Title

Which Streets are Complete? Mapping Pedestrian, Transit, and Cycling Infrastructure at Scale in San Francisco, CA

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Publication Date

2023

Peer reviewed|Thesis/dissertation

Which Streets are Complete? Mapping Pedestrian, Transit, and Cycling Infrastructure at Scale in San Francisco, CA

By

Marcel E. Moran

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

City and Regional Planning

in the

Graduate Division

of the

University of California, Berkeley

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Associate Professor Daniel G. Chatman, Chair
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Spring, 2023

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Abstract

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Contemporary American streets are dominated by the automobile, both its movement and storage, which took root in the early 20th century and has been supported by transportation planners in the decades since. Pedestrian fatalities remain stubbornly high – even in cities with "Vision Zero" goals – and cars generate significant levels of both local air pollution and globally-relevant greenhouse gasses. Moreover, the default use of curbside lanes as on-street parking precludes a number of other street designs, such as wider sidewalks, protected bike lanes, transit bulbs and islands, parklets, rain gardens, and street trees. This dissertation probes these long-standing and consequential street layouts with methods that are both highly granular (accurate to the block level), and at the same time, comprehensive to an entire municipality. San Francisco, California, a dense, high-income, and nominally "progressive" American city serves as the case for three separate analyses: an in-person census of roughly 3,000 municipal bus stops, and review of satellite-imagery of nearly 6,400 intersections for the presence or absence of marked crosswalks, and the provision of on-street parking and its obstruction of a growing bike-lane network. Chapter 1 demonstrates that crosswalk provision varies dramatically across San Francisco, from Census tracts with 100% of intersections exhibiting marked crosswalks, to others with less than 10% coverage. Chapter 2 entails the largest bus-stop census of its kind, covering the entire SFMTA system. This approach finds that one third of all bus stops are blocked by on-street parking, and two thirds lack seating of any kind, as well as spatial clusters of stop amenities. Indeed, both high-quality bus stops and marked crosswalks are present to a far greater extent in the city's northern half, unexplained fully by transit service, density, or pedestrian volumes. Lastly, Chapter 3 identifies fifty miles of *angled* parking in San Francisco, a format that roughly doubles on-street parking capacity, and decreases the opportunity for high-quality bicycle lanes. These studies provide both salient datasets to guide San Francisco's street improvements (of which some progress at City Hall has already occurred), and serve as proof of concepts for planners and researchers elsewhere to probe their own blocks granularly and at scale. Indeed, this dissertation demonstrates new frontiers in applied urban analytics, and broadens and challenges the academic literature on transportation equity. It does so by expanding the types of street elements to be spatialized across neighborhoods, and demonstrates how the provision of seemingly-mundane features such as bus stops, crosswalks, and on-street parking can mirror (and exacerbate) other long-running investment disparities.

Table of Contents

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For my mother and father,
Naomi and John

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Acknowledgements

A number of individuals supported me during my doctorate, starting with my mother and father, Naomi Macioce and John Moran, who taught me to follow my passions. I would also like to thank my brother and sister, Lyle Moran and Lea Bishop, for their steadfast encouragement throughout the PhD, as well as joining me in much-needed adventures outside of academia. Thank you to John Macioce, for being kind (and brave) enough to take interest in and read my articles. At Berkeley, I was supported by three outstanding advisors, Prof. Daniel Chatman, Prof. Daniel Rodríguez, and Prof. Karen Trapenberg Frick. Each dedicated a significant amount of time and effort to help me reach this accomplishment, amidst much else on their plates. Prof. Iryna Dronova, in addition to serving on my dissertation committee, also served as my Outside Field Advisor, for which I am very grateful. Prof. Susan Shaheen first welcomed me to Berkeley, which came at a critical moment in my professional life. My classmates, across many years of the program, were essential sounding boards for my work and dear friends along the way. I thank Madeleine Parker, Alli Appelbaum, Tamara Kerzhner, Chester Harvey, Ruoying Xu, Beki McElvain, Irene Farah, Michael Montilla, Chris Mizes, Abigail Cochran, Savannah Cox, Arezoo Besharati, Manuel Santana Palacios, Alex Ramiller, Laura Schmahmann, Meiqing Li, and countless others. I consistently benefitted from the expert advice of Berkeley librarians David Eifler and Kendra Levine. My PhD was generously supported by the Graduate Division, the Perloff Family, the Institute of European Studies, the Scandinavian Department, the Austrian Marshall Plan Foundation, Uppsala University, TU Wien, the Institute of Transportation Studies, and the United States Department of Transportation. Prof. Günter Emberger and Barbara Laa, of Vienna, and Prof. Maja Lagerqvist, of Stockholm, broadened my research to European cities and were exemplary collaborators. Anna Boch helped me believe pursuing a PhD was possible, set an amazing example herself, and was ever present as a confidant and booster. My friends are simply indispensable, including: Chris Lash, Kurt Tsuo, Claire Bulger, Molly Fitzpatrick, Molly Strauss, Iya Megre, Matt Zehnder, Joel Aguero, Ravi Mulani, Nikki Fillingim, Kat Calle, Jess Frisina, Michelle Sirois, Emmett Kistler, Jenn Wang, Cate Nelson, Joseph Poirier, Sam Lau, David Goldfarb, Hannah Blumenfeld, Steven Blumenfeld, James Winter, Christine Pu, Sarah Barnes, and Ashleigh Halverstadt. Lastly, I thank Alice Brewer for her love and support, both in France and California.

List of Figures

List of Tables

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Publications

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Moran, M.E. 2022. "Treating COVID with Bike Lanes: Design, Spatial, and Network Analysis of 'Pop-Up' Bike Lanes in Paris." *Transport Findings,* April. https://doi.org/10.32866/001c.33765

Moran, M.E. 2022. "Where the Crosswalk Ends: Mapping Crosswalk Coverage via Satellite Imagery in San Francisco." *Environment and Planning B: Urban Analytics and City Science.* https://doi.org/10.1177/23998083221081530

Moran, M.E. 2021. "Are Shelters in Place? Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco." *Journal of Public Transportation,* 24(1).

https://doi.org/10.1016/j.jpubtr.2022.100023

Moran, M.E. 2021. "Drawing the Map: The Creation and Regulation of Geographic Constraints on Shared Bikes and e-Scooters in San Francisco, CA" *Journal of Transport and Land Use*, *14*(1), 197-218. https://doi.org/10.5198/jtlu.2021.1816

Moran, M.E. 2020. "What's Your Angle? Analyzing Angled Parking using Satellite Imagery to Aid Bike-Network Expansion" *Environment and Planning B: Urban Analytics and City Science*, September. https://doi.org/10.1177/2399808320954205

Moran, M.E. 2020. "Eyes on the Bike Lane: Crowdsourced Traffic Violations and Bicycle Infrastructure in San Francisco, CA." *Transport Findings,* April. https://doi.org/10.32866/001c.12651

Moran, M.E., B. Laa, and G. Emberger. 2020. "Six Scooter Operators, Six Maps: Spatial Coverage and Regulation of Micromobility in Vienna, Austria." *Case Studies on Transport Policy*, March. https://doi.org/10.1016/j.cstp.2020.03.001

Chatman, D.G., and M.E. Moran. 2019. "Autonomous Vehicles in the United States: Understanding Why and How Cities and Regions Are Responding." University of California Institute of Transportation Studies. https://escholarship.org/uc/item/29n5w2jk.

Book Reviews

Moran, M.E. 2021. "Right of Way: Race, Class, and the Silent Epidemic of Pedestrian Deaths in America." *Journal of the American Planning Association.* April. https://doi.org/10.1080/01944363.2021.1885273

Moran, M.E. 2020. "Assembling Moral Mobilities: Cycling, Cities, and the Common Good." *Transport Reviews.* June. https://doi.org/10.1080/01441647.2020.1786479

Moran, M.E. 2020. "Cyclescapes of the Unequal City: Bicycle Infrastructure and Uneven Development." *Transport Reviews,* April. https://doi.org/10.1080/01441647.2020.1750502

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Popular Press and Media Appearances

Gordon, A. "Extremely Thorough Academic Study Confirms NYPD Park on Sidewalks." *VICE News* (2023). https://www.vice.com/en/article/3aknmj/extremely-thorough-academic-study-confirms-nypd-park-on-sidewalks

Carlson, S. "Study tracks NYPD's illegal parking habits." *All Things Considered, WNYC* (2023). https://www.wnyc.org/story/majority-nypd-vehicles-park-sidewalk-according-study/

John Milton, I. "Tracking the New York City Police Who Park on the Sidewalk." *Bloomberg/CityLab* (2023). https://www.bloomberg.com/news/articles/2023-04-12/mapping-the-nypd-s-sidewalk-parking-habit

Kalmowitz, A. "The NYPD Loves Parking on Sidewalks at the Expense of Everyone Else." *Jalopnik* (2023). *https://jalopnik.com/nypd-parks-on-sidewalks-at-nyc-citizen-expense-1850333066*

Moran, M.E. “Op-Ed: Paris Scooter Ban Is a Step Backward For Sustainable Transport.” *Streetsblog USA* (2023). https://usa.streetsblog.org/2023/04/03/op-ed-paris-scooter-ban-is-a-step-backward-for-sustainable-transport/

Cano, R. “S.F. Will Remove Parking Spaces Obstructing Muni Bus Stops Sooner than Expected. Here’s When it Will Start.” *San Francisco Chronicle* (2022). https://www.sfchronicle.com/sf/article/S-F-will-remove-parking-spaces-obstructing-Muni-17667831.php

Somera, M. “How Can We Make Biking in the Bay Area Less Intimidating?” *Bay Current* (2022). https://podcasts.apple.com/us/podcast/how-can-we-make-biking-in-the-bay-area-less-intimidating/id1588426532?i=1000559043923

Reid, C. “Every City’s Cycleway Network Should Be as Dense as Road Network, Says American Academic” *Forbes* (2022). https://www.forbes.com/sites/carltonreid/2022/03/31/every-citys-cycleway-network-should-be-as-dense-as-road-network-says-american-academic/?sh=222a0a1928e6

Knight, H. “He Mapped Every Crosswalk in SF. The Results Show a Startling Safety Gap for Some Neighborhoods,” *San Francisco Chronicle* (2022). https://www.sfchronicle.com/sf/bayarea/heatherknight/article/He-mapped-every-intersection-in-S-F-The-results-16842735.php

Rudick, R. “San Francisco Vows to End Parking at Transit Stops” *SF Streetsblog* (2021). https://sf.streetsblog.org/2021/12/02/san-francisco-vows-to-end-parking-at-transit-stops/

Cano, R. “S.F. bikeshare service raised its rates. Users say it's now the same price as an Uber” *San Francisco Chronicle* (2021) *https://www.sfchronicle.com/sf/article/S-F-bikeshare-service-raised-its-rates-Users-16512035.php*

Mayers, R. “Are Shelters in Place?” *Dense City Podcast* (2021) https://open.spotify.com/episode/41Lpy2O8EbFWboGooFjMNL?si=2X6cQrsbQgqmYqT6qgTDJg&dl_branch=1

Bliss, L. “Mapping the Best and Worst Bus Stops in San Francisco” *CityLab* (2021) https://www.bloomberg.com/news/articles/2021-08-03/how-better-bus-stops-can-boost-transit-ridership?srnd=citylab

Campodonico, C. “A Tale of Two Cities: Bus Stop Disparities are Stark Between City’s Northern and Southern Halves.” *Here/Say Media* (2021) https://heresaymedia.org/sfmta-bus-stop-disparities/

Moran, M.E. “Letter to the Editor.” *The New Yorker* (2021) https://www.newyorker.com/magazine/2021/05/24/letters-from-the-may-24-2021-issue

Moran, M.E. “Don’t Sacrifice Car-Free JFK for Museum Parking” *San Francisco Examiner* (2021) https://www.sfexaminer.com/opinion/dont-sacrifice-car-free-jfk-for-museum-parking/

Graf, C. “Is It Time to End Free Parking in San Francisco?” *San Francisco Examiner*

(2021) https://www.sfexaminer.com/news/is-it-time-to-end-free-parking-in-san-francisco/

Rudick, R. "Angled Parking Perpetuates Hazards," *Streetsblog San Francisco* (2020) https://sf.streetsblog.org/2020/09/03/angled-parking-perpetuates-hazards/

Moran, M.E. "Cycling in the Time of COVID-19," *Streetsblog San Francisco* (2020) https://sf.streetsblog.org/2020/03/27/paradox-of-cycling-in-the-time-of-covid-19/

Moran, M.E. "California's Rebate Blind Spot: Electric Bikes," *Streetsblog California* (2020) https://cal.streetsblog.org/2020/02/10/californias-rebate-blind-spot-electric-bikes/

Gill, G. "The Autonomous Vehicles Podcast" (June, 2019) https://podcasts.apple.com/us/podcast/uc-berkeley-marcel-moran/id1449787733?i=1000441783041

Moran, M.E. "Cities Can and Should Regulate Scooters, and AB 1112 Doesn't Help," *Streetsblog California* (2019). https://cal.streetsblog.org/2019/06/07/op-ed-cities-can-and-should-regulate-scooters-and-a-b-1112-doesnt-help/

Moran, M.E. "UC Berkeley Must Work to Introduce Scooters on Campus," *The Daily Californian* (2019). https://bit.ly/3jLfAzv

Professional Experience

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Graduate Student Researcher

Studied municipal-level policy regarding autonomous vehicles in the United States. Project was supported by California SB1 Funds (obtained via a competitive application) and included interviewing planners and city officials around the U.S. who have developed AV policies, as well as review of regulatory and legislative text.

2017-18 UC Berkeley, Transportation Sustainability Research Center
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Introduction: Studying Urban Streets at Scale

Streets are the most ubiquitous form of public space in American cities, stretching into every neighborhood, from dense cores to sprawling edges. How and where this land is governed, divided, maintained, policed, built upon, and priced represents perennial topics for city planners and transportation researchers. Urban streets have been analyzed in a number of ways, including historical analysis and cultural interpretation, quantitative measurements with increasing complexity and resolution, and qualitative observation, such as via 'public life studies.' This introductory chapter addresses the value provided by each of these research approaches, as well as how the contributions of this dissertation relate to them.

The automobile fomented seismic changes to American city streets, which are best understood on the decadal scale. Norton, in *Fighting Traffic* (2011), details the critical period between 1900 and 1940, during which cities in the United States transitioned from both neutrality and at times hostility toward the automobile, to a clear embrace of the automobile and a simultaneous diminution of the rights of pedestrians, cyclists, and transit riders. This occurred via the adoption of a number of formal and informal rules that benefitted the 'horseless carriage,' including mandating that pedestrians only cross streets at certain locations and certain times (from which the term 'jaywalking' emerged; Norton 2007), the decreased access to roads by cyclists (Friss 2015), and the loss of exclusive rights of way for streetcars and trolleys (Mallach 1979). Streets as places to linger, to play, to move about in a variety of ways and speeds transitioned to regimented zones emphasizing the fast throughput of automobiles and their (largely free) storage. A fundamental metric of traffic engineering – level of service (LOS) – arose to maximize vehicle speeds and minimize idling at the expense of other street users (Sisson 2020).

This trend did not simply concern the allotment of existing street space within cities, but also the financing of transport modes and their associated infrastructure. In the 19th century, cities largely treated transit as private enterprises, managed via permitted monopolies which did not receive public subsidization (Karlaftis, Wasson, and Steadham 1997). Most American streetcar companies needed public approval if routes were to change or fares raised, with many frozen at a nickel per ride (Ward 1964; Slater 1997). In practice, this meant that in light of inflation, many transit companies lost money and reduced service quality. Though a significant portion of the right of way was dedicated to transit, that foundation proved brittle during the Great Depression and in the postwar period.

The foundering of private transit in the 1930s, 40s, and 50s (Young 2015) occurred against the backdrop of states and the federal government taking an increasing role in the funding and design of car-centric streets and roads. Whereas the pre-automobile era of American road building was often managed by private companies which were given the right to charge tolls (Klein and Majewski 2011), the first half of the 20th century brought forth a range of legislation that shifted the financial burden for road financing toward governments, and also locked in suburban and rural biases to such programs (Jackson 1985). This included the 1916 Federal-Aid Road Act and the Federal-Aid Highway Act of 1944, and culminated in the Eisenhower Interstate Highway System, which featured a 9:1 Federal-State matching formula (Gutfreund 2004). Such programs not only starved cities of funding for the upkeep of their streets, given they largely omitted funding within urban areas, but also subsidized car-centric lifestyles and suburbs, which increased the share of driving commutes (Jackson 1985). Highway construction of the 1940s and the decades since also included the routing of elevated roads directly *through* cities, and not just as connections between them. From Miami's Overtown neighborhood (Avila 2014), to the Bronx (Bromley 1998), and West Oakland (Mohl 1997), minority and low-income neighborhoods bore the brunt of this road building, which primarily served the needs of white commuters and accelerated the phenomenon known as white flight (Archer 2020). Negative reactions to such infrastructure projects on racial, economic, and environmental grounds occurred both immediately – in terms of strident 'freeway revolts' (Crockett 2018) – and more recently, with the addition of catastrophic climate change serving as motivation to tear roads down (Vock 2022).

While American cities were being bisected by highways, municipal governments were also altering the rules and layouts of their own streets. The explosion in automobile ownership and usage generated two primary changes: the use of the curb for car parking (Segrave 2014), and the restriction of the remainder of street users, subordinating their needs to car travel (Loukaitou-Sideris and Ehrenfeucht 2009). To watch the famed 'Trip Down Market Street' video, captured in San Francisco mere days before the 1906 earthquake, demonstrates the transition happening in real time (Miles 1906). In the footage, adults cross the street wherever and whenever they choose, stepping before or after a streetcar passes. A boy zips on a bicycle in between horse-drawn carriages, making sure not to get his front tire caught in the tracks. Then, careening into the grainy frame comes an automobile, and then another, clearly traveling faster than anything else, and instantly creating a new kind of danger for the other street users. If the same video were shot a decade later, or two, the resulting film would depict a dramatic reordering of who may use such an urban artery, and how, with cars representing a larger and larger share of road users, pedestrians constrained to the sidewalks and timed crossings, transit sitting behind cars and without prioritization, and cyclists with no dedicated infrastructure at all.

The strength of the historical scholarship that charts this evolution is that it combines a number of different kinds of information – fiscal, cultural, legislative, geographic – to synthesize the broader shifts in street design and transportation behavior. Broadly, the automobile evolved in its cultural interpretation from a novel intruder of American city streets, to the focal point of road layouts, traffic regulations, and adjacent land uses (Thomson 1978). Slowly but steadily, traveling without a car in cities became more dangerous, less encouraged, and more associated with poverty (Bloom 2023; Hazelton-Boyle and Wellman 2022). This meant both modifications to streets in older American cities whose grids long predated the car, as well as newer cities arranging their road networks in broad, disconnected patterns inhospitable to transit, walking, and cycling (Moehring 2016). For example, Phoenix, AZ and Las Vegas, NV emphasized high speeds, limited-access roads, and sparingly-few amenities for other travelers (Nicolaides 2003). Critically, the urban street's previous function as a meeting place, a public living room, the stage for urban 'ballet' (Jacobs 1961) was largely replaced with automobile movement and parking as a default.

The three studies that comprise this dissertation engage with this historical scholarship in several ways. First, their starting place is the dominance of the automobile within San Francisco's right of way, which is the culmination of the planning and land-use decisions of the 20th century. Angled parking, which sits perpendicular to the flow of traffic, exemplifies the push to maximize streets' parking capacity, which inherently reduces the opportunity to support other travel modes. So too does a bus-transit system which allows for on-street parking to obstruct a third of all stops, and lacks seating at two-thirds of stops. Providing basic pedestrian infrastructure – marked crosswalks – at little more than half of all intersections further conveys the car's prioritization. Though San Francisco has made a number of decisions in recent years to counteract this paradigm, such as banning private vehicles from Market Street (Fitzgerald Rodriguez 2020), expanding bicycle infrastructure (Pyzyk 2019), and introducing bus rapid transit (Ionescu 2022) – this dissertation portrays the automobile's continuing supremacy, at the expense of cyclists, transit riders, and pedestrians.

The city as a laboratory, or a space to be studied quantitatively and spatially, dates back at least to John Snow's intellectual breakthrough in co-locating cases of cholera in London with a specific water pump (Cameron and Jones 1983). This is often considered the origin of geographic information science, which has in the centuries since evolved into a massive discipline, stretching across multiple academic disciplines. Prior to significant advances in available technology (described below), mapping urban life included W.E.B. Du Bois's hyper-granular depictions of Philadelphia's social classes (Du Bois and Eaton 1899), as well as the famed Chicago School of the early to mid-twentieth century, which considered how neighborhoods varied as a function of their distance to the city's center (Owens 2012). The analytical core of this work is to consider both *where* urban phenomena occur, as well as *how* location influences behavior, and reflects disparate societal investment or regulation.

Geographic information systems (GIS), as the combination of digital-cartography visualization and analysis are collectively termed, has shifted over the past half century from an analog, expensive, and proprietary discipline, to one which is nearly entirely digital (Goodchild 2000), web-based (Agrawal and Gupta 2017), and increasingly, open-source (Steiniger and Bocher 2009). This transition has meant that the financial barriers to GIS have fallen dramatically, such that free tools exist for even the most sophisticated types of operations.

In the context of cities, these developments have coincided with an explosion of urban research, from economics, sociology, urban planning, anthropology, geography, and environmental science. The trends of digitization and open-sourcing have not only broadened the kinds of analyses conducted, but also diversified who can create maps. 'Critical cartographies,' which consider how mapping has been used to oppress peoples (Perkins 2017), and 'countermapping,' in which community groups generate maps to shed light on government behavior or oppose pending planning decisions (Taylor and Hall 2013), are in part possible only because of GIS's democratization. These burgeoning categories exemplify such technology no longer being solely in the hands of governments, private companies, or universities, but available to nearly anyone or any group with internet access. In this vein, OpenStreetMap, a worldwide crowd-sourced mapping platform, was founded in 2004 because at the time the United Kingdom did not make its official mapping database available to the public for download (Bennett 2010).

The related subfield of 'remote sensing,' which relies on instruments that sense the earth's surface without making contact with it (primarily via satellites), has also transitioned from a slow, expensive, and narrow enterprise into a fast-growing set of data types and analysis tools that are being integrated into a range of academic programs (Campbell and Wynne 2011). Starting with the United States' establishment of the LandSat program in the 1970s (Loveland and Dwyer 2012), governments and private companies have launched satellites into orbit that house instruments which capture images of the earth across the electromagnetic spectrum, including both visible and non-visible ranges. While earlier satellites' resolution largely constrained possible analyses to studying changes at the landscape scale (such as forests and agriculture; Hansen and Loveland 2012), advances in sensor technology now mean that urban features can be visually identified, such as individual trees, street markings, and automobiles (Butler et al. 2014; Wagner et al. 2018).

This dissertation directly engages with the quantitative and spatial study of cities. The findings of each chapter are spatial in nature: identifying the geographic distribution of marked crosswalks, low-quality bus stops, and angled parking. The latter makes use of one of the most basic forms of spatial analysis: the intersection of two phenomena of interest. By detecting where angled parking intersects with (and interrupts) San Francisco's growing bike-lane network, it spotlights the tension between planners' conflicting priorities (vehicle storage versus safe bicycle movement) and connects to Henderson's concept of 'mobility stalemates' (2013). Both the crosswalk and bus-stop chapters use more advanced calculations, including 'hot spot' analyses, which determine how points with a shared attribute value cluster (Getis-Ord Gi*; Getis and Ord 1992). The parking and crosswalk studies both rely heavily on satellite imagery, taking advantage of Google Earth, which combines a number of different satellite inputs to create a high-resolution visualization and analysis platform at no cost to the user (Gorelick et al. 2017).

Public life studies encompass a diverse collection of urban research that centers the experience of the user in the built environment (Gehl and Svarre 2013). This includes the resident (Marcus and Sarkissian 1986), the pedestrian (Jacobs 1995), and other daily, ephemeral roles citizens play within cities (Whyte 2001). Part of this intellectual project is to emphasize that the user has often been omitted from planning and design processes, leaving much public space hostile, dangerous, and car centric. A quintessential study supporting this argument comes from Appleyard and Lintell, who demonstrated that across San Francisco, streets with high speeds had the least vibrant social interaction among neighbors, relative to slower-speed streets where residents could actually engage in social life on their block (1972).

Jane Jacobs' *Death and Life of Great American Cities* (1961) is a foundational text of this subfield, given much of her arguments flow from street-level observations. For example, she captured the fundamental value that foot traffic has a street's shared sense of safety, as well as how the details of building facades invite or discourage walking. Jan Gehl, another significant contributor to this research, identified a range of subtle characteristics that powerfully shape the welcoming nature of urban settings, such as the placement of benches in a park, or the arrangement of apartments within a development (Gehl 2011). These works sharply contrast with mid 20th Century planning, which was less concerned with the minute details of urban streets (Southworth and Ben-Joseph 2013).

The studies that comprise this dissertation also sit within this scholarship. First, the catalyst for each is an in-person observation and question: which intersections have crosswalks and which do not? How does the quality of bus stops vary from route to route, and neighborhood to neighborhood? Where is parking angled, and how might it interrupt or preclude bike lanes? These inquiries are rooted in the perspective of the pedestrian, the transit rider, and the cyclist. They take seriously the mundane details of urban travel, and seek to determine where supportive street layouts and amenities exist citywide. Only after flowing from these observations do these chapters then engage with GIS, large-scale spatial datasets, and satellite imagery. The quantitative and systematic findings of this two-step approach then engage with historical urban studies, and provide empirical evidence for the car-centricity of San Francisco in the 2020s.

In complementary ways, each branch of urban research described here addresses the issue of transportation equity. The most straightforward definition of the concept is a just distribution of both costs and benefits of the transportation system, as well as a just process by which that distribution is reached (Litman 2002). This concept has featured into social movements wherein organizations have demonstrated against and levied legal action at transit agencies for racialized disinvestments (Grengs 2002); in the spatial analysis of freeway pollution and pedestrian fatalities (Manville and Goldman 2017; Schneider et al. 2021; Susaneck 2023); and in the lived experience of women navigating subway systems and people of color facing harassment from law enforcement while biking (Barajas 2021; Loukaitou-Sideris 2014).

This dissertation advances the topic of transportation equity. It demonstrates new approaches, using field-collection and analysis of satellite imagery, to mapping street features in a manner that is granular, city-scaled, and replicable. These three original datasets are evaluated in terms of the transportation equity of San Francisco regarding pedestrians, transit riders, and cyclists, both separately and as a composite. These chapters thus generate new transportation-equity tests for cities, evaluating the spatial provision, clustering, and gaps of fundamental types of transportation infrastructure.

As the title suggests, the following chapters probe the 'completeness' of San Francisco's streets. This phrasing draws from the 'Complete Streets' paradigm (McCann and Rynne 2010), a movement in the transportation-planning profession and academy that explicitly critiques America's car-centric default (Jordan and Ivey 2021). If an 'incomplete' street is one that primarily serves car throughput and storage, a 'complete' street is one that in contrast also (or exclusively) serves pedestrians, cyclists, transit riders, as well as non-travelers (e.g. seating for café patrons, benches for people to gather, spaces for street vendors to sell goods, and for children to play). This terminology dates to 2003 (Zehngebot and Peiser 2014), and in the years since has increased in popularity and been furthered by the Complete Streets Coalition, the American Planning Association, and the National Association of City Transportation Officials. These organizations have disseminated guides, highlighted best practices, and convened planners, urban designers, and transportation engineers. Though not without critics (Zavestoski and Agyeman 2014), Complete Streets as a set of design and policy principles has found traction both within transportation-advocacy organizations (Rosenblum 2015), and official planning guidelines from municipalities, regional agencies, state DOTs, and the U.S. federal government (Gregg and Hess 2019).

Of course, this terminology is far more than simply descriptive, and in fact deeply laden with subjective and normative values. Calling streets with on-street parking and car traffic lanes 'incomplete' is rooted in critique, and puts at the forefront automobiles' negative externalities. This includes roadway fatalities (numbering roughly 40,000 annually in the United States), chronic air pollution and its manifold health consequences (Kweon et al. 2018; Currie and Walker 2011), and increasingly, the mindfulness of the transportation sector's contribution to the scourge of climate change (Ritchie 2020). Though these sentiments have always been present in transportation-planning dialogues (such as during the 1970s oil crisis and launch of the environmental movement; Bonham 2011), they have taken on increased importance in the 21st century. With this context, the studies that comprise this dissertation are embedded in the discussion about what belongs in public space, and the spatial distribution of these elements. They take the normative position that American urban streets should support non-car travel to a greater degree, and they seek to document the status quo granularly and at scale to substantiate debates regarding streets and their 'completeness.'

A linguistic and conceptual challenge of the Complete Streets paradigm (and research guided by it) is its binary nature: complete vs. incomplete. Of course, streets do not fit neatly into one of two boxes, but instead lie on a spectrum of their support for automobile use and parking, versus for pedestrians, cyclists, transit riders, and stationary uses. This dissertation addresses a street's 'completeness' in three discrete ways (parking layout, crosswalk provision, and bus stop quality), which is inherently reductive. Though, the presence of each street element represents a decision about what kind of travel should be most encouraged, at a spatial scale that moves beyond individual blocks, corridors, and even neighborhoods. In so doing, it operationalizes the idea of a complete street, by tracking specific infrastructure types.

The goal of the final discussion chapter is to determine the larger value of joining together these methodologies and historical context in the scrutiny of urban transport, as well as what specifically has been learned regarding San Francisco's street network. It also reflects on the studies that comprise this dissertation being covered by the media and integrated into San Francisco politics, as well as what these findings point to in terms of future research. At the close of this introduction, it is clear that each form of urban analysis – historical, GIS, public life – is varied, robust, and combined, can generate insights that include the details of a single block at the scale of an entire municipality. The chapters ahead take up this potential in earnest, by closely surveying the infrastructure, or lack thereof, that makes up the daily experience of non-car travelers.

<u>References</u>

Agrawal, S., and R. D. Gupta. 2017. "Web GIS and Its Architecture: A Review." *Arabian Journal of Geosciences* 10 (23): 518. https://doi.org/10.1007/s12517-017-3296-2.

Appleyard, D., and M. Lintell. 1972. "The Environmental Quality of City Streets: The Residents' Viewpoint." *Journal of the American Institute of Planners* 38 (2): 84–101. https://doi.org/10.1080/01944367208977410.

Archer, D.N. 2020. "'White Men's Roads Through Black Men's Homes'*: Advancing Racial Equity Through Highway Reconstruction." *Vanderbilt Law Review* 73 (5): 1259–1330.

Avila, E. 2014. *The Folklore of the Freeway: Race and Revolt in the Modernist City*. U of Minnesota Press.

Barajas, J.M. 2021. "Biking Where Black: Connecting Transportation Planning and Infrastructure to Disproportionate Policing." *Transportation Research Part D: Transport and Environment* 99 (October): 103027. https://doi.org/10.1016/j.trd.2021.103027.

Bennett, J. 2010. *OpenStreetMap*. Birmingham: Packt Publishing.

Bloom, N.D. 2023. *The Great American Transit Disaster: A Century of Austerity, Auto-Centric Planning, and White Flight*. University of Chicago Press.

Bonham, J. 2011. "Ideas in Motion: On the Bike." *Transfers* 1 (1): 137–46. https://doi.org/10.3167/trans.2011.010110.

Bromley, R. 1998. "Not so Simple! Caro, Moses, and the Impact of the Cross-Bronx Expressway." *Bronx County Historical Society Journal* 35 (1): 19.

Butler, P., N. Ramakrishnan, E.O. Nsoesie, and J.S. Brownstein. 2014. "Satellite Imagery Analysis: What Can Hospital Parking Lots Tell Us about a Disease Outbreak?" *Computer* 47 (4): 94–97. https://doi.org/10.1109/MC.2014.100.

Cameron, D., and I.G. Jones. 1983. "John Snow, the Broad Street Pump and Modern Epidemiology." *International Journal of Epidemiology* 12 (4): 393–96. https://doi.org/10.1093/ije/12.4.393.

Campbell, J.B., and R.H. Wynne. 2011. *Introduction to Remote Sensing, Fifth Edition*. Guilford Press.

Crockett, K. 2018. *People Before Highways: Boston Activists, Urban Planners, and a New Movement for City Making*. University of Massachusetts Press.

Currie, J., and R. Walker. 2011. "Traffic Congestion and Infant Health: Evidence from E-ZPass." *American Economic Journal: Applied Economics* 3 (1): 65–90. https://doi.org/10.1257/app.3.1.65.

Du Bois, W.E.B., and Isabel Eaton. 1899. *The Philadelphia Negro: A Social Study*. University of Pennsylvania Press.

Fitzgerald Rodriguez, J. 2020. "End of an Era: Market Street to Go Car Free Jan. 29." *San Francisco Examiner*, January 2, 2020, sec. The City. https://www.sfexaminer.com/news/end-of-an-era-market-street-to-go-car-free-jan-29/.

Friss, E. 2015. *The Cycling City: Bicycles and Urban America in the 1890s*. 1 edition. Chicago: University of Chicago Press.

Gehl, J. 2011. *Life Between Buildings: Using Public Space*. Island Press.

Gehl, J., and B. Svarre. 2013. *How to Study Public Life*. Island Press.

Getis, A., and J.K. Ord. 1992. "The Analysis of Spatial Association by Use of Distance Statistics." *Geographical Analysis* 24 (3): 189–206.

Goodchild, M.F. 2000. “Part 1 Spatial Analysts and GIS Practitioners.” *Journal of Geographical Systems* 2 (1): 5–10. https://doi.org/10.1007/s101090050022.
Gorelick, N., M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, and R. Moore. 2017. “Google Earth Engine: Planetary-Scale Geospatial Analysis for Everyone.” *Remote Sensing of Environment*, Big Remotely Sensed Data: tools, applications and experiences, 202 (December): 18–27. https://doi.org/10.1016/j.rse.2017.06.031.
Gregg, K., and P. Hess. 2019. “Complete Streets at the Municipal Level: A Review of American Municipal Complete Street Policy.” *International Journal of Sustainable Transportation* 13 (6): 407–18. https://doi.org/10.1080/15568318.2018.1476995.
Grengs, J. 2002. “Community-Based Planning as a Source of Political Change: The Transit Equity Movement of Los Angeles’ Bus Riders Union.” *Journal of the American Planning Association* 68 (2): 165–78. https://doi.org/10.1080/01944360208976263.
Gutfreund, O.D. 2004. *Twentieth-Century Sprawl: Highways and the Reshaping of the American Landscape*. Oxford University Press, USA.
Hansen, M.C., and T.R. Loveland. 2012. “A Review of Large Area Monitoring of Land Cover Change Using Landsat Data.” *Remote Sensing of Environment*, Landsat Legacy Special Issue, 122 (July): 66–74. https://doi.org/10.1016/j.rse.2011.08.024.
Hazelton-Boyle, J.K., and G.C. Wellman. 2022. “Transit Stigma: Transit Administrators’ Views of the Role of Policy Elites in Perpetuating Stigma.” *Public Works Management & Policy* 27 (3): 252–64. https://doi.org/10.1177/1087724X221088859.
Henderson, J. 2013. *Street Fight: The Struggle over Urban Mobility in San Francisco*. Amherst: University of Massachusetts Press.
Ionescu, D. 2022. “San Francisco Bus Rapid Transit Performing Well, One Month In.” *Planetizen*, May 5, 2022. https://www.planetizen.com/news/2022/05/117086-san-francisco-bus-rapid-transit-performing-well-one-month.
Jackson, K.T. 1985. *Crabgrass Frontier: The Suburbanization of the United States*. New York: Oxford University Press.
Jacobs, A.B. 1995. *Great Streets*. MIT Press.
Jacobs, J. 2002. *The Death and Life of Great American Cities*. Random House, Inc., 2002 ed. New York: Random House.
Jordan, S.W., and S. Ivey. 2021. “Complete Streets: Promises and Proof.” *Journal of Urban Planning and Development* 147 (2): 04021011. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000684.
Karlaftis, M. G., J. S. Wasson, and E. S. Steadham. 1997. “Impacts of Privatization on the Performance of Urban Trasnit Systems.” *Transportation Quarterly* 51 (3): 67–79.
Klein, D., and D. Majewski. 2011. “America’s Toll Road Heritage: The Achievements of Private Initiative in the 19th Century.” In *Street Smart: Competition, Entrepreneurship, and the Future of Roads*, 277–304. Transaction Publishers.
Kweon, B.S., P. Mohai, S. Lee, and A.M. Sametshaw. 2018. “Proximity of Public Schools to Major Highways and Industrial Facilities, and Students’ School Performance and Health Hazards.” *Environment and Planning B: Urban Analytics and City Science* 45 (2): 312–29. https://doi.org/10.1177/0265813516673060.
Litman, T. 2002. “Evaluating Transportation Equity.” *World Transport Policy & Practice* 8 (2): 50–65.
Loukaitou-Sideris, A. 2014. “Fear and Safety in Transit Environments from the Women’s Perspective.” *Security Journal* 27 (2): 242–56. https://doi.org/10.1057/sj.2014.9.

Loukaitou-Sideris, A., and R. Ehrenfeucht. 2009. *Sidewalks: Conflict and Negotiation Over Public Space*. Urban and Industrial Environments. Cambridge, Mass: MIT Press.
Loveland, T.R., and J.L. Dwyer. 2012. "Landsat: Building a Strong Future." *Remote Sensing of Environment*, Landsat Legacy Special Issue, 122 (July): 22–29. https://doi.org/10.1016/j.rse.2011.09.022.
Mallach, S. 1979. "The Origins of the Decline of Urban Mass Transportation in the United States, 1890-1930." *Urbanism Past & Present*, no. 8: 1–17.
Manville, M., and E. Goldman. 2017. "Would Congestion Pricing Harm the Poor? Do Free Roads Help the Poor?" *Journal of Planning Education and Research* 38 (3): 329–44. https://doi.org/10.1177/0739456X17696944.
Marcus, C.C., and W. Sarkissian. 1986. *Housing As If People Mattered: Site Design Guidelines for the Planning of Medium-Density Family Housing*. University of California Press.
McCann, B., and S. Rynne. 2010. "Complete Streets: Best Policy and Implementation Practices." Report Number 559. American Planning Association.
Miles, dir. 1906. *A Trip Down Market Street Before the Fire*. Film. San Francisco, CA. https://www.loc.gov/item/00694408.
Moehring, E.P. 2016. *Resort City In The Sunbelt, Second Edition: Las Vegas, 1930-2000*. University of Nevada Press.
Mohl, R.A. 1997. "Review of Ghosts along the Freeway; Crossroads: A Story of West Oakland." *The Public Historian* 19 (4): 112–14. https://doi.org/10.2307/3379516.
Nicolaides, B.M. 2003. "Suburbia and the Sunbelt." *OAH Magazine of History* 18 (1): 21–26.
Norton, P.D. 2007. "Street Rivals: Jaywalking and the Invention of the Motor Age Street." *Technology and Culture* 48 (2): 331–59.
———. 2011. *Fighting Traffic: The Dawn of the Motor Age in the American City*. Second Edition. Cambridge, Mass. London: The MIT Press.
Owens, B.R. 2012. "Mapping the City: Innovation and Continuity in the Chicago School of Sociology, 1920–1934." *The American Sociologist* 43 (3): 264–93. https://doi.org/10.1007/s12108-012-9160-7.
Perkins, C. 2017. "Critical Cartography." In *Routledge Handbook of Mapping and Cartography*, 80–89.
Pyzyk, K. 2019. "San Francisco to Expand Bike Lane Network, Boost Cyclist Safety." *Smart Cities Dive* (blog). May 10, 2019. https://www.smartcitiesdive.com/news/san-francisco-to-expand-bike-lane-network-boost-cyclist-safety/554516/.
Ritchie, H. 2020. "Cars, Planes, Trains: Where Do Co2 Emissions from Transport Come From?" Our World in Data. https://ourworldindata.org/co2-emissions-from-transport.
Rosenblum, J. 2015. "The Backstory: How Livable-Streets Advocates Changed Boston." PSU Transportation Seminars, October 16. https://pdxscholar.library.pdx.edu/trec_seminar/52.
Schneider, R.J., F.R. Proulx, R.L. Sanders, and H. Moayyed. 2021. "United States Fatal Pedestrian Crash Hot Spot Locations and Characteristics." *Journal of Transport and Land Use* 14 (1): 1–23.
Segrave, K. 2014. *Parking Cars in America, 1910-1945: A History*. McFarland.
Sisson, P. 2020. "It's Time for Transportation Planners to Move beyond 'Level of Service.'" *City Monitor* (blog). October 16, 2020. https://citymonitor.ai/transport/its-time-for-transportation-planners-to-move-beyond-level-of-service.
Slater, C. 1997. "General Motors and the Demise of Streetcars." *Transportation Quarterly* 51 (3): 45–66.

Southworth, M., and E. Ben-Joseph. 2013. *Streets and the Shaping of Towns and Cities*. Island Press.

Steiniger, S., and E. Bocher. 2009. "An Overview on Current Free and Open Source Desktop GIS Developments." *International Journal of Geographical Information Science* 23 (10): 1345–70. https://doi.org/10.1080/13658810802634956.

Susaneck, A.P. 2023. "American Road Deaths Show an Alarming Racial Gap." *New York Times*, April 26, 2023, sec. Opinion. https://www.nytimes.com/interactive/2023/04/26/opinion/road-deaths-racial-gap.html.

Taylor, K.H., and R. Hall. 2013. "Counter-Mapping the Neighborhood on Bicycles: Mobilizing Youth to Reimagine the City." *Technology, Knowledge and Learning* 18 (1): 65–93. https://doi.org/10.1007/s10758-013-9201-5.

Thomson, J.M. 1978. *Great Cities and Their Traffic*. Penguin Books.

Vock, D.C. 2022. "The Promise and Pitfalls of Tearing Down an Urban Freeway." *Route 50*, April 11, 2022. https://www.route-fifty.com/infrastructure/2022/04/promise-and-pitfalls-tearing-down-urban-freeway/365507/.

Wagner, F.H., M.P. Ferreira, A. Sanchez, M.C.M. Hirye, M. Zortea, Emanuel Gloor, Oliver L. Phillips, Carlos Roberto de Souza Filho, Yosio Edemir Shimabukuro, and Luiz E. O. C. Aragão. 2018. "Individual Tree Crown Delineation in a Highly Diverse Tropical Forest Using Very High Resolution Satellite Images." *ISPRS Journal of Photogrammetry and Remote Sensing*, SI: Latin America Issue, 145 (November): 362–77. https://doi.org/10.1016/j.isprsjprs.2018.09.013.

Ward, D. 1964. "A Comparative Historical Geographyof Streetcar Suburbs in Boston,Massachusetts and Leeds, England:1850–1920." *Annals of the Association of American Geographers* 54 (4): 477–89.

Whyte, W.H. 2001. *The Social Life of Small Urban Spaces*. 8th ed. edition. New York, NY: Project for Public Spaces.

Young, J. 2015. "Infrastructure: Mass Transit in 19th- and 20th-Century Urban America." *Oxford Research Encyclopedia of American History.*, March. https://oxfordre.com/americanhistory/view/10.1093/acrefore/9780199329175.001.0001/acrefore-9780199329175-e-28.

Zavestoski, S., and J. Agyeman, eds. 2014. *Incomplete Streets: Processes, Practices, and Possibilities*. Routledge.

Zehngebot, C., and R. Peiser. 2014. "Complete Streets Come of Age: Learning from Boston and Other Innovators." Planning. American Planning Association. https://www.planning.org/planning/2014/may/completestreets.htm.

Chapter 1:
Mapping Crosswalk Coverage via Satellite Imagery in San Francisco

Summary:
Marked crosswalks are the primary means of safeguarding pedestrian travel at intersections in American cities. In the face of decades-high pedestrian fatalities nationwide, the provision of adequate crosswalks is highly salient. Though, how they are spatially distributed across an entire city, and vary by neighborhood, has drawn little academic scrutiny. Given that, this chapter utilizes satellite imagery to map the presence of marked crosswalks throughout San Francisco, a dense, walkable city that has struggled to reach its pedestrian-safety goals. For the first time, this allows for a calculation of 'crosswalk coverage' for the city as a whole. Manual review of satellite imagery finds that crosswalks are present at 58% of San Francisco's roughly 6,400 intersections, though they are not evenly distributed across neighborhoods. Both hotspot analysis and comparing crosswalk coverage by Census tract demonstrates that northern neighborhoods – even outside of the downtown core – maintain higher percentages of intersections with crosswalks than those in the southern half. Though these patterns track somewhat with local pedestrian and automobile volumes, crosswalk coverage diverges from these trends in many ways. Intersections exhibit crosswalk 'corridor effects,' in that marked crosswalks often cluster along certain streets, including (but not limited to) commercial areas. In addition, crosswalks in four neighborhoods were analyzed to a deeper extent, including category (e.g. ladder, continental, standard), condition, and 'completeness' or the number of adjacent blocks with a connecting crosswalk. Across these roughly 1,000 intersections, coverage varied from 51% in the Bayview (a historic African American community) to 83% in Pacific Heights (a high-income, majority-white neighborhood). Neighborhoods also varied in terms of crosswalk completeness, illustrating that a binary 'crosswalk vs. no-crosswalk' analysis omits nuances of the pedestrian environment. Overall, satellite imagery can be used to identify marked crosswalks at scale, evaluate their quality, and probe geographic variation. Armed with such granular data, planners can consider the ways in which crosswalks are present throughout cities — and where notable gaps exist — in their pursuit of Vision Zero goals.

Introduction

In U.S. cities, a common approach to safeguard pedestrians at intersections is marked crosswalks, which visibly signal where crossings may occur on foot. For the purposes of this chapter, "marked crosswalks" and "crosswalks" are used interchangeably. Though technically in San Francisco *any* controlled intersection between streets with sidewalks includes a 'crosswalk' (wherein pedestrians have priority), the colloquial use of the term is employed here, meaning a crosswalk is one that is *visibly marked*. Crosswalks are often accompanied by other safety features, such as traffic lights, pedestrian signals, wheelchair-accessible curb ramps, stop signs, and refuge islands, among others. However, many urban intersections feature none of these amenities, or only provide crosswalks worn to the degree that renders them ineffective. There is evidence across multiple studies that crosswalks increase pedestrian safety (detailed in the literature review), though transportation scholars have yet to examine their *spatial* provision, including within urban areas. This gap in scholarship raises several pertinent questions: In cities, where are marked crosswalks provided and where are they not? How can we accurately measure their geographic distribution at scale? Are marked crosswalks provided at similar levels across neighborhoods?

While marked crosswalks are in some cities recorded in public datasets, the availability of high-resolution satellite imagery provides a scalable method of cataloging their spatial distribution, regardless of the state of municipal records. This approach allows for 'crosswalk coverage' — the percent of all intersections in a given area with marked crosswalks — to be calculated for the first time. San Francisco, a city of roughly 900,000 in Northern California, represents an ideal case for crosswalks to be mapped. First, compared to other U.S. municipalities, it is quite dense (Florida, 2012), and has a high walk mode-share (22% as of 2019; "City-Performance Scorecards" 2020). Second, San Francisco has launched a Vision Zero program in the face of rising roadway fatalities, with the goal of eliminating traffic deaths by 2024 (Moench, 2020). This indicates a municipal government both taking steps to further protect pedestrians and likely receptive to quantifying pedestrian amenities and potential disparities.

With this context, this paper proceeds with a literature review on the role of crosswalks and pedestrian safety, the recent increase in traffic fatalities nationwide (negating several decades of improvements), the gap in terms of spatial analysis of crosswalk distribution, and how satellite imagery has been employed to evaluate urban form. This is followed by a description of the methods used to identify and appraise crosswalks, results as to San Francisco's crosswalk coverage citywide and within four distinct neighborhoods, and a discussion of what such findings mean for transportation planners pursuing both Vision Zero specifically and transportation equity more broadly.

Literature Review

Cities have been traversed by foot as long as they have existed. The rise of automobiles in the early 20th century increased the danger of urban walking dramatically. Norton (2011) tracks the growing tension between pedestrians and cars in American cities during this period, which included the initial establishment of designated-crossing areas, as opposed to the prior norm wherein pedestrians crossed streets wherever they saw fit (Miles, 1906; Loukaitou-Sideris and Ehrenfeucht, 2009). The transition to marked crosswalks was not entirely smooth; pedestrians often flouted such rules, and the associated social reconstruction of the street as the primary domain of automobiles (Norton, 2007). This acrimony led to the pejorative term and new municipal infraction known as 'jaywalking,' (Millington, 2014).

In the decades since the crosswalk's introduction, it has become a standard component of American urban planning. The U.S. Department of Transportation's "Manual on Uniform Traffic Control Devices" (MUTCD) writes: "Crosswalk markings help to alert road users of a designated pedestrian crossing point across roadways" (2009). Though, the MUTCD only deems marked crosswalks as warranted when certain pedestrian-crossing thresholds are met, meaning a specific number of walkers over a given amount of time. Of course, this prevailing logic fails to take into account that individuals may be reticent to cross intersections *unless and until* marked crosswalks are provided. This car-centric bias at the foundation of pedestrian-crossing warrants — which prioritize automobile throughput — has been noted by others (Zegeer et al., 1983; Todd, 1992; Fitzpatrick et al., 2006; Schmitt, 2020). Yet, such guidelines still remain prominent in transportation planning and are echoed in state and municipal materials ("Crosswalk Policy and Design Guidelines," 2014).

Researchers have probed the safety effect of marked crosswalks for at least six decades (Jacobs and Wilson, 1967). Studies have compared collisions at and outside of crosswalks, finding statistically-significant reductions (Keall 1995, Feldman et al., 2010), and that motorists decrease their speeds when approaching crosswalks (Mitman et al., 2008). Other analyses have provided evidence that crosswalks also induce more walking, increase perception of safety among pedestrians, and decrease injury severity when collisions do occur (Havard and Willis, 2012; Schultz et al., 2015; Pfortmueller et al., 2014).

However, the conclusion that crosswalks improve pedestrian safety is not unanimous. Indeed, a study of 282 crossings within six U.S. cities found an *increase* in collisions among older adults at sites with marked crosswalks (though without stop signs or traffic signals), compared to unmarked locations (Koepsell et al., 2002). That said, several articles which found negligible benefits of crosswalks have been critiqued for not adequately controlling for traffic volume and the number of traffic lanes (Mead et al., 2013). More broadly, there is some debate over which pedestrian amenities provide the greatest marginal benefit in terms of reducing collisions, with evidence that raised medians (also known as "speed tables") may offer more protection than crosswalks on multilane roads (Zegeer et al., 2001).

Aside from the infrastructure itself, it is important to note that race may play a role in the efficacy of marked crosswalks. An experiment involving three White adults and three Black adults documented that the latter group was twice as likely to have drivers not yield to them at crosswalks, and had to wait 32% longer in order to cross (Goddard et al., 2015). Relatedly, in the United States people of color are overrepresented in terms of pedestrian collisions and fatalities (Campos-Outcalt et al. 2002; Atherton et al., 2016). These distressing trends add salience to the issue of how crosswalk provision relates to racial variation in American cities.

As to the *spatial* distribution of crosswalks, multiple queries within Google Scholar, Elsevier, JSTOR, and EBSCO (alternating search terms) uncovered few peer-reviewed articles. This is surprising in part because there are a number of studies on the geographic patterns of other transportation amenities, such as transit stops (Welch, 2013; Moran, 2021), sidewalks (Osama and Sayed, 2017; Woldeamanuel and Kent, 2016), and even street trees (Brooks et al., 2016). Indeed, there has been scrutiny of where pedestrian fatalities have occurred (Loukaitou-Sideris et al., 2007; Grisé et al., 2018) including clusters within communities of color (Pharr et al., 2013; Cottrill and Thakuriah, 2010). Though, these do not correspondingly evaluate the footprint of crosswalks. This is also true in terms of work on urban form more broadly; Ewing and colleagues (2003) detected a positive correlation between the level of sprawl in a metropolitan area and the number of pedestrian fatalities, though this analysis omitted crosswalks. One study did examine differences in pedestrian amenities in three cities (including crosswalks), but it compared just quarter-mile stretches in each as opposed to broader neighborhoods or entire municipalities (Thornton et al., 2016). Related work by Zhang and Zhang (2019) sought to determine how pedestrian-network analyses could be improved by transitioning from simple street networks, to 'formal pedestrian facilities,' including manually-identified crosswalks. In four neighborhoods, they found that incorporating a range of variables beyond the grid itself generated deeper understanding of pedestrians' options, particularly in lower-density areas.

Following progress in decreasing pedestrian fatalities between the 1970s and 2000s, there has since been an increase in such deadly collisions in the United States (Schneider, 2020). Unfortunately, pedestrian fatalities nationwide have increased by 46% between 2009 and 2016 (Hu and Cicchino, 2018), and gone up further since the onset of COVID-19 (Retting, 2021). Safety researchers have identified several reasons for this trend, including population growth in the Sunbelt — where car use and pedestrian deaths are highest on a per-capita basis (Retting, 2020) — increases in the proportion of automobiles which are Sport Utility Vehicles (Hu and Cicchino, 2018), and drivers distracted by electronic devices (Stimpson et al., 2013). This surge in pedestrian deaths has led many U.S. cities to adopt "Vision Zero" initiatives, which take inspiration from Sweden's success in reducing traffic fatalities by redesigning streets with safety in mind (Fleisher et al., 2016).

San Francisco has been examined specifically in terms of pedestrian safety. Two decades ago, its pedestrian collisions were spatially analyzed, with the authors finding positive correlations between collisions and traffic flows as well as population density (LaScala et al., 2000). Another study developed a pedestrian-volume model for the city, finding higher walking levels near "activity centers" (places with a high number of offices and shops), in less-hilly areas, as well as at intersections with controlled traffic signals (Schneider et al., 2013). This research does not distinguish between marked and unmarked crosswalks. Another local project sought to determine the effectiveness of different pedestrian 'countermeasures,' such as speed bumps, medians, and turn restrictions (Ford et al., 2008), concluding that in-street "Yield to Pedestrian" signs and pedestrian countdown signals (displaying time remaining) were particularly cost effective. Building on this work, a research team allocated a potential budget allotment for Vision Zero projects in San Francisco into a street-specific package of countermeasures (Kronenberg et al., 2015). By assessing the city's high-injury network (streets where a disproportionate percent of collisions occur), it recommended installing new pedestrian amenities at 195 intersections, though this did not include adding crosswalks where none were present.

In terms of the methods employed here, there is considerable research utilizing satellite imagery to identify urban features. This has included street networks (Xin et al., 2019), urban tree canopies (Moskal et al., 2011), sidewalks (Senlet and Elgammal, 2012), and parked cars, among others (Scharnhorst, 2018; Moran, 2020). Most germane to the question at hand, several groups have detected crosswalks from satellite imagery (Ahmetovic et al., 2017; Berriel et al., 2017a; Kasemsuppakorn and Karimi, 2013), indicating available sensor resolutions are adequate. These studies largely deal with the issue of classification accuracy, and do not delve into the issues of crosswalk-specific variation by geographical units, condition, or type. Perhaps most germane to the chapter at hand, Proulx and colleagues (2015) built a pedestrian-infrastructure database for roughly 100 miles of highways in California by manually digitizing crosswalks based on Google imagery (both satellite and street level).

Methods

Prior to analyzing satellite imagery for this chapter, attempts were made at obtaining records on the spatial distribution of crosswalks from relevant public agencies in San Francisco. Staff at the Municipal Transportation Agency (hereafter SFMTA) helpfully provided a geospatial dataset that included some information on intersections, though it did not cover the entire city, document what kind of crosswalks are present (ladder, continental, etc.), or allow for analysis of crosswalk condition in terms of quality and 'completeness' (i.e. how many adjacent blocks are connected).

Figure 1: Satellite imagery of intersections in San Francisco with (left) and without marked crosswalks (right).

Given this, satellite imagery of every intersection in San Francisco (viewed within the Google Earth application) was manually inspected. First, a binary crosswalk vs. no-crosswalk decision was made for roughly 6,400 intersections (see **Figure 1**), which forms the basis of the spatial analyses that follow. Second, in four distinct neighborhoods – Pacific Heights, the Mission, the Bayview, and the Outer Sunset – more detailed scrutiny of crosswalks was undertaken. For this subset of intersections (roughly 1,000 in total), the following attributes were recorded for each marked crosswalk:

- Category (standard, continental, or ladder), see **Figure 2a**;
- Condition, see **Figure 2b**;
- "Completeness," or how many adjacent blocks are connected by a crosswalk (e.g. 1/4, 2/4, 3/4, 4/4), see **Figure 2c**.

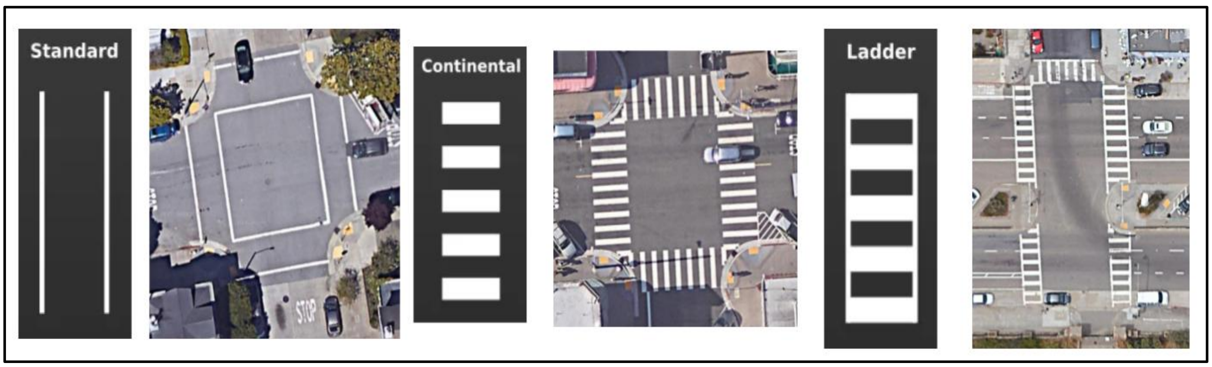
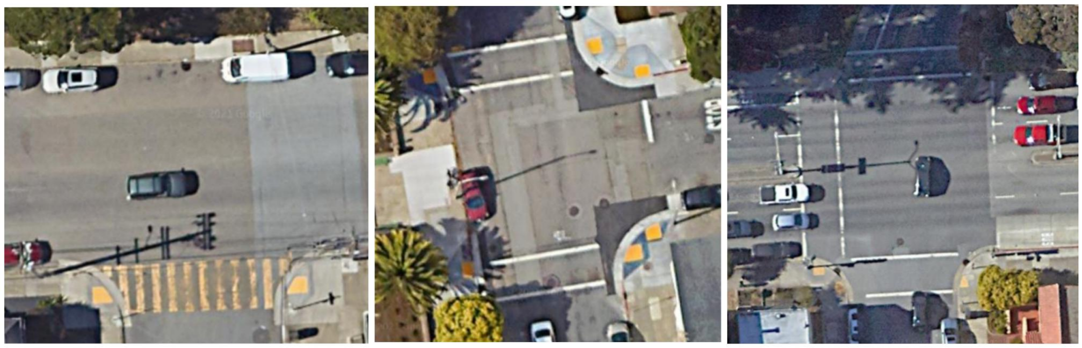


Figure 2a: Examples of three marked crosswalk categories in San Francisco visible from satellite imagery (top).
Figure 2b: Marked crosswalk condition rating scale, based on satellite imagery of San Francisco (middle).
Figure 2c: Examples of marked crosswalks varying in 'completeness' (bottom).



Crosswalk condition within these neighborhoods was manually coded in terms of a three-point scale (0, 1, or 2) with 2 being the highest rating (no visible issues), 1 indicating visible issues (such as worn markings), and 0 indicating poor condition to the extent that crosswalks may be difficult to detect at all. Road intersections without sidewalks (such as highway interchanges) were excluded, and do not factor into the calculation of crosswalk coverage at any scale. Satellite imagery of intersections was combined with municipal datasets which contain the polygons distinguishing both neighborhood and Census-tract boundaries (obtained from San Francisco's official open-data portal). The methodology employed here focuses the provision of crosswalks at intersections, and does not include *midblock* crosswalks. Manual classification was completed by a single researcher, which entailed approximately 90 hours of intersection review (roughly one minute of analysis per intersection). There is no financial cost involved to using the Google Earth platform, beyond a personal computer and broadband internet access. Though time-consuming, manual classification was used for both the binary "crosswalk vs. no crosswalk" determination citywide, and the more detailed four-neighborhood analysis, in order to ensure the highest-possible level of accuracy.

The four neighborhoods chosen for the secondary, deeper analysis vary in location, density, and socio-demographics (based on 2019 American Community Survey data, 5-year estimates); Pacific Heights is a generally high-income area with a majority of residents being white (67% of residents), the Mission District is home to a large Hispanic population (42% of residents, though facing gentrification pressures; Mirabal, 2009), the Bayview is a historic African-American neighborhood (34% of residents), and the Outer Sunset is relatively middle income (for San Francisco) and maintains a large Asian-American population (53% of residents). All four include both residential areas and commercial corridors, lie within different regions of the city (north, west, southeast, and central), and do not border each other. Residential density (measured as persons per square mile, 2019 ACS, 5-year estimates) is the highest in the Mission (38,706), followed by Pacific Heights (27,413), the Outer Sunset (21,694), and the Bayview (16,739).

In order to understand how pedestrian volume may influence crosswalk provision, data from the San Francisco pedestrian intersection volume model (Schneider et al., 2013) was extracted from the report's included table, geocoded, and digitally mapped. This includes 2-hr observation of pedestrian crossings at fifty intersections across the entire city (with extrapolations from that research team as to total weekly crossings). Geocoding existing data was also undertaken for automobile volume, drawn from San Francisco's traffic count between 2014 and 2018, which involved observations at roughly 4,000 intersections ("SFMTA Traffic Count Data, 2019). These datasets represent the most spatially-expansive (and recent) pedestrian and automobile volumes for San Francisco, which can then be compared to the resulting crosswalk coverage figures.

Results

Satellite-imagery based analysis of 6,399 intersections across San Francisco calculated an overall crosswalk coverage of 58%. Review of spatial patterns of these data indicate the highest percentage of intersections with marked crosswalks occur in San Francisco's dense northeast quadrant (which includes the central business district), with decreasing proportions of intersections with marked crosswalks in neighborhoods to the south (see **Figure 3**). Outside of the northeast quadrant, crosswalks are present to a greater extent in other northern neighborhoods running westward toward the Pacific Ocean, compared to those in the southern half. Rather than isolated intersections, non-marked crosswalks generally appear in clusters, meaning adjacent to at least one other intersection also lacking a crosswalk, which grow in size in the city's southern half. Indeed, a hotspot analysis of crosswalk coverage (Getis-Ord Gi*) illustrates that intersections with marked crosswalks cluster across the city's northern half (starting from the downtown and running westward), and that clusters of intersections without marked crosswalks ('coldspots') nearly all lie within the city's southern half (see **Figure 4**).

When crosswalks are aggregated by Census tract, geographic patterns in coverage become further evident; high-coverage tracts cluster in the northern half of San Francisco, and low-coverage tracts cluster in the southern half (see **Figure 5**). Again, this trend remains the case not just concerning the downtown core, but citywide and across a range of neighborhood types and densities. Beyond spatial patterns, the variation in general is quite stark; there are 14 tracts with 100% crosswalk coverage (covering 181 intersections) whereas one tract in the Inner Sunset neighborhood has only three marked crosswalks across 42 intersections (7% coverage). The large tract in the southwest corner of San Francisco, which stands out in that quadrant for high crosswalk coverage (95%) is dominated by multiple golf courses and a lake.

Two variables drawn from American Community Survey data were compared to crosswalk coverage at the Census tract level: density (persons per square mile) and average household income (based on 2019 figures, 5-year estimates). Simple linear regression analysis found no association between either density or average household income with crosswalk coverage at this scale, with R^2 values of 0.11 and 0.001, respectively.

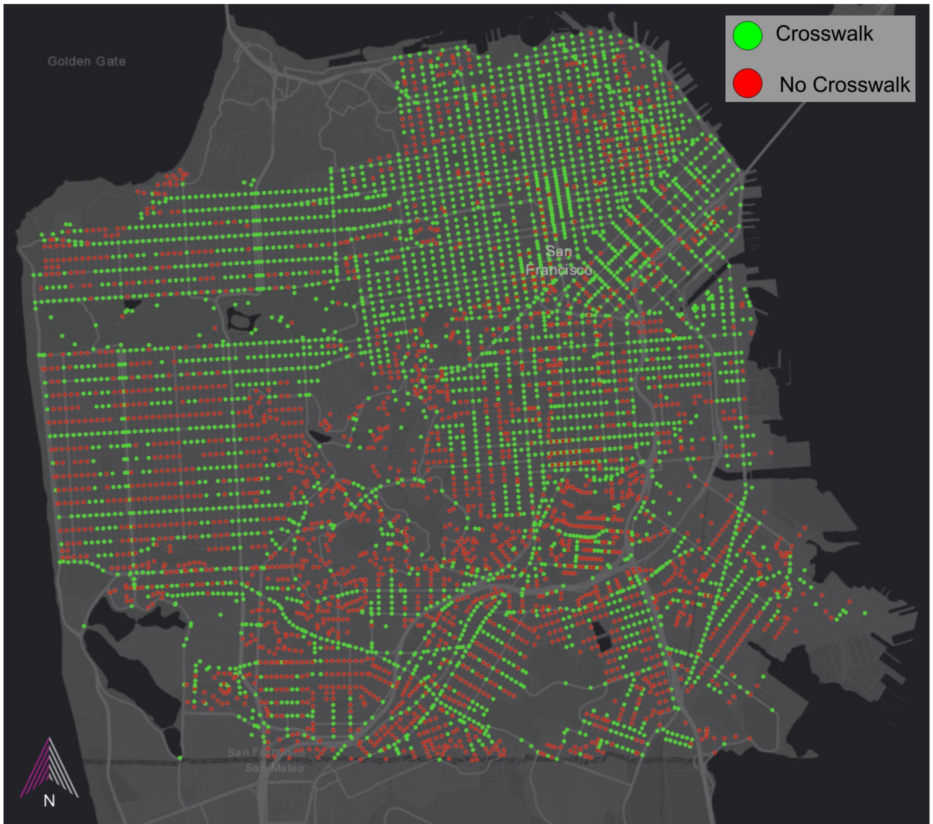


Figure 3: Presence of marked crosswalks at intersections in San Francisco, CA.

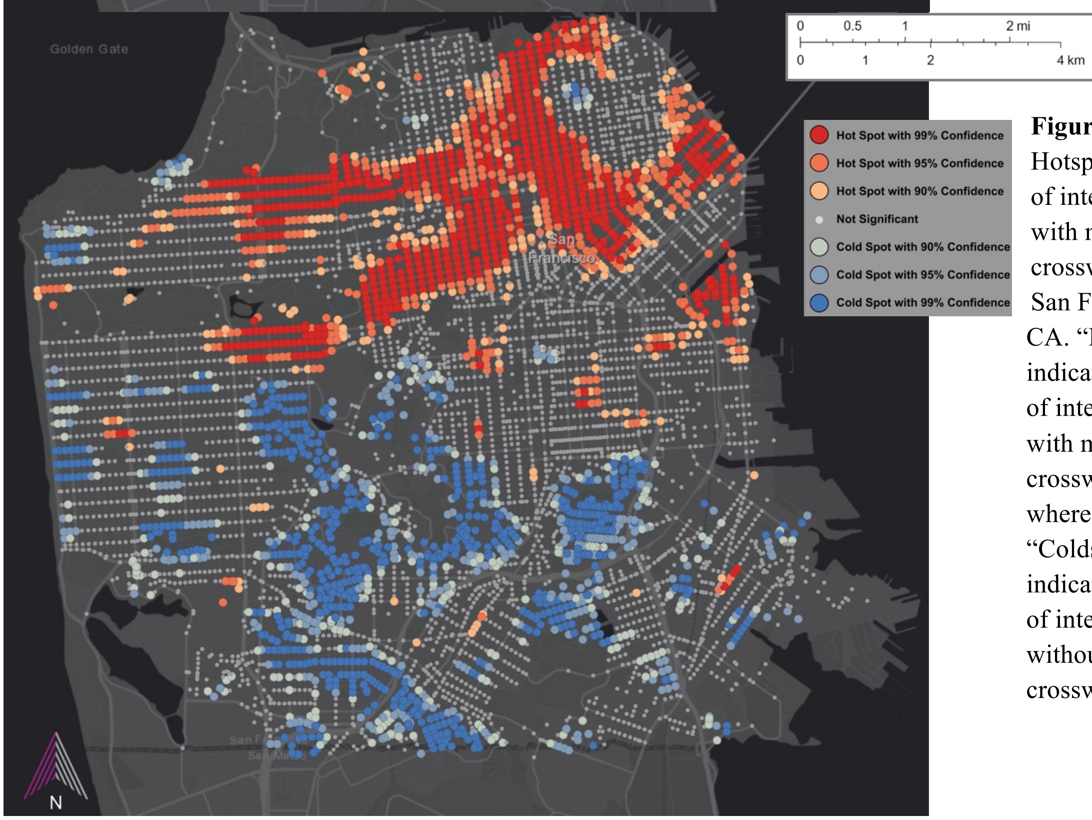


Figure 4: Hotspot analysis of intersections with marked crosswalks in San Francisco, CA. “Hotspots” indicate clusters of intersections with marked crosswalks, whereas “Coldspots” indicate clusters of intersections without marked crosswalks.

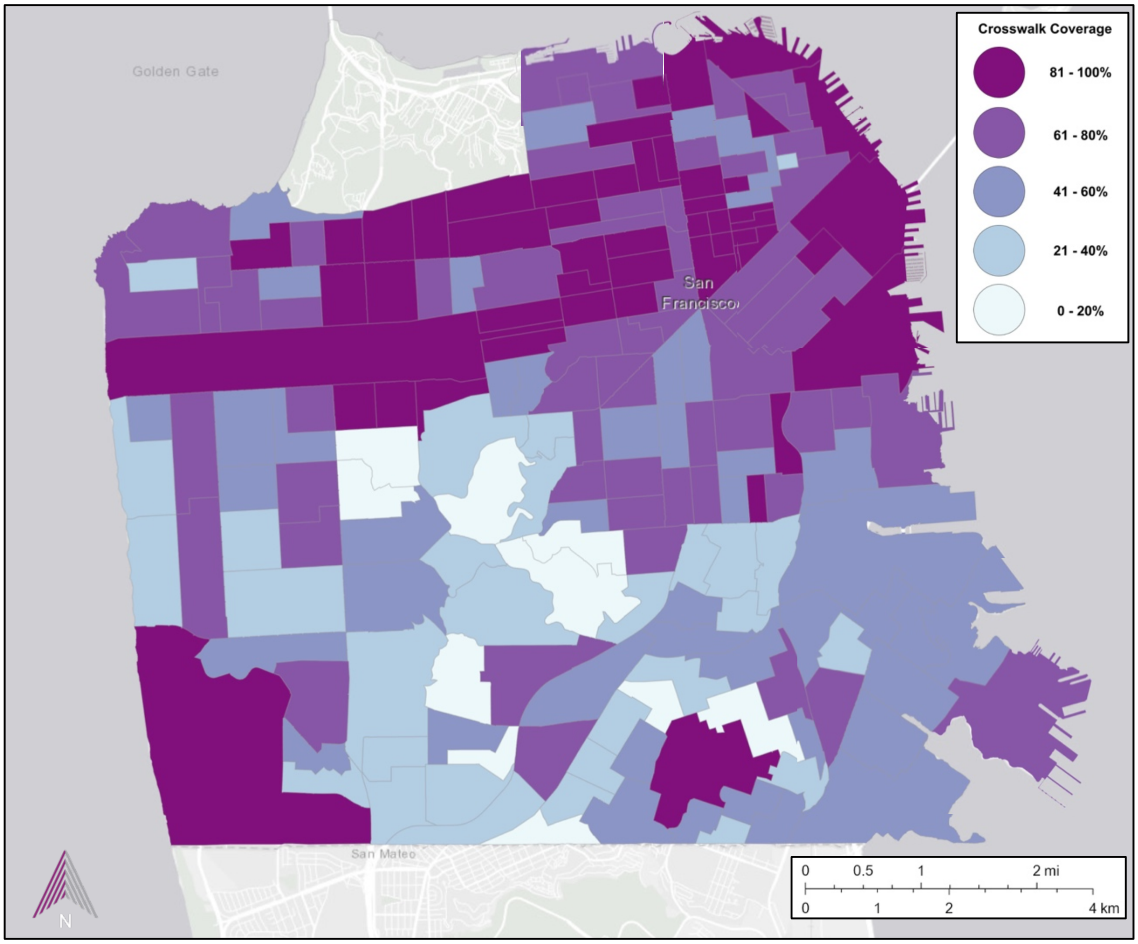


Figure 5: Crosswalk coverage by Census Tract in San Francisco, CA.

For the four San Francisco neighborhoods analyzed to a deeper extent, there were also differences in crosswalk coverage, category, quality, and completeness. Crosswalk coverage varied from 51% in the Bayview to 83% in Pacific Heights, with the Mission and the Outer Sunset neighborhoods falling in the middle (at 63% and 52%, respectively, see **Table 1**). The most common crosswalk type was continental (64% of all analyzed crosswalks), followed by standard (19%) and ladder (17%).

Neighborhood	Total Intersections	Intersections with Crosswalks	Crosswalk Coverage	Crosswalk Score (0-2)	Crosswalk 'Completeness'
San Francisco (total)	6,399	3,725	58%	-	-
Bayview	196	100	51%	1.60	74%
Mission	263	166	63%	1.63	90%
Outer Sunset	381	200	52%	1.71	86%
Pacific Heights	144	119	83%	1.71	97%

Table 1: Summary of Crosswalk Analysis for San Francisco writ large, and four specific neighborhoods.

Though continental crosswalks were the most common category in all four neighborhoods, the relative percentage of those varied by neighborhood, along with standard and ladder crosswalks. For example, 78% of crosswalks in the Mission were continental, versus only 52% in the Bayview. In addition, 28% of crosswalks in Pacific Heights were standard, versus just 7% in the Mission. ‘Corridor effects’ are evident at this sub-city scale, in that all intersections along certain streets feature marked crosswalks. For example, all 31 intersections of Noreiga Street, running east to west in the Outer Sunset, feature a crosswalk. In comparison, Moraga Street (running parallel to Noreiga, just one block north), maintains only five intersections with crosswalks (see **Figure 6**).

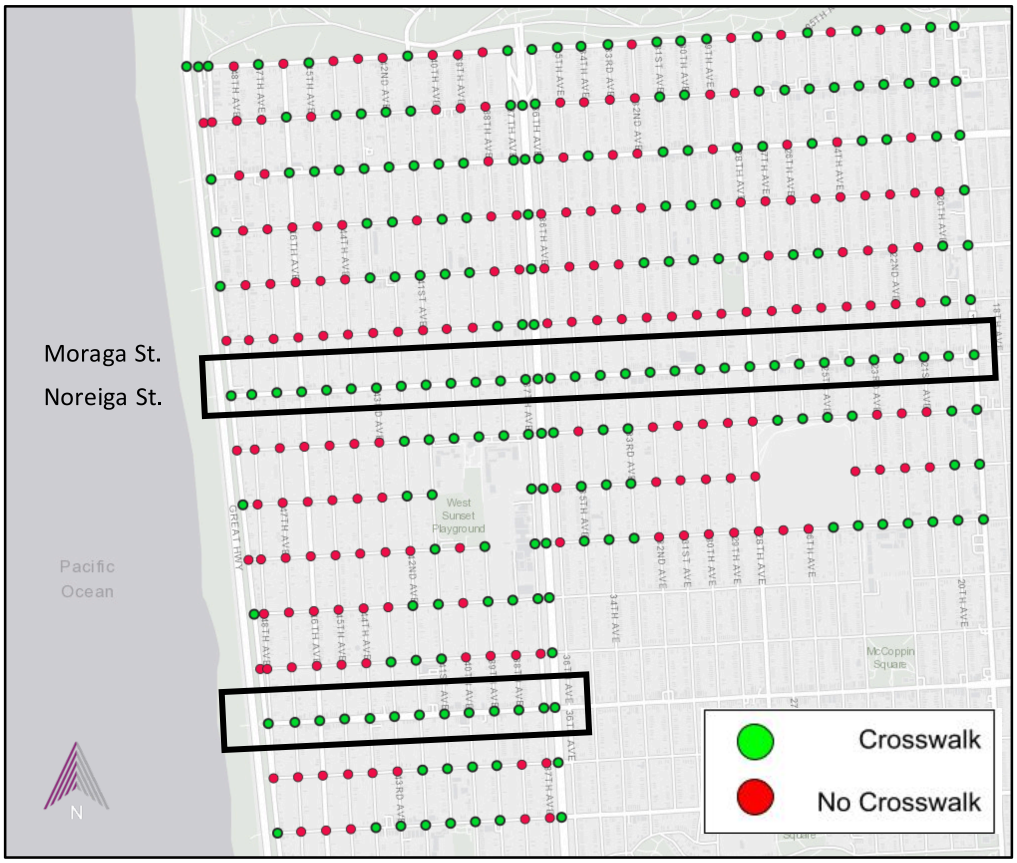


Figure 6: Crosswalk coverage in San Francisco’s Outer Sunset neighborhood, with several corridors highlighted.

In the four neighborhoods reviewed more extensively, crosswalk quality (rated from 0 – 2) averaged 1.7, indicating high visibility of marked crosswalks. Moreover, crosswalk quality varied minimally across the four neighborhoods (from 1.60 in the Bayview to 1.71 in Pacific Heights). This indicates crosswalks vary more so in terms of their geographical footprint than visibility. Of the 586 intersections with marked crosswalks in this subset, 87% of them were ‘complete,’ in that all adjacent blocks featured connecting crosswalks. The percentage of crosswalk-intersections that were complete did vary, with Pacific Heights having the highest rate (97% complete), followed by the Mission (90%), the Outer Sunset (86%), and the Bayview (74%).

Discussion

Marked crosswalks are an essential component of pedestrian infrastructure in U.S. cities, yet their spatial provision within and across neighborhoods has never been analyzed. Satellite imagery provides a highly-accurate way to map crosswalks' geographic footprint at scale, with San Francisco providing an ideal initial case. This approach introduces the measurement of 'crosswalk coverage' (percent of total intersections featuring a crosswalk), and in doing so indicates that crosswalks are provided unevenly across San Francisco. Marked crosswalks are present at 58% of roughly 6,400 total intersections, featured most often in its northern half (stretching from the downtown core to residential neighborhoods westward) and declining in non-uniform ways outside of that. Mapping crosswalk coverage hotspots and by Census Tract generates a stark picture of variation in pedestrian amenities, including one primarily residential tract in which just three of 42 intersections include crosswalks. There was no relationship found between Census tract density or average household income with crosswalk coverage. Should the city wish to extend pedestrian amenities to all neighborhoods more equally, this analysis could guide where to install new crosswalks and improve existing ones.

Of four neighborhoods analyzed to a deeper extent, coverage was highest in a high-income, largely white neighborhood (Pacific Heights), and lowest in a lower-income and more diverse neighborhood (the Bayview). Crosswalk provision in San Francisco is also often corridor dependent, in that specific streets feature crosswalks at each intersection, generally in commercial areas. Within four neighborhoods analyzed to a further extent, crosswalk 'completeness,' defined here as the number of adjacent blocks with a connecting crosswalk, also varied, from 97% in Pacific Heights, to 74% in the Bayview. This secondary statistic demonstrates that not only may intersections differ in which receive marked crosswalks at all, but the quality of crosswalks themselves, in terms of completeness, may diverge. Furthermore, given evidence that 'standard' crosswalk markings are less visible to motorists (Fitzpatrick et al., 2011), the identification of different percentages of crosswalk categories can empower cities to locate and potentially convert such intersections. This relates to San Francisco specifically, given its stated goal to "gradually have all crosswalk markings be converted to the high-visibility continental marking pattern" ("Crosswalks," 2015).

As to the pedestrian and automobile volumes drawn from previous studies, scrutiny of these datasets are useful in the interpretation of the crosswalk coverage generated here, but do not fully explain the observed geographic patterns. Indeed, for both pedestrian counts between 2009-2010 and vehicle counts between 2014-2018, there is an overall gradient moving from San Francisco's dense northeastern quadrant westward and southward. These trends, tied to a range of factors (land use, density, street width, commercial areas, etc.) no doubt influence where crosswalks are provided. Though, current crosswalk coverage citywide does not match these trends uniformly; indeed, pedestrian and automobile volume are lower in both the city's northern and southern halves stretching west to the Pacific Ocean, yet large differences in crosswalk coverage persist, with the northern half maintaining far higher shares of intersections with crosswalks. For example, the

Mission District recorded both higher pedestrian and automobile volume than Pacific Heights (and has a higher residential density), and yet the latter maintains higher crosswalk coverage. This might also be tied to differences in relative political power, wherein citizen complaints drive crosswalk installation. In addition, relying solely on pedestrian counts to determine where crosswalks are provided succumbs to a self-fulfilling prophecy; pedestrians may never feel comfortable crossing an intersection in significant numbers *unless and until* a marked crosswalk is present. Thus, planners should move from installing crosswalks 'reactively' (or only where warrants are met), and transition to 'proactive' crosswalk installation in order to spur walking.

Considering the benefits of crosswalks, both in terms of safeguarding pedestrians and encouraging walking, this chapter suggests that transportation planners can measure and address equity in crosswalk provision without a single existing record of their current distribution, category, or quality. In particular, analyzing crosswalks at larger scales can consider how pedestrian behavior may be less dependent on one specific intersection and more related to the overall crosswalk network.

Of course, this chapter does not presume that every intersection in a city (San Francisco or otherwise) requires marked crosswalks, particularly given finite resources for pedestrian infrastructure and genuine differences in traffic volume, street type, and surrounding land uses. Rather, it raises the salience of the overall pedestrian network (and its gaps), similar to how planners increasingly scrutinize transit and bicycle infrastructure and services. Moreover, San Francisco has recently improved the pedestrian environment in a number of neighborhoods, including by reducing speed limits, restricting turns on certain streets, and installing refuge islands (Sawyer, 2017; Graf, 2020; Huston, 2021). Still, calculating crosswalk coverage across different geographic units enables the evaluation of a city's transportation system that centers the experience of pedestrians. While some cities may already maintain robust accounts of crosswalk provision and quality (or at least date of last surfacing), many do not, and satellite imagery can fill this data gap.

In terms of future research, manually classifying satellite imagery of crosswalks, while highly accurate, could be expanded and accelerated by automating the process. As noted in the methods section, manual review of a city this size took approximately 90 hours of intersection analysis, not an amount of time many planning departments can dedicate to such a project. Given that, automated classification would allow for the completion of such work to be done much faster, enabling the study of much larger municipalities (such as Chicago, New York, and Los Angeles). Given previous work on supervised classification of urban-street features (noted in the literature review), this chapter could serve as a 'training set' for automating the process elsewhere for crosswalks. In the context of supervised classification, this entails using the set of manually-identified crosswalks from this case to train a GIS software algorithm to automatically locate all marked crosswalks in a new location or map extent.

In addition, street-level imagery, which is increasingly available for a number of cities (e.g. via Google, Bing, and Apple maps), could also be used in future work, given it has been recently deployed to detect crosswalks and other accessibility issues (Smith et al., 2013; Berriel et al. 2017b; Sharif et al., 2021). This is particularly the case when satellite imagery is obstructed by trees, buildings, or shadows, making crosswalk detection and evaluation difficult from the overhead/aerial perspective. Indeed, in the time since this study was published, researchers have developed automated tools for extracting crosswalk features from aerial imagery (Luttrell, 2022; Hosseini et al., 2023), and also automated crosswalk detection from street-view imagery collected by automobile-mounted cameras (Li et al., 2023). An intriguing aspect of the latter study is the ability to track crosswalk provision and quality *longitudinally,* taking advantage of Google's street-view archive dating back to 2007. These contributions indicate automated-detection accuracy is capable of tracking crosswalk coverage at speeds and scales far beyond manual review (without sacrificing accuracy) which lends itself to multi-city studies.

Moreover, generating crosswalk coverage for the first time raises the prospect of probing associations between this new metric and pedestrian-safety outcomes, particularly roadway collisions. Indeed, this new dataset offers the chance to understand if and how crosswalks safeguard pedestrians to different extents in different neighborhoods. Though pedestrian-collision data is available down to the block level in San Francisco, data for traffic and pedestrian volume (important control variables) are far less granular, which complicates such an analytical task. Furthermore, this chapter could be complemented by gathering a range of street and traffic characteristics (such as road width and speed limit) to perhaps reveal how such infrastructure patterns came about, and where crosswalk gaps are the most problematic in terms of transportation equity. Though this analysis found no relationship between either density or average household income with crosswalk coverage, there are certainly other variables to incorporate, including the location of primary schools, senior centers, and transit hubs. In addition, crosswalk location can also be included in the study of pedestrian route choice, which is increasingly taking place at the scale of entire cities (Sevtsuk et al., 2021).

Considering the range of variables at play, interviews with planners, residents, and pedestrian advocates represent an ideal next step in this research, and could add useful context and color to the spatial variations detected. This is particularly important given crosswalk coverage does not completely mirror pedestrian and automobile volume, which raises the question of how else crosswalk decisions are made by planners. In addition, there may be important differences in how and in what frequency residents petition local governments for marked crosswalks, such as via 311 services or at public meetings. Moreover, differences in crosswalk category may relate to changes in work crews tasked with installation over time, as well as prevailing guidance from traffic-safety bodies.

There are several limitations to this research. The first is that while satellite imagery is effective in terms of identifying and appraising crosswalks based on existing resolution, there have inevitably been changes to San Francisco’s intersections since these data were reviewed in 2021. This includes new crosswalks being installed and/or existing crosswalks being covered up during road paving or adjacent construction. Thus, more so than an up-to-the-minute record of crosswalks in San Francisco, this chapter represents the status of crosswalks at a single moment in time for this case, and a proof of concept for considering crosswalk coverage more broadly. In addition, there is some inherent reductiveness to the analysis here, such as the fact that certain complex intersections (where many roads converge) are reduced to a simple “crosswalk” or “no crosswalk” rating. This binary output, while useful when considering Census tracts, neighborhoods, and a city writ large, leaves out other details that complicate the picture of which intersections are actually most in need of improvement. An example of two intersections, ranging in complexity, is pictured in **Figure 7**.

Figure 7: Example intersection in San Francisco that vary in complexity. The intersection on the left has no marked crosswalks, whereas the intersection on the right does, though that binary distinction does not fully capture the pedestrian environment at either, or how planners may decide to modify them.

This project omits other amenities which undoubtedly contribute to the pedestrian experience, including traffic signaling (both for motorists and pedestrians), refuge islands, speed tables, and curb bulb-outs, among many others. Treasure Island (which is part of San Francisco) is excluded from this analysis due to large-scale construction taking place during this time frame, which rendered crosswalk analysis difficult. Similarly, the Presidio of San Francisco, part of the National Park Service, is not under SFMTA’s jurisdiction and is also excluded. Finally, like other cities during the COVID-19 pandemic, San Francisco has closed off a number of streets to non-local traffic (‘Slow Streets;’ Rudick, 2020), some permanently so, which may change how planners weigh the benefits and drawbacks of installing new crosswalks at certain intersections and along certain corridors. For example, for intersections now part of a ‘Slow Street,’ there may be less concern over inconsistent crosswalk provision. Moreover, the granularity of existing pedestrian and automobile volume data does not match the crosswalk analysis undertaken here. For example, though the State of California provides Annual Average Daily Traffic (AADT) Volume at roughly twenty locations in San Francisco, those readings do not include any spots within the four neighborhoods studied, and are almost entirely on highways that lack pedestrian crossings. This leaves open a great deal of ways to build on this new dataset going forward.

Overall, planning researchers and practitioners must not simply consider crosswalks at individual intersections, but their overall spatial distribution, which may mirror other types of public underinvestment, and make pedestrian-safety goals difficult to reach. Satellite imagery can reliably generate crosswalk-coverage maps, which enable comparisons at multiple geographic scales, and help prioritize upgrades.

References

Ahmetovic, D., R. Manduchi, J.M. Coughlan, and S. Mascetti. 2017. "Mind Your Crossings: Mining GIS Imagery for Crosswalk Localization." *ACM Transactions on Accessible Computing* 9 (4). https://doi.org/10.1145/3046790.

Atherton, E., Y. Chang, S. Davis, A. Dodds, S. Sklar, and H. Zaccaro. 2016. "Dangerous by Design." Smart Growth America, National Complete Streets Coalition. https://s3.amazonaws.com/cdn.smartgrowthamerica.org/dangerous-by-design-2016.pdf.

Berriel, R. F., A. T. Lopes, A. F. de Souza, and T. Oliveira-Santos. 2017a. "Deep Learning-Based Large-Scale Automatic Satellite Crosswalk Classification." *IEEE Geoscience and Remote Sensing Letters* 14 (9): 1513–17. https://doi.org/10.1109/LGRS.2017.2719863.

Berriel, R.F., F.S. Rossi, A.F. de Souza, and T. Oliveira-Santos. 2017b. "Automatic Large-Scale Data Acquisition via Crowdsourcing for Crosswalk Classification: A Deep Learning Approach." *Computers & Graphics* 68 (November): 32–42. https://doi.org/10.1016/j.cag.2017.08.004.

Brooks, K.R., W. Kelley, and S. Amiri. 2016. "Social Equity of Street Trees in the Pedestrian Realm." *Papers in Applied Geography* 2 (2): 216–35. https://doi.org/10.1080/23754931.2015.1121163.

Campos-Outcalt, D., C. Bay, A. Dellapenna, and M.K. Cota. 2002. "Pedestrian Fatalities by Race/Ethnicity in Arizona, 1990–1996." *American Journal of Preventive Medicine* 23 (2): 129–35. https://doi.org/10.1016/S0749-3797(02)00465-8.

"City Performance Scorecards." 2020. City and County of San Francisco. https://sfgov.org/scorecards/transportation/non-private-auto-mode-share.

Cottrill, C.D., and P. Thakuriah. 2010. "Evaluating Pedestrian Crashes in Areas with High Low-Income or Minority Populations." *Accident Analysis & Prevention* 42 (6): 1718–28. https://doi.org/10.1016/j.aap.2010.04.012.

"Crosswalk Policy and Design Guidelines." 2014. Town of Concord, MA. https://www.concordma.gov/DocumentCenter/View/244/Crosswalk-Policy-PDF.

"Crosswalks." 2015. *SF Better Streets* (blog). 2015. https://www.sfbetterstreets.org/find-project-types/pedestrian-safety-and-traffic-calming/crosswalks/.

Ewing, R., R.A. Schieber, and C.V. Zegeer. 2003. "Urban Sprawl as a Risk Factor in Motor Vehicle Occupant and Pedestrian Fatalities." *American Journal of Public Health* 93 (9): 1541–45. https://doi.org/10.2105/AJPH.93.9.1541.

Feldman, M., J.G. Manzi, and M.F. Mitman. 2010. "Empirical Bayesian Evaluation of Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco, California." *Transportation Research Record* 2198 (1): 8–14. https://doi.org/10.3141/2198-02.

Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, B. Ullman, N. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. 2006. *Improving Pedestrian Safety at Unsignalized Crossings*. Transit Cooperative Research Program and National Cooperative Highway Research Program. National Academies of Science, Engineering, and Medicine. https://doi.org/10.17226/13962.

Fitzpatrick, K., S.T. Chrysler, V. Iragavarapu, and E.S. Park. 2011. "Detection Distances to Crosswalk Markings: Transverse Lines, Continental Markings, and Bar Pairs." *Transportation Research Record* 2250 (1): 1–10. https://doi.org/10.3141/2250-01.

Fleisher, A., M.L. Wier, and M. Hunter. 2016. "A Vision for Transportation Safety: Framework for Identifying Best Practice Strategies to Advance Vision Zero." *Transportation Research Record* 2582 (1): 72–86. https://doi.org/10.3141/2582-09.

Florida, R. 2012. "America's Truly Densest Metro Areas." *CityLab*, October 15, 2012. https://www.bloomberg.com/news/articles/2012-10-15/america-s-truly-densest-metro-areas.

Ford, N.P., J.L. Fleck, B. Smith, F. Markowitz, S. Fielding, D. Ragland, J. Hua, et al. 2008. "San Francisco Pedsafe Phase Ii Final Implementation Report and Executive Summary." San Francisco Municipal Transportation Agency, UC Berkeley Traffic Safety Center. https://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/sf/pedsafety_sf.pdf.

Goddard, T., K.B. Kahn, and A. Adkins. 2015. "Racial Bias in Driver Yielding Behavior at Crosswalks." *Transportation Research Part F: Traffic Psychology and Behaviour* 33 (August): 1–6. https://doi.org/10.1016/j.trf.2015.06.002.

Graf, C. 2020. "Speed Limits to Be Reduced on Parts of Geary Boulevard." *San Francisco Examiner*, October 27, 2020. https://www.sfexaminer.com/news/speed-limits-to-be-reduced-on-parts-of-geary-boulevard/.

Grisé, E., R. Buliung, L. Rothman, and A. Howard. 2018. "A Geography of Child and Elderly Pedestrian Injury in the City of Toronto, Canada." *Journal of Transport Geography* 66 (January): 321–29. https://doi.org/10.1016/j.jtrangeo.2017.10.003.

Havard, C., and A. Willis. 2012. "Effects of Installing a Marked Crosswalk on Road Crossing Behaviour and Perceptions of the Environment." *Transportation Research Part F: Traffic Psychology and Behaviour* 15 (3): 249–60. https://doi.org/10.1016/j.trf.2011.12.007.

Hosseini, M., A. Sevtsuk, F. Miranda, R.M. Cesar, and C.T. Silva. 2023. "Mapping the Walk: A Scalable Computer Vision Approach for Generating Sidewalk Network Datasets from Aerial Imagery." *Computers, Environment and Urban Systems* 101 (April): 101950. https://doi.org/10.1016/j.compenvurbsys.2023.101950.

Hu, W., and J.B. Cicchino. 2018. "An Examination of the Increases in Pedestrian Motor-Vehicle Crash Fatalities During 2009–2016." *Journal of Safety Research* 67 (December): 37–44.

https://doi.org/10.1016/j.jsr.2018.09.009.

Huston, E. 2021. "With Traffic Deaths Unchecked, San Francisco Has Plans to Slow Drivers' Roll." *The Frisc* (blog). January 7, 2021. https://thefrisc.com/with-traffic-deaths-unchecked-san-francisco-has-plans-to-slow-drivers-roll-59ebe2ca5a95.

Jacobs, G. D., and D. G. Wilson. 1967. "A Study of Pedestrian Risk in Crossing Busy Roads in Four Towns." *Rrl Reports, Road Research Lab /UK/*. https://trid.trb.org/view/111166.

Kasemsuppakorn, P., and H.A. Karimi. 2013. "Pedestrian Network Extraction from Fused Aerial Imagery (Orthoimages) and Laser Imagery (Lidar)." *Photogrammetric Engineering & Remote Sensing* 79 (4): 369–79. https://doi.org/10.14358/PERS.79.4.369.

Keall, M.D. 1995. "Pedestrian Exposure to Risk of Road Accident in New Zealand." *Accident Analysis & Prevention* 27 (5): 729–40. https://doi.org/10.1016/0001-4575(95)00019-V.

Koepsell, T., L. McCloskey, M. Wolf, A.V. Moudon, D. Buchner, J. Kraus, and M. Patterson. 2002. "Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians." JAMA 288 (17): 2136–43. https://doi.org/10.1001/jama.288.17.2136.

Kronenberg, C., L. Woodward, B. DuBose, and D. Weissman. 2015. "Achieving Vision Zero: Data-Driven Investment Strategy to Eliminate Pedestrian Fatalities on a Citywide Level." *Transportation Research Record* 2519 (1): 146–56. https://doi.org/10.3141/2519-16.

LaScala, E.A., D. Gerber, and P.J. Gruenewald. 2000. "Demographic and Environmental Correlates of Pedestrian Injury Collisions: A Spatial Analysis." *Accident Analysis & Prevention* 32 (5): 651–58. https://doi.org/10.1016/S0001-4575(99)00100-1.

Li, M., H. Sheng, J. Irvin, H. Chung, A. Ying, T. Sun, A.Y. Ng, and D.A. Rodriguez. 2023. "Marked Crosswalks in US Transit-Oriented Station Areas, 2007–2020: A Computer Vision Approach Using Street View Imagery." *Environment and Planning B: Urban Analytics and City Science* 50 (2): 350–69. https://doi.org/10.1177/23998083221112157.

Loukaitou-Sideris, A., R. Liggett, and H.G. Sung. 2007. "Death on the Crosswalk: A Study of Pedestrian-Automobile Collisions in Los Angeles." *Journal of Planning Education and Research* 26 (3): 338–51. https://doi.org/10.1177/0739456X06297008.

Loukaitou-Sideris, A., and R. Ehrenfeucht. 2009. *Sidewalks: Conflict and Negotiation over Public Space*. Urban and Industrial Environments. Cambridge, Mass: MIT Press.

Luttrell, J.B. 2022. "Data Collection and Machine Learning Methods for Automated Pedestrian Facility Detection and Mensuration." MS: University of Southern Miss. https://aquila.usm.edu/dissertations/2034.

"Manual on Uniform Traffic Control Devices for Streets and Highways." 2009. Washington, D.C.: Federal Highway Administration, U.S. Department of Transportation. https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf.

Mead, J., C. Zegeer, and M. Bushell. 2013. "Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research," April. https://trid.trb.org/view/1284787.

Miles. 1906. *A Trip Down Market Street Before the Fire*. Film. San Francisco, CA. https://www.loc.gov/item/00694408.

Millington, G. 2014. "Jaywalking." In *Shades of Deviance*, edited by R. Atkinson. Routledge.

Mirabal, N.R. 2009. "Geographies of Displacement: Latina/Os, Oral History, and The Politics of

Gentrification in San Francisco's Mission District." *The Public Historian* 31 (2): 7–31. https://doi.org/10.1525/tph.2009.31.2.7.

Mitman, M.F., D.R. Ragland, and C.V. Zeeger. 2008. "Marked-Crosswalk Dilemma: Uncovering Some Missing Links in a 35-Year Debate - Meghan Fehlig Mitman, David R. Ragland, Charles V. Zegeer, 2008." *Transportation Research Record*, January. https://journals-sagepub-com.libproxy.berkeley.edu/doi/abs/10.3141/2073-10?casa_token=jYHo11FfCjMAAAAA%3AUD2YjWUhVGNeq3kOBhA6AMhpP4XGFOMjOuwvT6TRu648ub4VSneo9MGu0AQ1COCVtSap6XUvHWdb.

Moench, M. 2020. "What Will Stop S.F. Traffic Deaths? Politicians Push Street Changes, Outreach to Vulnerable." *San Francisco Chronicle*, November 11, 2020, sec. Local. https://www.sfchronicle.com/bayarea/article/What-will-stop-S-F-traffic-deaths-Politicians-15718181.php.

Moran, M.E. 2020. "What's Your Angle? Analyzing Angled Parking via Satellite Imagery to Aid Bike-Network Planning." *Environment and Planning B: Urban Analytics and City Science*, September, 2399808320954205. https://doi.org/10.1177/2399808320954205.

Moran, M.E. 2021. "Are Shelters in Place? Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco." *Journal of Public Transportation,* 23(3). https://escholarship.org/uc/item/3gj1t495#main

Moskal, L.M., D.M. Styers, and M. Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." *Remote Sensing* 3 (10): 2243–62. https://doi.org/10.3390/rs3102243.

Norton, P.D. 2007. "Street Rivals: Jaywalking and the Invention of the Motor Age Street." *Technology and Culture* 48 (2): 331–59.

Norton, P.D. 2011. *Fighting Traffic: The Dawn of the Motor Age in the American City*. Second printing edition. Cambridge, Mass. London: The MIT Press.

Osama, A., and T. Sayed. 2017. "Evaluating the Impact of Connectivity, Continuity, and Topography of Sidewalk Network on Pedestrian Safety." *Accident Analysis & Prevention* 107 (October): 117–25. https://doi.org/10.1016/j.aap.2017.08.001.

Pfortmueller, C.A., M. Marti, M. Kunz, G. Lindner, and A.K. Exadaktylos. 2014. "Injury Severity and Mortality of Adult Zebra Crosswalk and Non-Zebra Crosswalk Road Crossing Accidents: A Cross-Sectional Analysis." *PLOS ONE* 9 (3): e90835. https://doi.org/10.1371/journal.pone.0090835.

Pharr, J., C. Coughenhour, and T. Bungum. 2013. "Environmental, Human and Socioeconomic Characteristics of Pedestrian Injury and Death in Las Vegas, NV." *International Journal of Sciences* 2 (10): 9.

Proulx, F.R., Y. Zhang, and O. Grembek. 2015. "Database for Active Transportation Infrastructure and Volume." *Transportation Research Record* 2527: 99–106. https://doi.org/10.3141/2527-11.

Retting, R. 2020. "Pedestrian Traffic Fatalities by State." Governors Highway Safety Association. https://www.ghsa.org/sites/default/files/2020-02/GHSA-Pedestrian-Spotlight-FINAL-rev2.pdf.

Retting, R. 2021. "Pedestrian Traffic Fatalities By State: 2020 Preliminary Data." Governors

Highway Safety Association. https://www.ghsa.org/sites/default/files/2021-03/Ped%20Spotlight%202021%20FINAL%203.23.21.pdf.

Rudick, R. 2020. "San Francisco Picks 12 'Slow Streets.'" *Streetsblog San Francisco* (blog). April 21, 2020. https://sf.streetsblog.org/2020/04/21/san-francisco-picks-12-slow-streets/.

Sawyer, N. 2017. "SFMTA Board to Review Traffic, Parking Modifications for Arguello Boulevard Safety Project," January 2, 2017. https://www.sfexaminer.com/news/sfmta-board-to-review-traffic-parking-modifications-for-arguello-boulevard-safety-project/.

Scharnhorst, E. 2018. "Quantified Parking: Comprehensive Parking Inventories for Five U.S. Cities." Research Institute for Housing America. https://www.mba.org/2018-press-releases/july/riha-releases-new-report-quantified-parking-comprehensive-parking-inventories-for-five-major-us-cities.

Schmitt, A. 2020. *Right of Way: Race, Class, and the Silent Epidemic of Pedestrian Deaths in America*. Illustrated edition. Washington: Island Press.

Schneider, R.J., T. Henry, M.F. Mitman, L. Stonehill, and J. Koehler. 2013. "Development and Application of a Pedestrian Volume Model in San Francisco, California." *SAFE-Trec*. 26 pages.
https://escholarship.org/content/qt8cs2g40c/qt8cs2g40c_noSplash_0db25ac1fcc55e0aa9c91664b1f36562.pdf?t=nrdwsw.

Schneider, R.J. 2020. "United States Pedestrian Fatality Trends, 1977 to 2016." *Transportation Research Record* 2674 (9): 1069–83. https://doi.org/10.1177/0361198120933636.

Schultz, C.L., S.P. Sayers, S.A. Wilhelm Stanis, L.A. Thombs, I.M. Thomas, and S.M. Canfield. 2015. "The Impact of a Signalized Crosswalk on Traffic Speed and Street-Crossing Behaviors of Residents in an Underserved Neighborhood." *Journal of Urban Health : Bulletin of the New York Academy of Medicine* 92 (5): 910–22. https://doi.org/10.1007/s11524-015-9979-7.

Senlet, T., and A. Elgammal. 2012. "Satellite Image Based Precise Robot Localization on Sidewalks." In *2012 IEEE International Conference on Robotics and Automation*, 2647–53. https://doi.org/10.1109/ICRA.2012.6225352.

Sevtsuk, A., R. Basu, X. Li, and R. Kalvo. 2021. "A Big Data Approach to Understanding Pedestrian Route Choice Preferences: Evidence from San Francisco." *Travel Behaviour and Society* 25: 41–51.

"SFMTA Traffic Count Data." 2019. San Francisco Municipal Transportation Agency. https://www.sfmta.com/reports/sfmta-traffic-count-data.

Sharif, A., P. Gopal, M. Saugstad, S. Bhatt, R. Fok, G. Weld, K. Dey, and J. Froehlich. 2021. "Experimental Crowd+AI Approaches to Track Accessibility Features InSidewalk Intersections Over Time." In . New York, NY, USA. https://doi.org/10.1145/3441852.3476549.

Smith, V., J. Malik, and D. Culler. 2013. "Classification of Sidewalks in Street View Images." In *2013 International Green Computing Conference Proceedings*, 1–6. https://doi.org/10.1109/IGCC.2013.6604476.

Stimpson, J.P., F.A. Wilson, and R.L. Muelleman. 2013. "Fatalities of Pedestrians, Bicycle

Riders, and Motorists Due to Distracted Driving Motor Vehicle Crashes in the U.S., 2005–2010." *Public Health Reports* 128 (6): 436–42. https://doi.org/10.1177/003335491312800603.

Thornton, C.M., T.L. Conway, K.L. Cain, K.A. Gavand, B.E. Saelens, L.D. Frank, C.M. Geremia, K. Glanz, A.C. King, and J.F. Sallis. 2016. "Disparities in Pedestrian Streetscape Environments by Income and Race/Ethnicity." *SSM - Population Health* 2 (December): 206–16. https://doi.org/10.1016/j.ssmph.2016.03.004.

Todd, K. 1992. "Pedestrian Regulations in the United States: A Critical Review." *Transportation Quarterly* 46 (4). https://trid.trb.org/view/378178.

Welch, T.F. 2013. "Equity in Transport: The Distribution of Transit Access and Connectivity among Affordable Housing Units." *Transport Policy* 30 (November): 283–93. https://doi.org/10.1016/j.tranpol.2013.09.020.

Woldeamanuel, M., and A. Kent. 2016. "Measuring Walk Access to Transit in Terms of Sidewalk Availability, Quality, and Connectivity." *Journal of Urban Planning and Development* 142 (2): 04015019. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000296.

Xin, J., X. Zhang, Z. Zhang, and W. Fang. 2019. "Road Extraction of High-Resolution Remote Sensing Images Derived from DenseUNet." *Remote Sensing* 11 (2499): 18.

Zegeer, C.V., S. Khasnabis, and J.C. Fegan. 1983. "Development of Improved Pedestrian Warrant for Traffic Signals (Discussion-Closure)." *Transportation Research Record*, no. 904. https://trid.trb.org/view/195861.

Zegeer, C.V., J. Richard Stewart, H. Huang, and P. Lagerwey. 2001. "Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Analysis of Pedestrian Crashes in 30 Cities." *Transportation Research Record* 1773 (1): 56–68.

Zhang, H., and Y. Zhang. 2019. "Pedestrian Network Analysis Using a Network Consisting of Formal Pedestrian Facilities: Sidewalks and Crosswalks." *Transportation Research Record* 2673 (7): 294–307. https://doi.org/10.1177/0361198119846095.

Material for this chapter is published in:

Moran, M.E. 2022. "Where the Crosswalk Ends: Mapping Crosswalk Coverage via Satellite Imagery in San Francisco." *Environment and Planning B: Urban Analytics and City Science.*

Chapter 2:

Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco

Summary:
Transit stops serve as crucial components of journeys for riders, but their condition is often left out of equity considerations. Two important empirical questions are what stop amenities are present, such as places to sit, clear signage, shelters for inclement weather, and unobstructed curbs, and how are they distributed across systems, which may reveal neighborhood or route-specific disparities. San Francisco, CA represents an ideal case for which to pursue this question, given it maintains a 'transit first' policy directive that mandates public space prioritize transit over private automobiles. An in-person census of 2,964 street-level bus stops was conducted over three months, which finds that a majority of stops lack both seating and shelter of any kind, that route signage varies widely in format and legibility, and that roughly one third of all stops are legally obstructed by on-street parking, rendering them difficult to use and exposing riders to oncoming traffic. Stops in the city's northern half are more likely to feature seating, shelter, and unobstructed curbs, whereas amenity "coldspots" nearly all lie within the city's southern half. Stop amenities also vary sharply by bus route, such that routes with the longest headways (and thus waiting times) provide on average the least seating, shelter, and clear curbs. These three amenities – seating, shelter, and unobstructed curbs – are also present to a greater degree in Census tracts with higher shares of white residents. This census demonstrates that equity evaluations of transit must include stop amenities, which are often overlooked, can undermine transit's attractiveness, and even compound long-standing imbalances in service quality for underserved communities. Furthermore, studies of this kind can inform where amenity upgrades should be prioritized, targeting those areas currently lacking in high-quality stops, and raising the minimum standard of stop amenities overall. Finally, given data collected in this census is almost entirely unavailable to riders within current trip-planning and wayfinding applications, this work raises the possibility of expanding transit-data standards to include amenity details.

Introduction

Cities across the United States have set ambitious goals for increasing the share of trips which take place on transit, such as Boston (over 40% by 2030) and Portland (25% by 2035) ("Go Boston 2030," 2017; "Transportation System Plan," 2018). These targets relate to manifold objectives, including reducing congestion, as well as improving air-quality and lowering carbon emissions. Indeed, transit not only moves people more efficiently in terms of space on the road, but it also requires less energy per traveler (Barrero et al., 2008; Lowe et al., 2009; Hodges, 2010). Regardless of these potential benefits, transit ridership has been falling in nearly all U.S. cities over the last decade (Amin, 2018), and dropped precipitously during the COVID-19 pandemic (Hart, 2020). For transit systems to reverse these long and short-term trends, they must provide a level of service that competes with alternatives like personal automobiles, bicycles, and walking, but also ridehailing (such as Uber and Lyft), and micromobility (shared bikes and scooters). This is particularly relevant given a number of studies on emerging modes indicate a shift away from transit (Graehler, Jr. et al., 2018; Schaller, 2018).

Transit's attractiveness generally stems from the spatial extent of routes, their frequency, and fare prices. However, features such as clear signage, places to sit, shelters to provide shade and protection from inclement weather, ease in boarding and exiting vehicles (e.g. unobstructed curbs), and screens providing real-time arrival estimates are also influential. Indeed, as Portland, Oregon's TriMet agency puts it, "the public's first impression of TriMet and its services is the bus stop" (Baldwin et al., 2010). Though, cursory use of many transit systems indicates that stop amenities are often inadequate (lack of clear signage, seating, shelters, etc.) and inconsistently distributed (the number of amenities varies from stop to stop). Indeed, U.S. media outlets have held contests for 'sorriest bus stops' and made calls for 'worst bus stop signs,' with entrants showing stops located perilously close to high-speed arteries, framed in by concrete barriers, and lacking legible signage of any kind (Schmitt, 2018; Bliss, 2019). Beyond poking fun at such facilities, these articles highlight a notable gap in the transit literature: comprehensive analyses of stop amenities. Such data could shed light on a number of pertinent questions, particularly: how have resources been divided among routes and neighborhoods in terms of transit stops? Given the widespread goals of increasing transit ridership as well as improving the travel experience for those already riding, the paucity of research on stop amenities stands out.

One approach to fill this gap is to conduct a census: in-person visits to each stop in a given transit system in order to catalog the presence of seating, signage, curb obstructions, shelters, and other amenities. San Francisco, CA operates a fixed-route transit system (managed by the San Francisco Municipal Transportation Agency, or SFMTA) that includes buses, light-rail, cable cars, and street cars. San Francisco is guided by a 'Transit-First' policy which stipulates that: "travel by public transit, by bicycle and on foot must be an attractive alternative to travel by private automobile," and that "decisions regarding the use of limited public street and sidewalk space shall encourage the use of public rights of way by pedestrians, bicyclists, and public transit" ("Transit-First Policy," 2007). A census of San Francisco's bus stops is a direct way to evaluate if these directives are reflected in transit infrastructure. The city also stands out generally due to its innovative transportation policies, including one of the country's first dynamic parking-pricing schemes (Pierce and Shoup, 2013), pilot programs for shared bikes and scooters (Moran, 2021), a streamlined planning process for bicycle and bus lanes (Swan, 2019), and the banning of private automobiles from its main thoroughfare, Market Street (Fitzgerald Rodriguez, 2020). Given leadership on these fronts, it is of interest if San Francisco provides adequate bus-stop amenities, and if it does so consistently citywide.

This paper proceeds by reviewing academic studies of bus stops, including those which connect stop amenities to rider experience and changes in travel behavior. It then details the methods of this census, including which amenities were cataloged, and what other datasets (including route headways) were ushered to put the findings into context. The results section covers the low levels of seating and shelter present across bus stops citywide, the roughly one third of stops which are obstructed by on-street parking, and how these relate to San Francisco's geography and sociodemographics. Stop amenities are analyzed by route and headway category, which display wide variation. Finally, the conclusion section draws upon the findings of the census for policy recommendations for other transit systems grappling with inadequate and inconsistent stop amenities.

Literature Review

Scholars have analyzed bus stops in a number of different ways: critiques of stop design and quality, surveys of riders on stop preferences, testing of effects of stop amenities on ridership, and investigations of how transit agencies make decisions regarding stop investment and prioritization. As to the first category; there is evidence that the orientation of bus-shelter doors (either facing toward or away from the roadway) influence pollution riders are exposed to (Moore et al., 2012), and that many stops lack nearby crosswalks (Pulugurtha and Vanapalli, 2008; Hosford et al., 2020). Loukaitou-Sideris (1999) closely observed a small number of bus stops in Los Angeles to determine if certain features lend themselves to crime. Her study found that specific attributes likely do so, including bus shelters which are closed in by walls to the degree that the view of the interior space from the street was blocked. Corazza and Favaretto (2019) usher a great number of attributes about roughly 200 bus stops in a single district of Rome (including trash cans, street lights, and bollards, among others), which serves in part as inspiration this chapter.

As to surveys, the Federal Transit Administration sponsored a project that surveyed bus riders in four cities on stop design, finding highest preference for those with pitched roofs, one side fully open to the elements, and clear walls over opaque surfaces (Lusk, 2001). Another survey, based in the Twin-Cities region of Minnesota found that respondents perceived waiting times were shorter if stops had benches and shelters (Fan et al., 2016), and a subsequent study from the same area determined that adjacent trees also decreased perceived waiting times (Lagune-Reutler et al., 2016). These complement research which finds that providing real-time scheduling for arrivals can also make waiting less frustrating (Ferris et al., 2010; Watkins et al., 2011; Woetzel et al., 2018), and even improve riders' sense of safety (Abenoza et al., 2018). In addition, rider surveys have suggested that perceptions of bus-stop comfort can also factor into the decision to switch to a car (Han et al., 2018).

In addition to stated preferences, two studies have linked stop quality to rider behavior. In Salt Lake City, researchers documented that the installation of seating, shelters, and sidewalks correlated with increases in stop-level ridership and decreases in paratransit-service demand (Kim et al., 2018). Likewise, bus stops in Chicago which had real-time arrival screens installed were associated with increased ridership, when comparing routes which did and did not receive the new hardware (Tang and Thakuriah, 2012).

It is important to consider how transit agencies make decisions regarding stop amenities. One report on the topic concluded that "in most instances, the estimated number of passenger boardings has the greatest influence" (Fitzpatrick et al., 1996). For example, the WMATA system's "Guidelines: Design and Placement of Transit Stops" calls for a bus shelter to be present based on stop-specific ridership – in this case whether or not there are at least 50 boardings per day (2009). This logic is echoed by numerous other agencies, including Rogue Valley Transportation District in Oregon ("Bus Stop Design & Planning Guide," 2011), OmniTrans in Southern California (Parsons and Gruen, 2013), and GCRTA in the Cleveland, OH area (Feke et al., 2018). However, one obvious pitfall of this approach is that it can become a *self-fulfilling prophecy*, in that low-amenity stops may actively deter ridership, which means they will never qualify for upgrades. Second, this logic means that riders at more popular stops will inherently be provided better facilities than those who live or commute to less-popular stations.

There is also evidence that factors beyond ridership drive the distribution of stop amenities. Indeed, the Star Tribune in Minnesota compared bus boardings to stop amenities using publicly-released data (Roper, 2014), and identified hundreds of stops lacking a shelter of any kind even though they qualified for amenities given ridership benchmarks. At the same time, many other stops had shelters even though ridership was far lower. Moreover, a study of bus stops in Los Angeles indicated that the primary determinant of where shelters were present was the revenue-generating potential of shelter advertisements (Law and Taylor, 2001). This finding has particular importance for San Francisco; SFMTA at one point contracted out shelter construction to an advertising firm (Roth, 2009), an agreement which left it up to the private vendor to not only upgrade existing shelters, but install new ones as well (Gordon, 2007). Though, SFMTA's press release announcing the contract noted that "SFMTA will have approval over the construction schedule to ensure that priorities such as volume of passenger boardings and distribution throughout the city are followed" indicating support for linking ridership and stop investment.

Beyond these analyses, transit agencies, metropolitan planning organizations, design firms, and nonprofits have also produced resources on how transit stops can be improved, and have examined their own facilities. These measures emphasize stop siting, providing riders with a way to submit feedback regarding maintenance issues, maximizing seating along crowded sidewalks, incorporating lighting and heating, and modifying curbs with bus-stop bulbs (Robson and

Piczenik, 2009; NACTO, 2016; Farrington and Schwartz, 2017; Buchanan and Hovenkotter, 2018; Colosi et al., 2018). Beyond guidance, a small number of transit agencies have released audits on their own bus stops, such as those focused on accessibility (Finch, 2013; "Bus Stop Safety and Accessibility Study," 2018; "Space Coast Area Transit," 2018), or how amenities vary by which jurisdiction maintains them ("Metro Transit Bus Stop Amenities Study," 2018). In the Atlanta Region, several organizations have partnered for "Operation Bus Stop Census," which seeks to crowdsource information on stop quality across the MARTA system by releasing a free smartphone application anyone can use to submit information (Clanton, 2020).

Outside of stops, there is also ample evidence that transit service is inequitably provided, both in terms of mode and location. Golub and colleagues (2013) detail the history of transportation funding in Northern California's East Bay, which was biased in terms of suburban rail compared to urban buses, the latter of which served a more-diverse and low-income population (see also Attoh, 2019). This pattern of underinvestment in bus transit has been mirrored elsewhere, including Los Angeles, which involved a successful legal fight over inadequate funding (Grengs, 2007). Along with spatial and modal disparities, there are also specific populations who struggle with transit infrastructure generally and stops in particular, such as people with vision impairments (Azenkot et al., 2011). As one study notes:

> *One specific challenge for blind and low vision bus riders is locating and verifying bus stop locations, particularly in new or unfamiliar areas. They often search for physical landmarks such as the bus shelter, benches, or transit sign as a cue that they have reached the stop, but the design and location of the stop relative to the intersection are frequently quite variable.* (Campbell, 2014)

People with other disabilities also consistently experience difficulty in navigating transit systems, including stops (Wu et al., 2011), which can have significant consequences in terms of social exclusion (Stanley et al., 2011; Aarhaug and Elvebakk, 2015).

While there demonstrably are differences in bus stop quality across space, and issues with specific populations using them, a clear definition of equity is required regarding the distribution of bus-stop amenities. One approach, in line with a utilitarian conception of equity (Di Ciommo and Shiftan, 2017), would entail that the highest number of riders receive some amount of benefit (in the form of stop amenities) given existing budget constraints. This might result in stop amenities being concentrated *only* along the bus routes with high ridership, given it could maximize the number of riders using amenities. Though, as noted above, the spatial distribution of ridership may be in part tied to the presence of these very amenities, meaning that stop-investment patterns can themselves shape ridership.

In contrast, a conception of equity drawn from the work of Rawls (specifically his 'difference principle'), would favor distributing benefits such that those with the least resources receive a higher share than those better off to begin with (Rawls, 1999; Martens, 2016; Pereira et al., 2017). In the context of bus stops, this definition of equity would prioritize that amenities be present at stops in low-income and/or minority neighborhoods, and not primarily determined by ridership alone. Third, the 'social minimum' principle, advanced by Waldron (1986) and others (Weithman, 1995), focuses on the *minimum standard* of the distribution of goods. Applied here, that would entail that all stops in the system at least meet some established criteria. For example, that each bus stop has legible route signage, a curb unobstructed by parked automobiles, and at least seating for a single waiting rider.

Both of these latter approaches – priority for underserved neighborhoods, and bringing up stops to a minimum standard– would benefit riders most in need (regardless of what part of the bus system they use), and encourage more ridership. Of course, no transit agency has an unlimited budget, and so decisions regarding system investment must always be made with fiscal constraints in mind. This relates to both Rawls' difference principle and the interest for a minimum standard across stops. Indeed, given not every stop can be upgraded at once, these principles suggest that stop improvements should occur *first* in the areas most in need, which would both raise more stops to a minimum standard, and in doing so benefit the least well-off riders.

Overall, scholarship suggests that bus-stop amenities influence ridership, that a number of transit agencies are mindful of the need to improve their stops, and that such improvements could benefit riders who frequently face challenges with transit journeys. However, there are as of yet no comprehensive stop censuses, or spatial analysis of such findings across an entire city. Thus, the opportunity exists to conduct a bus-stop census, which can generate both locally-salient findings as to the distribution of stop amenities, and also insights for agencies elsewhere about how such data relate to equity goals.

Methods

The primary method of this census is in-person visits to every street-level bus stop in San Francisco managed by SFMTA. This does not include the Bay Area Rapid Transit (BART) or Caltrain systems (which are rail), nor does it include SFMTA stops for cable cars, street cars, or light-rail. However, this census does include stops which are shared among SFMTA's different modes for those which explicitly serve a bus route. This census also excludes bus stops that exclusively serve other systems, such as SamTrans, AC Transit, and Golden Gate Transit, which are centered in other counties.

Before this census began, attempts at obtaining detailed stop-amenity information from SFMTA were made. This included queries within SFMTA's website, and San Francisco's open-data portal, as well as email correspondence with SFMTA staff. These steps uncovered a single geospatial dataset which lists the location of each bus stop, though it only includes one binary amenity attribute: the presence or absence of a shelter. While this dataset is a useful starting point, it is reductive in terms of a stop's full condition, leaving out signage, seating, and curb status, among others. Likewise, SFMTA's general transit feed specification (GTFS) – which lists every stop system wide and is used by trip-planning applications – contains no amenity information. Headways (i.e. frequency) by route were drawn from SFMTA's system map (dated "Winter/Spring

2019”), which predates COVID-related service cuts (Cassidy, 2020). For buses, there are three headway categories: service every 10 minutes or less, service every 10-20 minutes, and service every 20-30 minutes.

This census took place over the months of May, June, and July 2020. Throughout the data-collection process, SFMTA records (updated as of April, 2020) on the location of every bus stop were referenced in order to ensure all were visited in person (outside of those within active-construction zones). The presence of the following amenities was recorded at each stop:

- Route Signage (see **Figure 1**)
    - Metal sign;
    - Paint on a metal pole;
    - Paint on a telephone pole;
    - Paint on the pavement; and
    - Marking on bus shelter;
- Shelter (e.g. roof of some kind);
- Seating;
- Electronic ETA Screen (and if present, if such screen is operating);
- Stop ID for the NextBus system (generally via stickers);
- Route/System Map; and
- Unobstructed Curb (vs. those blocked by on-street parking)

A photograph of each bus stop was also taken. While determining if most amenities were present was straightforward, evaluating the status of the curb requires more explanation. In San Francisco, curbs running along bus stops are marked in a number of different ways, including with large stencil-painted lettering which read “BUS STOP,” as well as by curbs painted the color red, or metal signs which read “No Parking.” Thus, determining whether or not a specific bus stop was obstructed by parking was not guided by the presence or absence of automobiles parked in front of it, but whether or not any of these marking types (lettering, curb coloring, or specific no-parking signage) was present. If none of these were visible (i.e. the curb was marked like any other) then it was cataloged as a parking-obstructed stop. There were also other ways to confirm this, such as signs indicating when parking was allowed, or if parking meters were present. In addition, route signage was only recorded as being present at stops if markings (be they stickers, signs, or paint) were legible in person.

Figure 1: Route signage examples of bus stops in San Francisco, CA, including (clockwise from top left): metal signs, paint on metal poles, shelter markings, paint on pavement, and paint on telephone poles.

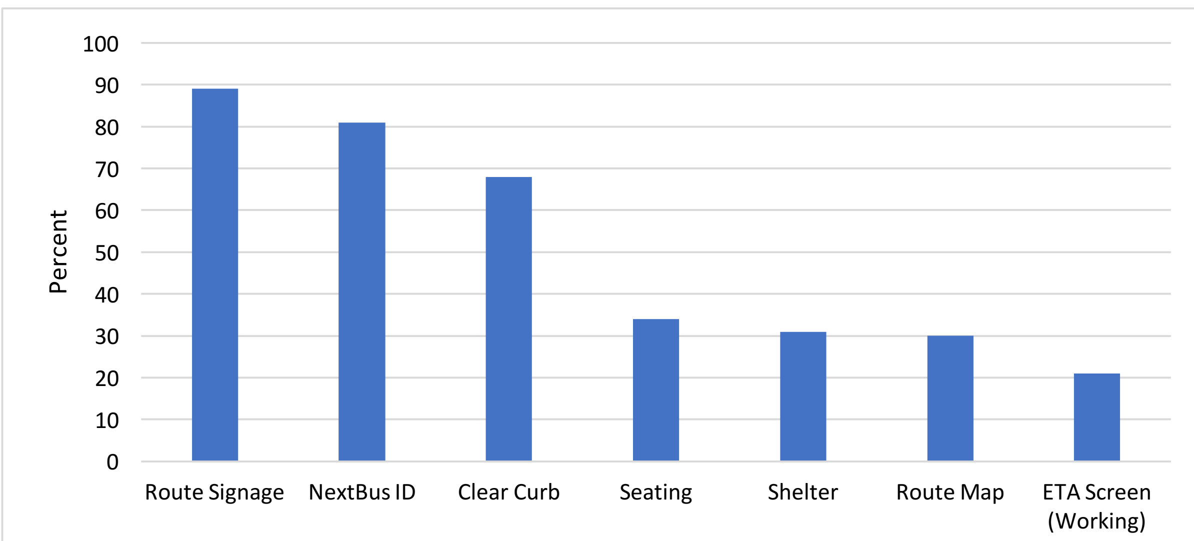
Beyond these specific amenities, in-person inspection of all bus stops allowed for more-qualitative observations as well, including signage legibility, sidewalk quality, how obstructed curbs varied by parking layout, and how different sidewalk designs influenced stop functionality.

Though a census of this kind could perhaps be conducted remotely, such as by employing "street view" imagery from Google Maps (as has been done for basic stop identification purposes; Hara et al., 2015), there are several advantages to the in-person method undertaken here. First, street view varies in terms of image quality, and level of obstruction from vehicles, which makes cataloging stop amenities difficult. Indeed, the resolution and angles of street view rarely allow for detection of NextBus ID stickers, electronic ETA signs (and if they are functioning), or pavement markings. Second, street view is not uniform in terms of timing across a city such as San Francisco. While major streets are captured by street-view vehicles at least once a year, images from less-central streets – many of which contain bus stops – can be several years old. Thus, an in-person census conducted over a relatively short period of time ensures that data are not only accurate but also temporally consistent.

Results

Between May and July, 2020, 2,964 SFMTA street-level bus stops were visited across San Francisco, with all present amenities cataloged (see Figure 2). In terms of seating, 34% of stops included seating of some kind, be it chairs or benches of varying materials and types. Similarly, 31% of stops featured shelters. Legible route signage of some kind was present at 89% of stops, with paint on metal street poles as the most common type (present at 41% of stops), followed by shelter markings (23%), paint on pavement (19%), metal signs (18%), and paint on telephone poles (7%). There were 516 stops (19% of all stops) which featured more than one type of legible route signage, such as both paint on the pavement and a shelter marking. A NextBus ID was posted at 81% of all stops, which came in various formats, including stickers, as a component of metal signs, paint on the pavement, and a few stops with hand-scrawled numbers. Working electronic screens displaying ETA information were present at 21% of stops, and an additional 2% of stops had ETA screens which were not functioning. Route maps were present at 30% of stops, and almost always as a component of bus shelters.

Figure 2: Bar chart of amenities across 2,964 SFMTA bus stops



Curbs were obstructed by on-street parking at 32% of stops, meaning there was not enough designated curb space (often called a “dedicated bus zone”) for a bus to pull up, which forces riders to step into the street to board, and often navigate through parked cars (see **Figure 3**).

Figure 3: Bus stops in San Francisco where on-street parking obstructs riders from entering and exiting the bus, both at those with and without shelters

All bus stops visited during the census had their geographic locations recorded based on GPS coordinates from ESRI's Survey123 smartphone application run on an iPhone 7, which is generally accurate within 10 meters of true positions, and allows for data exporting into spatial-analysis software (Lamoureux and Fast, 2019; Merry and Bettinger, 2019). When limiting the analysis to seating, several visible patterns emerge, including a higher share of stops featuring seating in the city's northern half (see **Figure 4a**). It is also evident that Bayview/Hunters Point, a historic African-American neighborhood in the southeast corner of the city, contains very few stops with seating at all. Using the municipally-designated geographical center of San Francisco (Rubenstein, 2016), it is possible to quantify the distribution of amenities by half. Indeed, among bus stops in the city's northern half, 45% provide seating, compared to just 22% in the southern half. That pattern is nearly identical for shelters: 42% of stops in the northern half feature shelters, compared to 22% in the southern half. In comparison, the differences in amenities between the eastern and western halves of the city are far smaller; seating is provided at the same percentage of stops (34%), and shelter is provided at 32% of stops in the eastern half versus 30% in the western half.

A "hotspot" analysis of these amenities further illustrates this high-level geographic pattern. The Getis-Ord Gi* test detects where stops with similar values (in this case, those with or without a given amenity) cluster together (Songchitruksa and Zeng, 2010). Applied to bus-stop data, clusters of stops providing seating are primarily present in the city's northern half, including its central-business district in the northeast quadrant and residential neighborhoods running west. In comparison, seating "coldspots" – clusters of stops lacking seating – nearly all lie in the city's southern half (see **Figure 5a**).

Mapping bus stops by curb type (clear vs. obstructed) displays a similar picture, in that stops clear of on-street parking are present to a far greater degree in the city's northern half (80%) than its southern half (53%) (see **Figure 4b**). Likewise, these differences were less pronounced in the eastern half vs. western half comparison (68% of stops with clear curbs in the eastern half vs. 65%

in the western half). The Getis-Ord Gi* test similarly indicates that clear curbs hotspots sit almost entirely within the city's northern half, notwithstanding a small hotspot also present in the southwest quadrant within a large private housing development (see **Figure 5b**). In addition, nearly every curb "coldspot" occurs within the city's southern half, including a broad portion of the southeast quadrant.

Beyond these north-south and east-west analyses, U.S. Census and bus-headway data were also integrated into spatial analyses in order to consider how amenities vary by route frequency and race. When broken down by Census tract (based on 2019 American Community Survey data), bus stops in tracts with a higher than average share of white residents are more likely to feature seating (37%), shelter (34%), and clear curbs (71%), than to those in tracts with a higher than average share of people of color (31%), (29%), and (62%), respectively. Indeed, for every one percentage increase in a tract's white residents, the odds that a given bus stop features seating increases 0.9%, 0.8% for shelters, and 1% for clear curbs (estimated from a logistic regression). In contrast, this relationship was not evident in terms of income; tracts household incomes both above and below the city's median figure ($112,449 as of 2019) were equivalent in terms of the likelihood stops feature seating, shelter, and unobstructed curbs. Lastly, the effect of a Census tract's density was different from both these of previous categories, in that those with lower-than average densities had stops 11-12% less likely to feature seating and shelter, but only 4% less likely to provide clear curbs.

Given the evidence of amenities following some corridor patterns from the spatial analyses (such as consistent seating), each bus route comprising the SFMTA system was analyzed in terms of what percentage of its stops include a given amenity. The provision of amenities varies significantly across routes: seating ranges from 10% of stops on some routes to 75% on others, shelter likewise varies from 5% to 76%, clear curbs from 16% to 100%, route maps from 0% to 74%, functioning ETA screens from 0% to 54%, route signage from 78% to 100%, and NextBus IDs from 66% to 100% (see **Table 2**, appendix).

Figure 4a: Map of bus stops in San Francisco, shaded by the presence of seating

Figure 4b: Map of bus stops in San Francisco, shaded by the presence of curb status

Figure 5a: Hotspot and Coldspot analysis (Getis-Ord Gi*) for bus-stop seating

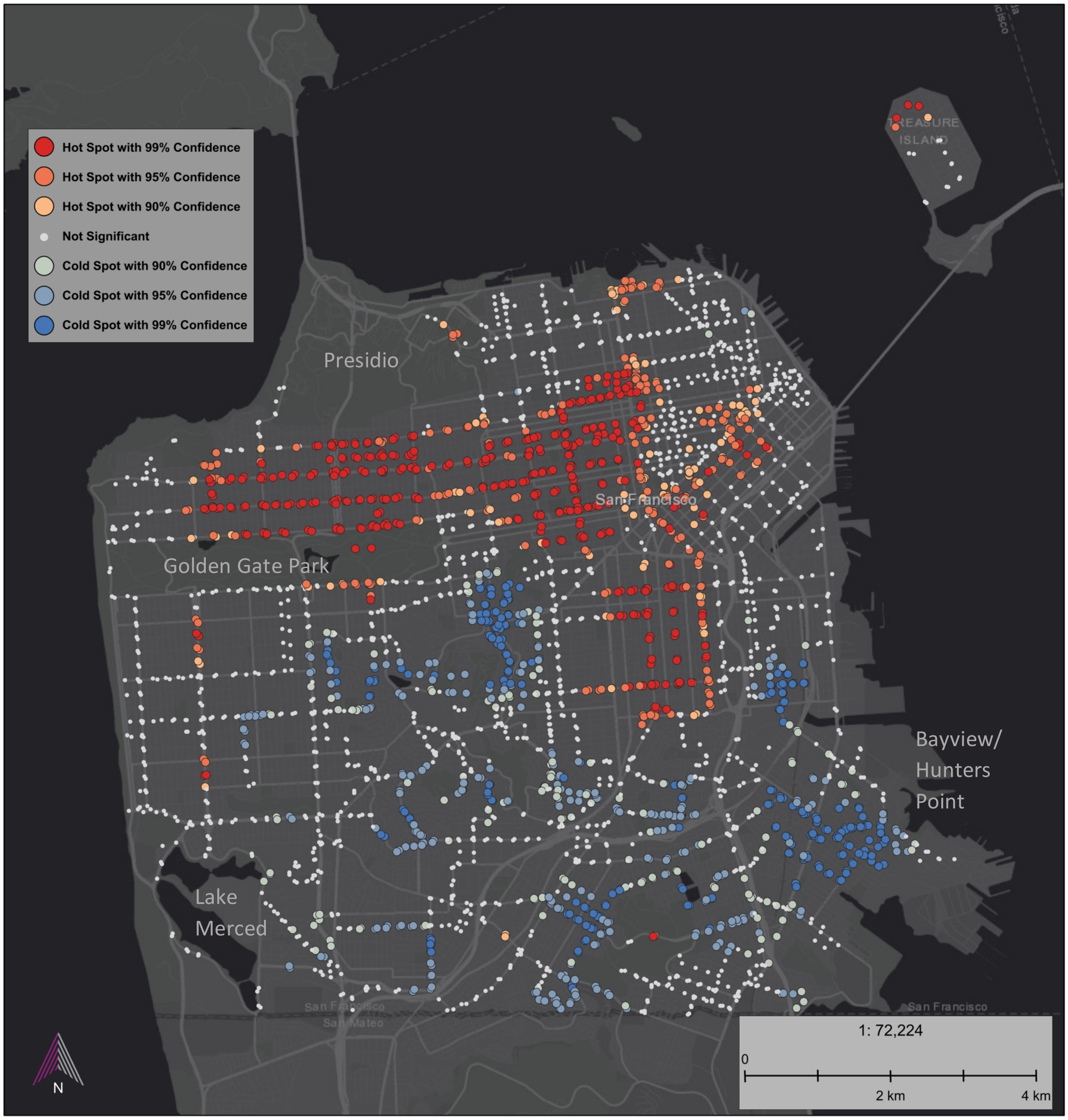
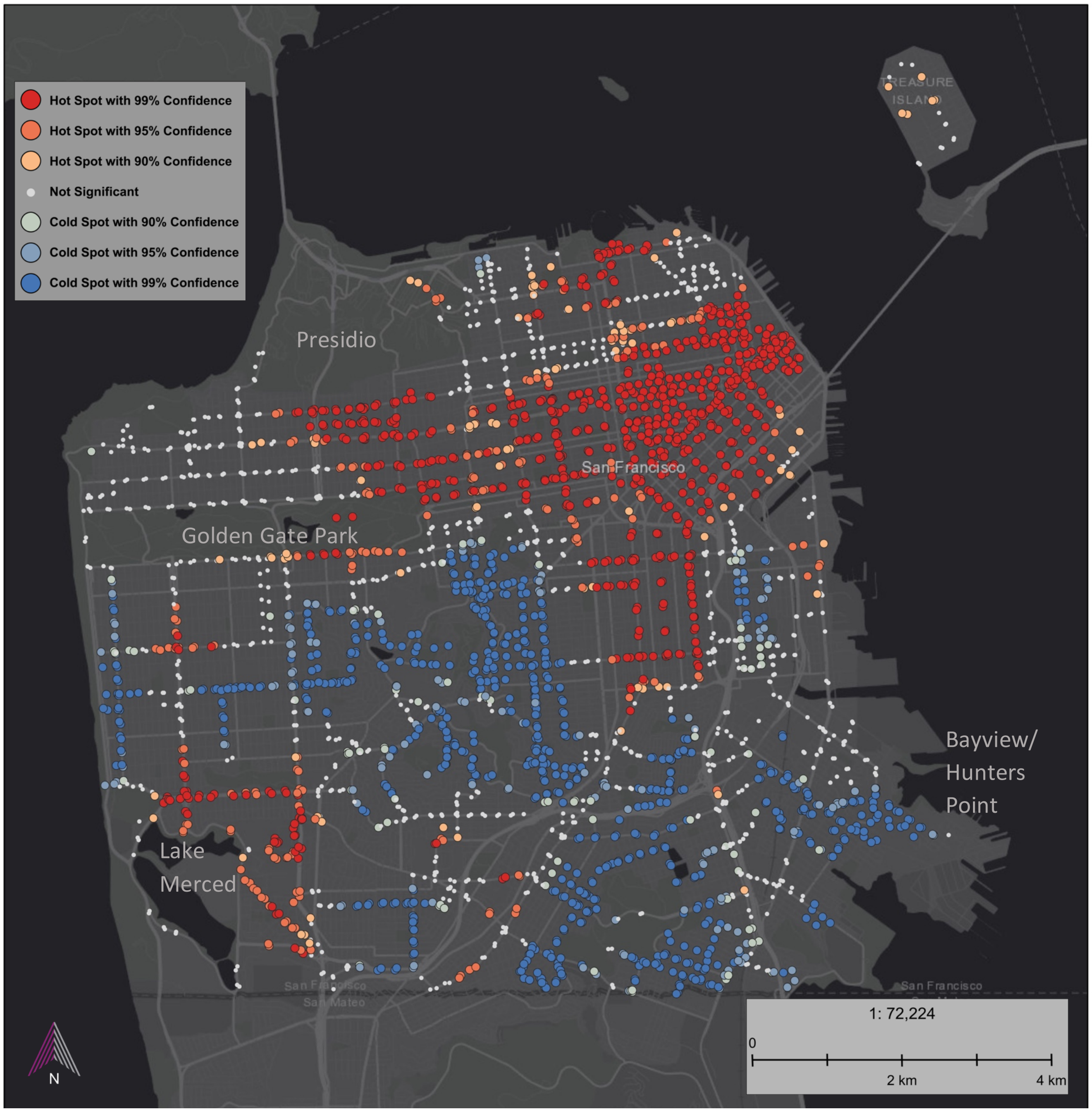


Figure 5b: Hotspot and Coldspot Analysis (Getis-Ord Gi*) for bus-stop curb status



When divided into three headway categories, routes with the most-frequent service (headways of 10 minutes or less) had the highest share of stops with seating (51%), shelters (51%), and clear curbs (88%). Routes with the second-most frequent service (headways between 10 and 20 minutes) had a lower percentage of stops with seating (40%), shelters (36%), and clear curbs (72%). Finally, those routes with the least-frequent service (headways between 20 and 30 minutes) had the lowest percentage of stops with seating (17%), shelters (15%), and clear curbs (44%).

Importantly, the variation in route frequency across San Francisco may be contributing to the geographic patterns of stop amenities. Indeed, of the stops in the northern half of the city, 45% are served by the most-frequent routes, 44% are served by the second-most frequent routes, and just 11% are served by the least-frequent routes. This represents a far-higher share of stops served by more-frequent routes than those stops in the southern half, where 16% are served by the most-frequent routes, 39% are served by the second-most frequent routes, and 45% are served by the least-frequent routes. This raises the question of if the north-south amenity disparities can be explained by the geographic differences in route frequency. A mediation analysis determined that differences in route frequency explain approximately 40% of the effect of location (north vs. south) on the presence of seating, which means that 60% of the geographic effect documented is *unexplained* by route frequency. This finding merits further analysis, including considering other potentially-relevant sociodemographic, transit-service, and land-use variables, which are addressed in the discussion section.

Confirmed by observations during the census, there is a clear inter-relatedness between seating, shelters, route maps, and ETA screens, which are generally either all present at a stop or all absent (see **Table 1**). For example, for those stops with shelters, 98% of them also provide seating. That group of amenities has a less strong relationship to unobstructed curbs and route signage, for example, if a curb is clear there is only a 47% chance the stop also features seating.

Table 1: Stop Amenity Inter-relatedness. ETA Screens are counted only for those which are functional

	Seating	**Route Signage**	**Shelter**	**Clear Curb**	**NextBus ID**	**Route Map**	**ETA Screen**
If **Seating** is present	-	85%	90%	92%	90%	88%	62%
If **Route Signage** is present	32%	-	29%	66%	87%	28%	20%
If **Shelter** is present	98%	83%	-	85%	91%	94%	67%

If **Curb** is **Clear**	47%	88%	43%	-	83%	42%	29%
If **NextBus ID** is present	37%	95%	35%	68%	-	34%	24%
If **Route Map** is present	99%	83%	98%	93%	91%	-	70%
If **ETA Screen** is present	100%	82%	99%	92%	93%	99%	-

In terms of qualitative observations made during the course of the census, first, many stickers on bus shelters, intended to alert riders as to which route a stop was served by, were worn out from the sun and illegible (see **Figure 6**). Second, the placement of NextBus ID stickers was far from uniform; many were posted very high up on metal or telephone poles (making them difficult to read), and others were obstructed by screws and bolts. Signage painted onto wooden telephone poles was by far the most challenging to read. Pavement paint was worn in many places to the degree that its markings were illegible. Pavement paint was also often obscured by parked cars, which can make it difficult to locate such stops if no other signage is present. To this point, 51% of the stops marked solely with pavement paint had parking-obstructed curbs (123 of 242 total), meaning that they are difficult for riders to locate. As noted in the methods section, only the presence of *legible* route signage were recorded during the census.

Figure 6: Examples (clockwise from top left) of shelter markings worn out from the sun, obscured NextBus ID stickers, telephone poles with difficult-to-read lettering, and worn out pavement paint

There were also aspects of sidewalks which influence stop quality. This includes sidewalk width and evenness. Indeed, very thin sidewalks – barely allowing for two people walking in opposite directions to pass each other – entails that someone waiting for a bus likely feels in the way of pedestrians and may instead wait on the street. In addition, some higher-income neighborhoods maintain a sidewalk design which leaves bus riders little room to wait. In these locations, stretches of vegetation (grass, shrubs, hedges) between the sidewalk and the road (known as a "planting strip") entail that riders must either wade through that area to board or be visible to arriving buses, or wait in the street. These types of issues likely render such stops non-functional for many riders with mobility impairments, large items such as strollers, and/or safety concerns (see **Figure 7**).

Figure 7: Examples of stops with accessibility issues, including (clockwise from top left) those which lack sidewalks, are fenced in by guardrails, are obstructed by perpendicular parking, and are blocked by dense vegetation

Discussion

Equity in transport must not only include a system's coverage, frequency, cost, and directness, but also the stops at which all trips begin and end. For this to happen, agencies must first maintain accurate records as to how stop amenities are distributed, from which they can then prioritize improvements. An in-person census of 2,964 street-level bus stops in San Francisco reveals inconsistency in and inadequacy of amenities, ranging from stops which are clearly marked, provide shelter, seating, real-time arrival information, clear curbs, and route maps, to those which are invisible to potential riders, uncomfortable for those waiting, and hemmed in by parked cars.

Employing a conception of equity based on the social minimum principle, which applied here scrutinizes stop amenities based on their *minimum level* of investment, this chapter finds significant deficits: shelters and seating are absent at a majority of all bus stops, nearly a third of all stops are obstructed by on-street parking, and more than one in ten stops lacks legible route signage of any kind. Moreover, employing Rawls' difference principle, which here concerns the spatial distribution of stop amenities, indicates that the northern half of the city has a greater percentage of stops with seating, shelter, and clear curbs. In addition, clusters of low-amenity stops lie within the city's southeast corner and its southern half generally. There is also evidence of a relationship between stop amenities and race, such that census tracts with higher shares of white residents are more likely to feature bus stops with seating, shelters, and clear curbs.

Breaking down stop amenities by bus route also reveal large disparities, from those routes which have seating at 75% of stops compared to just 10% along others. These differences are further evident when dividing routes by headways; those stops which are served least frequently by buses are least likely to provide seating, shelters, or clear curbs. In essence, the longer a rider likely has to wait for a bus in the SFMTA system, the lower the chance is there are amenities which would make such waiting comfortable. Thus, bus stops in San Francisco are inequitably invested in, with both a minimum level (or floor) of amenities that omits seating, shelter, and unobstructed curbs, and spatial disparities in stop quality that in part track with the city's racial geography.

Relatedly, there is also a connection between route frequency and the geographic distribution of stop amenities; stops in the north half of San Francisco are far more likely to be served by higher-frequency stops (though this does not fully explain the north-south amenity imbalance). This chapter does not challenge the general logic of providing stop amenities at high-usage stops, nor does it believe all stops should be equivalent in terms of investment, but it calls into question the paucity of amenities at low-usage stops, or put another way, the lack of a minimum standard for bus stops. Indeed, as the literature review demonstrates, amenities at a bus stop may actually *alter* ridership, meaning that a low-amenity stop can actively deter it from ever growing. When stops within an entire neighborhood lack basic amenities, as this census identifies in San Francisco, increasing bus ridership may prove difficult.

In addition, a number of qualitative issues were observed, including legibility issues with route signage and NextBus ID stickers, lack of sidewalks or those without pavement, and vegetation which impedes riders' ability to reach the curb. These instances indicate that as much value as there is in quantifying the presence of specific amenities across a system, there is also benefit to visually reviewing transit stops for basic accessibility issues.

There are several directions future research on bus stops can take. First, censuses of this kind generate a rich trove of data that create the opportunity for deeper analyses concerning the presence or absence of amenities and different features of the urban environment. This relates to employment density, automobile ownership, the number of adjacent traffic lanes and speed limits, as well as attributes such as topography, populations of seniors and children, and proximity to rail transit. Though some stop-amenity patterns may be linked to explicit agency policy, others may be less obvious. Furthermore, if transit-stop censuses are to take place elsewhere, researchers must consider how regional differences might dictate what constitute relevant amenities. For example, San Francisco has a mild climate – without particularly hot summers or cold winters – which means that there is no expectation that bus stops maintain heating or cooling capabilities. In contrast, northern cities such as Minneapolis, MN or Portland, ME may be places where bus-stop heating is of primary importance, whereas the availability of shade and air-conditioning could be a crucial amenity in cities such as Dallas, TX or Phoenix, AZ. There are also many other variables which could be related to stop amenities, such as street-tree coverage and/or intensity of the localized heat-island effect, road type and speed limits, and whether or not a stop serves multiple lines and is a common transfer point, among others. Moreover, censuses would benefit from rider interviews to understand if and how amenities influence trip making, as well as transit-agency interviews to determine what strategy was in place guiding the distribution of stop amenities to begin with.

Beyond this pressing research questions, several immediate policy recommendations flow from this census, for SFMTA as well as other agencies to which similar stop-amenity inadequacy and inconsistency likely apply. While time consuming, such a census is a straightforward, highly-accurate means of appraising stop amenities. This method is an ideal way to put oneself in the perspective of a system's current or potential riders in order to understand what may be encouraging or deterring usage. Indeed, close and repeated observation of stops over time can reveal subtle issues – like the placement of NextBus ID stickers – which may otherwise remain invisible. Of course, given the time-intensive nature of this method, future research could also leverage street-view imagery to evaluate bus stops, particularly considering its utility in studies of traffic signs, light poles, sidewalks, and street trees (among many other targets; Biljecki and Ito, 2021).

As to specific amenities, first, the signage inconsistency documented (on top of the 11% of stops with no signage at all) makes locating stops difficult, particularly for those who have low-vision, or who are infrequent riders. Though SFMTA indicated that it would add metal signs to all stops (Bialick, 2015), this is still far from being the case, with the most common route signage being paint on metal street poles. Second, stops in any system which require riders to wade through parked cars in order to board are incredibly inconvenient and plainly fail a 'transit-first' policy. Such a layout is difficult to navigate for anyone with a mobility impairment, or with a stroller, and explicitly privileges automobile storage over transit use. Similar issues with stop accessibility in other cities have drawn lawsuits arguing transit agencies are violating the Americans with Disabilities Act (Sachs, 2007; Nobles, 2016). Third, given evidence that wait times are perceived as significantly longer for those who have to stand, seating of some kind should be present at as many stops as possible, rather than the current state of the SFMTA system, which provides seating at less than half of all stops.

This chapter has several limitations. First, a census of bus stops leaves out other system features which undoubtedly influence travel, such as pricing, layout, vehicle quality, crowding, and the ability to reach stops safely (Spears et al., 2013). Second, this chapter does not address or account for other factors contributing to stop quality, such as placement in relation to the block or nearest intersection (Diab and El-Geneidy, 2015), how bus stops relate to the flow of pedestrians (Hall et al., 2006), or the relationship of stops to bus and bike lanes (Zhang et al., 2018). Third, simply noting the presence of an amenity at a certain stop can leave out important details; for example, many of the ETA screens across the SFMTA system are often incorrect even when they are to outward appearances functioning (Graf, 2020). Fourth, as would be the case at nearly any point in time, this chapter excluded a small number of bus stops in San Francisco due to active construction, which prevented amenities from being cataloged. Fifth, there are likely other amenities that could have been included in this census, such as adjacent street lights, trash cans, or sidewalk incline. Lastly, there are other forms of public transit citywide, including light-rail, commuter rail (Caltrain), and a subway system (BART), which this chapter does not address but nonetheless influences travel-behavior decisions and possibly SFMTA decision-making as to stop investments.

Finally, this census gathered data that could likely benefit riders if incorporated into trip-planning and wayfinding applications. One way this could be achieved is if GTFS, the technical standard for transit data sharing, is expanded to include stop amenities, such as seating and shelters. This would then require transit agencies to populate their stop records with current amenity information. Such additions could allow services like Google Maps or Apple Maps to alert users as to which stops have specific amenities, which could affect travel choices. For example, someone who has trouble standing for extended periods of time may want to filter nearby bus stops by those which provide seating. Or, riders may sort stops by the presence of shelter on a day with heavy rain. These scenarios only scratch the surface of possible advantages from making amenity information available to application developers, and eventually, travelers. Overall, stop amenities are an important component of transit trips, they can be reliably cataloged via manual visits, and reveal a great number of details about the allocation of resources across a system, which can inform improvements and perhaps even individual trip making.

References

Abenoza, R.F., V. Ceccato, Y.O. Susilo, and O. Cats. 2018. "Individual, Travel, and Bus Stop Characteristics Influencing Travelers' Safety Perceptions." *Transportation Research Record* 2672 (8): 19–28. https://doi.org/10.1177/0361198118758677.

Amin, R. 2018. "Transit Ridership on the Decline Across the U.S." *The Urbanist, SPUR*, December 2018. https://www.spur.org/publications/urbanist-article/2019-01-24/transit-ridership-decline-across-us.

Attoh, K.A. 2019. *Rights in Transit: Public Transportation and the Right to the City in California's East Bay*. Geographies of Justice and Social Transformation 40. Athens: The University of Georgia Press.

Azenkot, S., S. Prasain, A. Borning, E. Fortuna, R.E. Ladner, and J.O. Wobbrock. 2011. "Enhancing Independence and Safety for Blind and Deaf-Blind Public Transit Riders." *Human Factors in Computing Systems*, Conference on Human Factors in Computing Systems, , May, 3247–56. https://doi.org/10.1145/1978942.1979424.

Baldwin, B., H. Boll, A. Lehto, J. Tump, Y. Park, M. Wyffels, W. Schlegel, and D. Huntington. 2010. "Bus Stops Guidelines." Portland, OR: TriMet. https://nacto.org/wp-content/uploads/2015/04/bus_stop_guidelines_trimet.pdf.

Barrero, R., J.V. Mierlo, and X. Tackoen. 2008. "Energy Savings in Public Transport." *IEEE Vehicular Technology Magazine* 3 (3): 26–36. https://doi.org/10.1109/MVT.2008.927485.

Bialick, A. 2015. "Muni's Yellow Pole Markings at Transit Stops Will Be Replaced By Real Signs." *Streetsblog San Francisco* (blog). April 23, 2015. https://sf.streetsblog.org/2015/04/23/munis-yellow-pole-markings-at-transit-stops-will-be-replaced-by-real-signs/.

Biljecki, F., and K. Ito. 2021. "Street View Imagery in Urban Analytics and GIS: A Review." *Landscape and Urban Planning* 215 (November): 104217. https://doi.org/10.1016/j.landurbplan.2021.104217.

Bliss, L. 2019. "Very Bad Bus Signs and How to Make Them Better." *CityLab*, September 19, 2019. https://www.citylab.com/transportation/2019/09/bus-stop-sign-design-public-transit-investment-city-signage/598279/.

"Bus Stop Design & Planning Guide." 2011. Rogue Valley Transportation District. https://www.rvtd.org/Files/RVTD%20BUS%20STOP%20DESIGN%20GUIDELINES.pdf.

"Bus Stop Safety and Accessibility Study." 2018. Radford, VA: New River Valley Metropolitan Planning Organization. http://nrvrc.org/wp-content/uploads/2018/05/RT-Bus-Stop-Safety-and-Transportation-Study.pdf.

Campbell, M., C. Bennett, C. Bonnar, and A. Borning. 2014. "Where's My Bus Stop? Supporting Independence of Blind Transit Riders with StopInfo." In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility*, 11–18. ASSETS '14. Rochester, New York, USA: Association for Computing Machinery. https://doi.org/10.1145/2661334.2661378.

Cassidy, M. 2020. "Muni to Close Majority of Bus Lines Because of Coronavirus." *San Francisco Chronicle*, April 5, 2020, sec. Local. https://www.sfchronicle.com/bayarea/article/Muni-to-close-majority-of-bus-lines-due-to-15180935.php.

Clanton, N. 2020. "MARTA Army Wants Your Opinion on Atlanta Bus Stops." *Atlanta Journal Constitution*, February 5, 2020. https://www.ajc.com/news/transportation/marta-army-wants-your-opinion-atlanta-bus-stops/s3XY1sDz5fIVCMjupn82eP/.

Colosi, L., R. Burk, and K. Barr. 2018. "Harrisburg Bus Stop Optimization Project." City of Harrisburg Pennsylvania. https://static1.squarespace.com/static/56dc3f9cb654f9876576bab7/t/5c866701e4966b5f3f4b9bcc/1552312070233/HarrisburgBusStopOptimizationReport.pdf.

Corazza, M.V., and N. Favaretto. 2019. "A Methodology to Evaluate Accessibility to Bus Stops as a Contribution to Improve Sustainability in Urban Mobility." *Sustainability* 11 (3): 803. https://doi.org/10.3390/su11030803

Diab, E.I., and A.M. El-Geneidy. 2015. "The Farside Story: Measuring the Benefits of Bus Stop Location on Transit Performance." Transportation Research Record: Journal of the Transportation Research Board, no. 2538. https://trid.trb.org/view/1337034.

Di Ciommo, F., and Y. Shiftan. 2017. "Transport Equity Analysis." *Transport Reviews* 37 (2): 139–51. https://doi.org/10.1080/01441647.2017.1278647.

Erhardt, G.D., M. Graehler, Jr., and R.A. Mucci. 2018. "Understanding the Recent Transit Ridership Decline in Major US Cities: Service Cuts or Emerging Modes?" In . Washington, D.C. https://usa.streetsblog.org/wp-content/uploads/sites/5/2019/01/19-04931-Transit-Trends.pdf

Fan, Y., A. Guthrie, and D. Levinson. 2016. "Perception of Waiting Time at Transit Stops and Stations." Minneapolis, MN: Center for Transportation Studies - University of Minnesota. http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=2502.

Feke, M., B. Temming, and J. Freilich. 2018. "Bus Stop Design Guidelines." Cleveland, OH: Greater Cleveland Regional Transit Authority. https://www.riderta.com/sites/default/files/serviceplanning/BusStopDesignGuidelines.pdf

Ferris, B., K. Watkins, and A. Borning. 2010. "OneBusAway: Results from Providing Real-

Time Arrival Information for Public Transit." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1807–1816. CHI '10. Atlanta, Georgia, USA: Association for Computing Machinery. https://doi.org/10.1145/1753326.1753597.

Finch, C.D. 2013. "Bus Stop Accessibility Study." Roanoke Valley Area Metropolitan Planning Organization. https://rvarc.org/wp-content/uploads/2013/10/Bus-Stop-Accessibility-Study_9-26-13.pdf.

Fitzgerald Rodriguez, J. 2020. "End of an Era: Market Street to Go Car Free Jan. 29." San Francisco Examiner, January 2, 2020, sec. The City. https://www.sfexaminer.com/news/end-of-an-era-market-street-to-go-car-free-jan-29/.

Fitzpatrick, K., K. Hall, D. Perkinson, L. Nowlin, and R. Koppa. 1996. "Guidelines for the Location and Design of Bus Stops." Report 19. College Station, TX: Texas A&M University. https://nacto.org/docs/usdg/tcrp_report_19.pdf.

"Go Boston 2030." 2017. City of Boston. https://www.boston.gov/departments/transportation/go-boston-2030.

Golub, A., R.A. Marcantonio, and T.W. Sanchez. 2013. "Race, Space, and Struggles for Mobility: Transportation Impacts on African Americans in Oakland and the East Bay." *Urban Geography* 34 (5): 699–728. https://doi.org/10.1080/02723638.2013.778598.

Gordon, R. 2007. "S.F. Muni Board OKs Plan for Clear Channel to Sell Transit Shelter Ads." *San Francisco Chronicle*, September 4, 2007, sec. Bay Area & State. https://www.sfgate.com/bayarea/article/S-F-Muni-board-OKs-plan-for-Clear-Channel-to-2505237.php.

Graehler Jr, M., R.A. Mucci, and G.D. Erhardt. 2019. "Understanding the Recent Transit Ridership Decline in Major US Cities: Service Cuts or Emerging Modes?" In , 19. Washington, D.C. https://trid.trb.org/view/1572517.

Graf, C. 2020. "Muni Arrival Time System Set to Get $89 Million Upgrade." *San Francisco 20*, July 22, 2020, sec. The City. https://www.sfexaminer.com/news/muni-arrival-time-system-set-to-get-89-million-upgrade/.

Grengs, J. 2002. "Community-Based Planning as a Source of Political Change: The Transit Equity Movement of Los Angeles' Bus Riders Union." *Journal of the American Planning Association* 68 (2): 165–78. https://doi.org/10.1080/01944360208976263.

"Guidelines: Design and Placement of Transit Stops." 2009. Washington, D.C.: Washington Metropolitan Area Transit Authority. https://nacto.org/docs/usdg/design_and_placement_of_transit_stops_kfh.pdf.

Hall, S., J. Desyllas, and A. Byrne. 2006. "Bus Stops – How People Actually Use Them and the Implications for Design." *ETC Proceedings*, 31. https://stuff.mit.edu/afs/athena/course/11/11.951/OldFiles/oldstuff/albacete/Other_Docu ments/Europe%20Transport%20Conference/traffic_engineering_an/bus_stops_how_peop 1480.html

Han, Y., W. Li, S. Wei, and T. Zhang. 2018. "Research on Passenger's Travel Mode Choice Behavior Waiting at Bus Station Based on SEM-Logit Integration Model." *Sustainability* 10 (6): 1–23.

Hara, K., S. Azenkot, M. Campbell, C.L. Bennett, V. Le, S. Pannella, R. Moore, K. Minckler, R.H. Ng, and J.E. Froehlich. 2015. "Improving Public Transit Accessibility for Blind Riders by Crowdsourcing Bus Stop Landmark Locations with Google Street View: An Extended Analysis." *ACM Transactions on Accessible Computing* 6 (2): 5:1-5:23. https://doi.org/10.1145/2717513.

Hart, K. 2020. "Public Transit's Death Spiral." *Axios*, April 8, 2020, sec. Health. https://www.axios.com/coronavirus-public-transportation-subway-bus-ridership-9f039bd9-459b-45f9-954c-b26380a037dc.html.

Hodges, T. 2010. "Public Transportation's Role in Responding to Climate Change." US DOT Federal Highway Administration. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf.

Hosford, K., S. Tremblay, and M. Winters. 2020. "Identifying Unmarked Crosswalks at Bus Stops in Vancouver, Canada." *Transport Findings*, June. https://doi.org/10.32866/001c.13207.

Kim, Y.K., K. Bartholomew, and R. Ewing. 2018. "Impacts of Bus Stop Improvements." UT-18.04. Utah Department of Transportation - University of Utah Department of City & Metropolitan Planning. http://mrc.cap.utah.edu/wp-content/uploads/sites/8/2015/12/UT-18.04-Impacts-of-Bus-Stop-Improvements.pdf.

Lagune-Reutler, M., A. Guthrie, Y. Fan, and D. Levinson. 2016. "Transit Stop Environments and Waiting Time Perception: Impacts of Trees, Traffic Exposure, and Polluted Air." Transportation Research Record 2543 (1): 82–90. https://doi.org/10.3141/2543-09.

Lamoureux, Z., and V. Fast. 2019. "The Tools of Citizen Science: An Evaluation of Map-Based Crowdsourcing Platforms." *Spatial Knowledge and Information Canada* 7 (4): 7.

Law, P., and B.D. Taylor. 2001. "Shelter from the Storm: Optimizing Distribution of Bus Stop Shelters in Los Angeles." *Transportation Research Record* 1753 (1): 79–85. https://doi.org/10.3141/1753-10.

Loukaitou-Sideris, A. 1999. "Hot Spots of Bus Stop Crime." *Journal of the American Planning Association* 65 (4): 395–411. https://doi.org/10.1080/01944369908976070.

Lusk, A. 2001. "Bus and Bus Stop Designs Related to Perceptions of Crime." FTA

MI-26-7004-2001.8. Federal Transit Administration, U.S. Department of Transportation. https://cdn1.sph.harvard.edu/wp-content/uploads/sites/1008/2013/09/bus-and-bus-stop-lusk.pdf.

Merry, K., and P. Bettinger. 2019. "Smartphone GPS Accuracy Study in an Urban Environment." *PLOS ONE* 14 (7): e0219890. https://doi.org/10.1371/journal.pone.0219890.

"Metro Transit Bus Stop Amenities Study." 2018. Madison Area Transportation Planning Board. http://www.madisonareampo.org/planning/documents/BusStopAmenitiesStudy.pdf.

Moore, A., M. Figliozzi, and C.M. Monsere. 2012. "Air Quality at Bus Stops: Empirical Analysis of Exposure to Particulate Matter at Bus Stop Shelters." *Transportation Research Record*, January. https://doi.org/10.3141/2270-10.

Moran, M.E. 2021. "Drawing the Map: The Creation and Regulation of Geographic Constraints on Shared Bikes and E-Scooters in San Francisco, Ca." *Journal of Transport and Land Use* 14 (1): 197–218. https://doi.org/10.5198/jtlu.2021.1816.

NACTO, ed. 2016. *Transit Street Design Guide*. Washington: Island Press. https://nacto.org/2016/04/14/transit-street-design-guide/

"Next Generation Customer Information System." 2020. Presented at the SFMTA Board of Directors Meeting, San Francisco, CA, June 16. https://www.sfmta.com/sites/default/files/reports-and-documents/2020/06/6-16-20_item_14_contract_-_customer_info_system_-_slide_presentation.pdf.

Nobles, W.P. 2016. "New Orleans Faces Lawsuit over Inaccessible Bus Stops." *The Times-Picayune*, March 29, 2016, sec. New Orleans. https://www.nola.com/news/traffic/article_5a1506a5-c8ef-514a-a3ec-e4687ffa2413.html.

Parsons, and Gruen. 2013. "Transit Design Guidelines." OmniTrans. https://design.omnitrans.org/wp-content/uploads/2014/03/OmnitransDesignGuidelines-08.pdf.

Pereira, R.H.M., T. Schwanen, and D. Banister. 2017. "Distributive Justice and Equity in Transportation." *Transport Reviews* 37 (2): 170–91. https://doi.org/10.1080/01441647.2016.1257660.

Pierce, G., and D. Shoup. 2013. "Getting the Prices Right." *Journal of the American Planning Association* 79 (1): 67–81. https://doi.org/10.1080/01944363.2013.787307.

Pulugurtha, S., and V. Vanapalli. 2008. "Hazardous Bus Stops Identification: An Illustration Using GIS." *Journal of Public Transportation* 11 (2). https://doi.org/10.5038/2375-0901.11.2.4.

Rawls, J. 1999. *A Theory of Justice*. Revised Edition. Cambridge, MA: Belknap Press, Harvard University Press.

Roper, E. 2014. "Hundreds of Metro Bus Stops Have Thousands Seeking Shelters." *StarTribune*, September 2, 2014. https://www.startribune.com/2014-hundreds-of-metro-bus-stops-have-thousands-seeking-shelters/265979041/?refresh=true.

Rubenstein, S. 2016. "Sf Marks the Very Middle of Town, More or Less." *San Francisco Chronicle*, June 8, 2016. https://www.sfgate.com/bayarea/article/SF-marks-the-very-middle-of-town-more-or-less-7971599.php.

Sachs, P. 2007. "Repairs Lag, Costs Soar on Bend's Ada Fixes." *The Bulletin*, August 16, https://www.bendbulletin.com/localstate/repairs-lag-costs-soar-on-bend-s-ada-fixes/article_4c3978f5-5dbf-5705-abd7-2e808c3f90a8.html.

Schaller, B. 2018. "The New Automobility: Lyft, Uber and the Future of American Cities." Brooklyn, NY: Schaller Consulting. http://www.schallerconsult.com/rideservices/automobility.pdf.

Schmitt, A. 2018. "'Sorriest Bus Stops' Contest Final Four Battle: Vancouver vs. Pittsburgh." Streetsblog USA (blog). September 6, 2018. https://usa.streetsblog.org/2018/09/06/sorriest-bus-stops-contest-final-four-battle-vancouver-vs-pittsburgh/.

Songchitruksa, P., and X. Zeng. 2010. "Getis–Ord Spatial Statistics to Identify Hot Spots by Using Incident Management Data." *Transportation Research Record* 2165 (1): 42–51. https://doi.org/10.3141/2165-05.

"Space Coast Area Transit Bus Stop Accessibility Study." 2018. https://spacecoasttpo.com/wp-content/uploads/2018/12/SCTPO-Bus-Stop-ADA-FINAL-REPORT-11-28-18-1.pdf.

Spears, S., D. Houston, and M.G. Boarnet. 2013. "Illuminating the Unseen in Transit Use: A Framework for Examining the Effect of Attitudes and Perceptions on Travel Behavior." *Transportation Research Part A: Policy and Practice* 58 (December): 40–53. https://doi.org/10.1016/j.tra.2013.10.011.

Stanley, J., D.A. Hensher, J. Stanley, G. Currie, W.H. Greene, and D. Vella-Brodrick. 2011. "Social Exclusion and the Value of Mobility." *Journal of Transport Economics and Policy* 45 (2): 197–222.

Swan, R. 2019. "City Speeds up Approval Process for New Bike Lanes, Road Safety Improvements." *San Francisco Chronicle*, June 5, 2019. https://www.sfchronicle.com/bayarea/article/City-speeds-up-approval-process-for-new-bike-13937408.php#.

Tang, L., and P. Thakuriah. 2012. “Ridership Effects of Real-Time Bus Information System: A Case Study in the City of Chicago.” *Transportation Research Part C: Emerging Technologies* 22 (June): 146–61. https://doi.org/10.1016/j.trc.2012.01.001.

“Transit-First Policy.” 2007. San Francisco Municipal Transportation Agency. https://www.sfmta.com/transit-first-policy.

“Transportation System Plan.” 2018. Portland Bureau of Transportation. https://www.portlandoregon.gov/transportation/article/690972.

Waldron, J. 1986. “John Rawls and the Social Minimum.” *Journal of Applied Philosophy* 3 (1): 21–33. https://doi.org/10.1111/j.1468-5930.1986.tb00046.x.

Watkins, K.E., B. Ferris, A. Borning, G.S. Rutherford, and D. Layton. 2011. “Where Is My Bus? Impact of Mobile Real-Time Information on the Perceived and Actual Wait Time of Transit Riders.” *Transportation Research Part A: Policy and Practice* 45 (8): 839–48. https://doi.org/10.1016/j.tra.2011.06.010.

Weithman, P.J. 1995. “Waldron on Political Legitimacy and the Social Minimum.” *The Philosophical Quarterly (1950-)* 45 (179): 218–24. https://doi.org/10.2307/2220421.

Woetzel, J., J. Remes, B. Boland, K. Lv, S. Sinha, G. Strube, J. Means, J. Law, A. Cadena, and V. von der Tann. 2018. “Smart Cities: Digital Solutions for a More Livable Future.” McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/industries/capital%20projects%20and%20infrastructure/our%20insights/smart%20cities%20digital%20solutions%20for%20a%20more%20livable%20future/mgi-smart-cities-full-report.ashx.

Wu, W., A. Gan, F. Cevallos, and L. Shen. 2011. “Selecting Bus Stops for Accessibility Improvements for Riders with Physical Disabilities.” *Journal of Public Transportation* 14 (2). https://doi.org/10.5038/2375-0901.14.2.7.

Zhang, J., Z. Li, F. Zhang, Y. Qi, W. Zhou, Y. Wang, D. Zhao, and W. Wang. 2018. “Evaluating the Impacts of Bus Stop Design and Bus Dwelling on Operations of Multitype Road Users.” *Journal of Advanced Transportation* 2018 (December): 10. https://doi.org/10.1155/2018/4702517.

Material for this chapter is published in:

Moran, M.E. 2021. “Are Shelters in Place? Mapping the Distribution of Transit Amenities via a Bus-Stop Census of San Francisco.” *Journal of Public Transportation,* 24(1).

Appendix: Table 2. Stop Amenities by SFMTA Bus Route

Route	Headway	Seating	Shelter	Clear Curb	Route Map	ETA Screen	Route Signage	NextBus ID
1	10 min	44%	44%	86%	44%	34%	96%	90%
2	10-20 min	62%	58%	99%	59%	46%	87%	80%
3	10-20 min	44%	42%	86%	44%	32%	91%	82%
5	10 min	74%	75%	99%	73%	52%	96%	89%
6	10-20 min	31%	43%	77%	29%	25%	97%	91%
7	10 min	38%	45%	81%	38%	27%	98%	80%
8	10 min	48%	44%	81%	44%	31%	93%	84%
9	10 min	29%	37%	78%	27%	18%	92%	74%
10	10-20 min	29%	26%	61%	26%	9%	87%	84%
12	10-20 min	53%	46%	91%	47%	13%	95%	94%
14	10 min	56%	55%	95%	55%	46%	92%	85%
18	20-30 min	30%	28%	51%	27%	20%	95%	91%
19	10-20 min	30%	29%	62%	27%	14%	88%	80%
21	10-20 min	63%	71%	100%	63%	44%	83%	88%
22	10 min	53%	55%	90%	53%	42%	90%	82%
23	20-30 min	17%	16%	62%	18%	10%	85%	76%
24	10-20 min	36%	31%	59%	31%	27%	94%	95%
25	10 min	61%	61%	94%	0%	0%	94%	94%
27	10-20 min	53%	45%	94%	47%	29%	85%	79%
28	10 min	58%	57%	99%	55%	41%	94%	88%
29	10-20 min	38%	24%	72%	22%	17%	95%	82%
30	10 min	45%	40%	83%	42%	24%	95%	89%
31	10-20 min	53%	51%	66%	49%	41%	94%	94%
33	10-20 min	36%	36%	82%	36%	33%	94%	81%

35	20-30 min	10%	5%	32%	5%	3%	87%	76%
36	20-30 min	16%	13%	39%	13%	11%	95%	90%
37	20-30 min	16%	14%	35%	12%	9%	97%	76%
38	10 min	75%	76%	92%	74%	54%	91%	91%
39	20-30 min	15%	12%	47%	15%	12%	88%	85%
41	N/A	22%	20%	88%	20%	14%	94%	84%
43	10-20 min	31%	30%	61%	27%	23%	91%	80%
44	10-20 min	35%	34%	65%	33%	19%	90%	74%
45	10-20 min	33%	27%	88%	27%	17%	92%	87%
47	10 min	51%	36%	96%	42%	27%	93%	91%
48	10-20 min	31%	25%	52%	25%	18%	88%	88%
49	10 min	42%	32%	97%	32%	25%	85%	83%
52	20-30 min	25%	22%	49%	24%	16%	93%	75%
54	20-30 min	11%	11%	31%	11%	8%	91%	66%
55	10-20 min	52%	52%	91%	52%	35%	78%	70%
56	20-30 min	17%	12%	26%	10%	7%	93%	83%
57	20-30 min	18%	13%	89%	10%	5%	96%	82%
66	20-30 min	14%	14%	16%	12%	14%	88%	86%
67	20-30 min	13%	11%	32%	11%	8%	92%	82%
76	N/A	44%	31%	94%	31%	19%	88%	75%
79	N/A	50%	20%	100%	20%	20%	100%	100%
81	N/A	60%	60%	100%	60%	20%	100%	80%
82	N/A	35%	35%	95%	35%	25%	100%	85%
83	10-20 min	25%	25%	100%	25%	0%	100%	100%
88	N/A	39%	39%	94%	39%	39%	100%	94%
90	N/A	47%	42%	100%	42%	26%	96%	89%
91	N/A	42%	38%	87%	38%	26%	90%	87%

Chapter 3:
Analyzing Angled Parking via Satellite Imagery to Aid Bike-Network Planning

Summary:
U.S. cities prioritize the storage of automobiles over the safe movement of bicycles. While this generally occurs by allocating street curbs for car parking (rather than bike lanes), the privileging of the automobile is even more evident in the case of *angled* parking, in which cars sit roughly perpendicular to the flow of traffic. Such a layout takes up nearly double the space in the right of way as does parallel parking, leaving even less room for bike infrastructure. Though angled parking is defended as a traffic-calming measure, numerous studies indicate that this layout is associated with higher rates of collisions than parallel parking. In addition, angled parking also inherently increases the number of cars which can be parked along a given curb, which further incentivizes automobile travel. However, one challenge of understanding the impact that angled parking has on transportation safety and bicycle infrastructure is that cities do not always maintain accurate records as to where angled parking occurs. For example, San Francisco, CA has ambitious air-quality, carbon-emission, and active-transportation goals, all of which are made more challenging by angled parking. Yet, its supply of this parking layout is unquantified, given parking angle was omitted from the city's parking census. This study uses satellite imagery to resolve this data gap, and calculates that San Francisco dedicates 50 miles of street curbs to angled parking. While some assume angled parking is a planning response to San Francisco's famed hills, the majority of it occurs on streets with no incline at all. As to angled parking's traffic-calming effect, this benefit appears to be non-existent in San Francisco; average vehicle speeds differed by less than a half-mile per hour between angled-parking streets and adjacent non-angled streets. The angled parking identified here – particularly four miles which lie adjacent to the city's bike-lane network – represent opportunities for conversion to more multimodal road layouts. Overall, this methodology can serve as the basis for identifying angled parking in other cities, a configuration which should be re-evaluated by transportation planners given its car-centric effects, debatable ability to calm traffic, and preclusion of separated bicycle facilities.

Introduction

The designation of public curbs for private vehicle storage (on-street parking) is a dominant feature of American cities. These planning decisions prioritize empty automobiles over the safe movement of bicyclists. Angled parking – in which cars are parked perpendicular or similar angles to the flow of traffic – entail even more space in the public right of way is dedicated to car storage than parallel parking. Indeed, angled parking allows for roughly double the number of cars to be parked on along a given length of curb (see **Figure 1**).

Figure 1: Satellite image of angled parking in San Francisco, CA. In this image, ten cars are parked in an angled format on the left side, whereas there is room for close to six cars on the right side, in parallel format.

Angled parking thus reduces the space available that could otherwise be used for separated bike lanes, as well as widened sidewalks, parklets, street trees, and bikeshare stations. In addition, though angled parking is often supported for its traffic-calming benefits, the empirical basis for this claim is weak – and complicated by findings of increased automobile collisions compared to parallel parking. In addition, angled parking is far from the only option cities have at their disposal for street calming, and most others (e.g. speed bumps, chicanes, etc.) do not increase parking capacity. Given the growing push for 'complete streets' in cities around the world (LaPlante and McCann, 2008; McCann and Rynne, 2010; Moreland-Russell et al., 2013) – which entail less car dominance and more room for cyclists, pedestrians, and transit riders – angled parking should be scrutinized given its presence blunts more-balanced roadway layouts. However, in order to re-evaluate angled parking, transportation planners need accurate accounting as to how much of it and where it is present in their city. This is no trivial task and can be complicated by inadequate or our outdated records of municipal parking supply, which – even if current – may not contain attributes such as parking angle.

One way to circumvent parking records is to employ satellite imagery as a means of identifying angled parking. Such a method builds on previous use of remote sensing to document urban form, which can be supplemented with other spatial data sets, such as those indicating where bike lanes occur, as well as street-specific driving speeds. San Francisco, a city of roughly 900,000 in Northern California, represents an ideal case for identifying angled parking in this way. To begin, such parking undermines municipal priorities, including decreasing the use of automobiles from 48% of trips in 2017 to 20% by 2030 ("Climate Goals," 2017), reductions to air pollution and carbon emissions ("Reaching 80x50," 2016; "Air Quality Community Risk Reduction Plan," 2017), and eliminating pedestrian fatalities by 2024 ("Vision Zero Action Strategy," 2018). Each of these targets relates to automobile usage and traffic safety, both of which angled parking can influence, because it increases the supply of parking on a given street compared to parallel parking (which encourages driving), and because angled parking itself reduces pedestrian visibility and uses up space that could otherwise be diverted to bike lanes. To this point, in 2019 Mayor London Breed ordered the city to build at least 20 miles of new separated bike lanes by the end of 2021, which if accomplished would require a significant increase in the pace of the bike-lane construction (Swan, 2019). For context, at the end of 2018 San Francisco contained 19 miles of separated bike lanes, which means the new target requires a doubling of that mark by 2021 (Grochmal, 2019).

Though cursory travel within San Francisco reveals the presence of angled parking, it is unquantified in terms of size, location, and relationship to the bike-lane network. The San Francisco Municipal Transportation Agency (SFMTA), which oversees the city's public right of way, completed a comprehensive parking census in 2014, but omitted parking angle (Bialick, 2014). Written correspondence with staff at SFMTA confirmed that the amount and location of angled parking is unknown, and though pavement striping diagrams are publicly available for every street, they also do not consistently display parking-configuration details. One reason there may be scant information on this topic is that parking-layout changes have generally occurred sporadically over many decades. For example, SFMTA allowed residents of a specific street to vote on whether or not to convert existing parking to an angled layout, but that was not tied to similar processes elsewhere ("Angled Parking Vote Update," 2017).

Overall, there is ample reason to determine the amount and location of angled parking in San Francisco, and satellite imagery provides a way to do so without a large budget or parsing archival transportation plans. This paper proceeds with a literature review that covers arguments for and research into angled parking, a detailed description of how satellite imagery is used to identify it, results as to how much and where angled parking is present in San Francisco, if it provides any traffic calming effect, and a discussion as to what such information can provide to city planners tasked with increasing active transportation.

Literature Review

For the purposes of this chapter, angled parking refers to all curb-side parking that is not parallel (including perpendicular parking), which has also been called 'diagonal,' 'bay,' or 'echelon' parking. The rationale for such layouts in urban settings generally breaks into two components. First, angled parking can be a mechanism to simply increase parking capacity when its supply is considered inadequate for any given street, which is often the position of local residents and merchants. Second, proponents within the planning, traffic engineering, and urban design professions contend that angled parking functions as a street-calming measure, with the logic being that a narrower traffic lane (given more space in the right of way is dedicated to parking) causes motorists to drive more slowly. As an example, the City of Gaithersburg, Maryland succinctly captures this position, writing in its "Street Design Standards" that angled parking can be: "implemented to provide a road narrowing or mid-block deflection traffic calming benefit" (2018). This argument is replicated in numerous other planning guides, including New York City's "Street Design Manual" (2015).

However, this supposition has both logical and empirical flaws. First, it conflates the traffic-calming benefits of angled parking with narrower streets, not taking into account the prospect that achieving a narrower street *via* angled parking may introduce its own set of safety hazards. For example, angled parking worsens visibility at intersections; when it occurs all the way up to a crosswalk (no 'daylighting'), motorists cannot see pedestrians until they are much farther out into the street (see **Figure 2a**). Conversely, this also entails that the ability of pedestrians to see oncoming traffic is also reduced. In 2000, the U.S. Federal Highway Administration, released a report on pedestrian safety which recommended restricting parking at intersections for this very reason. Specifically, it pointed out that if parking by crosswalks is angled, such a layout reduces the *sight distance*, meaning that pedestrians must be farther out into the crosswalk to effectively see oncoming traffic in time to safely react ("Safer Journey," 2000).

Second, because angled parking takes up space that could be used for bike lanes, this potentially reduces any traffic-calming benefit for those traveling by bike, given that studies consistently demonstrate that bike lanes are associated with reductions in crashes (Chen et al., 2012; Pucher & Buehler, 2016; Marshall & Ferenchak, 2019). Moreover, city-specific and multi-city studies also demonstrate that the level of a bike lane's separation from cars (from sharrow to painted lane to separated lane) relates to its efficacy (Duthie et al., 2010; Ferenchak and Marshall, 2016; Cicchino et al., 2020), which means that even if angled parking leaves space left for a bike lane, it likely means a narrower and less-protective one. To this point, angled parking in San Francisco sometimes entails the interruption of bike lanes (see **Figure 2b**).

Figure 2a (left): An intersection with angled parking in San Francisco. Note that the crosswalk begins at the stop sign in the right of the photograph, yet pedestrians (especially children) are not visible to oncoming motorists until they step out beyond the parked cars.
Figure 2b (right): Satellite image of a street in San Francisco in which angled parking interrupts a painted bike lane (top half of image).

Third, angled parking also entails maneuvers for motorists during the act of entry and exit that can often require crossing into a lane of oncoming traffic. This feature conceivably increases the opportunities for crashes to occur, both with other motorists as well as with cyclists. Fourth, empirical evidence on the safety outcomes of angled parking challenges its traffic-calming reputation. Initial work that reviewed the difference in crashes between angled and parallel parking found that the former was associated with more crashes, even when controlling for different types of roadways and land uses (McCoy et al., 1990). This same research team evaluated the safety implications of converting parallel to angled parking, and determined that streets which converted to angled parking had significant increases in collisions (McCoy et al., 1991). Subsequent studies on angled-parking pilots have reached similar conclusions, including a review stating that: “when curbside parking is allowed, parallel is much safer than angle on a mileage basis for local, collector, and major routes and creates far less interference with traffic flows” (Box, 2002). Fifteen years later, another review recommended that: “when allowed, on-street parking should be parallel, not angled, because the latter is hazardous in all respects” (Biswas et al., 2017).

Remote sensing, in this case the use of satellite imagery, has been employed in a number of studies on cities, including to better understand urban form and its effects. In the context of parking, remote sensing has been utilized for at least two decades (Jensen and Cowen, 1999). As satellite imagery has improved in resolution and fallen in cost, studies have analyzed parking lot size and placement as they relate to urban heat island effects (Onishi et al., 2010), produced detailed parking maps of entire cities (Scharnhorst, 2018), and even used machine learning to predict the location of parking on roads obscured by building shadows or tree cover (He et al., 2019). Beyond academic research, there are also for-profit companies tracking parking via satellites as a measure of economic activity and indicator of company sales (Hope, 2014, Partnoy, 2019). Though, none of these studies or ventures have used such methods to distinguish between parallel and angled parking, or quantify the latter's distribution across a single city. Nor has there been an attempt to use satellite imagery to consider the implications of on-street parking on bicycling infrastructure or driving behavior.

Methods

Angled parking on city streets is a highly-visible feature from the perspective of any road user, be they pedestrians, cyclists, or motorists. Its conspicuousness also means that it can be identified from satellite imagery (given adequate resolution), such as those available at no cost from online mapping services such as Google Maps and Bing Maps. This study employs satellite imagery (acquired in mid-2019 from Google Maps) to locate all angled parking in the public right of way in San Francisco. Angled parking occurs in a number of layouts citywide, from fully-perpendicular parking to those which vary given the curvature of the street (see **Figure 3)**.

Figure 3: Examples of angled parking in San Francisco, CA.

For this chapter, every public street in San Francisco was manually reviewed for the presence of angled parking, which – when identified – was stored as a line within a vector-based GIS layer. At the time each angled-parking segment was recorded, the following attributes were coded:

- Length of curb space dedicated for each angled parking segment (in feet), via Google Maps measurement tool;
- Street category (residential, commercial, industrial, park / school / hospital / civic / religious center);

- Whether or not the street was a dead end;
- Whether the parking was fully perpendicular or at a different angle
- Whether a bike lane was present along the angled parking segment (and if so, what type of bike lane: sharrow, painted lane, separated lane); and
- Whether or not the opposite side of the street also had angled parking.

In terms of street category, this process was also manual; each street segment with angled parking was reviewed for the presence of residences, offices, shops, industrial sites, parks, schools, hospitals, and civic or religious centers. Only streets that were completely residential were categorized as such. Relatedly, streets that were 'mixed,' such as those containing both residences and commercial functions (e.g. restaurants, shops) were classified as commercial. This exercise excluded all parking lots, private roads, and driveways. This process was slow (according to the city's parking census, San Francisco has 900 miles of on-street parking), but it is likely highly accurate compared to automating identification with supervised classification. First, such an approach would likely have a high false-positive rate, including a large number of parking lots, as well as cars sitting next to each other in traffic (both irrelevant to this study). Second, automated classification could also likely struggle with street trees blocking angled parking below. Third, because a number of attributes of each angled parking segment were of interest (listed above), manual identification allowed for each of those to be coded manually as well (rather than estimated from other data sources). Fourth, and lastly, automated identification potentially would miss streets with angled parking that were empty at the time satellite images were acquired. In contrast, such segments could be identified during the manual process based on street markings.

Of course, manual identification of angled parking is not infallible. Given that, several quality-control steps were taken to ensure accuracy. First, roughly 10% of all identified angled parking (110 segments of 1,180 total) from Google Maps satellite imagery were cross-checked with equivalent imagery from Bing Maps. In addition, a small number of street segments (seven total) with angled parking required cross-checking with Google Maps 'street view' given tree cover. This number was quite small (less than 1% of total street segments) in part because San Francisco's overall tree cover is lower as a percentage of its total area compared to other large U.S. cities, at just 13.7% (Fracassa, 2019). Finally, 10% of all streets marked without angled parking were also cross checked against corresponding imagery from Bing Maps.

Once this data-collection process was complete, several other datasets were integrated into analysis steps to put the findings into context. The first of these was a digital elevation model (DEM) of San Francisco, downloaded from Stanford's Earthworks geospatial library collection. Using ArcMap Pro, this layer allowed for the incline (or percentage grade) of each angled-parking segment to be calculated. Second, San Francisco's bike-lane network was obtained as a vector-based GIS layer from the Metropolitan Transportation Commission's open data portal ("Regional Bike Facilities," 2018). This network varies from sharrows to fully-separated lanes, and serves as a way to cross-check bike infrastructure manually identified from satellite imagery along angled-parking segments.

Third, this study makes use of a dataset from Uber Inc., as part of their Movement platform, which is available for use by researchers at no cost (Hawkins, 2019). In 2019, Movement added average driving speeds at the street-segment level for a number of cities around the world, calculated from data collected by vehicles driving for Uber. This offers one way of testing if driving speed varies in any way between street segments with and without angled parking in San Francisco. Specifically, Movement driving speeds were compared between 301 angled-parking segments with adjacent non-angled segments. All speeds were drawn from vehicle averages over April, May, and June, 2019. For example, on Clement Street, average driving speed on a segment with angled parking was compared against that of the adjacent segment without angled parking (see **Figure 4**). These data are direction-specific, meaning they can be isolated down to the travel occurring directly along the side of the street with or without angled parking. There were 301 comparisons made after sorting angled-parking segments by those which had a street adjacent to them without angled parking, the same number of lanes, and the same speed limit (all others were excluded from this analysis).

Figure 4: Example of two street segments of Clement Street, both with angled parking (left) and without (right), for which Uber Movement driving speeds were compared.

There are several limitations to the methods employed here. One is that streets in San Francisco are in flux, so that angled parking identified from satellite imagery acquired in mid-2019 may have changed somewhat since. An example of this is construction sites, wherein angled parking present for work crews may be removed when the project is completed and the streets resurfaced. Along with these possible false positives, there are also likely a small number of angled-parking segments that went undetected, such as those with no cars parked there when the satellite imagery was acquired, and no pavement markings present that would aid in their classification. In addition, how streets were manually categorized (residential, commercial, industrial, etc.) is an imperfect process, given some street segments are mixtures of these categories, and others lie on the border (such as a residential street directly adjacent to a commercial corridor). Such categories should not be understood as airtight, but be an estimation given cues from satellite imagery. Moreover, streets with angled parking vary in terms of restrictions and allowances, including time limits, residential parking permit requirements, and metered parking, among others. These were not accounted for in this analysis.

Finally, the use of Uber Movement data to detect traffic calming also bring with it certain weaknesses. The first is that because not every angled parking segment has an adjacent non-angled segment, the comparisons made do not cover all of San Francisco's angled parking. Second, although both the number of lanes and speed limits are controlled for, this leaves out other, more-nuanced street variables such as width, length between intersections, speed bumps, pavement quality, built form, and slope. Comparisons were made with adjacent street segments in order to minimize such differences, but this does not completely resolve likely heterogeneity.

Results

Manual review of all public streets in San Francisco indicates that the city maintains approximately 50 miles of angled parking, which comprises 5.5% of the city's total curbside parking (900 miles). Assuming cars average 80 inches in width and 183 inches in length (based on the 2019 Toyota Corolla, a popular sedan), this would entail room for roughly 39,600 cars parked in a perpendicular fashion.[1] That is equal to roughly 375,000 square meters (92 acres), or space for 14 Madison Square Gardens. These 50 miles are spread across 1,180 street segments, with the shortest ones covering enough ground for 1-3 cars, and the longest (986 feet) with enough room for over 100 parked cars. Across the city angled-parking segments averaged 225 feet. The majority of angled parking in San Francisco is perpendicular (comprising 38 of the 50 miles), compared to other nonparallel angles (12 miles). This parking layout occurs in nearly all corners of the city, from its dense, downtown core, to its less-dense residential neighborhoods, commercial corridors, and industrial zones (see **Figure 5**).

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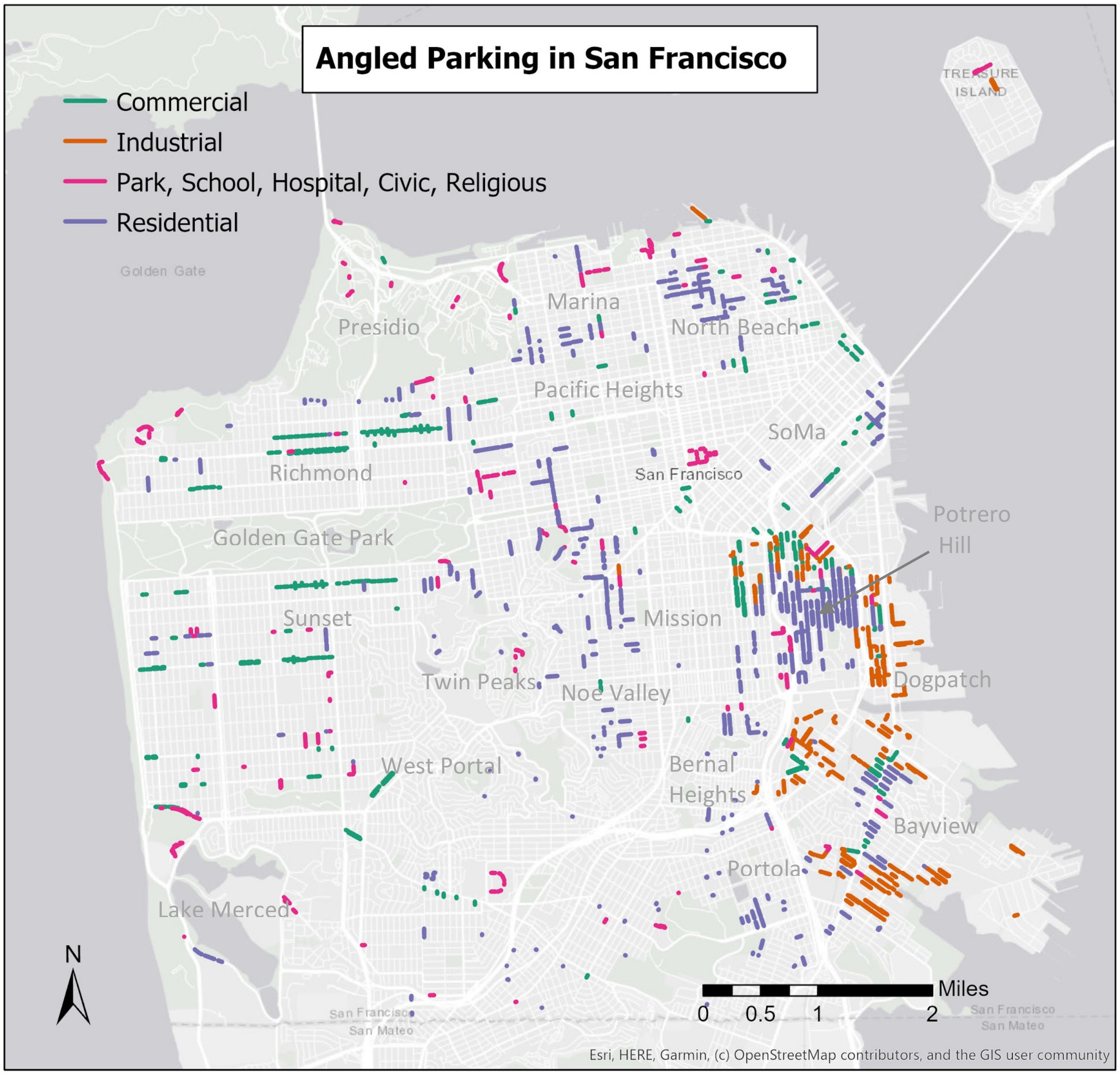
[1] This estimate is likely high given that A) not all angled parking in San Francisco is perpendicular, and B) there is of course space between cars parked at an angle to avoid vehicle damage and to allow for passengers to exit.

Figure 5: Map of Angled Parking, by street category, in San Francisco, CA.



As the map illustrates, angled parking is not evenly distributed across San Francisco. The highest concentration of angled parking is in the eastern half of the Mission District, along with Potrero Hill, and the Dogpatch (midway down the Eastern half of the city). The two other large clusters of angled parking are in the Bayview neighborhood in the Southeast corner of the city (the city's largest African-American neighborhood), and parts of North Beach (the city's historic Italian-American neighborhood). Outside of those clusters, angled parking is more sporadic, present on some commercial corridors as well as surrounding certain parks, schools, hospitals, and civic and religious centers. Many stretches of angled parking are isolated, and cover no more than a single block of a residential street, or alongside a single school or park. Angled parking is most common on residential streets (22.5%), followed by industrial and commercial streets (roughly 10% each) (see **Table 1**).

Table 1: Angled Parking in San Francisco, by street category, and dead-end streets.

	Residential	Commercial	Industrial	Parks, Schools, Hospitals, Civic and Religious Centers	Total
Overall Mileage	22.5	10.02	10.59	6.89	50
Percentage of Total	45%	20%	21.2%	13.8%	100%
Percent on Dead End Streets	8.6%	1.5%	7.9%	12.1%	7.5%

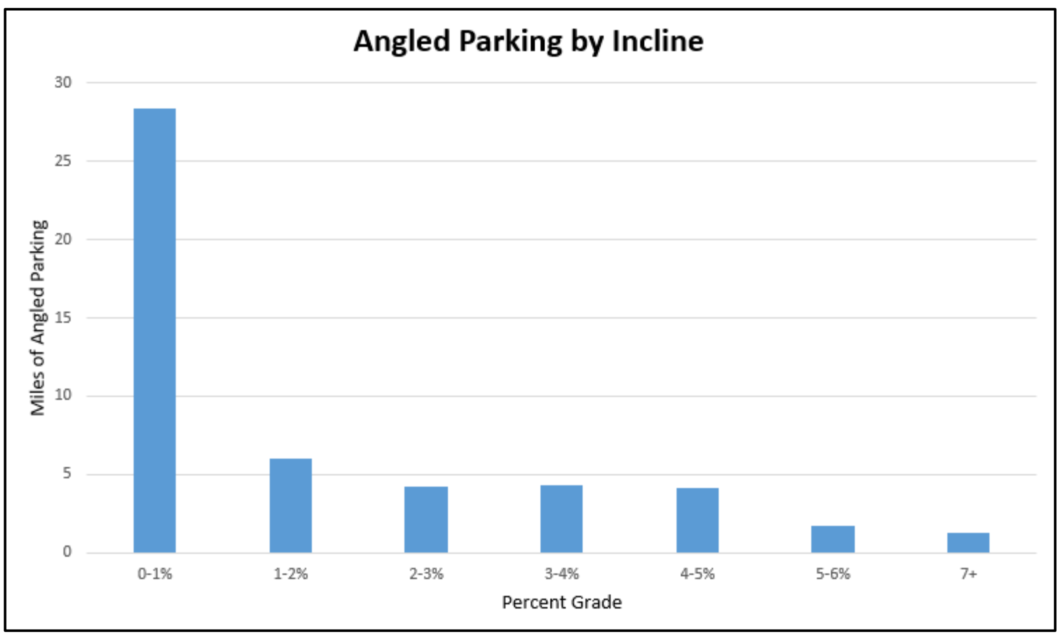
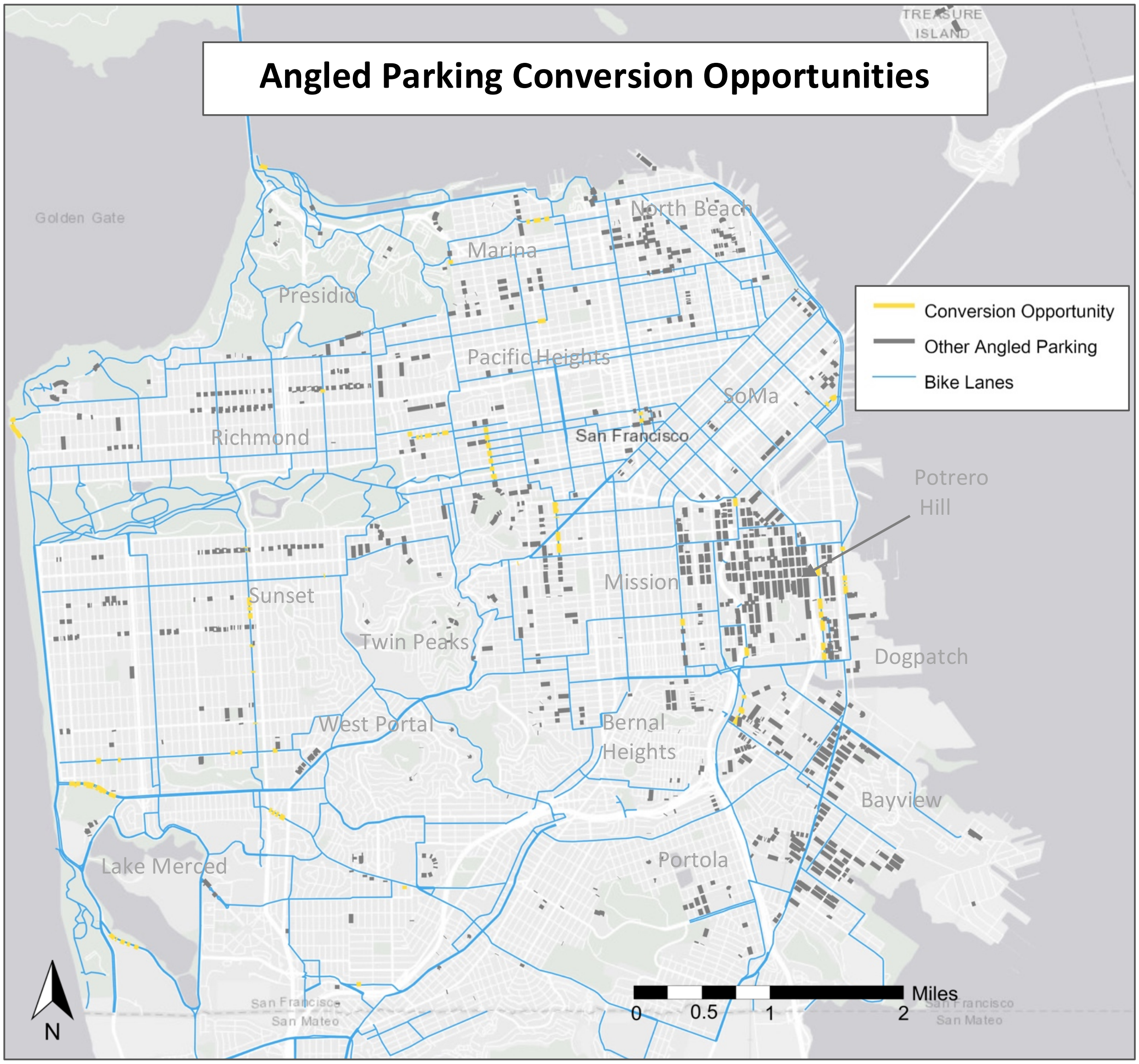


Figure 6: Chart of angled parking by incline (percent grade) in San Francisco, CA.

While many may assume that angled parking is a response to San Francisco's hills, more than half of the angled-parking mileage sits on streets with no incline at all (under 1% grade). Of the 50 miles identified, just 23% (11.4 miles) are on streets with 3-percent grade or higher (see **Figure 6)**. In addition, 93.5% of angled parking does not occur on dead-end streets, indicating that the vast majority of it influences thru traffic and takes away space that could otherwise be used for non-car modes.

In terms of its relationship to San Francisco's bike lane network, a total of four miles of angled parking occur on streets with different classes of bike lanes. This was based on the visible presence of a sharrow, painted lane, or separated lane from satellite imagery, which was also cross-checked against a vector-based GIS layer of the city's complete bike-lane network. Broken down by bike-lane type, the majority of this angled parking occurs next to sharrows (59%), followed by painted bike lanes (38%), and separated bike lanes (3%). In addition, there were ten instances of angled parking interrupting a bike lane, meaning one occurred on both sides of the angled-parking segment. The segments of angled parking lying adjacent to sharrows or painted lanes represent ideal opportunities for conversion to parallel-parking layouts in order to make room for separated lanes. These segments are dispersed throughout the city, which are labeled "conversion opportunities," and are shown in the context of San Francisco's current bike-lane network (see **Figure 7**).

Figure 7: Map of Angled Parking segments overlaid with San Francisco's bike-lane network.



Lastly, comparing driving speeds between 301 street segments with angled parking and adjacent street segments without (using data from Uber Movement) indicate little to no traffic-calming benefit. The comparison found less than a half-mile per hour difference between the two categories (0.34 MPH), with driving speeds along angled-parking segments at 15.39 MPH (SD = 3.26), compared to 15.73 MPH (SD = 3.17) on adjacent segments without angled parking. A paired t-Test indicated the difference in means across angled and non-angled parking street segments was not significant ($p = 0.39$). Indeed, for more than a third of all of pairs (112 instances) the segment with angled parking had *faster* speeds than the adjacent segment without such a layout.

Discussion and Conclusion

Angled parking is a car-intensive street design, which roughly doubles the number of cars that can be parked along a single curb compared to parallel parking. This not only privileges automobiles to a further extent, but also takes up road space that could otherwise be used for separated bike lanes as well as other non-car uses. In the case of San Francisco, such angled parking conflicts with ambitious goals around reducing car use and increasing active transportation. Using satellite imagery, this study identifies 50 miles of angled parking, across all categories of streets: residential, commercial, industrial, and by parks, schools, hospitals, and civic and religious centers. Contradicting the notion that angled parking is a policy response to San Francisco's steep hills, the majority of it identified here occurs on streets with less than 1% grade. This analysis demonstrates that angled parking is present in both high and low density areas, and does not appear to follow any spatial patterns or street conditions.

Furthermore, via the use of a driving-speeds dataset from Uber, this study adds to the evidence challenging the traffic-calming effects of angled parking. Across 301 pairs of adjacent street segments (both with and without angled parking), those with angled parking exhibited driving speeds at roughly one-third of a mile per hour lower, hardly enough of a difference to support this street layout if the goal is reducing collisions or their severity.

As to angled parking's relationship to San Francisco's bike-lane network, four miles were identified which run directly along streets with sharrows or painted lanes. So that these streets actually are amenable to cyclists, the angled parking present could be converted to parallel parking, the space savings of which can be used for separated bike lanes. Beyond just these instances, nearly all of the angled parking present in San Francisco should be questioned. One policy recommendation is to ban the future dedication of curb space to angled parking. A second is for SFMTA to establish a schedule for all existing segments to be converted over time. In addition to the segments along the bike-lane network, other priority cases could be those next to schools (to encourage students to bike to school), and those streets in which both curbs feature angled parking, which effectively turns the street into a parking lot.

Beyond San Francisco, this study demonstrates the way satellite imagery can be used to identify angled parking for an entire municipality, regardless of the state of public records, and at little to no cost. With this approach, transportation planners can consider angled parking allocation, which influences how much street space is left for other travelers. For example, the novel coronavirus (COVID-19) has moved many cities to reconsider how the right of way is used given the need for adequate social distancing (Diaz, 2020), including increased emphasis on wide sidewalks and bike lanes. Given this, accurate accounting as to where angled parking occurs can provide planners with the opportunity to address these segments in order to free up more space for pedestrians and cyclists. In terms of future research, this method for quantifying angled parking should be expanded to other cities. Indeed, this initial, manually-constructed dataset can serve as the training set for identifying angled parking via an automated approach. Common in remote-sensing research (Wei et al., 2013; Römer et al., 2014), this type of supervised classification could compute such urban features far faster, particularly for cities larger than San Francisco. For cities around the world attempting to support sustainable transportation, accounting for the uses of street curbs is critical to unlocking public space that can be dedicated to bicycle and pedestrian infrastructure. Satellite imagery provides a low-cost, straightforward way of identifying angled parking, which should be phased out in favor of more multimodal road layouts.

References

"Air Quality Community Risk Reduction Plan." 2017. San Francisco Planning Commission. https://sfplanning.org/air-quality-community-risk-reduction-plan#timeline.

"Angled Parking Vote Update." 2017. San Francisco Municipal Transportation Agency. https://www.sfmta.com/project-updates/angled-parking-vote-update.

Bialick, A. 2014. "Census: SF Has Enough Street Parking Spaces To Fill CA's Coastline." *Streetsblog San Francisco* (blog). May 23, 2014. https://sf.streetsblog.org/2014/05/22/census-sf-has-enough-public-parking-spaces-to-fill-cas-coastline/.

Biswas, S., S. Chandra, and I. Ghosh. 2017. "Effects of On-Street Parking in Urban Context: A Critical Review." *Transportation in Developing Economies* 3 (1): 10. https://doi.org/10.1007/s40890-017-0040-2.

Box, P.C. 2002. "Angle Parking Issues Revisited." *ITE Journal* 72 (3). https://trid.trb.org/view/710505.

Chen, L., C. Chen, R. Srinivasan, C.E. McKnight, R. Ewing, and M. Roe. 2012. "Evaluating the Safety Effects of Bicycle Lanes in New York City." *American Journal of Public Health* 102 (6): 1120–27. https://doi.org/10.2105/AJPH.2011.300319.

Cicchino, J.B., M.L. McCarthy, C.D. Newgard, S.P. Wall, C.J. DiMaggio, P.E. Kulie, B.N. Arnold, and D.S. Zuby. 2020. "Not All Protected Bike Lanes Are the Same: Infrastructure and Risk of Cyclist Collisions and Falls Leading to Emergency Department Visits in Three U.S. Cities." *Accident Analysis and Prevention* 141 (June). https://doi.org/10.1016/j.aap.2020.105490.

"Climate Goals, Targets and Trends: Measuring Progress towards Sustainable Mode Share and Reduced Emissions." 2017. San Francisco Municipal Transportation Agency. https://www.sfmta.com/about-us/sustainability-and-climate-action/climate-goals-targets-and-trends.

Cushing, M., J. Hooshmand, Bryan Pomares, and G. Hotz. 2016. "Vision Zero in the United States Versus Sweden: Infrastructure Improvement for Cycling Safety." *American Journal of Public Health* 106 (12): 2178–80. https://doi.org/10.2105/AJPH.2016.303466.

Diaz, J. 2020. "Cities Close Streets to Cars, Opening Space for Social Distancing." *The New York Times*, April 11, 2020, sec. U.S. https://www.nytimes.com/2020/04/11/us/coronavirus-street-closures.html.

Duthie, J., J.F. Brady, A.F. Mills, and R.B. Machemehl. 2010. "Effects of On-Street Bicycle Facility Configuration on Bicyclist and Motorist Behavior." *Transportation Research Record* 2190 (1): 37–44. https://doi.org/10.3141/2190-05.

Ferenchak, N.N., and W. Marshall. 2016. “The Relative (In)Effectiveness of Bicycle Sharrows on Ridership and Safety Outcomes.” https://trid.trb.org/view/1393928.

Fracassa, D. 2019. “Sf’s Budget for New Trees Surges, but City Falls Far Short of Planting Goal.” *San Francisco Chronicle*, June 28, 2019, sec. Local. https://www.sfchronicle.com/bayarea/article/SF-s-tree-planting-budget-surges-but-removals-14056408.php.

Grochmal, K. 2019. “20 More Miles of Protected Bike Lanes in the Next Two Years?” *Streetsblog San Francisco* (blog). May 29, 2019. https://sf.streetsblog.org/2019/05/29/20-more-miles-of-protected-bike-lanes-in-the-next-two-years/.

Hawkins, A.J. 2019. “Uber Launches a New Tool to Help Cities Track Average Vehicle Speeds by Street.” *The Verge*, May 14, 2019. https://www.theverge.com/2019/5/14/18623149/uber-movement-average-car-speed-data-cities.

He, S., F. Bastani, S. Jagwani, E. Park, S. Abbar, Mohammad Alizadeh, Hari Balakrishnan, Sanjay Chawla, Samuel Madden, and Mohammad Amin Sadeghi. 2019. “RoadTagger: Robust Road Attribute Inference with Graph Neural Networks.” Working Paper, 9. https://arxiv.org/pdf/1912.12408.pdf

Hope, B. 2014. “Startups Mine Market-Moving Data From Fields, Parking Lots—Even Shadows.” *Wall Street Journal*, November 20, 2014, sec. Markets. https://www.wsj.com/articles/startups-mine-market-moving-data-from-fields-parking-lotseven-shadows-1416502993.

Jensen, J.R., and D.C. Cowen. 1999. “Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes.” *Photogrammetric Engineering & Remote Sensing* 65 (5): 611–22.

LaPlante, J., and B. McCann. 2008. “Complete Streets: We Can Get There from Here.” *ITE Journal* 78 (5): 24.

Marshall, W.E., and N.N. Ferenchak. 2019. “Why Cities with High Bicycling Rates Are Safer for All Road Users.” *Journal of Transport & Health* 13 (June): 100539. https://doi.org/10.1016/j.jth.2019.03.004.

McCann, B., and S. Rynne. 2010. “Complete Streets: Best Policy and Implementation Practices.” Report Number 559. American Planning Association.

McCoy, P.T., M. Ramanujam, M. Moussavi, and J.L. Ballard. 1990. “Safety Comparison of Types of Parking on Urban Streets in Nebraska.” *Transportation Research Record* 1270: 28–41.

McCoy, T.A., P. McCoy T., R.J. Haden, and V.A. Signh. 1991. "Safety Evaluation of Converting On-Street Parking from Parallel to Angle." *Transportation Research Record*, no. 1327: 36–41.

Moreland-Russell, S., A. Eyler, C. Barbero, J.A. Hipp, and H. Walsh. 2013. "Diffusion of Complete Streets Policies across US Communities." *Journal of Public Health Management and Practice* 19: S89–S96.

Onishi, A., X. Cao, T. Ito, F. Shi, and H. Imura. 2010. "Evaluating the Potential for Urban Heat-Island Mitigation by Greening Parking Lots." *Urban Forestry & Urban Greening* 9 (4): 323–32. https://doi.org/10.1016/j.ufug.2010.06.002.

Partnoy, F. 2019. "Stock Picks From Space. Investors Are Using Real-Time Satellite Images to Predict Retailers' Sales. Is That Cheating?" *The Atlantic*, 2019. https://www.theatlantic.com/magazine/archive/2019/05/stock-value-satellite-images-investing/586009/.

Pucher, J., and R. Buehler. 2016. "Safer Cycling Through Improved Infrastructure." *American Journal of Public Health* 106 (12): 2089–91. https://doi.org/10.2105/AJPH.2016.303507.

"Reaching 80x50: Technology Pathways to a Sustainable Future." 2016. Siemens. https://sfenvironment.org/sites/default/files/fliers/files/sfe_cc_sustainable_future_siemens_climate_report.pdf.

Römer, H., J. Kersten, R. Kiefl, S. Plattner, A. Mager, and S. Voigt. 2014. "Airborne Near-Real-Time Monitoring of Assembly and Parking Areas in Case of Large-Scale Public Events and Natural Disasters." *International Journal of Geographical Information Science*, February. https://www.tandfonline.com/doi/abs/10.1080/13658816.2013.866240.

"Safer Journey: Interactive Pedestrian Safety Awareness." 2000. Federal Highway Administration. https://safety.fhwa.dot.gov/saferjourney1/library/matrix.htm.

Scharnhorst, E. 2018. "Quantified Parking: Comprehensive Parking Inventories for Five U.S. Cities." Research Institute for Housing America. https://www.mba.org/2018-press-releases/july/riha-releases-new-report-quantified-parking-comprehensive-parking-inventories-for-five-major-us-cities.

"Street Design Manual." 2015. Second Edition. NY, NY: New York City Department of Transportation. https://www1.nyc.gov/html/dot/downloads/pdf/nycdot-streetdesignmanual-interior.pdf.

"Street Design Standards and Traffic Calming Best Practices." 2018. City of Gaithersburg. https://www.gaithersburgmd.gov/Home/ShowDocument?id=4842.

Swan, R. 2019. "Breed Calls for 20 Miles of New Protected Bike Lanes in Sf in Two Years." *San Francisco Chronicle*, May 9, 2019, sec. Local.

https://www.sfchronicle.com/bayarea/article/Breed-calls-for-20-miles-of-new-protected-bike-13833234.php#.

"Vision Zero Action Strategy: Eliminating Traffic Deaths in San Francisco." 2018. Vision Zero SF - City and County of San Francisco. https://www.visionzerosf.org/wp-content/uploads/2019/04/VZAS_040419_web.pdf.

Wei, H., G. Zhou, Z. Zheng, X. Li, Y. Liu, Y. Zhang, S. Li, and T. Yue. 2013. "Vehicle Detection from Parking Lot Aerial Images." Melbourne, Australia: IEEE. https://ieeexplore.ieee.org/abstract/document/6723710.

Material for this chapter is published in:

Moran, M.E. "What's Your Angle? Analyzing Angled Parking using Satellite Imagery to Aid Bike-Network Expansion" *Environment and Planning B: Urban Analytics and City Science*.

Conclusion: Research Synthesis, Impact, and Reflections

The three chapters of this dissertation analyze urban streets in San Francisco via two shared approaches. First, they focus on block-level infrastructure: marked crosswalks, bus stops, and on-street parking (and its relationship to bike lanes). Each element is a fundamental support for or barrier to non-car travel and stationary street uses, and when invested in and designed appropriately, can contribute to a street being multimodal and more livable. This street-level scale matches the sensitivity of public life studies; concern with the most granular unit of the public right of way that may affect a single traveler or resident.

Second, the preceding chapters explore transport infrastructure at the scale of an entire municipality. The primary questions being asked of these data assembled are spatial: where are crosswalks present and where are they not? Are bus-stop amenities distributed randomly across the city, or are there geographic patterns to their provision? Where is angled parking allowed, and where does it interrupt the bike network? Individually, they newly spatialize core features of San Francisco's streets. Combined, they generate a composite, cartographic picture of pedestrian, transit, and parking infrastructure that can pinpoint neighborhoods and corridors underserved in multiple, overlapping ways. The goal of this final section is to first consider the dissertation in total and the value of this composite; what do these studies convey collectively that they do not individually? What synthesis is available, regarding both the methods undertaken in the study of streets, and the broader findings themselves? Second, it reflects on the impact these studies had on public policy debates in San Francisco, including subsequent changes to municipal transportation regulations and funding decisions. It concludes with parting thoughts on future research and lessons learned.

To begin, the ability to probe every street of a major American city to this level of detail suggests several aspects regarding contemporary urban analytics. In terms of satellite imagery, there are effectively no financial or computational barriers to resolving street-level objects such as individual automobiles, bike lanes, or crosswalks. Indeed, the latter two can even be evaluated in terms of type and condition. These chapters rely primarily on Google Earth, a platform which comes at no cost to the user, stores its data in the cloud, and requires only an internet connection. These are dramatic technological and financial changes in the history of remote sensing, which until very recently required navigating a range of government databases and/or paying for images of a resolution necessary for a given project. Not only does the availability of Google Earth (as well as other resources) ease the task of researchers and students, but it also opens the door for advocates and community groups to leverage such data types in issue campaigns and planning debates. 'Countermapping' is not limited to basic GIS analysis, but can now incorporate recently-acquired satellite imagery.

These studies also illustrate that urban researchers should re-calibrate their assumptions about the kinds of street-level datasets cities possess. At the outset of the work undertaken here, I contacted staff at the San Francisco Municipal Transportation Agency (SFMTA) inquiring if they maintained data on the geographic distribution of crosswalks, bus-stop amenities, and angled parking (bike-lane data were available). To my surprise, SFMTA did not have up-to-date or comprehensive data. Crosswalk data covered only half of the city's intersections, bus-stop records included only a 'shelter' vs. 'no-shelter' attribute, and data on angled parking were recorded on hundreds of separate, non-machine readable PDFs. Given the likelihood of similarly-scarce datasets elsewhere, researchers should be prepared to (a) inventory municipal datasets of cities of interest, (b) generate their own datasets when such holdings are either nonexistent or insufficient, and (c) share their data with relevant agencies following their collection.

In this vein, I posted all datasets informing these chapters online, available for download for any interested parties. A frequent response to these studies being presented at academic conferences was incredulity that I manually analyzed satellite imagery of every intersection in San Francisco (which I estimate took about 90 hours), or walked to nearly 3,000 bus stops (which took several months). The ubiquity of and ease of access to many publicly-generated datasets is unquestionably a boon to urban scholars, but their availability should be considered a starting place for research, but never thought of as exhaustive.

Locally, these studies establish a multi-dimensional picture of San Francisco in the early 21st Century. Amidst ambitious goals regarding active transportation, reducing roadway fatalities, and lowering carbon emissions, San Francisco's streets primarily prioritize automobile movement and storage. To increase parking capacity on public land, the city maintains fifty miles of angled parking, which roughly doubles the number of cars that can be parked on any given block, and uses up space that could be dedicated to adequate bicycle facilities, as well as parklets, rain gardens, seating, or other street features. Conventional wisdom in San Francisco was that such parking is a response to the city's famed hills, but the majority of it occurs on streets with no incline at all. For a city with a 'transit-first policy,' bus riders at most stops are provided no seating or shelter, while those at one-third of all stops must squeeze their way in between parked cars to board the bus, or to reach the curb upon exiting. Marked crosswalks are available at just 6 in 10 of all intersections. Indeed, that some census tracts provide crosswalks at 100% of intersections, whereas others maintain roughly 10% coverage, is a remarkable example of a disparity in infrastructure investment.

There are sobering overlaps across these chapters; such as roughly ten bus stops that are blocked by legal *angled* parking (see **Figure 1**), which severely diminishes visibility of waiting riders and creates a significant obstacle to boarding and disembarking. There are also 176 intersections that feature angled parking yet lack marked crosswalks, resulting in deficient crossing environments for pedestrians. Finally, there are 538 bus stops which sit adjacent to intersections without marked crosswalks, a situation which adds friction to a transit trip before a rider ever enters a bus.

Figure 1: A bus stop in San Francisco legally obstructed by angled (or perpendicular) parking. Photo by the Author.

In terms of spatial analysis, each chapter begins with an empirical question – how are these amenities for pedestrians, transit riders, and motorists distributed across San Francisco? Though I initially hypothesized that they may mirror the geography of wealth in the city, as transport services and investments often do (Golub and Martens 2014), both bus stops and crosswalks were characterized by notable north-to-south divides. Unlike Chicago, whose north-south distinction is broadly discussed in the academic community (and colloquially), residents and scholars of San Francisco rarely refer to such a geographic reality. The fact that San Francisco's southern half contains both high and low-income neighborhoods of varying densities, as well as significant racial diversity, challenges simple interpretations and points toward future research questions not previously part of local transportation debates. Why are marked crosswalks and high-quality bus stops so much less present there? Angled parking did not have as clear a geographic pattern, though it did cluster in several eastern neighborhoods.

The summation of the data gathered for each chapter is presented in **Figure 2**. Of course, a number of other variables (including bike racks, sidewalk width, speed limits, parking pricing, and speed bumps, among many others) would augment this composite. Indeed, a significant challenge of studying urban streets is the massive number of attributes that must be considered simultaneously. However, combining the three measured here immediately generates a complex understanding of street features, their spatial distribution, and how they intersect or are simultaneously absent.

Of particular interest are locations that lack marked crosswalks and seating at bus stops, and include angled parking. Such blocks not only maximize on-street automobile parking, but also fail to provide basic amenities for pedestrians or bus riders. Two neighborhoods stand out for meeting these criteria: Bayview-Hunter's Point and Potrero Hill-Dogpatch (see **Figure 3**). These areas contain San Francisco's two largest concentrations of angled parking, as well as bus stops which lack seating and intersections without crosswalks in large numbers.

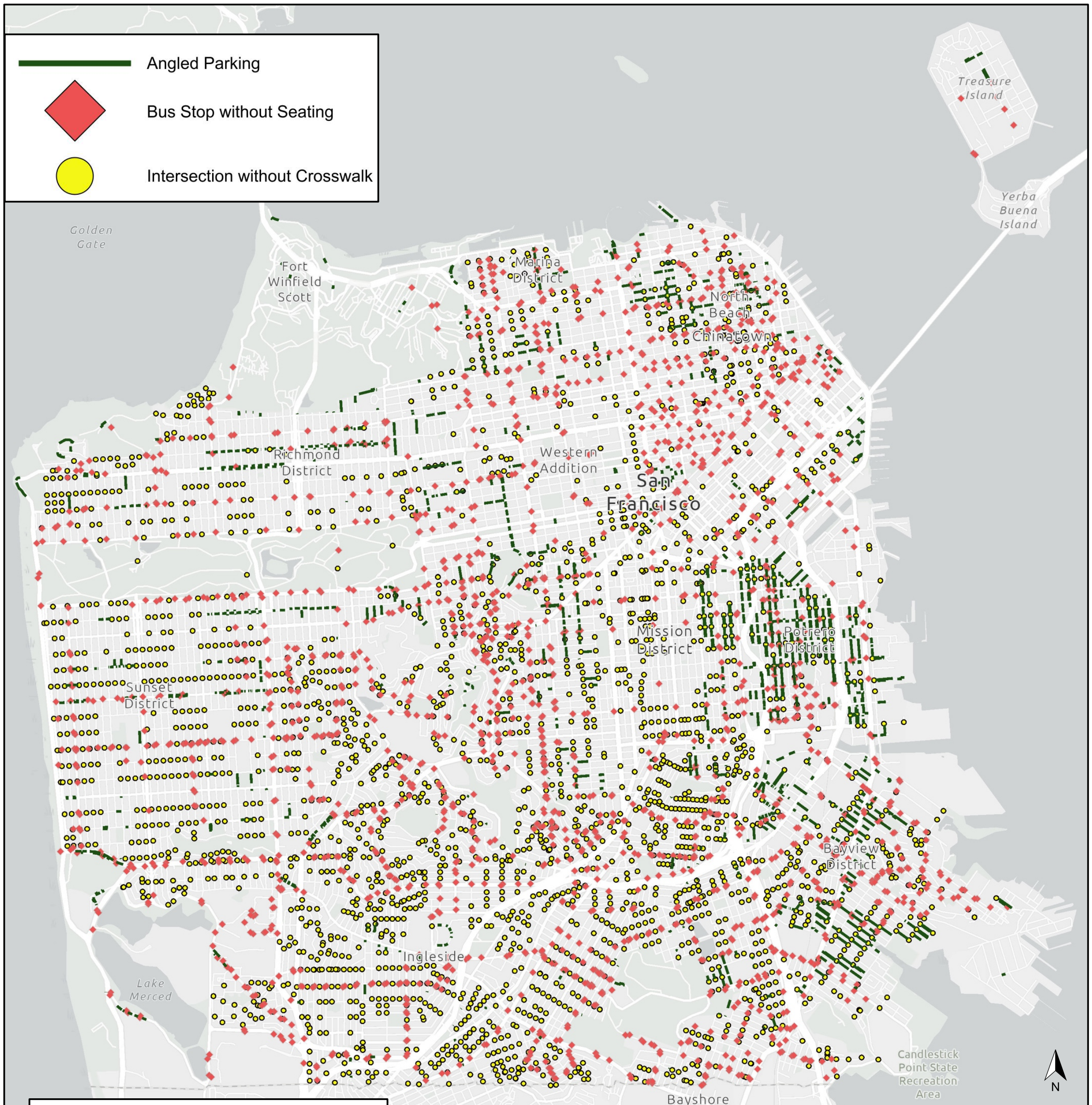


Figure 2: Composite map of crosswalk, bus stop, and angled parking datasets.

Figure 3: Composite map of crosswalk, bus stop, and angled parking datasets in Potrero Hill and Bayview-Hunter's Point.

This composite map also illustrates which neighborhoods have received the most pedestrian and transit-friendly investments. The bus-stop and crosswalk analyses independently indicate that high-amenity bus stops and higher 'crosswalk coverage' (percent of total intersections with marked crosswalks) were most likely to be present in San Francisco's northern half. Given there is scarce angled parking in this section of the city as well, the most complete streets citywide (pertaining solely to these three elements) lie within Alamo Square and Pacific Heights (higher socio-economic status neighborhoods), as well as Western Addition, which is more economically and racially diverse. These three neighborhoods are adjacent to each other, indicating a geographic center of gravity for streets with crosswalks, decent bus stops, and no angled parking.

These studies convey the value of studying our transportation system in new ways. There has been meaningful work regarding 'transit deserts' (Aman and Smith-Colin 2020), though there is also relevance to considering the rider experience outside of travel times and route coverage. Similarly, much of the literature on pedestrian behavior omits crosswalk footprints, though that is slowly changing as data availability increases (including from satellite imagery; Li et al. 2023; Hosseini et al. 2023). Parking is not understudied in American transportation planning, but *angled* parking has received less scrutiny. Angled parking is commonly touted as a traffic-calming tactic (Koucky 2018), a claim with debatable evidence, and one which this dissertation empirically refutes, for the San Francisco case. This points to the value these chapters hold for transportation engineering; the ability to expand tests of the effect of street designs on travel behavior beyond single streets or corridors, to broader scales and with greater statistical power.

The crosswalk and bus-stop chapters relate to a particular characteristic of American transportation planning: tying investment in pedestrian crossings and bus stops to the use of such facilities *before* amenities are provided. For example, San Francisco's guidelines for whether or not to provide a marked crosswalk ask if, at the intersection in question, at least "20 pedestrians per hour or 60 in four hours cross" (Robbins 2014). The liability of such an approach, borne out by previous research, is that an intersection's pedestrian traffic is influenced by its quality. The same holds true of bus stops; transit agencies often refrain from adding seating or shelter (and in San Francisco's case, unobstructed curbs) unless ridership thresholds are met.

These studies demonstrate the risks of such thresholds by identifying how low-amenity stops and intersections cluster, making transit ridership and walking less likely at broader scales. More so than any single bus stop or crossing, this shifts attention toward amenities and travel behavior across entire corridors and neighborhoods. While of course no agency or municipality has the funds for every single block to be uniform and of the highest quality, one transportation-equity implication of this dissertation (drawing on the social minimum principle; Waldron 1986), is to focus on least-served areas, where upgrades should be prioritized and the minimum-standard of streets raised.

Media outlets covered the articles upon which this dissertation is based. For the bus-stop census, they highlighted the spatial disparities in stop amenities (Bliss 2021; Campodonico 2021). One member of the San Francisco Board of Supervisors, Dean Preston, took particular interest in the finding that nearly one third of all bus stops allow for on-street parking in front of them, blocking riders from entering a bus, and forcing them to squeeze between parked cars. A legislative aide of Supervisor Preston, Preston Kilgore, reached out to me so that I could weigh in on a draft resolution calling for the removal of on-street parking adjacent to SFMTA stops. The resolution (537-21) subsequently passed unanimously. SFMTA responded with a plan to increase the speed with which it would remove on-street parking adjacent to bus stops. Finding this new schedule inadequate, Supervisor Preston called for the topic to be discussed at a public hearing, during which I shared a summary of my research. SFMTA then agreed to accelerate the pace with which it would remove parking in front of bus stops, targeting hundreds of stops in 2023 alone (Cano 2022).

Local media also took interest in the crosswalk study (Knight 2022). However, rather than the Board of Supervisors acting, Trevor Chandler, a member of a mayor-appointed community board reached out to me regarding San Francisco's Mission District. Chandler was frustrated to see the number of intersections lacking crosswalks in this neighborhood, and we met to discuss which locations might be worthwhile prioritizing in a request to the city. This eventually led to significant funds being allocated to increase the provision of crosswalks in the Mission District.

These public-policy responses to this dissertation, and my involvement in them at City Hall align with the tradition of 'advocacy planning.' As Krumholz argued in the context of his work in Cleveland in the 1960s and 70s, planners could operate "in a way that was activist and interventionist in style and redistributive in objective" (1982). The point of these chapters is not simply to identify disparities in pedestrian, transit, and bicycle infrastructure, but to impact public debates on these topics and inform policymakers on where to direct transportation investments. This also echoes the writing of Davidoff, who stressed that "appropriate planning action cannot be prescribed from a position of value neutrality" (1965). In this vein, each study takes the non-neutral position that San Francisco streets do not adequately support non-car travel, which cuts against the city's safety, air-pollution, and carbon-emission goals.

At the close of any research project, it is helpful to consider both what work should come next, building off current findings, and what might be done differently if given the chance. These chapters point to a range of future research projects. One straightforward addition is to employ these methodologies – both in-person street observation and analyses of satellite imagery – in other urban settings. I spoke with researchers in Sydney, Australia, who hoped to embark on their own bus-stop census, given their hypothesis that bus stops farther inland and more susceptible to extreme heat had fewer shelters and less shade. Closer to home, I met with a researcher affiliated with the city of Alameda, CA who wanted to use satellite imagery to map all of its marked crosswalks. These ramifications point to the value of establishing an online clearinghouse to host assorted methodology protocols, pool generated datasets, and encourage other researchers and advocates to contribute as well.

For those who wish to build on this research specifically in San Francisco, there are a number of opportunities to connect the infrastructure-centered findings here with behavioral data. The question of how angled parking, unmarked crosswalks, and low-quality bus stops relate to pedestrian, cycling, and transit activity is ripe for scrutiny. How might such street features, especially at the scale of a neighborhood or corridor, affect vehicle ownership or transit usage? Value would also likely come from comparing the maps of these street features with San Francisco's 'high-injury network,' the city's hotspots of roadway crashes.

This dissertation illustrates the ability to accurately detect minute features of the built environment, and highlights the possibility of automated classification in subsequent street analysis. The manual datasets generated for the study of angled parking and marked crosswalks could be used as training sets within GIS software to enable automated identification of those street features in other cities. This is particularly relevant for municipalities much larger than San Francisco (which is roughly 49 square miles), and with similar levels of development and street designs, where manual classification would be too labor and time intensive. Beyond parking, crosswalks, and bus stops, there are of course other street amenities that would be useful to investigate at this level of detail and scale. For example, how curb ramps – critical for persons with mobility impairments, mobility aids, and parents with strollers – are distributed across street networks could draw from the methods used here. Other examples include pedestrian refuge islands, speed bumps, traffic circles, pinch points, and chicanes. As noted in Chapter 1, many research teams have recently published exciting studies employing automated methods, including ambitious cross-city comparisons.

Outside of planning, engineering, and remote sensing, this dissertation also offers opportunities to incorporate these findings into ethnographic and sociological research. Given our increasing knowledge of the built environment's effects on mental health, neighborhood attachment, social disorder, and personal safety, it would be meaningful to interview residents regarding the distribution of street amenities, as well as how it influences their sense of space and place. Bus stops, crosswalks, and on-street parking relate to much more than just travel, and indeed, are important parts of how streets are experienced by residents during stationary activities.

Were I to start these projects over again, I would seek to engage with SFMTA leadership and staff to a greater extent. Though I always inquired first about the availability of data before I began these studies, I could have also worked with agency personnel as I built my datasets, for which they could have provided meaningful context. Conversations with SFMTA staff after the completion of these chapters highlighted potential reasons for patterns I found, such as budgetary constraints, street and sidewalk widths, and political impediments. This does not diminish the findings presented, but taking a more collaborative approach might have lead to different interpretations of the findings.

In closing, this dissertation demonstrates the relevance of using field collection and satellite imagery to deeply focus on everyday street elements, at the scale of an entire municipality. Such processes generate new types of datasets which shed light on the spatial provision of infrastructure that affects all street users, and can enter into public debates about supporting or deterring automobile use, walking, biking, and riding transit. These analyses, which are highly replicable beyond the confines of San Francisco, are critical to the 'Complete Streets' movement within urban planning, that seeks to rebalance the public right of way toward sustainable transport and away from our car-centric status quo.

References

Aman, J.J.C., and J. Smith-Colin. 2020. "Transit Deserts: Equity Analysis of Public Transit Accessibility." *Journal of Transport Geography* 89 (December): 102869. https://doi.org/10.1016/j.jtrangeo.2020.102869.

Bliss, L. 2021. "Mapping the Best and Worst Bus Stops in San Francisco." *Bloomberg CityLab*, August 3, 2021. https://www.bloomberg.com/news/articles/2021-08-03/how-better-bus-stops-can-boost-transit-ridership.

Campodonico, C. 2021. "A Tale Of Two Cities: Bus Stop Disparities Are Stark between City's Northern and Southern Halves." *The San Francisco Standard*, July 23, 2021, sec. Transportation. https://sfstandard.com/transportation/sfmta-bus-stop-disparities/.

Cano, R. 2022. "S.F. Will Remove Parking Spaces Obstructing Muni Bus Stops Sooner Than Expected. Here's When It Will Start." *San Francisco Chronicle*, December 20, 2022, sec. Bay Area. https://www.sfchronicle.com/sf/article/S-F-will-remove-parking-spaces-obstructing-Muni-17667831.php?utm_campaign=CMS%20Sharing%20Tools%20(Premium)&utm_source=t.co&utm_medium=referral.

Davidoff, P. 1965. "Advocacy and Pluralism in Planning." *Journal of the American Institute of Planners* 31 (4): 331–38. https://doi.org/10.1080/01944366508978187.

Golub, A., and K. Martens. 2014. “Using Principles of Justice to Assess the Modal Equity of Regional Transportation Plans.” *Journal of Transport Geography* 41 (December): 10–20. https://doi.org/10.1016/j.jtrangeo.2014.07.014.
Hosseini, M., A. Sevtsuk, F. Miranda, R.M. Cesar, and C.T. Silva. 2023. “Mapping the Walk: A Scalable Computer Vision Approach for Generating Sidewalk Network Datasets from Aerial Imagery.” *Computers, Environment and Urban Systems* 101 (April): 101950. https://doi.org/10.1016/j.compenvurbsys.2023.101950.
Knight, H. 2022. “He Mapped Every Crosswalk in S.F. The Results Show a Startling Safety Gap for Some Neighborhoods.” *San Francisco Chronicle*, February 9, 2022, sec. Bay Area. https://www.sfchronicle.com/sf/bayarea/heatherknight/article/He-mapped-every-intersection-in-S-F-The-results-16842735.php.
Koucky, M. 2018. “Traffic Calming and Speed Reduction on Neighbourhood Streets.” CIVITAS. https://civitas-sunrise.eu/wp-content/uploads/2020/06/SUNRISE-measures-D_traffic_calming.pdf.
Krumholz, N. 1982. “A Retrospective View of Equity Planning Cleveland 1969–1979.” *Journal of the American Planning Association* 48 (2): 163–74. https://doi.org/10.1080/01944368208976535.
Li, M., H. Sheng, J. Irvin, H. Chung, A. Ying, T. Sun, A.Y. Ng, and D.A. Rodriguez. 2023. “Marked Crosswalks in US Transit-Oriented Station Areas, 2007–2020: A Computer Vision Approach Using Street View Imagery.” *Environment and Planning B: Urban Analytics and City Science* 50 (2): 350–69. https://doi.org/10.1177/23998083221112157.
Radjawali, I., O. Pye, and M. Flitner. 2017. “Recognition through Reconnaissance? Using Drones for Counter-Mapping in Indonesia.” *The Journal of Peasant Studies* 44 (4): 817–33. https://doi.org/10.1080/03066150.2016.1264937.
Robbins, J. 2014. “SFMTA Crosswalk Guidelines,” May 29, 2014. http://www.sfbetterstreets.org/wp-content/uploads/2016/01/SFMTA-CrosswalkGuidelines-5-29-14.pdf.
Waldron, J. 1986. “John Rawls and the Social Minimum.” *Journal of Applied Philosophy* 3 (1): 21–33. https://doi.org/10.1111/j.1468-5930.1986.tb00046.x.