hall square to Kongens Nytorv pedestrian-only. This decision was praised and considered a success, providing inspiration to many capitals and major cities (Copenhagen Portal, 2021). These pedestrian-friendly and restrictive car policies in downtown help keep traffic counts low in the city center, which considering traffic counts are a variable in Harkey's model, this may be important in bicycling compatibility. Figure 3 shows these two pedestrian-only interventions as well as ones added later in the public space network.

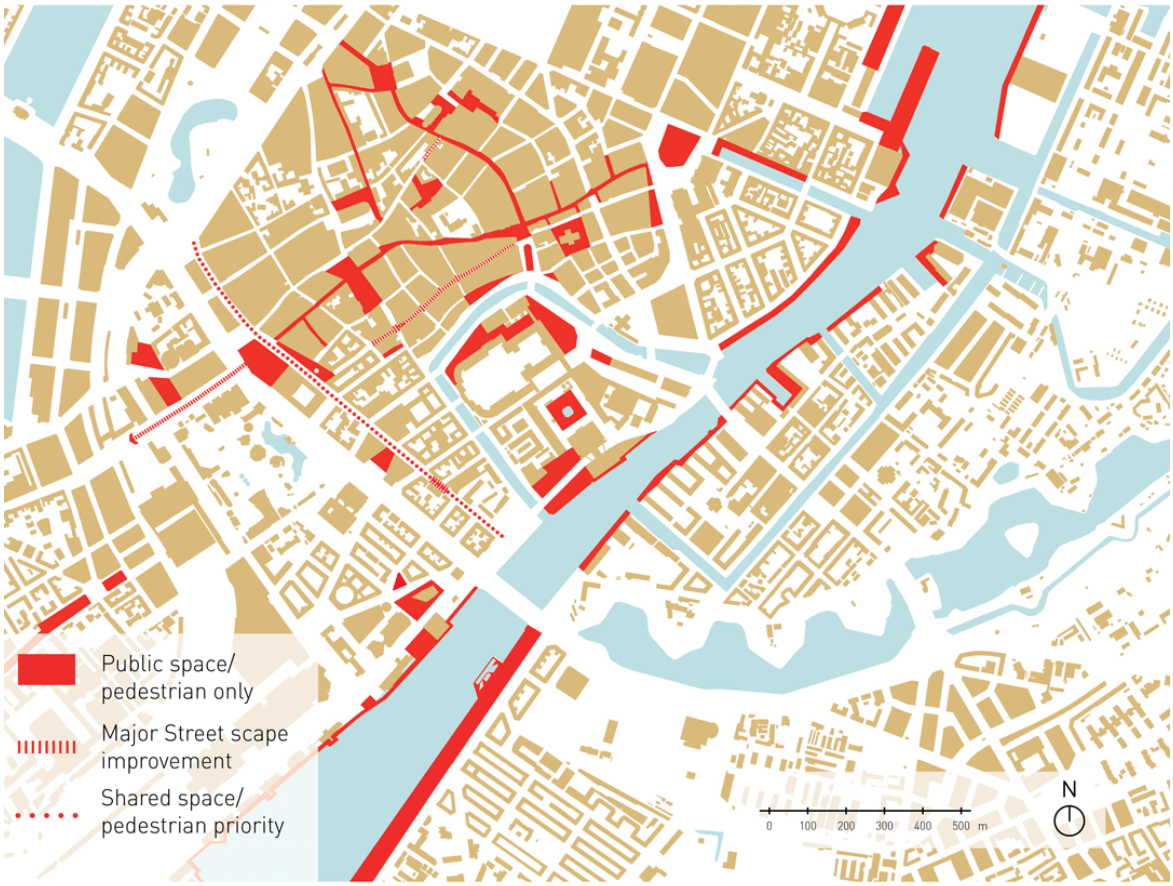

Figure 3 Car Restricted Access Spaces Copenhagen (Gehl, 2013)

Both cities have different policy landscapes surrounding cycling. Many policymakers and researchers consider complete street policy critical to cities in the United States like Seattle because it helps develop a political consensus that roads can serve other modes besides the automobile in a car-driven culture, and therefore infrastructure should reflect that (McCann, 2010). Seattle's policies reflect that approach showing a more gradual process for implementation of bicycle infrastructure.

In contrast, Copenhagen's transportation policy not only incorporates cycling and pedestrian space, but is often the focal point. For example, in 1930, Denmark made it mandatory for all roads funded by the national government to have a cycle track. In 1939, Denmark made

another requirement that all nationally-funded roads also have a pedestrian path (Henderson and Gulsrud, 2019). Later, after WWII and the oil crisis of the 1970s, Copenhagen experienced an economic crisis. But, with strong bicycle advocacy groups and limited money for automobile infrastructure, the city built cycle tracks on many key streets and drafted design standards for cycle tracks. Copenhagen may have complete streets, but it does not have a complete street policy. Instead, the city has bicycle infrastructure policies that help make complete streets. The impact of different policy approaches will be another aspect to take into account, and not just the street itself, in this study's assessment of complete streets.

Methodology

Seattle's Complete Street policy identifies twelve street types in total and these street types provide infrastructure design guidelines that impact all mode types: bicycle, pedestrian, transit rider, private vehicle owners, and so forth. To evaluate Seattle's complete streets' bicycle compatibility rating using Harkey's Bicycle Compatibility Index, this thesis used Seattle's street type diagram shown below in figure 4.

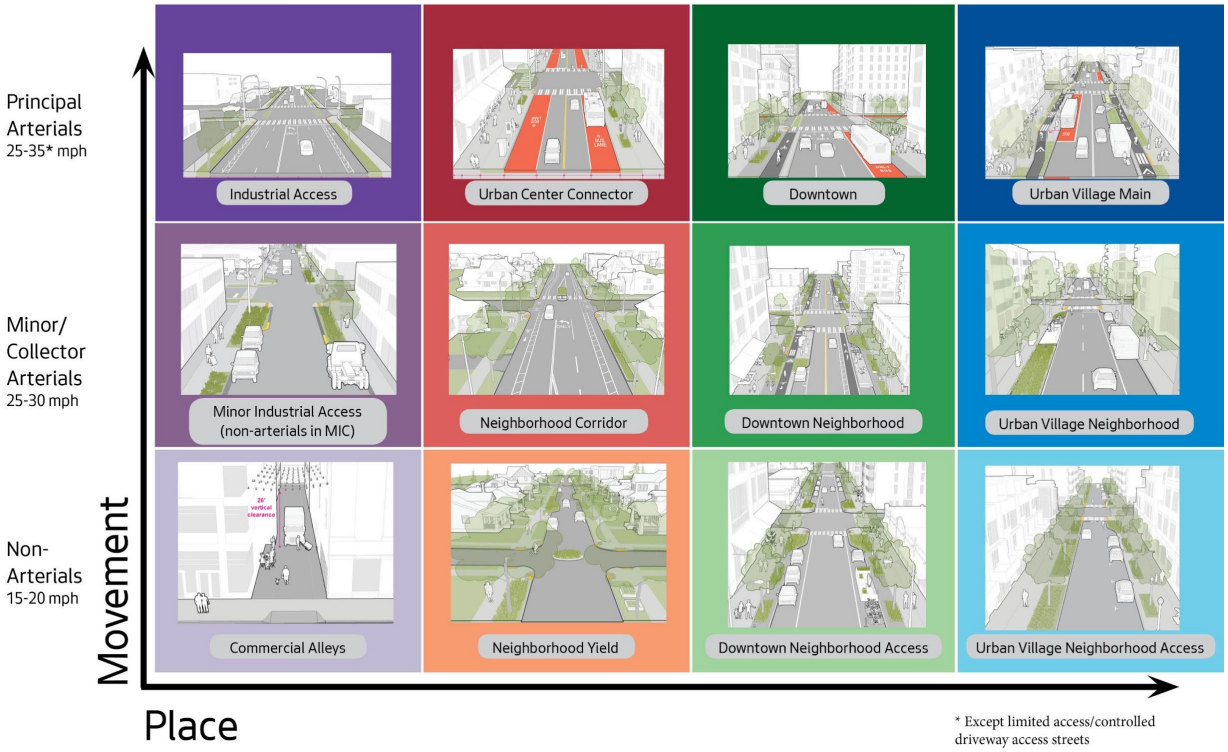

Figure 4 Street Type Design Standards (SDOT, 2020)

Using a process of geospatial analysis using Seattle OpenData files such as existing bike facilities, street types, and traffic data along with Google Satellite, this thesis identified each of Harkey's variables and assigned a score for seven of the twelve street types.

This study analyzed road segments, approximately one block or 160 meters in length, between two cross streets—this way, it was possible to measure the Bicycle Compatibility Index segment as accurately as possible. If more road segments were included in each example then there would be inconsistencies in BCI scores since each block is likely to have a different number of through traffic lanes, parking lanes, and/or bike lanes. The primary objective was to measure how the street type design standard fares in a real-life example. If another block of the same street type had different designs then the evaluation became less accurate. The secondary goal was to measure how the bicycle compatibility of complete streets fits within the street

network. If each block had different scores then the network assessment would become too patchworked and therefore challenging to conduct a proper analysis.

After selecting a one-block example, the task was to solve for each of Harkey's values and then apply them to Harkey's regression model, assigning each street type's real-life example a BCI value corresponding to its degree of compatibility for cycling. The research objective was to use street type design standards' BCI scores to offer a policy assessment and recommendations of Seattle's Complete Street Policy that would lend it to be more compatible with bicycling.

One of the reasons researchers found Harkey's BCI model more accurate is likely due to the number of variables. Harkey's model measures many different detailed road characteristics. Below is a list of his variables along with a short description.

David Harkey's variables:

BL (Bike Lane presence)

If there is a bike lane greater than or equal to .9 meters or 2.4 feet, this variable will be assigned a value of 1. If not then, the road will receive a 0. The presence of a bike lane can reduce the index value by an entire point, significantly impacting cyclists' comfort level.

BLW (Bicycle Lane Width)

The value assigned will be the width of the lane in meters to the nearest tenth. If no bicycle lane is present, this value will be 0. The larger the width, the more likely the index value to decrease.

CLW (Curb Lane Width)

The curb lane width is the width of the lane that is closest to the curb. This value does not include gutters, parking lanes, or bicycle lanes. The larger curb lane width will be more comfortable for cyclists riding adjacent.

CLV (Curb Lane Volume)

The model uses peak hour volume for the curb lane as a measure for traffic data, and a higher traffic volume in the curb lane will increase the index value.

OLV (Other Lane Volume)

The traffic volume of the other lanes in the same direction, also measured in peak hour volume.

SPD (Speed of Traffic)

The speed of traffic on the street, measured in km/hour. Instead of taking the speed limit, Harkey recommends using the 85th percentile, usually 15km greater than the speed limit.

PKG (Parking Lane)

Suppose there is a presence of a parking lane with more than 30 percent capacity. If there is, the variable value will be 1, and if not, 0. The presence of parking with cars coming and going can increase the index value and decrease cyclists' comfort.

AREA (Type of Roadside Development)

If the roadside development type is residential, then the value will be 1. If not, the value will be 0. Roadside development that is residential will decrease the index value, offering more comfort to cyclists.

AF (ft +fp +fn)

This variable is the adjustment factor. Ft is an adjustment factor for the traffic volume of trucks present in the curb lane. If more large-sized vehicles like trucks are driving in the curb lane, this will stress cyclists. The fp is the adjustment factor for parking turnover, which will depend on the time limit of parking. Lastly, the fn is the adjustment factor for right turn volumes. The same occurs for parking lanes with time limits, signifying that more cars are entering and exiting the bike lane. Fn was not used in this study.

With a significant number of variables, it can be challenging to find the necessary data across local GIS data networks. Neither Seattle nor Copenhagen have curb length in their databases, so to measure variables that relied on street or bike lane widths, this study used Google Satellite or Earth. In some cases, data like traffic counts was not available. Seattle only has traffic volume data for only arterial roads. Therefore, this study used Seattle street types that had corresponding traffic counts, all of which were arterial streets, therefore excluding residential streets. This approach worked for various reasons. Arterials accommodate a variety of transportation modes like buses, freight, cars, bikes, and people and therefore, they are likely to be higher targets for complete street design standards. They serve as more direct routes from point A to B than residential streets, often with minor variations in slope, making them more appealing routes to cyclists.

For the European case, this study examined Copenhaen's roadway design and policy standards related to bicycle infrastructure. Since Copenhagen does not have a comparable complete street policy, the city's design standards for cycle tracks or separated bicycle lanes were used. Cycle tracks correspond to specific road types outlined in the Copenhagen background/context section. After identifying the four roadways and their cycle track types, this

study followed a similar method to the Seattle format, selecting a city street that best served as an example of each of the four road types and evaluating its BCI using Harkey's model. Data was found using the same tools; Google Satellite, and Copenhagen OpenData sources. Both the Seattle and Copenhagen case studies reveal interesting aspects of how each city's street types are more or less compatible with biking.

Case Analysis

Seattle Complete Street BCI

This next section is intended to show the process and calculations of each Seattle street type example. The analysis shows each real-life example that was chosen alongside the corresponding street type diagram. Finally, a chart is included to show each of Harkey's variable values and how BCI was calculated.

Seattle Complete Street Policy describes 12 street types. Those that have an asterix below are considered arterials and have traffic data available in the form of Average Daily Traffic (ADT).

Seattle Street Type
Downtown*
Downtown Neighborhood*
Downtown Neighborhood Access
Neighborhood Corridor*
Urban Village Main*
Urban Village Neighborhood*

Urban Village Neighborhood Accessstreets illustrated
Urban Center Connector*
Industrial Access*
Minor Industrial Access
Neighborhood Yield
Commercial Alley

Table 2 List of Seattle Street Types in Complete Street Policy "Streets Illustrated" (SDOT, 2017)

Each street type example is shown below with a short explanation of why it was chosen, and in what ways it matches and may not be matching the corresponding diagram. The following charts show the Bicycle Compatibility Index formula, variables, and the final result of each street type's bicycle compatibility index score. Each example concludes with preliminary observations of the impact different variables may have on the final compatibility score.

Industrial Access

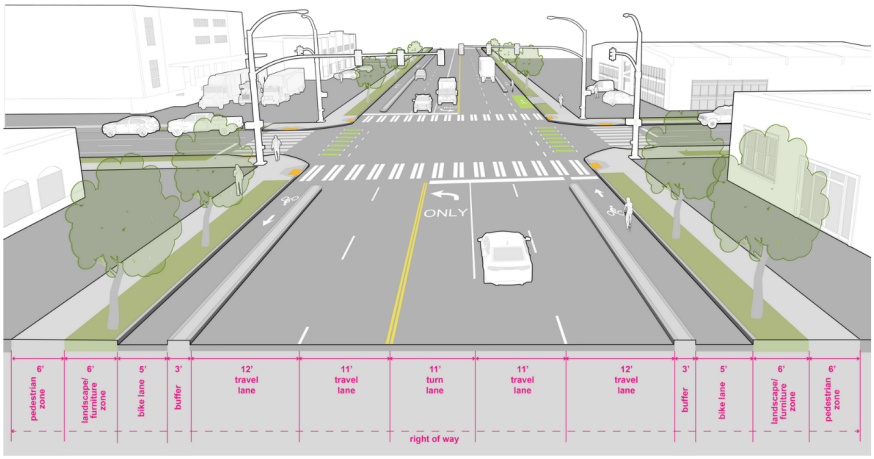

Figure 5 Industrial Access Diagram (SDOT, 2017)

Figure 6 20th Ave W between W Dravus St and Gilman Ave W(Google, 2021)

The Industrial Access Street type road segment is 20th Ave W between W Dravus St and Gilman Ave W. This road does appear exactly like the model above, having parking and only one traffic lane in either direction; however, it is one of the few road segments of Industrial Access street type within Seattle with a protected bike lane. The bike lane differs from the diagram in that it is bidirectional, a singular bike lane that accommodates riders in both directions often on only one side of the road.

Known Information	Translation to Known Variables
Number of lanes in one direction is one Bicycle lane or paved shoulder with 2.4m Curb lane width is 3.05 m 85th percentile speed = 55 km/h Roadside development is industrial On-street parking but does not appear 30% capacity Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 6,280 vehicles per day (vpd)	**N** = 1 **BL** = 1. **BLW** = 2.4 m **CLW**= 3.05 m **SPD** = 55 km/h **AREA** = **0** **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 6,280 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 6,280 x 0.10 x 0.55 = 345.4vph **CLV** =345.4/1 = 345.4vph **OLV** = 345.4 – 345.4 = 0 Assume T = 1 **CLTV** = 345.4 x 0.02 x 1 = 6.9 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 6.9) Fp = 0.0 (no on street parking) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	BCI Calculation
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.4)** – 0.498 **(3.05)** + 0.002**(413)** + 0.0004**(412)** + 0.022**(55)** + 0.506**(0)** – 0.264**(0)** + **0** = 2.12 **Compatibility Level** = Very High

Figure 7 Industrial Access BCI Calculations, 2021
Source: Seattle Opendata and Google Earth

After finding variable values and solving for bicycle compatibility, overall Industrial Access had a very high compatibility index. Some factors that may be influencing this score are a lower traffic count, 6,280 cars on an average day. Later street type examples show traffic can be much higher reaching tens of thousands cars per day. Other variables present are bike lanes, and although there is a parking lane, it does not appear to be thirty percent occupied (Google Satellite, 2021).

Urban Center Connector

Figure 8 Urban Center Connector Diagram (SDOT, 2017)

Figure 9 12th Ave S between XW S Lane St and Golf Dr S (Google, 2021)

In the 12th Ave S between XW S Lane St and Golf Dr S the most notable characteristics that are missing are bus transit lanes along with bus platforms. This attribute was impossible to

find in any of the Urban Center Connectors in real life. Urban Center Connectors in Seattle may have buses, but are unlikely to have dedicated bus lanes. The Urban Center Connector diagram shows an absence of a bike lane and no parking lane, which are also absent in the example. Finally, there are two lanes in both directions of the example just like the diagram.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is two No Bicycle lane or paved shoulder with 0 m Curb lane width is 3.66 m 85th percentile speed = 55 km/h Roadside development is mixed No on-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 20,058 vehicles per day (vpd)	**N** = 2 **BL** = 0. **BLW** = 0.0 m **CLW**= 3.66 m **SPD** = 55 km/h **AREA** = 0 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 20,058 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 20,058 x 0.10 x 0.55 = 1103.2vph **CLV** =1103.2/2 = 551.6vph **OLV** = 1103.2 – 551.6= 551.6 Assume T = 0.80 **CLTV** = 551.6 x 0.02 x 0.80 = 8.8 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 8.8) Fp = 0.0 (no on street parking) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(0)** – 0.410 **(0)** – 0.498 **(3.66)** + 0.002**(551.6)** + 0.0004**(551.6)** + 0.022**(55)** + 0.506**(0)** – 0.264**(0)** + **0** =4.36 **Compatibility Level** = Moderately Low

Figure 10 Urban Center Connector BCI, 2021
Source: Seattle Opendata and Google Earth

Overall Harkey's model gives this road sample a 4.36 index value, a moderately low bicycle compatibility. Compared to Industrial Access street type, Urban Center Connector has much higher traffic counts with 20,058 average vehicle count per day. It also has no biking lane, which may also be attributing to a lower compatibility score. Like all road segments of the Seattle Street types, the speed limit is the same at 25 miles per hour or 40 km per hour.

Downtown

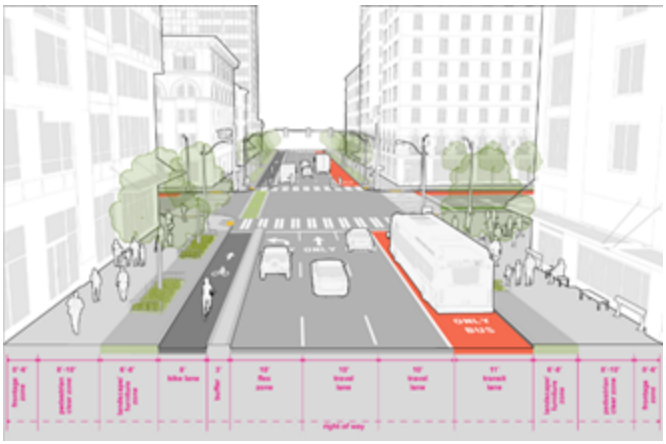

Figure 11 Downtown Diagram (SDOT, 2017)

Figure 12 2nd Ave between Marion St and Madison St (Google, 2021)

The example of Downtown, 2nd Ave between Marion St and Madison St, is very similar to the street type example diagram. There is a dedicated bus lane, something that was impossible to find in the Urban Center Connector, and it is a multi-lane street with three traffic lanes on a one-way road. The major exception is in this example there is a parking lane, however in the diagram there is not. The reason for including a parking lane is that in downtown Seattle it was

difficult to find roads without parking lanes. In fact much of downtown Seattle has parking. Therefore this is still an accurate depiction of a Downtown street type.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is three Bicycle lane or paved shoulder with 2.4 m Curb lane width is 3.05 m 85th percentile speed = 55 km/h Roadside development is commercial On-street parking over 30% occupied Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 17695 vehicles per day (vpd)	**N** = 3 **BL** = 1. **BLW** = 2.4 m **CLW**= 3.05 m **SPD** = 55 km/h AREA = 0 **PKG** = 1 **HV** = 0.0 **R** = N/A **AADT** = 17695 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 1 **PHV** = 17695 x 0.10 x 1 = 1769.5vph **CLV** =1769.5/3 = 590vph **OLV** = 1769.5 – 590 = 1179.5 Assume T = 0.80 **CLTV** = 590 x 0.02 x 0.80 = 9.4 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 9.4) Fp = 0.3 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.4)** – 0.498 **(3.05)** + 0.002**(590)** + 0.0004**(1179.5)** + 0.022**(55)** + 0.506**(1)** – 0.264**(0)** + **0.3** = 3.89 **Compatibility Level** = Moderately Low

Figure 13 Downtown BCI, 2021
Source: Seattle Opendata and Google Earth

The Downtown street type has a 3.89 score, which represents moderately low compatibility for bicycling. Traffic counts are on the higher end with an average of 17,695 cars per day. If parking was eliminated a moderately high compatibility score would be possible for this example.

Urban Village Main

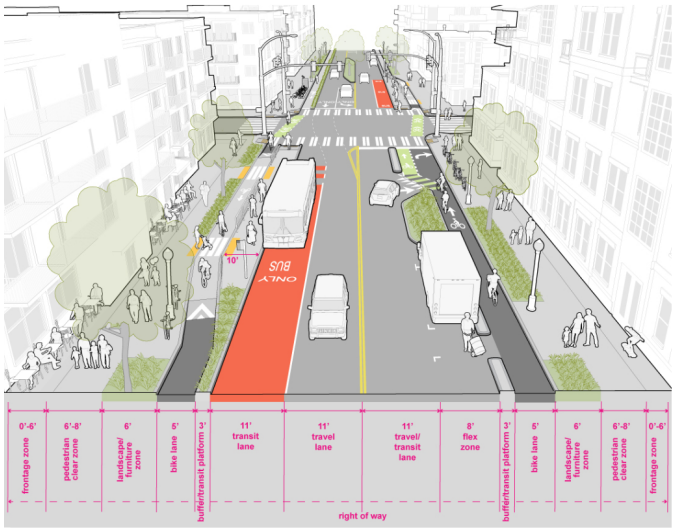

Figure 14 Urban Village Main Diagram (SDOT, 2017)

Figure 15 9th Ave N between Roy St and Westlake Ave N (Google, 2021)

The 9th Ave N between Roy St and Westlake Ave N example has protected bike lanes on either side of the road like in the diagram. While not having a dedicated bus lane, one side of the road segment does have multiple lanes of traffic. One roadway direction has a vehicular parking lane while the other direction does not, just like in the diagram. Since the different directions of

the street have different variables, they were evaluated with the BCI model separately, and then the average of the two bicycle compatibility scores were taken to find the total BCI score.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one Bicycle lane or paved shoulder with 2.4 m Curb lane width is 3.05 m 85th percentile speed = 55 km/h Roadside development is mixed On-street parking over 30% occupied Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 7800 vehicles per day (vpd)	**N** = 1 **BL** = 1. **BLW** = 2.4 m **CLW**= 3.05 m **SPD** = 55 km/h AREA = 0 **PKG** = 1 **HV** = 0.0 **R** = N/A **AADT** = 7800 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 7800 x 0.10 x .055 = 429vph **CLV** =429/1 = 429vph **OLV** = 429 – 429 = 0 Assume T = 1 **CLTV** = 429 x 0.02 x 1 = 8.58 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 8,58) Fp = 0.3 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.4)** – 0.498 **(3.05)** + 0.002**(429)** + 0.0004**(0)** + 0.022**(55)** + 0.506**(0)** – 0.264**(0)** + **0.3** = 2.77 **Compatibility Level** = Moderately High

Figure 16 Urban Village Main BCI Northbound, 2021
Source: Seattle Opendata and Google Earth

Known Information	**Translation to Known Variables**
Number of lanes in one direction is two Bicycle lane or paved shoulder with 2.4 m Curb lane width is 3.05 m 85th percentile speed = 55 km/h Roadside development is mixed No on-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 7800 vehicles per day (vpd)	**N** = 2 **BL** = 1. **BLW** = 2.4 m **CLW**= 3.05 m **SPD** = 55 km/h AREA = 0 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 7800 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 7800 x 0.10 x 0.55 = 429vph **CLV** =429/2 = 214.5vph **OLV** = 429 – 214.5 = 214.5 Assume T = 0.80 **CLTV** = 429 x 0.02 x 0.80 = 6.86 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 6.86) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.4)** – 0.498 **(3.05)** + 0.002**(214.5)** + 0.0004**(24.5)** + 0.022**(55)** + 0.506**(0)** – 0.264**(0)** + **0.0** = 1.93 **Compatibility Level** = Very High

Figure 17 Urban Village Main BCI Northbound, 2021
Source: Seattle Opendata and Google Earth

The BCI score is 2.35, or moderately high compatibility with cycling. That said, the northbound had a very high compatibility rating, and the major difference between northbound and southbound is southbound has a vehicular parking lane while northbound does not. Therefore if the parking lane were to be removed on the southbound side, the street would actually have high bicycling compatibility.

Neighborhood Corridor

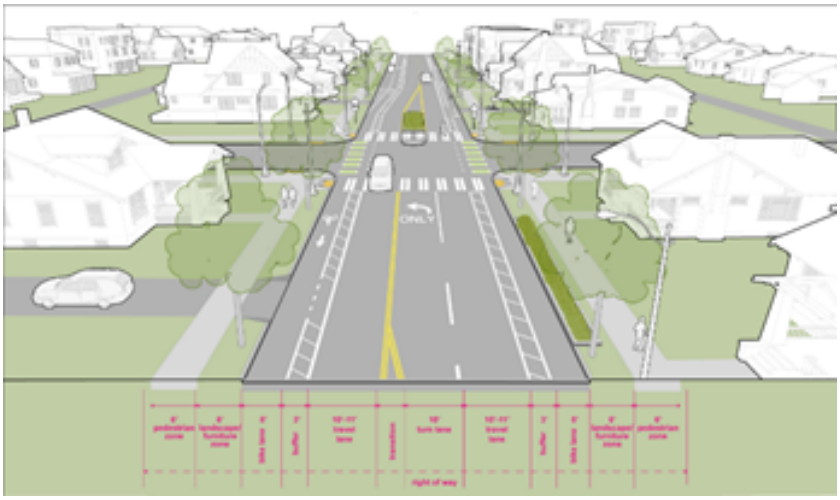

Figure 18 Neighborhood Corridor Diagram (SDOT, 2017)

Figure 19 15th Ave NE between Cowen Pl NE and NE 62nd St (Google, 2021)

The Seattle Street Type diagram of the Neighborhood Corridor does not have a vehicular parking lane in the block in the forefront, but does in the background block. The example, 15th Ave NE between Cowen Pl NE and NE 62nd St, does not have parking since the most prominent part of the diagram does not have it. There is also no left turn lane, but since David Harkey does

not factor in left turn lanes in his model (only through traffic lanes), this should not have a large impact on bicycling compatibility.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one Bicycle lane or paved shoulder with 2.4 m Curb lane width is 3.35 m 85th percentile speed = 55 km/h Roadside development is residential No on-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 10828 vehicles per day (vpd)	**N** = 1 **BL** = 1. **BLW** = 2.4 m **CLW**= 3.35 m **SPD** = 55 km/h AREA = 1 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 10828 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 10828 x 0.10 x .055 = 595.54vph **CLV** =595.54/1 = 595.54vph **OLV** = 595.54 – 595.54 = 0 Assume T = 1 **CLTV** = 595.54 x 0.02 x 1 = 11.9 *RTV* = N/A Ft = 0.1 (based on **CLTV** = 11.9) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.4)** – 0.498 **(3.35)** + 0.002**(595.54)** + 0.0004**(0)** + 0.022**(55)** + 0.506**(0)** – 0.264**(1)** + **0.1** = 2.28 **Compatibility Level** = Very High

Figure 20 Neighborhood Corridor BCI, 2021
Source: Seattle Opendata and Google Earth

Neighborhood Corridor has very high compatibility with a score of 2.28. At first glance, traffic counts are not significantly low, there are still 10,828 cars on average per day, however it is in a residential area, there is a bicycle lane, and no parking lane. This seems to help offset a moderate vehicular traffic count. Another attribute to note is that curb lane width is slightly higher than other roads seen so far.

Downtown Neighborhood

Figure 21 Downtown Neighborhood Diagram (SDOT, 2017)

Figure 22 Yesler Way between 2nd Ave AND 3rd Ave (Google, 2021)

The segment sample, Yesler Way between 2nd Ave and 3rd Ave, for Downtown Neighborhood may be difficult to see in figure 21 above, however it has parking lanes in both

directions of the street and no bike lane. It is one of the street type examples that is most similar to the complete street diagram.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one No Bicycle Lane Curb lane width is 3.05 m 85th percentile speed = 55 km/h Roadside development is commercial On-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 6601 vehicles per day (vpd)	**N** = 1 **BL** = 0. **BLW** = 0.0 m **CLW**= 3.05 m **SPD** = 55 km/h AREA = 0 **PKG** = 1 **HV** = 0.0 **R** = N/A **AADT** = 6601 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 6601 x 0.10 x .055 = 363vph **CLV** =363/1 = 363vph **OLV** = 363 – 363= 0 Assume T = 1 **CLTV** = 363 x 0.02 x 1 = 7.26 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 7.26) Fp = 0.3 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(0)** – 0.410 **(0)** – 0.498 **(3.05)** + 0.002**(363)** + 0.0004**(0)** + 0.022**(55)** + 0.506**(1)** – 0.264**(0)** + **0.3** = 4.89 **Compatibility Level** = Very Low

Figure 23 Downtown Neighborhood BCI, 2021

The Downtown Neighborhood example scored a 4.89 and therefore has a very low bicycling compatibility rating. In fact, it received the lowest compatibility of all complete street type examples. The traffic count was not especially high, only 6,601 cars per day; however, there is a vehicular parking lane and no biking lane. This is also a narrow street with a low curb lane width and only one traffic lane in either direction, all characteristics that negatively impact compatibility.

Urban Village Neighborhood

Figure 24 Urban Village Neighborhood Diagram (SDOT, 2017)

Figure 25 University Way NE between NE 45th St and NE 47th St (Google, 2021)

The Urban Village Neighborhood has a conflicting depiction, since the street block in the forefront of the diagram has a lane of street furniture and the street block further away shows parking lanes on either side. In actuality most real-life examples of Urban Village Neighborhood have parking lanes, therefore the sample segment, University Way NE between NE 45th St. and

NE 47th street closely resembles the block in the background of the diagram. There is a parking lane on both sides, no bike lane, and one lane in either direction.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one No Bicycle Lane Curb lane width is 3.66 m 85th percentile speed = 55 km/h Roadside development is mixed use On-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 5592 vehicles per day (vpd)	**N** = 1 **BL** = 0. **BLW** = 0.0 m **CLW**= 3.66m **SPD** = 55 km/h AREA = 0 **PKG** = 1 **HV** = 0.0 **R** = N/A **AADT** = 5592 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 5592 x 0.10 x .055 = 307.65vph **CLV** =307.65/1 = 307.65vph **OLV** = 307.65 – 307.65= 0 Assume T = 1 **CLTV** = 307.65 x 0.02 x 1= 6.15 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 6.15) Fp = 0.3 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(0)** – 0.410 **(0)** – 0.498 **(3.66)** + 0.002**(307.65)** + 0.0004**(0)** + 0.022**(55)** + 0.506**(1)** – 0.264**(0)** + **0.3** = 4.47 **Compatibility Level** = Very Low

Figure 26 Urban Village Neighborhood BCI, 2021

Overall the Urban Village Neighborhood street type scores very low, with a rating of 4.47. This street type was very similar to Downtown Neighborhood in traffic counts, number of traffic lanes, parking lane, absence of a bike lane and so forth. Likely the difference in scores can be attributed to the small variation in the two street types' traffic counts.

Copenhagen Street BLOS Score

Overview

For Copenhagen this study applied David Harkey's bicycle compatibility model to each of the four street types mentioned in Copenhagen's cycle track guidelines (determined by speed limit) using real-life examples. Below, Table 3 shows the corresponding street type and roadway example evaluated.

Street Speed Limits	Example
<40km/hr and under	Stengade Street between Baggesensgade and Nørrebrogade
40 =< 50km/hr	Islands Brygge Street between Sturlasgade and Islands Brygge
50 =< 70km/hr	Kalkbrænderihavnsgade between Strandvænget and Lautrupsgade
>= 70km/hr	Hillerødmotorvejen and Mosesvinget and Skolevangen

Table 3 Street Speeds with Examples, 2021
Source: Copenhagen Opendata and Google Earth

Streets with Speed Limit less than 40km/hr

Figure 27 Stengade Street between Baggesensgade and Nørrebrogade (Google, 2021)

A reminder that the guidelines for streets with speed limits of less than less than forty kilometers per hour do not require a cycle track. The example of Stengade Street between Baggesensgade and Nørrebrogade has a speed limit of thirty kilometers per hour and does not have a cycle track. The example was found through a process of both satellite and street view since some of the satellite images made it difficult to see road attributes. The figure below shows how the example's road attributes are plugged into the compatibility formula.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one No Bicycle Lane Curb lane width is 3.05 m 85th percentile speed = 45 km/h Roadside development is residential No on-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 2600 vehicles per day (vpd)	**N** = 1 **BL** = 0. **BLW** = 0.0 m **CLW**= 3.05m **SPD** = 45 km/h AREA = 1 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 2600 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 2600 x 0.10 x .055 = 143 vph **CLV** =143/1 = 143vph **OLV** = 143– 143= 0 Assume T = 1 **CLTV** = 143 x 0.015 x 1 = 2.15 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 2.15) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(0)** – 0.410 **(0)** – 0.498 **(3.05)** + 0.002**(143)** + 0.0004**(0)** + 0.022**(45)** + 0.506**(0)** – 0.264**(1)** + **0.0** = 3.16 **Compatibility Level** = Moderately High

Figure 28 Streets with less than 40km/hr BCI, 2021
Source: Copenhagen Opendata and Google Earth

The street segment example with a speed limit of less than forty kilometers an hour received a moderately high compatibility score. If the street had a parking lane with over 30% occupancy it would have received a moderately low compatibility rating, so the absence of a parking lane had a significant impact on its BCI. If it had a cycle track it would have received a very high rating, however the road was narrow, and there would not have been much room for dedicated space to cycle tracks. That aspect is worth mentioning since, especially in Europe, there are roads where it is impossible to accommodate both cycle tracks and vehicular lanes. To

improve bicycle compatibility in this case, it appears lower speed limits may help or making roadways pedestrian/bike-only.

Streets with Speed limit 40-50km/hr

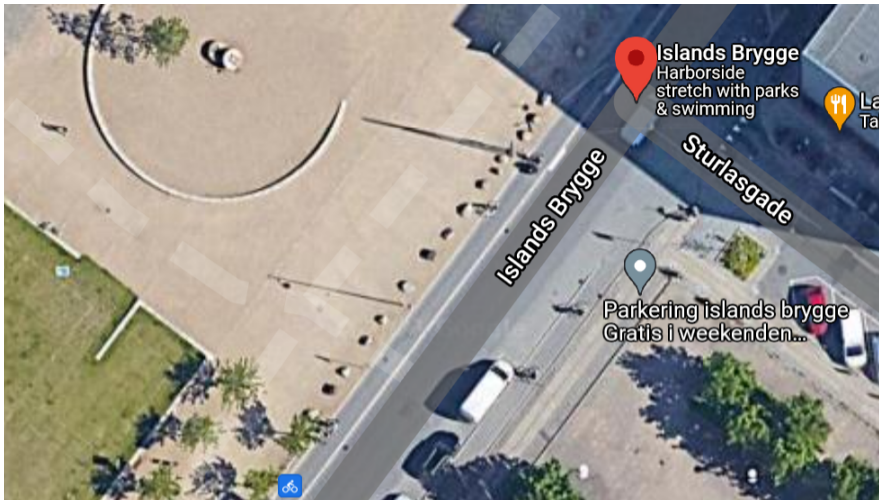

Figure 29 Islands Brygge Street between Sturlasgade and Islands Brygge (Google, 2021)

The example for streets with speed limits of forty to fifty kilometers per hour was Islands Brygge Street between Sturlasgade and Islands Brygge. This example has a parking lane and also cycle tracks on either side of the road. Recall that when the speed limit increases to forty or fifty kilometers per hour Denmark engineering guidelines require a cycle track at least 2.3m or 7.5 feet in width. If there is a vehicular parking lane, it should be placed so that it separates the cars from the bikes. This road segment example meets those requirements.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is one Separated Bicycle Lane Curb lane width is 3.0 m 85th percentile speed = 55 km/h Roadside development is mixed use On-street parking Large truck percentage is 0 percent Right-turn percentage is N/A Average daily traffic volume is 5400 vehicles per day (vpd)	**N** = 1 **BL** = 1. **BLW** = 2.3 m **CLW**= 3.0 m **SPD** = 55 km/h AREA = 0 **PKG** = 1 **HV** = 0.0 **R** = N/A **AADT** = 5400 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 5400 x 0.10 x .055 = 297 vph **CLV** =297/1 = 297vph **OLV** = 297– 297= 0 Assume T = 1 **CLTV** = 297 x 0.02 x 1 = 5.94 *RTV* = N/A Ft = 0.0 (based on **CLTV** = 5.94) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(2.3)** – 0.498 **(3)** + 0.002**(297)** + 0.0004**(0)** + 0.022**(55)** + 0.506**(1)** – 0.264**(0)** + **0.0** = 2.58 **Compatibility Level** = Moderately High

Figure 30 Streets with speed limits of 40 to 50km/hr BCI, 2021
Source: Copenhagen Opendata and Google Earth

This road category received a moderately high compatibility score, 2.58. Traffic counts are low, with 5,400 annual average number of cars per day. Without a vehicular parking lane the score would be higher, and there would be more space for the cycle track, which would increase bike lane width variable value in Harkey's volume. That change would raise compatibility and also meet Copenhagen bicycle infrastructure goals of widening cycle tracks.

Streets with Speed Limit 50 - 69km/hr

Figure 31 Kalkbrænderihavnsgade between Strandvænget and Lautrupsgade (Google, 2021)

Kalkbrænderihavnsgade between Strandvænget and Lautrupsgade serves as the fifty to just under sevently kilometer per hour road category. Recall that under this category there must be a cycle track with a minimum width of 2.3m or 7.5 feet and if cycle counts are high, the width should be even greater. In this case the width of the cycle track is significant at roughly 3.35m or almost 11 feet.

Known Information	**Translation to Known Variables**
Number of lanes in one direction is two Separated Bicycle Lane Curb lane width is 3.0 m 85th percentile speed = 75 km/h Roadside development is mixed use No on-street parking Large truck percentage is 2 percent Right-turn percentage is N/A Average daily traffic volume is 15700 vehicles per day (vpd)	**N** = 2 **BL** = 1. **BLW** = 3.35 m **CLW**= 3.05 m **SPD** = 75 km/h AREA = 0 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 15700 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 15700 x 0.10 x .055 = 863.5 vph **CLV** =863.5 /2 = 431.75vph **OLV** = 863.5 – 431.75= 431.75 Assume T = 0.80 **CLTV** = 863.5 x 0.035 x 0.80= 24.19 *RTV* = N/A Ft = 0.2 (based on **CLTV** = 24.19) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(3.35)** – 0.498 **(3.05)** + 0.002**(431.75)** + 0.0004**(431.75)** + 0.022**(75)** + 0.506**(0)** – 0.264**(0)** + **0.2**= 2.67 **Compatibility Level** = Moderately High

Figure 32 Streets with speed limits 50 - 69km/hr, 2021
Source: Copenhagen Opendata and Google Earth

This roadway example received a moderately high compatibility rating of 2.67. The wider cycle track appears to contribute to a higher score, even when traffic count is higher than the previous two road segment examples (15,700 cars per day annual average). There is no vehicular parking lane present which also helps bicycle compatibility.

Streets with Speed Limit over 70km/hr

Figure 33 Hillerødmotorvejen and Mosesvinget and Skolevange(Google, 2021)

The street example with a speed limit of over seventy kilometers per hour is most similar to a highway. In Copenhagen, higher speeds correspond directly with traffic counts. The example taken is the Hillerødmotorvejen between Mosesvinget and Skolevangen. With roads with speed limits of seventy kilometers per hour or higher, Denmark engineering standards require cycle tracks, but with a larger traffic barrier such as trees or other landscaping, not just a curb. In this example there is just a curb separating bicycles and vehicles, however other blocks in this motorway have more separation.

Known Information	Translation to Known Variables
Number of lanes in one direction is two Separated Bicycle Lane Curb lane width is 3.0 m 85th percentile speed = 85 km/h Roadside development is residential No on-street parking Large truck percentage is 4 percent Right-turn percentage is N/A Average daily traffic volume is 60,900 vehicles per day (vpd)	**N** = 2 **BL** = 1. **BLW** = 3.35 m **CLW**= 3.05 m **SPD** = 85 km/h AREA = 1 **PKG** = 0 **HV** = 0.0 **R** = N/A **AADT** = 60,900 vpd
Equations for Unknown Variables	**Calculation of Unknown Variables**
Peak-hour volume (vehicles per hour – vph) **PHV = AADT x K x D** Curb lane volume **CLV = PHV/N** Other lane volume **OLV = PHV – CLV** Curb lane truck volume **CLTV = PHV x HV x T** Right-turn volume **RTV = PHV x R** Adjustment Factor **AF** = ft + fp + fn	Assume K = 0.10. D = 0.55 **PHV** = 60,900 x 0.10 x .055 = 3,349.5 vph **CLV** =3,349.5/2 = 1674.75 vph **OLV** = 3,349.5 – 1674.75 = 1674.75 Assume T = 0.80 **CLTV** = 3,349.x 0.035 x 0.80= 93.79 *RTV* = N/A Ft = 0.4 (based on **CLTV** = 93.79) Fp = 0.0 (parking with high turnover) Fn = N/A **AF** = 0.0
BCI Equation and LOS Determination	Calculation of BCI
BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF** **Bicycle LOS** and **Compatibility Level**	**BCI** = 3.67 – 0.966 **(1)** – 0.410 **(3.35)** – 0.498 **(3.05)** + 0.002**(1674.75)** + 0.0004**(1674.75)** + 0.022**(85)** + 0.506**(0)** – 0.264**(1)** + **0.4**= 5.83 **Compatibility Level** = Extremely Low

Figure 34 Streets with speed limits of over 70km/hr, 2021
Source: Copenhagen Opendata and Google Earth

Overall the seventy kilometer per hour road received the worst compatibility score of all examples taken from both Seattle and Copenhagen, with a 5.83 representing extremely low bicycling compatibility. The bike lane width was still high at 3.35m or almost 11 feet, however the traffic count was the highest of all examples at 60,900 vehicles annually per day.

Street Type Comparison

Seattle

The table below summarizes Seattle complete street type Bicycle Compatibility scores and corresponding compatibility levels. The results demonstrate that Seattle's complete street

types have varying levels of bicycle compatibility from very high compatibility to very low compatibility.

Street Type	BCI	Bicycle Compatibility Level
Industrial Access	2.12	Very High
Neighborhood Corridor	2.28	Very High
Urban Village Main	2.35	Moderately High
Downtown	3.89	Moderately Low
Urban Center Connector	4.38	Moderately Low
Urban Village Neighborhood	4.47	Very Low
Downtown Neighborhood	4.89	Very Low

Table 4 Seattle Street Type BCI Values (Tiedeman, 2021)

Preliminary observations show that the most compatible street type for bicyclists is Industrial Access, and the least compatible is Downtown Neighborhood. The apparent differences between these two street types are vehicular traffic volume, presence of a parking lane (Industrial Access has a parking lane but low turnover), and the presence or absence of a bike lane (there is a separated bike lane in Industrial Access versus no lane in Downtown Neighborhood). With the presence of a parking lane, Downtown Neighborhood streets are likely to have higher parking presence and turnover, and, without a protected bike lane, bicycle compatibility is extremely low. On the other hand, the Industrial Access has a lower traffic volume with less parking and a separated bike lane, allowing for a lower index value, and therefore higher compatibility.

Neighborhood Corridor also has a very high compatibility rating, likely due to lower traffic volumes and separated bike lanes, while Urban Village Neighborhood struggles to be highly compatible with cycling. This is likely due to the presence of vehicular parking lanes and lack of bike lanes. Adding a bike lane and eliminating parking could greatly improve this street type's BCI value.

Copenhagen

Street Type	BCI	Bicycle Compatibility Level
Speed Limit = 30km/hr	3.16	Moderately High
Speed Limit = 40km/hr	2.58	Moderately High
Speed Limit = 50km/hr	2.66	Moderately High
Speed Limit = 70km/hr	5.55	Extremely Low

Table 5 Copenhagen Street BCI Values (Tiedeman, Kerry)

Overall, Copenhagen's street network performed well. Every street type except for the seventy kilometer per hour or more speed limit category scored between 2.58 - 3.16, a consistently moderately high compatibility level. Factors that may help with high scores are the presence of a bike lane, its width, and barrier and distance from street traffic. Having a minimum level of 2.3m or 7.5 feet helps to lower the index value, increasing compatibility. Another factor that could be improving compatibility ratings is that most examples did not have a parking lane, and the absence of a parking lane provided more space for a wider cycle track.

The seventy kilometer per hour or more road category scored very poorly in biking compatibility. It is important to note that Copenhagen has a limited number of high-speed roads

within the city boundaries, only a couple of arterials that help connect neighboring suburbs to Copenhagen's city center. The lack of seventy kilometer per hour roads is visually evident in figure 36, the network connectivity map below. Also, in the block just north of the street example, the cycle track is much farther off the road with trees and a grassy median separating the two transportation modes. Based on these two observations it appears that Copenhagen attempts to limit these types of roads within city limits and when unavoidable tries to create a greater separation between cars and bicycles, although not always.

Network Connectivity

As mentioned earlier in the background and context section, network connectivity can impact whether a cyclist chooses to ride. Therefore the second part of this study was to apply the BCI averages to each street type or street category within each city's street network. The comparison of both street networks demonstrates interesting findings.

Seattle

The network connectivity map below shows all arterial roads and street types mapped by BCI levels within Seattle (figure 35):

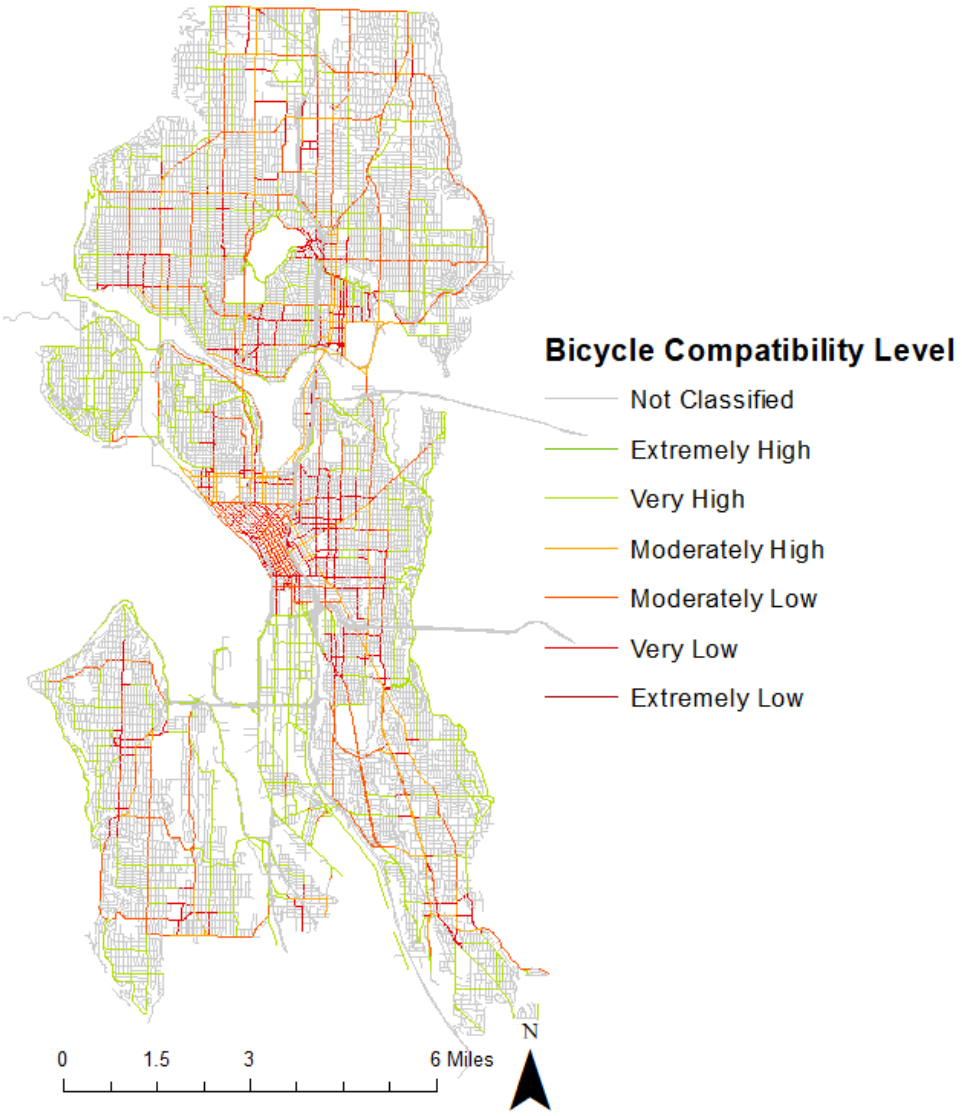

Figure 35 Map of Seattle's Arterial Streets with BCI, 2021
Source: Seattle Opendata and Google Earth

Copenhagen

The network connectivity map below (figure 36) shows all BCI levels for streets within Copenhagen municipality.

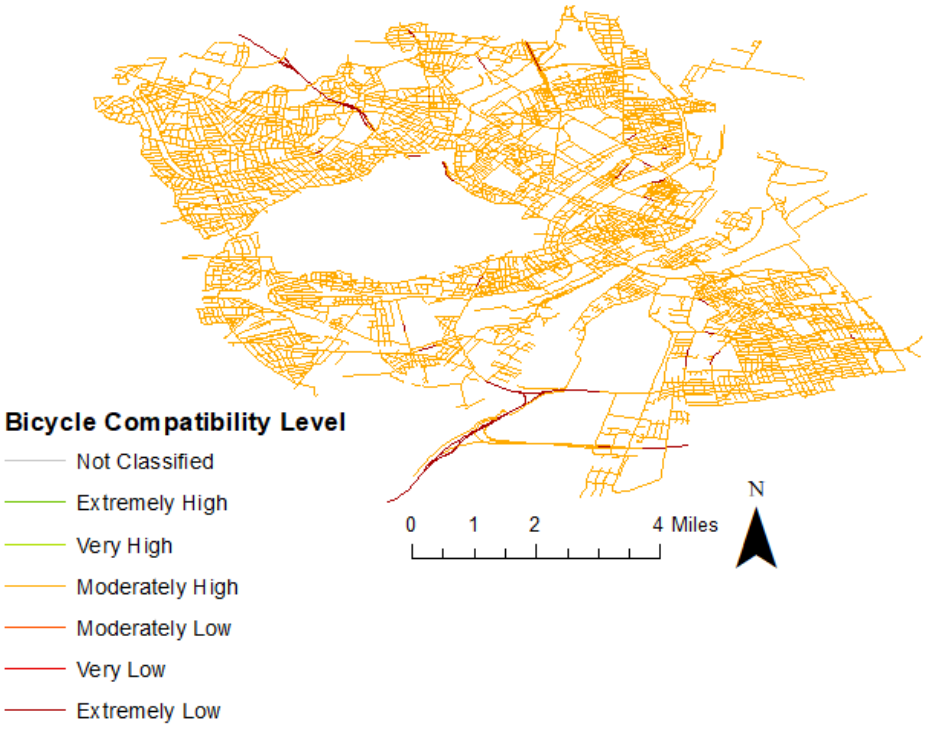

Figure 36 Map of Copenhagen Streets' BCI
Source: Copenhagen Opendata and Google Earth

Although different street types and road categories within each city's street network will have different traffic counts, the map representation of BCI and street type inform an interesting view of the overall bicycle compatibility of each city's street network. Observations of the two maps will be looked at more closely during the discussion.

Data Constraints

Road segment samples were chosen based on how closely they mirrored the street type diagrams. Considering that the diagram model is the gold standard for design, these examples offer a method to evaluate that standard. Although Copenhagen graphics were unavailable, their

road types and requirements for bicycle infrastructure were straightforward and therefore it was easy to find examples using Google Earth and Satellite.

The sample size for each street type in both Seattle and Copenhagen is small; each road segment only measured one city block. Since road characteristics like traffic count, parking, etc. will change block by block even for the same street type, BCI index values for each street type in this study are estimates.

As mentioned, Google Satellite and Google Earth were used to identify road characteristics and measure distances. Therefore although these tools are accurate, they are likely not the most precise. In the future, in person road measurements would be better. However, often the measurement discrepancies are likely to be off by very little, so it is unlikely that these discrepancies would make a significant impact on final compatibility scores.

Local data from both Seattle and Copenhagen open data were used as well to assign values to roadway variables. It is important to mention that some of the GPS files from each city were not up to date. To avoid using inaccurate data, information from GPS files was cross-referenced with Google Satellite, and Google Satellite was deemed to be the most up to date resource.

It is important to note that Harkey states that his model may only be appropriate for bike lane widths between .9 and 2.4m or 3 feet to 7.5 feet due to the construction of this model having only a limited range of widths. Therefore values beyond those specified width lengths may not work if applied to the BCI model. However, considering that Copenhagen promotes constructing wider lanes to relieve congestion issues, this study incorporated a greater range of width when necessary.

This study only evaluates arterials in Seattle, while in Copenhagen it was possible to evaluate at least one non-arterial road. This is due to the lack of availability of vehicular traffic count for non arterials in Seattle. Including residential streets would be an exciting angle for future research, especially since they may offer low-stress route alternatives to arterials, but currently is not possible at least within Seattle.

Finally, this study avoided evaluating bicycle compatibility at intersections. Intersections would serve as an interesting angle for further research as well with a dedicated study of their impact on bikeability.

Discussion

What Harkey's Variables Indicate for the Street Type Examples

Traffic Counts

This study uses Average Daily Traffic (ADT) for Seattle and Average Annual Daily Traffic (AADT) for Copenhagen. The difference between ADT and AADT is that AADT is measured annually while ADT is measured over a different length of time, likely less than a year. These were used interchangeably since they are measuring the same type of average, just over different time periods.

In this study, traffic counts of cars per day ranged from 2,600 vehicles per day to 60,900 vehicles per day. This is a significant range, but this study considers high traffic count to be over the 10,000 cars per day range. This higher traffic range is impacted by the number of traffic

lanes. The number of lanes will affect the curb lane volume which is the variable used in the multiple regression BCI. If a road has a high traffic count, but more traffic lanes, then the curb lane will have less volume. That said, for simplicity, this discussion looks at total vehicular traffic counts.

When there are traffic counts of over 10,000 cars per day, it becomes challenging to receive a high bicycle compatibility rating. For example, the Copenhagen street category of streets with speed limits of over seventy kilometers an hour had an AADT of 60,900, the highest traffic count in the range. It had other elements that are meant to positively impact bicycle compatibility; no parking lane, a wide bike lane or cycle track, and so forth, but that was not enough to offset such a high traffic count, and it received the lowest bicycle compatibility rating of all street types and categories.

That said, compatibility can improve when a cycle track is added for roads with moderate traffic counts (over 10,000 ADT but less than 25,000 ADT). In the Seattle examples, some of the highest BCI scores (indicative of lower bicycle compatibility) were Urban Center Connector and Downtown. Urban Connector had a score of 4.38, and Downtown had a score of 3.89. Urban Center Connector street type had a traffic count (ADT) of 20,058 and Downtown street type had 17,695 average number of cars per day. Note that Downtown street type has a bike lane while Urban connector does not. Although having a bike lane did not change its compatibility category, it did improve the BCI score significantly.

Another interesting observation is that Copenhagen has lower traffic counts than Seattle within the city. There were two exceptions; the road with a speed limit of seventy kilometers per hour had the highest traffic count, an AADT of 60,900, and the road with a speed limit of fifty to

sixty kilometers per hour had AADT of 15,700. However the other two road categories had AADT counts of 3,000 (less than 40km/hr) and 5,400 (40 - 50km/hr). Roads in Seattle of similar speed limits and proximity to downtown had far higher traffic counts (ADT). The Downtown street type had a traffic count of 17,695 (ADT) and Downtown Neighborhood street type had 6,601 (ADT). In Copenhagen, there appears to be a correlation between higher speed limits and traffic. Seattle street type examples all had the same twenty-five miles per hour speed limit , but a range of traffic counts (ADT). Urban Village Neighborhood had the lowest traffic with 5,592 vehicles per day on average and downtown had the highest with 17,695 vehicles per day on average.

Bike Lanes/Cycle Tracks

Bike lanes have a significant impact on bicycle compatibility and the wider the lane the more compatible. Copenhagen is successful at building wide bike lanes or cycle tracks. Not only are the city's bike lanes or cycle tracks recommended to be a minimum of 2.3m or 7.5 feet in width, but the city plans to expand widths of cycle tracks throughout the city. Seattle suggests bike lanes in only five of its twelve street type standards, and bike lanes that are separated from cars only need to be 5 feet or 1.5m wide. That said they do suggest a buffer of three feet, unlike Copenhagen, which usually relies on an elevated curb to create separation from cars.

Although Seattle depicts bike lanes in many of its street types, the city does not require the addition of a bike lane in every street type, and street types with high traffic counts (Urban Center Connector) or other stressors like parking (Downtown Neighborhood) would greatly

benefit from bike lanes. Not including bike paths on busier roads leads to lower compatibility scores.

Parking

Most of the Copenhagen street categories in this study did not have a parking lane. The only example that did was the forty kilometer per hour speed limit road category, which did not appear to have high parking turnover rates. For Seattle, four out of the seven street types sampled had a parking lane represented in their diagram. The real-life example for Industrial Access also had a parking lane, even when the diagram did not. The parking factor was not included in the Industrial Access street type's BCI since occupancy did not appear to be 30 percent and the diagram did not show it, but it is clear that Seattle finds it challenging to relinquish parking space for cars. Not only are cars pulling in and out of a parking lane stressful for cyclists but parking is also taking valuable street space away from potential bicycle infrastructure. Having parking lanes could also be contributing to higher traffic counts, another variable that negatively impacts bicycling compatibility. If car owners know that there is parking available, they may be more tempted to drive instead of using other transportation modes.

Speed Limit

The Seattle street type examples all had a speed limit of 25 mph, but bicycle compatibility scores ranged from high compatibility to very low compatibility. Therefore, for Seattle, the speed limit does not appear to make a substantial impact on bicycle compatibility. For Copenhagen, the speed limit determined the type of cycle track required and the highest

speed limit example had the lowest bicycle compatibility, due to increased traffic counts. Therefore in Copenhagen higher speed limits are associated with lower bicycle compatibility.

Network Connectivity

Copenhagen is far superior to Seattle in overall street network BCI levels, with the majority of roads having moderately high bicycle compatibility. This application is not very precise, but it still offers a preliminary understanding of how each city may be performing within its larger street network. When comparing the two, it is important to note that Copenhagen is much smaller than Seattle in terms of physical area. The Copenhagen street network also encompasses what are likely non-arterial roads, while Seattle shows the scores of only arterials. Therefore the side-by-side comparison does not tell the whole story. That said, looking at a more compact area of Seattle like downtown, which is more comparable to the physical area of Copenhagen, most streets have low bicycle compatibility. Therefore, it still appears that Copenhagen is performing better in BCI network connectivity.

Complete Streets and BCI for Seattle vs. Copenhagen - why Copenhagen may perform better overall

Copenhagen scores well overall in bicycle compatibility. There are likely many reasons for this. One may be that traffic counts are lower. For example, the Downtown street type in Seattle had an ADT of 17895. While this study does not use a downtown street in Copenhagen to evaluate BCI, a downtown street in Copenhagen like Vestergade has an AADT traffic count of 2200 cars. Arterials with lower traffic volumes are more compatible with Harkey's bikeability

scale than those with higher traffic volume. Lower traffic in Copenhagen may be because less space is dedicated to car traffic. There appears to be less parking lanes, and it also helps that much of downtown is pedestrian-only, and therefore not easy to traverse by car.

Another difference that may be impacting BCI and influencing Copenhagen's higher compatibility ratings could be the width of the cycle track and lack of parking. Seattle street guidelines require only a 5 feet or 1.5m bike lane minimum, while Copenhagen primarily constructs bike lanes at least 2.4m or 7.5 feet in width. Creating a separated bike lane, Seattle often uses a barrier of 3 feet or 1m, however, the bike lane itself is still narrow. Seattle also had parking lanes in four of the seven real-life street type examples, while Copenhagen only had a parking lane in one of four. Those parking lanes in Seattle are likely promoting car trips, since finding parking is often available on Seattle streets, in turn creating higher traffic counts, resulting in roadways that are more stressful for cyclists to ride.

Finally, another weakness of Seattle's Complete Street Policy is that guidelines are very general and improvements like adding sidewalks, lights, etc. to streetscape often rely on developer involvement. There is very little reference to what bike lanes, or as Copenhagen would call them cycle tracks should look like and where they should be placed within the complete street policy documents. Looking at Seattle's Bicycle Master Plan, the city does outline projects that will add bike lanes to the network by 2024. Seattle may benefit from mentioning these plans in its complete street policy.

General Thoughts on BLOS and Complete Streets

The expectation that busy streets do not offer a high level of bicycle service is partly true in the Seattle example. Seattle's street types; Urban Center Connector, Downtown, Downtown Neighborhood, and Urban Village Neighborhood all had moderately low to very low compatibility. However, Copenhagen's examples in part refute this, showing that when there are bike lanes and a lack of vehicular parking, bicycling compatibility can increase. Every street category except for seventy kilometers per hour roadways had moderately high bicycle compatibility.

When evaluating Seattle and Copenhagen case studies of complete streets, BLOS scores appear to be important but not absolute in attracting cyclists. In the case of Copenhagen, the roadway example with a speed limit of seventy kilometers per hour was highly incompatible for cyclists, but cyclist counts in this area were still high. Therefore it appears that even when road segments have low BLOS, there still can be other factors that will positively impact cyclist presence.

Although Copenhagen has shown that Complete Streets can have moderately high bicycle compatibility, the city still faces different challenges with busy multimodal roads. After all, complete streets do cause issues - congestion, stress, navigating intersections. Copenhagen is looking into alternatives to cope with new issues including developing transportation models that would "segregate" transportation modes like bike highways.

Conclusion and Policy Implications

The answer to the research question is that both case studies show that complete streets have varying levels of bicycle compatibility, but Harkey's BLOS model is not necessarily the most important factor in determining whether or not a roadway will attract cyclists. In fact, in certain examples, Mekuria's rating system may offer a more accurate depiction of the relationship between BLOS and cyclist appeal. Recall that any road with a separated bike lane received the highest compatibility score of LTS 1. In the Copenhagen case where the road sample with seventy kilometers per hour speed limit had a low BCI rating but a high bicycle count, an LTS 1 value may have been a better evaluation.

Better understanding how BCI value is applied to these two cities' street networks enables some valuable policy suggestions. For Seattle, the following policy recommendations could help improve bicycle infrastructure and compatibility for its street network.

Reevaluate Street Type Design Standards

In general, to attract the greatest common denominator of cyclists, Seattle should look to design standards and policy guidelines of cities that have succeeded in achieving a high volume of cyclists like Copenhagen. Since other places are doing much better, Seattle may want to change design standards or change policy entirely.

Update Design Standards for Bike Lanes to Reflect Future and Current Bike Facilities

Although some of the complete street policy street types do not show a bike lane, according to the Existing Facility Shapefile data, there are plans to construct bike lanes. An

example of this is the Urban Center Connector, a street type that does not have bike lanes in its illustration, but many real-life examples have bike lanes. Therefore, if SDOT plans to build bike paths on these street types, the diagram should reflect this design standard.

Evaluate the Necessity of Parking

Street Types with separated biking lanes but with high traffic volumes and parking, like Downtown, can still receive low compatibility scores. Therefore, SDOT should consider getting rid of parking lanes in their street designs to improve compatibility. Also removing parking can have secondary impacts like making it less attractive to drive therefore reducing traffic counts, and freeing more space for bicycle lanes.

Streets with High Traffic Volume need Bike Paths and Reevaluate Designs for Street Types that are Important Connectors to Downtown

For Seattle, this is crucial, especially since many roads have high traffic counts. Also in the case of the Urban Center Connector street type, often an important connection to the downtown area is likely to have both bicycle and car commuting, and therefore increasing bike compatibility is critical.

Thus, Seattle policymakers should reevaluate street type design standards such as Downtown Neighborhood, Urban Village Neighborhood, and Urban Center Connector. These roads often offer significant connections to Downtown and common routes for cyclist commuters or even cyclists seeking to access basic needs. Complete street design standards for these street types need to be more compatible with cycling.

In Figure 36, the Seattle Street Network map with compatibility index levels shows some very incompatible north-south connectors. Since Seattle's topography means that north-south

connectors are likely to involve fewer hills, these cyclists routes should have higher bicycle compatibility.

There are a few north-south connectors that have higher bicycling compatibility; arterials along the coast and in industrial areas. Seattle may consider an approach that uses those arterials with higher compatibility to their advantage by better connecting them to make a more comprehensive, more compatible network. An idea would be to consider making arterial roads that may experience lower traffic volumes into bicycle superhighways, encouraging more commuters to cycle from surrounding areas to downtown. Some of these distances would reflect the same commute distances that Copenhagen intends to target, 12-20km.

Reconsider Step by Step Process Like Complete Streets and have a more comprehensive bike infrastructure plan

Seattle's policy approach is a step-by-step process, often waiting on times when roads need to be serviced or when a developer plans to build on the street, rather than adding bicycle infrastructure right away. This approach can be slow in delivering sufficient bicycle infrastructure that would help the city to accomplish its sustainability goals. Complete street policy is not the same as having great bicycle infrastructure, and complete streets do not equate to a great biking environment. Complete streets may help promote all transportation modes, however it does not prioritize a single method, such as cycling. A recommendation would be to not eliminate vehicles but instead work to prioritize bicycling in complete street policy. Seattle should consider adopting the Copenhagen approach, developing a widespread policy that offers a more specific and simpler model for adding bicycle infrastructure.

Further Research

Calculating traffic data for residential streets to evaluate BLOS could be the next step to assess whether residential streets are more compatible with bicycling. In future research, there is an opportunity to see if policymakers should prioritize placing bike networks on residential streets and where those opportunities are.

Another area of research would be to apply the BLOS evaluation to every street in the Seattle and Copenhagen network by determining each street's traffic data. This exercise would offer a more comprehensive BLOS evaluation of the Seattle Street network.

Lastly this study shows that the relationship between BLOS and attracting ridership for cyclists is still unclear. Looking at Copenhagen's bicycle policy and culture to understand other factors that may have greater influence on cycling rider counts would also be an interesting area for future research.

References

Berney, Rachel. 2018. *Advancing Bicycle Urbanism: Reimagining Bicycle Friendly Cities.* Seattle: Routledge.

Booth, Derek B., Troost, Kathy Goetz, and Schimel, Scott A., 2009, Geologic map of northeastern Seattle (part of the Seattle North 7.5' x 15' quadrangle), King County,Washington: U.S. Geological Survey Scientific Investigations Map 3065, scale 1:12000 and database.

Brand, Christian, Thomas Götschi, Evi Dons, Regine Gerike, Esther Anaya-Boig, Ione Avila-Palencia, Audrey de Nazelle, et al. 2021. "The Climate Change Mitigation Impacts of Active Travel: Evidence from a Longitudinal Panel Study in Seven European Cities." *Global Environmental Change* 67. Elsevier Ltd: 102224. doi:10.1016/j.gloenvcha.2021.102224.

Broach, Joseph, Jennifer Dill, and John Gliebe. 2012. "Where Do Cyclists Ride? A Route Choice Model Developed with Revealed Preference GPS Data." *Transportation Research Part A: Policy and Practice* 46 (10): 1730–40. https://doi.org/10.1016/j.tra.2012.07.005.

Brown, Barbara B, Ken R Smith, Doug Tharp, Carol M Werner, Calvin P Tribby, Harvey J Miller, and Wyatt Jensen. 2016. "A Complete Street Intervention for Walking to Transit, Nontransit Walking, and Bicycling: A Quasi-Experimental Demonstration of Increased Use." Journal of Physical Activity & Health 13 (11). CHAMPAIGN: HUMAN KINETICS PUBL INC: 1210–19. doi:10.1123/jpah.2016-0066.

Burden, Dan & Litman, Todd. (2011). America Needs Complete Streets. ITE Journal (Institute of Transportation Engineers). 81. 36-43.

Chisholm, Derek and Healy, Justin. 2018. "Middle modalism; The proliferation of e-bikes and implications for planning and urban design." In A*dvancing Bicycle Urbanism: Reimagining Bicycle Friendly Cities,* edited by Rachel Berney, 96-115. Seattle: Routledge.

City of Copenhagen. 2011. "City of Copenhagen's Bicycle Strategy 2011 - 2025."

Colville-Andersen, Mikael. 2018. Copenhagenize. Island Press.

Copenhagen Portal. 2021. "Strøget - The World's Longest Pedestrian Street - Copenhagen - Copenhagen Visitors<." n.d. Accessed December 1, 2021.https://www.copenhagenet.dk/cph-map/CPH-Pedestrian.asp.

Dill, Jennifer, and Nathan McNeil. "Four Types of Cyclists?: Examination of Typology for Better Understanding of Bicycling Behavior and Potential." Transportation Research Record

2387, no. 1 (January 2013): 129–38.
https://doi-org.offcampus.lib.washington.edu/10.3141/2387-15.

Etingoff, Kimberly. 2015. *Urban Development for the 21st Century: Managing Resources and Creating Infrastructure*. CRC Press. Dill, Jennifer, and Nathan McNeil. 2013. "Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential." *Transportation Research Record* 2387 (1): 129–38.
https://doi.org/10.3141/221.
https://www.portlandoregon.gov/transportation/article/158497.

Forsyth, Ann, and Kevin Krizek. 2011. "Urban Design: Is There a Distinctive View from the Bicycle?" Journal of Urban Design 16 (4). Taylor & Francis Group: 531–49.
doi:10.1080/13574809.2011.586239.

Gehl, Jan. 1989. "A Changing Street Life in a Changing Society." *Places.*

Gehl, Jan. 2013. "Copenhagen_pedestrians_Gehl." n.d. Gehl (blog). Accessed December 12, 2021.
https://gehlpeople.com/wp-content/uploads/2015/01/copenhagen_pedestrians_Gehl.gif.G eller, "Four Types of Transportation Cyclists | Bicycle Counts | The City of Portland, Oregon." n.d. Accessed March 8, 2064

Google Earth Pro 6.2.1.6014 (beta). (March 10, 2021). *Seattle, Washington USA*. 47°37'00.5"N 122°20'04.5"W, Eye alt 36 mi. Borders and labels; places layers.
<http://www.google.com/earth/index.html> (Accessed March 10, 2021).

Harkey, David L., Donald W. Reinfurt, and Matthew Knuiman. 1998. "Development of the Bicycle Compatibility Index." USDOT, FHWA-RD-98-072, Final Report.

Henderson, Jason, and Natalie Marie Gulsrud. 2019. Street Fights in Copenhagen. 1st ed. Milton: Routledge. doi:10.4324/9780429444135.

Københavns Kommune. 2020. "Trafikhastigheder - Datasæt." Accessed November 1, 2021.
https://www.opendata.dk/city-of-copenhagen/trafikhastigheder.

Københavns Kommune. 2020. "Trafiktællinger - Datasæt." Accessed November 1, 2021.
https://www.opendata.dk/norddjurs-kommune/trafiktaelling.

Lagerwey, Peter, Jennifer Toole, Robert Schneider, William Schultheiss, & Phil Miller. 2007. "Seattle Bicycle Master Plan." Department of Transportation, City of Seattle, WA.

Litman, Todd. 2011. "The Value of Designing Roads For Diverse Modes, Users and Activities," 29.

MacLeod, Kara E, Rebecca L Sanders, Ashleigh Griffin, Jill F Cooper, and David R Ragland. 2018. "Latent Analysis of Complete Streets and Traffic Safety Along an Urban Corridor."

Journal of Transport & Health 8. OXFORD: Elsevier Ltd: 15–29. doi:10.1016/j.jth.2017.05.001.

McCann, Barbara. 2013. *Completing Our Streets.* Washington, DC: Island Press.

McCann ·, Barbara. 2010. "Complete Streets Lessons from Copenhagen." Smart Growth America. July 1, 2010. https://smartgrowthamerica.org/complete-streets-lessons-from-copenhagen/.

Mekuria, Maaza, Peter G. Furth, Hilary Nixon. 2012. "Low-stress Bicycling and Network Connectivity." Mineta Transportation Institute.

Mooney, Stephen J., Caroline Magee, Kolena Dang, Julie C. Leonard, Jingzhen Yang, Frederick P. Rivara, Beth E. Ebel, Ali Rowhani-Rahbar, and D. Alex Quistberg. "'Complete Streets' and Adult Bicyclist Fatalities: Applying G-Computation to Evaluate an Intervention That Affects the Size of a Population at Risk." American Journal of Epidemiology 187, no. 9 (September 1, 2018): 2038–45. https://doi.org/10.1093/aje/kwy100.

Pucher, John, Jennifer Dill, and Susan Handy. "Infrastructure, Programs, and Policies to Increase Bicycling: An International Review." Preventive Medicine 50 (January 1, 2010): S106–25. https://doi.org/10.1016/j.ypmed.2009.07.028.

Pucher, John, and Ralph Buehler. 2008. "Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany." Transport Reviews 28 (4). ABINGDON: Routledge: 495–528. doi:10.1080/01441640701806612.

Pucher, John, and Lewis Dijkstra. 2003. "Promoting Safe Walking and Cycling to Improve Public Health: Lessons From The Netherlands and Germany." American Journal of Public Health (1971) 93 (9). WASHINGTON: Am Public Health Assoc: 1509–16. doi:10.2105/AJPH.93.9.1509.

Pritchard, Ray, Yngve Frøyen, and Bernhard Snizek. 2019. "Bicycle Level of Service for Route Choice—A GIS Evaluation of Four Existing Indicators with Empirical Data." *ISPRS International Journal of Geo-Information* 8 (5): 214. https://doi.org/10.3390/ijgi8050214.

Robertson, Kipp. 2017. "Bicycle-Friendly Seattle Not so Charming When It Comes to Bike Theft." MyNorthwest.Com. May 30, 2017. https://mynorthwest.com/643299/seattle-bike-theft-problem/.

Seattle City Council Bills and Ordinances. 2007. "Ordinance 122386." Accessed January 15, 2021. http://clerk.ci.seattle.wa.us/search/results?d=CBOR&s1=115861.cbn.&Sect6=HITOFF&l=20&p=1&u=/%7Epublic/cbor2.htm&r=1&f=G.

City of Seattle. 2019. “1.2 A Complete Streets Approach : Seattle Streets Illustrated.” Accessed January 15, 2021. https://streetsillustrated.seattle.gov/overview/complete-streets/.

Seattle Department of Transportation. 2017. “2 Street Type Standards :: Seattle Streets Illustrated.” Accessed December 16, 2021. https://streetsillustrated.seattle.gov/street-type-standards/.

Seattle Department of Transportation. 2021. “2021 - 2024 Implementation Plan - Bicycle Master Plan.” City of Seattle, WA.

Seattle Department of Transportation. 2016. “City of Seattle Freight Master Plan.” City of Seattle, WA.

Seattle Department of Transportation. N.d. “Complete Streets Review Story Map.” Accessed January 15, 2021. https://seattlecitygis.maps.arcgis.com/apps/MapSeries/index.html?appid=eaf1b68cb55b4d5d86022becf0a0f47f.

Seattle Department of Transportation. 2017. “In Street, Major Separation.” Accessed February 10, 2021. https://streetsillustrated.seattle.gov/design-standards/bicycle/in-street-major-separation/

Seattle Department of Transportation. 2020. “Seattle Bicycling Parking Guidelines.” City of Seattle, WA.

Seattle Department of Transportation. N.d. “Story Map Series.” Accessed December 11, 2021. https://seattlecitygis.maps.arcgis.com/apps/MapSeries/index.html?appid=eaf1b68cb55b4d5d86022becf0a0f47f.

Seattle Department of Transportation. 2014.“Seattle Bicycle Master Plan.” City of Seattle, WA.

Smart Growth America. 2021. “What Are Complete Streets?” Accessed January 18, 2021. https://smartgrowthamerica.org/program/national-complete-streets-coalition/publications/what-are-complete-streets/.

Tilahun, Nebiyou Y, David M Levinson, and Kevin J Krizek. 2007. “Trails, Lanes, or Traffic: Valuing Bicycle Facilities with an Adaptive Stated Preference Survey.” Transportation Research. Part A, Policy and Practice 41 (4). OXFORD: Elsevier Ltd: 287–301. doi:10.1016/j.tra.2006.09.007.

US Department of Transportation “Complete Streets.” 2015. Accessed January 18, 2021. https://www.transportation.gov/mission/health/complete-streets.

Washington Department of Ecology. 2018. “State Environmental Policy Act Handbook.”

Appendix A

The BCI Index model:

BCI = 3.67 – 0.966**BL** – 0.410**BLW** – 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** – 0.264**AREA** + **AF**

BL =	Presence of bicycle lane or paved shoulder >= 0.9 m No = 0 Yes = 1	**PKG** =	Presence of a parking lane with more than 30 percent occupancy No = 0 Yes = 1
BLW =	Bicycle lane (or paved shoulder) width meters (to the nearest tenth)		
CLW =	Curb lane width meters (to the nearest tenth	**AREA** =	Type of roadside development Residential = 1 Other type = 0
CLV =	Curb lane volume, vehicles per hour in one direction	**AF** =	ft + fp + fn
OLV =	Other lane(s) volume – same direction vehicles per hour	Where **ft** =	adjustment factor for truck volumes (see below)
SPD =	85th percentile speed of traffic km/h	**fp** =	adjustment factor for parking turnover (see below)
		fn =	adjustment for right turn volume (see below)

Adjustment Factors

Hourly Curb Lane Large Truck Volume	**ft**
>= 120	0.5
60 – 119	0.4
30 – 59	0.3
20 – 29	0.2
10 – 19	0.1
< 10	0.0

Parking Time Limit (min)	**fp**
<= 15	0.6
16 – 30	0.5
31 – 60	0.4
61 – 120	0.3
121 – 240	0.2
241 – 480	0.1
>480	0.0

Hourly Right Turn Volume	**fn**
>= 270	0.1
< 270	0.0

Level	BCI Range	Compatibility Level
A	0—1.50	Extremely High
B	1.51—2.30	Very High
C	2.31—3.40	Moderately High
D	3.41—4.40	Moderately Low
E	4.41—5.30	Very Low
F	> 5.30	Extremely Low

Appendix B

Below is a data dictionary for Seattle and Copenhagen data resources. This study used these shapefiles to find quantitative values for several of the bicycle compatibility index variables. They were also used to help create network connectivity maps of bicycle level of service for both Copenhagen and Seattle.

Data Layer	Existing Bike Facilities
Data source	SDOT Seattle GEODATA
Format	Shapefile
Scales	Seattle, by street network, up to date existing inventory
Attributes	*Existing_Facility_Type* – Existing Bike Facility Category Description
Data filtering	Not including *Planned_Facility_Type* since I am doing an evaluation on the existing infrastructure.
Data limitations	Technically, I should have data about how wide the bike plans are according to BCI. However this data is not available for all types of bike lanes. SDOT does provide definitions, offering numerical measurements (which may not be precisely accurate) of "in road, minor separation" and "in road, major separation." I used those definitions to determine the minimum standard of bike lane width, and this informed my first and second index value of BCI.

Data Layer	Seattle Streets
Data source	SDOT Seattle GEODATA
Format	Shapefile
Scales	Seattle, by street network, up to date existing inventory (weekly) and as needed
Attributes	**Seattle Streets** *Street Type* – Street Segment width in feet, *ONEWAY* – One Way Street (Y/N), *SPEEDLIMIT* – Street speed limit in MPH

Data Layer	Traffic Flow Counts, 2018
Data source	SDOT Seattle GEODATA
Format	Shapefile
Scales	Seattle, by street network, 2018
Attributes	*ADT*

Data filtering	*ADT* – Average Daily Traffic: derived by averaging 24-hour daily traffic volumes for both directions, then adjusting for seasonal variations by applying an annual adjustment factor. This number is given in thousands of vehicles.
Data limitations	Under normal circumstances, it would be best to have the most recent traffic volumes (2019) However, several factors include COVID-19, which may change data, and the fact that the 2018 shapefile is available. I chose to go with the 2018 numbers.

Data Layer	Blockface
Data source	SDOT Seattle GEODATA
Format	Shapefile
Scales	Seattle, by street network
Attributes	*Existing_Facility_Type* – Existing Bike Facility Category Description
Data filtering	*Parking_Category* and *Parking_Time_Limit* – limit of time for paid parking
Data limitations	Indicates if there is a parking lane, however not the occupancy. Seattle does have data to show occupancy for On-Street Paid Parking, but not unpaid parking. The BCI asks for occupancy of parking lanes at over 30%. Since Seattle is a big city, I will account that any parking lane presence will mean that it is over 30% occupied. The parking time limit is only available for paid parking. However, there are many areas of Seattle that are "Restricted Zones." Restricted zones mean only residents can park in areas during certain times of the day. Because these are extended periods, usually over 241 minutes (4 hours), I will not include these areas in my BCI, only the limited time in paid parking data.

Data Layer	Land Use Zoning, n/d
Data source	SDOT Seattle GEODATA
Format	Shapefile
Scales	Parcel
Attributes	*ZONING – the* type of zone (residential, commercial, industrial…)
Data filtering	Zoning is simplified into either residential or not residential. The number will be assigned as 1 if residential and 0 if any other type.

Data Layer	Trafiktaelling
Data source	Kobehavns-Kommune
Format	Shapefile
Scales	Points of Traffic Data Count
Attributes	*aadt_koret* – Average Annual Daily Traffic for Cars

Data Layer	Trafikhastigheder
Data source	Kobehavns-Kommune
Format	Shapefile
Scales	Copenhagen Street Network to date existing inventory
Attributes	*hastigheds* – Speed Limit
Data limitations	Some roads were not classified, but there were very few.